Waste Reduction Guide

Electrotechnologies

32053 PDF

Substantial Waste Reduction Opportunities in Industrial Lighting (SWROIL)

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Industrial Energy Advisory Service (IdEA$)

- Operated by the Johnson Research Center of The University of Alabama in Huntsville (UAH)
- Sponsored by the Alabama Department of Economic and Community Affairs (ADECA), Science, Technology and Energy Division
- Helps Alabama business, industry and public institutions find ways to reduce energy costs

IdEA$ Services

- Tollfree Information Hotline 1-800-VP-IDEAS
- Energy IdEA$ Newsletter
- Energy Technology Training
  - IdEA$ Energy Symposium
  - Energy Cost Control seminars
  - Presentations to business broups
- On-Site Technical Assistance
  - Energy audits
  - Energy accounting studies
  - In-house seminars

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Lighting Training Objective

- Provide information and tools for participants to use to help clients identify cost-effective opportunities for lighting energy reduction

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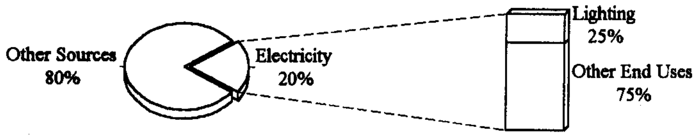
Lighting Training Agenda

- **Economic/Environmental Potential from Lighting Upgrades**
- Lighting Fundamentals
- Light Sources and Characteristics
- Ballasts and Luminaires
- Lighting Design and Maintenance Principles
- Lighting Upgrade Opportunities
- Conducting a Lighting Survey
- Analyzing Lighting Upgrade Opportunities
- Persuading the Client
- Case Study

LIGHTING UPGRADE POTENTIAL
Session Objectives

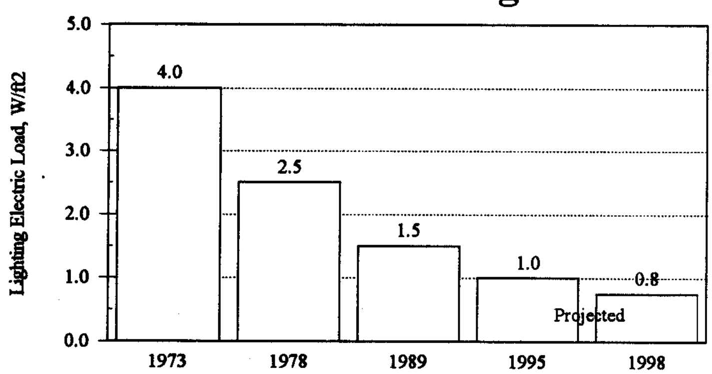
- Recognize the economic and environmental potential from lighting upgrades
- Understand the relationship between components of life cycle cost of lighting systems
- Discuss factors motivating clients to invest in lighting efficiency upgrades

Total U.S. Energy Use



Source: EPRI

Lighting Efficiency Improvements in Office Buildings



Source: EPRI 1992

Lighting Energy Efficiency
Laws, Codes and Standards

- Energy Policy Act of 1992 (EPACT)
- ASHRAE/IES Standard 90.1
- DOE Standard (10 CRF Part 435)
- CABO Model Energy Code
- State Energy Codes
- ANSI/CBM Standards

EMISSION FACTORS

	SO2 (g/kWh)	NOx (g/kWh)	CO2 (lb/kWh)
U.S. Average	5.8	2.5	1.5
Region 4 Average (AL,FL,GA,KY, MS,NC,SC,TN)	6.9	2.5	1.5
Alabama	7.0	2.5	1.6
Kentucky	10.3	4.3	2.2
South Carolina	2.5	1.2	0.8
Tennessee	10.6	2.6	1.5

Source: EPA Green Lights

Lighting Economics
Assumptions for Examples

- 2x4 troffer with four lamps
- Average energy cost: $0.07/kWh
- Annual fixture operation: 3500 hrs
- Lamp life: 20,000 hrs
- Labor to replace lamps: $6/lamp
- System life: 10 years
- No inflation or time value of money

Lighting Economics
Example 1 - Annual Operating Cost

Given: *Case A*
Fixture Power: 176 W
Lamp Cost: $1 each

Case B
Fixture Power: 109 W
Lamp Cost: $3 each

Lighting Economics
Example 1

Find: Annual Energy Cost (AEC)
Annual Material Cost (AMC)
Annual Labor Cost (ALC)
Total Annual Operating Cost (AOC)

Lighting Economics
Example 1A

Solution: AEC(A) = 0.176 kW x 3500 hrs/yr x \$0.07/kWh
= \$43.12/yr

$$AMC(A) = 4 \text{ lamps} \times \frac{3500 \text{ hrs/yr}}{20000 \text{ hrs/lamp}} \times \$1/\text{lamp}$$
= 0.7 lamps/yr x \$1/lamp = \$0.70/yr

ALC(A) = 0.7 lamps/yr x \$6/lamp = \$4.20/yr

AOC(A) = AEC(A) + AMC(A) + ALC(A)
= \$43.12 + \$0.70 + \$4.20
= \$48.02/yr

Lighting Economics
Example 1B

Solution: AEC(B) = 0.109 kW x 3500 hrs/yr x \$0.07/kWh
= \$26.70/yr

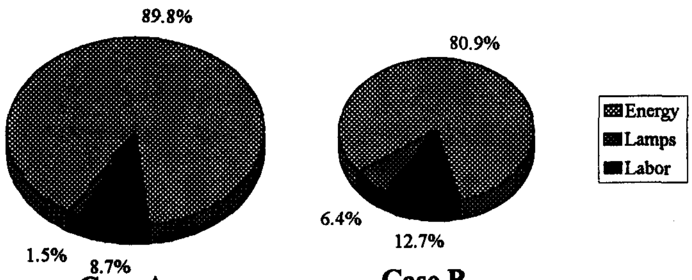
$$AMC(B) = 4 \text{ lamps} \times \frac{3500 \text{ hrs/yr}}{20000 \text{ hrs/lamp}} \times \$3/\text{lamp}$$
= 0.7 lamps/yr x \$3/lamp = \$2.10/yr

ALC(B) = 0.7 lamps/yr x \$6/lamp = \$4.20/yr

AOC(B) = AEC(B) + AMC(B) + ALC(B)
= \$26.70 + \$2.10 + \$4.20
= \$33.00/yr

Example 1

Total Annual Operating Cost



TKS

Lighting Economics

Example 2 - Lifetime Costs

Given: Initial Cost(A): \$40
Initial Cost(B): \$80

Find: Lifetime Owning & Operating Cost (LOC)

Lighting Economics

Example 2

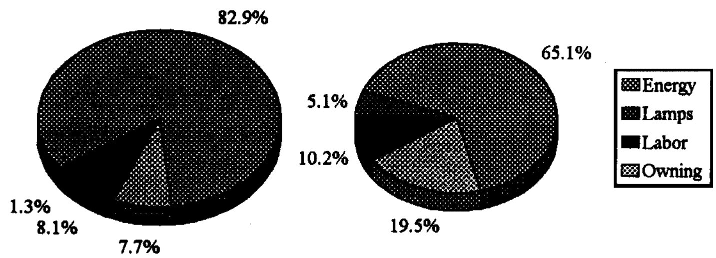
Solution: LOC = IC + 10(AEC + AMC + ALC)

LOC(A) = \$40 + 10(\$43.12 + \$0.70 + \$4.20)
= \$40 + \$431.20 + \$7.00 + \$42.00
= \$520.20

LOC(B) = \$80 + 10(\$26.70 + \$2.10 + \$4.20)
= \$80 + \$267.00 + \$21.00 + \$42.00
= \$410.00

Example 2

Lifetime Owning & Operating Cost



Case A **Case B**

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Lighting Economics

Energy Cost

1. Energy cost is the dominant component of the annual operating costs of lighting systems

2. Energy cost is the dominant component of total life cycle costs of lighting systems

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Lighting Training Agenda

- Economic/Environmental Potential from Lighting Upgrades
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LIGHTING FUNDAMENTALS
Session Objectives

- Recognize the factors which affect our ability to see
- Understand the terminology and concepts related to quantity and quality of light

LIGHTING FUNDAMENTALS
Notes from IES Video

LIGHTING FUNDAMENTALS
Quantity of Illumination

- Light Output (lumens)
- Light Level (footcandles)
- Brightness (footlamberts)

IESNA ILLUMINANCE RECOMMENDATIONS

Category		lux (FC)	Type of Activity
SPACE	A	20-30-50 (2-3-5)	Public spaces with dark surroundings
	B	50-75-100 (5-7.5-10)	Simple orientation for short visits
	C	100-150-200 (10-15-20)	Working spaces where visual tasks occasionally performed
TASK	D	200-300-500 (20-30-50)	High contrast or Large size
	E	500-750-1000 (50-75-100)	Medium contrast or Small size
	F	1000-1500-2000 (100-150-200)	Low contrast or Very small size

IESNA WEIGHTING FACTORS

Category A - C	"-1"	"0"	"+1"
Occupant's Age	< 40	40 - 55	> 55
Room Surface Reflectances	> 70%	30 - 70%	< 30%
Category D - I	**"-1"**	**"0"**	**"+1"**
Worker's Age	< 40	40 - 55	> 55
Speed / Accuracy	Not Important	Important	Critical
Task Background Reflectance	> 70%	30 - 70%	< 30%

IESNA WEIGHTING FACTORS

- Method:
  - Add weighting factors algebraically
- Rules:
  - If total <= -2, use lowest recommended value
  - If total >= +2, use highest recommended value
  - If -2 < total < +2, use middle recommended value

Source: IESNA

LIGHTING FUNDAMENTALS
Quality of Illumination

- Glare - Visual Comfort Probability (VCP)
- Uniformity of Illuminance on Tasks - Spacing Criteria (SC)
- Color Rendition (CRI)

QUALITY MEASURES
Glare

- Sensation produced by luminance within the visual field, sufficiently greater than the luminance to which the eye adapted to cause visual problems
  - Discomfort glare
    - Annoyance; some loss of visual performance
  - Disability glare
    - Total loss of visual performance
  - Direct
  - Reflected

Source: IESNA

LIGHTING QUALITY
Color Rendering Index (CRI)

- Appearance of Colored Objects
- Ranges from 0 - 100
  - Higher value means better color rendering
    - 75 -100 CRI Excellent
    - 65 - 75 CRI Good
    - 55 - 65 CRI Fair
    - 0 - 55 CRI Poor
- Relative to a Reference Source (of same CCT)
- Average Shift of 8 Standard Colors

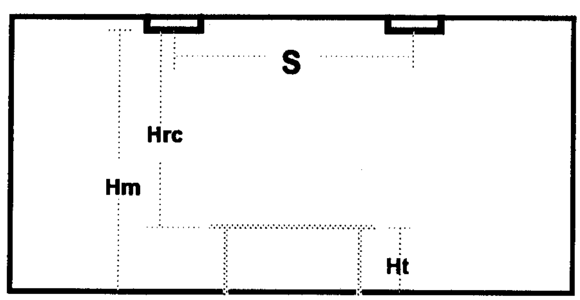
Source: Sylvania Lighting and EPA Green Lights 1993

TYPICAL CRI VALUES

SOURCE		CRI
Incandescent/Halogen		100
Fluorescent		
Cool White	T12	62
Warm White	T12	53
Rare Earth (RE)	T12	75-85
T8		75-85
T10		80
Mercury Vapor	(clear/coated)	22-52
Metal-Halide	(clear/coated)	65-85
High-Pressure Sodium		25
White HPS		80
Low-Pressure Sodium		0

Source: EPA Green Lights 1993

UNIFORMITY - Spacing Criteria (SC)



Hrc ≡ Hm - Ht **Smax = S.C. x Hrc**

ex: Hrc = 9.5' - 2.5' = 7' **Smax = 1.2 x 7' = 8.4'**

QUALITY MEASURES
Visual Comfort Probability

- Rating of lighting system expressed as % of people, when viewing from a specified location and in specified direction, will find system acceptable in terms of discomfort glare
- Minimum recommended for interiors = 70
- IES RP24 for VDT applications = 80

Source: IESNA

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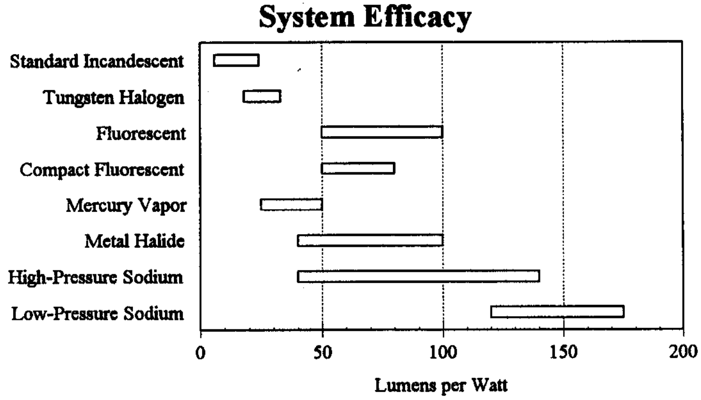
CHARACTERISTICS OF LIGHT SOURCES

- Efficiency - lumens per watt
- Average Rated Life - hours
- Color Rendering Index (CRI)
- Correlated Color Temperature (CCT)]
- Start/Re-Strike Time
- Lumen Maintenance

LAMP CHARACTERISTICS

System Efficacy

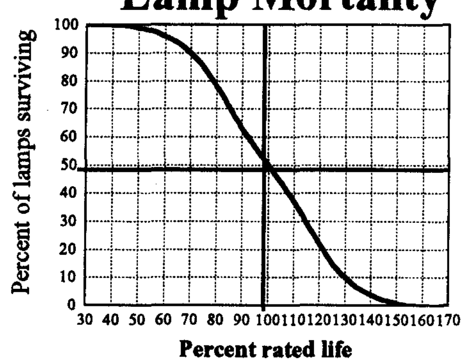


LAMP CHARACTERISTICS
Average Rated Life

- Average rated lamp life is the point at which 50% of an infinitely large group of lamps will have failed
- Rated life does NOT mean that every lamp will burn that long

Source: Lindsey - Applied Illumination Engineering, 1991

AVERAGE RATED LAMP LIFE
Lamp Mortality



Source: Lindsey - Applied Illumination Engineering, 1991

LAMP CHARACTERISTICS
Lamp Lumen Depreciation (LLD)

$$\text{LLD} = \frac{\text{Mean Lumens (@ 40\% life)}}{\text{Initial Lumens}}$$

Mean lumens also called Design lumens

Ex 2: 32 w T8 Fluorescent $\quad \text{LLD} = \dfrac{2{,}610}{2{,}900} = 0.90$ Source: IESNA

LAMP CHARACTERISTICS

Color Rendering Index (CRI)

- Appearance of Colored Objects
- Ranges from 0 - 100
  - Higher value means better color rendering
    - 75 -100 CRI Excellent
    - 65 - 75 CRI Good
    - 55 - 65 CRI Fair
    - 0 - 55 CRI Poor
- Relative to a Reference Source (of same CCT)
- Average Shift of 8 Standard Colors

Source: Sylvania Lighting and EPA Green Lights 1993

LAMP CHARACTERISTICS

Correlated Color Temperature (CCT)

- Appearance of Light Source
- Kelvin Scale
  - Ex: 2700K (Incandescent)
- Correlated to Reference Source (Black Body)
- Describes "Warm" or "Cool"
  - Higher Color Temp is Cooler Appearance
  - Lower Color Temp is Warmer Appearance

Source: Sylvania Lighting

LAMPS

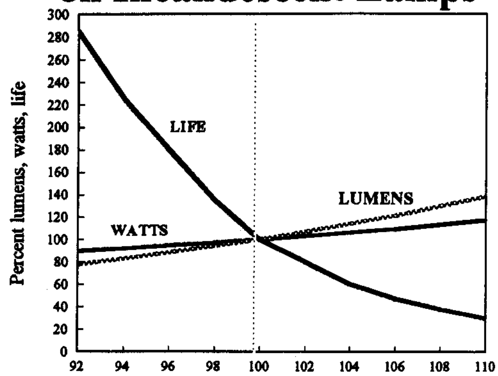
Incandescent Filament

Definition:

A lamp in which light is produced by a filament heated to incandescence by an electric current.

Source: IESNA

EFFECT of VOLTAGE
on Incandescent Lamps



Source: Sylvania Lighting

INCANDESCENT LAMP
Advantages

- Point Source
  - Good optical control
- Easily Dimmed
  - Low cost
- Excellent Color Rendering
  - Warm, pleasant
- Versatile
  - Many wattages
  - Many shapes

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INCANDESCENT LAMP
Disadvantages

- Short life
  - 750 - 1,000 hrs typical
- Voltage sensitive
  - Higher than normal line voltage will reduce life
- Vibration sensitive
  - If fragile filament vibrated, will reduce life
- Hot source
  - Adds to building heat, beam heat can degrade mat'ls
- Shock hazard
  - Filament exposed when bulb broken

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LAMPS

Fluorescent

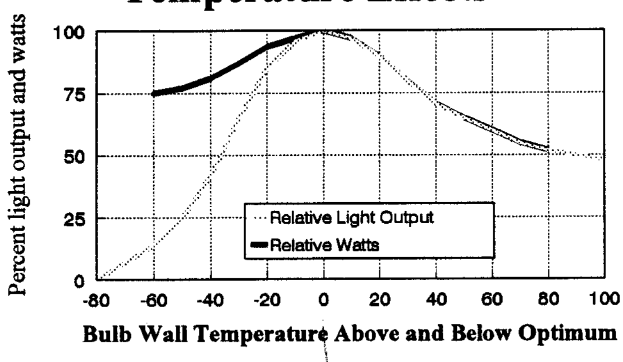
Definition:

A low-pressure mercury electric discharge lamp in which a fluorescing coating (phosphor) transforms some of the ultraviolet energy generated by the discharge into light.

Source: IESNA

FLUORESCENT LAMPS

Temperature Effects

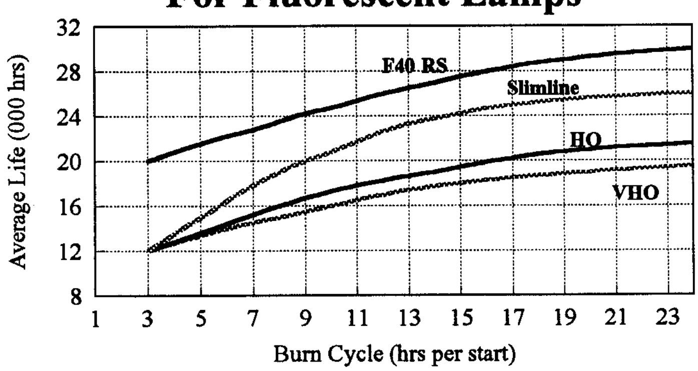


80°F

Source: Sylvania Lighting

AVERAGE LIFE vs BURN CYCLE

For Fluorescent Lamps



Source: Applied Illumination Engineering - Lindsey 1991

LAMPS

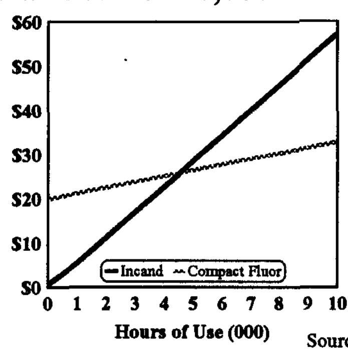
Compact Fluorescent Options

- Integrally (self) ballasted
  - Used in place of incandescent lamp in Edison sockets
  - Magnetic
  - Electronic
- Component
  - Lamp separate from ballast
  - First - ballast adaptor
  - Next - ballast wired into fixture
    - Future - 2-lp ballasts

EPA Green Lights - 1993 and JLF

COMPACT FLUORESCENT vs INCANDESCENT

Total Cost for 10,000 Hrs Use



Source: Sylvania Lighting

COMPACT FLUORESCENT LAMPS

Performance Characteristics

- Power consumption
  - 1/5 of incandescents
- Lamp life
  - 10 times longer than incandescents
- Color quality
  - CCT = 2700K, CRI = 80
- Starting
  - Pre-heat (blink-blink-on)
  - Rapid-start (instant on)
  - Temperature
    - Varies, watch for outdoor appl

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COMPACT FLUORESCENT LAMPS
Performance Concerns

- Physical size
  - Fit
- Power quality
  - Power factor
  - Total Harmonic Distortion (THD)
- Sensitivity
  - Orientation
  - Temperature
    - Downlight self-heating
      - Fixture venting

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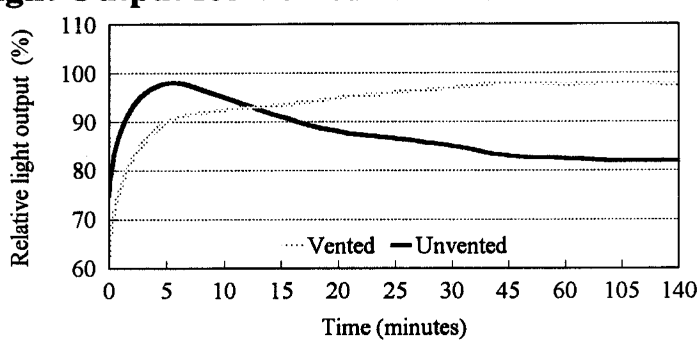
COMPACT FLUORESCENT
Light Output for Vented & Unvented Fixtures



Re: LBL M.J.S. - Energy Engineering 89:2 1992

LAMPS
Metal Halide

Definition:

A high intensity discharge (HID) lamp in which the major portion of the light is produced by a radiation of metal halides and their products of dissociation - possibly in combination with metallic vapors such as mercury. Includes clear and phosphor coated lamps.

Source: IESNA

METAL HALIDE LAMPS
Advantages

- Crisp, white light source
  - Desirable for commercial lighting
- High efficacy
  - 55 - 110 LPW
- Good CRI
  - 65 - 70

Source: Advanced Lighting Guidelines (Rev 1) - 1993

METAL HALIDE LAMPS
Disadvantages

- Color shift
  - Due to additive mix, ballast voltage, shock
- Long strike/re-strike time
  - 2 - 10 min/<15 min
- Position sensitive
  - Lumen output varies with position angle
- Sensitive to low temperature
  - Operation below 10 F can affect life
- Non-passive failure
  - Safety concern

Source: Advanced Lighting Guidelines (Rev 1) - 1993

LAMPS
High Pressure Sodium (HPS)

Definition:

A high intensity discharge (HID) lamp in which light is produced by radiation from sodium vapor operating at a partial pressure of about 13,300 Pa. Includes clear and diffuse-coated lamps.

Source: IESNA

HIGH-PRESSURE SODIUM LAMPS

Advantages

- High Efficacy
  - 60 -127 LPW
- Highest Discharge Lamp Mean Lumens
- Very Long Life
  - 24,000 + hours
- Small Light Source Size
  - Good optical control

Source: GE Lighting

HIGH-PRESSURE SODIUM LAMPS

Disadvantages

- Color
  - Yellow (Orange)
- Low CRI
  - 25 - 34
- Strike/Re-strike time
  - 2 - 3 min/< 1 min
- Maintenance
  - End-of-life cycling can destroy starter

Source: Applied Illumination Engineering - Lindsey - 1991

LAMPS

Low Pressure Sodium

Definition:

A discharge lamp in which light is produced by radiation from sodium vapor operating at a partial pressure of 0.1 to 1.5 Pa.

Source: IESNA

LAMPS
Low-Pressure Sodium (LPS)

- Replace on system basis
- Starts red
  - Neon used to vaporize sodium
- Monochromatic light source
  - Easily filtered from astronomer's telescopes
- Poor CRI
  - Zero or less
- Highest lumen maintenance
  - Wattage increases to maintain

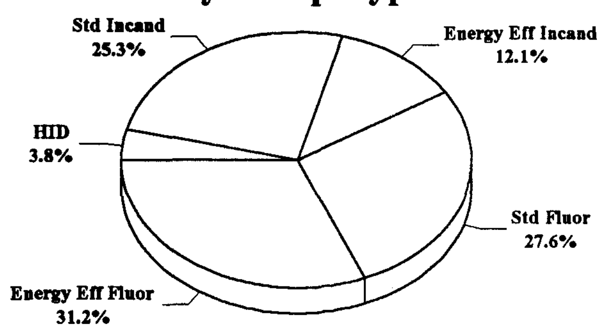
Source: Philips Lighting - 1992

LAMPS
Low-Pressure Sodium (LPS)

- LPW = 140
- 10,000 - 18,000 hour life rating
- Used for safety/security applications
- Disposal issue
  - Metallic sodium

Source: Philips Lighting - 1992

COMMERCIAL LIGHTING ENERGY
by Lamp Type



Source: Lighting in Commercial Buildings - March 1992

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BALLAST FUNCTIONS

- Provides the correct **starting** voltage
- **Matches** the line voltage to the operating voltage of the lamp
- **Limits** the lamp current

BALLAST FACTS

Watts Consumed - NO Lamps 2-Lamp Ballasts

	Ballast	Watts
430 ma	Rapid Start	6.5
800 ma	HO	12.5
1200 ma	VHO	13.5

Source - CBM

BALLAST FACTS

Factors Affecting Ballast Life

- Heat (> 90 deg C)
- Input voltage (+5% -7.5%)
- Fixture heat dissipation

Source - CBM

BALLAST REFRESHER

Ballast Life Expectancy

Type	Years
Older Core & Coil	12 - 15
"Energy-Saving"	> 15
Electronic	25

Source - CBM

BALLAST REFRESHER

Ballast Factor

The % rated lamp lumens actually produced by a specified lamp/ ballast combination

$$\text{B.F.} = \frac{\text{Commercial Ballast Light Output}}{\text{"Perfect" Reactor Ballast Light Output}}$$

Ex: 2 lamps rated @ 3,000 lumens operated on a 2-lamp ballast w/BF=95% will only produce 3,000 x 2 x 0.95 = 5,700 lumens.

Source - CBM

BALLAST FACTOR MATRIX

Lamp

Ballast	34 W	40 W	60 W	75 W
Older Core & Coil	0.88	0.94	0.87	0.94
Energy Eff	0.86	0.94	0.85	0.93
Htr Cut-Out	0.79	0.83	NA	NA

Re: Energy Engineering 89:2 1992

CERTIFIED BALLAST MANUFACTURERS ASSOC.

ANSI Certification Requirements

√Ballast performance meets or exceeds ANSI C82.1:

1. Will comply with the lamp manufacturer's published lamp mortality curves
2. Will produce 95% (+/-2.5%) of rated lumen output (ballast factor)
3. Will not cause premature lamp failures

Source: CBM

BALLAST TYPES

- Conventional magnetic ballast
  - Core and coil design
  - Wire wrapped around a laminated iron core
  - Provides ballasting function by electromagnetic inductance
  - Operates at 60 hz
- Hybrid magnetic or filament cutout
  - Incorporate electronic switching device to disconnect cathode heating current after starting
  - Operates at 60 hz, usually w/ low BF
  - 10% less lamp life

Source: Lithonia "by DESIGN" 1/92 and EPA Green Lights 1993

BALLAST TYPES

- Hybrid electronic ballast
  - Combination of electronic and electromagnetic components
  - Operates at 20 - 30 Khz
- Solid state electronic ballast
  - Composed on all electronic components
    - Some use integrated circuits
  - Operates at 20 - 40 Khz
  - Offers greatest potential for system performance

Source: Lithonia "by DESIGN" 1/92

ELECTRONIC BALLASTS

Reduce energy by operating lamps at high frequency (20,000 - 40,000 hz)

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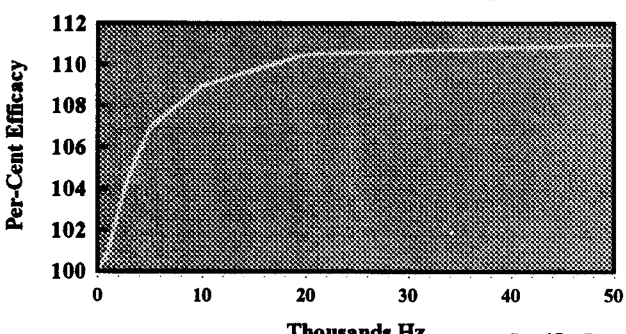
ELECTRONIC BALLASTS

Lamp Efficacy vs Frequency



Specifier Reports 12/91

ELECTRONIC BALLAST EFFICIENCY

For 2-40 Watt Lamps

Ballast Type	Watts Input
Older Core & Coil	96 w
Energy Saving	88 w
Electronic	73 w

Specifier's Reports - 12/91

ELECTRONIC BALLAST CONSIDERATIONS

Instant-Start vs Rapid-Start

- Instant-start
  - NO power on cathodes
  - Lower system wattage, higher LPW
  - 25% shorter lamp life (15,000 hrs)
  - Parallel operation
- Rapid-start
  - Continuous power on cathodes
  - Higher system wattage, lower LPW
  - Normal lamp life (20,000 hrs)
  - Series operation

ELECTRONIC BALLASTS

Advantages

- Converts power to light more efficiently
  - 25% more efficient
- Cooler operation
  - Reduces air-conditioning load
- Lower flicker rate
  - Important at high light levels (inspection)
- Lower sound level
  - No more hum!
- Light weight
  - Reduced shipping costs

ELECTRONIC BALLASTS
Disadvantages

- Reliability
  - Improving
  - Choose ballasts w/proven record
  - & good warranty
- Costs
  - Slowly decreasing
- Availability
  - Sometimes hard to get
- Power quality
  - Specify THD < 33%

POWER REDUCERS

- An Impedance element placed in series between ballast and fluorescent lamp
- Reduces BOTH power AND light output
- Saves 80 - 700 kwh per year ($5 - $80)
- Costs $20 - $65 per reducer

Source: Specifier's Reports - 8/92

POWER REDUCERS
Alternatives

- Reduced wattage lamps
- De-lamping or luminaire de-energization
- Specular reflectors
- Ballast replacement
- Lighting circuit adjustors
- Dimming electronic ballasts

Source: Specifier's Reports - 8/92

LUMINAIRE COMPONENTS

- Lamps
  - and lamp holders (sockets)
- Ballasts
  - to start & operate lamps
- Reflectors
  - to direct light in desired direction
- Shielding/diffusion components
  - Lens, louver
    - to reduce visual discomfort
    - to distribute light evenly
- Housings to contain elements above

Source: Advanced Lighting Guidelines (Rev 1) - 1993

LUMINAIRE EFFICIENCY

- Electrical
  - Power to light conversion
- Optical
  - Light control
- Thermal
  - Interaction between light generating elements and their thermal sensitivity

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LUMINAIRE COMPONENTS
Internal Reflecting Materials

- Diffuse finishes
  - White paint
- Specular finishes
  - Precise redirection of light
    - Anodized, specular aluminum R = 85-90%
      - Enhanced w/thin-film dielectric coatings R = 88-94%
    - Vacuum-deposited, specular silver R = 91-95%

Source: Advanced Lighting Guidelines (Rev 1)- 1993

LIGHTING RETROFIT OPTIONS
Increasing Luminaire Efficiency

- Specular Reflectors
- Lens/Louver Upgrade
- Fixture Cleaning Program
- Replace with New Efficient Fixtures
- Task Lighting

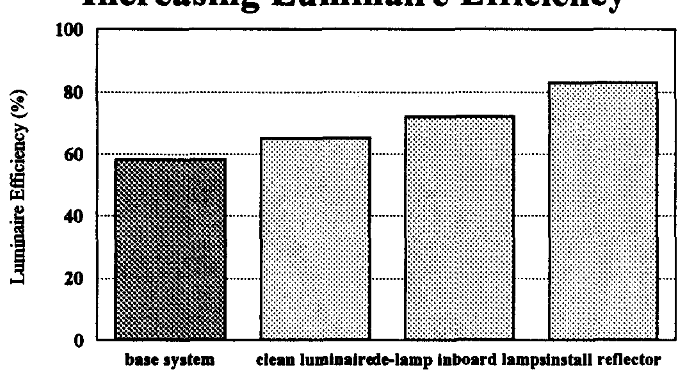
Source: EPA Green Lights - 1993

LIGHTING RETROFIT OPTIONS
Specular Reflectors

- Improve 2 X 4 troffer efficiency by up to 17%
  - More if troffer interior deteriorated
- Check for accessibility to ballast compartment
- Relocate lamps for max performance
  - Use UL classified components
- Disconnect unused ballasts
- Perform trial installation
  - Determine effects on light level/distribution
    - Watch spacing criteria (SC)

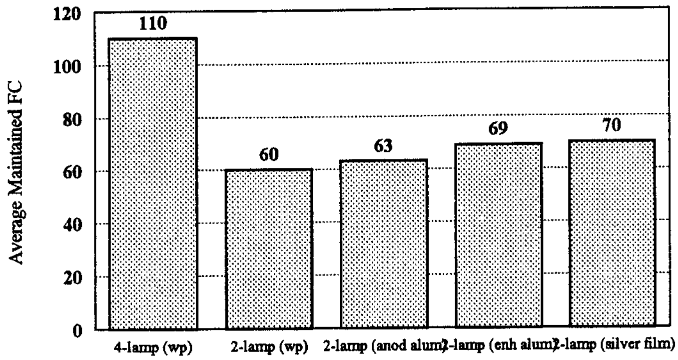
Source: EPA Green Lights - 1993

LIGHTING RETROFIT OPTIONS
Increasing Luminaire Efficiency



Source: EPA Green Lights - 1993

LIGHTING RETROFIT OPTIONS
Specular Reflector Performance



Source: Specifier Reports - 1992

FLUORESCENT REFLECTORS
Material Reflectance Data

Condition	Total R	Specular R	Diffuse R
White Paint (Base)	87.6	2.9	84.7
Alum Reflect D	85	83.2	1.8
Alum Reflect C	83.7	76.3	7.4
Silver Reflect J	96.7	93.2	3.5
Silver Reflect G	94.3	92.6	1.7

Source: Specifier's Report 1992

FLUORESCENT REFLECTORS
Incremental Effects of Retrofit Changes

Condition	Luminaire Efficiency
4-lamp Uncleaned Hi-Loss Ball	54.8%
4-lamp Uncleaned Lo-Loss Ball	58.4%
4-lamp Cleaned Lo-Loss Ball	66.7%
2-lamp Cleaned Lo-Loss Ball	73.4%
2-lamp w/reflector	85.4%

Source: Specifier's Report - 1992

FLUORESCENT REFLECTORS
Photometric Data

Condition	Luminaire Efficiency	SC
4-lamp Fix (Base)	65.6%	1.3
Alum Reflect A	73.2%	0.9
Alum Reflect C	74.9%	0.9
Alum Reflect E	74.3%	0.8
Silver Reflect H	84.8%	0.7
Silver Reflect J	81.9%	0.9
Silver Reflect M	81.4%	1.4

Source: Specifier's Report - 1992

SWROIL
Lighting Training Agenda

- Economic/Environmental Potential from Lighting Upgrades
- Lighting Fundamentals
- Light Sources and Characteristics
- Ballasts and Luminaires
- **Lighting Design and Maintenance Principles**
- Lighting Upgrade Opportunities
- Conducting a Lighting Survey
- Analyzing Lighting Upgrade Opportunities
- Persuading the Client
- Case Study

LUMEN METHOD

$$\text{Footcandles} = \frac{\text{lumens}}{\text{square feet}}$$

Source: IESNA

ZONAL CAVITY METHOD

Initial Illuminance

$$FC = \frac{\#\text{ Fixtures} \times \#\text{ Lps/Fixture} \times \text{Lumens/Lp} \times CU}{\text{Area}}$$

$$\#\text{ Fixtures} = \frac{FC \times \text{Area}}{\#\text{ Lps/Fixture} \times \text{Lumens/Lp} \times CU}$$

Source: IESNA

COEFFICIENT of UTILIZATION (CU)

- Expressed as:
  - A percentage of the lumens produced by the lamps that reach the work plane
- Function of:
  - Luminaire efficiency and intensity distribution
  - Room surface reflectances
  - Room geometry (RCR)

Source: IESNA

ROOM CAVITY RATIO (RCR)

RCR is a number indicating room cavity proportions calculated from length, width, and height.

$$RCR = \frac{5\,h\,(L + W)}{L\,W}$$

Constant 5 in numerator provides ratios ranging from 1 to 10 for most rooms.
Large rooms have small RCRs.
Small rooms and rooms with high ceilings have large RCRs.
The smaller the RCR, the higher the CU.

Source: Applied Illumination Engineering - Lindsey, 1991

TYPICAL CU TABLE

Rc =	80			70			50			30			10			0
Rw =	50	30	10	50	30	10	50	30	10	50	30	10	50	30	10	0
RCR	Coefficients of Utilization for 20% effective floor cavity Reflectance (Rf = 20%)															
0	75	75	75	73	73	73	70	70	70	67	67	67	64	64	64	63
1	67	65	63	66	64	62	63	62	60	61	60	58	59	58	57	55
2	60	57	54	59	56	53	57	54	52	55	53	51	53	51	50	49
3	54	50	47	53	49	46	52	48	45	50	47	45	48	46	44	43
4	49	44	40	48	44	40	47	43	40	45	42	39	44	41	39	37
5	44	39	35	43	38	35	42	38	34	41	37	34	40	36	34	33
6	40	34	31	39	34	31	38	34	30	37	33	30	36	32	30	29
7	36	30	27	35	30	27	34	30	27	33	29	26	32	29	26	25
8	32	27	23	32	27	23	31	26	23	30	26	23	29	26	23	22
9	29	24	20	28	23	20	28	23	20	27	23	20	26	23	20	19
10	26	21	18	26	21	18	25	21	18	24	20	18	24	20	18	16

ZONAL CAVITY METHOD

Maintained Illuminance

Initial Illuminance (FC) reduced by
Light Loss Factor (LLF)

$$FC_{maintained} = FC_{initial} \times LLF$$

JLF

LIGHT LOSS FACTORS

Non-Recoverable

a. Luminaire Ambient Temperature

b. Voltage to Luminaire

c. Ballast Factor

d. Luminaire Surface Depreciation

Source: IESNA

LIGHT LOSS FACTORS
Recoverable

e. Lamp Burnout Factor

f. Lamp Lumen Depreciation (LLD)

g. Luminaire Dirt Depreciation (LDD)

h. Room Surface Dirt Depreciation (RSDD)

Source: IESNA

LIGHTING MAINTENANCE
Principles

- Light output of all lighting systems decreases over time
- Many lighting systems are overdesigned to compensate for future, unnecessary light loss
- Improving maintenance practices can reduce light loss (depreciation) and can:
  - allow reductions in energy consumption, or
  - improve light levels
- Group maintenance practices save money

Source: EPA Green Lights - 1993

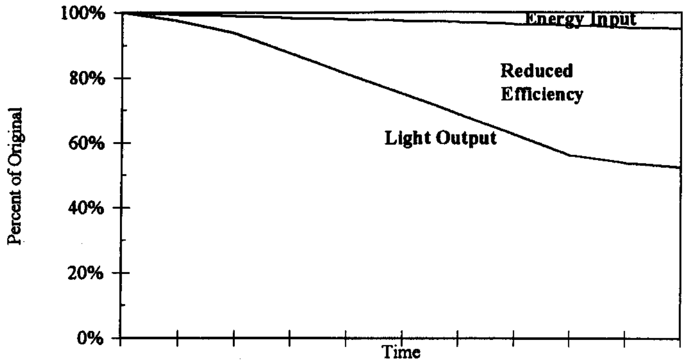
LIGHTING MAINTENANCE
Principles

- Proper maintenance is most neglected, most cost-effective means of reducing overall cost of lighting
- If maintenance is not performed, performance suffers gradually
- Final result is system performing at 50-60% of capability

Source: Lindsey - Applied Illumination Engineering - 1991

LIGHTING MAINTENANCE

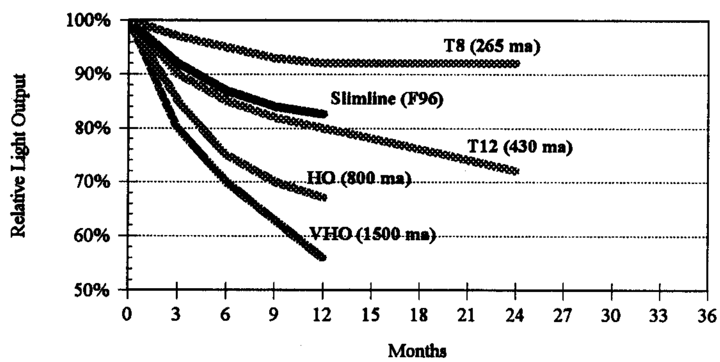
Neglected Lighting Systems Lose Efficiency Over Time



Source: EPA Green Lights - 1993

LIGHTING MAINTENANCE

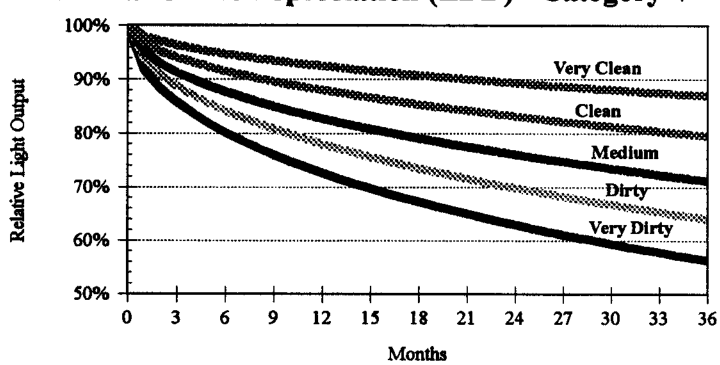
Fluorescent Lamp Lumen Depreciation (LLD)



Source: EPA Green Lights - 1993

LIGHTING MAINTENANCE

Luminaire Dirt Depreciation (LDD) - Category V



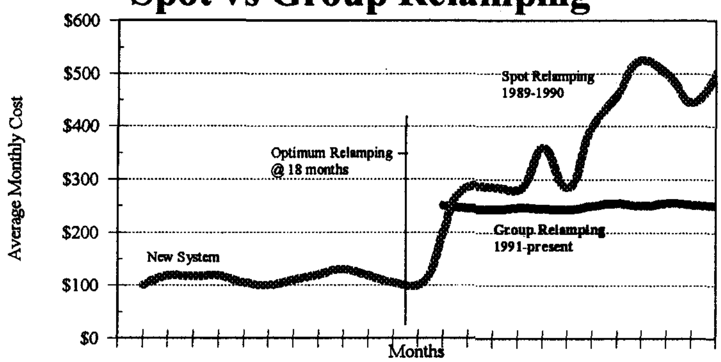
Source: IESNA Lighting Handbook

LIGHTING MAINTENANCE
Benefits of Group Relamping

- Lower labor cost
- More light
- Fewer un-replaced burnouts
- Less lamp stocking
- Fewer work interruptions

Source: GE Lighting - 1992

CASE STUDY
Spot vs Group Relamping



Source: EPA Green Lights - 1993

GROUP RELAMPING EXAMPLE

	Spot Relamping (on burn-out)		Group Relamping (@ 70% of rated life)	
Relamp cycle	20,000	hours	14,000	hours
Average relamps	525	relamps/yr	750	relamps/yr
Average material cost	$1,391	/year	$1,988	/year
Average labor cost	$3,150	/year	$1,125	/year
Average disposal cost	$263	/year	$375	/year
AVG. MAINT. BUDGET	$4,804	/year	$3,488	/year
Assumptions:				
Material	$2.65	/lamp	$2.65	/lamp
Labor (relamp & clean)	$6.00	/lamp	$1.50	/lamp
Disposal (recycle)	$0.50	/lamp	$0.50	/lamp
Operation	3,500	hours/yr	3,500	hours/yr
Fixtures	1,000	lensed troffers	1,000	lensed troffers
Lamps/fixture	3	F32T8	3	F32T8

SWROIL
Lighting Training Agenda

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- Light Sources and Characteristics
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- Lighting Design and Maintenance Principles
- Lighting Upgrade Opportunities
- Conducting a Lighting Survey
- **Analyzing Lighting Upgrade Opportunities**
- **Persuading the Client**
- Case Study

LIGHTING ECONOMICS
Session Objectives

- **Know how to calculate:**
  - lighting energy use and cost
  - annualized lighting maintenance (replacement) costs
  - after-tax energy savings
  - cooling savings (heating costs) resulting from lighting savings
  - present value of future costs
  - economic decision statistics for retrofit projects

Life Cycle Cost

The sum of time-equivalent costs of acquiring, owning, operating and maintaining a system over a designated study period.

Lighting Economics
Principles of Life Cycle Costing

- Lighting alternative designs must be equivalent
- All significant initial and future costs must be considered
- Costs must account for the time value of money

Source: IES ED-150.9

Lighting Economics
Lighting System Life Cycle Costs

- Initial Costs
- Energy Costs
- Maintenance Costs

Source: IES ED-150.9

Lighting Economics
Lighting System Life Cycle Costs

- **Initial Costs**
  - Equipment
  - Installation
  - Wiring
  - HVAC
- Energy Costs
- Maintenance Costs

Source: IES ED-150.9

Lighting Economics
Lighting System Life Cycle Costs

- Initial Costs
- **Energy Costs**
  - Direct Lighting Costs
  - Lighting-Related HVAC (Indirect) Costs
- Maintenance Costs

Source: IES ED-150.9

Direct Lighting Energy Costs

- Energy Use (kWh) =
  Lighting Power (kW)
  x Operating Time (hrs)
- Energy Cost Savings =
  Actual Avoided Costs
  (based on rate schedule)

Typical Lighting Operation

Building Type	Annual Hours of Operation
Assembly	2760
Avg. Non-Residential	3500
Education	2605
Food Sales	5200
Food Service	4580
Health Care	7630
Lodging	8025
Mercantile	3325
Office	2730
Warehouse	3295

Source: DOE/EIA "Lighting in Commercial Buildings"

Basics of Energy Accounting
Important Definitions

- Energy - capacity to do work, kilowatt-hour (kWh)
- Power - energy per unit time, kilowatt (kW)
- Demand - highest average power in demand interval
- Load Factor - ratio of average power to peak demand
- Power Factor - measure of real vs. apparent power

Basics of Energy Accounting
Components of a Typical Electric Bill

- Customer Charges - availability, meter, administrative
- Demand Charges - based on peak demand, may ratchet
- Energy Charges - charge for kWh used
  (usually a declining block rate)
- Power Factor Charges - if charged, typically a surcharge below specified P.F., or bill demand on kVA rather than kW
- Fuel Adjustment Charges - varies seasonally
- Utility Taxes

Basics of Energy Accounting
Example Electric Rate Schedules

- For the example rate schedules shown, what are the cost savings due to a reduction of one kWh of energy use?
  - based on average cost per kWh from monthly bill?
  - based on energy (kWh) savings without demand (kW) reduction?
  - based on energy (kWh) savings with demand (kW) reduction?

	TVA Example 1	TVA Example 2	TVA Example 3
Billing Demand, kW	750	1,000	500
Energy Consumed, kWh	180,000	180,000	180,000
Load Factor, %	33%	25%	50%

Customer Charge	$7.35	$7.35	$7.35	$7.35
Demand Charge				
First 50 kW	$0.00	0.00	0.00	0.00
Next 950 kW	$8.10	5,670.00	7,695.00	3,645.00
Next 1500 kW	$8.52	0.00	0.00	0.00
Additional kW	$8.94	0.00	0.00	0.00
Total Demand Charge		**$5,670.00**	**$7,695.00**	**$3,645.00**
Energy Charge				
First 15,000 kWh/month	$0.05860	879.00	879.00	879.00
Additional kWh/month	$0.03022	4,986.30	4,986.30	4,986.30
Total Energy Charge		**$5,865.30**	**$5,865.30**	**$5,865.30**
Subtotal		$11,542.65	$13,567.65	$9,517.65
Utility Tax	4%	$461.71	$542.71	$380.71
Total Bill		**$12,004.36**	**$14,110.36**	**$9,898.36**
Cost/kWh		$0.0667	$0.0784	$0.0550

	LPM Example 1	LPM Example 2	LPM Example 3
Billing Demand, kW	750	1,000	500
Energy Consumed, kWh	180,000	180,000	180,000
Load Factor, %	33%	25%	50%

Customer Charge	$0.00	$0.00	$0.00	$0.00
Demand Charge				
Per kW	$4.74	3,555.00	4,740.00	2,370.00
Total Demand Charge		**$3,555.00**	**$4,740.00**	**$2,370.00**
Energy Charge				
First 250*kW kWh/month	$0.044418	7,995.24	7,995.24	5,552.25
Additional kWh/month	$0.030220	0.00	0.00	1,662.10
Total Energy Charge		**$7,995.24**	**$7,995.24**	**$7,214.35**
Energy Cost Recovery ($/kW	**$0.017880**	**$3,218.40**	**$3,218.40**	**$3,218.40**
Subtotal		$14,768.64	$15,953.64	$12,802.75
State Utility License Tax	**1.8%**	$265.84	$287.17	$230.45
Subtotal (2)		$15,034.48	$16,240.81	$13,033.20
Utility Tax (on Sub(2)/1.022)	4%	$578.03	$624.41	$501.09
Total Bill		**$15,612.50**	**$16,865.21**	**$13,534.29**
Cost/kWh		$0.0867	$0.0937	$0.0752
Energy Charge step, kWh		*187,500*	*250,000*	*125,000*

Basics of Energy Accounting
Example Electric Rate Schedules

- How would cost savings be affected if "off-peak" rates for energy and demand were one-half of "on-peak" rates?
  - if energy reduction was equally split between "on-peak" and "off-peak" periods?
  - if energy reduction occurred only during "off-peak" hours?

Average vs. Avoided Energy Cost

With most electric rate schedules, use of average cost of electricity rather than avoided cost can lead to misleading results.

Lighting-Related HVAC Energy

- **How much lighting energy becomes a load on the HVAC system?**
  - How much heat is generated?
  - Where does it go?
  - How does it affect the energy consumption of the HVAC system?

Lighting-Related HVAC Energy

- Lighting-Related HVAC Energy (kWh) =

  Direct Lighting Energy (kWh)

  x % of year HVAC System Operates

  x % of light heat impacting HVAC load

  ÷ % efficiency of HVAC system

Lighting-Related HVAC Energy

- Efficiency = $\frac{\text{Energy Units Delivered to (Removed from) Space}}{\text{Energy Units Into System}}$

- Efficiency (Cooling) = $\frac{\text{SEER (Btuh/W)}}{\text{3.413 (Btuh/W)}}$

Lighting-Related HVAC Energy

- Mendelsohn and Rundquist have published example data (see "The Domino Effect," Strategic Planning for Energy and the Environment)

- For example, additional A/C benefit:

Atlanta, GA	19%
Chicago, IL	13%
Denver, CO	14%
Houston, TX	27%
Los Angeles, CA	21%
Minneapolis, MN	12%
New York, NY	13%
Seattle, WA	6%

Lighting Economics
Lighting System Life Cycle Costs

- Initial Costs
- Energy Costs
- **Maintenance Costs**
  - Relamping
  - Reballasting
  - Cleaning
  - Miscellaneous Maintenance
  - Insurance & Property Taxes
  - Depreciation

Source: IES ED-150.9

Economic Analysis
Income Tax Impact

Given: Gross (Energy) Savings = \$100
Tax Rate = 40%

Find: Net (After-Tax) Energy Savings

Economic Analysis
Income Tax Impact

Solution: Increase in Taxable Income = \$100

Tax = Increase in Taxable Income x Tax Rate
= \$100 x 40% = \$40

Net Savings = Gross Savings - Tax
= \$100 - \$40 = \$60

Economic Analysis
Income Tax Impact

Net Savings = Gross Savings - Tax
= Gross Savings
- (Gross Savings x Tax Rate)
= Gross Savings x (1 - Tax Rate)

(when no depreciation)

Economic Analysis
Depreciation

- Depreciation is an expense in the sense that something of value is being "used up"
- Expenses reduce income which lowers taxes

Economic Analysis
Depreciation Example

Given:
Gross (Energy) Savings = $100
Tax Rate = 40%
Depreciation = $50 (for current year)

Find:
Net (After-Tax) Energy Savings

Economic Analysis
Depreciation Example

Solution:

Incr. in Taxable Inc. = Gross Savings - Depreciation
= \$100 - \$50 = \$50

Tax = Incr. in Taxable Inc. x Tax Rate
= \$50 x 40% = \$20

Net Savings = Gross Savings - Tax
= \$100 - \$20 = \$80

Economic Analysis

- Basic decisions to be made:

1. Do I accept or reject this project?
2. Which of these proposed projects do I select?

- What decision statistics should be used?

Economic Analysis
Example Decision Statistics

- Simple Payback Period (SPB)
- Discounted Payback Period (DPB)
- Life Cycle Cost (LCC)
- Internal Rate-of-Return (IRR)
- Adjusted Internal Rate-of-Return (AIRR)
- Savings-to-Investment Ratio (SIR)

Economic Analysis
Time Value of Money

- How much is $100 today worth:
  - in one year?
  - in five years?

- What is the value today of $1000 to be received:
  - one year from today?
  - ten years from today?

Economic Analysis
Time Value of Money

- Discounting is the method of converting future amounts to their present value so they can be added, compared, etc.

- An interest rate, or minimum attractive rate of return is needed to discount a future amount to its present value

Economic Analysis
Terminology

- P = present value, $
- F = future value, $
- A = annually recurring amount, $
- i = interest (discount) rate, %
- n = term, number of years
- SPV = Single Present Value factor
- UPV = Uniform Present Value factor

Single Present Value (SPV) Discount Factors

for finding the present value (P) of a future amount (F)

(P/F,i%,n)

$P = F\ [1/(1+i)^{\wedge}n]$

Years	Interest Rate (i)																			
(n)	1%	2%	3%	4%	5%	6%	7%	8%	9%	10%	11%	12%	13%	14%	15%	20%	25%	30%	35%	40%
1	0.990	0.980	0.971	0.962	0.952	0.943	0.935	0.926	0.917	0.909	0.901	0.893	0.885	0.877	0.870	0.833	0.800	0.769	0.741	0.714
2	0.980	0.961	0.943	0.925	0.907	0.890	0.873	0.857	0.842	0.826	0.812	0.797	0.783	0.769	0.756	0.694	0.640	0.592	0.549	0.510
3	0.971	0.942	0.915	0.889	0.864	0.840	0.816	0.794	0.772	0.751	0.731	0.712	0.693	0.675	0.658	0.579	0.512	0.455	0.406	0.364
4	0.961	0.924	0.888	0.855	0.823	0.792	0.763	0.735	0.708	0.683	0.659	0.636	0.613	0.592	0.572	0.482	0.410	0.350	0.301	0.260
5	0.951	0.906	0.863	0.822	0.784	0.747	0.713	0.681	0.650	0.621	0.593	0.567	0.543	0.519	0.497	0.402	0.328	0.269	0.223	0.186
6	0.942	0.888	0.837	0.790	0.746	0.705	0.666	0.630	0.596	0.564	0.535	0.507	0.480	0.456	0.432	0.335	0.262	0.207	0.165	0.133
7	0.933	0.871	0.813	0.760	0.711	0.665	0.623	0.583	0.547	0.513	0.482	0.452	0.425	0.400	0.376	0.279	0.210	0.159	0.122	0.095
8	0.923	0.853	0.789	0.731	0.677	0.627	0.582	0.540	0.502	0.467	0.434	0.404	0.376	0.351	0.327	0.233	0.168	0.123	0.091	0.068
9	0.914	0.837	0.766	0.703	0.645	0.592	0.544	0.500	0.460	0.424	0.391	0.361	0.333	0.308	0.284	0.194	0.134	0.094	0.067	0.048
10	0.905	0.820	0.744	0.676	0.614	0.558	0.508	0.463	0.422	0.386	0.352	0.322	0.295	0.270	0.247	0.162	0.107	0.073	0.050	0.035
11	0.896	0.804	0.722	0.650	0.585	0.527	0.475	0.429	0.388	0.350	0.317	0.287	0.261	0.237	0.215	0.135	0.086	0.056	0.037	0.025
12	0.887	0.788	0.701	0.625	0.557	0.497	0.444	0.397	0.356	0.319	0.286	0.257	0.231	0.208	0.187	0.112	0.069	0.043	0.027	0.018
13	0.879	0.773	0.681	0.601	0.530	0.469	0.415	0.368	0.326	0.290	0.258	0.229	0.204	0.182	0.163	0.093	0.055	0.033	0.020	0.013
14	0.870	0.758	0.661	0.577	0.505	0.442	0.388	0.340	0.299	0.263	0.232	0.205	0.181	0.160	0.141	0.078	0.044	0.025	0.015	0.009
15	0.861	0.743	0.642	0.555	0.481	0.417	0.362	0.315	0.275	0.239	0.209	0.183	0.160	0.140	0.123	0.065	0.035	0.020	0.011	0.006
16	0.853	0.728	0.623	0.534	0.458	0.394	0.339	0.292	0.252	0.218	0.188	0.163	0.141	0.123	0.107	0.054	0.028	0.015	0.008	0.005
17	0.844	0.714	0.605	0.513	0.436	0.371	0.317	0.270	0.231	0.198	0.170	0.146	0.125	0.108	0.093	0.045	0.023	0.012	0.006	0.003
18	0.836	0.700	0.587	0.494	0.416	0.350	0.296	0.250	0.212	0.180	0.153	0.130	0.111	0.095	0.081	0.038	0.018	0.009	0.005	0.002
19	0.828	0.686	0.570	0.475	0.396	0.331	0.277	0.232	0.194	0.164	0.138	0.116	0.098	0.083	0.070	0.031	0.014	0.007	0.003	0.002
20	0.820	0.673	0.554	0.456	0.377	0.312	0.258	0.215	0.178	0.149	0.124	0.104	0.087	0.073	0.061	0.026	0.012	0.005	0.002	0.001
21	0.811	0.660	0.538	0.439	0.359	0.294	0.242	0.199	0.164	0.135	0.112	0.093	0.077	0.064	0.053	0.022	0.009	0.004	0.002	0.001
22	0.803	0.647	0.522	0.422	0.342	0.278	0.226	0.184	0.150	0.123	0.101	0.083	0.068	0.056	0.046	0.018	0.007	0.003	0.001	0.001
23	0.795	0.634	0.507	0.406	0.326	0.262	0.211	0.170	0.138	0.112	0.091	0.074	0.060	0.049	0.040	0.015	0.006	0.002	0.001	0.000
24	0.788	0.622	0.492	0.390	0.310	0.247	0.197	0.158	0.126	0.102	0.082	0.066	0.053	0.043	0.035	0.013	0.005	0.002	0.001	0.000
25	0.780	0.610	0.478	0.375	0.295	0.233	0.184	0.146	0.116	0.092	0.074	0.059	0.047	0.038	0.030	0.010	0.004	0.001	0.001	0.000

Uniform Present Value (UPV) Discount Factors

for finding the present value (P) of a series of uniformly recurring future amounts (A)

(P/A,i%,n)

P = A [((1+i)^n-1)/(i*(1+i)^n)]

Years	Interest Rate (i)																			
(n)	1%	2%	3%	4%	5%	6%	7%	8%	9%	10%	11%	12%	13%	14%	15%	20%	25%	30%	35%	40%
1	0.990	0.980	0.971	0.962	0.952	0.943	0.935	0.926	0.917	0.909	0.901	0.893	0.885	0.877	0.870	0.833	0.800	0.769	0.741	0.714
2	1.970	1.942	1.913	1.886	1.859	1.833	1.808	1.783	1.759	1.736	1.713	1.690	1.668	1.647	1.626	1.528	1.440	1.361	1.289	1.224
3	2.941	2.884	2.829	2.775	2.723	2.673	2.624	2.577	2.531	2.487	2.444	2.402	2.361	2.322	2.283	2.106	1.952	1.816	1.696	1.589
4	3.902	3.808	3.717	3.630	3.546	3.465	3.387	3.312	3.240	3.170	3.102	3.037	2.974	2.914	2.855	2.589	2.362	2.166	1.997	1.849
5	4.853	4.713	4.580	4.452	4.329	4.212	4.100	3.993	3.890	3.791	3.696	3.605	3.517	3.433	3.352	2.991	2.689	2.436	2.220	2.035
6	5.795	5.601	5.417	5.242	5.076	4.917	4.767	4.623	4.486	4.355	4.231	4.111	3.998	3.889	3.784	3.326	2.951	2.643	2.385	2.168
7	6.728	6.472	6.230	6.002	5.786	5.582	5.389	5.206	5.033	4.868	4.712	4.564	4.423	4.288	4.160	3.605	3.161	2.802	2.508	2.263
8	7.652	7.325	7.020	6.733	6.463	6.210	5.971	5.747	5.535	5.335	5.146	4.968	4.799	4.639	4.487	3.837	3.329	2.925	2.598	2.331
9	8.566	8.162	7.786	7.435	7.108	6.802	6.515	6.247	5.995	5.759	5.537	5.328	5.132	4.946	4.772	4.031	3.463	3.019	2.665	2.379
10	9.471	8.983	8.530	8.111	7.722	7.360	7.024	6.710	6.418	6.145	5.889	5.650	5.426	5.216	5.019	4.192	3.571	3.092	2.715	2.414
11	10.368	9.787	9.253	8.760	8.306	7.887	7.499	7.139	6.805	6.495	6.207	5.938	5.687	5.453	5.234	4.327	3.656	3.147	2.752	2.438
12	11.255	10.575	9.954	9.385	8.863	8.384	7.943	7.536	7.161	6.814	6.492	6.194	5.918	5.660	5.421	4.439	3.725	3.190	2.779	2.456
13	12.134	11.348	10.635	9.986	9.394	8.853	8.358	7.904	7.487	7.103	6.750	6.424	6.122	5.842	5.583	4.533	3.780	3.223	2.799	2.469
14	13.004	12.106	11.296	10.563	9.899	9.295	8.745	8.244	7.786	7.367	6.982	6.628	6.302	6.002	5.724	4.611	3.824	3.249	2.814	2.478
15	13.865	12.849	11.938	11.118	10.380	9.712	9.108	8.559	8.061	7.606	7.191	6.811	6.462	6.142	5.847	4.675	3.859	3.268	2.825	2.484
16	14.718	13.578	12.561	11.652	10.838	10.106	9.447	8.851	8.313	7.824	7.379	6.974	6.604	6.265	5.954	4.730	3.887	3.283	2.834	2.489
17	15.562	14.292	13.166	12.166	11.274	10.477	9.763	9.122	8.544	8.022	7.549	7.120	6.729	6.373	6.047	4.775	3.910	3.295	2.840	2.492
18	16.398	14.992	13.754	12.659	11.690	10.828	10.059	9.372	8.756	8.201	7.702	7.250	6.840	6.467	6.128	4.812	3.928	3.304	2.844	2.494
19	17.226	15.678	14.324	13.134	12.085	11.158	10.336	9.604	8.950	8.365	7.839	7.366	6.938	6.550	6.198	4.843	3.942	3.311	2.848	2.496
20	18.046	16.351	14.877	13.590	12.462	11.470	10.594	9.818	9.129	8.514	7.963	7.469	7.025	6.623	6.259	4.870	3.954	3.316	2.850	2.497
21	18.857	17.011	15.415	14.029	12.821	11.764	10.836	10.017	9.292	8.649	8.075	7.562	7.102	6.687	6.312	4.891	3.963	3.320	2.852	2.498
22	19.660	17.658	15.937	14.451	13.163	12.042	11.061	10.201	9.442	8.772	8.176	7.645	7.170	6.743	6.359	4.909	3.970	3.323	2.853	2.498
23	20.456	18.292	16.444	14.857	13.489	12.303	11.272	10.371	9.580	8.883	8.266	7.718	7.230	6.792	6.399	4.925	3.976	3.325	2.854	2.499
24	21.243	18.914	16.936	15.247	13.799	12.550	11.469	10.529	9.707	8.985	8.348	7.784	7.283	6.835	6.434	4.937	3.981	3.327	2.855	2.499
25	22.023	19.523	17.413	15.622	14.094	12.783	11.654	10.675	9.823	9.077	8.422	7.843	7.330	6.873	6.464	4.948	3.985	3.329	2.856	2.499

Estimating the IRR from Simple Payback

1. Compute simple payback based on net annualized savings.
   - Simple Payback = $\frac{P}{A}$
2. Estimate useful life of project.
3. Enter UPV (or UPV*) table at year n = useful life.
4. Move across row until simple payback value is found (or values bounding it).
5. Move up the column to read corresponding interest rate, i% (interpolate if necessary) - this is the IRR for the project.

Dealing With Uncertainty About Future Energy Prices

- Use UPV* tables for estimating IRR when energy costs (savings) are assumed to escalate (inflate) at a constant rate
- Consult NISTIR 85-3273-8, "Energy Prices and Discount Factors for Life-Cycle Cost Analysis 1994," for regional and fuel-specific estimates of future prices
  - required for federal sector LCC analysis
  - supplement to NIST Handbook 135, "Life Cycle Costing Manual for the Federal Energy Management Program"
  - built into BLCC computer program

Lighting Economic Analysis

Computer Tools

- Spreadsheets
- EPA Green Lights Software
  - QUIKALC
  - Decision Support System
- Other Government Software
  - BLCC
  - FEDS, LSST, LTSM
- EPRI LightPAD
- Manufacturer Software
  - E.g., Sylvia pc

Modified Uniform Present Value (UPV*) Discount Factors

for finding the present value (P) of a series of future amounts based on a current amount A(0) escalating at a given inflation rate (e)

(P/A(0),i%,n)

$P = A(0)*[(1+e)/(i-e)]*[1-((1+e)/(1+i))^n]$

5% Escalation/inflation rate (e)

Years (n)	Interest Rate (i) 1%	2%	3%	4%	5%	6%	7%	8%	9%	10%	11%	12%	13%	14%	15%	20%	25%	30%	35%	40%
1	1.040	1.029	1.019	1.010	1.000	0.991	0.981	0.972	0.963	0.955	0.946	0.938	0.929	0.921	0.913	0.875	0.840	0.808	0.778	0.750
2	2.120	2.089	2.059	2.029	2.000	1.972	1.944	1.917	1.891	1.866	1.841	1.816	1.793	1.769	1.747	1.641	1.546	1.460	1.383	1.313
3	3.244	3.180	3.118	3.058	3.000	2.944	2.889	2.836	2.785	2.735	2.687	2.640	2.595	2.551	2.508	2.311	2.138	1.987	1.853	1.734
4	4.412	4.303	4.198	4.097	4.000	3.907	3.817	3.730	3.646	3.566	3.488	3.413	3.340	3.270	3.203	2.897	2.636	2.413	2.219	2.051
5	5.626	5.459	5.299	5.146	5.000	4.860	4.727	4.598	4.476	4.358	4.245	4.137	4.033	3.933	3.837	3.410	3.054	2.756	2.504	2.288
6	6.889	6.649	6.421	6.205	6.000	5.805	5.619	5.443	5.275	5.115	4.962	4.816	4.677	4.544	4.417	3.858	3.406	3.034	2.725	2.466
7	8.201	7.874	7.565	7.274	7.000	6.741	6.496	6.264	6.045	5.837	5.640	5.452	5.275	5.106	4.946	4.251	3.701	3.258	2.897	2.600
8	9.566	9.135	8.732	8.354	8.000	7.668	7.356	7.062	6.786	6.526	6.281	6.049	5.831	5.624	5.429	4.595	3.949	3.439	3.031	2.700
9	10.984	10.433	9.921	9.444	9.000	8.586	8.199	7.838	7.500	7.184	6.887	6.609	6.347	6.101	5.870	4.895	4.157	3.586	3.135	2.775
10	12.459	11.769	11.133	10.544	10.000	9.496	9.028	8.593	8.188	7.812	7.461	7.133	6.827	6.541	6.272	5.158	4.332	3.704	3.216	2.831
11	13.992	13.145	12.368	11.655	11.000	10.397	9.840	9.326	8.851	8.411	8.003	7.625	7.273	6.945	6.640	5.389	4.479	3.799	3.279	2.873
12	15.585	14.561	13.628	12.777	12.000	11.289	10.637	10.039	9.490	8.983	8.517	8.086	7.687	7.318	6.976	5.590	4.602	3.876	3.328	2.905
13	17.242	16.018	14.912	13.910	13.000	12.173	11.420	10.733	10.105	9.530	9.002	8.518	8.072	7.661	7.282	5.766	4.706	3.939	3.367	2.929
14	18.965	17.519	16.221	15.053	14.000	13.049	12.188	11.407	10.697	10.051	9.462	8.923	8.430	7.977	7.562	5.921	4.793	3.989	3.396	2.947
15	20.755	19.064	17.555	16.207	15.000	13.916	12.941	12.062	11.268	10.549	9.896	9.303	8.762	8.269	7.817	6.055	4.866	4.029	3.419	2.960
16	22.617	20.654	18.916	17.373	16.000	14.776	13.681	12.699	11.818	11.024	10.307	9.659	9.071	8.537	8.051	6.174	4.927	4.062	3.437	2.970
17	24.552	22.291	20.302	18.549	17.000	15.627	14.406	13.319	12.347	11.477	10.696	9.993	9.358	8.784	8.264	6.277	4.979	4.089	3.451	2.977
18	26.564	23.976	21.716	19.737	18.000	16.470	15.118	13.921	12.858	11.910	11.064	10.306	9.625	9.012	8.458	6.367	5.022	4.110	3.462	2.983
19	28.656	25.710	23.157	20.937	19.000	17.305	15.817	14.507	13.349	12.323	11.412	10.599	9.873	9.221	8.636	6.446	5.059	4.127	3.470	2.987
20	30.831	27.496	24.626	22.148	20.000	18.132	16.503	15.076	13.822	12.718	11.741	10.874	10.103	9.414	8.798	6.516	5.089	4.141	3.477	2.990
21	33.091	29.334	26.124	23.370	21.000	18.952	17.176	15.629	14.279	13.094	12.052	11.132	10.317	9.592	8.946	6.576	5.115	4.153	3.482	2.993
22	35.441	31.226	27.650	24.605	22.000	19.764	17.836	16.167	14.718	13.454	12.347	11.374	10.516	9.756	9.081	6.629	5.137	4.162	3.486	2.995
23	37.884	33.174	29.207	25.851	23.000	20.568	18.484	16.691	15.141	13.797	12.625	11.600	10.700	9.907	9.204	6.675	5.155	4.169	3.489	2.996
24	40.424	35.179	30.793	27.109	24.000	21.364	19.120	17.199	15.549	14.124	12.889	11.813	10.872	10.046	9.317	6.716	5.170	4.175	3.492	2.997
25	43.065	37.243	32.410	28.379	25.000	22.153	19.744	17.694	15.941	14.437	13.138	12.012	11.032	10.174	9.420	6.752	5.183	4.180	3.493	2.998

Modified Uniform Present Value (UPV*) Discount Factors

for finding the present value (P) of a series of future amounts based on a current amount A(0) escalating at a given inflation rate (e)

(P/A(0),i%,n)

P = A(0)*[(1+e)/(i-e)]*[1-((1+e)/(1+i)) ^ n]

10% Escalation/inflation rate (e)

Years	Interest Rate (i)																			
(n)	1%	2%	3%	4%	5%	6%	7%	8%	9%	10%	11%	12%	13%	14%	15%	20%	25%	30%	35%	40%
1	1.089	1.078	1.068	1.058	1.048	1.038	1.028	1.019	1.009	1.000	0.991	0.982	0.973	0.965	0.957	0.917	0.880	0.846	0.815	0.786
2	2.275	2.241	2.209	2.176	2.145	2.115	2.085	2.056	2.028	2.000	1.973	1.947	1.921	1.896	1.871	1.757	1.654	1.562	1.479	1.403
3	3.567	3.496	3.427	3.360	3.295	3.232	3.171	3.112	3.055	3.000	2.946	2.894	2.844	2.794	2.747	2.527	2.336	2.168	2.020	1.888
4	4.974	4.848	4.727	4.611	4.499	4.392	4.288	4.189	4.093	4.000	3.911	3.825	3.741	3.661	3.584	3.233	2.936	2.681	2.461	2.269
5	6.506	6.307	6.117	5.935	5.761	5.595	5.437	5.285	5.139	5.000	4.866	4.738	4.616	4.498	4.384	3.880	3.463	3.114	2.820	2.569
6	8.175	7.880	7.600	7.335	7.083	6.844	6.617	6.401	6.196	6.000	5.814	5.636	5.467	5.305	5.150	4.474	3.928	3.481	3.112	2.804
7	9.993	9.577	9.185	8.816	8.468	8.140	7.831	7.538	7.262	7.000	6.752	6.517	6.295	6.084	5.883	5.018	4.336	3.792	3.351	2.989
8	11.973	11.406	10.877	10.382	9.919	9.485	9.078	8.696	8.337	8.000	7.682	7.383	7.101	6.835	6.584	5.516	4.696	4.055	3.545	3.134
9	14.128	13.379	12.684	12.039	11.439	10.881	10.361	9.876	9.423	9.000	8.604	8.234	7.886	7.560	7.254	5.973	5.012	4.277	3.703	3.248
10	16.477	15.507	14.614	13.791	13.031	12.329	11.679	11.077	10.519	10.000	9.518	9.069	8.650	8.260	7.895	6.392	5.291	4.465	3.832	3.338
11	19.034	17.802	16.675	15.644	14.699	13.832	13.035	12.301	11.624	11.000	10.423	9.889	9.394	8.935	8.508	6.776	5.536	4.624	3.938	3.408
12	21.819	20.276	18.876	17.605	16.447	15.392	14.428	13.547	12.740	12.000	11.320	10.694	10.118	9.586	9.095	7.128	5.752	4.759	4.023	3.464
13	24.852	22.945	21.227	19.678	18.278	17.010	15.861	14.817	13.866	13.000	12.209	11.486	10.823	10.215	9.656	7.451	5.942	4.873	4.093	3.507
14	28.156	25.823	23.738	21.871	20.196	18.690	17.334	16.110	15.003	14.000	13.090	12.263	11.509	10.821	10.193	7.746	6.109	4.970	4.150	3.541
15	31.754	28.927	26.419	24.190	22.205	20.433	18.848	17.426	16.149	15.000	13.963	13.026	12.177	11.407	10.706	8.018	6.256	5.051	4.196	3.568
16	35.673	32.274	29.283	26.644	24.310	22.242	20.404	18.768	17.307	16.000	14.828	13.775	12.827	11.971	11.197	8.266	6.385	5.120	4.234	3.589
17	39.941	35.884	32.341	29.239	26.515	24.119	22.004	20.134	18.475	17.000	15.686	14.511	13.460	12.516	11.667	8.494	6.499	5.179	4.265	3.606
18	44.589	39.776	35.606	31.983	28.826	26.067	23.649	21.525	19.653	18.000	16.535	15.234	14.076	13.042	12.116	8.703	6.599	5.228	4.290	3.619
19	49.651	43.975	39.094	34.886	31.246	28.088	25.340	22.942	20.843	19.000	17.377	15.945	14.676	13.549	12.546	8.894	6.687	5.270	4.310	3.629
20	55.165	48.502	42.819	37.956	33.782	30.186	27.079	24.386	22.043	20.000	18.212	16.642	15.260	14.039	12.957	9.070	6.765	5.305	4.327	3.637
21	61.170	53.384	46.797	41.204	36.438	32.363	28.866	25.856	23.255	21.000	19.039	17.327	15.828	14.511	13.350	9.231	6.833	5.335	4.340	3.644
22	67.709	58.650	51.045	44.639	39.221	34.622	30.703	27.353	24.477	22.000	19.858	18.000	16.381	14.967	13.726	9.378	6.893	5.361	4.351	3.648
23	74.832	64.328	55.583	48.272	42.136	36.966	32.592	28.878	25.711	23.000	20.670	18.660	16.920	15.406	14.086	9.513	6.946	5.382	4.360	3.652
24	82.589	70.452	60.428	52.114	45.190	39.398	34.534	30.431	26.956	24.000	21.475	19.309	17.444	15.831	14.430	9.637	6.992	5.400	4.368	3.655
25	91.038	77.056	65.603	56.178	48.389	41.923	36.530	32.013	28.213	25.000	22.273	19.947	17.954	16.240	14.759	9.751	7.033	5.416	4.374	3.658

Case Study Data

Fixture Data (from EPA GreenLights Quikalc V2.05)

Fixture Code	Fixture Type	Lamps Fixture	Lamp Type	Ballast Type	Lamps/ Ballast	Ballast Factor	System Watts
717	2x4-4L	4	F40T12	Standard	2	0.95	190
728	2x4-4L	4	F32T8	Electronic	4	0.90	105
495	2x4-2L	2	F40T12	Standard	2	0.95	95
504	2x4-2L	2	F32T8	Electronic	2	0.90	62

Cost Data and Assumptions

Description	Cost per Fixture Material	Cost per Fixture Labor
Silver-film Reflector	$45.00	$15.00
Aluminum Reflector	$35.00	$15.00
Electronic Ballast (2- or 4-lamp)	$30.00	$15.00
Reflector + Ballast		$20.00
Occupancy Sensor	$60.00	$15.00
F40T12 lamp	$1.00	
F32T8 lamp	$3.00	
Lamp Replacement Labor	$10.00 /hr	
Spot Replacement	15 min/lamp	
Group Replacement	1.5 min/lamp	
Cooling Operation	6 months/yr	
Cooling SEER	9.2 Btuh/W	
% Light Heat into Space	90%	
Discount Rate	4%	
Average Energy Cost	$0.0700 /kWh	
Incremental Energy Cost	$0.0302 /kWh	
Incremental Demand Cost	$8.10 /kW	

Filename: UAHMDHL0.WK1
Project: Madison Hall Classroom
Description: 24' x 24' x 10' Classroom with nine 2'x4' 4-tube troffers
Continue spot replacement of lamps
Use average cost of energy

INPUT DATA	EXISTING	E.B./T-8	SILVER REFL	E.B./T-8/S.R.	ALUM REFL
Fixture Characteristics					
Fixture Type	GL#717 - 2x4-4L	GL#728 - 2X4-4L	GL#495 - 2x4-2L	GL#504 - 2x4-2L	GL#495 - 2x4-2L
Number of Fixtures	9	9	9	9	9
Fixture Power, W/fixture	190	105	95	62	95
Estimated Useful Life, yrs	15	15	15	15	15
Lamp Characteristics					
Lamp Type	F40T12	F32T8	F40T12	F32T8	F40T12
Lamps per Fixture	4	4	2	2	2
Lamp Life, hrs	20000	20000	20000	20000	20000
Lamp Output, lumens (initial)	3150	2900	3150	2900	3150
Situation					
Daily Operation, hrs/day	12	12	12	12	12
Weekly Operation, days/wk	5	5	5	5	5
Annual Operation, wks/yr	50	50	50	50	50
Area Served, ft2	576	576	576	576	576
Measured Light Level, fc					
Quality of Light (subjective)					
Cooling Impact					
Cooling Operation, months/yr	6	6	6	6	6
Cooling SEER, Btuh/W	9.7	9.7	9.7	9.7	9.7
Light Heat into Cooled Space, %	90%	90%	90%	90%	90%
Installation & Replacement					
Fixed Installation Cost, $	$0.00	$0.00	$0.00	$0.00	$0.00
Variable Installation Cost, $/fixture	$0.00	$57.00	$62.00	$101.00	$52.00
Replacement Lamp Cost, $/lamp	$1.00	$3.00	$1.00	$3.00	$1.00
Replacement Labor, hrs/lamp	0.25	0.25	0.25	0.25	0.25
Labor Cost, $/hr	$10.00	$10.00	$10.00	$10.00	$10.00
Energy					
Energy Cost Method (0=avg, 1=incr)	0	0	0	0	0
Average Energy Cost, $/kWh	$0.0700	$0.0700	$0.0700	$0.0700	$0.0700
Incremental Energy Cost, $/kWh	$0.0302	$0.0302	$0.0302	$0.0302	$0.0302
Incremental Demand Cost, $/kW/month	$8.10	$8.10	$8.10	$8.10	$8.10
Financial					
Incremental Income Tax Rate, %	0.0%	0.0%	0.0%	0.0%	0.0%
Depreciation Rate, %/yr	0.0%	0.0%	0.0%	0.0%	0.0%
Discount Rate, %	4.0%	4.0%	4.0%	4.0%	4.0%

CALCULATED DATA		EXISTING	E.B./T-8	SILVER REFL	E.B./T-8/S.R.	ALUM REFL
Situation						
Total Light Output, lumens		113400	104400	56700	52200	56700
Lamp Efficacy, lumens/W		66.3	110.5	66.3	93.5	66.3
Total Connected Load, kW		1.710	0.945	0.855	0.558	0.855
Annual Operation, hrs/yr		3000	3000	3000	3000	3000
Power Density, W/ft2		2.97	1.64	1.48	0.97	1.48
Installation & Replacement						
Total Installed Cost, $		$0.00	$513.00	$558.00	$909.00	$468.00
Average Lamp Replacements, lamps/yr		5.4	5.4	2.7	2.7	2.7
Replacement Costs, $/lamp		$3.50	$5.50	$3.50	$5.50	$3.50
Total Annual Replacement Cost, $		$18.90	$29.70	$9.45	$14.85	$9.45
Energy						
Lighting Energy Consumption, kWh/yr		5130	2835	2565	1674	2565
Lighting-Related Cooling Energy, kWh/yr		812	449	406	265	406
Total Energy Consumption, kWh/yr		5942	3284	2971	1939	2971
Annual Energy Cost (avg), $		$415.96	$229.87	$207.98	$135.73	$207.98
Financial						
Before-Tax Operating Cost, $/yr		$434.86	$259.57	$217.43	$150.58	$217.43
Depreciation, $/yr		$0.00	$0.00	$0.00	$0.00	$0.00
Net Influence on Taxable Income, $/yr		$434.86	$259.57	$217.43	$150.58	$217.43
After-Tax Cash Flow, $/yr		$434.86	$259.57	$217.43	$150.58	$217.43
Environmental Emissions	lbs/kWh					
Carbon Dioxide, lbs/yr	1.48	8794.5	4860.1	4397.3	2869.8	4397.3
Sulfur Dioxide, lbs/yr	0.016	95.1	52.5	47.5	31.0	47.5
Nitrous Oxides, lbs/yr	0.007	41.6	23.0	20.8	13.6	20.8
Decision Statistics						
Simple Payback, yrs			2.9	2.6	3.2	2.2
Simple (Investor's) Rate of Return, %			34.2%	39.0%	31.3%	46.5%
Discounted Payback, yrs			3.2	2.8	3.5	2.3

Filename: UAHMDHL1.WK1
Project: Madison Hall Classroom
Description: 24' x 24' x 10' Classroom with nine 2'x4' 4-tube troffers
Continue spot replacement of lamps

INPUT DATA	EXISTING	E.B./T-8	SILVER REFL	E.B./T-8/S.R.	ALUM REFL
Fixture Characteristics					
Fixture Type	GL#717 - 2x4-4L	GL#728 - 2X4-4L	GL#495 - 2x4-2L	GL#504 - 2x4-2L	GL#495 - 2x4-2L
Number of Fixtures	9	9	9	9	9
Fixture Power, W/fixture	190	105	95	62	95
Estimated Useful Life, yrs	15	15	15	15	15
Lamp Characteristics					
Lamp Type	F40T12	F32T8	F40T12	F32T8	F40T12
Lamps per Fixture	4	4	2	2	2
Lamp Life, hrs	20000	20000	20000	20000	20000
Lamp Output, lumens (initial)	3150	2900	3150	2900	3150
Situation					
Daily Operation, hrs/day	12	12	12	12	12
Weekly Operation, days/wk	5	5	5	5	5
Annual Operation, wks/yr	50	50	50	50	50
Area Served, ft2	576	576	576	576	576
Measured Light Level, fc					
Quality of Light (subjective)					
Cooling Impact					
Cooling Operation, months/yr	6	6	6	6	6
Cooling SEER, Btuh/W	9.7	9.7	9.7	9.7	9.7
Light Heat into Cooled Space, %	90%	90%	90%	90%	90%
Installation & Replacement					
Fixed Installation Cost, $	$0.00	$0.00	$0.00	$0.00	$0.00
Variable Installation Cost, $/fixture	$0.00	$57.00	$62.00	$101.00	$52.00
Replacement Lamp Cost, $/lamp	$1.00	$3.00	$1.00	$3.00	$1.00
Replacement Labor, hrs/lamp	0.25	0.25	0.25	0.25	0.25
Labor Cost, $/hr	$10.00	$10.00	$10.00	$10.00	$10.00
Energy					
Energy Cost Method (0=avg, 1=incr)	1	1	1	1	1
Average Energy Cost, $/kWh	$0.0700	$0.0700	$0.0700	$0.0700	$0.0700
Incremental Energy Cost, $/kWh	$0.0302	$0.0302	$0.0302	$0.0302	$0.0302
Incremental Demand Cost, $/kW/month	$8.10	$8.10	$8.10	$8.10	$8.10
Financial					
Incremental Income Tax Rate, %	0.0%	0.0%	0.0%	0.0%	0.0%
Depreciation Rate, %/yr	0.0%	0.0%	0.0%	0.0%	0.0%
Discount Rate, %	4.0%	4.0%	4.0%	4.0%	4.0%

CALCULATED DATA		EXISTING	E.B./T-8	SILVER REFL	E.B./T-8/S.R.	ALUM REFL
Situation						
Total Light Output, lumens		113400	104400	56700	52200	56700
Lamp Efficacy, lumens/W		66.3	110.5	66.3	93.5	66.3
Total Connected Load, kW		1.710	0.945	0.855	0.558	0.855
Annual Operation, hrs/yr		3000	3000	3000	3000	3000
Power Density, W/ft2		2.97	1.64	1.48	0.97	1.48
Installation & Replacement						
Total Installed Cost, $		$0.00	$513.00	$558.00	$909.00	$468.00
Average Lamp Replacements, lamps/yr		5.4	5.4	2.7	2.7	2.7
Replacement Costs, $/lamp		$3.50	$5.50	$3.50	$5.50	$3.50
Total Annual Replacement Cost, $		$18.90	$29.70	$9.45	$14.85	$9.45
Energy						
Lighting Energy Consumption, kWh/yr		5130	2835	2565	1674	2565
Lighting-Related Cooling Energy, kWh/yr		812	449	406	265	406
Total Energy Consumption, kWh/yr		5942	3284	2971	1939	2971
Annual Energy Cost (Incr), $		$345.79	$191.09	$172.89	$112.84	$172.89
Financial						
Before-Tax Operating Cost, $/yr		$364.69	$220.79	$182.34	$127.69	$182.34
Depreciation, $/yr		$0.00	$0.00	$0.00	$0.00	$0.00
Net Influence on Taxable Income, $/yr		$364.69	$220.79	$182.34	$127.69	$182.34
After-Tax Cash Flow, $/yr		$364.69	$220.79	$182.34	$127.69	$182.34
Environmental Emissions	lbs/kWh					
Carbon Dioxide, lbs/yr	1.48	8794.5	4860.1	4397.3	2869.8	4397.3
Sulfur Dioxide, lbs/yr	0.016	95.1	52.5	47.5	31.0	47.5
Nitrous Oxides, lbs/yr	0.007	41.6	23.0	20.8	13.6	20.8
Decision Statistics						
Simple Payback, yrs			3.6	3.1	3.8	2.6
Simple (Investor's) Rate of Return, %			28.0%	32.7%	26.1%	39.0%
Discounted Payback, yrs			3.9	3.3	4.2	2.8

File I.D.: MDH307A

Description:
Madison Hall - Room 307 Pre-test

Test Personnel (note functions performed):
Kenny Spain, recording data; Bob Quick, reading light meter; Jim Hughes (Falcon), positioning light meter/tripod; Jim Brooks and Sharon Lester (TVA), measuring electrical data.

Pre-Test Checklist:

All lamps burning?	Yes
Lights/HVAC on at least one hour	Yes
Window wells/location blocked?	Yes
Light meter zeroed?	Yes
Alignment marks placed?	Yes

Reminders:
Do not block light sensor.
Vary order of readings test-to-test.
Note any anomalies.

	Start	End	Max	Min	Avg
Date	09/15/92				
Time	11:30	11:51			
Hours on lamps	Random				
Room Temp, F	74.3	73.8	74.3	72.2	73.2
Room RH, %	55.0	54.4	57.1	54.2	55.6
Volts					278.2
Amps					5.173
kVA					1.439
kW					1.428
VAR					179.6
Power Factor					0.99
THD (Volts)					1.50%
THD (Amps)					8.25%

Electrical data is five minute average taken at 14:40 on 09/15/92.

158.7 Avg W/fixt

Vertical Illuminance, footcandles (on chalkboard)

	B	C	D	E	F	G	Avg
84"	58.2	52.2	47.0	55.2	63.3	55.8	55.3
66"	48.6	47.5	48.6	51.5	53.5	50.6	50.1
48"	42.7	43.0	45.4	46.8	46.2	44.3	44.7
Avg	49.8	47.6	47.0	51.2	54.3	50.2	50.0

Horizontal Illuminance (30"), footcandles

	A	B	C	D	E	F	G	Avg
1	53.1	58.4	60.5	62.3	63.5	65.1	62.8	60.8
2	58.9	66.1	68.6	70.4	71.4	72.7	71.0	68.4
3	60.2	68.1	71.2	73.1	75.0	74.7	73.8	70.9
4	62.4	67.4	70.5	72.6	73.8	72.7	72.9	70.3
5	58.6	66.2	69.9	71.6	72.7	70.5	71.4	68.7
6	58.0	65.4	69.5	70.9	72.3	68.5	69.9	67.8
7	56.5	63.5	68.4	70.1	71.8	64.7	66.5	65.9
Avg	58.2	65.0	68.4	70.1	71.5	69.8	69.8	67.6

Comments:
Room has additional chalkboard on sidewall with door. Fixture lenses and lamps had significant dirt accumulation. Found middle fixture at back of room with 2 lamps off at 14:21 (after test); lamps came back on without any action taken at 14:34. Subsequent inspection revealed ballasts in fixture were original equipment (mfg 1966) so newer ballast from another fixture in room was used in th fixture when reflectors were installed. Fixture inventory found one with two 1966 magnetic ballast, four with two 1984 standard magnetic ballasts each, four with two 1990 energy-saving magnetic ballasts each. 29 each 34W lamps were in use, 7 each 40W lamps. Fixtures nearest blackboard (top) had 34W lamps, other two in test area had 40W lamps.

Madison Hall Lighting Test Summary

	Electrical			Horizontal Illuminance				Vertical Illuminance			
	Load	Change		@ 30"	Change			on board	Change		
	kW	kW	%	fc	fc	%	fc/kW	fc	fc	%	fc/kW
Baseline (use Room 200 post-test)	1.554	0.000	0.0%	91.8	0.0	0.0%	59.1	60.2	0.0	0.0%	38.7
Elec ballast (EB) with 4 ea T8 lamps	0.863	-0.691	-44.5%	97.1	5.3	5.8%	112.5	63.6	3.4	5.6%	73.7
EB with 2 ea T8 lamps & silver reflector	0.585	-0.969	-62.4%	77.9	-13.9	-15.1%	133.2	51.1	-9.1	-15.1%	87.4
Silver reflector & new T12 lamps	0.744	-0.810	-52.1%	64.1	-27.7	-30.2%	86.2	43	-17.2	-28.6%	57.8
Aluminum reflector & new T12 lamps	0.744	-0.810	-52.1%	58.7	-33.1	-36.1%	78.9	39.4	-20.8	-34.6%	53.0

Madison Hall Lighting Test Summary

Room	Project/Comment	FileID	ElecLoad kW	Average Illuminance, fc Horz (30")	Vert (board)
200	**New lenses and F40T12CW lamps**				
	Pre-test electrical (as found)	200E1	1.395		
	Pre-test (as found)	200A		84.4	57.2
	After cleaning lenses	200B		87.7	59.6
	After installing new lenses	200C		87.1	53.0
	After new lamps (5 hrs lamp op)	200D		105.9	65.7
	Post-test electrical		1.554		
	Post-test (100 hrs lamp op)	200F		91.8	60.2
201	**Elec ballast (EB) with 4 ea T8 lamps**				
	Pre-test electrical (as found)	201E1	1.390		
	Pre-test (as found)	201A		85.4	53.9
	Initial after (25 hr)	201B		98.7	63.7
	Post-test electrical	200E2	0.863		
	Post-test (100 hrs lamp op)	201F		97.1	63.6
300	**EB with 2 ea T8 lamps & silver reflector**				
	Pre-test electrical (as found)	300E1	1.432		
	Pre-test (as found)	300A		78.8	53.4
	Initial after (1 hr)	300B		77.4	50.4
	Initial after (23 hr)	300C		78.4	51.0
	Post-test electrical	300E2	0.585		
	Post-test (100 hrs lamp op)	300F		77.9	51.1
307	**Silver reflector & new T12 lamps**				
	Pre-test (as found)	307A	1.428	67.6	50.0
	After installation (20 min)	307B		68.8	45.6
	Post-test electrical	307E2	0.744		
	Post-test (100 hrs lamp op)	307F		64.1	43.0
308	**Aluminum reflector & new T12 lamps**				
	Pre-test (as found)	308A	1.393	96.7	54.3
	After installation (30 hr)	308B		59.9	39.7
	Post-test electrical	308E2	0.744		
	Post-test (100 hrs lamp op)	308F		58.7	39.4

Summary of Analysis

Filename	Cost of Energy	Lamp Replacement	Fixture Power	Occupancy Sensor	Simple Payback			
					E.B./T-8	Silver Refl	E.B./T-8/S.R	Alum Refl
UAHMDHL0	Average	Spot	Estimate	No	2.9	2.6	3.2	2.2
UAHMDHL1	Incremental	Spot	Estimate	No	3.6	3.1	3.8	2.6
UAHMDHL2	Incremental	Spot	Actual	No	4.0	3.2	4.5	2.7
UAHMDHL3	Incremental	Group	Actual	No	3.6	3.1	4.4	2.6
UAHMDHL4	**Incremental**	**Spot**	**Actual**	**Yes**	**3.7**	**3.2**	**4.5**	**2.8**
UAHMDHL5	Average	Spot	Actual	Yes	2.7	2.5	3.5	2.1

	Existing	E.B./T-8	Silver Refl	E.B./T-8/S.R	Alum Refl
First Cost	$0.00	$588.00	$633.00	$984.00	$543.00
Annual Energy Cost	314.24	151.85	130.91	102.94	130.91
Annual Replacement Cost	18.90	22.28	7.09	11.14	7.09
Total Annual Cost	$333.14	$174.13	$138.00	$114.08	$138.00
Annual Savings	$0.00	$159.01	$195.14	$219.06	$195.14
Simple Payback	NA	3.7	3.2	4.5	2.8
Simple Rate of Return	NA	27.0%	30.8%	22.3%	35.9%
Discounted Payback	NA	4.1	3.5	5.0	3.0
Life Cycle Cost	$3,704	$2,524	$2,167	$2,252	$2,077
Net Savings	NA	$1,180	$1,537	$1,452	$1,627
Internal Rate of Return	NA	26.2%	30.2%	21.0%	35.6%
Adjusted Internal Rate of Return	NA	11.9%	12.9%	10.5%	14.1%
Savings-to-Investment Ratio	NA	3.0	3.4	2.5	4.0

Chapter 1

Green Lights Program

This chapter contains a collection of documents that describe the Green Lights Program, support services offered by EPA, and environmental benefits that result from the reducing electricity consumption through the use of energy-efficient lighting technologies. The following documents are included in this chapter:

General Information

- Green Lights Informational Brochure
- Principles of Agreement Between Partners and EPA

Partner Support Programs

- Green Lights Electronic Bulletin Board
- National Lighting Product Information Program (NLPIP)
- Light Briefs
- Lighting Upgrade Manual
- Lighting Upgrade Workshops
- Green Lights Financing Directory
- Green Lights Ally Programs
- Decision Support System
- Quikalc
- IRRkalc
- Implementation Planning Assistance
- Corporate Communications
- Case Studies

Environmental Protection

- EPA's Role in Environmental Protection
- Lighting and the Environment: The Connection
- Green Lights Pollution Prevention Assessment
- Emission Factors by Region/State

United States
Environmental Protection
Agency

Air and Radiation
6202J

EPA 430-F-92-013
August 1992

Green Lights Program

A Bright Investment in the Environment

The U.S. Environmental Protection Agency's (EPAs) Green Lights Program is a breath of fresh air for the nation's environmental health and economic growth. Green Lights, a voluntary program that encourages the widespread use of energy-efficient lighting, is proving that environment and industry can work together to create a cost-efficient and environmentally aware America.

As part of this unique partnership, Green Lights participants—including corporations, environmental groups, electric utilities, and state, city, and local governments—have come together to promote the widespread use of efficient lighting systems that reduce pollution. By investing in these technologies, Green Lights participants realize average returns of 25 percent, with average savings in lighting electricity bills of 50 percent or more. Through the use of these technologies, partners are reducing emissions of pollutants associated with global warming, acid rain, and smog.

As the first of similar market-driven, non-regulatory "green" programs sponsored by EPA, Green Lights is revolutionizing the way America cleans up the environment.

Energy-Efficient Lighting Prevents Pollution

Increased energy efficiency is the cornerstone of EPA's new pollution prevention strategy. Green Lights encourages voluntary reductions in energy use through revolutionary lighting technologies.

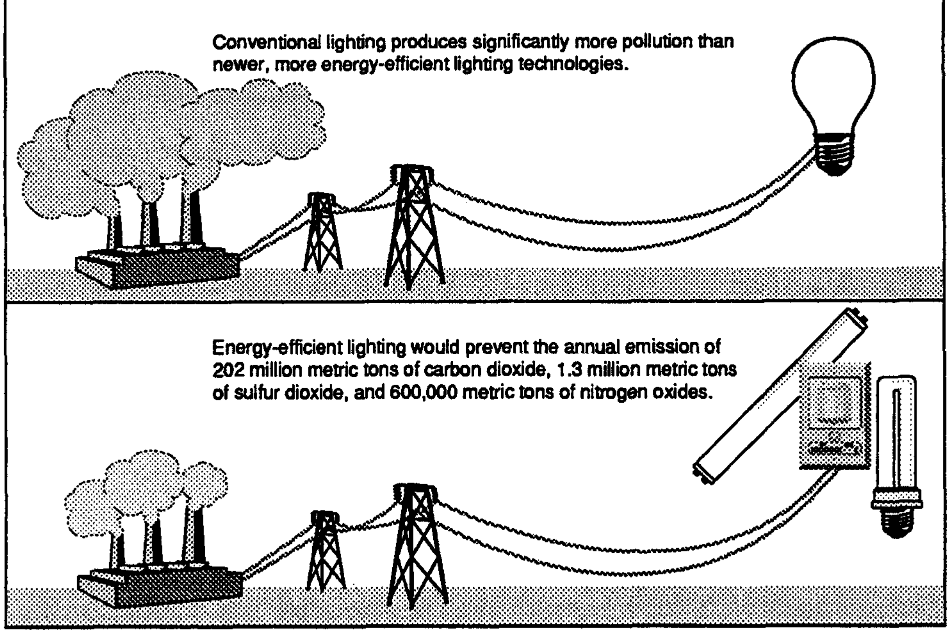
The process by which energy-efficient lighting reduces pollution is simple. Lighting accounts for 20-25 percent of electricity used annually in the United States. Lighting for industry, businesses, offices, and warehouses represents 80-90 percent of total lighting electricity use.

Generating electricity involves the burning of fossil fuels or running a nuclear reactor or hydroelectric plant. These processes often result in various types of pollution, including acid mine drainage, oil spills, natural gas leakage, toxic waste, and air pollutants.

Energy-efficient lighting can reduce lighting electricity demand by over 50 percent, thereby enabling the power plant to burn less fuel. It is estimated that every kilowatt-hour of electricity avoided prevents the emission of 1.5 pounds of carbon dioxide, 5.8 grams of sulfur dioxide, and 2.5 grams of nitrogen oxides. It also reduces other types of pollution resulting from mining and transporting power plant fuels and disposing of power plant wastes.

If energy-efficient lighting were used everywhere profitable, the nation's demand for electricity could be cut by more than 10 percent. This would result in reductions of annual carbon dioxide emissions of 202 million metric tons (4 percent of the national total)—the equivalent of the exhaust emitted from 44 million cars. Reductions in annual emissions of sulfur dioxide would total 1.3 million metric tons (7 percent of the national total), and reductions in annual emissions of nitrogen oxides would amount to 600,000 metric tons (4 percent of the national total). By the year 2000, Green Lights is expected to save 226.4 billion kWh, resulting in total electricity demand savings of 39.8 million kilowatts.

A Cleaner Approach to Lighting



Tackling the Barriers to Innovation

A goal of Green Lights is to encourage the widespread use of lighting technologies that use less energy. In doing so, Green Lights endeavors to reduce air pollution, while redirecting dollars toward profitable investment. Indeed, if energy-efficient lighting technologies are used nationwide, they will reduce electricity bills by $16 billion per year.

Although the market is encouraging the use of energy-efficient lighting technologies, Green Lights is designed to tackle the barriers that impede the widespread use of these technologies.

Common Problems	The Green Lights Solution
Lighting Is a Low Priority - Few organizations focus on the opportunity to invest in their own lighting systems.	✔ **Green Lights** participants see lighting as an investment—a source of profits. Signing the MOU makes lighting an organizational priority.
Lack of Information and Expertise - Lighting information travels slowly outside the world of the lighting industry.	✔ **Green Lights** provides informational tools to help lighting investors make an informed upgrade decision.
Difficult Financing - Investments in energy-efficient lighting require up-front capital.	✔ **Green Lights** has developed a registry of financing resources available free of charge to all Green Lights participants.
Restricted Markets - Low demand for energy-efficient lighting technologies results in lack of consumer understanding about potential cost savings and enhanced lighting. Prices remain high due to small production runs.	✔ **Green Lights** promotes energy-efficient lighting technologies as cost-effective and high-quality products to consumers, and informs manufacturers about benefits of investing in new technologies.
Split Incentives Between Landlord and Tenant - To realize savings from a lighting upgrade, each tenant must renegotiate the lease with the landlord. The landlord rarely installs energy-efficient lighting in new construction, since utility charges are passed on to tenant.	✔ **Green Lights** is developing standard lease language that removes the split incentive barrier between landlord and tenant.

Success Story: American Express

American Express, a Green Lights Partner since February 1991, upgraded the lighting at its 1.6 million-square-foot facility in lower Manhattan. More than 17,000 T12 "cool white" fluorescent lamps (the standard "tube" often seen in commercial lighting) were replaced with the more energy-efficient and superior quality T8 variety. The building's existing hybrid ballasts were replaced with electronic ballasts that consume less electricity, weigh less, make less noise, and create virtually no lamp flicker. Two hundred occupancy or motion sensors were installed throughout the building, reducing average annual lighting hours from 6,300 to 5,200. Motion sensors control lighting, depending on the presence of a person in the area.

As a result of the lighting upgrade, American Express has reduced the number of kilowatt-hours by approximately 4.5 million per year. Annual savings from the project are expected to be more than $280,000—with an internal rate of return calculated at 38 percent. The annual pollution prevented is also impressive: 785,000 pounds of carbon dioxide, 5,500 pounds of sulfur dioxide, and 3,150 pounds of nitrogen oxides.

Giving the Green Light to Energy Efficiency

Your Part

To become a Green Lights Partner, an organization signs a Memorandum of Understanding (MOU) with EPA. In the MOU, Green Lights participants agree to survey their facilities and, within 5 years of signing the MOU, to upgrade 90 percent of their square footage, where it is profitable and where lighting quality is maintained or enhanced. Participants also agree to appoint an implementation manager who oversees participation in the program. As of August 1992, over 600 organizations have joined Green Lights.

EPA's Part

The MOU also states EPA's commitment to Green Lights Partners. EPA provides Partners with the following products, information, and services:

Decision Support System - a state-of-the-art computer software package that enables Partners to survey lighting systems in facilities, assess lighting options, and select the best energy-efficient upgrade.

Financing Registries - user-friendly computer data bases of every third party financing program available.

Ally Programs - Allies include lighting manufacturers, lighting management companies, and electric utilities that have agreed to educate customers about energy-efficient lighting.

Endorser Program - Endorsers are membership associations and other organizations that promote Green Lights.

Public Recognition - Green Lights places public-service advertising in major magazines, newspaper articles, reports on new lighting technologies, a newsletter, and other materials. To encourage participants to promote their own Green Lights activities, EPA distributes ready-to-use promotional materials.

In addition, EPA contracts and grants provide the following services:

Lighting Services Group - provides technical support, including a technical services hotline, workshops, and a comprehensive *Lighting Upgrade Manual*.

National Lighting Product Information Program - serves as "consumer reports" of lighting, making valuable product information available.

Green Lights

For more information, contact: Green Lights, U.S. EPA, 401 M Street, SW (6202J), Washington, DC 20460
Green Lights Hotline: (202) 775-6650, FAX: (202) 775-6680

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U.S. EPA GREEN LIGHTS
Memorandum of Understanding for Partners

Basic Principles of Agreement

The US Environmental Protection Agency and Green Lights Partner agree in good faith that:

- the purposes of Green Lights are to prevent air pollution, reduce electricity bills, increase competitiveness and enhance national energy security;
- the **Green Lights Memorandum of Understanding (MOU) is a voluntary agreement which can be terminated by** Green Lights Partner with no notice or penalties;

EPA Agrees to:

- provide **Green Lights Partner** with recognition for its public service in protecting the environment;
- develop a decision support system to help Partners conduct lighting surveys and options analyses;
- create Green Lights Allies Programs for lighting manufacturers, lighting management companies and electric utilities to aid Partners on technical and financing issues;
- start an independent lighting product information program to provide brand name product information;
- develop workshops and training programs;
- work to remove any unjustified regulatory barriers to energy-efficient lighting;

A Green Lights Partner agrees to:

- survey the lighting in all of its U.S facilities;
- consider a full range of lighting options to reduce energy use;
- retrofit 90% of the square footage of its facilities with options that maximize energy savings only to the extent that such options are; (1) profitable (2) do not compromise lighting quality
- complete retrofit within 5 years of signing the agreement;
- annually document the improvements it makes
- design all new facilities to meet the most current building efficiency standards;
- educate its employees about the benefits of energy-efficient lighting.

1.2 PARTNER SUPPORT PROGRAMS

The success of the Green Lights Program depends on the actions taken by Partners and Allies to implement energy-efficient lighting upgrade projects that ultimately result in sustained pollution prevention. EPA's Partner support programs provide planning and implementation assistance and guidance for successful lighting upgrade projects.

The Partner support programs are organized into the following four sections:

- Information
- Analysis Tools
- Planning
- Communications

Information

One of the obstacles to implementation is the scarcity of objective information on which to base upgrade decisions. The Green Lights Program has developed the following information resources for use by program participants:

Green Lights Electronic Bulletin Board

Green Lights participants can gain up-to-the minute program and technical information, documents, software programs, and databases through the Green Lights Electronic Bulletin Board. It operates at 2400 baud and can be reached with a modem at (202) 775-6671. Most of the files are available for downloading as needed by individual users. The bulletin board also features a mail system in which users can provide feedback on various program, lighting, and environmental issues. The modem number for the bulletin board is (202) 775-6671.

For additional information, please contact the Green Lights Information Hotline at (202) 775-6650 or fax (202) 775-6680.

National Lighting Product Information Program (NLPIP)

EPA is co-sponsoring this program that produces *Specifier Reports* -- bulletins containing objective information and independent performance test results of name-brand lighting upgrade products. *Specifier Reports* published in 1992 addressed electronic ballasts, power reducers, specular reflectors, parking lot luminaires, occupancy sensors, and compact fluorescent packages. Future issues will address retail display lighting, hybrid electromagnetic ballasts, exit signs, and other upgrade technologies. The Green Lights Program distributes one copy of *Specifier Reports* to each Partner and Ally Liaison upon publication. Additional copies may be purchased from the Lighting Research Center.

For additional information, send a fax to the Lighting Research Center, Rensselaer Polytechnic Institute at (518) 276-2999 (fax).

Light Briefs

EPA publishes 2-page *Light Briefs* on various implementation issues. These publications are intended to provide an introduction to lighting upgrade issues. The first four *Light Briefs* focused on technologies: occupancy sensors, electronic ballasts, specular reflectors, and efficient fluorescent lamps. Later releases covered rolling financing strategies, financing options, measuring lighting upgrade profitability, and waste disposal. Future editions will address other issues raised by program participants. Current copies have been mailed out to all Green Lights Liaisons. In addition, you may read the *Light Brief* text on the Green Lights Electronic Bulletin Board (modem: 202-775-6671).

For additional information, please contact the Green Lights Information Hotline at (202) 775-6650 or fax (202) 775-6680.

Lighting Upgrade Manual

This extensive document provides a concise overview of implementation issues. It is a practical reference for every phase of the lighting upgrade process -- including organizing staff, setting goals, surveying facilities, evaluating lighting systems, financing upgrades, planning projects, requesting bids, disposing of lamps and ballasts, maintaining lighting systems, and reporting project results. In addition, the *Manual* provides extensive technical reference information. The *Manual* is distributed to all participants at the regional Lighting Upgrade Workshops (described below). Portions of the *Manual* are also available on the Green Lights Electronic Bulletin Board (modem: 202-775-6671).

For additional information, please contact the Technical Hotline at (202) 862-1145 or fax (202) 862-1144.

Lighting Upgrade Workshops

These 2-day workshops are held in major cities across the country. Workshops are open to the public, but space is limited and priority is given to Green Lights Partners and Surveyor Ally candidates.

Conducted by the Lighting Services Group, Green Lights participants receive practical training in:

- lighting upgrade technologies
- decision support system surveys and analysis
- upgrade project planning and management (financing options, lighting evaluations, lighting maintenance, equipment disposal, and progress reporting)

To preregister or to obtain more information about upcoming workshops, call the Technical Hotline at (202) 862-1145 or fax (202) 862-1144.

Green Lights Financing Directory

This computerized directory consists of two indexed databases: *Utility Financing* and *Non-Utility Financing*. The utility financing database contains information on utility incentive programs -- such as rebates, direct assistance, and loans -- for installing energy-efficient technologies. The non-utility financing database contains information on companies that provide financing services. These organizations are either financing companies or lighting/energy services companies that coordinate with banks, leasing firms, or investor groups. Financing options offered by these firms include conventional loans, guaranteed savings insurance, capital leases, and shared savings.

Each database is updated regularly. Information in the utility database is researched and confirmed by EPA. Non-utility listings are included as provided by the sources, without further confirmation or verification.

The software requires an IBM-compatible PC, DOS version 2.0 or higher, 2 Megabytes available hard disk space, 640k RAM, and a high-density floppy disk drive. In addition, this directory may be downloaded from the Green Lights Bulletin Board (modem: 202-775-6671).

To request a diskette, contact the Green Lights Information Hotline at (202) 775-6650 or fax (202) 775-6680. For additional information, please contact the Technical Hotline at (202) 862-1145 or fax (202) 862-1144.

Green Lights Ally Programs

EPA has developed five Green Lights Ally programs that include the various sectors of the lighting industry as participants in the Green Lights Program. These Ally programs involve the following industry groups:

- Lighting Equipment Manufacturers
- Lighting Management Companies
- Electric Utilities
- Surveyors
- Distributors

Each Ally joins the Green Lights program by signing a Memorandum of Understanding with EPA that commits the Ally and EPA to work together to help develop and improve EPA's Green Lights support programs as well as maximize energy savings and pollution prevention in their own facilities. For additional information and requirements relating to participation in Ally programs, please call the Green Lights Ally Hotline at (703) 642-5315 or fax (703) 642-8094.

Please note that EPA does not endorse any Ally's products or services.

Analysis Tools

The proper selection of energy-efficient lighting technologies is a task that must meet the many objectives of superior upgrade design. These include determining appropriate light levels, improving visual comfort, maximizing source and luminaire efficiency, applying automatic controls, developing maintenance strategies, and conducting a rigorous financial analysis. EPA has developed tools to help Partners and Allies rapidly analyze lighting systems and determine appropriate upgrade solutions.

Green Lights/Decision Support System *(GL/DSS)*

EPA has developed an innovative software package to help Partners and Allies survey office, warehouse, and general retail facilities, identify applicable lighting upgrade technologies, and quantify costs and benefits. This expert system recommends lighting upgrade packages that maximize energy savings and maintain or improve lighting quality (based on user-entered factors). In combination with other Green Lights Program support materials and services, this decision support system helps Partners work with the lighting industry in making informed upgrade decisions. And it facilitates project planning by producing reports that clearly indicate product types, quantities, installation locations, and minimum performance requirements.

Based on user-entered lighting survey data, *GL/DSS* assesses existing lighting conditions and selects appropriate upgrade technologies for commercial and industrial spaces such as offices, hallways, conference rooms, stockrooms, distribution centers, transfer stations, supermarkets, and general retail (high volume) sales floors. The system chooses upgrade technologies from large databases that include performance and cost data.

Because user training is required for effective use of the software, the *GL/DSS* is distributed *only to those who attend one of the EPA-sponsored training workshops* held in cities throughout the country.

The software is designed to work on most PCs in use today. The minimum hardware requirements are:

- IBM PC or compatible (286 or higher)
- DOS version 3.3 or 5.0
- 512K RAM free
- hard disk with at least 10 megabytes free
- printer (many supported)

For general information about the Decision Support System, please refer to Appendix A, or contact the Technical Hotline at (202) 862-1145 or fax (202) 862-1144.

For software technical support, contact the Decision Support System assistance line at (703) 934-3150.

Quikalc

This PC-based analysis program is designed to calculate the benefits resulting from a specific lighting upgrade. Unlike *GL/DSS*, this analysis tool calculates results for only one fixture type at a time and does not recommend a specific upgrade package. Instead, it analyzes a simplified 20-year pre-tax cash flow that compares two packages of lighting components and controls, and calculates the IRR for upgrading to the second package. The spreadsheet incorporates a database of upgrade packages that can be user-selected by entering a four-digit upgrade code. And *Quikalc* now allows the user to input and analyze custom fixtures that are not currently a part of the database. In addition to calculating IRR, the spreadsheet also calculates demand and energy savings, avoided costs, pollution prevention, cost of conserved energy, percent change in lumen output, and percent energy savings. This software can be downloaded from the Green Lights Electronic Bulletin Board (modem: 202-775-6671).

For more information, refer to Appendix A, or call the Green Lights Information Hotline at (202) 775-6650 or fax (202) 775-6680.

IRRkalc

This simple stand-alone program is specifically designed to calculate a project's internal rate of return based on the following five input variables:

- project cost
- annual energy cost savings
- maintenance cost savings
- average annual inflation
- tax adjustment multiplier

This software can be downloaded from the Green Lights Electronic Bulletin Board (modem: 202-775-6671).

For more information, refer to Appendix A, or call the Green Lights Information Hotline at (202) 775-6650 or fax (202) 775-6680.

Planning and Implementation

The commitment to maximize energy savings by upgrading all of a corporation's facilities often requires a change in the way management prioritizes investments in facilities, environmental protection, employee productivity, and maintenance practices. For some corporations, this change will require significant planning and coordination among several diverse sectors of the organization.

Kick-Off Meetings

Shortly after joining the Green Lights Program, Partners should plan a kick-off meeting with the assistance of EPA representatives or their contractor staff. This meeting should be attended by middle and senior level staff, as well as facilities engineers from the various divisions or regions within the company.

The objectives of such a meeting is to affirm the company's commitment to maximizing energy savings in lighting systems as agreed in the Memorandum of Understanding. In addition, the intent of the Program and EPA's Partner Support programs are discussed. This meeting is the initial forum for discussing involvement by specific individuals on the Green Lights project implementation team, consisting of the Implementation Manager, regional/divisional coordinators, facility staff, financial analyst, public relations, environmental affairs, and senior management.

Subsequent to the general meeting, a planning meeting should be facilitated by a company representative who has attended a Lighting Upgrade workshop. This meeting of the Partner's Green Lights project implementation team would discuss the following issues related to project planning and implementation.

- Establishing leadership; designating project management roles
- Establishing communication and coordination within the team
- Identifying financing needs and resources
- Planning trial installations for evaluating new lighting technologies
- Setting goals and developing 5-year action plans
- Determining approach to use in specifying lighting upgrades

For additional information, please call the Technical Hotline at (202) 862-1145 or fax (202) 862-1144.

Partner Visits

In some cases, representatives of EPA or its contractor staff may be available to visit Partner facilities. The purpose of these visits is to address specific implementation barriers that may exist. Such barriers include organizing staff, project financing, surveying techniques, evaluation of trial installations, and reporting. During these visits, some of the planning activities described under Kick-Off meetings can be conducted. Lighting Services Group staff may provide assistance or training in the use of the analysis tools described above, and may provide a brief technical review of completed surveys on specific facilities. In addition, preliminary surveys may be conducted and trial installation projects defined for immediate implementation. In some cases, Lighting Services Group staff will visit upgraded facilities to gather information for case studies or to provide direction for maximizing energy savings.

For additional information, please call the Technical Hotline at (202) 862-1145 or fax (202) 862-1144.

Telephone Follow-Up

EPA and its contractor staff continuously review the roster of participants and keep in contact with Partners. Frequently, these calls provide a convenient opportunity to discuss project specifics, methodologies, difficulties, and to answer technical or program questions, etc. The objective is to help Partners get the most out of the program and to provide guidance for maximizing energy savings.

For additional information, please call the Technical Hotline at (202) 862-1145 or fax (202) 862-1144.

Communications

Because saving energy and preventing pollution is good news for U.S. business and the American public, Green Lights helps Partners communicate their participation to their employees, customers, shareholders, and the business community. When Partners and Allies submit project upgrade reports to the EPA, success stories can be identified and publicized. In addition, regular reporting will help the Green Lights Program staff evaluate program effectiveness and enhance technical support to Partners.

Corporate Communications

Green Lights has developed a variety of communications materials and publications designed to recognize participants for their commitment to the program. These materials include:

- The Green Lights *Update*, the program's monthly newsletter
- Green Lights video and slide presentations
- A package of public service advertisements

Green Lights is also working with Partners to encourage individual and collective promotion of energy-efficient lighting. Green Lights Corporate Communications materials are designed to accomplish the following:

- Educate employees about their organization's participation in Green Lights and the benefits of energy-efficient lighting

- Assist Green Lights Partners in the development and production of written materials that incorporate the Green Lights logo.

- Help Green Lights Partners announce their participation in Green Lights to clients and constituents

- Help recruit other companies into the Green Lights Program.

For additional information, call the Green Lights Information Hotline at (202) 775-6650 or fax (202) 775-6680.

Case Studies

One of the most successful means for promoting lighting efficiency is through the use of case studies. These "success stories" may be used for the purposes of corporate recognition, program promotion, lighting education, and building confidence in cost-effective lighting technologies. Working with the Green Lights corporate communications staff, your case studies may ultimately be publicized in Green Lights Program materials, industry publications, local newspapers, or even national media.

Green Lights staff will review the Implementation Reports for potential case study projects. At the same time, Partners and Allies may nominate specific projects for potential case study development. The attributes of an effective case study are:

- Recent project completion

- Use of state-of-the-art lighting or controls technology

- Includes a quote from building owner and/or occupant

- Includes descriptions of unique project management details such as technology evaluation, alternative financing, equipment disposal, etc.

Partners and Allies are encouraged to submit case study information to the Green Lights staff for review and possible publication. Case study information can be submitted by completing a Lighting Case Study Questionnaire or by providing existing case study text (and graphics if available).

For additional information, call the Green Lights Information Hotline at (202) 775-6650.

Upgrade Project Reporting

Compliance with the project documentation requirement in the Memorandum of Understanding can be conveniently fulfilled by submitting the standard, one-page Implementation Reports for each facility on a regular basis. Quarterly project reports are suggested because they will enable frequent re-evaluation of program's effectiveness, they require a less concentrated effort than annual reporting, success stories (case studies) can be identified and publicized soon after installations are complete, and Partner support programs can be more responsive to expressed needs.

Partners and Allies submit their reports on the one-page *Implementation Report* form specifically developed for documenting upgrade details. This form should be filled out for each facility that has been upgraded or is in the process being upgraded. Specific instructions for progress reporting are included in the *Lighting Upgrade Manual.*

EPA receives these reports and follows-up as necessary to obtain complete information, assist with future technology selections, or coordinate case study development. This information is entered in a separate database that is used for determining the overall impact of the program as well as for analyzing trends in upgrade choices, costs, methods, acceptance, and profitability. Such analysis will provide valuable input to shaping future lighting industry products and services.

For additional information, please call the Technical Hotline at (202) 862-1145 or fax (202) 862-1144.

1.3 ENVIRONMENTAL PROTECTION

Green Lights presents a opportunity for U.S. businesses to make a significant contribution to protecting the environment. By switching to energy-efficient lighting, less electricity is consumed, thereby reducing the pollution associated with electricity generation at power plants.

Environmental protection through energy-efficiency is discussed in the following sections.

- EPA's Role in Environmental Protection
- U.S. Views on Global Climate Change
- Lighting and the Environment: The Connection
- Pollution Prevention Assessment: Methodology for Emission Factors

EPA's Role in Environmental Protection

The Environmental Protection Agency (EPA) is responsible for implementing the Federal laws designed to protect the environment. EPA was created through Reorganization Plan #3 of 1970, which was devised to consolidate the Federal Government's environmental regulatory activities into a single agency. The plan was sent by the President to Congress on July 9, 1970, and the Agency began operation on December 2, 1970.

The Green Lights Program is sponsored by the Office of Air and Radiation. Other energy-efficiency programs sponsored by this office include the following:

- Golden Carrot Refrigerator Program
- EPA Energy Star Computer Program
- Integrated Resource Planning
- Consortium for Energy Efficiency (start up)
- Green Buildings Program

Lighting and the Environment: The Connection

How Can Lighting Damage the Environment?

Although it appears innocuous, lighting causes **air pollution.** Here's how: Each day, your local power plant will commonly burn coal, oil, and gas to generate electricity for your lighting system as well as for your other electrical needs. While burning these fossil fuels produces a readily available and instantaneous supply of electricity, it also generates air pollutants: **carbon dioxide (CO_2), sulfur dioxide (SO_2), and nitrogen oxides (NO_x).**

In addition, electricity generation produces toxic trace metals including beryllium, cadmium, chromium, copper, manganese, mercury, nickel, and silver. Stripmining, natural gas leaks, boiler ash, and spent nuclear waste also are by-products of electricity generation.

Air Pollution Causes Global Warming, Acid Rain, and Smog

Each of these pollutants causes environmental damage. Carbon dioxide (CO_2) causes global warming, sulfur dioxide (SO_2) causes acid rain, and nitrogen oxides (NO_x) cause both acid rain and smog.

Green Lights Pollution Prevention

As Green Lights participants switch to energy-efficient lighting, the United States prevents pollution, and businesses reduce their overhead expenses. EPA summarizes this information in two ways: first, by reporting **achieved** reductions as a result of completed upgrades; and, second by reporting **projected** reductions in the next five years.

Computation of Achieved Pollution Prevention: All Green Lights participants submit Implementation Reports that characterize their lighting upgrades. Based on reported kWh reductions achieved from completed lighting upgrades, Green Lights uses the national average emission factors given in Table 1 (next page) to estimate pollution prevention impacts.

Computation of Projected Pollution Prevention: Participants report all of their facilities' square footage to the Program Office when they join Green Lights. The projected pollution prevention is calculated by multiplying the aggregate square footage by .00125 kW/ft^2 saved x 3,500 operating hours per year x the emission factors given in Table 1.

Year 2000 Pollution Reduction Projections

The U.S. government has estimated that Green Lights can reduce energy consumption by 226 BkWh in the year 2000. This calculation is based on macro projections of national energy and lighting electricity use and aggregate assumptions about the efficiency of new technologies and their penetration into the marketplace. It is *not* based on a square footage upgrade assessment.

Also, the U.S. government assessment assumes a different generating mix in 1990 versus in 2000 and assumes that efficiency will reduce electricity generation in the order of "dirtiest first." As a result, the government estimates that lighting upgrades will eliminate 202 million metric tons of CO_2, 1.3 million metric tons of SO_2, and 0.6 million metric tons of NO_x.

Table 1. National Emission Factors (per kWh sold) by Fuel Type - 1990

Fuel Type	CO_2 (lb/kWh)	NO_x (g/kWh)	SO_2 (g/kWh)
Coal	2.4	4.0	10.0
Fuel Oil	2.0	1.9	5.4
Gas	1.3	2.1	0
TOTAL	1.5	2.5	5.8

Table 2. Heavy (Trace) Metal Emission Factors (per kWh sold) - 1990

Heavy Metal Pollutant	Emission Factors (mg/kWh)
Beryllium	0.02
Cadmium	0.05
Chromium	1.30
Copper	0.59
Manganese	2.27
Mercury	0.04
Nickel	1.18
Silver	0.25

The amount of pollution Green Lights can prevent in the year 2000 is equivalent to:

- **In terms of CO_2**, removing 44 million automobiles from the road each year (1/3 of the 1992 U.S. fleet) or filling the Minneapolis Metrodome with CO_2 over 71,000 times.
- **In terms of SO_2**, all the SO_2 emissions from all the utilities in Texas and Kentucky, the first and fifth largest coal burning states in the U.S., respectively;
- **In terms of NO_x**, all the NO_x emissions from all the utilities in California, New York, and Ohio; and,
- **In terms of mercury**, removing 10.6 tons or 31% of the mercury installed in electrical lighting equipment in 1988.

For Additional Information:

1. Refer to the Green Lights "Pollution Prevention Methodology" and "Regional Emission Factors".
2. For literature on global warming, acid rain, and smog, contact the EPA Public Information at 202-260-2080.

Sources and Contacts:

1. ATC, 1991 (March 1). Emissions and Controls of Toxics from Fuel Combustion Sources.
2. DOE/EIA, 1992 (January). Department of Energy/Energy Information Administration, Electric Power Annual 1990 (DOE/EIA-0348(90). Phone number is 202-586-8800.
3. ICF Incorporated, 1991a (September 30). "Conversions of prevented pollution", Memo from Jim Stimmel (ICF Inc.) to Bob Kwartin (Environmental Protection Agency).
4. ICF Incorporated, 1991b (September 30). Waste and Risk Characteristics of Heavy Metal Mining.
5. ICF Incorporated, 1992 (February 18). "Supporting Document for Green Lights Pollution Prevention: Emission Factors for CO_2, NOx, and SO_2". Memo from Peter Weisberg (ICF Inc.) to Bob Kwartin (Environmental Protection Agency).
6. U.S. Department of State, 1992 (undated). "U.S. Views on Global Climate Change". Phone number is 202-647-4069.

GREEN LIGHTS POLLUTION PREVENTION ASSESSMENT (Methodology for Emission Factors for CO_2, NO_x, and SO_2)

February 18, 1992

Below, Table 1 presents 1990 average emission factors for three pollutants - CO_2, NO_x, and SO_2 - caused by domestic electricity generation. These factors are given in terms of grams or pounds of pollutant emitted per kilowatt-hour sold and should replace the 1988 emission factors given in the Green Lights Pollution Prevention Methodology. The methodology for determining these average emission factors as well as any weaknesses or caveats follows Table 1.

Table 1. Emission Factors - 1990 (per kWh sold)

Fuel Type	CO_2 (lb/kWh)	NO_x (g/kWh)	SO_2 (g/kWh)
Coal	2.4	4.0	10.0
Fuel Oil	2.0	1.9	5.4
Gas	1.3	2.1	0
National Avg.	1.5	2.5	5.8

1. Methodology

Better information from the DOE/EIA (1992a) simplified the process of determining emission factors and did not require the back of the envelope methodology used in EPA's original emission rate memo (EPA 1990).

A. Emissions[1]

Information is available from DOE/EIA (1992a) on the total emissions of CO_2, NO_x, and SO_2 that results exclusively from domestic electric utility net generation and independent power producers (IPPs) for all fuel types[2]. These emissions are presented in Table 2.

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[1]Emission data are collected from EIA's Form 767 and involves the mandatory reporting of all electric power plants with a total existing or planned organic- or nuclear-fueled steam-electric generator nameplate rating of 10 megawatts or more (900 such plants). It is assumed that the overwhelming majority of emissions results from electric utilities that meet this criterion. The data collected are used in conjunction with EPA's Compilation of Air Pollutant Emission Factors, Volume 1 (October 1986) to determine emissions. A full discussion of this EPA compilation is beyond the scope of this report.

[2]Emissions are clearly disaggregated in DOE/EIA's, Electric Power Annual, (1992a), Table 43.

Table 2. Emissions from Electric Utility Net Generation and Independent Power Producers by Fuel Type - 1990

--- TOTAL EMISSIONS ---

Pollutant	Coal	Oil	Gas	Other[3]	Total[4]
SO_2 - gigagrams	14,379	581	0	46	15,006
NO_x - gigagrams	5,693	205	508	15	6,420
CO_2 - MM metric tons	1,541	108	157	12	1,976

B. Sales

Electric utility net generation and IPP generation data that are responsible for the above mentioned emissions can be adjusted to sales data by using the following equation:

[Domestic Utility Net Electricity Generation + IPP Generation[5] - Transmission/Distribution/Unaccounted (T/D/U) Losses = Electricity Sales].

Table 3 presents data for the above equation.

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[3]DOE/EIA reports that "Other" includes emissions from light oil, methane, coal/oil mixture, propane gas, blast furnace gas, wood, and refuse.

[4]Sum of components may not equal total due to independent rounding.

[5]Electric utility generation data is based EIA's Form-759 (EIA/DOE 1991a). This form is a mandatory census of all operators of electric utility plants producing electric power for public use. It is not clear, however, if this form is distributed to and reflects independent power producers (IPPs).

Evidence from ICF Resources indicates that the generation data from IPPs are incorporated in data for total electric utility net generation, and thus should not be added here to avoid double-counting. DOE/EIA also states, "an independent power producer, which may be affiliated with another utility, is a utility that is found by FERC to lack market power." Further, "the distinction between electric utilities and independent power producers is not clearly delineated" (DOE/EIA 1991b). Thus, for this methodology, electric utility generation is assumed to include electricity generation by IPPs.

Table 3. Electric Utility Net Generation, T/D/U Losses, and National Total Electricity Sales by Fuel Type - 1990 (Billion kWh)

Fuel Type	Utility Generation	T/D/U Loss[6]	Total Elec Sales[7]
Coal	1,559.6	124	1,435.6
Fuel Oil	117.0	9	108.2
Natural Gas	264.1	21	243.1
Non-Fossil	864.4	69	795.4
TOTAL	2,808.1	224[8]	2,582.2

C. Average Emission Factors

Dividing the emissions for each pollutant found in Table 2 by the total electricity sales found in Table 3 yields emission factors by fuel type given in Table 1.

2. Weaknesses/Caveats

A. Different Methods for Collecting Emission and Generation Data: The calculation for determining emission factors involved using data from two different sources: Emission data was collected using EIA Form-767 while electric utility generation data was collected using EIA Form-759. Although information on the abstract of each form and evidence from ICF Resources imply that the data come from the same universe, namely electric utility generation, EIA could neither confirm nor deny this assumption.

B. Estimates of T/D/U Losses: Although total transmission/distribution/unaccounted (T/D/U) loss is available for total utility electricity generation, T/D/U loss is not available by fuel type. T/D/U loss is assumed to be directly proportional to the total amount of utility electricity generation supplied to the grid (see footnotes 6 and 8)

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[6]Total T/D/U loss was available only for 1989 and was 238.3 BkWh for both utility and non-utility electric generation (DOE/EIA 1991a). Since non-utility electric generation is not considered, non-utility T/D/U loss should not be considered. To split T/D/U loss into utility and non-utility T/D/U loss, it is assumed that T/D/U loss is related to the amount of electricity supplied to the grid. Since non-utilities supplied 184.8 BkWh of electricity to the grid in 1989 or 5.9% of the total, non-utility T/D/U loss can be assumed to be 14.0 BkWh. Subtracting non-utility T/D/U loss from total T/D/U loss yields 224 BkWh of electric utility generation T/D/U loss.

[7]Sum of components may not equal due to independent rounding.

[8]T/D/U electric utility generation loss was disaggregated according to fuel type based on the percentage the fuel contributed to utility generation.

C. Electric Utility Generation Creates Other Life-Cycle Emissions: Mining, transporting and distributing different fuels (and the disposal of their non-CO_2 waste-products) also consume energy and results in emissions of greenhouse gases. Also not included, is the required energy (and resulting emissions) for constructing, manufacturing, and assembling the generating plants.

D. Power Factor: The effect of power factor on electricity generation is the subject of debate. At least one expert argues that a low power factor - typically associated with magnetically-ballasted compact fluorescent lamps (i.e., about 0.5) - increases the reactive power associated with the circuit. This increase in reactive power would require that the utility generate more power to deliver a kWh to a customer using a compact fluorescent than to a customer using an incandescent (power factor = 1.0). Thus, kWh saved may not directly relate to the emissions prevented during electricity generation.

3. Emission Factors by EPA Region and State

Regional and state emission factors were calculated using the methodology presented above and are presented in Appendix A (attached).

4. References

DOE/EIA 1992a. Electric Power Annual, Tables 13, 14, 43, and 44, January 1992.

DOE/EIA 1991b. Annual Outlook for U.S. Electric Power, footnotes 6 (p. 6) and 35 (p. 19), July 1991.

EPA 1990. Internal Memo: "Electricity emission rates for back-of-the-envelope calculations", Robert Kwartin, U.S. Environmental Protection Agency and Dave DeBusk, The Bruce Company, June 25, 1990.

QUESTIONS: CALL THE GREEN LIGHTS TECHNICAL HOTLINE AT 202-862-1145

EMISSION FACTORS BY REGION/STATE - 1990

	------- EMISSIONS --------			Net Generation (Million kWh)	Total Electric Sales (Million kWh)	-- EMISSION FACTORS --		
	SO2 (Billion grams)	NOx (Billion grams)	CO2 (MM lbs)			SO2 (g/kwh)	NOx (g/kwh)	CO2 (lb/kWh)
	(1)	(2)	(3)	(4)	(5)	(1/5)	(2/5)	(3/5)
REGION 1								
CT	56	22	25,028	32,156	29,569	1.9	0.7	0.8
ME	11	3	3,990	9,064	8,335	1.3	0.3	0.5
MA	211	76	54,890	36,479	33,544	6.3	2.3	1.6
NH	63	22	11,522	10,810	9,940	6.3	2.2	1.2
RI	1	2	1,050	592	544	1.7	3.3	1.9
VT	4	1	392	4,993	4,591	0.8	0.2	0.1
Regional Total	346	125	96,872	94,094	86,524	4.0	1.4	1.1
REGION 2								
NJ	70	50	25,142	36,489	33,553	2.1	1.5	0.7
NY	447	153	145,946	128,655	118,305	3.8	1.3	1.2
PR	NA	NA	NA	NA	NA	NA	NA	NA
VI	NA	NA	NA	NA	NA	NA	NA	NA
Regional Total	517	203	171,088	165,144	151,858	3.4	1.3	1.1
REGION 3								
DE	73	24	16,336	7,100	6,529	11.1	3.6	2.5
DC	3	1	878	361	332	8.2	2.7	2.6
MD	258	88	56,754	31,497	28,963	8.9	3.0	2.0
PA	1,129	332	220,882	165,683	152,354	7.4	2.2	1.4
VA	143	64	45,528	47,200	43,403	3.3	1.5	1.0
WV	881	274	155,940	77,364	71,140	12.4	3.9	2.2
Regional Total	2,487	782	496,318	329,205	302,720	8.2	2.6	1.6
REGION 4								
AL	492	175	111,588	76,232	70,099	7.0	2.5	1.6
FL	611	283	187,850	123,624	113,678	5.4	2.5	1.7
GA	795	208	138,770	97,565	89,716	8.9	2.3	1.5
KY	702	292	150,682	73,807	67,869	10.3	4.3	2.2
MS	116	45	28,288	22,924	21,080	5.5	2.2	1.3
NC	305	143	94,992	79,845	73,421	4.2	2.0	1.3
SC	158	73	48,826	69,260	63,688	2.5	1.2	0.8
TN	722	174	103,462	73,903	67,957	10.6	2.6	1.5
Regional Total	3,901	1,394	864,458	617,160	567,509	6.9	2.5	1.5
REGION 5								
IL	844	308	127,116	126,977	116,762	7.2	2.6	1.1
IN	1,396	433	219,706	97,738	89,875	15.5	4.8	2.4
MI	359	253	141,326	89,059	81,894	4.4	3.1	1.7
MN	137	102	67,694	41,550	38,207	3.6	2.7	1.8
OH	2,048	466	252,794	126,510	116,332	17.6	4.0	2.2
WI	261	130	76,742	45,551	41,886	6.2	3.1	1.8
Regional Total	5,045	1,691	885,378	527,385	484,956	10.4	3.5	1.8

Sources: DOE/EIA, "Electric Power Annual", January 1992, Tables 13 and 43.
ICF Incorporated. Memo on Emission Factors, Peter Weisberg, February 18, 1992.

NA: Information not available.

EMISSION FACTORS BY REGION/STATE - 1990

	------- EMISSIONS --------			Net	Total Electric	-- EMISSION FACTORS --		
	SO2	NOx	CO2	Generation	Sales	SO2	NOx	CO2
	(Billion grams)		(MM lbs)	(Million kWh)	(Million kWh)	(g/kwh)	(g/kwh)	(lb/kWh)
	(1)	(2)	(3)	(4)	(5)	(1/5)	(2/5)	(3/5)
REGION 6								
AR	63	70	48,484	37,053	34,072	1.8	2.1	1.4
LA	75	104	73,630	58,168	53,488	1.4	2.0	1.4
NM	61	80	63,100	28,491	26,199	2.3	3.0	2.4
OK	93	114	75,108	45,063	41,438	2.3	2.8	1.8
TX	529	541	384,746	234,047	215,218	2.5	2.5	1.8
Regional Total	821	909	645,068	402,822	370,415	2.2	2.5	1.7
REGION 7								
IA	186	99	59,576	29,048	26,711	7.0	3.7	2.2
KS	163	104	63,122	33,869	31,144	5.2	3.3	2.0
MO	725	238	106,806	59,011	54,264	13.4	4.4	2.0
NE	46	68	30,450	21,631	19,891	2.3	3.4	1.5
Regional Total	1,120	509	259,954	143,559	132,010	8.5	3.9	2.0
REGION 8								
CO	106	99	66,740	31,313	28,794	3.7	3.4	2.3
MT	37	52	35,372	25,719	23,650	1.6	2.2	1.5
ND	161	100	60,500	26,824	24,666	6.5	4.0	2.5
SD	28	17	6,356	6,427	5,910	4.8	2.9	1.1
UT	83	83	66,438	32,260	29,665	2.8	2.8	2.2
WY	81	133	90,566	39,378	36,210	2.2	3.7	2.5
Regional Total	496	484	325,972	161,921	148,894	3.3	3.2	2.2
REGION 9								
AZ	116	106	70,712	62,289	57,278	2.0	1.9	1.2
CA	7	108	61,662	114,528	105,314	0.1	1.0	0.6
HI	24	13	13,672	7,996	7,353	3.3	1.7	1.9
NV	55	56	39,256	19,286	17,734	3.1	3.2	2.2
Am Somoa	NA	NA	NA	NA	NA	NA	NA	NA
Guam	NA	NA	NA	NA	NA	NA	NA	NA
Regional Total	203	283	185,302	204,099	187,679	1.1	1.5	1.0
REGION 10								
AK	1	1	1,012	4,493	4,132	0.2	0.2	0.2
ID	0	0	0	8,618	7,925	0.0	0.0	0.0
OR	5	5	3,084	49,172	45,216	0.1	0.1	0.1
WA	64	34	18,172	100,479	92,395	0.7	0.4	0.2
Regional Total	70	40	22,268	162,762	149,668	0.5	0.3	0.1

NATIONAL TOTALS AND AVERAGES								
	15,006	**6,420**	**3,952,678**	**2,808,151**	**2,582,232**	**5.8**	**2.5**	**1.5**

Sources: DOE/EIA, "Electric Power Annual", January 1992, Tables 13 and 43.
ICF Incorporated. Memo on Emission Factors, Peter Weisberg, February 18, 1992.

NA: Information not available.

Chapter 4

FINANCING OPTIONS

Many profitable lighting upgrade projects are delayed due to restricted availability of capital. Utility incentives, national purchasing agreements, equipment financing, and performance guarantees can help Partners overcome this obstacle and obtain the financial advantages of energy efficiency.

Executive Summary

Principles

- Alternatives to using in-house capital for purchasing lighting upgrades include:
  - -- **Conventional** Financing
  - -- **Lease Purchase** Financing
  - -- **Shared Savings** Financing
- These financing options can provide *positive cash flow* when the periodic energy cost savings exceed the payment amounts.
- The *risk* of the investment can be reduced or eliminated with:
  - -- **Guaranteed Savings** Insurance
  - -- **Shared Savings** Financing
- National purchasing agreements can reduce costs and improve service.

Action Steps

- Use the computerized Green Lights Financing Directory for:
  - -- determining availability of utility incentives
  - -- reviewing services and terms offered by financing organizations
- Work with your financial and tax analysts to determine the appropriate financing option based on:
  - -- cost of capital
  - -- eligibility for utility incentives
  - -- perceived investment risk
  - -- flexibility
- Work with manufacturers and service companies to investigate national purchasing agreements.

4.1 INTRODUCTION

There are several forms of utility incentives and financing options that reduce or eliminate the need for capital, reduce risk, and improve cash flow. Although third-party financing may be a slightly more expensive approach to procuring lighting upgrades, it may still be the best alternative because it allows you to retain more capital for use in your specific business activities.

This section addresses the attributes of the more popular financing options used for procuring lighting upgrades. Note, however, that terms and conditions for each option vary among the various financing sources.

To obtain information on about the utilities and financing companies who offer these options, refer to the Green Lights Financing Directory. A current version can be downloaded by modem from the Green Lights Electronic Bulletin Board at (202) 775-6671.

4.2 UTILITY INCENTIVES

Electric utilities in some areas are helping their customers reduce the initial cost of lighting improvements by offering rebates and other incentives. With reduced customer loads, an electric utility is able to meet new customer demand at a lower cost than building new generating capacity.

Before you proceed with your lighting upgrades, contact your local utility and obtain specific incentive program information. Pay particular attention to customer eligibility criteria and qualifying technologies. And verify the *deadline* for the rebate application or upgrade completion to qualify for the financial incentives. To determine the incentives that may apply to your upgrades, consult the computerized Green Lights Financing Directory that includes descriptions utility incentive programs and other financing sources.

Utility incentives can take several forms:

Rebates

- The utility company reimburses the building owner for a portion of the cost of implementing lighting efficiency improvements.
- Rebates may be based on load reduction ($ per kW), or based on a fixed rebate for each energy-efficient product purchased ($ per item).
- A given technology may qualify under one or more programs offered by the utility. Typically, only one incentive program application may be submitted per building. Check with your utility representative for details.
- Rebates have been the most common form of utility incentives during the last several years.

Direct Utility Assistance

- The utility pays some or all of the lighting improvement cost directly to the installing contractor *selected by the customer.*
- Alternatively, the utility provides lighting upgrade products or services to the customer *through utility personnel or contractors selected by the utility.*

Low Interest Loans

- Some utilities offer low-interest financing for energy conservation projects. Loan payments may be added to your utility bills.

4.3 NATIONAL ACCOUNT AGREEMENTS

National purchasing agreements, also called national accounts, are negotiated relationships between suppliers and nation-wide buyers of products and services. National accounts provide the following benefits:

- streamlines coordination of lighting equipment purchases
- guarantees the availability of selected technology
- ensures competitive prices
- allows for multi-location shipping direct from the manufacturer
- standardizes installation and maintenance of the lighting equipment
- provides added support services

National account programs can assist Green Lights Partners and Allies by simplifying the lighting upgrade procurement process.

National Account Case Studies

This section presents national account case studies for three Green Lights Partners and two Green Lights Allies. Specific company names are not provided to preserve the confidentiality of the national account agreements discussed.

Green Lights Partner A

Partner A, a nation-wide retail chain, has had a national account with lighting fixture Manufacturer 1 for twenty-five years. Partner A purchases over $200,000 annually in fixtures from Manufacturer 1. The national account ensures a competitive price and guarantees the availability of specialty lighting products. There is no written purchasing agreement and subsequently the Partner may change lighting equipment manufacturers at any time.

Partner A leases and does not own their store space. Accordingly, they do not purchase lighting fixtures. Instead, they specify Manufacturer 1's fixtures in their building specifications, and the building owner buys these fixtures through the Partner's national account. This manufacturer's fixtures are critical for this Green Lights Partner and they do not want a substitute product.

More importantly, when planning to implement their national account, this Partner wanted to take full advantage of the discounts available through volume purchasing. To maximize the benefits of national account purchasing, the Partner reduced the diversity of fixtures purchased company-wide by agreeing on a couple of standard fixtures. The centralized specification and procurement resulted in greater savings to the Partner.

Another advantage of national accounts is enhanced service delivery/scheduling. The building owner may obtain Manufacturer 1's fixtures from a local distributor or may call an 800 telephone number for rush delivery. The products are often shipped from the factory and invoiced to the building contractor through the local distributor. Partner A's Implementation Manager noted that the distributor still retains the normal price mark-up and that the cost discounts are made by the factory.

Partner A negotiates their national account price with Manufacturer 1 based on their projected annual purchase volume. Green Lights Partner A projects its annual purchase volume at the beginning of each year. Because they have a twenty-five year purchasing history with Manufacturer 1, Partner A's Implementation Manager noted that the prices have not fluctuated significantly with changes in their demand. It was also noted that the prices have increased by approximately two or three percent per year.

Green Lights Partner B

Green Lights Partner B has had national accounts with three different lamp, ballast, and fixture manufacturers for several years prior to joining Green Lights. Once they became a Green Lights participant, Partner B had numerous offers from various lighting company sales representatives. Based on this Partner's history of national accounts, Partner B knew it could get better prices by buying directly from the manufacturer.

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More importantly, Partner B did not want to work with a multitude of regional sales representatives. They wanted a national account with a company large enough to accommodate the range of upgrade equipment and services needed in their Green Lights Program. Partner B approached Lighting Management Company 2 and discussed the inherent benefits of working together on the upgrades.

By the end of 1991, Partner B had negotiated a national account with Lighting Management Company 2 to perform upgrade feasibility studies at over two hundred of their facilities, to develop a priority list of the first thirty facilities to be upgraded, and to upgrade these facilities. This is not a written agreement and Partner B is not committed to purchase goods or services (beyond the survey) from Lighting Management Company 2. This Lighting Management Company also established a national account representative for Green Lights Partner B. Partner B cited the single point of contact and the single point of responsibility as an important advantage of the national account. It avoids having to work through the Ally's chain of command and multiple account representatives to resolve problems or to accomplish goals.

Partner B had tested and evaluated many of the new lighting technologies and specified to Lighting Management Company 2 the lamps, ballasts, and fixtures they wanted to use in the upgrades. They also specified disposal requirements, the use of Manufacturer 3's ballasts, and the use of lamps from Manufacturer 4 and Manufacturer 5. Manufacturer 4's lamps are purchased through Partner B's national account and upgraded in the facilities by Lighting Management Company 2.

Because each of Partner B's facilities is a separate profit center, this Partner had to make the Green Lights Program essentially a "no brainer" exercise and decision for each facility manager. Partner B approached Lighting Management Company 2 with the idea for a 100 percent financing proposal which Company 2 agreed it could offer the Partner's facilities. As a result, the facilities have no initial out-of-pocket expenses. And with the savings, they can either pay off the loan (in which case they may show negative cash flow) or they can pay down the loan (and show positive cash flow). Partner B informs the facility managers of the Green Lights Program and introduces their national account upgrade partner - Company 2. Lighting Management Company 2 independently negotiates upgrades with each facility.

Green Lights Partner C

Partner C builds several new facilities each year and typically purchases 20,000 fixtures annually. Several years ago they negotiated an agreement with Manufacturer 6 to manufacture a specially-designed fixture. A national account agreement was developed between the Partner and the fixture manufacturer to ensure a minimum annual purchase of the specially-designed fixture.

Subsequently, other lighting fixture manufacturing firms have developed an equivalent fixture. Therefore, Partner C issues an annual request for proposals (RFPs) to purchase the fixture on a national account basis. Partner C representatives are able to purchase the fixtures through their national account and from their local distributors. Partner C also issues an RFP every other year for a national account agreement with a lamp manufacturer.

The unit cost for the fixture is based on Partner C's projected purchases. Partner C noted that the more fixtures and lamps they purchase, the greater the discount and the lower the price.

Another advantage of using national accounts noted by Partner C is the use of drop-shipping. Since Partner C needs the fixtures and lamps at building sites throughout the country, their national accounts allow products to be drop-shipped directly to job sites. Therefore, Partner C does not warehouse and then re-ship the products, which results in greater savings.

Green Lights Ally 1

Green Lights Ally 1's national account program is at least ten years old. Their three national account managers coordinate the purchasing program, write the agreements, and develop price lists. The Ally solicits national accounts from companies based on the following guidelines: (1) volume of purchases, (2) purchasing company must be in one or more of their twenty regions, and (3) must purchase a minimum of $100,000 annually.

Their national account program operates exclusively through local distributors. In the case of products drop-shipped directly to a site, the distributor invoices the transaction. Ally 1 noted that the majority of their shipments are directly from local distributor stocks.

Ally 1 negotiates national account prices based on a buyer's projected annual purchases. Generally, the agreements are re-negotiated every one or two years and include an automatic volume/price adjustment. If the purchasing company does not meet the projected volume, either the agreement is re-negotiated based on a lower purchasing level and discount or is terminated.

Green Lights Ally 2

Green Lights Ally 2 has also had a national account program for more than a decade. It actively recruits national accounts from companies that purchase over $100,000 annually, that are multi-locational, and that have either centralized purchasing or specification. Purchasing companies are assigned to one of their five national account managers.

Ally 2 also solicits distributors for bids on national accounts. Bidding ensures competition among wholesalers and further guarantees a lower price to the national account purchaser.

Green Lights Ally 2 noted that the national account savings derive from the purchaser getting what they want (no substitution) and reducing the overhead and administrative burden to get it (by planning and stream-lining product specification).

Steps You Should Take

National account agreements may or may not be written agreements. To be legally binding, the agreements are written, agreed to, and signed by both parties. An RFP to solicit bids on a national account may or may not be issued. This section describes the steps Green Lights Partners and Allies may pursue to take advantage of national account purchasing.

Green Lights Partners

Green Lights Partners interested in exploring national account opportunities should:

- Determine their current quantity and price for the lamps, fixtures, and services purchased
- Plan and aggregate company-wide purchases to gain the maximum discount and the benefits
- Reduce the diversity of fixtures (i.e., increase the purchase quantities per fixture type) to further maximize national account savings
- Identify which products will be specified for purchase and if substitutes will be accepted
- Determine projected annual purchasing volume
- Contact the appropriate manufacturers to inquire about establishing a national account
- Issue an RFP, if necessary, to solicit bids from interested lamp, ballast, fixture, and service companies for products and services to be included in a national account agreement

Green Lights Allies

Green Lights Allies interested in the benefits of establishing national accounts should:

- Develop promotional/educational materials on national accounts for distribution to Partners
- Designate national account managers to serve as the single point of contact between the Ally and Partner
- Develop competitive national account price lists and work with their distributors to ensure national accounts are uniformly implemented
- Monitor RFPs for national accounts
- Develop competitive bids

4.4 OVERVIEW OF FINANCING OPTIONS

Financing organizations can provide the needed capital for implementing a lighting upgrade. These financing options are designed to reduce or eliminate the up-front project expenditures and distribute these costs over time. In many cases, the periodic energy cost savings exceed the periodic financing payments, resulting in positive cash flow from the beginning of the project. In addition to providing capital, several organizations provide the expertise to design and install the upgrades while assuming some or all of the performance risk.

There are many variations of financing options available to Green Lights Partners. In the descriptions that follow, we outline the most common attributes of the financing methods. However, please note that the specific terms and conditions vary among the large number of financing entities. To obtain information on companies that provide these financing options, please refer to the computerized Green Lights Financing Directory (downloadable from the Green Lights Electronic Bulletin Board at (202) 775-6671). Because tax laws are frequently revised and sometimes difficult to interpret, check with your tax and financial analysts to determine "bottom-line impacts" before entering into an agreement with a financing company.

The table on the next page describes the various attributes of financing options available for procuring lighting upgrades.

There are other financing options that may be applicable to projects that involve cogeneration or thermal storage systems. However, these financing options are beyond the scope of the *Lighting Upgrade Manual.*

Lease Purchase

Two basic types of leases can be used for financing energy efficiency improvements. These are *capital leases* and *operating leases.*

Capital leases are installment purchases. Little or no initial capital outlay is required to purchase the equipment. You are considered the owner of the equipment and may take deductions for depreciation and for the interest portion of payments to the lessor. Similar to conventional loans, *capital leasing* is "on-balance-sheet" financing, meaning that the transaction will be recorded on your balance sheet as both a liability and an asset. Capital leases are offered by banks, leasing companies, installation contractors, suppliers, and some electric utilities. Under an *operating lease*, the lessor owns the equipment that is, in effect, "rented" (leased) to you for a monthly fee during the contract period. Because the lessor is considered the owner of the energy-efficient equipment, he claims the tax benefits associated with the depreciation of the equipment. At the end of the contract term, you can elect to purchase the equipment at fair market value (or at a predetermined amount), renegotiate the lease, or have the equipment removed.

Many lighting upgrades will not qualify for an operating lease based on the criteria defined by the Financial Accounting Standards Board (FASB) Statement No. 13. To be considered an operating lease, such criteria disallows automatic ownership transfer and bargain purchase options, sets maximum lease term at 75% of economic life, and limits the present value of rental payments (plus any residual value guarantee) to less than 90% of fair value of the leased equipment. Shared savings financing may offer many of the advantages of operating leases.

Shared Savings

Shared savings is a unique financing method whose primary benefit to Partners is to reduce the risk of the lighting upgrade investment. A sample of one company's Energy Services Agreement (Shared Savings) is provided at the end of this section. Here are the features of the shared savings financing approach:

OVERVIEW OF FINANCING OPTIONS

	CASH PURCHASE	CONVENTIONAL FINANCING	CAPITAL LEASE	SHARED SAVINGS
Initial Payment	100% of project cost	0-30% of project cost	$0 or deposit	$0
Periodic Payments	none	fixed	fixed	% of energy cost savings
Payment Source	capital	capital	capital	operations
Performance Risk	owner 100%*	owner 100%*	owner 100%*	investor 100%
Contract Termination Options**	n/a	principal payoff	principal payoff	fair market value buyout; renew; return
Ownership	building owner	building owner	building owner	investor
Tax Deductions***	depreciation	depreciation and interest	depreciation and interest	shared savings payments

* Owner's risk may be reduced with guaranteed savings insurance
** At end of term
*** Subject to change in tax laws; consult with tax advisor regarding eligibility

- *No Down Payment:* The entire cost of the upgrade is paid for by the third-party financing source.

- *Third-Party Ownership:* The third party investor provides the capital for the project and owns the improvements during the term of the agreement. *As a result, the financing obligation does not appear on your balance sheet.* At the end of the contract term, you have the option to purchase the improvements at an agreed-upon value, renegotiate the contract terms, or terminate the agreement and allow the investor to recover the equipment.

- *Performance-Based Payments:* Periodic "energy service" payments are *variable* and based on the measured or calculated energy cost savings performance attributed to the upgrades. These payments will typically be made from your operating budget (not your capital budget). You pay a portion of this cost savings back to the investor according to the ratios outlined in the contract. The energy services contractor takes responsibility for maintaining the system in order to ensure energy savings.

- *Positive Cash Flow:* Because you make no down payment, and periodic payments are taken from realized savings, the resulting cash flow is always positive.

- *No Performance Risk:* Because the third-party investor only gets paid in proportion to the financial performance of the upgrade, the risk of the investment is shifted to the third party. However, the overall costs associated with reducing risk through shared savings should be carefully evaluated. See Section 4.4.

Guaranteed Savings Insurance

Guaranteed Savings Insurance may be applied to the following types of financing approaches:

- cash purchase
- conventional financing
- lease purchase

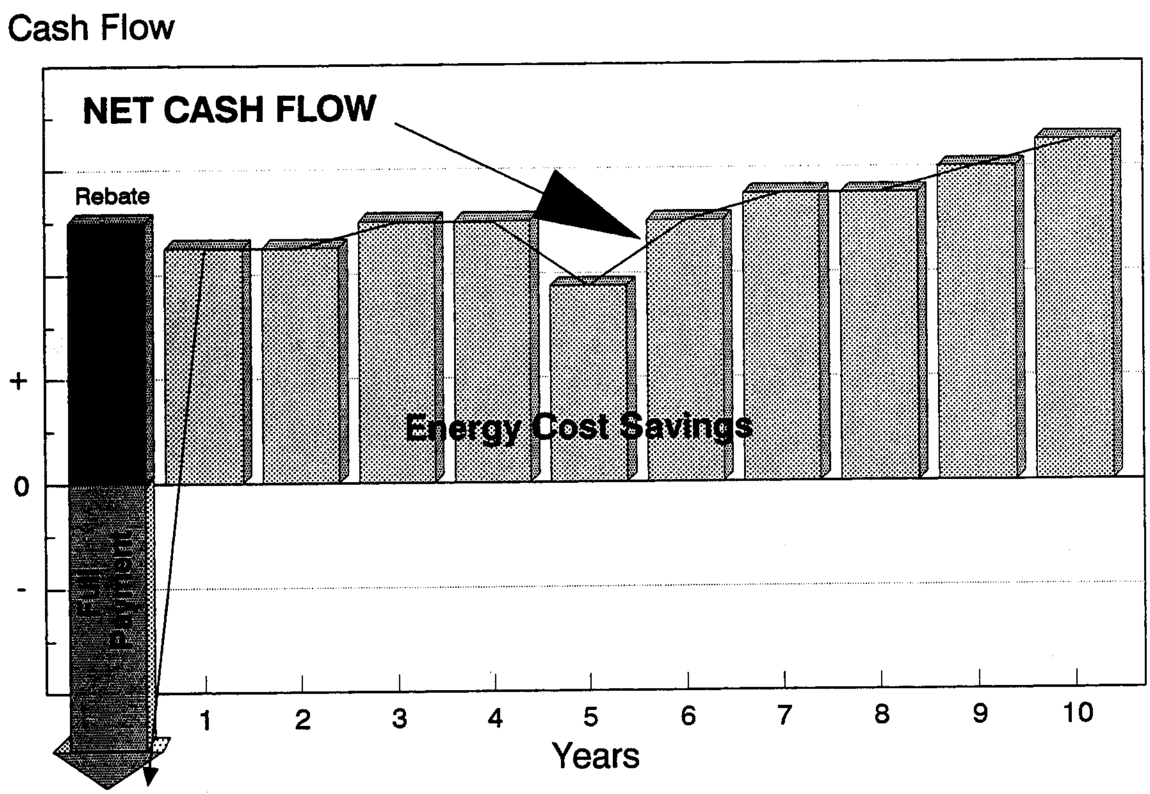
The guaranteed savings option consists of an agreement to ensure that the periodic energy cost savings will exceed an established minimum dollar value. In many cases, this minimum guaranteed savings value is set equal to the financing payment value for the same period *in order to ensure a positive cash flow* during the financing term.

Entering into a guaranteed savings agreement is like buying an insurance policy. To compensate the guarantor for assuming some of the performance risk as well as costs associated with ensuring guaranteed performance (such as maintenance and monitoring costs), the Partner will pay an indirect insurance premium. When combined with conventional or lease financing, this premium can be added to the monthly payment or paid directly to the guarantee provider. This guarantee is usually provided by the supplier, installer, or energy service company who sold the upgrade.

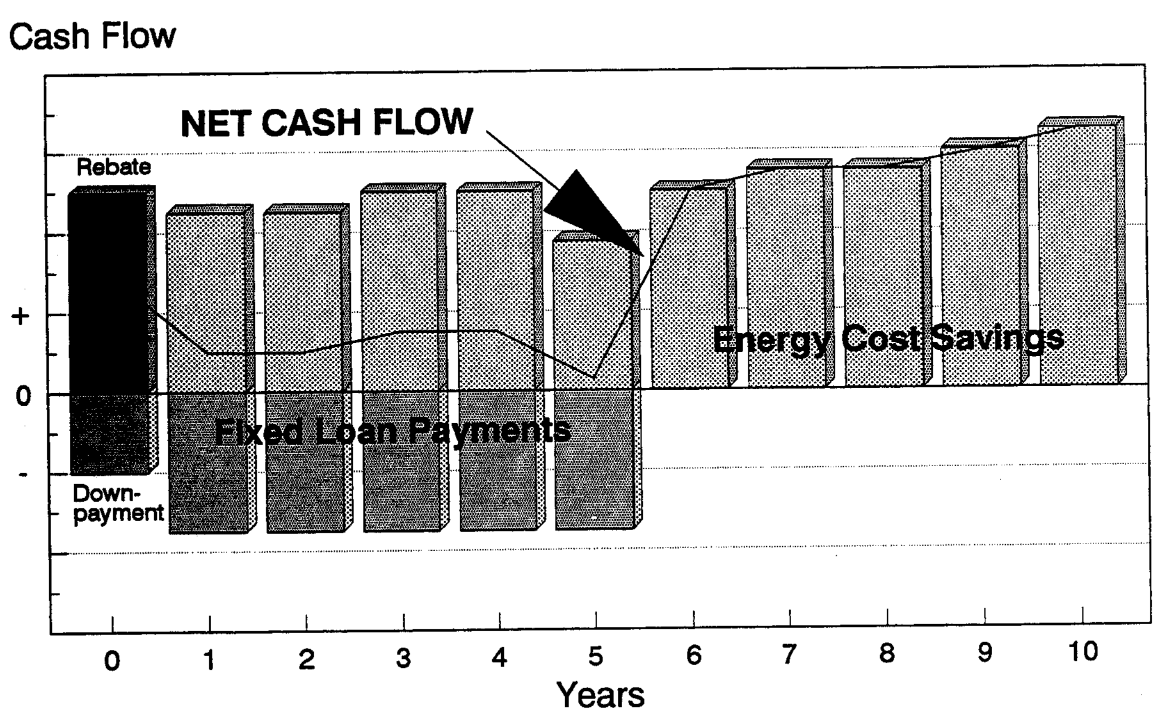
Cash Flow

The following representative cash flow diagrams illustrate how these financing alternatives can produce positive cash flow. If rebates are offered, they are usually paid to the owner of the lighting upgrades. Providers of shared savings financing may factor in the rebates when determining financing terms.

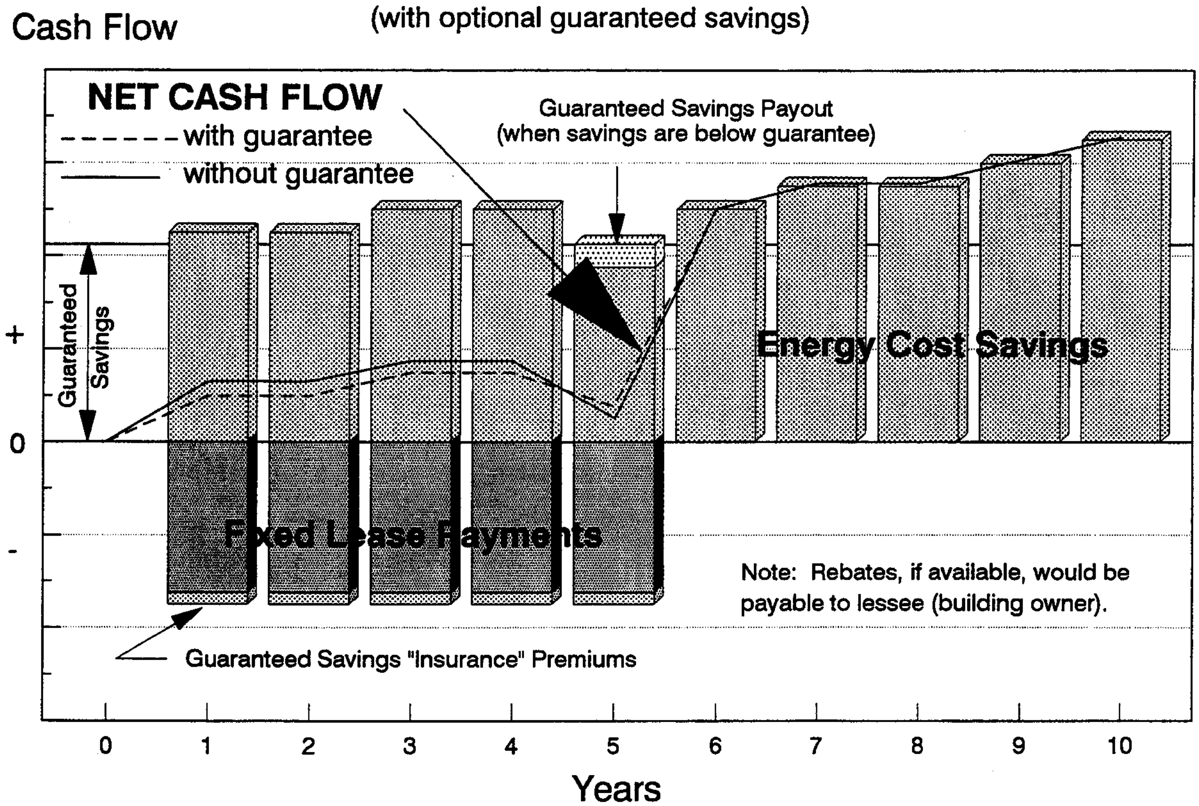
CASH PURCHASE



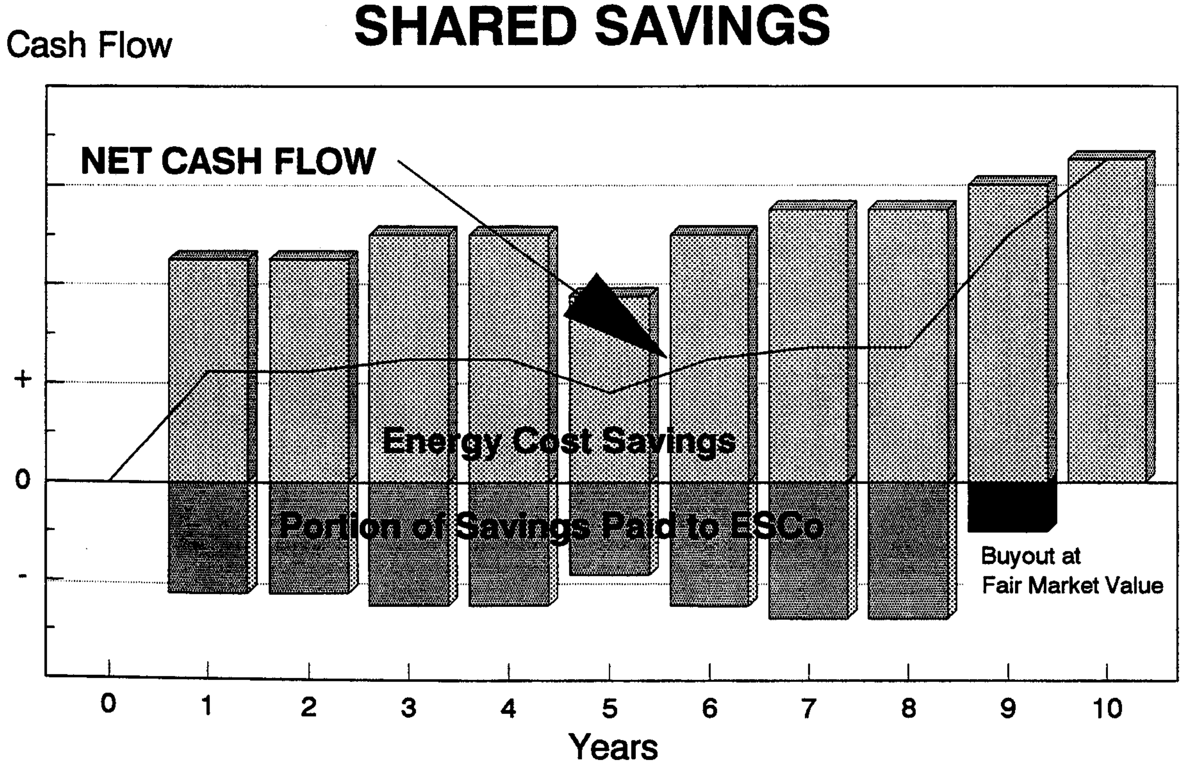
CONVENTIONAL FINANCING



CAPITAL LEASE



SHARED SAVINGS



4.5 CHOOSING A FINANCING OPTION

With so many options available to Partners for financing lighting upgrades, how does one go about determining which method would be most advantageous? The final answer cannot be computed with purely quantitative methods. The financing decision must take into account the following factors:

- cost of capital
- eligibility for utility incentives
- perceived risk
- impact on balance sheet
- flexibility

Cost of Capital

In any economic study, the "cost of capital" must be considered. The capital cost factor that is most commonly applied in financial analysis is the Present Value Discount Rate, expressed as a percentage. In simplest terms, the discount rate may be assumed to be the corporation's minimum required rate of return on invested capital. Green Lights Partners may choose the prime interest rate plus six points to determine their discount rate. Most corporations have a specific discount rate that is used in their financial analyses.

There is a simple relationship between the cost of capital and the attractiveness of third-party financing. The higher the cost of capital (i.e. higher discount rate), the more attractive third-party financing becomes. Perform a Net Present Value (NPV) analysis of the 20-year cash flows resulting from your proposed financing alternatives. The option with the highest NPV would be the most attractive financing alternative for your corporation, based on your cost of capital.

Eligibility for Utility Incentives

Before entering into a shared savings financing agreement, check with your local utility to determine who is eligible to receive the incentives -- the Partner or the investor. If the third-party investor is to receive the incentive, negotiate reduced payments that take into account the value of the utility incentives paid to the financing entity.

Perceived Risk

Compared to other investments, lighting upgrades are low-risk investments. Nevertheless, returns on lighting investments are dependent on such external factors as electricity rates, building occupancy, and usage factors. To reduce these risks, your financial officer may choose to pay additional premiums for a savings guarantee or enter into a shared savings agreement. Note, however, that the risks associated with achieving reduced electrical load are minimal; actual load reductions can be easily measured in the field (refer to Section 5.3: Field Measurements).

Impact on Balance Sheet

With conventional loans or capital leases, the transaction is recorded on the company's balance sheet as both an asset and a liability. For companies that are not in a position to incur additional liabilities, or are concerned about impacts on their return on assets, the shared savings approach should be considered. This is the only commonly available financing option for lighting upgrades that is considered to be "off balance sheet." Operating leases are another form of "off balance sheet" financing, but lighting upgrades seldom qualify for financing with an operating lease. See Section 4.3.

Flexibility

Regardless of the financing approach, verify that no penalties will be incurred by prepayment or early buy-out of the financing liability. For shared savings agreements, make certain that provisions exist for purchasing the equipment at fair market value prior to the end of the contract term. In addition to these contract termination options, also look for financing sources that can adapt the financing agreement to include future purchases of energy-efficient equipment.

4.6 GREEN LIGHTS FINANCING DIRECTORY

The computerized Green Lights Financing Directory provides information on both utility incentives and non-utility financing options. This database will be updated regularly and can be downloaded from the Green Lights Electronic Bulletin Board (modem: 202-775-6671).

Utility Incentives

To quickly identify rebates or other utility incentives that may apply to your lighting upgrade, select the Utility Financing choice on the main menu. By selecting your utility from the menu, the program will display the specific incentive levels, eligibility criteria, and contact information. You may choose to print out the retrieved data for future reference.

For each utility program, the data is displayed as follows:

- utility name
- program name
- incentive type (rebate, loan, etc.)
- sectors (eligible customer groups)
- situation (retrofit, new construction, outdoor)
- contact information
- program details

The database can also be searched by technology. For example, you could create a list of all incentive programs that address T8 fluorescent lamps.

Non-Utility Financing Sources

By selecting the financing products module, you now have access to a database of organizations that can provide project financing options. Note that each organization may have minimum requirements for project size and client gross revenue. In addition, maximum contract terms and loan amounts are specified for each organization.
For each financing organization, the data is displayed as follows:

- name
  address
  contact name
  phone number

- type of organization

- for each financing product offered:
  - equipment covered
  - terms
  - markets
  - census regions

- sources of capital

- eligibility criteria

4.7 SAMPLE DOCUMENTS

The following sample documents are provided for informational purposes only. They may not be used for contracting purposes. Please note that other financing companies have different formats for structuring their agreements.

Chapter 5

LIGHTING EVALUATIONS

This section focuses on the questions that need to be addressed when evaluating any lighting upgrade and the methods that can be used to answer those questions. A checklist at the end of this section systematically lays out suggested methods for evaluating a lighting upgrade project.

Executive Summary

Principles

- The performance of lighting equipment can be estimated (calculated) or measured directly

- Lighting systems may be evaluated on the basis of:
  -- light level
  -- energy efficiency
  -- occupancy/utilization
  -- quality/user acceptance

Action Steps

- Assess *current* lighting system:
  -- Measure light levels
  -- Determine existing user satisfaction
  -- Survey lighting system to determine potential lighting upgrade options

- Evaluate lighting *upgrade options:*
  -- Perform trial installation and measure illuminance and/or energy consumption
  -- Estimate first cost, operating costs, and disposal costs

- Verify lighting upgrade performance
  -- Measure user acceptance
  -- Measure system energy consumption

5.1 INTRODUCTION

Glowing stories of cost and energy savings are often provided in lighting product literature. But how do Green Lights Partners know that the claimed cost and energy savings will be realized if they use the advertised products? Although reputable manufacturers rarely make claims in product literature that are untrue, product literature sometimes omits information relevant to a complete evaluation of lighting system performance. To gain confidence in the decision to upgrade lighting equipment, the Green Lights Partner should make assessments of *estimated* (calculated) and *actual* (measured) performance.

In addition, *occupant response* should be considered as an important part of the lighting upgrade evaluation. No calculations or computer simulations can adequately model human response to lighting, so occupant reactions should be measured directly.

5.2 ESTIMATING PERFORMANCE

Estimates of expected performance can be considered at three levels:

- ***The product level.*** Some information on the expected performance of lighting products, such as lamps and ballasts, can be easily obtained from manufacturer's literature. However, this information should be validated by reading independent literature and verified information from the product manufacturer.

- ***The system level.*** A lighting system is typically a fixture composed of lamps, ballasts, and optical components (lens or reflectors). You can evaluate the expected performance of lighting systems through calculations of illuminance (or more commonly, light level) and energy consumption.

- ***The whole-building level.*** Whole-building evaluations address the effect of lighting systems on the building environment, e.g., the interaction of the lighting with the HVAC (heating, ventilating, and air conditioning) systems. You can obtain information on expected whole-building energy performance through computer simulation using thermal and lighting modeling software.

Estimating Lighting Product Performance

Although lighting product information can be easily obtained from manufacturers, independent information should also be used. Three useful sources of independent information on lighting products are:

- *Guide to Performance Evaluation of Efficient Lighting Products*, Lighting Research Center (co-funded by EPA), First Edition, June 1991.

- *Specifier Reports,* Lighting Research Center (co-funded by EPA), 1991-3 (ongoing).

- *1992 Advanced Lighting Guidelines,* California Energy Commission.

The *Guide to Performance Evaluation of Efficient Lighting Products* has been distributed to all Green Lights Partners and Allies. It was developed to help readers evaluate new lighting solutions and to simplify the process of specifying lighting. The *Guide* contains:

- A glossary of lighting terms

- Summaries of key performance issues and methods for testing different efficient lighting technologies

- Directories of independent testing laboratories, publications relevant to lighting, and organizations involved with lighting standards

As an aid to consistent information collection, the *Guide* supplies a set of comprehensive forms for requesting product performance information from manufacturers.

Specifier Reports are a series of bulletins that provide product-specific testing information. They also examine how well lighting products work in combination with other lighting products and how lighting products affect whole-building performance and occupant response. The *Specifier Reports* provide data obtained using both standard and "benchmark" test methods. As reports are published, they will be distributed to all Partners and Allies.

The 1992 Advanced Lighting Guidelines contain a series of publications that presents application guidelines for state-of-the-art lighting upgrade technologies.

Estimating Lighting System Performance

Lighting upgrades can also be considered at the system level. To evaluate any lighting upgrade system, you will need estimates of at least four quantities:

- illuminance provided on the work surface
- power taken to provide that illuminance
- energy consumed to produce that illuminance over time
- cost of the lighting system.

These quantities should be estimated prior to installation and measured after completion of installation. Section 5.3 will cover some methods for performing field measurements.

Estimating Illuminance

Proper light levels are necessary to enable people to work quickly, accurately, and comfortably. Accordingly, the one lighting criterion that should always be checked is the illuminance on the task. For a regular array of fixtures, the illuminance on a horizontal plane (work surface) can be estimated by using simple arithmetic and manufacturers' photometric data. If the proposed lighting installation is not a regular array of fixtures, a computer program will be needed to calculate the illuminance. Most lighting consultants and manufacturers can make the necessary calculations. (Note that the Decision Support System performs these calculations in the process of selecting the appropriate upgrade technologies.)

Compare the estimated illuminance with the values recommended by the Illuminating Engineering Society of North America (IESNA) in their *Lighting Handbook*. Illuminance levels greatly above the recommended values are unnecessary and illuminance levels markedly below the recommended values are unwise. What constitutes a large departure from the recommended illuminance is a matter of judgement, but as a rough guide, a 20% difference is usually considered acceptable. For example, if the recommended illuminance is 50 footcandles, then illuminances in the range of 40 to 60 footcandles will all be acceptable. After completing the project, you should take actual measurements of illuminance (see Section 5.3).

Although illuminance is important to occupant acceptance, it is not the only aspect of lighting which can affect how acceptable people find the lighting. *Other aspects such as glare, flicker, veiling reflections, color rendering, and shadows are important.* None of these aspects of lighting can be estimated by simple numerical calculation. You can find a discussion of these factors in the IESNA *Lighting Handbook*. However, to ensure that all of these aspects are addressed in an upgrade design, consider seeking advice from an experienced lighting consultant.

Estimating Electrical Load

To obtain an estimate of the electrical load of an installation, first add up the wattages of all the lamps and ballasts to be used in the installation.

The total wattage of different lamp/ballast combinations should be available from the manufacturers or from the *Specifier Reports*. Remember to take into account factors such as delamping, power reducers, and phantom tubes - all of which reduce electrical load.

Obviously, the electrical load of the installation will vary with the total area of the space to be lit. Therefore, for comparison purposes, you may need to calculate the **lighting power density** by dividing the electrical load of the installation (watts) by the area to be lit (ft^2).

> *Example*: The electrical load of a 50' x 30' office is 2160 watts. Therefore, the lighting power density for this installation is 1.44 watts/ft^2 (2160 watts/1500 ft^2).

You can use the lighting power density, expressed in watts per square foot, to compare different alternative lighting systems, *assuming that each system produces the same illuminance and maintains comparable lighting quality*. Most commercial and industrial lighting installations will have lighting power densities in the range of 1.0–2.5 watts/ft^2. Lower values are more desirable as long as occupant acceptance and productivity are not adversely affected.

If the different lighting systems to be compared produce different illuminances, you will need to calculate the **installation efficacy** in order to make comparisons. Installation efficacy measures the quantity of lumens falling on the working plane from the installation for each watt of power applied. Obtain the installation efficacy by dividing illuminance produced by the installation by the lighting power density of the installation.

> ***Example***: In the 50' x 30' office considered previously, the installation produces an illuminance of 50 footcandles and has an lighting power density of 1.44 watts/ft^2. Therefore, the installation efficacy of this installation is 34.7 lumens/watt (50 footcandles/1.44 watts/ft^2).

As a guideline, installation efficacies should be at least 20 lumens/watt. Higher values are, in principle, more desirable. Note that installation efficacy is only applicable to uniform lighting, where the whole working plane is lit to the same illuminance. This measure is not meaningful when supplemental task lights -- such as desklamps -- are used.

Estimating Energy Consumption

Estimates of the energy consumed by the installation are deduced over an assumed period of time, which may be a fiscal year or a suitable payback period. Obtain an estimate of energy consumption by multiplying the electrical load of the installation by its hours of use.

> ***Example*** Assume that the 50' x 30' office discussed previously is used for 2080 hours a year (40 hours/week x 52 weeks/year). The annual energy consumption for the lighting installation is therefore 4493 kilowatt-hours (2160 watts x 2080 hours / 1000 watts/kilowatt).

The hours of use will vary with the organization. If your organization has very rigid hours of work, you may be able to predict the hours of use accurately. If it does not, then you may wish to use survey or direct measurement methods as described on page 85 to obtain a reliable measure of the hours of use.

Effect on HVAC Energy Consumption. Lighting systems generate heat that must be removed by the air conditioning system. Therefore, savings in lighting energy costs through efficiency upgrades can be enhanced by the resulting savings in air conditioning costs. And in most cases, these savings far outweigh any increases in heating costs that may result from reduced lighting system heat output.

The actual savings in air conditioning that may be expected from reduced lighting use depends on several factors:

- geometry and thermal characteristic of the building
- efficiency and type of HVAC system
- heating and cooling loads (full-load operating hours)
- lighting system operating hours

The U.S. Department of Energy (DOE) and the Electric Power Research Institute (EPRI) are conducting ongoing studies on the interaction of lighting and HVAC. While general rules have many exceptions, the typical range of HVAC savings in a commercial building is 6-29% of the lighting kilowatt-hour savings. This range in savings is predominantly influenced by climate. Methodologies for estimating air conditioning savings have been published in Strategic Planning for Energy and the Environment, Vol. 11, No. 1, Association of Energy Engineers, 1991, in an article entitled, "The Domino Effect: Lighting/Air Conditioning/Energy/Environment" by Cary Mendelssohn and Robert A. Rundquist.

Estimating Cost

The total cost of any proposed lighting installation is the sum of three costs:

- first cost
- operating and maintenance costs
- disposal cost

First Cost

Methods of estimating the first cost of a proposed lighting installation are discussed in Chapter 6 of the Manual, Requests for Proposals.

Operating and Maintenance Costs

Operating costs are more difficult to estimate than first costs because they depend on a number of factors, which may themselves have to be estimated. To estimate operating costs, first determine the values of the following factors:

- Electrical load (kilowatts), which can be either the
  - -- installed wattage (kilowatts) or
  - -- effective wattage if dimming or power reducing equipment is used (kilowatts)
- Hours of use over a relevant period of time (hours)
- Unit cost of electricity for each time period (dollars/kilowatt-hour)
- Electricity maximum demand costs (dollars)
  - -- times when use occurs
  - -- electricity usage during maximum demand periods (kilowatts)
  - -- electricity maximum demand charges (dollars/kilowatt)
- Maintenance costs, such as cleaning and relamping

Next, use the following formula to determine the electricity cost over the relevant period:

ELECTRICITY COST = [electrical load x hours of use x unit cost of electricity for each time period] + electricity maximum demand cost

Basically, the electricity cost is the product of the electrical load, the hours of use, and the unit cost of electricity, plus any cost of lighting used in periods of maximum electricity demand. Contact your utility representative for electricity rates for your organization and for methods of calculating the electricity maximum demand cost. Utilities use various methods of calculating the demand costs.

Finally, calculate the total operating cost of the installation:

Total operating cost = electricity cost + maintenance costs

Disposal Cost

Disposal costs are made up of the cost for removing the lighting equipment and the cost of disposing it. The factors to consider with regard to disposal are discussed in Chapter 8 of the Manual.

5.3 FIELD MEASUREMENTS

Field measurements may be made at various stages of a lighting upgrade project:

- Before proceeding with the upgrade, field measurements can be used to *assess the existing lighting installation.*
- By performing a *trial installation*, field measurements can be used to guide the decision on whether or not to cancel or modify the proposed upgrade specification, or to proceed

with the upgrade in all proposed locations.

- After completing the lighting upgrade, field measurements can be used to *verify that the upgrade meets it objectives.*

Field measurements address four questions:

- Do the *light levels* meet IESNA recommended levels?
- How can the *energy efficiency* of the installation be improved?
- Is energy being wasted in *unoccupied spaces*?
- Is the lighting *acceptable* to the people who use it?

In some cases, field measurements can be complex; some guidance is given in this section for carrying out some simple field measurements.

Measuring Light Levels

The most widely available instrument that can be used for measuring light levels is an illuminance meter. With this instrument and a degree of common sense, anyone can carry out a simple photometric survey. To accurately assess light levels before and after a trial installation, follow the steps outlined below:

Start with new lamps and clean fixtures.

Light output can be affected by age of the lamps and dirtiness of the fixture. Although light level readings may be made with lamps and fixtures in the "as is" condition, these readings should *not* be used as a baseline for comparison purposes.

The baseline light level readings should be made only after the following steps have been taken:

- Clean the existing fixtures in the trial installation area.
- Use new lamps (same wattage and type used in existing system); allow for a 100-hour "burn-in" period before taking measurements.

After the trial installation is complete, light level measurements should be performed under the SAME conditions.

- Clean any optical surfaces that have not been replaced with new or clean components.
- Use new lamps that have been burned in for 100 hours.

Allow time for system warm-up.

Most lighting installations take some time to reach a stable condition after switch-on. Twenty minutes are typically required for installations using fluorescent lamps, and it may take even longer for some high-intensity discharge lamps. Allowing thirty minutes between switch-on and the first measurement is good practice.

Eliminate daylight effects.

Daylight and sunlight can produce very large variations in lighting. To evaluate an electric lighting installation without any daylight contribution, you will have to make the photometric survey after dark or with the blinds closed.

Check supply voltage.

Light output of most lamps is directly affected by the supply voltage. At the time of the survey, you should measure the supply voltage to verify that it is not below acceptable levels (check with your electric utility).

Properly position the illuminance meter.

When making illuminance measurements, put the illuminance meter at the proper height on the work surface, and be careful not to shadow the meter by holding it close to your body. Also be careful to avoid reflections off clothing that could influence the measurement.

Record light level readings.

Use the illuminance meter to measure the illuminance at a variety of locations:

- Measure light levels at specific task locations
- Check uniformity of illumination by measuring light levels at the work plane height (usually 30" above the floor) at various locations including:
  - -- directly under fixtures
  - -- between fixtures (both laterally and longitudinally)
  - -- adjacent to walls
  - -- in corners
- Measure light levels on vertical task surfaces (if applicable); evaluate aesthetics of resulting light levels on walls (check for shadows on walls due to fixture cut-off angle.)

Be certain to record the *locations* of readings for the baseline case so you can repeat the procedure when evaluating the upgrade in a trial installation.

The average illuminance measured in the room should be corrected to account for lamp and dirt depreciation effects to determine the average *maintained* illuminance. (Refer to Chapter 9 for a discussion of how lighting system output gradually diminishes over time.) The average maintained illuminance should be compared with recommendations made by the IESNA *Lighting Handbook.*

Measuring Energy Efficiency

The energy efficiency of a lighting installation can be measured at three levels:

- electrical load
- energy consumed
- useful energy consumed

Measuring Electrical Load

Direct measurements of voltage and amperage (current) on a number of fixtures can be performed by using "clip-on" instruments, which eliminate the need to dismantle the fixture but still require the services of an electrician. Direct measurement may be the only option for determining electrical load in installations where power reducers or dimming control systems are used.

Measuring Energy Consumed

Direct measurement of energy consumption is achieved by metering the lighting circuit separately -- a procedure known as sub-metering. However, sub-metering requires a detailed knowledge of the electrical system to ensure that the lighting installation is the only load connected to the metered circuit. It will also require the services of a qualified electrician.

Alternatively, you can estimate the energy consumed by multiplying the electrical load of the installation by the system hours of use. The electrical load can be obtained as described above. The hours of use can be measured by installing a light-activated elapsed time meter in one or more sample fixtures.

Measuring Useful Energy Consumed

While energy consumed, based on electrical load and hours of use, is a meaningful measure, it leaves open the question about whether or not the energy is being consumed for any purpose. If the lighting is on in an unoccupied area, that energy is being wasted. In order to determine the amount of useful energy consumed, measure the lighting use when the space is occupied.

Most occupancy sensor manufacturers rent or sell kits that contain an occupancy sensor and an elapsed time recorder. The device will compare the total time that the lights are left on to the time that the space is actually occupied. The difference between these two values represents the potential savings that could be achieved by installing automatic switching controls.

Measuring User Acceptance

There are two methods of measuring user acceptance:

- Questionnaire Survey; and
- Complaint Analysis

Questionnaire Survey

A simple questionnaire may be used for measuring user acceptance of the lighting system both *before* and *after* the completion of a lighting upgrade.

User issues to address in the questionnaire include:

- light levels
- discomfort glare (direct and reflected)
- color rendering
- physical effects (eyestrain, headaches, etc.)
- convenience and safety
- architectural/aesthetic appeal
- importance of energy efficiency
- overall acceptance rating

The survey of the user response to the *new* system should be conducted several weeks after the installation has been completed in order to allow time for the users to adapt to the new system. Note that user satisfaction results may be enhanced simply by educating employees about the advantages of energy-efficient lighting *prior to* the installation of the lighting upgrade.

When reviewing the results, keep in mind that the assessments are largely subjective; look for *trends* that characterize the general level of acceptance of the users as a whole. To address unique complaints from individuals, refer to the following information on complaint analysis.

Complaint Analysis

Another approach to assessing user acceptance is to collect complaints of eyestrain or discomfort related to the lighting and analyze of the nature of the complaints. The most probable cause of complaints can often be deduced from the origin of the complaints.

If the complaints come from people doing different tasks in different parts of the installation, then the whole installation may be at fault. If the complaints are from a specific area, then whatever distinguishes that area from the rest of the space may be the cause of the complaints. Distinguishing features can include the work done in the area and the lighting of the area.

Try to attribute the complaints to task difficulty or limited visual capabilities. If the complaints are related to a specific task, then either the task is inherently very difficult or the lighting is inappropriate for the task. If only a few people complain about a task but others do the same task under the same lighting without complaint, then the problem may lie in the individuals' visual capabilities rather than the lighting. Special provisions may be made to accommodate the lighting needs of that individual, such as providing a task light.

Once you have eliminated inherent task difficulty and limited visual capability as sources of complaints, then lighting is likely to be the cause. Any lighting installation which consistently produces complaints of eyestrain and headaches cannot be considered satisfactory.

If a questionnaire survey or the incidence of complaints has indicated some dissatisfaction with the lighting, the next question to answer is what aspect of the lighting is wrong. This can be done by a photometric survey followed by comparison with recommended lighting standards.

If the measured illuminance levels are satisfactory according to the recommendations, but the questionnaires and/or complaints indicate that there is a lot of dissatisfaction with the lighting, you probably need outside help. Among the other possible sources of complaints about a lighting installation are glare, shadows, veiling reflections, flicker, and luminance distributions. Identifying these conditions, determining how to eliminate them, and determining the psychological impact of the lighting changes may be better handled by a professional lighting consultant.

5.4 EVALUATION CHECKLIST

This checklist shows how the different techniques of evaluating lighting upgrade performance can be used in a lighting upgrade project.

The checklist is divided into three parts, each part leading to a decision point:

- Part 1 is concerned with identifying the viability of an upgrade project.
- Part 2 covers the detailed design of the lighting upgrade.
- Part 3 is concerned with verifying that the upgrade is satisfactory to the occupants and is performing as expected.

Part 1: Assess Current Lighting System

1. Measure the illuminance provided by existing lighting; compare existing lighting with current standards.
2. Measure user satisfaction with existing lighting.
3. Survey your existing lighting system with assistance from lighting professionals and/or the Green Lights Decision Support System.
4. Make preliminary estimates of energy and cost savings to assess the viability of possible lighting upgrades.

Decision: Continue or cancel lighting upgrade project.

Part 2: Evaluate Lighting Upgrade Options

1. Obtain specific upgrade options from consultant or the Green Lights Decision Support System; be sure that qualitative aspects of lighting have been considered.
2. Select lighting upgrade options to be pursued.
3. Confirm product data for proposed upgrade.
4. Estimate illuminance or perform illuminance measurements in a trial installation.
5. Estimate electrical load and energy consumption of proposed upgrade; alternatively, load and consumption values can be directly measured in a trial installation.
6. Estimate lighting power density or installation efficacy and compare with current values.
7. Check compliance of proposed upgrade with federal, state, and local codes.
8. Estimate first cost, operating cost, and disposal cost.
9. Evaluate financial viability of lighting upgrade.
10. Construct budget for lighting upgrade project.

Decision: Prepare lighting upgrade specification or cancel project.

Part 3: Verify Lighting Upgrade Performance

1. Measure occupant acceptance of lighting upgrade.
2. Measure electrical load of installation.
3. Measure energy consumed by installation over known period.
4. Estimate energy wasted over a known period.

Decision: Extend, keep, modify, or remove lighting upgrade.

Appendix D

LIGHTING SURVEY REFERENCE SHEETS

This appendix contains a complete set of Lighting Survey Reference Sheets. The Reference Sheets were designed to assist users in completing the GL/DSS survey forms. The Tables on these sheets describe valid answers for various questions on the forms, such as ceiling types, room surface colors, fixture conditions, etc. Especially important are the fixture diagrams, shown on Reference Sheets #5 - #7. These are examples of all of the fixture types included in the Green Lights/Decision Support System.

LIGHTING SURVEY REFERENCE SHEET #1

Table 1. DIRT CONDITIONS

Condition	Description	Example
Very Clean	No dirt generated in or entering space; excellent removal or filtration	High grade offices, laboratories, clean rooms
Clean	Very little dirt generated in or entering space; better than average removal or filtration	Most offices, light assembly, inspection
Medium	Noticeable dirt generated in or entering space; below average removal or filtration	Semi-conditioned storage, transfer stations, light manufacturing
Dirty	Rapid dirt accumulation; ventilation but not filtration	Manufacturing, high speed printing
Very Dirty	Constant dirt accumulation; no ventilation or filtration	Where luminaires are in immediate area of generated dirt

Table 2. CEILING TYPES

Code	Ceiling Type
2x4	2x4 grid, suspended
2x2	2x2 grid, suspended
1x1	1x1 grid, suspended
DRY	Drywall
UNF	Unfinished/exposed slab or structure

Table 3. TEMPERATURE CONTROLS

Control	Description
Heated	Temperature kept above 60° F in cold weather
Cooled	Temperature kept below 78° F in warm weather
Refrigerated	Temperature kept below comfort zone
Unconditioned	No temperature control provided

Table 4. ROOM SURFACE COLORS

	Ceiling	Walls	Floor
LIGHT	White ceiling tiles, structure painted white, flat white drywall	White or pastel paint or wallpaper (untextured)	White or pastel tiles, marble, or carpeting, white painted concrete
MEDIUM	Colored ceiling tiles, structure painted light color, exposed slab, textured drywall	Colored paint or wallpaper, exposed slab	Colored tiles, marble, carpeting, light hardwood, exposed slab
DARK	Dark ceiling tiles, unpainted structure, wood paneling, heavily textured drywall	Black, brown, or dark gray paint or wallpaper, wood paneling, exposed metal	Black, brown, dark gray tiles, marble, or carpeting, dark hardwood

Table 5. PRIMARY ACTIVITIES IN OFFICE SPACES

Code	Activity	Target Footcandles
READ/WRITE (LOW): 30 FC	Reading/writing tasks of high contrast and/or large size	30
READ/WRITE (AVERAGE): 50 FC	Reading/writing tasks of average contrast and size	50
READ/WRITE (HIGH): 100 FC	Reading/writing tasks of medium/ low contrast and/or small size	100
VDT/CRT: 25 FC	Computer use with low ambient light plus existing or new task lights to illuminate reading/writing tasks	25
DRAFTING: 75 FC	Drafting tasks involving high contrast media, blue line, blueprints	75

LIGHTING SURVEY REFERENCE SHEET #2

Table 6. PRIMARY VISUAL TASKS IN WAREHOUSE/GENERAL RETAIL SPACES

Primary Visual Task	Target Footcandles	Applicable Space Types
Small Item Storage	30	Warehouse/Storage
Medium Item Storage	15	Warehouse/Storage
Bulky Item Storage	7.5	Warehouse/Storage
Loading & Unloading	20	Warehouse/Storage
Inactive/Automated Storage	7.5	Warehouse/Storage
Staging	30	Warehouse/Storage
Rapid Merchandise Selection	100	Merchandise Sales Floor
Familiar Merchandise Selection	75	Merchandise Sales Floor
Unfamiliar Merchandise Selection	30	Merchandise Sales Floor
Sales Transaction/Checkout	75	Merchandise Sales Floor
Stockroom Storage	30	Merchandise Sales Floor
Circulation	20	Merchandise Sales Floor

Table 7. FIXTURE CONDITIONS

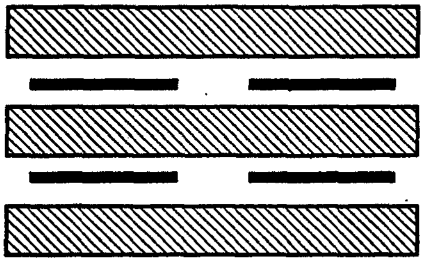
Code	Condition of Fixtures with Lens and Troffer
TGLG TGLP TPLG TPLP	Troffer in Good Condition, Lens in Good Condition Troffer in Good Condition, Lens in Poor Condition Troffer in Poor Condition, Lens in Good Condition Troffer in Poor Condition, Lens in Poor Condition
Good Condition:	Troffer and lens are like new, or can be restored to like new with cleaning.
Poor Condition:	**Troffer** - yellow or discolored, heavily scratched or dulled, chipped, shows heat marks, or fits poorly in ceiling. **Lens** - yellow or discolored, milky white with variable translucence, cracked, or shows heat marks.
Code	**Condition of Fixtures without Lens or Troffer**
GOOD POOR	Fixture reflective surfaces can be cleaned to like new condition Fixture reflective surfaces are permanently dulled, stained, rusted, or clouded

LIGHTING SURVEY REFERENCE SHEET #3

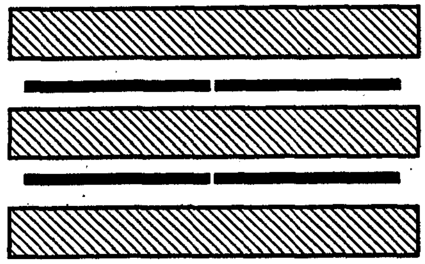
Table 8. WAREHOUSE/GENERAL RETAIL FIXTURE LAYOUTS

Aisle-Specific Layouts for Ceiling Mounted Fixtures

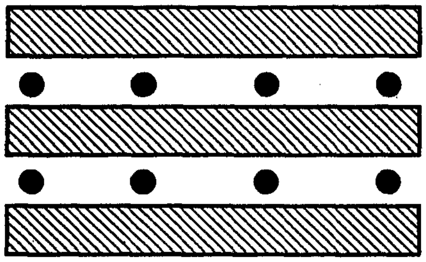
1. Spaced ceiling mounted fluorescent fixtures, parallel to aisles



2. End to end ceiling mounted fluorescent fixtures, parallel to aisles

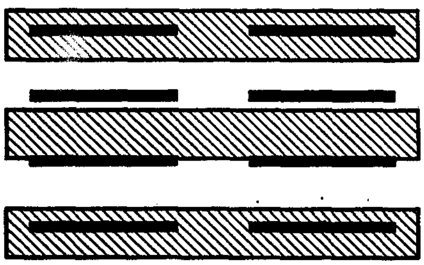


3. Ceiling mounted HID or incandescent fixtures in square or rectangular grid

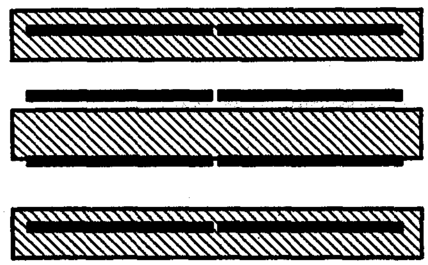


General (Non Aisle-Specific) Layouts for Ceiling Mounted Fixtures

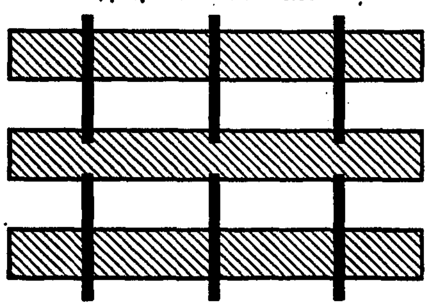
4. Spaced ceiling mounted fluorescent fixtures, parallel to aisles



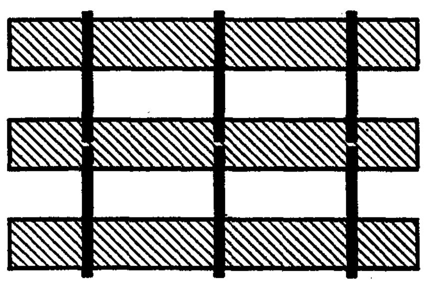
5. End to end ceiling mounted fluorescent fixtures, parallel to aisles



6. Spaced ceiling mounted fluorescent fixtures, perpendicular to aisles

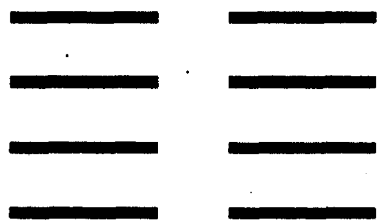
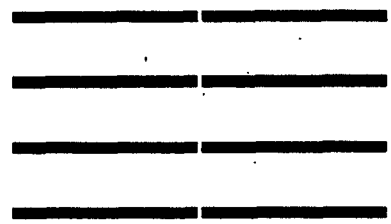
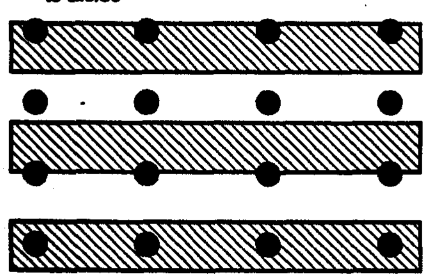
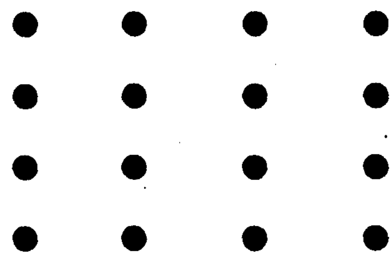


7. End to end ceiling mounted fluorescent fixtures, perpendicular to aisles



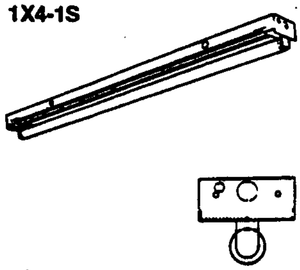
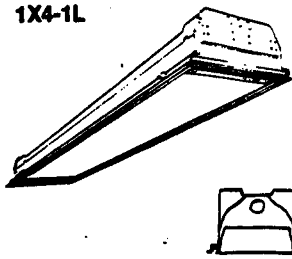
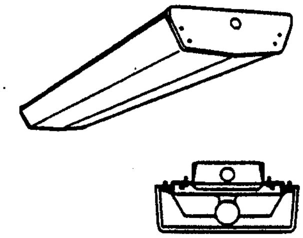
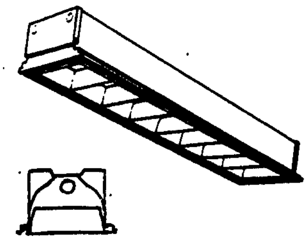
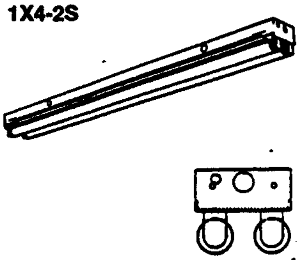
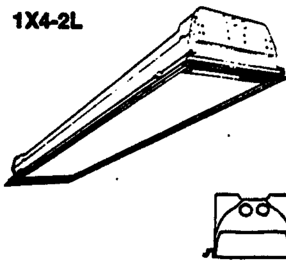
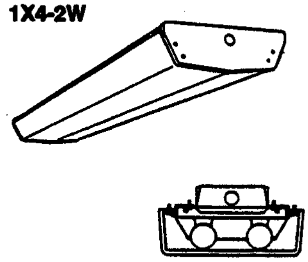
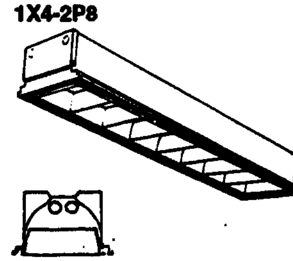
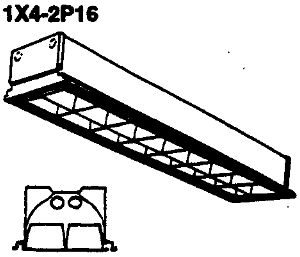
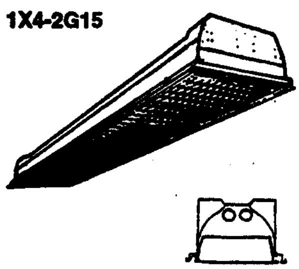
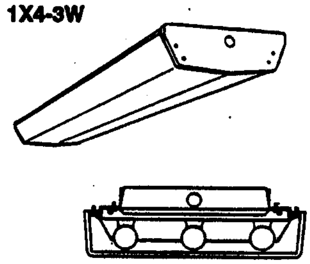
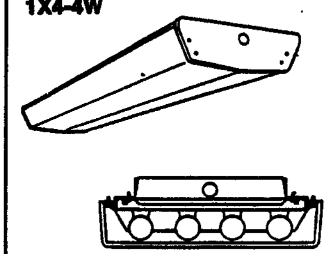
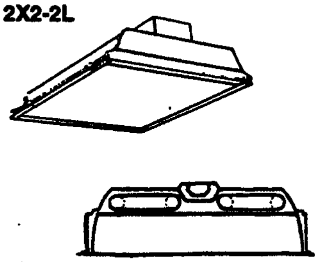
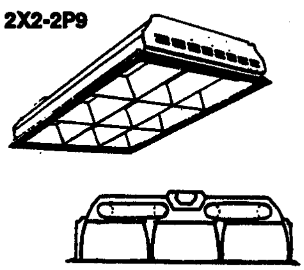
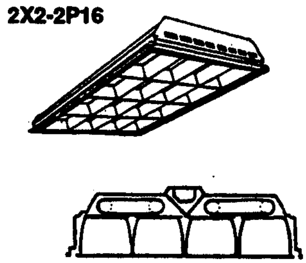
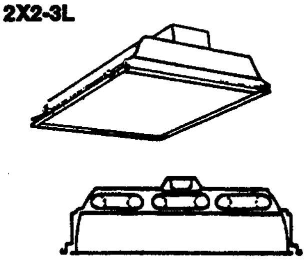
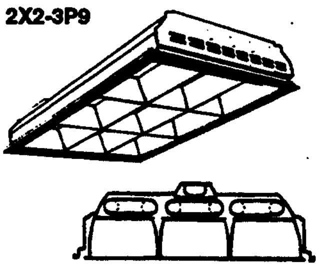
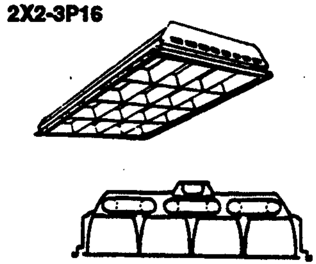
LIGHTING SURVEY REFERENCE SHEET #4

Table 8. WAREHOUSE/GENERAL RETAIL FIXTURE LAYOUTS (cont.)

General (Non Aisle-Specific) Layouts for Ceiling Mounted Fixtures	
8. Spaced ceiling mounted fluorescent fixtures in open spaces 	9. End to end ceiling mounted fluorescent fixtures in open spaces 
10. Ceiling mounted HID or incandescent fixtures in square or rectangular grid, not specific to aisles 	11. Ceiling mounted HID or incandescent fixtures in square or rectangular grid, in open spaces 
Layouts for Office/Support Spaces	
12. General illumination fixtures, any pattern, in "OFFICE OR SUPPORT" spaces	13. Non-general illumination fixtures, any pattern, in "OFFICE OR SUPPORT" spaces
Miscellaneous Fixture Layouts	
14. End to end fluorescent fixtures, mounted on some, but not all, rack or shelf units in sub-room	15. End to end fluorescent fixtures, mounted on all rack or shelf units in sub-room
16. Fixed task or display lights	17. Adjustable task or display lights
18. Exit signs	19. Other

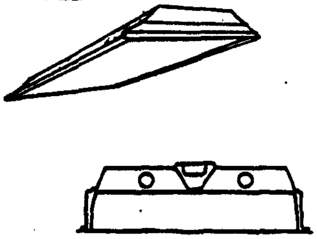
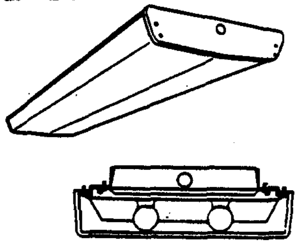
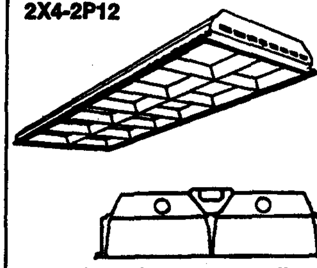
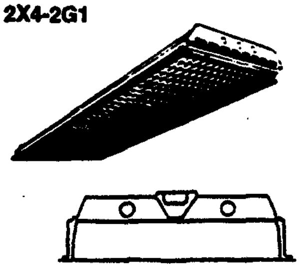
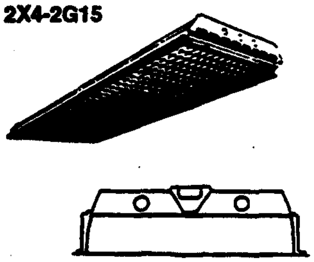
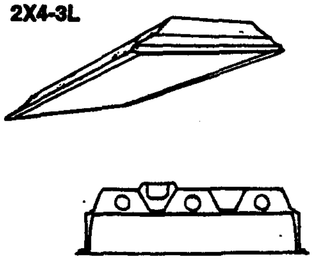
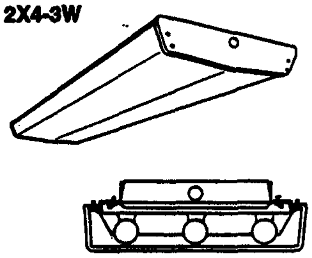
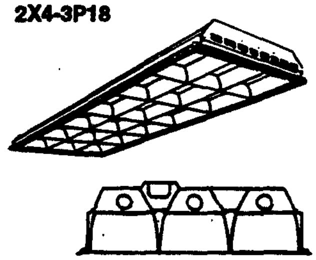
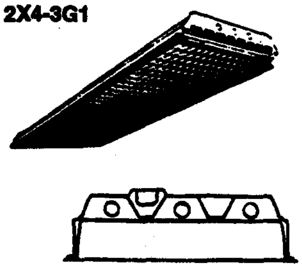
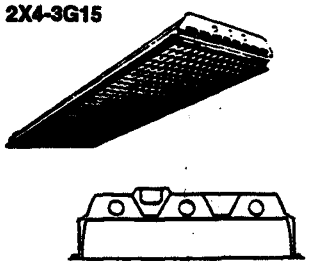
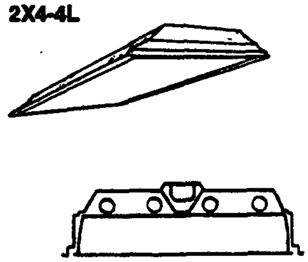
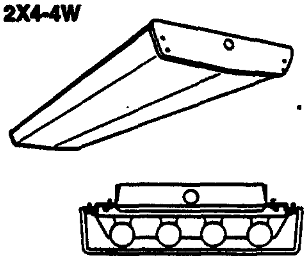
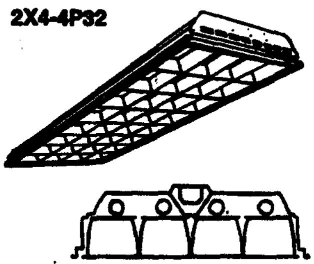
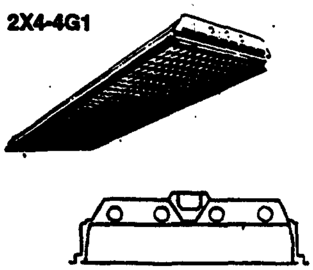
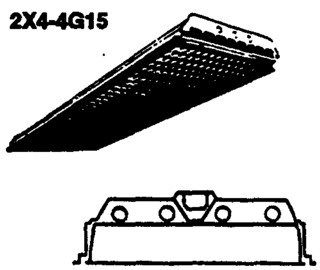
LIGHTING SURVEY REFERENCE SHEET #5

Table 9. 1x4 AND 2x2 FLUORESCENT FIXTURE TYPES

1X4-1S  1-lamp 4 foot fluorescent strip fixture	**1X4-1L**  1x4 1-lamp fluorescent lensed troffer	**1X4-1W**  1x4 (nominal) 1-lamp fluorescent wraparound fixture	**1X4-1P8**  1x4 1-lamp fluorescent troffer with 8-cell parabolic louver
1X4-2S  2-lamp 4 foot fluorescent strip fixture	**1X4-2L**  1x4 2-lamp fluorescent lensed troffer	**1X4-2W**  1x4 (nominal) 2-lamp fluorescent wraparound fixture	**1X4-2P8**  1x4 2-lamp fluorescent troffer with 8-cell parabolic louver
1X4-2P16  1x4 2-lamp fluorescent troffer with 16-cell parabolic louver	**1X4-2G15**  1x4 2-lamp specular grid louver with 1.5" by 1.5" cells	**1X4-3W**  1x4 (nominal) 3-lamp fluorescent wraparound fixture	**1X4-4W**  1x4 (nominal) 4-lamp fluorescent wraparound fixture
2X2-2L  2x2 2-lamp fluorescent lensed troffer	**2X2-2P9**  2x2 2-lamp fluorescent troffer with 9-cell parabolic louver	**2X2-2P16**  2x2 2-lamp fluorescent troffer with 16-cell parabolic louver	**2X2-3L**  2x2 3-lamp fluorescent lensed troffer
2X2-3P9  2x2 3-lamp fluorescent troffer with 9-cell parabolic louver	**2X2-3P16**  2x2 3-lamp fluorescent troffer with 16-cell parabolic louver		

LIGHTING SURVEY REFERENCE SHEET #6

Table 10. 2X4 FLUORESCENT FIXTURE TYPES

2X4-2L  2x4 2-lamp fluorescent lensed troffer	**2X4-2W**  2x4 (nominal) 2-lamp fluorescent wraparound fixture	**2X4-2P12**  2x4 2-lamp fluorescent troffer with 12-cell parabolic louver	**2X4-2G1**  2x4 2-lamp specular grid louver with cells 1" x 1" or less
2X4-2G15  2x4 2-lamp specular grid louver with 1.5" x 1.5" cells	**2X4-3L**  2x4 3-lamp fluorescent lensed troffer	**2X4-3W**  2x4 (nominal) 3-lamp fluorescent wraparound fixture	**2X4-3P18**  2x4 3-lamp fluorescent troffer with 18-cell parabolic louver
2X4-3G1  2x4 3-lamp specular grid louver with cells 1" x 1" or less	**2X4-3G15**  2x4 3-lamp specular grid louver with 1.5" x 1.5" cells	**2X4-4L**  2x4 4-lamp fluorescent lensed troffer	**2X4-4W**  2x4 (nominal) 4-lamp fluorescent wraparound fixture
2X4-4P32  2x4 4-lamp fluorescent troffer with 32-cell parabolic louver	**2X4-4G1**  2x4 4-lamp specular grid louver with cells 1"x1" or less	**2X4-4G15**  2x4 4-lamp specular grid louver with 1.5" x 1.5" cells	

LIGHTING SURVEY REFERENCE SHEET #7

Table 11. HID AND 1X8 FLUORESCENT FIXTURE TYPES

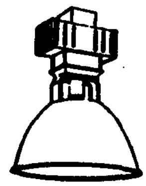
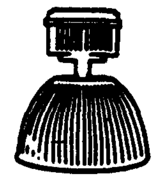
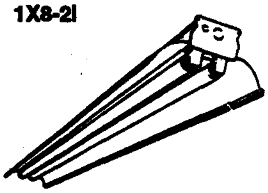
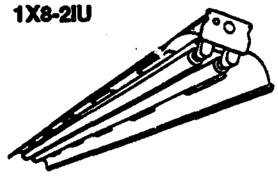
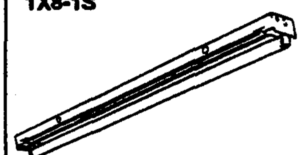
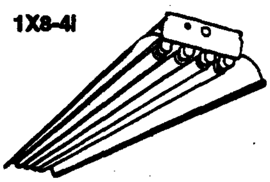
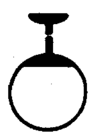
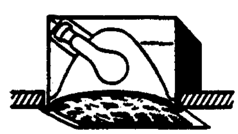
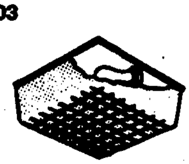
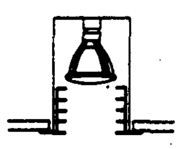
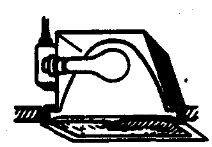
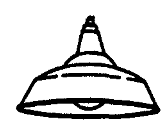
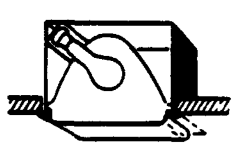
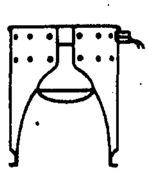
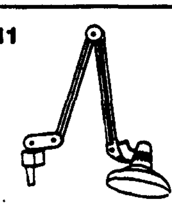
EAR  Enclosed aluminum reflector industrial HID fixture	**EPR**  Enclosed prismatic reflector industrial HID fixture	**OAR**  Open aluminum reflector industrial HID fixture	**OPR**  Open prismatic reflector industrial HID fixture
1X8-2I  1x8 2-lamp fluorescent industrial fixture	**1X8-2IU**  1x8 2-lamp fluorescent industrial fixture with 5% uplighting	**1X8-1S**  1x8 1-lamp fluorescent strip fixture	**1X8-2S**  1x8 2-lamp fluorescent strip fixture
1X8-4I  1x8 4-lamp fluorescent industrial fixture			

Table 12. INCANDESCENT/COMPACT FLUORESCENT FIXTURE TYPES[1]

IC-001  Pendant diffusing sphere	**IC-002**  Medium distribution unit with lens plate	**IC-003**  Prismatic square surface drum	**IC-004**  Enclosed reflector
IC-005  Recessed baffled downlight with 5-1/2" diameter aperture	**IC-006**  Wide distribution unit with lens plate	**IC-007**  Flood lamp without shielding	**IC-008**  Porcelain-enameled ventilated standard dome
IC-009  Recessed unit with dropped diffusing glass	**IC-010**  Flood lamp with specular anodized reflector skirt	**IC-011**  Incandescent or compact fluorescent task light	**IC-012** Any previously unidentified incandescent or compact fluorescent fixture

[1] Pictures used by permission of the Illuminating Engineering Society (IES).

LIGHTING SURVEY REFERENCE SHEET #8

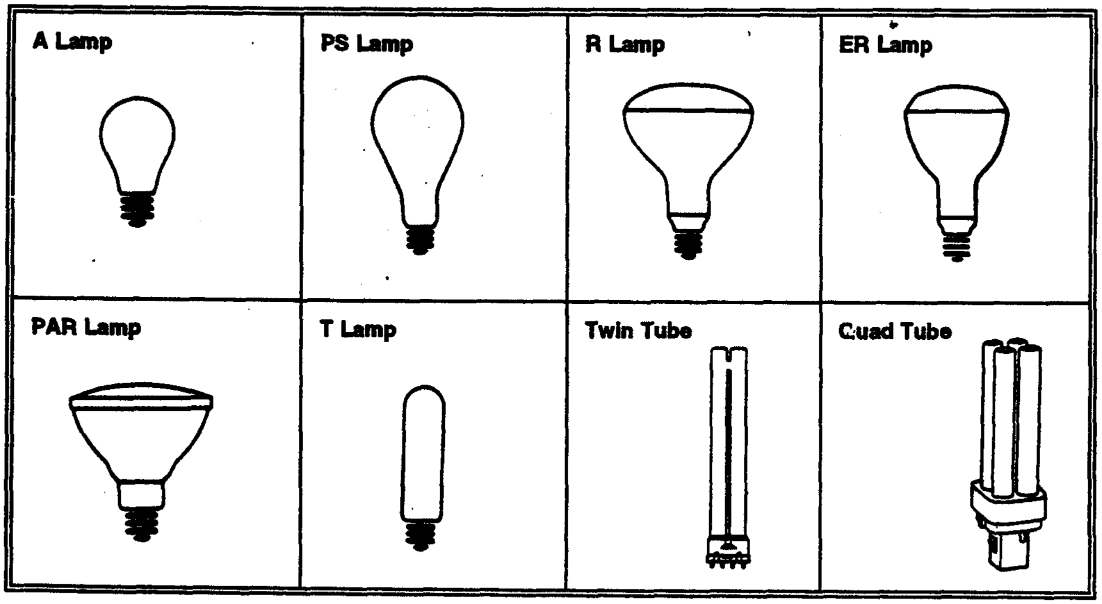
Table 13. LAMPS FOR FLUORESCENT FIXTURES

Code	2 ft. Lamps	Code	4 ft. Lamps	Code	8 ft. Lamps
T1235U3	T12 34-35 Watt U3	T1042	T10 42 Watt	96T864	8' T8 64 Watt
T1235U6	T12 34-35 Watt U6	T1234	T12 34 Watt	96T1260	8' T12 60 Watt energy saver slimline
T1240U3	T12 40 Watt U3	T1240	T12 40 Watt	96T1275	8' T12 75 Watt slimline
T1240U6	T12 40 Watt U6	T12HL	T12 40 Watt high lumen	96T1295	8' T12 95 Watt energy saver high output
T539	T5 39 Watt 22.5"	T832	T8 32 Watt	96T12110	8' T12 110 Watt high output
T8U31	T8 31 Watt U-tube			96T12185	8' T12 185 Watt energy saver 1500 MA
				96T12215	8' T12 215 Watt 1500 MA

Table 14. LAMPS FOR INCANDESCENT AND COMPACT FLUORESCENT FIXTURES

Code	Compact Fluorescents	Code	Incandescents	Code	Incandescents
10Q5	5-inch 10 Watt Quad tube	25A	25 Watt A lamp	175PS	175 Watt PS lamp
13Q5	5-inch 13 Watt Quad tube	40A	40 Watt A lamp	189PS	189 Watt PS lamp
13Q6	6-inch 13 Watt Quad tube	50A	50 Watt A lamp	200A	200 Watt A lamp
13T7	7-inch 13 Watt Twin tube	50ER	50 Watt ER lamp	200PS	200 Watt PS lamp
15Q5	5-inch 15 Watt Quad tube	50R	50 Watt R lamp	200R	200 Watt R lamp
18Q7	7-inch 18 Watt Quad tube	60A	60 Watt A lamp	200PAR	200 Watt PAR lamp
20Q6	6-inch 20 Watt Quad tube	75A	75 Watt A lamp	250PS	250 Watt PS lamp
26Q8	8-inch 26 Watt Quad tube	75ER	75 Watt ER lamp	250R	250 Watt R lamp
27Q7	7-inch 27 Watt Quad tube	75PAR	75 Watt PAR lamp	300PS	300 Watt PS lamp
5T4	4-inch 5 Watt Twin tube	75R	75 Watt R lamp	300PAR	300 Watt PAR lamp
7T5	5-inch 7 Watt Twin tube	100A	100 Watt A lamp	300R	300 Watt R lamp
9Q4	4-inch 9 Watt Quad tube	100PAR	100 Watt PAR lamp	500PS	500 Watt PS lamp
9T6	6-inch 9 Watt Twin tube	100R	100 Watt R lamp	500PAR	500 Watt PAR lamp
		120ER	120 Watt ER lamp	500R	500 Watt R lamp
		150A	150 Watt A lamp	750PS	750 Watt PS lamp
		150PAR	150 Watt PAR lamp	750R	750 Watt R lamp
		150PS	150 Watt PS lamp	1000PS	1000 Watt PS lamp
		150R	150 Watt R lamp	1000R	1000 Watt R lamp

Table 15. GENERAL INCANDESCENT AND COMPACT FLUORESCENT LAMP TYPES



LIGHTING SURVEY REFERENCE SHEET #9

Table 16. LAMPS FOR HID FIXTURES

Code	HIDs
250HPS	250 Watt high pressure sodium
250MH	250 Watt metal halide
250MV	250 Watt mercury vapor
400HPS	400 Watt high pressure sodium
400MH	400 Watt metal halide
400MV	400 Watt mercury vapor
1000HPS	1000 Watt high pressure sodium
1000MH	1000 Watt metal halide
1000MV	1000 Watt mercury vapor

Table 17. LAMPS AND UNIT TYPES FOR EXIT SIGNS (see Table 15 for general lamp types)

Code	Exit Sign Lamp or Unit Type
10T	10 Watt T-lamp, long life
20T6.5	6.5-inch 20 Watt T-lamp
25T6.5	6.5-inch 25 Watt T-lamp
40A	40 Watt A-lamp
5T4	4-inch 5 Watt Twin tube
60A	60 Watt A-lamp
7T5	5-inch 7 Watt Twin tube
9T6	6-inch 9 Watt Twin tube
ELECTROLUM	Electroluminescent unit
LED	LED unit
TRIT	Tritium unit

Table 18. FLUORESCENT BALLAST TYPES[2]

Ballast Code	Ballast Type	Possible Label Characteristics for 4' Lamps
STAND	Standard Electromagnetic	- CBM Certification - No "Circle E" Certification - Line current (amps) for two T12 40 Watt lamps: 0.34 to 0.36 if 277 volts 0.79 to 0.80 if 120 volts
EFFIC	Efficient Electromagnetic	- CBM Certification - "Circle E" Certification - Line current (amps) for two T12 40 Watt lamps: 0.32 to 0.35 if 277 volts 0.73 to 0.76 if 120 volts
HYBRD	Hybrid Cathode Cutting	- No CBM Certification - "Circle E" Certification - Line current (amps) for two T12 40 Watt lamps: 0.26 if 277 volts 0.60 to 0.63 if 120 volts - Opti-miser[R], PowRkut[R], or Universal Plus[R]
ELECT	Electronic	- No CBM Certification - "Circle E" Certification - Line current (amps) for two T12 40 Watt lamps: 0.27 to 0.29 if 277 volts 0.61 to 0.68 if 120 volts
HID	Ballast for HID sources	NA

[2] Call your ballast manufacturer or the Green Lights Lighting Services Group if you have difficulty identifying your ballasts.

Chapter 8

WASTE DISPOSAL

Upgrading a lighting system will likely involve the removal and disposal of lamps, ballasts or fixtures. Some of this material may be classified as a hazardous substance and must be handled accordingly. Other materials can be recycled or should be disposed of in an environmentally responsible manner. This section provides an overview of issues relating to disposal of lamps and ballasts.

Executive Summary

Principles

- The Federal Government does not specify the method of disposal for ballasts *except in the case of ballasts that are leaking PCBs.*
- Some states have requirements for the transportation and disposal of non-leaking ballasts that contain PCBs.
- Under current Federal law, mercury-containing lamps may be a hazardous waste and must be handled accordingly.
- Some states further regulate lamp disposal.
- EPA encourages environmentally responsible disposal or recycling of all lighting upgrade wastes.

Action Steps

- Investigate and follow local requirements for handling and disposing of lamps and ballasts.
- Identify ballasts that contain PCBs and ballasts that are leaking PCBs.
- Remove, handle, and dispose of *leaking* PCB-containing ballasts as a regulated hazardous substance.
- Dispose of ballasts containing PCBs (but not leaking) by high-temperature incineration or disposal at chemical or hazardous waste landfill sites.
- Maintain permanent records of PCB-containing ballast disposal.
- If they test hazardous, manage mercury-containing wastes in compliance with hazardous waste regulations.

Note: The information in this section is believed to be correct as of February 1993. EPA does not provide legal advice, and this section is not intended to do so. Generators of wastes should check with local, state, and regional authorities for the most up-to-date information.

8.1 FLUORESCENT LIGHT BALLASTS

The primary environmental concern regarding the disposal of used fluorescent lighting ballasts is the health risks associated with contact with polychlorinated biphenyls (PCBs). PCBs, potential carcinogens, are toxic chemical compounds that were widely used as insulators in electrical equipment such as capacitors, switches, and voltage regulators until the early 1980s.

Production of PCBs was banned in the United States in 1976 by the U.S. Environmental Protection Agency. PCBs are regulated under the Toxic Substances Control Act (TSCA) in Volume 40 Code of Federal Regulations (CFR) Part 761.

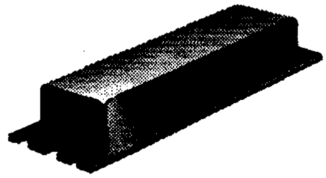
The proper method for disposing of used ballasts depends on a number of factors relating to the type and condition of the ballasts, as well as the regulations or recommendations that are in effect in the state where the ballasts will be discarded. Federal regulations pertain to the disposal of ballasts that are leaking PCBs. Under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), certain generators of PCB-containing ballasts can be held liable for disposing of ballasts in an unapproved manner. In order to determine the appropriate disposal method for PCB-containing ballasts, refer to the decision flow chart on the following page.

Because disposal requirements vary from state to state, check with regional or local authorities for all applicable regulations in your area. For your convenience, a listing of information sources is included in Section 8.4.

Identifying PCB-Containing Ballasts

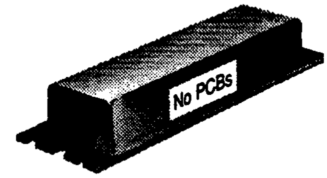
Fluorescent lighting ballasts contain a small capacitor that may contain high concentrations of PCBs (greater than 90% pure PCBs or 900,000 ppm). Use the following guidelines to identify ballasts that contain PCBs.

- All light ballasts manufactured through 1979 contain PCBs.
- Ballasts manufactured after 1979 that do not contain PCBs are labeled "**No PCBs**". These labels, however, are not certain proof that a ballast does not contain PCBs.
- If a ballast is not labeled "No PCBs" <u>it should be assumed to contain PCBs</u>.
- It is extremely important to determine if a ballast containing PCBs is leaking, <u>before</u> it is removed from the fixture, so that it can be handled properly.



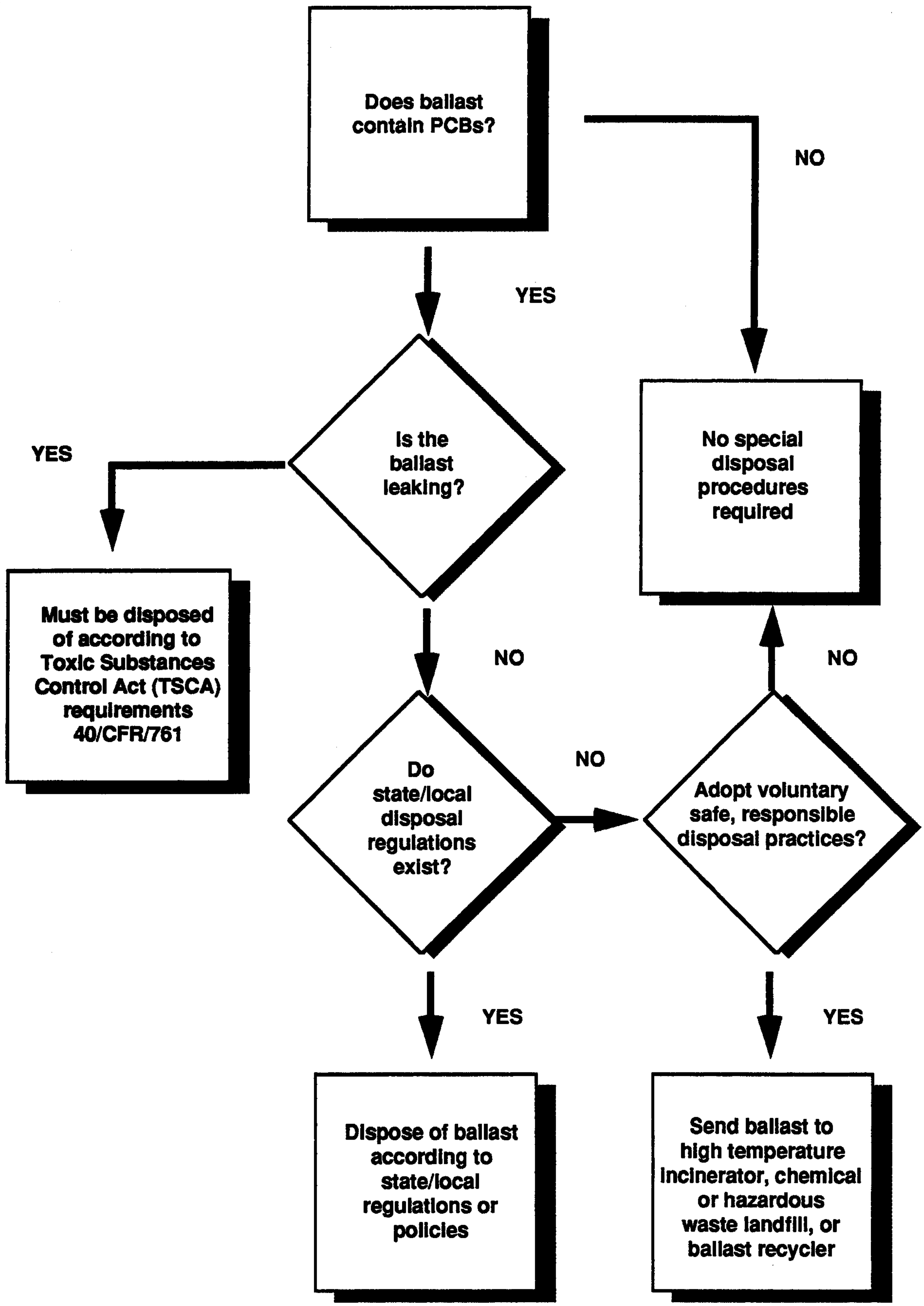
Contains PCBs

Manufactured through 1979



Probably does not contain PCBs

Manufactured after 1979


Does ballast contain PCBs?
NO
YES
Is the ballast leaking?
YES
No special disposal procedures required
Must be disposed of according to Toxic Substances Control Act (TSCA) requirements 40/CFR/761
NO
NO
NO
Do state/local disposal regulations exist?
Adopt voluntary safe, responsible disposal practices?
YES
YES
Dispose of ballast according to state/local regulations or policies
Send ballast to high temperature incinerator, chemical or hazardous waste landfill, or ballast recycler

Federal Guidelines: Non-Leaking PCB-Containing Ballast Disposal

If fluorescent light ballasts are not leaking PCBs, their disposal is not regulated under TSCA. The disposal of non-leaking PCB containing ballasts is regulated under CERCLA. Building owners who release a pound or more of PCBs (roughly equivalent to 12-16 ballasts) in a 24 hour period into the environment are required under CERCLA to notify the National Response Center. Building owners may be liable for throwing away PCB-containing ballasts in a dumpster or local landfill under CERCLA.

Small capacitor fluorescent lighting ballasts that contain PCBs are exempt from Federal TSCA requirements under 40 CFR 761.60(b)(2)(ii). (See the definition of small capacitor ballasts on the next page.) However, EPA does encourage proper disposal of PCB containing ballasts, as described in the 1979 preamble to 40 CFR 761 and reiterated in the final ruling on August 25, 1982 (47 FR 37342):

"EPA encourages commercial and industrial firms that use and dispose of large quantities of small PCB Capacitors to establish voluntarily a collection and disposal program that would result in the waste capacitors going to chemical or hazardous waste landfills or high-temperature incinerators."

Some EPA regional offices (e.g. Regions 9 & 10) publish policies governing disposal of PCB-containing ballasts which may be adopted by individual states in their region. States are not obligated to adopt regional policies. (See Section 8.4 for more information.)

Definition of a Small Capacitor Ballast

Ballasts contain a capacitor that contains dielectric fluid. The ballast is classified as a small capacitor ballast if the weight of the dielectric fluid is less than 1.36 kg (3 lbs.). If the weight is unknown, the following assumptions are made:

- A capacitor whose total volume is less than 1,639 cubic centimeters (100 cubic inches) contains less than 1.36 kg of dielectric fluid.
- A capacitor whose total volume is more than 3,278 cubic centimeters (200 cubic inches) contains more than 1.36 kg dielectric fluid (i.e. is not a small capacitor ballast and is subject to 40 CFR Part 761).
- A capacitor whose total volume is between 1,639 and 3,278 cubic centimeters is considered to contain less than 1.36 kg dielectric fluid if the total weight of the capacitor is less than 4.08 kg (9 lbs).

Federal Requirements: Leaking PCB-Containing Ballast Disposal

Ballasts in a lighting system may be punctured or damaged, exposing an oily tar-like substance. If the leaking ballast is identified as containing PCBs, the ballast and all materials that come in contact with it are considered hazardous waste and are fully regulated and subject to federal requirements for PCBs under 40 CFR Part 761. ***Leaking PCB-containing ballasts must be incinerated at an EPA-approved high-temperature incinerator.*** (See Section 8.4 for more information).

It is very important that the removal, handling and disposal of leaking PCB-containing ballasts be done properly. Extra precautions must be taken to contain the exposure to the leaking ballast, since ***all materials that come in contact with the ballast or the leaking substance must also be treated as hazardous waste.***

The handling and disposal of leaking PCB-containing ballasts should be completed by personnel or contractors that are specifically trained and authorized to do so.

For proper packing, storage, transportation, and disposal information, call the TSCA assistance information hot-line at (202) 554-1404.

State Requirements: Non-Leaking PCB-Containing Ballast Disposal

Although many states do not regulate the disposal of non-leaking PCB-containing ballasts, the disposal standards for these ballasts are more stringent in some states than Federal TSCA or CERCLA guidelines. State standards can take several forms (e.g., written regulations, regional policies, written and verbal recommendations, transportation documentation only).

Some states do not regulate PCB-containing ballasts as a hazardous waste, but prohibit their disposal in municipal landfills. The table on the following page provides a listing of regulations and recommendations for each state.

When performing lighting upgrades, make sure your contractor removes all disconnected PCB-containing light ballasts from the luminaires. Non-leaking PCB-containing ballasts may be hazardous if left in the luminaires, especially in the event of a fire in the building.

Non-Leaking PCB-Containing Ballast Disposal Methods

EPA recommends two methods for disposing of *non-leaking* PCB-containing ballasts: high-temperature incineration and chemical or hazardous waste landfill.

High-Temperature Incineration

High-temperature incineration is the method preferred by many companies because it eliminates PCB-containing ballasts from the waste stream permanently. Incineration costs more than sending a PCB-containing ballast to a hazardous waste landfill, but the additional cost of incineration is one many companies are willing to absorb. There is a short term shortage of incineration capacity which should be alleviated by mid-1992.

Hazardous Waste Landfill

PCB-containing ballasts may be sent to a chemical or hazardous waste landfill for burial. Landfill disposal is less expensive than high-temperature incineration, but does not eliminate PCBs from the waste stream permanently. While chemical or hazardous waste landfill disposal is considered an acceptable, regulated disposal method, your company may be legitimately concerned about potential future liability in connection with this method.

Packing Ballasts for Disposal

Ballasts are packed, in accordance with PCB regulations, in 55-gallon drums for transportation -- regardless of chosen disposal method.

- One drum holds 150 to 300 ballasts depending on how tightly the ballasts are packed.

- Void space is filled with an absorbent packing material for safety reasons.

STATE PCB-CONTAINING BALLAST DISPOSAL REQUIREMENTS

State	Regulation or Recommendation	Comments
AK		
AL	Yes	In-State landfill requires prior approval.
AR	Yes	Regulates transportation of PCBs > 50 ppm.
AZ	Yes	Can be sent to Municipal Landfill if packed in approved drums.
CA	Yes	PCB ballasts must be incinerated or sent to a chemical waste landfill.
CO		
CT	Yes	PCB ballasts must be incinerated or sent to a chemical waste landfill.
DE		
FL		
GA		
HI		
IA		
ID	Yes	Follow EPA Region 10 policy (>5 ballasts/yr. must be incinerated or sent to a chemical waste landfill.)
IL		
IN	Yes	In-State landfill requires prior approval.
KS		
KY		
LA		
MA	Yes	All PCB ballasts regulated as a hazardous waste. Does not require licensed transporter.
MD	Yes	>1 KG of PCBs (40-44 ballasts): Must incinerate or send to chemical waste landfill.
ME	Yes	All PCBs >50 ppm regulated as hazardous waste.
MI		
MN	Yes	All PCBs >50 ppm regulated as hazardous waste.
MO		
MS		
MT		
NC		
ND		
NE		
NH		
NJ		
NM		
NV	Yes	Recommends incineration or chemical waste landfill.
NY		
OH		
OK		
OR	Yes	Follow EPA Region 10 policy (>5 ballasts/yr. must be incinerated or sent to a chemical waste landfill.)
PA	Yes	Regulates on a per case basis. Generators contact Dept. of Environmental Resources.
RI	Yes	All PCBs >50 ppm regulated as PCB waste. Log system substitutes for standard manifesting.
SC	Yes	In-State disposal requires prior approval.
SD		
TN	Yes	In-State disposal requires prior approval.
TX	Yes	3lbs. or over per item or more than 20 items per 10 day period from a specific project, location, or generator must be incinerated or sent to a chemical waste landfill. ALL WASTES generated from a renovation project over 200 square feet in size must be incinerated.
UT		
VA		
VT	Yes	All PCBs >50 ppm regulated as hazardous waste.
WA	Yes	Follow EPA Region 10 policy (>5 ballasts/yr. must be incinerated or chemical waste landfill.)
WDC		
WI	Yes	All PCBs >50 ppm regulated as PCB waste.
WV		
WY		

15 states

STATE MERCURY-CONTAINING LAMP DISPOSAL REQUIREMENTS

State	Regulation or Recommendation	Comments
CA	Yes	Over 25 lamps per 24 hour period must be disposed of as a hazardous waste.
MN	Yes	Mercury containing lamps must be stored according to Minnesota Pollution Control Agency (MPCA) guidelines or shipped to a recycling facility out-of-state in accordance with MPCA requirements.
		ALL OTHER STATES HAVE NO REQUIREMENTS

Although the information in these tables is believed to be accurate as of February 1992, it is not intended as legal advice. Check with the State authorities before disposing of lamps and ballasts.

Ballast Disposal Costs

High-temperature incineration and hazardous waste landfill costs can vary considerably. Disposal prices vary according to:

- quantity of waste generated
- location of removal site
- proximity to an EPA-approved high-temperature incinerator or hazardous waste landfill.

Negotiate with hazardous waste brokers, transporters, waste management companies, and disposal sites to obtain lower fees.

High-Temperature Incineration Costs

Incineration costs are calculated by weight:

- Costs range from $1/lb to $2.75/lb;
- Average cost is $1.85/lb, which equals
- Approximately $5.75 per ballast.

Note: Estimated costs do not include packaging, transportation, or profile fees.

Chemical or Hazardous Waste Landfill Costs

Chemical or hazardous waste landfill costs are calculated by the drum.

- Costs range from $65/drum to $385/drum;
- Average cost is $150/drum; which equals
- Approximately $1/ballast.

Note: Tightly packed drums lower your disposal costs. Estimated costs do not include packaging, transportation, or profile fees.

Transportation Costs

Transportation fees are calculated as cents per pound per mile and vary according to:

- Number of drums to be removed from the site;
- Distance from your location to the location of the high-temperature incinerator or hazardous waste landfill.

Transporters may be required to be registered or licensed to be authorized to move hazardous waste in certain states. Documentation of the movement of hazardous waste may be required even if a state does not regulate disposal or require the use of a licensed transporter.

Profile Fees

Operators of the high-temperature incinerator or hazardous waste landfill may charge a profile fee to document incoming hazardous waste. Profile fees vary depending on the volume of waste materials generated:

- Profile fees range from $0 to $300 per delivery;

- Fees may be waived if a certain volume or frequency of deliveries is assured or a working relationship has been established with a broker, lighting management company, or other contractor.

Record Keeping

- Keep records (including year, make, and quantity) of all light ballasts removed in lighting upgrades that are not labeled "No PCBs".

- Require your contractor to provide you with certificates of destruction for all PCB-containing ballasts that are incinerated or hazardous waste landfilled.

- Request documentation from hazardous waste haulers who may be transporting your PCB containing light ballasts.

Recycling of Ballasts

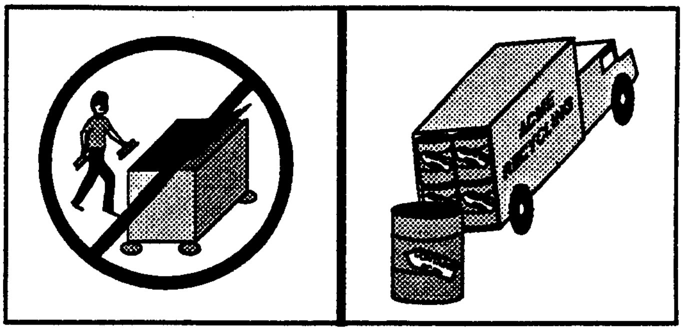
- Used non-leaking ballasts may be recycled regardless of whether they contain PCBs.

- Ballasts can be recycled to reclaim valuable metals and reduce the volume of solid waste sent to landfill sites.

- Recyclers remove the chamber which contains the capacitor to reduce the volume and weight of materials sent to landfill or incinerator. The remaining ballast can yield copper, steel, and other valuable materials.

- Recycling prevents toxic substances from being burned at your local incinerator or buried in a landfill.

A list of companies that recycle ballasts is included in Section 8.4. If you are unable to locate a contractor in your area who provides recycling services, you may send an inquiry to Green Lights Customer Service Center by fax at (202) 775-6680.



8.2 LAMPS CONTAINING MERCURY

Fluorescent and high-intensity discharge (HID) lamps contain small quantities of mercury, cadmium and antimony that can potentially be harmful to the environment and to human health. To prevent these materials from polluting the environment, used lamps must be handled in an environmentally safe manner.

Federal Regulations

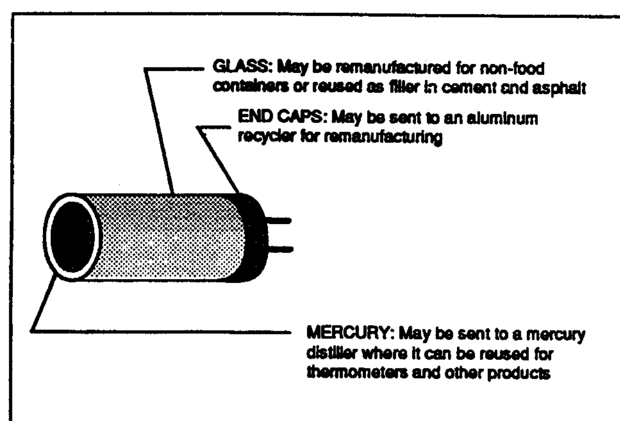
Under current Federal law, mercury-containing lamps -- such as fluorescent lamps -- may be a hazardous waste. Under the Resource Conservation and Recovery Act (RCRA), used fluorescent lamps (like most other wastes) are subject to evaluation against the RCRA hazardous waste characteristics, including the toxicity characteristic. The generator of the waste is responsible for making this determination. Wastes found to exhibit toxicity characteristics are defined as hazardous wastes and must be managed according to hazardous waste storage, treatment, and disposal regulations, unless otherwise excluded. The mercury content of fluorescent lamps can cause them to be hazardous under this regulation, requiring their management as a hazardous waste. Generators of used fluorescent lamps should contact the RCRA Hotline for further explanation of the hazardous waste management rules (1-800-424-9346 or, in the Washington DC area, 703-920-9810). EPA encourages all Green Lights participants, as well as other fluorescent lamp users, to handle fluorescent lamps in compliance with hazardous waste regulations as appropriate.

State Regulations

Some states also classify used mercury-containing lamps as hazardous waste and may regulate their disposal. As of January 1993, California and Minnesota are the only states that have a policy regarding disposal of fluorescent lamps. Check with your regional EPA office or state agency (listed in Section 8.4) for requirements concerning disposal of mercury-containing lamps in your area.

Recycling Fluorescent Lamps

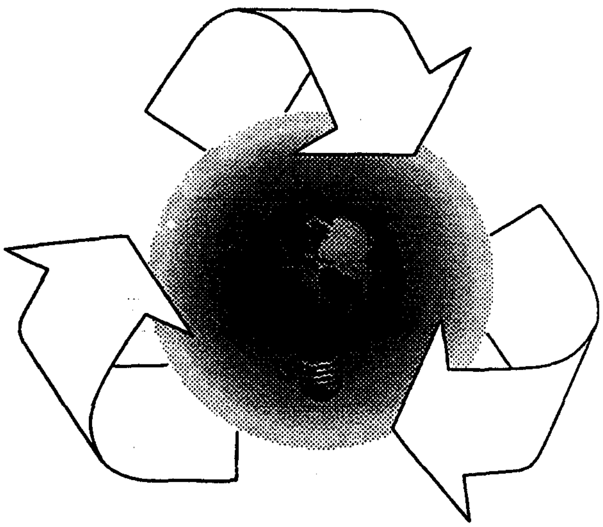
Recycling fluorescent lamps recovers materials, such as mercury, glass and aluminum, that can be used in manufacturing other products. Recycling can also remove potentially harmful materials from the waste stream. There is a net recycling cost of approximately 10 cents per linear foot for a fluorescent lamp. A list of recycling facilities is included in Section 8.4.



Recycling HID Lamps

Some lamp recycling companies recycle high intensity discharge (HID) lamps as well as fluorescent tubes. Contact the lamp recycling companies in Section 8.4 for more information.

If you wish to recycle your fluorescent lamps and cannot locate a contractor in your area who provides recycling services, send your inquiry by fax to the Green Lights Customer Service Center at (202) 775-6680.



8.3 WORKING WITH CONTRACTORS

Your lighting upgrade project specification should include provisions for proper handling and safe disposal of lamps, ballasts, and other hazardous materials that may be associated with the project.

Here are some general guidelines:

- Investigate your disposal options thoroughly.
- Do not expect your contractor to be well-versed in all disposal requirements and options.
- Ask your lighting or electrical contractor to provide disposal services (either directly or through a sub-contractor) as part of their contract.
- Be specific in your disposal requests (e.g., high-temperature incineration of PCB-containing ballasts at an EPA-approved incinerator).
- Require documentation from the contractor (or sub-contractor) for transportation and proper disposal of hazardous wastes.
- Ask for certifications, licenses, and references from all subcontractors providing waste disposal services.

8.4 INFORMATION RESOURCES

EPA Regional Offices

REGION I (ME, VT, NH, MA, CT, RI)
Environmental Protection Agency
John F. Kennedy Federal Building
Room 2203
Boston, MA 02203
(617) 565-3420

REGION II (NY, NJ, PUERTO RICO, VIRGIN ISLANDS)
Environmental Protection Agency
Jacob K. Javitz Federal Building
26 Federal Plaza
New York, NY 10278
(212) 264-2657

REGION III (PA, WVA, VA, MD, DE, WASHINGTON D.C.)
Environmental Protection Agency
841 Chestnut Building
Philadelphia, PA 19107
(215) 597-9800

REGION IV (TN, KY, NC, SC, GA, AL, MS, FL)
Environmental Protection Agency
345 Courtland Street, N.E.
Atlanta, GA 30365
(404) 347-4727

REGION V (IL, WI, IN, MI, MN, OH)
Environmental Protection Agency
230 South Dearborn Street
Chicago, IL 60604
(312) 353-2000

REGION VI (NM, TX, OK, AR, LA)
Environmental Protection Agency
First Interstate Bank Tower at Fountain Place
12th Floor/Suite 1200
1445 Ross Avenue
Dallas, TX 75202
(214) 655-6444

REGION VII (NE, KS, MO,IA)
Environmental Protection Agency
726 Minnesota Avenue
Kansas City, KS 66101
(913) 551-7000

REGION VIII (MT, WY, ND, SD, UT, CO)
Environmental Protection Agency
Suite 500
999 18th Street
Denver, CO 80202-2405
(303) 293-1603

REGION IX (CA, NV, AZ, HI, AMERICAN SAMOA, GUAM)
Environmental Protection Agency
75 Hawthorne Street
San Francisco, CA 94105
(415) 744-1017

REGION X (WA, OR, ID, AK)
Environmental Protection Agency
1200 Sixth Avenue
Seattle, WA 98101
(206) 442-1200

State Solid and Hazardous Waste Agencies

ALABAMA
Department of Environmental Management
Land Division -- Solid/Hazardous Waste
1751 Federal Drive
Montgomery, AL 36130
(205) 271-7761/7735

ALASKA
Department of Environmental Conservation
Environmental Quality Management Section
Solid Waste Management Section
Pouch O
Juneau, AK 99811
(907) 465-2667

ARIZONA
Department of Health Services
Office of Waste and Quality Management
2005 North Central Avenue
Phoenix, AZ 85004
(602) 257-2235

ARKANSAS
Department of Pollution Control and Ecology
Solid Waste Division
P.O. Box 9583
Little Rock, AR 72219
(501) 562-7444

CALIFORNIA
Department of Toxic Substances Control
P.O. Box 806
Sacramento, CA 95812-0806
(916) 322-3700

COLORADO
Department of Health
Hazardous Materials and Waste Management Division
4210 East 11th Avenue
Denver, CO 80220
(303) 331-4830

CONNECTICUT
Department of Environmental Protection
Division of Environmental Quality
Waste Management Unit
State Office Building
165 Capitol Avenue
Hartford, CT 06106
(203) 566-8476

DELAWARE
Department of Natural Resources and Environmental Control
Division of Environmental Control
Solid Waste/Hazardous Waste Section
Edward Tatnall Building
P.O. Box 1401
Dover, DE 19901
(302) 736-47812

Delaware Solid Waste Authority
P.O. Box 71
New Castle, DE 19901
(302) 736-5361

DISTRICT OF COLUMBIA
Public Space Maintenance Administration
Bureau of Sanitation Services
Solid Waste Disposal Division
4701 Shepherd Pkwy, S.W.
Washington, D.C. 20032
(202) 767-8512

Department of Consumer and Regulatory Affairs
Environmental Control Division
Pesticides and Hazardous Waste Section
5010 Overlook Avenue, S.W.
Washington, D.C. 20032
(202) 783-3194

FLORIDA
Department of Environmental Regulation
Division of Environmental Programs
2600 Blairstone Road
Tallahassee, FL 32301
(904) 487-1855

GEORGIA
Department of Natural Resources
Environmental Protection Division
Land Protection Branch
270 Washington Street, SW
Atlanta, GA 30334
(404) 656-2833

HAWAII
Department of Health
Pollution Investigation and Enforcement Division
P.O. Box 3378
Honolulu, HI 96801
(808) 548-6355

IDAHO
Department of Health and Welfare
Division of Environment
Bureau of Hazardous Materials
450 W. State Street
Boise, ID 83720
(208) 334-5879

ILLINOIS
Environmental Protection Agency
Land Pollution Control Division
2200 Churchill Road
P.O. Box 19276
Springfield, IL 62794-9276
(217) 782-6762

INDIANA
Office of Solid and Hazardous Waste Management
105 South Meridian Street
Indianapolis, IN 46206-6015
(317) 232-4473

IOWA
Department of Natural Resources
Environmental Protection Division
Air Quality and Solid Waste Protection Bureau
Wallace State Office Building
900 East Grand Avenue
Des Moines, IA 50319
(515) 281-8690

KANSAS
Department of Health and Environment
Solid Waste Management Division
Forbes AFB Bldg. No. 740
Topeka, KS 66620
(913) 296-1500

KENTUCKY
Environmental Protection Department
Division of Waste Management
Ft. Boone Plaza
18 Reilly Road
Frankfort, KY 40601
(502) 564-6716

LOUISIANA
Department of Environmental Quality
Office of Solid and Hazardous Waste
Solid Waste Division
P.O. Box 44307
Baton Rouge, LA 70804
(504) 342-4677

MAINE
Department of Environmental Protection
Bureau of Oil & Hazardous Materials Control
State House Station 17
Augusta, ME 0433
(207) 289-2651

Waste Management Agency
State House Station 154
Augusta, ME 0433
(207) 289-5300

MARYLAND
Department of the Environment
Hazardous and Solid Waste Management Administration
2500 Broening Avenue
Baltimore, MD 21224
(301) 631-6400

MASSACHUSETTS
Executive Office of Environmental Affairs
Department of Environmental Quality Engineering
Solid and Hazardous Waste Division
1 Winter Street
Boston, MA 02108
(617) 292-5589

MICHIGAN
Department of Natural Resources
Hazardous Waste Division
P.O. Box 30028
Lansing, MI 48909
(517) 373-2730

Department of Natural Resources
Ground Water Quality Division -- Solid Waste
P.O. box 30028
Lansing, MI 48909
(517) 373-2794

MINNESOTA
Minnesota Pollution Control Agency
Solid and Hazardous Waste Division
520 Lafayette Road North
St. Paul, MN 55155
(612) 296-7340

MISSISSIPPI
Department of Natural Resources
Bureau of Pollution Control
P.O. Box 10358
Jackson, MS 39209
(601) 961-5171

MISSOURI
Department of Natural Resources
Division of Environmental Quality
Waste Management Program
Jefferson State Office Building
205 Jefferson Street
P.O. Box 176
Missouri Boulevard
Jefferson City, MO 65102
(314) 751-3176

MONTANA
Department of Health and Environmental Sciences
Environmental Sciences Division
Solid Waste Management Bureau
Cogswell Building
Helena, MT 59620
(406) 444-2821

NEBRASKA
Department of Environmental Control
P.O. Box 94877
State Office Building
Lincoln, NE 68509
(402) 471-2186

NEVADA
Department of Conservation and Natural Resources
Division of Environmental Protection
201 South Fall Street, Capitol Complex
Carson City, NV 89710
(702) 885-4670

NEW HAMPSHIRE
Department of Environmental Services
Hazardous Waste Bureau/Solid Waste Bureau
Concord, NH 03301
(603) 271-2906
Underground Storage Tanks
(603) 271-3503

NEW JERSEY
Department of Environmental Protection
Solid Waste Division/Hazardous Waste Bureau
401 East State Street
CN 402
Trenton, NJ 08625
(609) 292-9120/9877

NEW MEXICO
Health and Environment Department
Environment Improvement Division
Harold Runnels State Office Bldg.
1190 St. Francis Drive
P.O. Box 968
Santa Fe, NM 87504
(505) 827-2779/2929

NEW YORK
Department of Environmental Conservation
Solid Waste Management Division
Bureau of Hazardous Waste
50 Wolf Road
Albany, NY 12233
(518) 457-5861/3254

NORTH CAROLINA
Department of Environment, Health, and Natural Resources
Solid Waste Management/Hazardous Waste Division
P.O. Box 27687
Raleigh, NC 27611
(919) 733-2178

NORTH DAKOTA
Health Department
Environmental and Waste Management Research Division
1200 Missouri Avenue
Bismarck, ND 58505
(701) 224-2382

OHIO
Environmental Protection Agency
Office of Solid and Hazardous Waste
P.O. Box 1049
1800 Watermark Drive
Columbus, OH 43266-0149
(614) 644-2917

OKLAHOMA
Health Department
Environmental Health Services
Hazardous Waste Service
P.O. box 53551
Oklahoma City, OK 73152
(405) 271-5338

Oklahoma Corporation Commission
UST Department
Jim Thorpe Building
Oklahoma City, OK 73109
(405) 521-3107

OREGON
Department of Environmental Quality
Division of Hazardous and Solid Waste
Executive Building
811 SW Sixth Avenue
Portland, OR 97204
(503) 229-5254

PENNSYLVANIA
Department of Environmental Resources
Bureau of Solid Waste Management
Fulton Building
P.O. Box 2063
Harrisburg, PA 17120
(717) 787-9870

PUERTO RICO
Environmental Quality Board
Solid and Hazardous Waste Bureau
P.O. Box 11488
Santurce, PR 00910
(809) 725-5140

RHODE ISLAND
Department of Environmental Management
Air and Hazardous Materials
291 Promenade Street
Providence, RI 02908
(401) 277-2797

SOUTH CAROLINA
Board of Health and Environmental Control
Bureau of Solid and Hazardous Waste
2600 Bull Street
Columbia, SC 29201
(803) 734-5200

SOUTH DAKOTA
Department of Water and Natural Resources
Environmental Health Division
Joe Foss Building
Pierre, SD 57501
(605) 773-3329

TENNESSEE
Department of Public Health
Bureau of Environmental Health Services
Solid Waste Management Division
Cordell Hull Building
Nashville, TN 37129
(615) 741-3424

TEXAS
Texas Water Commission
P.O. Box 13087
Capitol Station
Austin, TX 78711
(512) 463-7760

Department of Health
Bureau of Solid Waste
1100 W. 49th Street
Austin, TX 78756
(512) 458-7271

UTAH
Department of Health
Division of Environmental Health
Bureau of Solid and Hazardous Waste
P.O. Box 16690
288 North 1460 West
Salt Lake City, UT 84116-0690
(801) 538-6170

VERMONT
Agency of Natural Resources
Waste Management Division
103 S. Main Street
Waterbury, VT 05676
(802) 244-8702

VIRGINIA
Department of Waste Management
101 North Fourteenth Street
11th Floor, Monroe Building
Richmond, VA 23219
(804) 225-2667

WASHINGTON
Department of Ecology
Solid and Hazardous Waste Program
Mail Stop IV-11
Olympia, WA 98504-8711
(206) 459-6316

WEST VIRGINIA
Department of Natural Resources
1201 Greenbriar St.
Charleston, WV 25311
(304) 348-5935

WISCONSIN
Department of Natural Resources
Bureau of Solid Waste Management
101 South Webster Street
Madison, WI 53707
(608) 266-1327

WYOMING
Department of Environmental Quality
Solid Waste Management Program
122 West 25th Street
Cheyenne, WY 82002
(307) 777-7752

TSCA, RCRA, and CERCLA Information Lines

Toxic Substances Control Act (TSCA)
Assistance Information Hotline
(202) 554-1404

Resource Conservation and Recovery Act
(RCRA) Hotline
(800) 424-9346

National Response Center (NRC) Hotline
(800) 424-8802

EPA Approved Disposal Locations

Commercially permitted PCB INCINERATORS operating as of October 1991:

Aptus, Inc.
P.O. Box 1328
Coffeyville, KS 67337
(316) 251-6380

Chemical Waste Management
P.O. Box 2563
Port Arthur, TX 77643
(409) 736-2821

Rollins
P.O. Box 609
Deer Park, TX 77536
(713) 930-2300

Commercially permitted Hazardous WASTE LANDFILLS operating as of October 1991:

CECOS International
P.O. Box 340 LPO
Niagara Falls, NY 14302
(716) 282-2676

CECOS International
5092 Aber Road
Williamsburg, OH 45176
(513) 720-6114

Chem-Security Systems Incorporated
Star Route, Box 9
Arlington, OR 98712
(503) 454-2643

Chemical Waste Management
Call 1-800-843-3604 for
information on CWM disposal
facilities nation-wide.

Envirosafe Services Inc. of Idaho
P.O. Box 16217
Boise, ID 83715-6217
(800) 274-1516

U.S. Ecology, Inc.
Box 578
Beatty, NV 89003
(702) 553-2203

U.S. Pollution Control, Inc.
Grayback Mountain
8960N Hwy 40
Lake Point, UT 84074
(801) 534-0054

RECYCLING RESOURCES

Lamp Recycling Services

Advanced Environmental Recycling Corp.
Allentown, PA
(215) 797-7608

Lighting Resources, Inc.
Pomona, CA
(714) 622-0881

Mercury Technologies Corporation
San Rafael, CA
(415) 499-1000

Mercury Recovery Systems
Monrovia, CA
(818) 301-1372

Nine West Technologies
Newark, NJ 07102
(201) 623-0007

Quick Silver Products, Inc.
Brisbane, CA
(415) 468-2000

Ballast Recycling Services

Eastern Environmental Technologies
Norwalk, CT
(203) 856-2014

Ensquare, Inc.
Newton Upper Falls, MA
(617) 969-9238

Environmental Energy Group
Denton, TX
(817) 383-3632

FulCircle Ballast Recyclers
Cambridge, MA
(617) 876-2229
Bronx, NY
(212) 328-4667

Lighting Resources, Inc.
Pomona, CA
(714) 622-0881

Salesco U.S.A.
Honolulu, HI
(800) 368-9095
Phoenix, AZ
(800) 368-9095
San Diego, CA
(619) 793-3460
Boston, MA
(617) 344-4074

Transformer Service, Inc.
Concord, NH 03302
(603) 224-4006

THIS IS NOT A COMPLETE LIST OF COMPANIES WHO PROVIDE RECYCLING AND DISPOSAL SERVICES THROUGHOUT THE UNITED STATES. COMPANIES LISTED IN THIS SECTION ARE NOT ENDORSED BY THE EPA OR THE GREEN LIGHTS PROGRAM. EPA DOES NOT SCREEN LISTED COMPANIES AND CANNOT CONFIRM THE METHODS THESE COMPANIES MAY USE IN THEIR RECYCLING PROCESS.

Chapter 9

LIGHTING MAINTENANCE

An efficient lighting system must be properly maintained to continue to provide high quality, efficient lighting. Systematic lighting management methods and services from lighting specialists can help organize the process and assure continued high performance of any lighting system.

Executive Summary

Principles

- Light output of all lighting systems decreases over time.
- Many lighting systems are over-designed to compensate for future, unnecessary light loss.
- Improving maintenance procedures can increase efficiency and reduce maintenance costs.

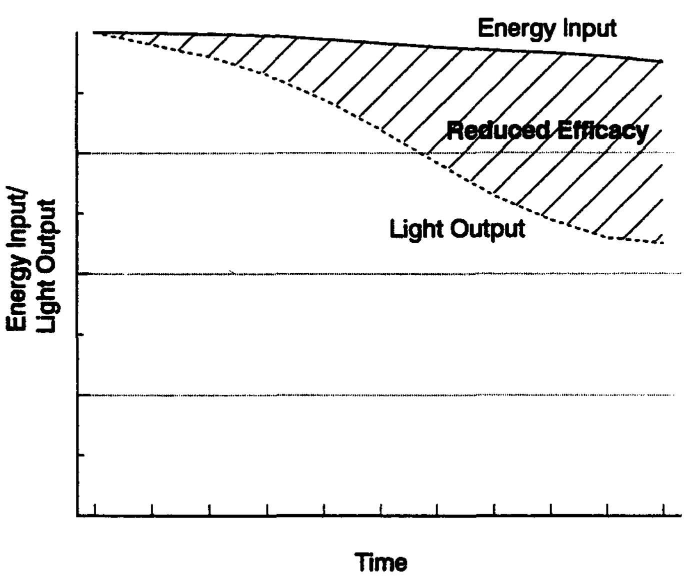
Action Steps

- Plan your lighting maintenance for the most light and the lowest cost of light.
- Group relamp to reduce lumen depreciation and maintenance costs.
- Clean fixtures at the time of relamping; (more often in dirty locations).
- Write a lighting maintenance policy.
- Design your lighting upgrade projects to incorporate effective maintenance.
- Get help when needed from:
    - lighting management companies
    - consultants
    - distributors
    - manufacturers.

9.1 INTRODUCTION

Lighting maintenance is more than simply replacing lamps and ballasts when they go out. Facility managers today must *manage* their lighting resources (i.e. fixtures, lamp/ballast inventory, labor, energy) in order to sustain the quality of a lighting system.

The light output of a luminaire decreases with age and use, yet the energy input is relatively unchanged. (See graph below.) Because the human eye is extremely adaptive to gradually changing lighting conditions, most occupants do not notice the gradual decline in light levels. But eventually, the reduction will affect the appearance of the space as well as the productivity and safety of the occupants.



Neglected lighting systems lose efficiency over time.

In the past, lighting designers have dealt with this problem by increasing the number of fixtures or lamps to compensate for the future light loss. While this simplifies maintenance, it is not an acceptable solution due to the added initial equipment cost, energy cost, and energy-related pollution.

Today, the design of efficient lighting systems in new buildings and in upgrade projects achieves efficiency, in part, by reducing the maintenance "cushion" of over-lighting. As a result, an efficient lighting system *requires* well-planned, strategically-timed maintenance to sustain adequate lighting levels. It is reassuring to remember, however, that a well maintained, efficient lighting system costs less to operate than a haphazardly maintained, inefficient lighting system.

This section discusses the causes of lighting depreciation and the measures that can reduce light loss and costs.

9.2 LIGHT OUTPUT DEPRECIATION

There are three causes of light output depreciation:

- lamp and ballast failures
- lamp lumen depreciation
- luminaire dirt depreciation

Light output depreciation will gradually decrease system efficiency over time. Combined, these factors commonly reduce light output by 20-60%. Except for lamp and ballast failure, there is no corresponding energy reduction associated with the light loss.

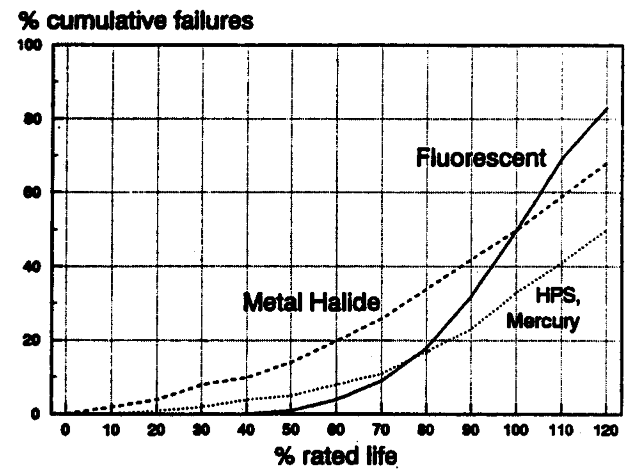
Lamp and Ballast Failures

When lamps and ballasts fail, they no longer provide light for the space. Often, however, failed lamps and ballasts remain in fixtures for months.

Lamp Failures

Lamp manufacturers list the "average rated life" for their products. The average rated life is the number of hours until one-half of the lamps can be expected to have failed. A few lamps may fail soon after installation, and the rate of failure will increase as the lamps are used. (See graph below.) There are other factors that affect lamp life:

- average operating time between starts
- improper installation
- type of ballast circuit



Source: GE Lighting

With an understanding of the type of lamps in use and the operating conditions, it is possible to predict lamp failure rate accurately enough to schedule the replacement of all the lamps just before substantial failures begin. This *group replacement* of lamps will reduce the light loss caused by lamp failure and will reduce the time, effort, and complaints associated with *spot replacement* of lamps. The few lamps that fail between group replacements can be tolerated or spot-replaced as needed.

Incandescent	1,000 hours
Halogen	2,000 hours
Fluorescent	12-20,000 hours
Sodium	12-24,000 hours
Metal Halide	20-24,000 hours
Mercury	20-24,000+ hours

Typical rated average lamp life

Ballast Failures

Ballasts last much longer than lamps. Ballast life is primarily affected by the operating temperature of the ballast. Since operating temperature varies with the type of ballast, the heat retention characteristics of the luminaire enclosure, and the fixture mounting method, ballast life is more difficult to predict than lamp life. Electronic ballasts can be expected to operate longer than magnetic ballasts because electronic ballasts produce less heat. While there is no reliable long-term test data available, ballast life is generally described by ballast manufacturers as shown in the table below.

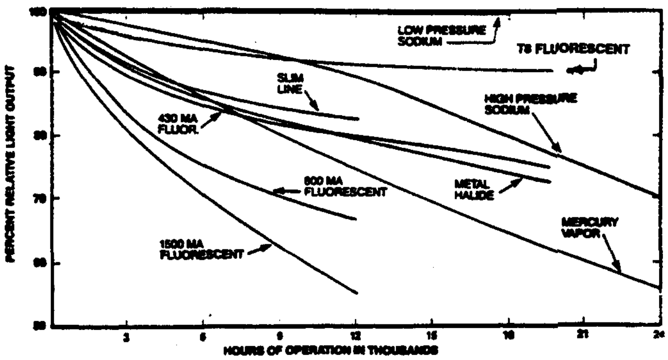
Similar to lamps, the ballast failure rate can be expected to be minimal in the first 70% of average life and increase substantially beyond that point. By monitoring ballast failures in a facility, it may be possible to predict the value of the potential maintenance savings achievable by replacing ballasts before they fail.

Magnetic	10-14 years
Efficient Magnetic	12-15 years
Cathode Cutout	15-17 years
Electronic	20-25+ years

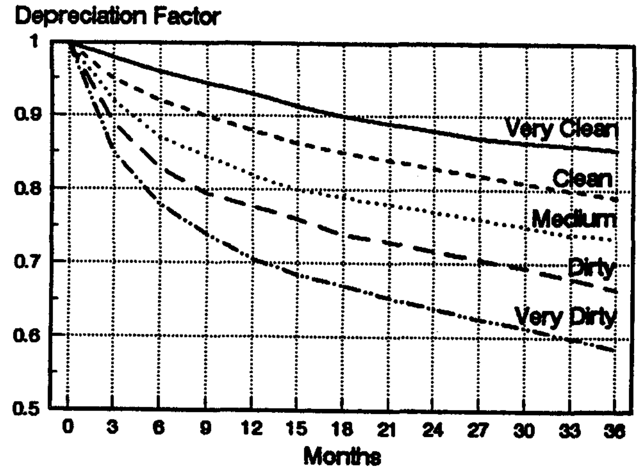
Typical ballast life

Lamp Lumen Depreciation (LLD)

As a lamp ages (through use), the amount of light it produces declines. This is called lamp lumen depreciation (LLD). LLD can be caused by several factors, such as carbon deposits inside the bulb wall or deterioration of the phosphor coating inside the bulb. Incandescent and high pressure sodium lamps have minimal LLD, which means they maintain a high percentage of their initial output throughout their useful life. Fluorescent, mercury and metal halide lamps, however, exhibit significant lumen depreciation. (See next graph.)



Lamp Lumen Depreciation of Standard Lamps
Source: U.S. Department of Energy



Note: LDD values shown are for fixtures w/closed top and closed bottom (transparent or translucent), IES Category 5. Source: IES

Luminaire Dirt Depreciation

To calculate average light levels, a lighting designer considers the light output of a lamp at the average age the lamp is expected to reach in use. By replacing lamps earlier, it is possible achieve the same light levels with fewer lamps and less energy. While this has little value for incandescent and high pressure sodium, it can result in significant savings in fluorescent, metal halide and mercury systems.

Luminaire Dirt Depreciation (LDD)

Dust, smoke film, oil and dirt accumulates on the reflective surfaces of fixtures, lenses and lamps. As a result, less of the light produced by the lamps is delivered into the room. This depreciation can be very minor in closed fixtures located in clean rooms, but it can be very severe in open fixtures in dirty environments. (See next graph.) Estimating the effect of dirt depreciation is important for determining fixture cleaning schedules.

9.3 MAINTENANCE PLANNING

Many maintenance managers are hesitant to replace lamps that are still operating. But group relamping and cleaning can actually be less expensive than sporadic spot maintenance. Through strategic planning and management of the overall lighting system performance, costs can be reduced and lighting quality improved.

Note: There are a number of resources to help plan lighting management. See Section 9.4 for more information.

Step 1: Define Existing Condition

The first step in planning a lighting maintenance strategy is to define the existing condition of the lighting systems. The following must be determined:

- type of lamps and ballasts in use
- average age of the lamps/ballasts
- total annual hours of lighting operation
- product costs
- spot replacement labor costs
- group replacement labor costs
- energy costs
- the rate of dirt accumulation

The following scale is used to determine the rate of dirt accumulation: 1= very clean (new office buildings -- no smoking), 2= clean (older office buildings), 3= medium (adjacent to heavy manufacturing), 4=dirty (heavy manufacturing), 5= very dirty (heavy manufacturing with no exhausting of dirty air).

Step 2: Predict Light Loss Factors

Armed with the above information, it is possible to determine existing and future light loss. The mortality, lumen depreciation, and dirt depreciation curves are used to determine the *maintained* lumens, which is the percentage of *initial* lumens that remain as the system ages. The formula for light loss factor (LLF) is:

LLF = LLD x LDD x LBO

Where,
LLD = Lamp lumen depreciation
LDD = Luminaire dirt depreciation
LBO = Lamp burn out, or lamp mortality rate

It is important to note that these three are the *recoverable* components to the LLF. There are also *nonrecoverable* factors, such as voltage variation (VV) and ballast factor (BF).

Step 3: Establish a Relamping Interval

By determining an acceptable level of light loss and an acceptable number of lamp failures (or spot replacements), it is possible to estimate an appropriate time to group re-lamp the lighting system. Compare the cost of several group re-lamp intervals and the cost of spot replacement. See Section 9.4 for information on where to get help.

Step 4: Develop a Maintenance Method

There are several factors to consider when planning a lighting maintenance strategy:

- Use existing staff, hire new staff, or use a contractor.
- Complete during regular hours, nights, weekends.
- Manage quality control.
- Dispose of lamps and ballasts.
- Re-lamp building-wide or in stages.
- Establish product types.
- Establish testing procedures for exit and emergency lighting.

Step 5: Budget for Maintenance

Budgeting is the most difficult part of planning a maintenance program. Spot maintenance of a lighting system can be sporadic on a daily basis but the annual cost will be fairly constant after the first few years. Strategic maintenance, on the other hand, is easier to manage on a daily basis and may cost less overall, but the cost fluctuates each year.

For example: To maintain the fluorescent lighting in a facility that operates 4000 hours per year on a spot basis would require the replacement of about 20% of the lamps every year. To maintain the same facility on a group basis would require very little replacement for three years, and then 100% replacement every forth year.

Because budgets are often established a year in advance, it is necessary to predict relamp timing and budget accordingly. As an alternative, lighting maintenance budgets can be leveled by completing an equal portion of the group maintenance each year. In the example above, for instance, completing a group relamp of 25% of the facility each year, will keep the annual cost relatively even.

Step 6: Write a Lighting Maintenance Policy

For a lighting maintenance program to be most effective, it needs to be implemented on a continuous basis over the life the lighting system. Having completed a lighting management analysis, developed a method, and established a budget, it is important to write a lighting maintenance policy. This will assist in getting the program approved and will enable the plan to be implemented by other personnel in the future or in other facilities. Include justification for the maintenance plan so that future managers can understand the analysis. Most importantly, it will assure a systematic continuation of the program.

Step 7: Implement the Strategy

A well-planned strategy can be easy to implement. Many companies use outside contractors to complete major tasks and then use inside staff to provide spot maintenance. Others find it more appropriate to contract with an outside lighting or electrical company to completely manage the lighting, or to designate and train a lighting management team within the company.

Whichever method is used, strategic lighting management -- while justified by energy savings alone -- will also make lighting maintenance a predictable task and minimize unscheduled maintenance requirements.

9.4 GETTING HELP

As the demand for planned lighting maintenance has increased, so have the services offered by the lighting industry. The following are some of the resources available to help analyze, plan and implement efficient lighting maintenance.

Lamp Manufacturers

While strategic lighting management will decrease the overall cost of lighting for a facility, the savings are primarily in energy, labor, and initial equipment costs. In fact, group maintenance will almost always result in the use of more lamps. As a result, lamp manufacturers have an interest in providing assistance in analyzing lighting management strategies. Most of this assistance is valuable and reliable and is offered free or at a very low cost. Contact your lamp supplier or manufacturer for information. Many of the manufacturers are also Green Lights Manufacturer Allies. Assistance from lamp manufacturers is available through:

- local factory representatives
- distributors
- software tools
- training programs

Lighting Management Companies

Lighting management companies (LMCs) are maintenance or electrical contractors that specialize in lighting installation, upgrade, management, and maintenance. Many offer a free or low cost service to determine optimum lighting maintenance programs as described in Section 9.3. The industry is young; very few lighting management companies existed ten years ago. But many companies now have extensive experience, and the industry continues to grow rapidly.

Some LMCs may offer consulting services to help develop in-house lighting management programs, but most are interested in providing upgrade installation and maintenance contract services. Many of these are Green Lights Lighting Management Company Allies.

9.5 EXAMPLE

The following example demonstrates how strategically planned lighting maintenance can reduce energy consumption, prevent pollution, and control costs. In this example, a group relamping strategy is implemented in an existing building that uses 250 four-lamp fluorescent fixtures, operating 4000 hours per year. With a rated lifetime of 20,000 hours, the average lamp can be expected to last five years.

After the system has been operating for a number of years, 200 lamps will need to be replaced in an average year. However, if the facility is group relamped on a three-year cycle, 1000 lamps must be purchased and installed every three years. In addition, it should be expected that 40 of the lamps (4 percent) will fail during those three years and need to be spot replaced. The facility will purchase more lamps than before, but labor costs will be drastically reduced.

With group relamping and cleaning, the overall illuminance can be expected to increase. It will then be possible to replace each 40-watt lamp with, for example, a 34-watt lamp of lower output and still maintain adequate illuminance.

Including the lost value of the discarded lamps, group relamping with low-wattage lamps will pay for itself in 1.6 years. Once the group relamping program is established, the average annual cost of lamps, labor, and energy under the group relamping program will be about $1,500 less than the average annual cost without group relamping. (See table below.)

Average Annual Cost	**Spot Relamping**	**Group Relamping**
Relamping labor (spot)	$1,200	$84
Lamps (spot)	420	42
Relamping labor (group)	----	417
Lamps (group)	----	1,000
Energy @ $0.065	11,765	10,335
TOTAL	**$13,385**	**$11,878**
ANNUAL SAVINGS	**----**	**$1,507**

Appendix A

OVERVIEW OF GREEN LIGHTS ANALYSIS SOFTWARE

The Green Lights Program has developed three unique software programs to help Partners and Allies analyze upgrade options and determine profitability. This appendix provides brief descriptions of these software programs.

The Green Lights analysis software programs include:

- *Green Lights/Decision Support System*
- *Quikalc*
- *IRRkalc*

A.1 GREEN LIGHTS DECISION SUPPORT SYSTEM

The *Green Lights/Decision Support System (GL/DSS)* is a convenient tool for Partners and Allies to use in surveying their facilities, identifying applicable lighting upgrade technologies, and quantifying costs and benefits. The *GL/DSS* is a software package that is designed to meet the following objectives:

- Organize and reduce the effort involved in collecting building data
- Provide room-by-room lighting upgrade recommendations based on pollution prevented and profitability as defined by the Green Lights Memorandum of Understanding (MOU)
- Improve the ability of Partners to work with consultants, designers, lighting management companies and vendors to achieve upgrades that meet Green Lights program goals

Based on user-entered lighting survey data, the *GL/DSS* assesses existing lighting conditions and selects appropriate upgrade technologies from large databases that include performance and cost data. The lighting upgrade packages recommended by the *GL/DSS* will maximize energy savings and maintain or improve lighting quality.

GL/DSS users also have the opportunity to identify preferences for specific lighting technologies or approaches that either should or should not be applied to a building or designated areas of a building. Preferences can be specified for the following:

- Fixture replacement vs. modification
- Inclusion/exclusion of specific equipment types
- Lighting maintenance approach
- Task lighting approach
- Target footcandle definition

The *GL/DSS* is designed to recommend technologies that will provide the most energy savings within the financial requirements. Imposing lighting technology preferences could result in decreased energy savings and is not encouraged.

In combination with other Green Lights Program support materials and services, the *GL/DSS* allows Partners to use in-house resources to make informed upgrade decisions. It also facilitates project planning by producing reports that clearly indicate product types, quantities, locations, minimum performance requirements, and estimated project costs. The following reports are produced by the *GL/DSS*:

- **Executive Summary Report** - high level summary of key financial, energy, and equipment information
- **Financial Report** - projected financial results for the recommended upgrade, including IRR, NPV, percent energy savings, and project costs
- **Facility Manager's Report** - description of upgrade packages selected for each existing package including the quantity, kilowatts avoided, and annual kilowatt-hour savings
- **Room Definition and Analysis Summary Report** - description of every room in the building, including the number, wattage, and layout for existing and upgrade fixtures, footcandle levels, analysis method used, and unit power density
- **Equipment Specifications Guideline Report** - specifications for each type of upgrade equipment, quantities of equipment needed, and the rooms where the equipment will be installed
- **Building Survey Report** - comprehensive listing of all information collected during the lighting survey data collection process
- **User Preference Report** - description of the User Preferences that have been applied to an analysis

The Office Module

The Office Module of the *GL/DSS* was the first module to be introduced. This module covers the following types of facilities and equipment:

- Commercial office buildings, including office and meeting spaces, hallways, rest rooms, lobbies, and typical support spaces (mechanical, electrical, and storage closets)

- Lighting equipment typically found in office buildings, primarily lensed and parabolic fluorescent fixtures, downlight cans, and exit signs

The Office Module of the *GL/DSS* uses a "hole in the ceiling" approach to defining lighting upgrades. It does not attempt to redesign the fixture layout, but it simply maintains the same number and size of fixtures.

To select fixture upgrades, the *GL/DSS* searches databases of applicable options to find the package of lamps, ballasts, and/or fixtures that maintains target light levels at the lowest wattage. Energy savings are maximized in the Office Module using the following approach:

In Spaces with Evenly-Spaced Ceiling Fixtures (offices, conference rooms and hallways)

- Based on the building survey data and databases of fixture performance, existing light levels are calculated, incorporating light loss factors (for lumen depreciation from dirt, aging lamps, etc.). The existing light levels are then compared with task-specific targets defined with guidance from recommendations by the Illuminating Engineering Society of North America (IESNA).

- Upgrade technologies are selected that maximize energy savings while ensuring that existing light levels are either maintained or reduced to recommended light level targets.

- Opportunities for controls -- such as occupancy sensors and timed switching -- are considered for reducing the operating hours of the lighting system.

- In offices with systems furniture and/or extensive computer use, opportunities for task lighting and lower ambient light levels are identified.

In Other Spaces (stairwells, rest rooms, non-uniformly lit offices, etc.)

- Lighting upgrades are chosen that maximize energy savings while *maintaining* existing light levels.

- Opportunities for controls -- such as occupancy sensors and timed switching -- are considered for reducing the operating hours of the lighting system.

The Warehouse/General Retail Module

The second and most recent *GL/DSS* module developed is the Warehouse/General Retail Module. This module covers the following types of facilities and equipment:

- Warehouse/General Retail buildings, including distribution centers, transfer stations, stockrooms, supermarkets, general retail (high volume) sales floors, and other types of spaces with similar lighting and visual requirements

- Lighting equipment typically found in these space types, such as fluorescent strip and industrial fixtures, incandescent and high intensity discharge (HID) fixtures, and exit signs

The Warehouse/General Retail Module is *not* appropriate for evaluating high-end retail sales floors, display cases, track lighting, and other environments with special lighting needs.

The Warehouse/General Retail Module uses *two* approaches to lighting upgrades. It assesses the wattage savings achieved by:

- using the same number or fewer fixtures (50% or 25% of existing) with the same layout and wiring, and

- by redesigning the fixture layout

The most cost-effective option with the highest wattage savings will be the recommended upgrade.

To select fixture upgrades, the *GL/DSS* searches databases of applicable options to find the package of lamps, ballasts, and/or fixtures that maintains target light levels at the lowest wattage. Energy savings are maximized in the Warehouse/General Retail Module using the following approach:

- Based on the primary visual task identified in the building survey data, target light levels are assigned, using Illuminating Engineering Society of North America (IESNA) guidance.

- Based on building survey data, spaces are categorized as having either open or aisle layouts. This triggers either a horizontal or vertical footcandle analysis, as applicable.

- Upgrade technologies are selected that maximize energy savings while ensuring that target light levels are achieved.

- Opportunities for controls -- such as occupancy sensors and timed switching -- are considered for reducing the operating hours of the lighting system.

Availability of the GL/DSS

The *GL/DSS* software is distributed *only to those who attend one of the EPA-sponsored training workshops* held in cities throughout the country. The software is designed to work on most PCs in use today. The minimum hardware requirements are:

- IBM PC or compatible
- DOS version 3.3 or 5.0
- 512K RAM free
- hard disk with at least 10 megabytes free
- printer (many supported)

This section contains an article that was published in the March 1992 edition of Building Operating Management. The article provides a clear overview of the purpose, components and benefits of the system's office module.

For more detailed information about the *Green Lights/Decision Support System*, refer to the separate User's Manual volume, or contact the Lighting Services Group at (202) 862-1145 or fax (202) 862-1144.

Software Smooths Lighting Retrofits

by Bob Kwartin and Damon Wood

Green Lights Software Helps Partners Get Upgrade Projects Off On The Right Foot

ENERGY-EFFICIENT lighting — once thought to be merely reduced-wattage lamps and ballasts — now encompasses a wide array of upgrade options that can bewilder even the most savvy of facility managers. Further complicated by conflicting vendor claims and a scarcity of objective information, the task of specifying lighting upgrade technologies can be an ordeal. No wonder so many profitable lighting upgrade projects have died in the planning stages.

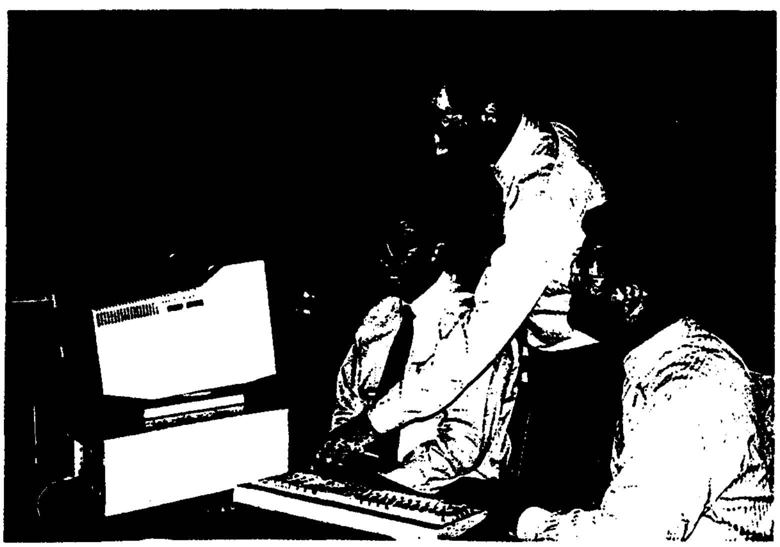
But relief is at hand. Now you can use your personal computer for selecting the appropriate mix of products and services that will maximize energy savings and maintain lighting quality in your office facilities. *Green Lights / Office* is a powerful tool to help Partners and Allies follow through on their commitment to install energy-efficient lighting technologies throughout their offices.

This IBM-compatible software package:

- Organizes and reduces the effort involved in building survey data collection.
- Provides room-by-room lighting upgrade recommendations that fulfill the intent of the Green Lights Memorandum of Understanding.
- Improves the ability of Green Lights Partners to work with consultants, lighting management companies and vendors to implement upgrades that meet Green Lights program goals.

In combination with other Green Lights program support materials and services, *Green Lights / Office* allows Partners to use in-house resources for making informed upgrade decisions. And it facilitates project planning by producing reports that clearly indicate product types, quantities, locations and minimum performance requirements.

■ *Green Lights/Office* software is distributed only to those who attend one of the EPA-sponsored workshops.

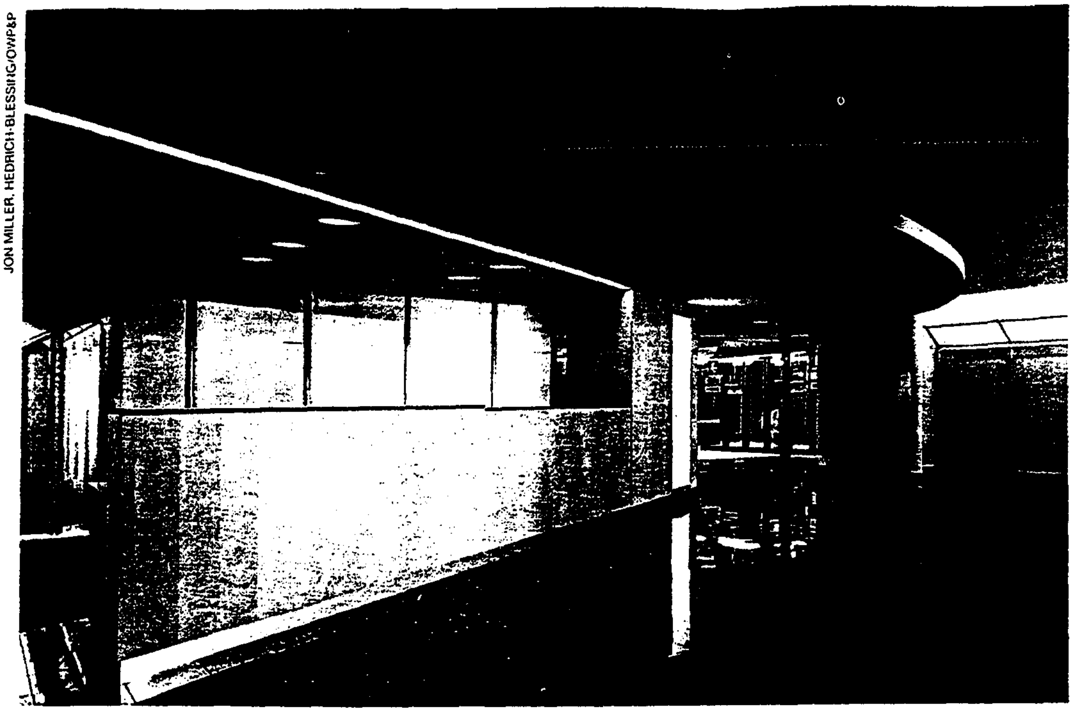


FIRST MODULE. Released in December 1991, *Green Lights / Office* is the first of several Green Lights Decision Support System modules to be introduced. EPA is developing other modules that address warehouses, general retail stores and manufacturing plants. These modules will be loadable into the Green Lights Decision Support System "shell" and will enable you to choose between all available modules when surveying different types of buildings.

Based on user-entered lighting survey data, *Green Lights / Office* assesses existing lighting conditions and selects appropriate upgrade technologies for offices, hallways, conference rooms and other office spaces. The system chooses upgrade technologies from large databases that include performance and cost data.

These databases include combinations of the following technologies for selection by *Green Lights / Office*. For fluorescent upgrades: new 2-by-4-, 2-by-2- and 1-by-4-foot fixtures; delamping with and without specular reflectors; triphosphor lamps (both 4 foot and 2 foot) in the T12, T10, T8 and T5 families; and electronic, hybrid and electromagnetic ballasts.

JON MILLER, HEDRICH-BLESSING/OWP&P



■ The software provides room-by-room lighting upgrade recommendations that fulfill the intent of the Green Lights Memorandum of Understanding.

LITHONIA LIGHTING

For incandescent upgrades: compact fluorescent conversions; high-intensity discharge conversions; exit-sign conversion kits (compact fluorescents); and new exit sign units (LED, electroluminescent and tritium).

SYSTEM COMPONENTS. *Green Lights / Office* helps you perform the various tasks required to survey your facilities and perform energy and financial analyses. With its structured data collection approach and powerful data processing program, the system streamlines the survey and analysis process.

To begin the data collection step, the system prints blank forms for recording lighting survey data. To make appropriate upgrade decisions, *Green Lights / Office* analyzes building operations data, financial parameters, room characteristics, visual tasks and existing lighting equipment. Because light levels are calculated — not measured — you do not need a light meter to perform the lighting survey. User-defined databases — including fixture types, space types, and identical rooms — help organize data and minimize duplication of effort during the data collection phase.

With the help of pull-down menus, the software invites you to enter data in a "macro to micro" sequence. Data common to the entire facility are entered first, and these data then become the defaults for fields that appear in subsequent screens. After entering data, you can check your work by printing out the forms showing the data filled in.

TECHNOLOGY SELECTION. Prior to running the analysis, you have the opportunity to identify preferences for specific lighting technologies that should (or should not) be used in designated spaces. Although this feature adds analytical flexibility, its use is discouraged because the system —

when constrained by user preferences — may not recommend technologies that will provide the most energy savings within the financial requirements.

Green Lights / Office assesses existing lighting conditions in each space and selects appropriate upgrades. From a system-generated list of eligible upgrade packages, the system picks the lowest-wattage package that either maintains existing light levels or reduces them to levels based on Illuminating Engineering Society recommendations. Light-loss factors, such as lamp-lumen depreciation and luminaire dirt depreciation, are included in the light level calculations.

Using information entered regarding the schedules of occupancy and illumination, the system recommends either occupancy sensors or automatic timed switching to reduce lighting system operating hours.

■ The software assesses the existing lighting conditions in a given space and selects appropriate upgrades based on accepted industry illumination levels.

LITHONIA LIGHTING

Green Lights / Office identifies opportunities for task lighting in rooms with systems furniture or extensive computer use. The system targets lower ambient light levels and adds task lighting systems that yield improved visual comfort and reduced lighting energy consumption.

After defining equipment selections, the system then performs a 20-year after-tax financial analysis to determine the internal rate of return for the project to verify that it meets the "prime plus six" profitability criteria. The savings calculations take into account changes in life-cycle energy, labor, equipment and maintenance costs.

REPORT GENERATION. One of the greatest advantages of the system is its ability to rapidly compile the results of an extensive lighting analysis into useful, readable reports. *Green Lights / Office* prints three different reports that appeal to specific project participants. The Facility Manager's report contains a summary of energy savings by upgrade package, descriptions of each existing fixture type with associated upgrade package, locations where the upgrade packages are recommended, and technology notes to guide you in making appropriate equipment purchases. The Financial Report contains the project's after-tax internal rate of return, the value of applicable utility rebates (if any), the net initial investment, average annual cost savings, and 20-year after-tax cash flows. The Equipment Specification Guidelines contain total quantities of lighting upgrade products, minimum performance specifications (as used in the analysis), and a room-by-room listing of existing equipment and recommended upgrade products.

There are many lighting analysis software programs available today. So why develop another one? *Green Lights / Office* was designed to help Partners comply with the Green Lights Memorandum of Understanding, the agreement between the corporation and EPA. The software design was guided by the Memorandum, in which Partners agree to install packages of lighting upgrades that, together, maximize energy savings, maintain or improve lighting quality, and earn an internal rate of return equal to the prime interest rate plus six percentage points. *Green Lights / Office* simply determines what these packages would consist of based on user-entered data.

Because of its specific intended use, *Green Lights / Office* doesn't perform certain functions as do some other lighting software packages.

• *Green Lights / Office* does not bypass industry expertise. By providing generic direction to Partners, *Green Lights / Office* will promote efficient interaction with suppliers of technologies and services. The system does not name specific product manufacturers, and product costs are not provided in a way that allows the system to be used as a bid benchmark.

•*Green Lights / Office* is not a design tool. The system cannot recommend a specific fixture layout using fewer or different fixtures. A lighting designer or consultant can assess energy-saving opportunities afforded by new lighting designs.

•*Green Lights / Office* will not produce a comparison of individual upgrade options. Because the Memorandum of Understanding requires that the combination of packages meet the savings, quality and financial criteria, the software does not break the total project cost into component parts.

•*Green Lights / Office* cannot assess user acceptance. Because the system cannot "see" your facility, there are a variety of application and implementation issues that must be considered before installing lighting upgrades. A well-planned trial installation is recommended for assessing potential upgrade acceptability before you commit to a course of action.

END-USER FEEDBACK...

"Green Lights/Office allows me to ask the right questions when dealing with local suppliers. With the user preference feature, I can modify the parameters enough to tailor the lighting analysis to our needs and still comply with the Memorandum of Understanding."
— *Michael Bacon, Senior Plant Engineer, Whirlpool Corporation*

"Using Green Lights/Office, we have audited more than 6 million square feet of our facilities. This software is our primary tool for analyzing and justifying the cost effectiveness of lighting upgrades at the Boeing Company."
— *Stephen Cassens, Senior Electrical Engineer, The Boeing Company*

"Green Lights/Office is an excellent vehicle for guiding Partners through the steps and complexities involved in performing lighting upgrades. The system produces a credible analysis along with a basic working plan for implementation."
— *Tom Roessler, sales manager, IllumElex Corporation*

GETTING STARTED. Because *Green Lights / Office* embodies both a unique survey approach and a sophisticated decision methodology, EPA provides extensive user support. An integrated package of training, printed materials, and telephone technical support will provide you with all of the necessary tools to use the system productively.

The software is distributed only to those who attend one of the EPA-sponsored training workshops now being held in cities throughout the country. These workshops feature "hands-on" training using the system. Because space is limited, Green Lights Partners receive first priority for attending workshops. In addition to becoming familiar with the system, the workshop participants discuss project implementation issues and learn about state-of-the-art lighting upgrade technologies.

In addition to receiving the software, workshop attendees also receive the Lighting Upgrade Manual, which contains guidelines and procedures for implementing lighting upgrade projects. Topics include financing options, lighting evaluations, requesting proposals, lighting maintenance and waste disposal. In addition, the manual contains extensive reference materials on lighting fundamentals, upgrade technologies and Green Lights/ Office.

The software is designed to work on most PCs. The minimum hardware requirements are: IBM PC or compatible; DOS version 3.0 or higher; 512K RAM free; hard disk with at least 8 megabytes free; printer (many supported).

To find out about the current workshop schedule or to obtain more specific information about *Green Lights / Office* software, call the Green Lights Technical Information Line at 202-862-1145.

Bob Kwartin is director of the U.S. Environmental Protection Agency's Green Lights Program. Damon Wood is a senior associate with ICF Incorporated, EPA's mission contractor for the Green Lights Program.

A.2 *QUIKALC*

Quikalc Instructions

Introduction

Quikalc is a PC-based computer program designed to accurately estimate the energy, environmental, and financial results of a specific lighting upgrade. *Quikalc* compares the "before" and "after" performance of a lighting system. It is important to note however, that unlike the *Green Lights Decision Support System (DSS)*, *Quikalc* only calculates the performance of one fixture type at a time. Therefore, to analyze the lighting in a building that contains several fixture types requires several "runs" of *Quikalc*. The cash flows from each fixture type can then be aggregated into a combined project cash flow.

Existing fixture, upgrade, and operating data are entered on 24 input screens. The results can be immediately displayed in a "results window" that appears at the bottom of the screen. The results window enables the user to see how changes in the input data affect the projected performance of the upgrade. The following key results are displayed in the results window:

- Internal Rate of Return (IRR)
- Net Present Value (NPV)
- Annual Kilowatt-Hour Savings (kWh/yr)
- Percent Lighting Energy Savings (%)
- Percent Change in Lumen Output (%)
- Cost of Conserved Energy ($/kWh)

Users can also view or print financial and pollution prevention reports, as well as a summary of the lighting systems selected.

Although *Quikalc* is a powerful analytical tool that calculates the performance of an upgrade selected by the user, it does not recommend any specific upgrades. Therefore, knowledge of lighting quality and compatibility issues is essential for selecting efficient, high-quality upgrade options. *QUIKALC* WILL NOT PREVENT THE USER FROM SELECTING INCOMPATIBLE OR INFERIOR UPGRADES. For example, *Quikalc* will allow you to calculate the energy and pollution results of replacing four 2x4 troffers with one 400-watt industrial high pressure sodium luminaire, even though it would be an unlikely upgrade scenario.

Note that *Quikalc* is designed to evaluate lighting retrofit and renovation applications only (as opposed to new construction applications where no prior system existed).

Hardware Requirements

Quikalc requires an IBM-compatible DOS-based computer with at least 640K of installed RAM, 520K of available RAM, and a hard drive. A 286 or higher processor is recommended. *Quikalc* does not support the use of a mouse and should not be used with one.

Most monitors are supported. Some monochromatic monitors require the DOS command **MODE BW80** before the program will display. (If the screen is blank after running the program, return to the DOS prompt and type **MODE BW80** and start *Quikalc* again.)

Quikalc will support most printers. It has been tested on HP Laserjet-compatible printers but should also print on other types, although page breaks may not align properly with some printers or printer drivers.

Using Quikalc

Install the program using the **QINSTALL** command (**A:QINSTALL**, if the diskette is in the A: drive). The installation program will create the \QUIKALC subdirectory on your hard drive (or allow the user to change the subdirectory name, if desired). The program will then load the *Quikalc* files into the subdirectory. You start the program by typing **RUN QUIKALC** at the DOS prompt for the directory where *Quikalc* has been installed.

After a few moments, an introductory screen appears, along with a function-key menu at the bottom of the screen. (Note: If the title screen and the flashing "Loading...Please wait" message remains on the screen indefinitely, there is not enough memory available to run the program. Reboot the computer and make more memory available.) The function keys provide the following:

<F2> INPUT

Use this key to begin entering data on the 24 input screens. You will enter the input screens at Screen 1 and can quickly move to any of the 24 screens using PgDn and PgUp. (Hint: The screens are continuous. Therefore, you can also use the arrow keys to move between screens, but this is not recommended since it will disrupt the alignment of each screen and cause data input to be more difficult.)

<F3> CALCULATE

When you first enter *Quikalc*, the fields in the results window are blank. When you press <F3>, all input screens are automatically filled in with sample data, and the program calculates the results that appear in the results window and on the other reports. After entering or changing the data, you must again press the <F3> key to calculate and update the results window. As you change input data, the results window will *not* be updated until you re-calculate by pressing <F3>.

<F4> VIEW

Use this function key to view the output reports or the fixture table. There are four choices: Fixture Table, Summary Report, Advantages Report, and Cashflow Report.

- Select *Fixture* table to view the database of fixture types.
- Select *Summary* report to view a summary of the data inputs describing the existing and proposed systems, including details of the fixtures, lamps, ballasts, and operating characteristics involved in the analysis.
- Select the *Advantages* report, to view the summary of financial results, energy savings and pollution prevention.
- Select the *Cashflow* report to view a twenty-year cash flow projection for both the existing and proposed systems.

To return to the data entry screens, press **<F2>** and **<ENTER>**. This will return you to Screen 1 of the data entry section.

<F5> SAVE

Use this function key to save your input data for future modification and analysis. You will need to provide a name for your file. (If you do not enter a new name, your data will over-write the sample input data provided with the program.)

To later retrieve a saved file, type **RUN QUIKALC <Filename>** at the DOS prompt. For example, if you saved the input as OFFICE2, type **RUN QUIKALC OFFICE2** at the DOS prompt.

<F6> PRINT

Each of the reports listed above can be printed by selecting **<F6>** and choosing the report. In addition, you can print the Fixture Table and the Data Input Screens. Select:

- Reports (Summary and Advantages)
- Tables (Cashflow tables)
- Fixture tables (fixture database)
- Input screens (data entry screens)

A sample of each report and a copy of the fixture table are included at the end of these instructions.

<F7> EXIT

Use this key to exit *Quikalc* and return to DOS.

Input Screen Instructions

Screen 1:
Company and Project Information

What: There are three fields that need to be entered: Company name, Facility name, and Project description.

Why: This information will appear as titles on each page of the output.

Screen 2:
Operating Hours

What: The **Operating Hours** are the approximate number of hours that the existing lighting system is used per year. This is sometimes referred to as "burning hours." This number needs to include hours for the cleaning crew, as well as burning hours while the space is unoccupied.

How: Enter the number of hours per year the existing lighting system operates. The number of hours can be calculated by multiplying the average weekly burning hours by the number of weeks per year.

Why: The operating hours are needed to calculate the energy used by the existing lighting system. Load (kW) x annual burning hours = kilowatt-hours used each year.

Note: Hours for proposed system are entered on Screen 17.

Screen 3:
Energy Costs

What: Electric utilities charge for each kilowatt-hour of electricity used, typically $0.03 to $0.12 per kWh. Most utility rate schedules also include a charge for the monthly peak demand, measured in kilowatts.

How: Enter the kWh usage charge (per kWh) in line A and the demand charge (per KW) in line B. Alternatively, you may enter an average kWh charge (including the demand charges) in line A and $0.00 on line B. (The second method will result in a less accurate analysis.)

Why: Utility energy and demand charges are needed to calculate the projected energy cost cash flow for both the existing and proposed lighting systems.

Note: The units for both lines are dollars, not cents.

Screen 4:
Peak Demand - Coincidence

What: The **Peak Demand** is the maximum rate of energy consumption during a specific period of time. The peak usually occurs during mid-afternoon when the air conditioning system, lighting system, and other electrical equipment are in use. Since the building is usually fully occupied when the peak demand occurs, most of the lights are usually operating when the peak demand occurs. The **Coincidence of Demand** is the percentage of the lighting system load that is energized at the time of the building's peak electricity demand.

How: Enter the coincidence of demand on line A for the existing lighting and on line B for the proposed lighting. This value is typically 90% to 100% when no automatic lighting controls are used. The value must be entered as a decimal (.95 for 95%). This value cannot exceed 100%. If the proposed upgrade includes controls (Screen 17), the coincidence of demand for the proposed system is probably less than the existing system.

Why: The coincidence of demand is included to make the energy cost calculation more accurate. The coincidence factor is used to determine how much of the effective demand charge is reduced when the lighting load is reduced.

Screen 5:
Net Present Value

What: **Net Present Value** (NPV) is the current benefit (in dollars) of a project or investment. It is the sum of all discounted future dollars a project will generate (savings), minus the initial project cost. In the calculation, future cash flows are converted into present dollars by the discount rate. A NPV greater than zero indicates a profitable project. NPV is calculated over a specified period of time (term) at a specified discount rate.

How: In line A, enter the number of years for the term of the analysis (*Quikalc* will accept a maximum term of 20 years). In line B, enter the discount rate. This is the buyer's cost of capital (borrowing interest rate) or opportunity cost (investment rate less risk adjustments).

Why: The NPV analysis can be calculated for any number of years. To improve accuracy, your NPV should consider the life of the investment, which in most cases will be the life of the lighting equipment. If a shorter analysis period is selected -- five years, for example -- it will not take into account the energy cost savings and other benefits occurring after the fifth year. The discount rate is necessary for the NPV calculation.

Screen 6:
Internal Rate of Return

What: The internal rate of return (IRR) is comparable to the interest yield of an investment. It is the discount rate at which the net present value of a cash flow equals zero. *Quikalc* will calculate the IRR for a specified period of time (term). The Green Lights Memorandum of Understanding states that if the IRR is greater than the prime rate plus 6%, the project is considered profitable. *Quikalc* requires an estimate of IRR to begin the calculation. The program will successfully calculate the IRR within a wide range above or below your estimate. 100% is a good initial estimate and will rarely need to be changed.

How: In line A, enter the estimated IRR as a decimal. Enter the term for the calculation (1-20 years) on line B.

Why: The IRR calculation is a iterative process, therefore you must first provide a "guess" or estimate.

Note: If the program returns and ERR message in the IRR results window, you need to adjust your estimate.

Screen 7:
Pollution Prevention Factors

What: Utilities often burn fossil fuels in order to generate electricity. Fossil fuel combustion generates air pollutants, such as carbon dioxide (CO_2), sulfur dioxide (SO_2) and nitrogen oxides (NO_x). These pollutants are emitted in varying magnitudes, depending on the combination of fuel types used by the utility generating your electricity. If available, you can enter the emission factors for your utility. For simplicity, you can use the national averages or the regional factors that are available from the Green Lights Electronic Bulletin Board (202-775-6671), Green Lights Customer Service (202-775-6650), the *Lighting Upgrade Manual*, or the reverse side of the Implementation Report form.

How: Line A, enter the *pounds* of carbon dioxide emitted by generating plants for each kilowatt-hour of energy sold (lbs/kWh). The national average = 1.5 lbs/kWh.

Line B, enter the *grams* of sulfur dioxide emitted by generating plants for each kilowatt-hour of energy sold (g/kWh). The national average is 5.8 g/kWh.

Line C, enter the *grams* of nitrogen oxides emitted by generating plants for each kWh sold (g/kWh). The national average is 2.5 g/kWh.

Why: By providing the emission factors, *Quikalc* will calculate the amount of pollution prevented by the proposed upgrade. Pollution prevention is the main purpose of the EPA Green Lights Program.

Screen 8:
EXISTING Fixture Information

What: *Quikalc* analyzes only one fixture type at a time. In this screen, enter the code for the existing fixture type and the quantity of those fixtures in use.

How: Line A: Select the existing fixture code from *Quikalc* fixture table. To view the table on screen, type <F4> for view, and <F> for fixture. Use the arrow keys and the Page Up/Down keys to scroll through the table. Choose the fixture code based on fixture type (size), number of lamps per fixture, type of lamps, and type of ballast. Note that after entering the code on Screen 8 and pressing the <F3> key (to calculate), the fixture type that you selected is displayed. Use this to check that the proper fixture type has been entered.

Line B: Enter the total number of EXISTING fixtures in use.

Why: In order for *Quikalc* to perform energy and economic analyses, the user must provide the existing fixture type. The number of fixtures is needed to determine the energy and maintenance costs.

Note: If the quantity of fixtures is estimated, the IRR will be correct, but an exact number is needed for an accurate NPV. IRR is independent of project size, NPV is not.

Screen 9:
EXISTING Lamp Information

What: In order to calculate energy and maintenance costs of the existing lighting system, the user must provide lamp and ballast information (typically available from suppliers). The user inputs existing lamp information on this screen.

Why: As lamps burn out, they need to be replaced. The lamp replacement cost (lamp, labor, and disposal) is considered in the economic calculations. The rated lamp life is used to determine the number of lamps that must be replaced each year.

How: After pressing <F3> on Screen 8, the existing lamp type will appear on this screen. This is the lamp in the fixture you selected from the fixture table. The number following the slash in this field is the color rendering index of the lamp. (Quikalc does not support all levels of lamp color rendering.) The lamp type can not be changed on this screen. Return to Screen 8 and enter another fixture code to change the lamp type.

Line A: Enter the rated life of the lamp.

Line B: Enter the price you pay for each lamp (including sales tax). This is for the lamp only -- do not include labor or other costs.

Line C: Labor cost to replace each lamp. Whether group relamping or spot relamping, enter the cost to replace each lamp. If fixtures are cleaned during relamping, include the fixture cleaning cost -- be sure to include all costs, including set up time, etc.

Line D: Enter the lamp disposal cost. If recycling fluorescent lamps, the disposal cost would be in the range of 5-15 cents per linear foot of lamp. Refer to the Green Lights *Lighting Upgrade Manual* for more disposal information, or contact the Customer Service Center (202-775-6650) and request waste disposal information.

Note: The sum of line A, B, and C equals the total cost to replace each existing lamp.

Screen 10:
EXISTING Ballast Information

What: This screen is very similar to Screen 9, except that fields are for ballast data rather than lamp data.

Why: Like lamps, ballasts will eventually fail and need to be replaced. The ballast replacement cost (ballast, labor, and disposal) is considered in the economic calculations. The rated life for the ballast is used to determine the number of ballasts that must be replaced each year.

How: EXISTING Ballast: After pressing <F3> with data entered on Screen 8, the existing ballast type will appear in this field. The ballast type can not be changed on this screen. Return to Screen 8 and enter another fixture code to change the ballast type.

Line A: Enter the rated life of the ballast. Magnetic fluorescent ballasts typically operate 30,000 - 35,000 hours, depending on operating conditions. Electronic ballasts typically operate 55,000 - 65,000 hours. Check with your supplier to get estimated life for the products you are using.

Line B: Purchase cost per ballast, including sales tax.

Line C: Labor cost to replace each ballast, including all benefits and miscellaneous costs.

Line D: Enter the ballast disposal cost. Ballasts made before 1980 most likely contain PCB's. Many states regulate the disposal of PCB-containing ballasts. Incineration typically costs $5 - $10 per ballast, and disposal in a chemical waste landfill typically costs $2 - $8 per ballast. Refer to the Green Lights *Lighting Upgrade Manual* for more disposal information, or contact the Customer Service Center (202-775-6650) and request waste disposal information.

Screen 11:
PROPOSED Fixture Information - General

What: This screen is similar to Screen 8, except PROPOSED fixture information is entered, rather than existing. To view the fixture codes, use <F4> to view, and <F> for fixture table.

How: Line A: The proposed fixture code is selected from the *Quikalc* fixture table. Choose the fixture code based on fixture type (size), number of lamps per fixture, type of lamps, and type of ballast. Note that after entering the code and pressing the <F3> key, the fixture type that you selected is displayed. Use this to check that the proper fixture type has been entered.

Line B: Enter the total number of PROPOSED fixtures in the lighting system.

Note: If you do not plan to upgrade or replace the fixture, the PROPOSED fixture code must be the same as the EXISTING fixture code. Examples of this situation would be installing an occupancy sensor or changing the number of fixtures. If lamps or ballasts change, then a new fixture code is needed.

Screen 12:
PROPOSED Fixture Information - Costs

What: There are many different ways to upgrade a lighting system. One way is to install completely new fixtures. Another way is to alter the existing fixture by changing the lamp type, replacing the lens, etc. This screen is used to enter the cost of NEW fixtures, ONLY if you plan to replace the existing fixture with a NEW fixture.

Why: If new fixtures are used, this cost is multiplied by the number of fixtures to determine the initial cost of the project.

How: Enter the cost for each new proposed fixture. Include all materials, labor, lamp cost, and ballast cost. *If new fixtures are not used, enter $0.00 in the field.*

Note: If a value other than $0.00 is entered here, then you MUST answer "No" to questions 13B and 14B.

Rebates for fixtures and other technologies may be entered on Screen 18.

Screen 13:
PROPOSED Lamp Information

What: This screen is very similar to Screen 9, except these fields are for the PROPOSED lamp. This information is needed to calculate the lamp installation and replacement costs.

How: After pressing <F3> to calculate, the proposed lamp type for the fixture type selected on Screen 11 will be displayed.

Line A: If you plan to install this lamp in the existing fixtures, enter "Yes" here. If you are not replacing the lamps in the existing system, or if you entered a cost for NEW fixtures (including lamps) on Screen 12, enter "No."

Line B: Enter rated lamp life.

Line C: Enter your cost per lamp (including sales tax) -- lamp only. *Enter a cost here even if you entered "No" in line A.*

Line D: Enter the labor cost to INSTALL each lamp. (If you entered "No" in line B, this cost will be ignored.) This is the cost to install the lamps *at the time of the upgrade.*

Line E: Enter the labor cost to REPLACE each lamp. This is the cost to replace the lamp during normal maintenance in the future. Include fixture cleaning if appropriate. *Enter a cost here even if you entered "No" in line A.*

Line F: Some states regulate the disposal of lamps. Enter the lamp disposal cost here. *Enter a cost here even if you entered "No" in line A.*

Note: Line E should reflect either spot or group relamping labor cost per lamp, depending on your maintenance method. Generally, group maintenance costs are lower per lamp than spot relamping costs.

Screen 14:
PROPOSED Ballast Information

What: This information is needed to calculate the proposed ballast installation and replacement cost.

How: PROPOSED Ballast: After pressing <F3>, the proposed ballast type for the ballast(s) in the fixture you selected on Screen 11 will be displayed. In the field below the ballast type, enter the number of hours for the ballast life.

Line A: If you plan to install this ballast in the existing fixtures, enter "Yes" here. If you are not replacing the ballasts in the existing system, or if you entered a cost for NEW fixtures (including ballasts) on Screen 12, enter "No."

Line B: Enter the estimated ballast life (in hours). *Enter a cost here even if you entered "No" in line A.* Magnetic fluorescent ballasts typically operate 30,000 - 35,000 hours, depending on operating conditions. Electronic ballasts typically operate 55,000 - 65,000 hours. Check with your supplier to get estimated life for the products you are using.

Line C: Enter your cost per ballast (include sales tax). *Enter a cost here even if you entered "No" in line A.*

Line D: Enter the labor cost to INSTALL each ballast. (If you entered "No" in line B, this cost will be ignored.) Include any re-wiring cost, etc. This is the cost to install ballasts *at the time of the upgrade.*

Line E: Enter the labor cost to REPLACE each ballast. This is the cost to replace the ballast during normal future maintenance. Include fixture cleaning if appropriate. *Enter a cost here even if you entered "No" in line A.*

Line F: Enter the ballast disposal cost here. *Enter a cost here even if you entered "No" in line A.* If you are using new ballasts, the new ballasts will not contain PCBs, so the disposal cost will likely be minimal.

Screen 15:
Reflectors

What: Because of their polished, mirror-like surface, reflectors can direct light out of the fixture more efficiently, thereby increasing lumen output. Enter information on this screen if your upgrade includes reflectors. *If you do not plan to use reflectors, you MUST enter $0.00 in line A.*

Why: The cost of the reflector (including labor) is added to the overall cost of the project. The increase in light output is used -- along with change in lamp type and maintenance considerations -- to calculate the overall change in lumen output of the proposed system, which is displayed in the results window.

How: Line A: Enter the cost of each reflector. This cost must include the material cost and the labor cost. *This field must be zero if no reflector is proposed.* Remember that rebate information is included on Screen 18.

Line B: Enter the percentage of increased light output resulting from the reflector. This percent must be entered as a decimal, usually in the range of 0.05 - 0.25, depending on reflector performance. Note that the increase should be based on the same number and type of lamps.

Note: If you are reducing the number of lamps in the fixture when you install reflectors, be sure that your PROPOSED fixture on Screen 11 contains the new number of lamps.

Screen 16:
Power Reducers

What: The purpose of power reducing products is to reduce the active power demand of a fluorescent lighting system. These devices also reduce the light output of a system. *Enter information on this screen only if your upgrade includes power reducers.*

Why: The cost of the power reducer (including labor) is added to the overall cost of the project. The percentage of decreased light output resulting from the power reducer is a part of the change in lumen output of the system. The percent of decreased wattage is used to calculate the change in power consumption by the proposed system.

How: Line A: Enter the cost of each power reducer. This cost must include the material cost and the labor cost. *This field must be $0.00 if no power reducer is proposed.*

Line B: Enter the percentage of decreased light output resulting from the power reducer. Enter as a decimal.

Line C: Enter the percentage of decreased wattage resulting from the power reducer. Enter as a decimal.

Note: Because current limiters reduce the operating temperature of the luminaire, the inherent efficacy may be improved. Refer to NLPIP *Specifier Report* on Power Reducers (Volume 1 Issue 2).

Screen 17:
Occupancy Sensors / Timed Switching

What: Occupancy sensors and other controls reduce the number of operating hours of a lighting system. Lights that are often left on when the space is unoccupied are automatically turned off. *Enter data in this screen only if occupancy sensors or time switching is proposed.*

Why: The cost of the control device is part of the total initial cost of the proposed system. The operating hours are needed to calculate the energy used by the proposed lighting system. Load (kW) x annual burning hours = kilowatt hours used each year.

How: Line A: Enter the cost of each control device. Include materials and labor. *Enter $0.00 if no sensor/switch is proposed.*

Line B: Enter the number of fixtures that are controlled by each unit. For example, if 36 luminaires will be controlled by 9 sensors, then 4 luminaires are controlled by each sensor -- therefore enter 4.0.

Line C: Controls will usually decrease the lighting operating hours. Enter the yearly operating hours for the PROPOSED lighting system. (The EXISTING operating hours are displayed on the reminder line after pressing <F3>.)

Screen 18:
Rebates

What: To encourage energy efficiency and to reduce demand, many utilities offer rebates for energy efficient products. If you plan to participate in your utility's rebate program, enter the rebate amounts on this screen.

Why: Each rebate amount is multiplied by the number of each product that will be used, and the total rebate is subtracted from the initial project cost.

How: Rebate programs often provide a dollar amount for each technology installed. Enter the rebate amount for the upgrade of fixtures, lamps, and ballasts, and the amount for installation of reflectors, power reducers, and occupancy sensors. Do not enter total rebate amounts; enter the rebate per item. If there is no rebate, enter $0.00.

Note: The rebates will only be calculated for the upgrades selected on Screens 11 through 17. Therefore, if you enter a rebate for a reflector, and do not enter a cost for select reflectors on Screen 15, the rebate will not be calculated.

Screen 19:
Maintenance Methods

What: All lamps fail, and will need to be replaced. Replacing lamps one at a time as they burn out is called SPOT relamping. Light output can be increased and the labor cost to replace each lamp can be reduced if all the lamps are replaced at the same time, which is called GROUP relamping.

Why: *Quikalc* calculates lumen depreciation, and determines the number of lamps used based on the maintenance method.

How: There are two fields on this screen: Existing maintenance and Proposed maintenance methods. Type in either "SPOT" or "GROUP" in each of the fields. Upper and lower cases may be used, but spelling must be correct. If Group is selected, enter the percent of rated life at which group relamping is performed. This is typically 70 to 80 percent. (If SPOT is entered, the group relamping interval is ignored by *Quikalc*.

Screen 20:
Air Conditioning Savings

What: Lighting systems produce heat. The heat is removed from the building by the HVAC system when the building overheats and aids the heating system when the building requires heat. Reducing the lighting load will usually result in a reduction of air conditioning costs that far exceeds the possible increase in heating costs.

Why: Use this screen if you wish to consider the additional savings through reduced air conditioning loads. Studies show that lighting upgrades can reduce the cooling load by as much as 30 percent. Remember that due to internal heat gain (people, lighting, computers, etc.), the cooling system may operate even when it is cold outside.

How: Line A: Number of months of cooling system operation. See chart below.

Line B: Enter the cooling system coefficient of performance. This number ranges from 2.0 to 4.0 (typically 2.7) depending on the efficiency of the cooling system.

COOLING MONTHS

City	Months
Atlanta, GA	6.93
Boston, MA	4.57
Chicago, IL	4.83
Cincinnati, OH	5.64
Dallas, TX	7.99
Denver, CO	5.13
Detroit, MI	4.44
Houston, TX	9.70
Indianapolis, IN	5.52
Kansas City, MO	5.94
Los Angeles, CA	7.52
Milwaukee, WI	4.83
Minneapolis, MN	4.34
Nashville, TN	6.56
New Orleans, LA	9.15
New York, NY	4.62
Omaha, NE	5.31
Pittsburgh, PA	5.06
Portland, ME	3.58
Raleigh, NC	6.93
San Francisco, CA	5.13
Seattle, WA	2.17
Tampa, FL	10.63
Washington, DC	6.01

Screen 21:
Inflation Rates

What: The costs of materials, labor, and energy usually increase each year. You may specify an annual, compounded inflation rate for both electricity costs and material/labor costs.

Why: The annual inflation rates are used in the analysis to increase costs incurred in future years. This will increase the accuracy of the cash flows and the IRR.

How: Line A: Enter (as a decimal) the annual inflation rate for material and labor costs.

Line B: Enter (as a decimal) the annual inflation for energy costs.

Screen 22:
Future Renovation Costs

What: If you were not considering an upgrade at this time, it is probable that due to age and use, your lighting system would require some significant repair or replacement sometime in the next twenty years. The cost that would be incurred for the renovation is part of your EXISTING cash flow of costs. This screen allows you to estimate a future lighting improvement cost and number of years from today that it would occur.

How: Line A: Enter the number of years from today when the upgrade will occur.

Line B: Estimate the total cost of the lighting improvement in today's dollars (i.e., what it would cost today.)

Why: This amount is a part of the EXISTING cash flow. It becomes a cost in the future year that you specify.

Note: The cost is adjusted for inflation to the year in which it occurs. The financial impact is discounted in the NPV and IRR calculation.

Screen 23 - Screen 24:
Custom Fixtures #1 and #2

What: If the database does not contain a particular fixture that you wish to include in the analysis, you may create it here as a custom fixture.

How: Complete the thirteen fields that describe the fixture. The fields for "Fixture type", "Lamp type", and "Ballast type" are labels and must begin with a letter or an apostrophe ('). For the other ten fields, a specific numerical value is required. Refer to lamp, ballast and luminaire manufacturer data for these values. For luminaire dirt depreciation values, refer to the IES Lighting Ready Reference.

Note: Screen 23 is the description for fixture #100 and Screen 24 is fixture #101 in the Fixture Table. If you use these custom fixtures, remember to use the proper code on Screen 8 for Existing Fixture and/or Screen 11 for Proposed Fixture.

Quikalc Sample Report

The following report is a sample of Quikalc's easy-to-read output. This information can be either printed on a laserjet printer <**F6**> or viewed on-screen <**F4**>.

EPA GREEN LIGHTS QUIKALC 2.05 | Green Light Corporation
System Summary, Part 1 | Headquarters Building
page 1 of 6 01/07/93 | Upgrade: 2x4 fixtures

	Existing System	Proposed System
FIXTURES		
Fixture code	717	729
Type	2X4-4L	2X4-4L
Fixtures needed	1000	1000
Watts/fixture	190	95
Coincidence w/ peak demand	90.0%	90.0%
Total cost/new fixture	$0.00	$0.00
Rebate/new fixture (only at start)		$0.00
Operating hours	3120	2550
LAMPS		
Type	T1240/62	T832/75
CRI	62	75
Initial lumens	3050	2900
Rated life (hours)	20000	20000
Disposal cost/lamp	$0.50	$0.50
Lamps/fixture	4	4
Lamps needed	4000	4000
Lamp cost	$1.20	$3.00
Installation labor/lamp	N/A	$1.50
Total installation/lamp	N/A	$5.00
Replacement labor/lamp	$3.50	$1.50
Total replacement/lamp	$5.20	$5.00
Rebate/lamp (only at start)		$0.00
LAMP MAINTENANCE METHOD	Spot	Group
Frequency (hours)	20,000	15,000
Maint. cost/lamp	$5.20	$5.00

EPA GREEN LIGHTS QUIKALC 2.05 | Green Light Corporation
System Summary, Part 2 | Headquarters Building
page 2 of 6 01/07/93 | Upgrade: 2x4 fixtures

	Existing System	Proposed System
BALLASTS		
Type	Standard	Low Wattage Electroni
Ballast factor	0.95	0.78
Life (hours)	35000	63000
Disposal cost/ballast	$5.00	$0.00
Ballasts/fixture	2	1
Ballasts needed	2000	1000
Equipment cost/ballast	$10.00	$26.00
Installation labor/ballast	N/A	$16.00
Total installation/ballast	N/A	$52.00

Replacement labor/ballast	$14.00	$14.00
Total replacement/ballast	$29.00	$40.00
Rebate/ballast (only at start)		$0.00

BALLAST MAINTENANCE

Frequency (hours)	35,000	63,000
Maint. cost/ballast	$29.00	$40.00

	Proposed System
OTHER EQUIPMENT	
Reflectors	NO
Cost per fixture	$0.00
Total needed	0
Rebate per unit	$0.00
Increased light output	0%
Power Reducers	NO
Cost per fixture	$0.00
Total needed	0
Rebate per unit	$0.00
Decreased fixture wattage	0%
Decreased light output	0%
Controls: Occupancy Sensors/Timed switching	YES
Cost per controller	$60.00
Number of fixtures per controller	3
Total needed	333
Rebate per Controller	$0.00
Operating hour reduction due to controls	18%
OTHER INPUT VALUES	
Cost per kWh	$0.055
Monthly kW demand charge	$7.75
Internal rate of return term	20 years
Net present value term	20 years
Net present value discount rate	8.0%
CO2 pollution factor	1.5 lbs/kWh
SO2 pollution factor	5.8 g/kWh
NOx pollution factor	2.5 g/kWh
Increased light output from reflectors	0%
Decreased light output from power reducers	0%
Decreased fixture wattage from power reducers	0%
Air conditioning operating months per year	6.0
Air conditioning system COP	2.7
Inflation rate - labor and materials	3.0%
Inflation rate - electricity	5.0%
Future renovation cost	$100,000
Future renovation time from today	12 years

EPA GREEN LIGHTS QUIKALC 2.05 — Green Light Corporation
Results of Proposed System — Headquarters Building
page 4 of 6 — 01/07/93 — Upgrade: 2x4 fixtures

FINANCIAL RESULTS

Net present value	$505,553
Internal rate of return	46.8%
Cost of conserved energy	$0.0111 per kWh
Simple payback	2.3 years
Total upgrade project cost	$92,000
Total rebates	$0

ELECTRICAL ENERGY SAVINGS

Peak kW avoided	99.8 kW
Total Annual kWh saved	408,975 kWh
% of kWh avoided	59%
Lighting portion of savings	350,550 kWh
Air conditioning portion of savings	58,425 kWh
% of lighting savings added through HVAC saving	17%

POLLUTION PREVENTION

Annual lbs. CO2 reduced	613,463 lbs/year
Cumulative lbs CO2 reduced over term	12,269 lbs x1000
Annual lbs. SO2 reduced	5,225 lbs/year
Cumulative lbs. SO2 reduced over term	104.50 lbs x1000
Annual lbs. NOx reduced	2,252 lbs/year
Cumulative lbs. NOx reduced over term	45.04 lbs x1000

LIGHTING QUALITY

The PROPOSED system will provide 85%
of the light output of the EXISTING lighting system.

Color rendering of EXISTING lamps:	62
Color rendering of PROPOSED lamps:	75

MAINTENANCE

Suggested relamping schedule	71 months

EPA GREEN LIGHTS QUIKALC 2.05 — Green Light Corporation
Existing/Proposed Cash Flow Tables — Headquarters Building
page 5 of 6 — 01/07/93 — Upgrade: 2x4 fixtures

Yr.	Existing Energy Cost	Existing Maint. Cost	Existing Total Cost	Proposed Energy Cost	Proposed Upgrade/ Maint.cost	Proposed Total Cost
0	0	0	0	0	92,000	92,000
1	59,421	8,668	68,089	26,062	3,502	29,564
2	62,392	8,928	71,320	27,365	3,607	30,972
3	65,512	9,195	74,707	28,734	3,715	32,449
4	68,787	9,471	78,259	30,170	5,649	35,819
5	72,227	9,755	81,982	31,679	5,818	37,497
6	75,838	10,048	85,886	33,263	5,993	39,256
7	79,630	10,349	89,979	34,926	6,173	41,099

8	83,611	10,660	94,271	36,672	6,358	43,030
9	87,792	10,980	98,772	38,506	6,549	45,054
10	92,182	11,309	103,491	40,431	6,745	47,176
11	96,791	11,648	108,439	42,453	6,948	49,400
12	101,630	191,584	293,214	44,575	7,156	51,731
13	106,712	12,358	119,070	46,804	7,371	54,175
14	112,047	12,729	124,776	49,144	7,592	56,736
15	117,650	13,110	130,760	51,601	7,820	59,421
16	123,532	13,504	137,036	54,181	8,054	62,236
17	129,709	13,909	143,618	56,890	8,296	65,186
18	136,194	14,326	150,520	59,735	8,545	68,280
19	143,004	14,756	157,760	62,722	8,801	71,523
20	150,154	15,199	165,353	65,858	9,065	74,923
Sum	1,964,815	412,486	2,377,300	861,771	225,755	1,087,526

EPA GREEN LIGHTS QUIKALC 2.05 — Green Light Corporation
Comparison Cash Flow Tables — Headquarters Building
 01/07/93 — Upgrade: 2x4 fixtures

Yr.	Total Existing System Cost	Total Proposed System Cost	Change in Cashflow	Cumm. Savings	Cumm. NPV	Cumm. IRR
0	0	92,000	(92,000)	n.a.	n.a.	n.a.
1	68,089	29,564	38,524	(53,476)	(56,329)	-58.1%
2	71,320	30,972	40,347	(13,128)	(21,738)	-9.6%
3	74,707	32,449	42,258	29,130	11,808	14.9%
4	78,259	35,819	42,439	71,569	43,002	27.2%
5	81,982	37,497	44,485	116,054	73,278	34.1%
6	85,886	39,256	46,630	162,685	102,663	38.3%
7	89,979	41,099	48,881	211,566	131,185	40.9%
8	94,271	43,030	51,241	262,807	158,869	42.5%
9	98,772	45,054	53,717	316,524	185,741	43.6%
10	103,491	47,176	56,315	372,839	211,825	44.3%
11	108,439	49,400	59,039	431,878	237,146	44.8%
12	293,214	51,731	241,483	673,360	333,042	46.1%
13	119,070	54,175	64,895	738,255	356,904	46.3%
14	124,776	56,736	68,040	806,295	380,069	46.5%
15	130,760	59,421	71,339	877,635	402,558	46.6%
16	137,036	62,236	74,800	952,435	424,391	46.7%
17	143,618	65,186	78,431	1,030,866	445,589	46.7%
18	150,520	68,280	82,241	1,113,107	466,170	46.7%
19	157,760	71,523	86,237	1,199,344	486,152	46.8%
20	165,353	74,923	90,430	1,289,774	505,553	46.8%
Sum	2,377,300	1,087,526	1,289,774	1,289,774	505,553	n.a.

Quikalc Fixture Table

Use the following table to determine the code number for comparing existing and proposed fixtures. Each column in the table is defined below:

Column 1: Fixture Code Number

Column 2: Fixture Type

- The first three digits describe the nominal size of the fixture
(e.g., 1x4 = 1' x 4' fixture)
- The next digit is the number of lamps per fixture
- The last digits describe the luminaire type. Examples:

L	clear prismatic lens
W	wrap-around lens
S	strip fixture (no lens)
P9	parabolic - 9 cells
P18	parabolic - 18 cells
P32	parabolic - 32 cells
G15	grid lens - 1.5" cells
G1	grid lens - 1" cells
I	industrial luminaire
OAR	open/aluminum reflector
EPR	enclosed/prismatic reflector

example: 1x4-1L = 1'x4', one-lamp, clear prismatic lens

Column 3: Number of Lamps per Fixture

Column 4: Lamp Type

Examples:

T12HL/73 = High-lumen T12 fluorescent lamp with color rendering index of 73

T1042/80 = 42-watt T10 lamp with 80 CRI

96T12110 = 8-foot, 110W T12 lamp

13Q5 = 13-watt, 5-inch quad-tube fluorescent

LED = LED exit sign

Column 5: Ballast Type

Column 6: Number of Lamps per Ballast

Column 7: Ballast Factor

Column 8: System Wattage

FIXT CODE	FIXT TYPE	LPS FIX	LAMP TYPE	BALLAST TYPE	LAMPS/ BALLAST	BALLAST FACTOR	SYS WATTS
100	1x8-4S	4	T832/75	Electronic	4	0.87	109
101	2x2-2L	2	T8/17/75	Electronic	2	0.90	39
102	1X4-1L	1	T1042/80	Efficient Magnetic	1	0.95	45
103	1X4-1L	1	T1042/80	Hybrid	1	0.84	38
104	1X4-1L	1	T1042/80	Electronic	1	0.86	37
105	1X4-1L	1	T1042/80	Low Wattage Electror	1	0.41	20
106	1X4-1L	1	T1234/62	Standard	1	0.87	40
107	1X4-1L	1	T1234/62	Efficient Magnetic	1	0.87	36
108	1X4-1L	1	T1234/62	Electronic	1	0.86	30
109	1X4-1L	1	T1234/62	Hybrid	1	0.79	29
110	1X4-1L	1	T1240/62	Standard	1	0.95	48
111	1X4-1L	1	T1240/62	Efficient Magnetic	1	0.94	44
112	1X4-1L	1	T1240/62	Electronic	1	0.90	36
113	1X4-1L	1	T1240/62	Hybrid	1	0.83	36
114	1X4-1L	1	T1240/62	Low Wattage Electror	1	0.41	19
115	1X4-1L	1	T12HL/73	Efficient Magnetic	1	0.93	44
116	1X4-1L	1	T12HL/73	Hybrid	1	0.81	37
117	1X4-1L	1	T12HL/73	Electronic	1	0.89	36
118	1X4-1L	1	T832/75	Efficient Magnetic	1	0.94	36
119	1X4-1L	1	T832/75	Electronic	1	0.90	31
120	1X4-1L	1	T832/75	Low Wattage Electror	1	0.83	26
121	1X4-1L	1	T832/75	Low Wattage Electror	1	0.47	18
122	1X4-1P8	1	T1042/80	Efficient Magnetic	1	0.95	45
123	1X4-1P8	1	T1042/80	Electronic	1	0.86	37
124	1X4-1P8	1	T1042/80	Hybrid	1	0.84	38
125	1X4-1P8	1	T1042/80	Low Wattage Electror	1	0.41	20
126	1X4-1P8	1	T1234/62	Standard	1	0.87	40
127	1X4-1P8	1	T1234/62	Efficient Magnetic	1	0.87	36
128	1X4-1P8	1	T1234/62	Hybrid	1	0.79	29
129	1X4-1P8	1	T1234/62	Electronic	1	0.86	30
130	1X4-1P8	1	T1240/62	Standard	1	0.95	48
131	1X4-1P8	1	T1240/62	Efficient Magnetic	1	0.94	44
132	1X4-1P8	1	T1240/62	Electronic	1	0.90	36
133	1X4-1P8	1	T1240/62	Hybrid	1	0.83	36
134	1X4-1P8	1	T1240/62	Low Wattage Electror	1	0.41	19
135	1X4-1P8	1	T12HL/73	Efficient Magnetic	1	0.93	44
136	1X4-1P8	1	T12HL/73	Hybrid	1	0.81	37
137	1X4-1P8	1	T12HL/73	Electronic	1	0.89	36
138	1X4-1P8	1	T832/75	Efficient Magnetic	1	0.94	36
139	1X4-1P8	1	T832/75	Electronic	1	0.90	31
140	1X4-1P8	1	T832/75	Low Wattage Electror	1	0.83	26
141	1X4-1P8	1	T832/75	Low Wattage Electror	1	0.47	18
142	1X4-1S	1	T1042/80	Efficient Magnetic	1	0.95	45
143	1X4-1S	1	T1042/80	Hybrid	1	0.84	38
144	1X4-1S	1	T1042/80	Electronic	1	0.86	37
145	1X4-1S	1	T1042/80	Low Wattage Electror	1	0.41	20
146	1X4-1S	1	T1234/62	Standard	1	0.87	40
147	1X4-1S	1	T1234/62	Efficient Magnetic	1	0.87	36
148	1X4-1S	1	T1234/62	Hybrid	1	0.79	29

149	1X4-1S	1	T1234/62	Electronic	1	0.86	30
150	1X4-1S	1	T1234/62	Hybrid	1	0.79	29
151	1X4-1S	1	T1240/62	Standard	1	0.95	48
152	1X4-1S	1	T1240/62	Efficient Magnetic	1	0.94	44
153	1X4-1S	1	T1240/62	Electronic	1	0.90	36
154	1X4-1S	1	T1240/62	Hybrid	1	0.83	36
155	1X4-1S	1	T1240/62	Low Wattage Electror	1	0.41	19
156	1X4-1S	1	T12HL/73	Efficient Magnetic	1	0.93	44
157	1X4-1S	1	T12HL/73	Hybrid	1	0.81	37
158	1X4-1S	1	T12HL/73	Electronic	1	0.89	36
159	1X4-1S	1	T832/75	Efficient Magnetic	1	0.94	36
160	1X4-1S	1	T832/75	Electronic	1	0.90	31
161	1X4-1S	1	T832/75	Low Wattage Electror	1	0.83	26
162	1X4-1S	1	T832/75	Low Wattage Electror	1	0.47	18
163	1X4-1W	1	T1042/80	Efficient Magnetic	1	0.95	45
164	1X4-1W	1	T1042/80	Electronic	1	0.86	37
165	1X4-1W	1	T1042/80	Hybrid	1	0.84	38
166	1X4-1W	1	T1042/80	Electronic	1	0.86	37
167	1X4-1W	1	T1042/80	Low Wattage Electror	1	0.41	20
168	1X4-1W	1	T1234/62	Standard	1	0.87	40
169	1X4-1W	1	T1234/62	Efficient Magnetic	1	0.87	36
170	1X4-1W	1	T1234/62	Hybrid	1	0.79	29
171	1X4-1W	1	T1234/62	Electronic	1	0.86	30
172	1X4-1W	1	T1240/62	Standard	1	0.95	48
173	1X4-1W	1	T1240/62	Efficient Magnetic	1	0.94	44
174	1X4-1W	1	T1240/62	Electronic	1	0.90	36
175	1X4-1W	1	T1240/62	Hybrid	1	0.83	36
176	1X4-1W	1	T1240/62	Low Wattage Electror	1	0.41	19
177	1X4-1W	1	T12HL/73	Efficient Magnetic	1	0.93	44
178	1X4-1W	1	T12HL/73	Hybrid	1	0.81	37
179	1X4-1W	1	T12HL/73	Electronic	1	0.89	36
180	1X4-1W	1	T832/75	Efficient Magnetic	1	0.94	36
181	1X4-1W	1	T832/75	Electronic	1	0.90	31
182	1X4-1W	1	T832/75	Low Wattage Electror	1	0.83	26
183	1X4-1W	1	T832/75	Low Wattage Electror	1	0.47	18
184	1X4-2G15	2	T1042/80	Efficient Magnetic	2	0.95	90
185	1X4-2G15	2	T1042/80	Hybrid	2	0.84	76
186	1X4-2G15	2	T1042/80	Electronic	2	0.86	74
187	1X4-2G15	2	T1042/80	Low Wattage Electror	2	0.41	40
188	1X4-2G15	2	T1234/62	Standard	2	0.87	79
189	1X4-2G15	2	T1234/62	Efficient Magnetic	2	0.87	72
190	1X4-2G15	2	T1234/62	Electronic	2	0.86	60
191	1X4-2G15	2	T1234/62	Hybrid	2	0.79	58
192	1X4-2G15	2	T1240/62	Standard	2	0.95	95
193	1X4-2G15	2	T1240/62	Efficient Magnetic	2	0.94	88
194	1X4-2G15	2	T1240/62	Electronic	2	0.90	72
195	1X4-2G15	2	T1240/62	Hybrid	2	0.83	72
196	1X4-2G15	2	T1240/62	Low Wattage Electror	2	0.41	37
197	1X4-2G15	2	T12HL/73	Efficient Magnetic	2	0.93	88
198	1X4-2G15	2	T12HL/73	Hybrid	2	0.81	74
199	1X4-2G15	2	T12HL/73	Electronic	2	0.89	72

200	1X4-2G15	2	T832/75	Efficient Magnetic	2	0.94	72
201	1X4-2G15	2	T832/75	Electronic	2	0.90	62
202	1X4-2G15	2	T832/75	Low Wattage Electror	2	0.83	51
203	1X4-2G15	2	T832/75	Low Wattage Electror	2	0.47	36
204	1X4-2L	2	T1042/80	Efficient Magnetic	2	0.95	90
205	1X4-2L	2	T1042/80	Hybrid	2	0.84	76
206	1X4-2L	2	T1042/80	Electronic	2	0.86	74
207	1X4-2L	2	T1042/80	Low Wattage Electror	2	0.41	40
208	1X4-2L	2	T1234/62	Standard	2	0.87	79
209	1X4-2L	2	T1234/62	Efficient Magnetic	2	0.87	72
210	1X4-2L	2	T1234/62	Hybrid	2	0.79	58
211	1X4-2L	2	T1234/62	Electronic	2	0.86	60
212	1X4-2L	2	T1240/62	Standard	2	0.95	95
213	1X4-2L	2	T1240/62	Efficient Magnetic	2	0.94	88
214	1X4-2L	2	T1240/62	Hybrid	2	0.83	72
215	1X4-2L	2	T1240/62	Electronic	2	0.90	72
216	1X4-2L	2	T1240/62	Low Wattage Electror	2	0.41	37
217	1X4-2L	2	T12HL/73	Efficient Magnetic	2	0.93	88
218	1X4-2L	2	T12HL/73	Hybrid	2	0.81	74
219	1X4-2L	2	T12HL/73	Electronic	2	0.89	72
220	1X4-2L	2	T832/75	Efficient Magnetic	2	0.94	72
221	1X4-2L	2	T832/75	Electronic	2	0.90	62
222	1X4-2L	2	T832/75	Low Wattage Electror	2	0.83	51
223	1X4-2L	2	T832/75	Low Wattage Electror	2	0.47	36
224	1X4-2P16	2	T1042/80	Efficient Magnetic	2	0.95	90
225	1X4-2P16	2	T1042/80	Hybrid	2	0.84	76
226	1X4-2P16	2	T1042/80	Electronic	2	0.86	74
227	1X4-2P16	2	T1042/80	Low Wattage Electror	2	0.41	40
228	1X4-2P16	2	T1234/62	Standard	2	0.87	79
229	1X4-2P16	2	T1234/62	Efficient Magnetic	2	0.87	72
230	1X4-2P16	2	T1234/62	Electronic	2	0.86	60
231	1X4-2P16	2	T1234/62	Hybrid	2	0.79	58
232	1X4-2P16	2	T1240/62	Standard	2	0.95	95
233	1X4-2P16	2	T1240/62	Efficient Magnetic	2	0.94	88
234	1X4-2P16	2	T1240/62	Electronic	2	0.90	72
235	1X4-2P16	2	T1240/62	Hybrid	2	0.83	72
236	1X4-2P16	2	T1240/62	Low Wattage Electror	2	0.41	37
237	1X4-2P16	2	T12HL/73	Efficient Magnetic	2	0.93	88
238	1X4-2P16	2	T12HL/73	Hybrid	2	0.81	74
239	1X4-2P16	2	T12HL/73	Electronic	2	0.89	72
240	1X4-2P16	2	T832/75	Efficient Magnetic	2	0.94	72
241	1X4-2P16	2	T832/75	Electronic	2	0.90	62
242	1X4-2P16	2	T832/75	Low Wattage Electror	2	0.83	51
243	1X4-2P16	2	T832/75	Low Wattage Electror	2	0.47	36
244	1X4-2P8	2	T1042/80	Efficient Magnetic	2	0.95	90
245	1X4-2P8	2	T1042/80	Hybrid	2	0.84	76
246	1X4-2P8	2	T1042/80	Electronic	2	0.86	74
247	1X4-2P8	2	T1042/80	Low Wattage Electror	2	0.41	40
248	1X4-2P8	2	T1234/62	Standard	2	0.87	79
249	1X4-2P8	2	T1234/62	Efficient Magnetic	2	0.87	72
250	1X4-2P8	2	T1234/62	Electronic	2	0.86	60

251	1X4-2P8	2	T1234/62	Hybrid	2	0.79	58
252	1X4-2P8	2	T1240/62	Standard	2	0.95	95
253	1X4-2P8	2	T1240/62	Efficient Magnetic	2	0.94	88
254	1X4-2P8	2	T1240/62	Hybrid	2	0.83	72
255	1X4-2P8	2	T1240/62	Electronic	2	0.90	72
256	1X4-2P8	2	T1240/62	Low Wattage Electror	2	0.41	37
257	1X4-2P8	2	T12HL/73	Efficient Magnetic	2	0.93	88
258	1X4-2P8	2	T12HL/73	Hybrid	2	0.81	74
259	1X4-2P8	2	T12HL/73	Electronic	2	0.89	72
260	1X4-2P8	2	T832/75	Efficient Magnetic	2	0.94	72
261	1X4-2P8	2	T832/75	Electronic	2	0.90	62
262	1X4-2P8	2	T832/75	Low Wattage Electror	2	0.83	51
263	1X4-2P8	2	T832/75	Low Wattage Electror	2	0.47	36
264	1X4-2S	2	T1042/80	Efficient Magnetic	2	0.95	90
265	1X4-2S	2	T1042/80	Hybrid	2	0.84	76
266	1X4-2S	2	T1042/80	Electronic	2	0.86	74
267	1X4-2S	2	T1042/80	Low Wattage Electror	2	0.41	40
268	1X4-2S	2	T1234/62	Standard	2	0.87	79
269	1X4-2S	2	T1234/62	Efficient Magnetic	2	0.87	72
270	1X4-2S	2	T1234/62	Electronic	2	0.86	60
271	1X4-2S	2	T1234/62	Hybrid	2	0.79	58
272	1X4-2S	2	T1240/62	Standard	2	0.95	95
273	1X4-2S	2	T1240/62	Efficient Magnetic	2	0.94	88
274	1X4-2S	2	T1240/62	Hybrid	2	0.83	72
275	1X4-2S	2	T1240/62	Electronic	2	0.90	72
276	1X4-2S	2	T1240/62	Low Wattage Electror	2	0.41	37
277	1X4-2S	2	T12HL/73	Efficient Magnetic	2	0.93	88
278	1X4-2S	2	T12HL/73	Hybrid	2	0.81	74
279	1X4-2S	2	T12HL/73	Electronic	2	0.89	72
280	1X4-2S	2	T832/75	Efficient Magnetic	2	0.94	72
281	1X4-2S	2	T832/75	Electronic	2	0.90	62
282	1X4-2S	2	T832/75	Low Wattage Electror	2	0.83	51
283	1X4-2S	2	T832/75	Low Wattage Electror	2	0.47	36
284	1X4-2W	2	T1042/80	Efficient Magnetic	2	0.95	90
285	1X4-2W	2	T1042/80	Hybrid	2	0.84	76
286	1X4-2W	2	T1042/80	Electronic	2	0.86	74
287	1X4-2W	2	T1042/80	Low Wattage Electror	2	0.41	40
288	1X4-2W	2	T1234/62	Standard	2	0.87	79
289	1X4-2W	2	T1234/62	Efficient Magnetic	2	0.87	72
290	1X4-2W	2	T1234/62	Electronic	2	0.86	60
291	1X4-2W	2	T1234/62	Hybrid	2	0.79	58
292	1X4-2W	2	T1240/62	Standard	2	0.95	95
293	1X4-2W	2	T1240/62	Efficient Magnetic	2	0.94	88
294	1X4-2W	2	T1240/62	Hybrid	2	0.83	72
295	1X4-2W	2	T1240/62	Electronic	2	0.90	72
296	1X4-2W	2	T1240/62	Low Wattage Electror	2	0.41	37
297	1X4-2W	2	T12HL/73	Efficient Magnetic	2	0.93	88
298	1X4-2W	2	T12HL/73	Hybrid	2	0.81	74
299	1X4-2W	2	T12HL/73	Electronic	2	0.89	72
300	1X4-2W	2	T832/75	Efficient Magnetic	2	0.94	72
301	1X4-2W	2	T832/75	Electronic	2	0.90	62

302	1X4-2W	2	T832/75	Low Wattage Electror	2	0.83	51
303	1X4-2W	2	T832/75	Low Wattage Electror	2	0.47	36
304	1X4-3W	3	T1042/80	Efficient Magnetic	2	0.95	135
305	1X4-3W	3	T1042/80	Hybrid	2	0.84	114
306	1X4-3W	3	T1042/80	Electronic	2	0.86	111
307	1X4-3W	3	T1042/80	Electronic	3	0.85	107
308	1X4-3W	3	T1042/80	Low Wattage Electror	3	0.41	63
309	1X4-3W	3	T1234/62	Standard	2	0.87	119
310	1X4-3W	3	T1234/62	Efficient Magnetic	2	0.87	108
311	1X4-3W	3	T1234/62	Hybrid	2	0.79	87
312	1X4-3W	3	T1234/62	Electronic	3	0.87	89
313	1X4-3W	3	T1234/62	Electronic	2	0.86	90
314	1X4-3W	3	T1240/62	Standard	2	0.95	143
315	1X4-3W	3	T1240/62	Efficient Magnetic	2	0.94	132
316	1X4-3W	3	T1240/62	Electronic	3	0.89	106
317	1X4-3W	3	T1240/62	Electronic	2	0.90	108
318	1X4-3W	3	T1240/62	Hybrid	2	0.83	108
319	1X4-3W	3	T1240/62	Low Wattage Electror	3	0.41	58
320	1X4-3W	3	T12HL/73	Efficient Magnetic	2	0.93	132
321	1X4-3W	3	T12HL/73	Hybrid	2	0.81	111
322	1X4-3W	3	T12HL/73	Electronic	2	0.89	108
323	1X4-3W	3	T12HL/73	Electronic	3	0.89	108
324	1X4-3W	3	T832/75	Efficient Magnetic	2	0.94	108
325	1X4-3W	3	T832/75	'Electronic (3lps)	3	0.89	86
326	1X4-3W	3	T832/75	Electronic	2	0.90	93
327	1X4-3W	3	T832/75	Low Wattage Electror	3	0.82	75
328	1X4-3W	3	T832/75	Low Wattage Electror	2	0.47	54
329	1X4-4W	4	T1042/80	Efficient Magnetic	2	0.95	180
330	1X4-4W	4	T1042/80	Electronic (4 laps)	4	0.86	148
331	1X4-4W	4	T1042/80	Electronic	2	0.86	148
332	1X4-4W	4	T1042/80	Hybrid	2	0.84	152
333	1X4-4W	4	T1234/62	Standard	2	0.87	158
334	1X4-4W	4	T1234/62	Efficient Magnetic	2	0.87	144
335	1X4-4W	4	T1234/62	Electronic (4 lps)	4	0.82	122
336	1X4-4W	4	T1234/62	Hybrid	2	0.79	116
337	1X4-4W	4	T1234/62	Electronic	2	0.83	116
338	1X4-4W	4	T1240/62	Standard	2	0.95	190
339	1X4-4W	4	T1240/62	Efficient Magnetic	2	0.95	160
340	1X4-4W	4	T1240/62	Electronic (4 lps)	4	0.89	142
341	1X4-4W	4	T1240/62	Hybrid	2	0.83	144
342	1X4-4W	4	T1240/62	Electronic	2	0.90	144
343	1X4-4W	4	T12HL/73	Efficient Magnetic	2	0.95	160
344	1X4-4W	4	T12HL/73	Electronic (4 lps)	4	0.89	138
345	1X4-4W	4	T12HL/73	Hybrid	2	0.80	137
346	1X4-4W	4	T12HL/73	Electronic	2	0.88	132
347	1X4-4W	4	T832/75	Efficient Magnetic	2	0.94	144
348	1X4-4W	4	T832/75	Electronic	2	0.90	124
349	1X4-4W	4	T832/75	Electronic (4 lps)	4	0.87	109
350	1X4-4W	4	T832/75	Low Wattage Electror	4	0.78	95
351	2X2-2L	2	T1235U3/62	Efficient Magnetic	2	0.87	72
352	2X2-2L	2	T1235U3/62	Electronic	2	0.86	60

353	2X2-2L	2	T1235U3/62	Standard	2	0.87	79
354	2X2-2L	2	T1235U3/62	Efficient Magnetic	2	0.87	72
355	2X2-2L	2	T1235U3/62	Electronic	2	0.86	60
356	2X2-2L	2	T1240U3/62	Standard	2	0.95	95
357	2X2-2L	2	T1240U3/62	Efficient Magnetic	2	0.94	88
358	2X2-2L	2	T1240U3/62	Standard	2	0.87	79
359	2X2-2L	2	T1240U3/62	Hybrid	2	0.83	72
360	2X2-2L	2	T1240U3/62	Electronic	2	0.90	72
361	2X2-2L	2	T1240U3/62	Low Wattage Electror	2	0.41	37
362	2X2-2L	2	T1240U6/62	Standard	2	0.95	95
363	2X2-2L	2	T1240U6/62	Standard	2	0.95	95
364	2X2-2L	2	T1240U6/62	Efficient Magnetic	2	0.94	88
365	2X2-2L	2	T1240U6/62	Electronic	2	0.90	72
366	2X2-2L	2	T1240U6/62	Hybrid	2	0.83	72
367	2X2-2L	2	T1240U6/62	Low Wattage Electror	2	0.41	37
368	2X2-2L	2	T539/82	Electronic	2	0.93	70
369	2X2-2L	2	T8U32/75	Efficient Magnetic	2	0.94	72
370	2X2-2L	2	T8U32/75	Electronic	2	0.90	62
371	2X2-2L	2	T8U32/75	Low Wattage Electror	2	0.83	51
372	2X2-2L	2	T8U32/75	Low Wattage Electror	2	0.47	36
373	2X2-2P16	2	T1235U3/62	Standard	2	0.87	79
374	2X2-2P16	2	T1235U3/62	Efficient Magnetic	2	0.87	72
375	2X2-2P16	2	T1235U3/62	Electronic	2	0.86	60
376	2X2-2P16	2	T1235U3/62	Standard	2	0.87	79
377	2X2-2P16	2	T1235U3/62	Efficient Magnetic	2	0.87	72
378	2X2-2P16	2	T1235U3/62	Electronic	2	0.86	60
379	2X2-2P16	2	T1240U3/62	Standard	2	0.95	95
380	2X2-2P16	2	T1240U3/62	Efficient Magnetic	2	0.94	88
381	2X2-2P16	2	T1240U3/62	Electronic	2	0.90	72
382	2X2-2P16	2	T1240U3/62	Hybrid	2	0.83	72
383	2X2-2P16	2	T1240U3/62	Low Wattage Electror	2	0.41	37
384	2X2-2P16	2	T1240U6/62	Efficient Magnetic	2	0.94	88
385	2X2-2P16	2	T1240U6/62	Electronic	2	0.90	72
386	2X2-2P16	2	T1240U6/62	Hybrid	2	0.83	72
387	2X2-2P16	2	T1240U6/62	Low Wattage Electror	2	0.41	37
388	2X2-2P16	2	T8U32/75	Efficient Magnetic	2	0.94	72
389	2X2-2P16	2	T8U32/75	Electronic	2	0.90	62
390	2X2-2P16	2	T8U32/75	Low Wattage Electror	2	0.83	51
391	2X2-2P16	2	T8U32/75	Low Wattage Electror	2	0.47	36
392	2X2-2P9	2	T1235U3/62	Efficient Magnetic	2	0.87	72
393	2X2-2P9	2	T1235U3/62	Electronic	2	0.86	60
394	2X2-2P9	2	T1235U6/62	Standard	2	0.87	79
395	2X2-2P9	2	T1235U6/62	Efficient Magnetic	2	0.87	72
396	2X2-2P9	2	T1235U6/62	Electronic	2	0.86	60
397	2X2-2P9	2	T1240U3/62	Standard	2	0.95	95
398	2X2-2P9	2	T1240U3/62	Efficient Magnetic	2	0.94	88
399	2X2-2P9	2	T1240U3/62	Hybrid	2	0.83	72
400	2X2-2P9	2	T1240U3/62	Electronic	2	0.90	72
401	2X2-2P9	2	T1240U3/62	Low Wattage Electror	2	0.41	37
402	2X2-2P9	2	T1240U6/62	Standard	2	0.95	95
403	2X2-2P9	2	T1240U6/62	Efficient Magnetic	2	0.94	88

404	2X2-2P9	2	T1240U6/62	Hybrid	2	0.83	72
405	2X2-2P9	2	T1240U6/62	Electronic	2	0.90	72
406	2X2-2P9	2	T1240U6/62	Low Wattage Electror	2	0.41	37
407	2X2-2P9	2	T539/82	Electronic	2	0.93	70
408	2X2-2P9	2	T8U32/75	Efficient Magnetic	2	0.94	72
409	2X2-2P9	2	T8U32/75	Electronic	2	0.90	62
410	2X2-2P9	2	T8U32/75	Low Wattage Electror	2	0.83	51
411	2X2-2P9	2	T8U32/75	Low Wattage Electror	2	0.47	36
412	2X2-3L	3	T1235U3/62	Standard	2	0.87	119
413	2X2-3L	3	T1235U3/62	Efficient Magnetic	2	0.87	108
414	2X2-3L	3	T1235U3/62	Electronic (3 lps)	3	0.87	89
415	2X2-3L	3	T1235U3/62	Electronic	2	0.86	90
416	2X2-3L	3	T1240U3/62	Standard	2	0.95	143
417	2X2-3L	3	T1240U3/62	Efficient Magnetic	2	0.94	132
418	2X2-3L	3	T1240U3/62	Electronic (3lps)	3	0.89	106
419	2X2-3L	3	T1240U3/62	Hybrid	2	0.83	108
420	2X2-3L	3	T1240U3/62	Electronic	2	0.90	108
421	2X2-3L	3	T1240U3/62	Low Wattage Electror	3	0.41	58
422	2X2-3L	3	T8U32/75	Efficient Magnetic	2	0.94	108
423	2X2-3L	3	T8U32/75	Electronic	2	0.90	93
424	2X2-3L	3	T8U32/75	Electronic (3 lps)	3	0.89	86
425	2X2-3L	3	T8U32/75	Low Wattage Electror	3	0.82	75
426	2X2-3L	3	T8U32/75	Low Wattage Electror	2	.0.47	54
427	2X2-3P16	3	T1235U3/62	Standard	2	0.87	119
428	2X2-3P16	3	T1235U3/62	Efficient Magnetic	2	0.87	107
429	2X2-3P16	3	T1235U3/62	Electronic (3 lps)	3	0.88	92
430	2X2-3P16	3	T1235U3/62	Electronic	2	0.86	92
431	2X2-3P16	3	T1240U3/62	Efficient Magnetic	2	0.95	128
432	2X2-3P16	3	T1240U3/62	Electronic (3 lps)	3	0.87	107
433	2X2-3P16	3	T1240U3/62	Hybrid	2	0.82	113
434	2X2-3P16	3	T1240U3/62	Electronic	2	0.91	106
435	2X2-3P16	3	T1240U3/62	Low Wattage Electror	3	0.41	58
436	2X2-3P16	3	T8U32/75	Efficient Magnetic	2	0.94	101
437	2X2-3P16	3	T8U32/75	Electronic	2	0.94	91
438	2X2-3P16	3	T8U32/75	Electronic (3 lps)	3	0.94	93
439	2X2-3P16	3	T8U32/75	Low Wattage Electror	3	0.82	75
440	2X2-3P16	3	T8U32/75	Low Wattage Electror	2	0.47	54
441	2X2-3P9	3	T1235U3/62	Standard	2	0.87	119
442	2X2-3P9	3	T1235U3/62	Efficient Magnetic	2	0.87	107
443	2X2-3P9	3	T1235U3/62	Electronic (3 lps)	3	0.88	92
444	2X2-3P9	3	T1235U3/62	Electronic	2	0.86	92
445	2X2-3P9	3	T1240U3/62	Efficient Magnetic	2	0.95	128
446	2X2-3P9	3	T1240U3/62	Electronic	3	0.87	107
447	2X2-3P9	3	T1240U3/62	Hybrid	2	0.82	113
448	2X2-3P9	3	T1240U3/62	Electronic	2	0.91	106
449	2X2-3P9	3	T1240U3/62	Low Wattage Electror	3	0.41	58
450	2X2-3P9	3	T8U32/75	Efficient Magnetic	2	0.94	101
451	2X2-3P9	3	T8U32/75	Electronic	2	0.94	91
452	2X2-3P9	3	T8U32/75	Electronic	3	0.94	93
453	2X2-3P9	3	T8U32/75	Low Wattage Electror	3	0.82	75
454	2X2-3P9	3	T8U32/75	Low Wattage Electror	2	0.47	54

455	2X4-2G1	2	T1042/80	Efficient Magnetic	2	0.95	90
456	2X4-2G1	2	T1042/80	Hybrid	2	0.84	76
457	2X4-2G1	2	T1042/80	Electronic	2	0.86	74
458	2X4-2G1	2	T1234/62	Standard	2	0.87	79
459	2X4-2G1	2	T1234/62	Efficient Magnetic	2	0.87	72
460	2X4-2G1	2	T1234/62	Electronic	2	0.86	60
461	2X4-2G1	2	T1234/62	Hybrid	2	0.79	58
462	2X4-2G1	2	T1240/62	Standard	2	0.95	95
463	2X4-2G1	2	T1240/62	Efficient Magnetic	2	0.94	88
464	2X4-2G1	2	T1240/62	Hybrid	2	0.83	72
465	2X4-2G1	2	T1240/62	Electronic	2	0.90	72
466	2X4-2G1	2	T12HL/73	Efficient Magnetic	2	0.93	88
467	2X4-2G1	2	T12HL/73	Hybrid	2	0.81	74
468	2X4-2G1	2	T12HL/73	Electronic	2	0.89	72
469	2X4-2G1	2	T832/75	Efficient Magnetic	2	0.94	72
470	2X4-2G1	2	T832/75	Electronic	2	0.90	62
471	2X4-2G15	2	T1042/80	Efficient Magnetic	2	0.95	90
472	2X4-2G15	2	T1042/80	Hybrid	2	0.84	76
473	2X4-2G15	2	T1042/80	Electronic	2	0.86	74
474	2X4-2G15	2	T1234/62	Standard	2	0.87	79
475	2X4-2G15	2	T1234/62	Efficient Magnetic	2	0.87	72
476	2X4-2G15	2	T1234/62	Hybrid	2	0.79	58
477	2X4-2G15	2	T1234/62	Electronic	2	0.86	60
478	2X4-2G15	2	T1240/62	Standard	2	0.95	95
479	2X4-2G15	2	T1240/62	Efficient Magnetic	2	0.94	88
480	2X4-2G15	2	T1240/62	Hybrid	2	0.83	72
481	2X4-2G15	2	T1240/62	Electronic	2	0.90	72
482	2X4-2G15	2	T12HL/73	Efficient Magnetic	2	0.93	88
483	2X4-2G15	2	T12HL/73	Hybrid	2	0.81	74
484	2X4-2G15	2	T12HL/73	Electronic	2	0.89	72
485	2X4-2G15	2	T832/75	Efficient Magnetic	2	0.94	72
486	2X4-2G15	2	T832/75	Electronic	2	0.90	62
487	2X4-2L	2	T1042/80	Efficient Magnetic	2	0.95	90
488	2X4-2L	2	T1042/80	Hybrid	2	0.84	76
489	2X4-2L	2	T1042/80	Electronic	2	0.86	74
490	2X4-2L	2	T1042/80	Low Wattage Electror	2	0.41	40
491	2X4-2L	2	T1234/62	Standard	2	0.87	79
492	2X4-2L	2	T1234/62	Efficient Magnetic	2	0.87	72
493	2X4-2L	2	T1234/62	Electronic	2	0.86	60
494	2X4-2L	2	T1234/62	Hybrid	2	0.79	58
495	2X4-2L	2	T1240/62	Standard	2	0.95	95
496	2X4-2L	2	T1240/62	Efficient Magnetic	2	0.94	88
497	2X4-2L	2	T1240/62	Electronic	2	0.90	72
498	2X4-2L	2	T1240/62	Hybrid	2	0.83	72
499	2X4-2L	2	T1240/62	Low Wattage Electror	2	0.41	37
500	2X4-2L	2	T12HL/73	Efficient Magnetic	2	0.93	88
501	2X4-2L	2	T12HL/73	Hybrid	2	0.81	74
502	2X4-2L	2	T12HL/73	Electronic	2	0.89	72
503	2X4-2L	2	T832/75	Efficient Magnetic	2	0.94	72
504	2X4-2L	2	T832/75	Electronic	2	0.90	62
505	2X4-2L	2	T832/75	Low Wattage Electror	2	0.83	51

506	2X4-2L	2	T832/75	Low Wattage Electror	2	0.47	36
507	2X4-2P12	2	T1042/80	Efficient Magnetic	2	0.95	90
508	2X4-2P12	2	T1042/80	Hybrid	2	0.84	76
509	2X4-2P12	2	T1042/80	Electronic	2	0.86	74
510	2X4-2P12	2	T1042/80	Low Wattage Electror	2	0.41	40
511	2X4-2P12	2	T1234/62	Standard	2	0.87	79
512	2X4-2P12	2	T1234/62	Efficient Magnetic	2	0.87	72
513	2X4-2P12	2	T1234/62	Electronic	2	0.86	60
514	2X4-2P12	2	T1234/62	Hybrid	2	0.79	58
515	2X4-2P12	2	T1240/62	Standard	2	0.95	95
516	2X4-2P12	2	T1240/62	Efficient Magnetic	2	0.94	88
517	2X4-2P12	2	T1240/62	Hybrid	2	0.83	72
518	2X4-2P12	2	T1240/62	Electronic	2	0.90	72
519	2X4-2P12	2	T1240/62	Low Wattage Electror	2	0.41	37
520	2X4-2P12	2	T12HL/73	Efficient Magnetic	2	0.93	88
521	2X4-2P12	2	T12HL/73	Hybrid	2	0.81	74
522	2X4-2P12	2	T12HL/73	Electronic	2	0.89	72
523	2X4-2P12	2	T832/75	Efficient Magnetic	2	0.94	72
524	2X4-2P12	2	T832/75	Electronic	2	0.90	62
525	2X4-2P12	2	T832/75	Low Wattage Electror	2	0.83	51
526	2X4-2P12	2	T832/75	Low Wattage Electror	2	0.47	36
527	2X4-2W	2	T1042/80	Efficient Magnetic	2	0.95	90
528	2X4-2W	2	T1042/80	Hybrid	2	0.84	76
529	2X4-2W	2	T1042/80	Electronic	2	0.86	74
530	2X4-2W	2	T1042/80	Low Wattage Electror	2	0.41	40
531	2X4-2W	2	T1234/62	Standard	2	0.87	79
532	2X4-2W	2	T1234/62	Efficient Magnetic	2	0.87	72
533	2X4-2W	2	T1234/62	Electronic	2	0.86	60
534	2X4-2W	2	T1234/62	Hybrid	2	0.79	58
535	2X4-2W	2	T1234/62	Electronic	2	0.86	60
536	2X4-2W	2	T1234/62	Hybrid	2	0.79	58
537	2X4-2W	2	T1240/62	Standard	2	0.95	95
538	2X4-2W	2	T1240/62	Efficient Magnetic	2	0.94	88
539	2X4-2W	2	T1240/62	Hybrid	2	0.83	72
540	2X4-2W	2	T1240/62	Electronic	2	0.90	72
541	2X4-2W	2	T1240/62	Low Wattage Electror	2	0.41	37
542	2X4-2W	2	T12HL/73	Efficient Magnetic	2	0.93	88
543	2X4-2W	2	T12HL/73	Hybrid	2	0.81	74
544	2X4-2W	2	T12HL/73	Electronic	2	0.89	72
545	2X4-2W	2	T832/75	Efficient Magnetic	2	0.94	72
546	2X4-2W	2	T832/75	Electronic	2	0.90	62
547	2X4-2W	2	T832/75	Low Wattage Electror	2	0.83	51
548	2X4-2W	2	T832/75	Low Wattage Electror	2	0.47	36
549	2X4-3G1	3	T1042/80	Efficient Magnetic	2	0.92	134
550	2X4-3G1	3	T1042/80	Hybrid	2	0.83	117
551	2X4-3G1	3	T1042/80	Electronic	2	0.88	114
552	2X4-3G1	3	T1042/80	Electronic	3	0.88	107
553	2X4-3G1	3	T1234/62	Standard	2	0.87	119
554	2X4-3G1	3	T1234/62	Efficient Magnetic	2	0.87	107
555	2X4-3G1	3	T1234/62	Hybrid	2	0.78	98
556	2X4-3G1	3	T1234/62	Electronic	3	0.88	92

557	2X4-3G1	3	T1234/62	Electronic	2	0.86	92
558	2X4-3G1	3	T1240/62	Standard	2	0.95	143
559	2X4-3G1	3	T1240/62	Efficient Magnetic	2	0.95	128
560	2X4-3G1	3	T1240/62	Electronic	3	0.87	107
561	2X4-3G1	3	T1240/62	Electronic	2	0.91	106
562	2X4-3G1	3	T1240/62	Hybrid	2	0.82	113
563	2X4-3G1	3	T12HL/73	Efficient Magnetic	2	0.93	132
564	2X4-3G1	3	T12HL/73	Hybrid	2	0.81	111
565	2X4-3G1	3	T12HL/73	Electronic	2	0.89	108
566	2X4-3G1	3	T12HL/73	Electronic	3	0.89	108
567	2X4-3G1	3	T832/75	Efficient Magnetic	2	0.94	101
568	2X4-3G1	3	T832/75	Electronic	2	0.94	93
569	2X4-3G1	3	T832/75	Electronic	3	0.94	91
570	2X4-3G15	3	T1042/80	Efficient Magnetic	2	0.92	134
571	2X4-3G15	3	T1042/80	Electronic	2	0.88	114
572	2X4-3G15	3	T1042/80	Hybrid	2	0.83	117
573	2X4-3G15	3	T1042/80	Electronic	3	0.88	107
574	2X4-3G15	3	T1234/62	Standard	2	0.87	119
575	2X4-3G15	3	T1234/62	Efficient Magnetic	2	0.87	107
576	2X4-3G15	3	T1234/62	Hybrid	2	0.78	98
577	2X4-3G15	3	T1234/62	Electronic	3	0.88	92
578	2X4-3G15	3	T1234/62	Electronic	2	0.86	92
579	2X4-3G15	3	T1240/62	Standard	2	0.95	143
580	2X4-3G15	3	T1240/62	Efficient Magnetic	2	0.95	128
581	2X4-3G15	3	T1240/62	Electronic	3	0.87	107
582	2X4-3G15	3	T1240/62	Electronic	2	0.91	106
583	2X4-3G15	3	T1240/62	Hybrid	2	0.82	113
584	2X4-3G15	3	T12HL/73	Efficient Magnetic	2	0.93	132
585	2X4-3G15	3	T12HL/73	Hybrid	2	0.81	111
586	2X4-3G15	3	T12HL/73	Electronic	3	0.89	108
587	2X4-3G15	3	T12HL/73	Electronic	2	0.89	108
588	2X4-3G15	3	T832/75	Efficient Magnetic	2	0.94	101
589	2X4-3G15	3	T832/75	Electronic	2	0.94	93
590	2X4-3G15	3	T832/75	Electronic	3	0.94	91
591	2X4-3L	3	T1042/80	Efficient Magnetic	2	0.95	135
592	2X4-3L	3	T1042/80	Hybrid	2	0.84	114
593	2X4-3L	3	T1042/80	Electronic	2	0.86	111
594	2X4-3L	3	T1042/80	Electronic	3	0.85	107
595	2X4-3L	3	T1042/80	Low Wattage Electror	3	0.41	63
596	2X4-3L	3	T1234/62	Standard	2	0.87	119
597	2X4-3L	3	T1234/62	Efficient Magnetic	2	0.87	108
598	2X4-3L	3	T1234/62	Electronic	3	0.87	89
599	2X4-3L	3	T1234/62	Hybrid	2	0.79	87
600	2X4-3L	3	T1234/62	Electronic	2	0.86	90
601	2X4-3L	3	T1240/62	Standard	2	0.95	143
602	2X4-3L	3	T1240/62	Efficient Magnetic	2	0.94	132
603	2X4-3L	3	T1240/62	Electronic	3	0.89	106
604	2X4-3L	3	T1240/62	Hybrid	2	0.83	108
605	2X4-3L	3	T1240/62	Electronic	2	0.90	108
606	2X4-3L	3	T1240/62	Low Wattage Electror	3	0.41	58
607	2X4-3L	3	T12HL/73	Efficient Magnetic	2	0.93	132

608	2X4-3L	3	T12HL/73	Hybrid	2	0.81	111
609	2X4-3L	3	T12HL/73	Electronic	2	0.89	108
610	2X4-3L	3	T12HL/73	Electronic	3	0.89	108
611	2X4-3L	3	T832/75	Efficient Magnetic	2	0.94	108
612	2X4-3L	3	T832/75	Electronic	3	0.89	86
613	2X4-3L	3	T832/75	Electronic	2	0.90	93
614	2X4-3L	3	T832/75	Low Wattage Electror	3	0.82	75
615	2X4-3L	3	T832/75	Low Wattage Electror	2	0.47	54
616	2X4-3P18	3	T1042/80	Efficient Magnetic	2	0.92	134
617	2X4-3P18	3	T1042/80	Hybrid	2	0.83	117
618	2X4-3P18	3	T1042/80	Electronic	2	0.88	114
619	2X4-3P18	3	T1042/80	Electronic	3	0.88	107
620	2X4-3P18	3	T1042/80	Low Wattage Electror	3	0.41	63
621	2X4-3P18	3	T1234/62	Standard	2	0.87	119
622	2X4-3P18	3	T1234/62	Efficient Magnetic	2	0.87	107
623	2X4-3P18	3	T1234/62	Hybrid	2	0.78	98
624	2X4-3P18	3	T1234/62	Electronic	2	0.86	92
625	2X4-3P18	3	T1234/62	Electronic	3	0.88	92
626	2X4-3P18	3	T1240/62	Standard	2	0.95	143
627	2X4-3P18	3	T1240/62	Efficient Magnetic	2	0.95	128
628	2X4-3P18	3	T1240/62	Hybrid	2	0.82	113
629	2X4-3P18	3	T1240/62	Electronic	3	0.87	107
630	2X4-3P18	3	T1240/62	Electronic	2	0.91	106
631	2X4-3P18	3	T1240/62	Low Wattage Electror	3	0.41	58
632	2X4-3P18	3	T12HL/73	Efficient Magnetic	2	0.93	132
633	2X4-3P18	3	T12HL/73	Hybrid	2	0.81	111
634	2X4-3P18	3	T12HL/73	Electronic	2	0.89	108
635	2X4-3P18	3	T12HL/73	Electronic	3	0.89	108
636	2X4-3P18	3	T832/75	Efficient Magnetic	2	0.94	101
637	2X4-3P18	3	T832/75	Electronic	2	0.94	93
638	2X4-3P18	3	T832/75	Electronic	3	0.94	91
639	2X4-3P18	3	T832/75	Low Wattage Electror	3	0.82	75
640	2X4-3P18	3	T832/75	Low Wattage Electror	2	0.47	54
641	2X4-3W	3	T1042/80	Efficient Magnetic	2	0.95	135
642	2X4-3W	3	T1042/80	Hybrid	2	0.84	114
643	2X4-3W	3	T1042/80	Electronic	2	0.86	111
644	2X4-3W	3	T1042/80	Electronic	3	0.85	107
645	2X4-3W	3	T1042/80	Low Wattage Electror	3	0.41	63
646	2X4-3W	3	T1234/62	Standard	2	0.87	119
647	2X4-3W	3	T1234/62	Efficient Magnetic	2	0.87	108
648	2X4-3W	3	T1234/62	Electronic	3	0.87	89
649	2X4-3W	3	T1234/62	Hybrid	2	0.79	87
650	2X4-3W	3	T1234/62	Electronic	2	0.86	90
651	2X4-3W	3	T1240/62	Standard	2	0.95	143
652	2X4-3W	3	T1240/62	Efficient Magnetic	2	0.94	132
653	2X4-3W	3	T1240/62	Electronic	3	0.89	106
654	2X4-3W	3	T1240/62	Electronic	2	0.90	108
655	2X4-3W	3	T1240/62	Hybrid	2	0.83	108
656	2X4-3W	3	T1240/62	Low Wattage Electror	3	0.41	58
657	2X4-3W	3	T12HL/73	Efficient Magnetic	2	0.93	132
658	2X4-3W	3	T12HL/73	Hybrid	2	0.81	111

659	2X4-3W	3	T12HL/73	Electronic	2	0.89	108
660	2X4-3W	3	T12HL/73	Electronic	3	0.89	108
661	2X4-3W	3	T832/75	Efficient Magnetic	2	0.94	108
662	2X4-3W	3	T832/75	Electronic	2	0.90	93
663	2X4-3W	3	T832/75	Electronic	3	0.89	86
664	2X4-3W	3	T832/75	Low Wattage Electror	3	0.82	75
665	2X4-3W	3	T832/75	Low Wattage Electror	2	0.47	54
666	2X4-4G1	4	T1042/80	Efficient Magnetic	2	0.95	180
667	2X4-4G1	4	T1042/80	Hybrid	2	0.84	152
668	2X4-4G1	4	T1042/80	Electronic	4	0.86	148
669	2X4-4G1	4	T1042/80	Electronic	2	0.86	148
670	2X4-4G1	4	T1234/62	Standard	2	0.87	158
671	2X4-4G1	4	T1234/62	Efficient Magnetic	2	0.87	144
672	2X4-4G1	4	T1234/62	Electronic	4	0.82	122
673	2X4-4G1	4	T1234/62	Hybrid	2	0.79	116
674	2X4-4G1	4	T1234/62	Electronic	2	0.86	120
675	2X4-4G1	4	T1240/62	Standard	2	0.95	190
676	2X4-4G1	4	T1240/62	Efficient Magnetic	2	0.94	176
677	2X4-4G1	4	T1240/62	Electronic	4	0.89	142
678	2X4-4G1	4	T1240/62	Electronic	2	0.90	144
679	2X4-4G1	4	T1240/62	Hybrid	2	0.83	144
680	2X4-4G1	4	T12HL/73	Efficient Magnetic	2	0.93	176
681	2X4-4G1	4	T12HL/73	Hybrid	2	0.81	148
682	2X4-4G1	4	T12HL/73	Electronic	2	0.89	144
683	2X4-4G1	4	T12HL/73	Electronic	4	0.89	144
684	2X4-4G1	4	T832/75	Efficient Magnetic	2	0.94	144
685	2X4-4G1	4	T832/75	Electronic	2	0.90	124
686	2X4-4G1	4	T832/75	Electronic	4	0.87	109
687	2X4-4G15	4	T1042/80	Efficient Magnetic	2	0.95	180
688	2X4-4G15	4	T1042/80	Hybrid	2	0.84	152
689	2X4-4G15	4	T1042/80	Electronic	2	0.86	148
690	2X4-4G15	4	T1042/80	Electronic	4	0.86	148
691	2X4-4G15	4	T1234/62	Standard	2	0.87	158
692	2X4-4G15	4	T1234/62	Efficient Magnetic	2	0.87	144
693	2X4-4G15	4	T1234/62	Electronic	4	0.82	122
694	2X4-4G15	4	T1234/62	Hybrid	2	0.79	116
695	2X4-4G15	4	T1234/62	Electronic	2	0.86	120
696	2X4-4G15	4	T1240/62	Standard	2	0.95	190
697	2X4-4G15	4	T1240/62	Efficient Magnetic	2	0.94	176
698	2X4-4G15	4	T1240/62	Electronic	4	0.89	142
699	2X4-4G15	4	T1240/62	Electronic	2	0.90	144
700	2X4-4G15	4	T1240/62	Hybrid	2	0.83	144
701	2X4-4G15	4	T12HL/73	Efficient Magnetic	2	0.93	176
702	2X4-4G15	4	T12HL/73	Hybrid	2	0.81	148
703	2X4-4G15	4	T12HL/73	Electronic	4	0.89	144
704	2X4-4G15	4	T12HL/73	Electronic	2	0.89	144
705	2X4-4G15	4	T832/75	Efficient Magnetic	2	0.94	144
706	2X4-4G15	4	T832/75	Electronic	2	0.90	124
707	2X4-4G15	4	T832/75	Electronic	4	0.87	109
708	2X4-4L	4	T1042/80	Efficient Magnetic	2	0.94	169
709	2X4-4L	4	T1042/80	Electronic	4	0.89	144

710	2X4-4L	4	T1042/80	Electronic	2	0.88	143
711	2X4-4L	4	T1042/80	Hybrid	2	0.78	138
712	2X4-4L	4	T1234/62	Standard	2	0.87	158
713	2X4-4L	4	T1234/62	Efficient Magnetic	2	0.87	138
714	2X4-4L	4	T1234/62	Hybrid	2	0.79	119
715	2X4-4L	4	T1234/62	Electronic	4	0.83	121
716	2X4-4L	4	T1234/62	Electronic	2	0.83	116
717	2X4-4L	4	T1240/62	Standard	2	0.95	190
718	2X4-4L	4	T1240/62	Efficient Magnetic	2	0.95	160
719	2X4-4L	4	T1240/62	Electronic	4	0.89	138
720	2X4-4L	4	T1240/62	Hybrid	2	0.80	137
721	2X4-4L	4	T1240/62	Electronic	2	0.88	132
722	2X4-4L	4	T12HL/73	Efficient Magnetic	2	0.95	160
723	2X4-4L	4	T12HL/73	Electronic	4	0.89	138
724	2X4-4L	4	T12HL/73	Hybrid	2	0.80	137
725	2X4-4L	4	T12HL/73	Electronic	2	0.88	132
726	2X4-4L	4	T832/75	Efficient Magnetic	2	0.94	133
727	2X4-4L	4	T832/75	Electronic	2	0.94	122
728	2X4-4L	4	T832/75	Electronic	4	0.90	105
729	2X4-4L	4	T832/75	Low Wattage Electror	4	0.78	95
730	2X4-4P32	4	T1042/80	Efficient Magnetic	2	0.95	180
731	2X4-4P32	4	T1042/80	Hybrid	2	0.84	152
732	2X4-4P32	4	T1042/80	Electronic	2	0.86	148
733	2X4-4P32	4	T1042/80	Electronic	4	0.86	148
734	2X4-4P32	4	T1234/62	Standard	2	0.87	158
735	2X4-4P32	4	T1234/62	Efficient Magnetic	2	0.87	144
736	2X4-4P32	4	T1234/62	Electronic	4	0.82	122
737	2X4-4P32	4	T1234/62	Hybrid	2	0.79	116
738	2X4-4P32	4	T1234/62	Electronic	2	0.86	120
739	2X4-4P32	4	T1240/62	Standard	2	0.95	190
740	2X4-4P32	4	T1240/62	Efficient Magnetic	2	0.94	176
741	2X4-4P32	4	T1240/62	Electronic	4	0.89	142
742	2X4-4P32	4	T1240/62	Electronic	2	0.90	144
743	2X4-4P32	4	T1240/62	Hybrid	2	0.83	144
744	2X4-4P32	4	T12HL/73	Efficient Magnetic	2	0.93	176
745	2X4-4P32	4	T12HL/73	Hybrid	2	0.81	148
746	2X4-4P32	4	T12HL/73	Electronic	2	0.89	144
747	2X4-4P32	4	T12HL/73	Electronic	4	0.89	144
748	2X4-4P32	4	T832/75	Efficient Magnetic	2	0.94	144
749	2X4-4P32	4	T832/75	Electronic	2	0.90	124
750	2X4-4P32	4	T832/75	Electronic	4	0.87	109
751	2X4-4P32	4	T832/75	Low Wattage Electror	4	0.78	95
752	2X4-4W	4	T1042/80	Efficient Magnetic	2	0.94	169
753	2X4-4W	4	T1042/80	Electronic	4	0.89	144
754	2X4-4W	4	T1042/80	Electronic	2	0.88	143
755	2X4-4W	4	T1042/80	Hybrid	2	0.78	138
756	2X4-4W	4	T1234/62	Standard	2	0.87	158
757	2X4-4W	4	T1234/62	Efficient Magnetic	2	0.87	138
758	2X4-4W	4	T1234/62	Hybrid	2	0.79	119
759	2X4-4W	4	T1234/62	Electronic	4	0.83	121
760	2X4-4W	4	T1234/62	Electronic	2	0.83	116

761	2X4-4W	4	T1240/62	Standard	2	0.95	190
762	2X4-4W	4	T1240/62	Efficient Magnetic	2	0.95	160
763	2X4-4W	4	T1240/62	Electronic	4	0.89	138
764	2X4-4W	4	T1240/62	Hybrid	2	0.80	137
765	2X4-4W	4	T1240/62	Electronic	2	0.88	132
766	2X4-4W	4	T12HL/73	Efficient Magnetic	2	0.95	160
767	2X4-4W	4	T12HL/73	Electronic	4	0.89	138
768	2X4-4W	4	T12HL/73	Hybrid	2	0.80	137
769	2X4-4W	4	T12HL/73	Electronic	2	0.88	132
770	2X4-4W	4	T832/75	Efficient Magnetic	2	0.94	133
771	2X4-4W	4	T832/75	Electronic	2	0.94	122
772	2X4-4W	4	T832/75	Electronic	4	0.90	105
773	2X4-4W	4	T832/75	Low Wattage Electror	4	0.78	95
774	1X8-1S	1	96T1275	Standard	2	0.95	86
775	1X8-1S	1	96T12110	Standard	2	0.95	127
776	1X8-1S	1	96T12215	Standard	2	0.95	215
777	1X8-2S	2	96T1275	Standard	2	0.95	172
778	1X8-2S	2	96T12110	Standard	2	0.95	253
779	1X8-2S	2	96T12215	Standard	2	0.95	430
780	1X8-2I	2	96T1275	Standard	2	0.95	172
781	1X8-2I	2	96T12110	Standard	2	0.95	253
782	1X8-2I	2	96T12215	Standard	2	0.95	430
783	1X8-4I	4	96T1275	Standard	2	0.95	344
784	1X8-2IU	2	96T1275	Standard	2	0.95	172
785	1X8-2IU	2	96T12110	Standard	2	0.95	253
786	1X8-1S	1	96T1275	Electronic	2	0.89	63
787	1X8-1S	1	96T12110	Electronic	2	0.89	101
788	1X8-2S	2	96T1275	Electronic	2	0.86	125
789	1X8-2S	2	96T12110	Electronic	2	0.90	201
790	1X8-1S	1	96T1260	Standard	2	0.89	70
791	1X8-1S	1	96T1295	Standard	2	0.89	111
792	1X8-1S	1	96T12185	Standard	2	0.89	187
793	1X8-1S	1	96T1260	Efficient Magnetic	2	0.89	56
794	1X8-1S	1	96T1295	Efficient Magnetic	2	0.89	104
795	1X8-1S	1	96T12185	Efficient Magnetic	2	0.89	163
796	1X8-1S	1	96T1260	Electronic	2	0.85	50
797	1X8-1S	1	96T1295	Electronic	2	0.85	87
798	1X8-2S	2	96T1260	Standard	2	0.89	140
799	1X8-2S	2	96T1295	Standard	2	0.89	221
800	1X8-2S	2	96T12185	Standard	2	0.89	373
801	1X8-2S	2	96T1260	Efficient Magnetic	2	0.89	111
802	1X8-2S	2	96T1295	Efficient Magnetic	2	0.89	207
803	1X8-2S	2	96T12185	Efficient Magnetic	2	0.89	325
804	1X8-2S	2	96T1260	Electronic	2	0.80	100
805	1X8-2S	2	96T1295	Electronic	2	0.84	173
806	1X8-2I	2	96T1260	Standard	2	0.89	140
807	1X8-2I	2	96T1295	Standard	2	0.89	221
808	1X8-2I	2	96T12185	Standard	2	0.89	373
809	1X8-2I	2	96T1260	Efficient Magnetic	2	0.89	111
810	1X8-2I	2	96T1295	Efficient Magnetic	2	0.89	207
811	1X8-2I	2	96T12185	Efficient Magnetic	2	0.89	325

812	1X8-2I	2	96T1260	Electronic	2	0.80	100
813	1X8-2I	2	96T1295	Electronic	2	0.84	173
814	1X8-2IU	2	96T1260	Standard	2	0.89	140
815	1X8-2IU	2	96T1295	Standard	2	0.89	221
816	1X8-2IU	2	96T12185	Standard	2	0.89	373
817	1X8-2IU	2	96T1260	Efficient Magnetic	2	0.89	111
818	1X8-2IU	2	96T1295	Efficient Magnetic	2	0.89	207
819	1X8-2IU	2	96T12185	Efficient Magnetic	2	0.89	325
820	1X8-2IU	2	96T1260	Electronic	2	0.80	100
821	1X8-2IU	2	96T1295	Electronic	2	0.84	173
822	1X8-4I	4	96T1260	Standard	2	0.89	280
823	1X8-4I	4	96T1295	Standard	2	0.89	442
824	1X8-4I	4	96T12185	Standard	2	0.89	746
825	1X8-4I	4	96T1260	Efficient Magnetic	2	0.89	222
826	1X8-4I	4	96T1295	Efficient Magnetic	2	0.89	414
827	1X8-4I	4	96T12185	Efficient Magnetic	2	0.89	650
828	1X8-4I	4	96T1260	Electronic	2	0.85	200
829	1X8-4I	4	96T1295	Electronic	2	0.85	346
830	1X8-1S	1	96T1275	Efficient Magnetic	2	0.95	68
831	1X8-1S	1	96T12110	Efficient Magnetic	2	0.95	119
832	1X8-1S	1	96T12215	Efficient Magnetic	2	0.95	188
833	1X8-2S	2	96T1275	Efficient Magnetic	2	0.95	136
834	1X8-2S	2	96T12110	Efficient Magnetic	2	0.95	237
835	1X8-2S	2	96T12215	Efficient Magnetic	2	0.95	375
836	1X8-2I	2	96T1275	Efficient Magnetic	2	0.95	136
837	1X8-2I	2	96T12110	Efficient Magnetic	2	0.95	237
838	1X8-2I	2	96T12215	Efficient Magnetic	2	0.95	375
839	1X8-4I	4	96T1275	Efficient Magnetic	2	0.95	272
840	1X8-2IU	2	96T1275	Efficient Magnetic	2	0.95	136
841	1X8-2IU	2	96T12110	Efficient Magnetic	2	0.95	237
842	1X8-2I	2	96T1275	Electronic	2	0.86	125
843	1X8-2I	2	96T12110	Electronic	2	0.90	201
844	1X8-4I	4	96T1275	Electronic	2	0.89	250
845	1X8-2IU	2	96T1275	Electronic	2	0.86	125
846	1X8-2IU	2	96T12110	Electronic	2	0.90	201
847	1X8-1S	1	96T864	Low Wattage Electror	2	0.82	53
848	1X8-1S	1	96T864	Electronic	2	0.90	59
849	1X8-2S	2	96T864	Low Wattage Electror	2	0.82	105
850	1X8-2S	2	96T864	Electronic	2	0.90	118
851	1X8-2I	2	96T864	Low Wattage Electror	2	0.82	105
852	1X8-2I	2	96T864	Electronic	2	0.90	118
853	1X8-2IU	2	96T864	Low Wattage Electror	2	0.82	105
854	1X8-2IU	2	96T864	Electronic	2	0.90	118
855	1X8-4I	4	96T864	Low Wattage Electror	2	0.82	210
856	1X8-4I	4	96T864	Electronic	2	0.90	236
857	OAR	1	400MH	HID	1	1.00	460
858	OAR	1	400MH	HID	1	1.00	460
859	OAR	1	400MH	HID	1	1.00	460
860	OAR	1	400HPS	HID	1	1.00	475
861	OAR	1	400HPS	HID	1	1.00	475
862	OAR	1	400HPS	HID	1	1.00	475

863	OAR	1	250HPS	HID	1	1.00	305
864	OAR	1	250HPS	HID	1	1.00	305
865	OAR	1	250HPS	HID	1	1.00	305
866	OPR	1	400MH	HID	1	1.00	460
867	OPR	1	400HPS	HID	1	1.00	460
868	OPR	1	400HPS	HID	1	1.00	460
869	OPR	1	250HPS	HID	1	1.00	305
870	OPR	1	250HPS	HID	1	1.00	305
871	OPR	1	400MH	HID	1	1.00	460
872	OPR	1	400HPS	HID	1	1.00	460
873	OPR	1	250HPS	HID	1	1.00	305
874	OPR	1	400MH	HID	1	1.00	442
875	EPR	1	250MH	HID	1	1.00	282
876	EPR	1	250MH	HID	1	1.00	282
877	OAR	1	250MV	HID	1	1.00	290
878	OAR	1	400MV	HID	1	1.00	445
879	OAR	1	1000MV	HID	1	1.00	1075
880	OPR	1	1000HPS	HID	1	1.00	1062
881	OPR	1	1000MH	HID	1	1.00	1075
882	EAR	1	250MH	HID	1	1.00	282
883	EAR	1	250MH	HID	1	1.00	282
884	OAR	1	1000HPS	HID	1	1.00	1062
885	OAR	1	1000MH	HID	1	1.00	1075
886	OPR	1	250MV	HID	1	1.00	290
887	OPR	1	400MV	HID	1	1.00	445
888	OPR	1	1000MV	HID	1	1.00	1075
889	Comp. Fl	1	5T4	5W Reactor	1	0.98	9
890	Comp. Fl	1	7T5	7W Reactor	1	0.90	11
891	Comp. Fl	1	9T6	9W Reactor	1	0.81	13
892	Comp. Fl	1	9Q4	9W Reactor	1	0.81	13
893	Comp. Fl	1	10Q5	10/13W Autotrans	1	0.95	16
894	Comp. Fl	1	13Q5	13W Reactor	1	0.98	17
895	Comp. Fl	1	13T7	13W Reactor	1	0.98	17
896	Comp. Fl	1	13Q6	10/13W Autotrans	1	0.95	18
897	Comp. Fl	1	18Q7	18W Autotrans	1	0.95	25
898	Comp. Fl	1	15Q5	16W Reactor	1	0.95	20
899	Comp. Fl	1	20Q6	22W Reactor	1	0.95	27
900	Comp. Fl	1	27Q7	Reactor	1	0.95	34
901	Comp. Fl	1	26Q8	26W Autotrans	1	0.95	37
902	Comp. Fl	1	HPS50	Screw-in	1	1.00	62
903	Incand.	1	25A	None	0	1.00	25
904	Incand.	1	40A	None	0	1.00	40
905	Incand.	1	50A	None	0	1.00	50
906	Incand.	1	60A	None	0	1.00	60
907	Incand.	1	75A	None	0	1.00	75
908	Incand.	1	100A	None	0	1.00	100
909	Incand.	1	150A	None	0	1.00	150
910	Incand.	1	200A	None	0	1.00	200
911	Incand.	1	50R	None	0	1.00	50
912	Incand.	1	75R	None	0	1.00	75
913	Incand.	1	100R	None	0	1.00	100

914	Incand.	1	150R	None	0	1.00	150
915	Incand.	1	200R	None	0	1.00	200
916	Incand.	1	300R	None	0	1.00	300
917	Incand.	1	75PAR	None	0	1.00	75
918	Incand.	1	100PAR	None	0	1.00	100
919	Incand.	1	150PAR	None	0	1.00	150
920	Incand.	1	300PAR	None	0	1.00	300
921	Incand.	1	50ER	None	0	1.00	50
922	Incand.	1	75ER	None	0	1.00	75
923	Incand.	1	120ER	None	0	1.00	120
924	Incand.	1	150PS	None	0	1.00	150
925	Incand.	1	175PS	None	0	1.00	175
926	Incand.	1	189PS	None	0	1.00	189
927	Incand.	1	200PS	None	0	1.00	200
928	Incand.	1	200PAR	None	0	1.00	200
929	Incand.	1	250PAR	None	0	1.00	250
930	Incand.	1	300PS	None	0	1.00	300
931	Incand.	1	500PS	None	0	1.00	500
932	Incand.	1	500PAR	None	0	1.00	500
933	Incand.	1	500R	None	0	1.00	500
934	Incand.	1	750PS	None	0	1.00	750
935	Incand.	1	750R	None	0	1.00	750
936	Incand.	1	1000PS	None	0	1.00	1000
937	Incand.	1	1000R	None	0	1.00	1000
938	Incand.	1	300R	None	0	1.00	300
939	EXIT-Inc.	2	25T6.5	None	0	1.00	50
940	EXIT-Inc.	1	25T6.5	None	0	1.00	25
941	EXIT-Inc.	2	20T6.5	None	0	1.00	40
942	EXIT-Inc.	1	20T6.5	None	0	1.00	20
943	EXIT-Inc.	1	40A	None	0	1.00	40
944	EXIT-Inc.	1	60A	None	0	1.00	60
945	EXIT-CFL	1	9T6	Magnetic	1	0.8	13
946	EXIT-CFL	1	7T5	Magnetic	1	0.8	11
947	EXIT-CFL	1	5T4	Magnetic	1	0.8	9
948	EXIT-CFL	2	9T6	Magnetic	1	0.8	26
949	EXIT-CFL	2	7T5	Magnetic	1	0.8	22
950	EXIT-CFL	2	5T4	Magnetic	1	0.8	18
951	EXIT-Trit.	0	TRIT	None	0	1.00	0
952	EXIT-Inc.	2	10T-long life	None	0	1.00	20
953	EXIT-LED	0	LED	None	0	1.00	7
954	EXIT-Inc.	1	10T-long life	None	0	1.00	10
955	EXIT-EL	0	ELECTROLUM	None	0	1.00	1

A.3 *IRRKALC*

This simple stand-alone program is specifically designed to calculate a project's internal rate of return based on the following input variables:

- project cost
- annual energy cost savings
- maintenance cost savings
- inflation factors
- tax adjustment multiplier

This software can be downloaded from the Green Lights Electronic Bulletin Board (modem: 202-775-6671).

For additional information, please contact the Lighting Services Group at (202) 862-1145 or fax (202) 862-1144.

Appendix B

LIGHTING UPGRADES

This appendix provides brief descriptions of currently available lighting upgrade technologies. For each upgrade listed, technologies are defined, common applications are listed, and any limitations are identified. Many product variations exist within each technology described; for application assistance for specific product types, contact a professional lighting consultant or the Lighting Services Group.

B.1 FLUORESCENT UPGRADES

The following upgrades may be performed on existing 2'x4' fluorescent luminaires. Variations for 2'x2', 1'x4', and 1'x8' troffers may be feasible; contact your local utility representative or lighting professional for further assistance.

1. Delamping

Definition: Delamping is simply the removal of one or more lamps from a fixture.

Applications: To save additional energy and to discourage occupant relamping, disconnect and remove the ballast that operated the removed lamps.

Two approaches to delamping may be used:

- *Uniform delamping* for reducing light levels throughout the space
- *Task-oriented delamping* to place more light directly in the work area and less light in the circulation areas

Relocating lamps so that they are centered on each half of the fixture will improve light output and distribution, and will result in a more acceptable upgrade appearance.

Qualifications: Delamping may be combined with the use of higher output lamps, reflectors, lens upgrades, luminaire cleaning, and task lighting to minimize light output reduction.

In general, light levels are reduced in proportion to the number of lamps removed. However, in enclosed luminaires, delamping will result in a 5-10% increase in efficacy (lumens per watt) due to the cooler operating temperature and reduced lamp shadowing that results. Depending on ambient temperature, delamping an open strip luminaire may either increase or decrease efficacy.

If the remaining lamps are not relocated, the appearance of a delamped fixture may not be acceptable.

The ballast used for operating the removed lamps should be disconnected. In addition, removing the unused sockets will prevent "snap-back" (re-installing lamps where they have been removed).

Delamping may not be feasible in two-lamp fixtures where the removal of one lamp extinguishes the other lamp. In such cases, consider installing partial output (low ballast factor) electronic ballasts.

2. Specular Reflectors with Delamping

Definition: Removal of one or more lamps and installation of a specular "mirror-like" reflector inside the fixture -- mounted behind the lamps -- to improve fixture efficiency by as much as 17%. (Efficiency can be improved by more than 17% if the existing luminaire surface has deteriorated.)

Applications: Typically, the remaining two lamps in a 2'x4' fixture are relocated to positions centered on each side of the fixture for maximum utilization of the reflector. This enhances light output and distribution and will result in a more acceptable luminaire appearance.

The ballast used for operating the removed lamps should be disconnected.

Reflectors may be combined with installation of higher output lamps and/or improved lenses to minimize light output reduction (and in some cases, increase light output).

To maintain light output over time, reflector surfaces should be cleaned at regular intervals.

Qualifications: When using 50% of the original lamps in 2'x4' troffers, average light levels are typically reduced by 30-45% *(assuming comparable conditions of luminaire dirt and lamp age)*. If existing luminaires show some surface deterioration (reduced efficiency that cleaning can't improve), reductions in light output resulting from installing reflectors and delamping will be lessened. To assess the performance of specular reflectors in your facility, set up a trial installation to compare the lighting in a room with clean, delamped luminaires to one with reflectors installed. (See Chapter 5 for specific procedures to follow for conducting a photometric survey using a light meter.)

Even a well-designed reflector may affect light distribution. Potential effects should be assessed carefully using either fixture photometric data (primarily spacing criteria) or a trial installation. (See Chapter 5.) "Imaging" reflector designs -- those that are designed to only make the fixture *appear* to have all four lamps installed -- may reduce both light distribution and output.

If lamps need to be relocated or if the reflector is being used as part of an electrical enclosure, specify only UL-classified reflectors and accessories.

Check the design for accessibility to the ballast compartment.

Differences between manufacturers' reflector designs and materials can cause wide variations in reflector performance. *For independently measured performance data for specific name-brand reflectors, refer to Specifier Reports: Specular Reflectors, Volume 1 Issue 3, National Lighting Product Information Program.*

3. Current Limiters

Definition: Current limiters (also called "power reducers") are retrofit devices for fluorescent fixtures that reduce light output with a nearly corresponding reduction in energy consumption.

Applications: Most current limiters are designed to achieve a pre-set light output reduction -- and energy savings -- of 20, 33, or 50%.

Current limiters enable light-output reductions as an alternative to delamping. They may be preferred to delamping in applications involving 2-lamp luminaires where the removal of one lamp will also extinguish the other lamp.

Current limiters may be installed directly inside the ballast compartment or installed as companion lamp. The use of the companion lamp design is discouraged because it can be easily removed from the luminaire, eliminating future energy savings.

For maximum energy savings and efficiency, consider partial-output electronic ballasts as an alternative.

Qualifications: Current limiters do not improve the inherent efficacy of the lamp/ballast system. However, due to the relationship between operating temperature and fluorescent efficacy, slight increases in efficacy may result with current limiters installed in enclosed fixtures.

Current limiters may not be used with some electronic ballasts.

Most current limiters increase total harmonic distortion in rapid start systems to over 32%, which is considered an unacceptable level by most building engineers and utility companies. In addition, some current limiters can increase the current crest factor to over 1.7 in rapid start systems, which can void some lamp warranties. Check with the manufacturer of your lamps and ballasts to determine if the installation of current limiters will have any effect on their warranties.

For independently measured performance data for specific name-brand current limiters, refer to Specifier Reports: Power Reducers, Volume 1 Issue 2, National Lighting Product Information Program.

4. Electronic Ballasts

Definition: Electronic, high-frequency versions of conventional magnetic "core-and-coil" ballasts.

Applications: In nearly every fluorescent lighting system, electronic ballasts can replace conventional ballasts. They provide about the same amount of light while reducing energy use up to 25%.

Other advantages are reduce weight, less humming noise, virtually no flicker, and the capability to operate up to four lamps at a time.

"Dimmable" ballasts are specifically designed to vary the light output of a fluorescent luminaire based on input from a light sensor, manual dimmer, or occupancy sensor.

Some electronic ballasts are designed to offer both full and partial output ("low-wattage") capability. If partial output ballasts (low ballast factor) are specified in your upgrade, consider requesting that units be manufactured with single-option wiring to simplify installation and prevent installation at the full output setting. Partial output electronic ballasts are lower wattage versions that produce a nearly corresponding reduction in light output. These ballasts should be used for minimizing electricity consumption where reduced illumination is acceptable.

Qualifications: Both magnetic and electronic ballasts may cause electrical disturbances that can interfere with the operation of sensitive electronic equipment. Specify electronic ballasts with input current harmonics that meet the proposed ANSI standard: total harmonic distortion (THD) not to exceed 32% of line current. Note that some utilities will not offer rebates on electronic ballasts unless the THD is at or below 20%. Magnetic ballasts typically cause THD of 12-20%, while some electronic ballasts are available with THD under 5% and others have a measured THD that is well over 40%. The majority of electronic ballasts on the market today produce less than 30% THD.

Not all lamps work with all ballasts. Check with your lighting consultant or supplier about compatibility.

Verify the "ballast factor" of the product you are considering. Lower values will reduce light levels and energy consumption.

Verify input wattage values for your proposed lamp-ballast combination because manufacturers' products will vary in this regard. Lower input wattages will increase energy savings and profitability, but will typically decrease light output.

Performance data for specific name-brand electronic ballasts can be found in Specifier Reports: Power Reducers, Volume 1 Issue 1, National Lighting Product Information Program. The data tables include listings of system input power, ballast factor, ballast efficiency factor, total harmonic distortion, and lamp compatibility.

5. Energy-Efficient Magnetic Ballasts

Definition: These ballasts are premium versions of the older standard magnetic "core-and-coil" ballasts and are now the standard for magnetic ballast production.

Applications: All magnetic ballast applications for full-size fluorescent lamps.

Qualifications: *Other more efficient ballast options exist.*

6. Hybrid Electromagnetic Ballasts (Heater Cutout Ballasts)

Definition: Energy-efficient magnetic ballasts that incorporate electronic components that cut off power to the cathodes (filaments) after the lamps are lit, resulting in an additional 2-watt savings per standard lamp.

Applications: All magnetic ballast applications for 4-foot T-10 or T-12 rapid start fluorescent lamps.

Qualifications: Most hybrid design ballasts provide approximately 8-15% less light output than standard magnetic or electronic ballasts (due to low ballast factor).

Hybrid ballasts should not be used in any dimming applications or with T-12 32-watt heater cutout lamps.

Some heater cutout ballasts will not start T-10 lamps over the full range of primary voltage (ref: California Energy Commission, March 1990)

For maximum efficiency and energy savings, consider installing electronic ballasts as an alternative.

7. 32W Heater Cutout Fluorescent Lamps

Definition: Energy-saving fluorescent lamps that incorporate a pair of thermally-activated switches that open after the lamp has completed its normal rapid-start ignition sequence, resulting in an additional 2-watt savings per lamp.

Applications: F40 lamp applications, subject to the following qualifications.

Qualifications: Heater cutout lamps should be used only on rapid-start circuits and not in fixtures with electronic ballasts, current limiters, or starters.

The thermally-activated switches require a reset time of about one to ten minutes after the lamp is turned off (depending on ambient temperature and enclosure). This may present a limitation when used in frequently-switched areas. In addition, heater cutout lamps should not be used in emergency lighting fixtures.

Heater cutout lamps have a shorter rated life than other F40T12 lamps.

For maximum energy savings and efficiency, consider installing T-8 lamps and electronic ballasts as an alternative.

8. 34W Energy Saver Fluorescent Lamps

Definition: Essentially standard 40-watt fluorescent lamps that are filled with an argon-krypton gas mixture (rather than just argon) that causes the lamp to draw only 34 watts.

Applications: This lamp may be used to replace standard 40-watt lamps in spaces that are currently over-illuminated. The savings of 6 watts per lamp reduces energy use by about 15%.

Qualifications: Although its unit wattage is reduced, its light output is also reduced. When operated on a standard or energy efficient magnetic ballast, it only generates about 81% of the light output of a standard 40-watt lamp-ballast system.

This lamp-ballast system is less energy efficient than the standard argon-gas lamp-ballast system because it generates fewer lumens per watt. This is due to increased ballast losses. In addition, these lamps cannot be dimmed as easily as standard 40-watt F40T12 lamps, and they are more sensitive to temperature.

For maximum energy savings and efficiency, consider installing T-8 lamps with electronic ballasts as an alternative.

9. T-8 Lamp-Ballast Upgrade

Definition: The T-8 lamp-ballast system has the highest efficacy of any fluorescent system -- over 90 lumens per watt when used with an electronic ballast.

Applications: T-8 lamps have the same medium bipin bases of T-12 lamps, allowing them to fit into the same sockets. T-8 lamps operate on a reduced current (265 mA) and, therefore, must be operated using a ballast that is designed for T-8 lamp operation. T-8 lamps are available in 2', 3', 4', 5', and 8' straight tubes, and 2' U-tubes with either the standard 6" leg spacing now available for retrofit, or the 1.625" leg spacing for new applications.

All T-8 lamps use tri-phosphor coatings that improve color rendering performance.

One manufacturer produces a 36W T-8 lamp for 4' luminaires that produces over 30% more lumens than standard 32W T-8 systems when used with a dedicated higher-output electronic ballast. This system may be used to partially offset light reductions associated with delamping strategies, while providing over 90 lumens per watt.

Qualifications: Because converting to T-8 lamps requires new ballasts, the cost of new ballasts should be included in the project cost estimate. Consider installing electronic T-8 ballasts for maximum efficiency.

10. 40W T-10 Lamps

Definition: A high-efficiency, high lumen output (approx. 3600 lumens) F40 fluorescent lamp. Using T-10 lamps instead of standard 40-watt cool-white T-12 lamps will increase light levels by about 17%.

Applications: T-10 lamps may be used with conventional T-12 ballasts.

Because T-10 lamps have a color rendering index of 80 or more, they improve the color rendering quality of the lighting system.

T-10 lamps are currently available as straight four-foot lamps.

T-10 lamps are commonly used for increasing light levels, usually after strategically removing one or more lamps from a multi-lamp fixture and/or installing reflectors.

Qualifications: Some heater cutout ballasts will not start T-10 lamps over the full range of primary voltage (ref: California Energy Commission, March 1990)

11. 40W T-12 High Lumen Lamps

Definition: Standard-size T-12 F40 lamps with a thick tri-phosphor coat that produces 6-8% more light with no increase in energy consumption compared to standard 40-watt lamps.

Applications: High-lumen T-12 lamps should be used where both a modest increase in light output and improved color rendering (CRI 70-80) are desired.

12. Lens/Louver Upgrade

Definition: Clear acrylic lenses and large cell parabolic louvers are efficient fixture shielding materials.

Applications: Fixture efficiency can be significantly improved by replacing opaque diffusers or small-cell louvers with clear acrylic lenses or large-cell parabolic louvers.

To determine impacts on visual comfort, refer to the product's Visual Comfort Probability (VCP) data or perform a trial installation. Visual comfort is improved when light emitted at higher angles is shielded.

Qualifications: Smaller cell parabolic louvers (2" or smaller cells) provide high visual comfort (>0.90) but significantly reduce efficiency.

If sufficient plenum space is available above the ceiling grid, deep-cell parabolic louver upgrades can be retrofit in many kinds of existing fluorescent fixtures. Alternatively, consider installing new deep-cell parabolic louver fixtures.

13. Replace with New Efficient Fixtures

Definition: Removing the existing luminaires and replacing them with new luminaires consisting of high-efficiency components such as T-8 lamps, electronic ballasts, deep-cell parabolic louver, and optional daylight-dimming control. In addition, indirect lighting systems are now available for retrofit applications.

Applications: Conditions that enhance the cost-effectiveness of new fixtures include:

- where multiple luminaire component replacements are considered (new lamps, ballasts, reflectors, lenses, etc.)
- where deep-cell parabolic louvers or indirect lighting systems are desired for combined efficiency and glare control
- where the space will be remodeled or the fixture locations will be changed

Qualifications: Before installing new luminaires, ask a lighting designer to verify the correct number and spacing of the luminaires based on published photometric data and the desired illumination level.

14. Task Lighting with Delamping

Definition: Providing light sources at specific task locations while reducing ambient (overhead) lighting.

Applications: "Task/Ambient" lighting designs are best suited for office environments with significant VDT usage and/or where modular furniture can incorporate task lighting under shelves.

In other cases, desk lamps may be used to provide task illumination.

Qualifications: Energy savings result when the energy saved from delamping exceeds the added energy used for the task lights. In some cases, the use of incandescent task lights may *add* more load than can be eliminated from the ambient lighting system. Compact fluorescent task lights are very efficient sources for task lighting.

Non-adjustable task light strips that are permanently mounted under cabinet shelves can cause reflected glare on work surfaces. To reduce reflected glare, specify compact fluorescent task lights that allow users to position the light to the side of the task.

15. Group Relamping and Cleaning with Delamping

Definition: Relamping and cleaning light fixtures according to a schedule determined by lamp life, lumen depreciation characteristics, and ambient dirt conditions. Refer to Chapter 9 for a complete discussion of group relamping and cleaning.

Application: Periodic group relamping and cleaning will significantly improve luminaire efficiency and reduce maintenance costs. The resulting increased light output from properly maintained luminaires may justify delamping, use of partial output electronic ballasts, or relamping with fewer higher-output lamps.

B.2 INCANDESCENT UPGRADES

Wherever feasible, alternatives to the use of incandescent lamps should be pursued. With recent advances in compact fluorescent and halogen lamps, the continued use of standard incandescent lamps is difficult to justify.

1. Compact Fluorescent Lamps

Definition: Compact fluorescent lamps are an energy-efficient, long-lasting substitute for the incandescent lamp. They are available in "twin-tube" and "quad tube" configurations (that require a separate ballast attachment) or self-ballasted units. Several retrofit adapters are available for convenient retrofit in existing incandescent sockets.

Applications: Compact fluorescents may be used in a variety applications including downlights, surface lights, pendant fixtures, task lights, compact troffers, sconces, exit lights, step lights, and flood lights. Although some compact fluorescent packages are too bulky to fit in some standard table lamps, plug-in (wall outlet) ballasts are now available that enable the use of screw-in compact fluorescent lamps to be used in table lamps without a ballast attachment.

Qualifications: Compact fluorescents may not be suitable in high ceiling applications (greater than 12') or where tight control of beam spread is necessary.

Where dimming is important, compact fluorescents may not be appropriate for lighting retrofits. Some dimming compact fluorescents are available, but a new fixture is usually required.

Some compact fluorescent lamps have difficulty starting when with ambient temperature drops below 40°F, while others are designed to start at temperatures below freezing. Refer to manufacturer specifications.

The light output of compact fluorescent lamps is significantly reduced when used in fixtures that trap heat near the lamp or when exposed to cold temperatures. In addition, the *orientation* of the lamp can also significantly affect lumen output. Trial installations are recommended before purchasing large quantities.

Most lamps operating on magnetic ballasts require one to three seconds to start and rise to full output. Where instantaneous lighting is required, select T-5 rapid start systems or use electronic ballasts.

A *Specifier Report* that compares the performance of various name-brand compact fluorescent lamps is now available.

2. Compact Halogen Lamps

Definition: Tungsten-halogen incandescent lamps that are adapted for use as direct replacements for standard incandescent lamps. Halogen lamps are more efficient, produce a whiter light, and last longer than conventional incandescent lamps.

Traditional tungsten halogen lamps are manufactured as a double-ended tube. Compact halogen lamps consist of a small tungsten-halogen capsule lamp within a standard lamp shape similar to PAR lamps or general service A-type lamps.

Applications: The best applications are in accent lighting and retail display lighting, especially where tight control of beam spread is necessary. Other good applications include downlighting and "instant on" power floodlighting. The use of an optional infrared (IR) coating applied to the halogen capsule or specially designed reflectors can further increase the efficacy of this light source in PAR lamp applications.

Compact halogen lamps may be used in full-range dimming applications, but dimming below 35% of full light output may affect lamp life.

Qualifications: Lamps with optional diodes (for improving lamp optics) can flicker and have adverse effects on dimming and power quality.

Due to their lower efficacy, compact halogen lamps should not be used in applications where compact fluorescent lamps would serve satisfactorily.

3. Exit Sign Upgrades

Definition: The use of high-efficiency light sources in existing or replacement exit signs. The light source may be one of the following:

- Compact fluorescent lamps (retrofit or new signs)
- Tritium or Self-Luminous (new signs)
- Light Emitting Diode (L.E.D.) (new signs)
- Electroluminescent (E.L.) (new signs; retrofit panels to be introduced later in 1993)

Applications: All emergency exit signs should illuminate 24 hours per day and be able to continue operation in the event of a power failure. Significant energy savings can be achieved by simply replacing or upgrading the exit signs with a low-energy model.

Qualifications: Check with local building codes for accepted emergency exit sign illuminance options.

4. Compact H.I.D. Sources

Definition: New manufacturing methods have produced low-wattage (<100-watt) versions of metal halide and high pressure sodium lamps.

Applications: Primarily intended for new construction or remodeling applications, compact HID lamps are point sources which lend themselves to projection and floodlight applications as well as general illumination.

Qualifications: All metal halide lamps are susceptible to lamp-to-lamp color differences and color shift over life.

Compact "white" high pressure sodium lamps offer improved color rendering compared to standard HPS lamps, but after their "color life," the color quality becomes similar to standard HPS lamps.

All HID lamps require warm-up and restrike periods, so frequent switching installations should not utilize these lamps.

B.3 H.I.D. UPGRADES

The primary method for improving the efficiency of HID systems is to replace the light source with a more efficacious system. Other energy saving techniques that apply to fluorescent upgrades are also applicable to HID systems: Delamping, central panel dimming, low-wattage lamps and ballasts, group relamping/cleaning, painting room surfaces with higher reflectivity paint, and task lighting.

Conversion to High-Efficiency H.I.D. System

Definition: Replacement or retrofit of existing high-bay or outdoor lighting system with metal halide (MH), high pressure sodium (HPS), or low pressure sodium (LPS) lamps. Refer to Appendix D for a complete discussion of these lamps and their characteristics.

Applications: The most cost-effective upgrades involve replacing less efficient sources such as incandescent, HO/VHO fluorescent, or mercury vapor with MH, HPS, or LPS. This may involve a one-for-one luminaire replacement or a new layout of luminaires to take advantage of the different light distribution characteristics of HID fixtures.

Qualifications: The selection of the HID luminaire should be based on the following criteria that pertain to the task:

color rendering quality
efficiency
lamp life
lumen maintenance
light distribution

Refer to Appendix D for a complete discussion of these characteristics.

B.4 CONTROLS UPGRADES

These upgrades are designed to help eliminate unnecessary use of lighting. They limit the hours or intensity of lighting system operation based on occupancy, time, or ambient light levels.

1. Occupancy Sensors

Definition: A device that detects occupancy of a room. It activates a control device that turns on the light fixtures. If no motion is detected within a specified period of time, the lights are turned off until motion is sensed again.

Applications: *Occupancy sensors are suitable for a very wide range of lighting control applications and should be considered in every upgrade decision.*

Occupancy sensors are available in ceiling-mounted versions (that require a separate switching device) or wall-mounted versions (that can replace existing wall switches).

Common applications for wall-mounted sensors include separately switched areas such as conference rooms, classrooms, individual offices, and storage rooms. Ceiling-mounted sensors should be used in areas where wall-mounted switches would be inadequate, such as open office areas and spaces where objects obstruct the coverage of a wall-mounted sensor.

Qualifications: The specification and placement of occupancy sensors should be performed by an experienced professional to ensure adequate occupancy sensing coverage. A properly designed and installed system should not disrupt normal business activity.

Occupancy sensor systems must be "tuned" after installation. This involves adjusting sensitivity and time delay settings as appropriate for the space. Most suppliers of occupancy sensors offer this post-installation service.

Occupancy sensors are not vandal-proof and are not recommended in areas prone to vandalism.

Before installing occupancy sensors in a system with heater cutout lamps or HID lamps, consider the potential annoyance of restrike delays.

For HID systems, consider installing capacitive switching luminaires that are designed to be controlled by occupancy sensors. Upon sensing motion, the occupancy sensor will send a signal to the bi-level HID system that will instantly bring the light levels from a standby reduced level to 80% of full output, followed by the normal warmup time between 80% and 100% of full light output. Depending on the lamp type and wattage, the standby lumens are roughly 15-40% of full output and the input watts are 30-60% of full wattage. Therefore, during periods that the space is unoccupied and the system is dimmed, savings of 40-70% are achieved.

For independently measured performance data for specific name-brand occupancy sensors, refer to Specifier Reports: Occupancy Sensors, Volume 1 Issue 5, National Lighting Product Information Program.

2. Scheduling Controls

Definition: Scheduling controls can be installed to ensure that lighting systems are turned off or dimmed according to an established schedule. These devices range from simple time switches to programmable "sweep" systems.

Applications: Time switches are used to control lighting systems with predictable operation periods, such as outdoor signs, security lighting, and corridors.

Programmable time switches are devices that can be programmed for facilities having different daily operating schedules, such as different weekend/weekday schedules.

Sweep systems establish a programmed schedule for sequentially turning off lights throughout a floor or an entire building. A typical application is found in office buildings, where the systems ensure that lighting is not unnecessarily left on by the occupants. An important feature provides warning to occupants that allows them to override the sweep for their workspace.

Qualifications: Unlike occupancy sensors, scheduling controls do not have the flexibility to eliminate wasted energy consumption during normal business hours.

24-hour emergency lighting should be provided in areas with scheduling controls to provide safe access to lighting control override switches.

3. Photocell Controls

Definition: Photocells are devices used to sense light. Based upon the level of light, the photocell will open or close a relay or automatically adjust a dimmer setting. Many fluorescent dimming applications utilize a photocell that sends a signal to one or more dimmable electronic ballasts via a low-voltage circuit.

Applications: Photocells can be useful for control of lighting systems based upon the quantity of daylight available in window areas; this is known as *daylight-dimming or switching*. Photocells can also be used for adjusting fixture light output to compensate for aging lamps and accumulated dirt on luminaires; this is known as *lumen maintenance control*.

Because dimming (low-voltage) circuits are usually separate from existing power circuits, users have great flexibility in determining which fixtures will be controlled by the photocell.

Light levels should be maintained in accordance with standards established by the Illuminating Engineering Society of North America. (Refer to Appendix D.)

Qualifications: Lumen maintenance controls (in interior spaces) save energy when accompanied by a good lighting maintenance program that includes group relamping and cleaning.

4. Tuning

Definition: Using manual dimming controls, the light output from individual fixtures or groups of fixtures to match the area's visual requirements.

Applications: The most common application of tuning is in spaces where the visual task changes frequently. (For example bookkeeping and VDT usage.) Other applications include adjusting light level for various occupants of a space based on age and visual task requirements -- such as in a conference room.

Tuning can be accomplished by manually adjusting the potentiometer on a dimmable electronic ballast, or by installing an appropriate manual dimmer control at the switch location.

Qualifications: Compact fluorescents and full-size fluorescents operating on magnetic ballasts require specialized dimming controls.

5. Panel-Level Dimming

Definition: This strategy involves installing a control system at the electric panel to uniformly control all light fixtures on the designated circuits.

Applications: Circuit dimming can be controlled by inputs from occupancy sensors, photocells, timeclocks, energy management systems, and manual adjustments.

Panel-level dimming is a method for dimming HID systems.

Slight improvements in efficiency result from the dimming of fluorescent systems while slight reductions in efficiency result from the dimming of HID systems.

Qualifications: Some panel-level dimming systems are incompatible with electronic ballasts.

Appendix C

GLOSSARY

AMPERE: The standard unit of measurement for electric current that is equal to one coulomb per second. It defines the quantity of electrons moving past a given point in a circuit over a period of time. Amp is an abbreviation.

ARC TUBE: A tube enclosed within the outer glass envelope of a HID lamp and made of clear quartz or ceramic that contains the arc stream.

BALLAST: A device used to operate fluorescent and HID lamps. The ballast provides the necessary starting voltage, while limiting and regulating the lamp current during operation.

BALLAST CYCLING: Undesirable condition whereby the ballast turns lamps on and off (cycles) due to the overheating of the thermal switch inside the ballast. This may be due to incorrect lamps, improper voltage being supplied, high ambient temperature around the fixture, or the early stage of ballast failure.

BALLAST EFFICIENCY FACTOR: The Ballast Efficiency Factor (BEF) is the Ballast Factor (see below) divided by the input power of the ballast. The higher the BEF -- *within the same lamp-ballast type* -- the more efficient the ballast.

BALLAST FACTOR: The Ballast Factor (BF) for a specific lamp-ballast combination represents the percentage of the rated lamp lumens that will actually be produced by the combination.

CANDELA: Unit of luminous intensity, describing the intensity of a light source in a specific direction.

CANDELA DISTRIBUTION: A curve, often on polar coordinates, illustrating the variation of luminous intensity of a lamp or luminaire in a plane through the light center.

CANDLEPOWER: A measure of luminous intensity of a light source in a specific direction, measured in candelas (see above).

COEFFICIENT OF UTILIZATION: The ratio of lumens from a luminaire received on the work plane to the lumens produced by the lamps alone. (Also called "CU")

COLOR RENDERING INDEX (CRI): A scale for the effect of a light source on the color appearance of an object in comparison with the color appearance under a reference light source. Expressed in a scale from 1 to 100, where 100 is no color shift. In general, a low CRI rating indicates that the colors of objects will appear unnatural under that particular light source.

COLOR TEMPERATURE: The color temperature is a specification of the color appearance of a light source, relating the color to a reference source that is heated to a particular temperature, measured by the thermal unit Kelvin. The measurement can also be described as the "warmth" or "coolness" of a light source. Generally, sources below 3200K are considered "warm;" while those above 4000K are considered "cool" sources.

COMPACT FLUORESCENT: A small fluorescent lamp that is often used as an alternative to incandescent lighting. The lamp life is about 10 times longer than incandescent lamps and is 3-4 times more efficacious. Also referred to as PL, Twin-Tube, CFL, or BIAX lamps.

CONSTANT WATTAGE (CW) BALLAST: A premium type of HID ballast in which the primary and secondary coils are isolated. Considered a high performance, high loss ballast featuring excellent output regulation.

CONSTANT WATTAGE AUTOTRANSFORMER (CWA) BALLAST: A popular type of HID ballast in which the primary and secondary coils are electrically connected. Considered an appropriate balance between cost and performance.

CONTRAST: The relationship between the luminance of an object and its background.

CRI: (SEE COLOR RENDERING INDEX)

CUT-OFF ANGLE: The angle from a fixture's vertical axis at which a reflector, louver, or other shielding device cuts off direct visibility of a lamp. It is the complementary angle of the shielding angle.

DAYLIGHT COMPENSATION: A dimming system controlled by a photocell that reduces the output of the lamps when daylight is present. As daylight levels increase, lamp intensity decreases. An energy-saving technique used in areas with significant daylight contribution.

DIFFUSE: Term describing dispersed light distribution. Refers to the scattering or softening of light.

DIFFUSER: A translucent piece of glass or plastic sheet that shields the light source in a fixture. The light transmitted throughout the diffuser will be redirected and scattered.

DIRECT GLARE: Glare that is produced by a direct view of light sources. Often the result of insufficiently shielded light sources. (See GLARE)

DOWNLIGHT: A type of ceiling luminaire, usually fully recessed, where most of the light is directed downward. May feature an open reflector and/or shielding device.

EFFICACY: A metric used to compare light output to energy consumption. Efficacy is measured in lumens per watt. Efficacy is similar to efficiency, but is expressed in dissimilar units. For example, if a 100 watt source produces 9000 lumens, then the efficacy is 90 lumens per watt.

ELECTRO-LUMINESCENT: A light source technology used in exit signs that provides uniform brightness, long lamp life (approximately eight years), while consuming very little energy (less than one watt per lamp).

ELECTRONIC BALLAST: A ballast that uses semi-conductor components to increase the frequency of fluorescent lamp operation -- typically in the 20-40 kHz range. Smaller inductive components are used to provide the lamp current control. Fluorescent system efficiency is increased due to high frequency lamp operation.

ELECTRONIC DIMMING BALLAST: A variable output electronic fluorescent ballast.

EMI: Abbreviation for Electromagnetic Interference. High frequency interference (electrical noise) caused by electronic components or fluorescent lamps that interferes with the operation of electrical equipment. EMI is measured in micro-volts, and can be controlled by filters. Because EMI can interfere with communication devices, the Federal Communication Commission (FCC) has established limits for EMI.

ENERGY-SAVING BALLAST: A type of magnetic ballast designed so that the components operate more efficiently, cooler and longer than a "standard magnetic" ballast. By U.S. law, standard magnetic ballasts can no longer be manufactured.

ENERGY-SAVING LAMP: A lower wattage lamp - generally producing fewer lumens.

FC: See FOOTCANDLE)

FLUORESCENT LAMP: A light source consisting of a tube filled with argon, along with krypton or other inert gas. When electrical current is applied, the resulting arc emits ultraviolet radiation that excites the phosphors on the inside of the lamp wall, causing them to radiate visible light.

FOOTCANDLE (FC): The English unit of measurement of the illuminance (or light level) on a surface. One footcandle is equal to one lumen per square foot.

GLARE: The effect of brightness or differences in brightness within the visual field sufficiently high to cause annoyance, discomfort or loss of visual performance.

HALOGEN: (See TUNGSTEN HALOGEN LAMP)

HARMONIC DISTORTION: A harmonic is a sinusoidal component of a periodic wave having a frequency that is a multiple of the fundamental frequency. Harmonic distortion from lighting equipment can interfere with other appliances, as well as the operation of electric power networks. The total harmonic distortion (THD) is usually expressed in a percentage of the fundamental line current. THD for 4-foot fluorescent ballasts usually range from 20% to 40%. For compact fluorescent ballasts, THD levels greater than 50% are not uncommon.

HID: Abbreviation for High Intensity Discharge. Generic term used to describe mercury vapor, metal halide, high pressure sodium, and (informally) low pressure sodium light sources and luminaires.

HIGH-BAY: Pertains to the type of lighting in an industrial application where the ceiling is 20 feet or higher. Also describes the application itself.

HIGH OUTPUT (HO): A lamp or ballast designed to operate at higher currents (800 mA) and produce more light.

HIGH POWER FACTOR: A ballast with a .9 or higher rated power factor, which is achieved by using a capacitor.

HIGH PRESSURE SODIUM LAMP: A high intensity discharge (HID) lamp whose light is produced by radiation from sodium vapor (and mercury).

HOT RESTART or HOT RESTRIKE: The phenomenon of re-striking the arc in an HID light source after a momentary power loss. Hot restart occurs when the arc tube has cooled a sufficient amount.

IESNA: Abbreviation for Illuminating Engineering Society of North America.

ILLUMINANCE: A photometric term that quantifies light incident on a surface or plane. Illuminance is commonly referred to as *light level*. It is expressed as lumens per square foot (footcandles), or lumens per square meter (lux).

INDIRECT GLARE: Glare that is produced from a reflective surface.

INSTANT START: A fluorescent circuit that ignites the lamp instantly with a very high starting voltage from the ballast. Instant start lamps have single-pin bases.

LAMP LUMEN DEPRECIATION FACTOR (LLD): A factor that represents the reduction of lumen output over time. The factor is commonly used as a multiplier to the initial lumen rating in illuminance calculations, which compensates for the lumen depreciation. The LLD factor is a dimensionless value between 0 and 1.

LAY-IN-TROFFER: A fluorescent fixture; usually a 2' x 4' fixture that sets or "lays" into a specific ceiling grid.

LENS: Transparent or translucent medium that alters the directional characteristics of light passing through it. Usually made of glass or acrylic.

LOUVER: Grid type of optical assembly used to control light distribution from a fixture. Can range from small-cell plastic to the large-cell anodized aluminum louvers used in parabolic fluorescent fixtures.

LOW POWER FACTOR: Essentially, an uncorrected ballast power factor of less than .90 (SEE NPF)

LOW-PRESSURE SODIUM: A low-pressure discharge lamp in which light is produced by radiation from sodium vapor. Considered a monochromatic light source (most colors are rendered as gray).

LOW VOLTAGE LAMP: A lamp - typically compact halogen - that provides both intensity and good color rendition. Lamp operates at 12V and requires the use of a transformer. Popular lamps are MR11, MR16, and PAR36.

LOW-VOLTAGE SWITCH: A relay (magnetically-operated switch) that permits local and remote control of lights, including centralized time clock or computer control.

LUMEN: A unit of light flow, or luminous flux. The lumen rating of a lamp is a measure of the total light output of the lamp.

LUMINAIRE: A complete lighting unit consisting of a lamp or lamps, along with the parts designed to distribute the light, hold the lamps, and connect the lamps to a power source. Also called a fixture.

LUMINAIRE EFFICIENCY: The ratio of total lumen output of a luminaire and the lumen output of the lamps, expressed as a percentage. For example, if two luminaires use the same lamps, more light will be emitted from the fixture with the higher efficiency.

LUMINANCE: A photometric term that quantifies brightness of a light source or of a surface that is illuminated and reflects light. It is expressed as footlamberts (English units) or candelas per square meter (Metric units).

LUX (LX): The metric unit of measure for illuminance of a surface. One lux is equal to one lumen per square meter. One lux equals .093 footcandles.

MERCURY VAPOR LAMP: A type of high intensity discharge (HID) lamp in which the major portion of the light is produced by radiation from mercury vapor. Emits a blue-green cast of light. Available in clear and phosphor-coated lamps.

METAL HALIDE: A type of high intensity discharge (HID) lamp in which the major portion of the light is produced by radiation of metal halide and mercury vapors in the arc tube. Available in clear and phosphor-coated lamps.

MR-16: A low-voltage quartz reflector lamp, only 2" in diameter. Typically the lamp and reflector are one unit, which directs a sharp, precise beam of light.

NADIR: A reference direction directly below a luminaire, or "straight down" (0 degree angle).

NPF (NORMAL POWER FACTOR): A ballast/lamp combination in which no components (e.g. capacitors) have been added to correct the power factor, hence normal (essentially low) power factor (typically .5 or 50%).

OCCUPANCY SENSOR: Control device that turns lights off after the space becomes unoccupied. May be ultrasonic, infrared or other type.

OPTICS: A term referring to the components of a light fixture (such as reflectors, refractors, lenses, louvers, etc.) or to the light emitting or light-controlling performance of a fixture.

PAR LAMP: A Parabolic Aluminized Reflector lamp. An incandescent, metal halide, or compact fluorescent lamp used to redirect light from the source using a parabolic reflector. Lamps are available with flood or spot distributions.

PAR 36: A PAR lamp that is 36 one-eighths of an inch in diameter with a parabolic shaped reflector (SEE PAR LAMP).

PARABOLIC LUMINAIRE: A popular type of fluorescent fixture which has a louver composed of aluminum baffles that are curved in a parabolic shape. The resultant light distribution produced by this shape provides reduced glare, better light control, and is considered to have greater aesthetic appeal.

PARACUBE: A metallic coated plastic louver made up of small squares. Often used to replace the lens in an installed troffer to enhance its appearance. The paracube is visually comfortable, but the luminaire efficiency is lowered. Also used in rooms with computer screens because of their glare-reducing qualities.

PHOTOCELL: A light sensing device used to control luminaires and dimmers in response to detected light levels.

PHOTOMETRIC REPORT: A photometric report is a set of printed data describing the light distribution, efficiency, and zonal lumen output of a luminaire. This report is generated from laboratory testing.

POWER FACTOR: The ratio of A.C. volts x amps through a device to A.C. wattage of the device. A device such as a ballast that measures 120 volts, 1 amp, and 60 watts has a power factor of 50%. (volts x amps = 120 VA, therefore 60 watts / 120 VA = .5) Some utilities charge customers for low power factor systems.

PREHEAT: A type of ballast/lamp circuit that uses a separate starter to heat up a fluorescent lamp before high voltage is applied to start the lamp.

QUAD-TUBE LAMP: A compact fluorescent lamp with a double twin tube configuration.

RADIO FREQUENCY INTERFERENCE (RFI): Interference to the radio frequency band caused by other high frequency equipment or devices in the immediate area. Fluorescent lighting systems generate RFI.

RAPID START (RS): The most popular fluorescent lamp/ballast combination used today. This ballast is designed to quickly and efficiently preheat lamp cathodes to start the lamp. Uses a "bi-pin" base.

ROOM CAVITY RATIO: Room Cavity Ratio (RCR) is a ratio of room dimensions used to quantify how light will interact with room surfaces. A factor used in illuminance calculations.

REFLECTANCE: The ratio of light reflected from a surface to the light incident on the surface. Reflectances are often used for lighting calculations. The reflectance of a dark carpet is around 20%, and a clean white wall is roughly 50% to 60%.

REFLECTOR: The part of a light fixture that shrouds the lamps and redirects some of the light emitted from the lamp.

REFRACTOR: A device used to redirect the light output from a source, primarily by bending the waves of light.

RECESSED: The term used to describe the doorframe of a troffer where the lens or louver lies above the surface of the ceiling.

REGULATION: The ability of a ballast to hold constant (or nearly constant) the output watts (light output) during fluctuations in the voltage feeding of the ballast. Normally specified as +/- percent change in output compared to +/- percent change in input.

RELAY: A device that performs the actual on or off switching of an electrical load due to small changes in current or voltages. Examples: low voltage relay and solid state relay.

RETROFIT: Refers to upgrading a fixture, room, building, etc., by installing new parts or equipment.

SEMI-SPECULAR: Term describing the light reflection characteristics of a material. Some of the light is reflected directionally, with some amount of scatter.

SHIELDING ANGLE: The angle measured from the ceiling plane to the line of sight where the bare lamp in a luminaire becomes visible. Higher shielding angles reduce direct glare. It is the complementary angle of the cutoff angle. (See CUTOFF ANGLE).

SPACING CRITERION: A maximum distance that interior fixtures may be spaced that ensures uniform illumination on the work plane. The height above the work multiplied by the spacing criterion equals the center-to-center luminaire spacing.

SPECULAR: Mirrored or polished surface. The angle of reflection is equal to the angle of incidence. This word is used to describe the finish of the material used in some louvers and reflectors.

STROBOSCOPIC EFFECT: Condition where rotating machinery or other rapidly moving objects appear to be standing still due to the alternating current supplied to light sources. Sometimes called "strobe effect."

T12 LAMP: Industry standard for a fluorescent lamp that is 12 one-eighths (1½ inches) in diameter. Other sizes are T10 (1¼ inches) and T8 (1 inch) lamps.

TANDEM WIRING: A wiring option in which a ballasts is shared by two or more luminaires. This reduces labor, materials, and energy costs. Also called "master-slave" wiring.

THERMAL FACTOR: A factor used in lighting calculations that compensates for the change in light output of a fluorescent lamp due to a change in bulb wall temperature. It is applied when the lamp-ballast combination under consideration is different from that used in the photometric tests.

TRIGGER START: Type of ballast commonly used with 15-watt and 20-watt straight fluorescent lamps.

TROFFER: The term used to refer to a recessed fluorescent light fixture (combination of trough and coffer).

TUNGSTEN HALOGEN LAMP: A gas-filled tungsten filament incandescent lamp with a lamp envelope made of quartz to withstand the high temperature. This lamp contains a certain proportion of halogens, namely iodine, chlorine, bromine, and fluorine that slows down the evaporation of the tungsten. Also commonly referred to as a quartz lamp.

TWIN-TUBE: (See COMPACT FLUORESCENT LAMP)

ULTRA VIOLET (UV): Invisible radiation that is shorter in wavelength and higher in frequency than visible violet light (literally beyond the violet light).

UNDERWRITERS' LABORATORIES (UL): An independent organization whose responsibilities include rigorous testing of electrical products. When products pass these tests, they can be labeled (and advertised) as "UL listed." UL tests for product safety only.

VANDAL-RESISTANT: Fixtures with rugged housings, break-resistant type shielding and tamperproof screws.

VCP: Abbreviation for Visual Comfort Probability. A rating system for evaluating direct discomfort glare. This method is a subjective evaluation of visual comfort expressed as the percent of occupants of a space who will be bothered by direct glare. VCP takes into account luminaire luminances at different angles of view, luminaire size, room size, luminaire mounting height, illuminance, and room surface reflectivity. VCP tables are often provided as part of photometric reports.

VERY HIGH OUTPUT (VHO): A fluorescent lamp that operates at a "very high" current (1500 mA), producing more light output than a "high output" lamp (800 mA) or standard output lamp (430 mA).

VOLT: The standard unit of measurement for electrical potential. It defines the "force" or "pressure" of electricity.

VOLTAGE: The difference in electrical potential between two points of an electrical circuit.

WALLWASHER: Term used to describe the luminaires designed to illuminate vertical surfaces.

WATT (W): The unit for measuring electrical power. It defines the rate of energy consumption by an electrical device when it is in operation. The energy cost of operating an electrical device is determined by its wattage times the hours of use. In single phase circuits, it is related to volts and amps by the formula: Volts x Amps x P.F. = Watts. (Note: For A.C. circuits, P.F. must be included.)

WORK PLANE: The level at which work is done and at which illuminance is specified and measured. For office applications, this is typically a horizontal plane 30 inches above the floor (desk height).

ZENITH: The direction directly above the luminaire (180 degree angle).

Appendix D

LIGHTING FUNDAMENTALS

A basic understanding of lighting fundamentals is essential for specifiers and decision-makers who are evaluating lighting upgrades. This section provides an overview of design parameters, technologies, and terminology used in the lighting industry.

The function of a lighting system is to provide sufficient illumination in a space that will enable the occupants to successfully complete their tasks. Although lighting can be costly, the quality and quantity of illumination can dramatically affect occupant productivity, comfort, and safety. Proper attention to the quality and quantity of illumination can also enhance the appearance of a space.

D.1 ILLUMINATION

There are several measures of illumination that are used in the design of both new and retrofit lighting projects:

Quantity Measures

Common Term	Technical Term	Units
light output	luminous flux	lumens (lm)
light level	illuminance	footcandles (fc)
brightness	luminance	footlamberts (fL)

Quality Measures

Attribute	Design Parameter
glare	visual comfort probability (VCP)
uniformity	spacing criteria (SC)
color rendition	color rendering index (CRI)

These terms are described in more detail in the sections that follow.

Quantity of Illumination

The diagram at right shows the interaction between light output, light level, and brightness. Although they are quantitative measures, they directly affect the quality of illumination.

Light Output

The most common measure of light output (or luminous flux) is the **lumen.** Light sources are usually given an output rating in lumens. For example, a T-12 40-watt fluorescent lamp may have a rating of 3050 lumens. Similarly, a light fixture's output can be expressed in lumens. As lamps and fixtures age and become dirty, their lumen output decreases -- this phenomenon is referred to as lumen depreciation. Most lamp ratings are based on *initial* lumens (i.e., when the lamp is new).

Light Level

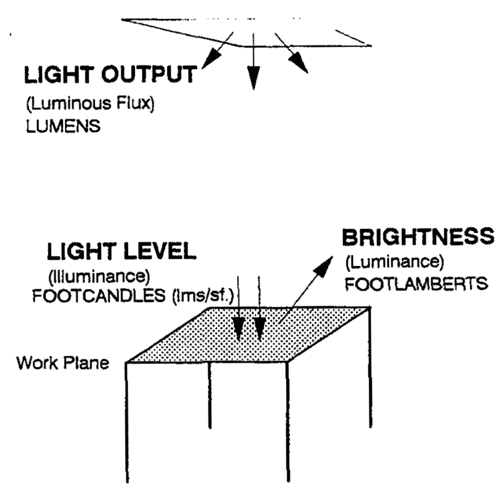
Light intensity measured on a plane at a specific location is called **illuminance.** Illuminance is measured in **footcandles** which are defined as *workplane lumens per square foot.* Illuminance may be measured using a light meter located on the work surface where tasks are being performed. Using simple arithmetic and manufacturers' photometric data, illuminance may be predicted for a defined space. (*Lux* is the metric unit for illuminance, measured in lumens per square meter. To convert footcandles to lux, multiply footcandles by 10.76.)

Brightness

Another measurement of light is **luminance** -- sometimes referred to as brightness. This is light "leaving" a surface, which takes into account the illuminance on the surface and the reflectance of the surface.

The human eye does not actually see illuminance, it sees luminance. Therefore, the ability to see is affected by both the amount of light delivered into the space and the reflectance of the surfaces in the space.

Refer to the glossary in Appendix C for more detailed definitions.



Determining Adequate Light Levels

The Illuminating Engineering Society of North America has developed a procedure for determining the appropriate average light level for a particular space. This procedure -- used extensively by designers and engineers -- recommends a target light level by considering the following:

- the task(s) being performed (contrast, size, etc.)
- the ages of the occupants
- the importance of speed and accuracy

Then, the appropriate type and quantity of lamps and light fixtures may be selected based on the following:

- fixture efficiency
- lamp lumen output
- the reflectances of surrounding surfaces
- the effects of light losses from lamp lumen depreciation, dirt accumulation, and ballast efficiency
- room size and shape
- availability of natural light (daylight)

When designing a new or upgraded lighting system, one must be careful to *avoid overlighting a space.* In the past, spaces were designed for as much as 200 footcandles in places where 50 footcandles may not only be adequate, but superior. This was partly due to the misconception that the more light in a space, the higher the quality. Not only does overlighting waste energy, but it can also reduce lighting quality. Refer to the table below for light levels recommended by the Illuminating Engineering Society of North America. Within a listed range of illuminance, the proper level is determined by: age of the occupant(s), speed and accuracy requirements, reflectances and contrast.

For more information, refer to the IES Lighting Handbook Application Volume, 1987.

TYPE OF ACTIVITY	RANGE OF ILLUMINANCE
Public spaces with dark surroundings	2-3-5 FC
Simple orientation for short temporary visits	5-7½-10 FC
Working spaces where visual tasks are only occasionally performed	10-15-20 FC
Performance of visual tasks of:	
High contrast or large size	20-30-50 FC
Medium contrast or small size	50-75-100 FC
Low contrast or very small size	100-150-200 FC
Low contrast and very small size over a prolonged period	200-300-500 FC
Performance of very prolonged and exacting visual tasks	500-750-1000 FC
Performance of very special visual tasks of extremely low contrast and small size	1000-1500-2000 FC

Quality of Illumination

Improvements in lighting quality can yield high dividends for U.S. businesses. Gains in worker productivity may result by providing corrected light levels with reduced glare. And even though the cost of energy for lighting is substantial, it is small compared to the cost of labor. Therefore, these gains in productivity may be even more valuable than the energy savings associated with new lighting technologies. In retail spaces, attractive and comfortable lighting designs can attract clientele and enhance sales.

The three quality issues addressed in this section are:

- glare
- uniformity of illuminance on tasks
- color rendition

Glare

Perhaps the most important factor with respect to lighting quality is *glare*. Glare is a sensation caused by luminances in the visual field that are too bright. Discomfort, annoyance, or reduced productivity can result.

A bright object alone does not necessarily cause glare, but a bright object in front of a dark background, however, usually will cause glare. The relationship between the luminance of an object and its background is called *contrast*. Although the visual task generally becomes easier with increased contrast, too much contrast causes glare and makes the visual task much more difficult.

Glare can be reduced by not exceeding proper light levels and by using lighting equipment designed to reduce glare. A louver or shield is commonly used to block direct view of a light source. Indirect lighting, or uplighting, can create a low glare environment by uniformly lighting the ceiling. Also, proper fixture placement can reduce **reflected glare** that reflects off of the work surfaces or computer screens.

Standard data now provided with luminaire specification sheets include tables of its **Visual Comfort Probability (VCP)** rating for a given room geometry. The VCP index provides an indication of the percentage of people in a given space that would find the glare from a fixture to be acceptable. A minimum VCP of 70 is often recommended for commercial interiors, while luminaires with VCPs exceeding 80 are becoming more common in computer areas.

Uniformity of Illuminance on Tasks

The uniformity of illuminance is a quality issue that addresses how evenly light is spread over a task area. Although a room's *average* illuminance may be appropriate, uniformity may be compromised due to:

- improper fixture placement based on the luminaire's **spacing criteria** (ratio of maximum recommended fixture spacing distance to mounting height above task height)

- retrofit of fixture with reflectors with a design that narrows the fixture's light distribution

The problems that non-uniform illuminance causes are:

- inadequate light levels in some areas

- visual discomfort when tasks require frequent shifting of view from underlit to overlit areas

- bright spots and patches of light on floors and walls that cause distraction and generate a low quality appearance

Color Rendition

The ability to see colors properly is another aspect of lighting quality. Light sources vary in their ability to accurately reflect the true colors of people and objects. The color rendering index (CRI) scale is used to compare the effect of a light source on the color appearance of its surroundings.

The CRI is defined on a scale between 0 and 100.

A higher CRI means a better color rendering, or less color shift. CRIs in the range of 75-100 are considered excellent, 65-75 are good, 55-65 are fair, and 0-55 are poor.

The CRI values for selected light sources are tabulated with other lamp data on the following page.

D.2 LIGHT SOURCES

Several different light sources are used in commercial, industrial, and retail facilities. Each lamp type has particular advantages; selecting the appropriate source depends on installation requirements, life-cycle cost, color qualities, dimming capability, and the effect desired. The major types of lamps are:

- Incandescent
- Fluorescent
- High Intensity Discharge
  - -- Mercury Vapor
  - -- Metal Halide
  - -- High Pressure Sodium
  - -- Low Pressure Sodium

Before describing each of these lamp types, some of the characteristics that are common to all lamps are defined below.

Characteristics of Light Sources

In the table on the following page, the characteristics of electric light sources are summarized. These characteristics are described in detail on the pages that follow.

Efficiency

Some lamp types are more efficient in converting energy into visible light than others. The *efficacy* of a lamp refers to the number of lumens leaving the lamp compared to the number of watts required by the lamp (and ballast), expressed in *lumens per watt*. By using a source with a higher efficacy, less electrical energy is needed to light a space.

Color Temperature

Another characteristic of a light source is the color temperature. This is a measurement of "warmth" or "coolness" provided by the lamp. A warmer source is preferred in dining areas and living rooms; a cooler source if often preferred in an office environment.

Color temperature refers to the color of a blackbody radiator at a given absolute temperature, expressed in Kelvins. A blackbody radiator changes color as its temperature is increased -- first to red, then to orange, yellow, and finally bluish white at the highest temperature. *Note that a "warm" color light source actually has a lower color temperature.* For example, a cool-white fluorescent lamp appears bluish in color with a color temperature of around 4100 K. A warmer fluorescent lamp appears more yellowish with a color temperature of around 3000 K. Refer to the diagram on page D-7 for color temperatures of various light sources.

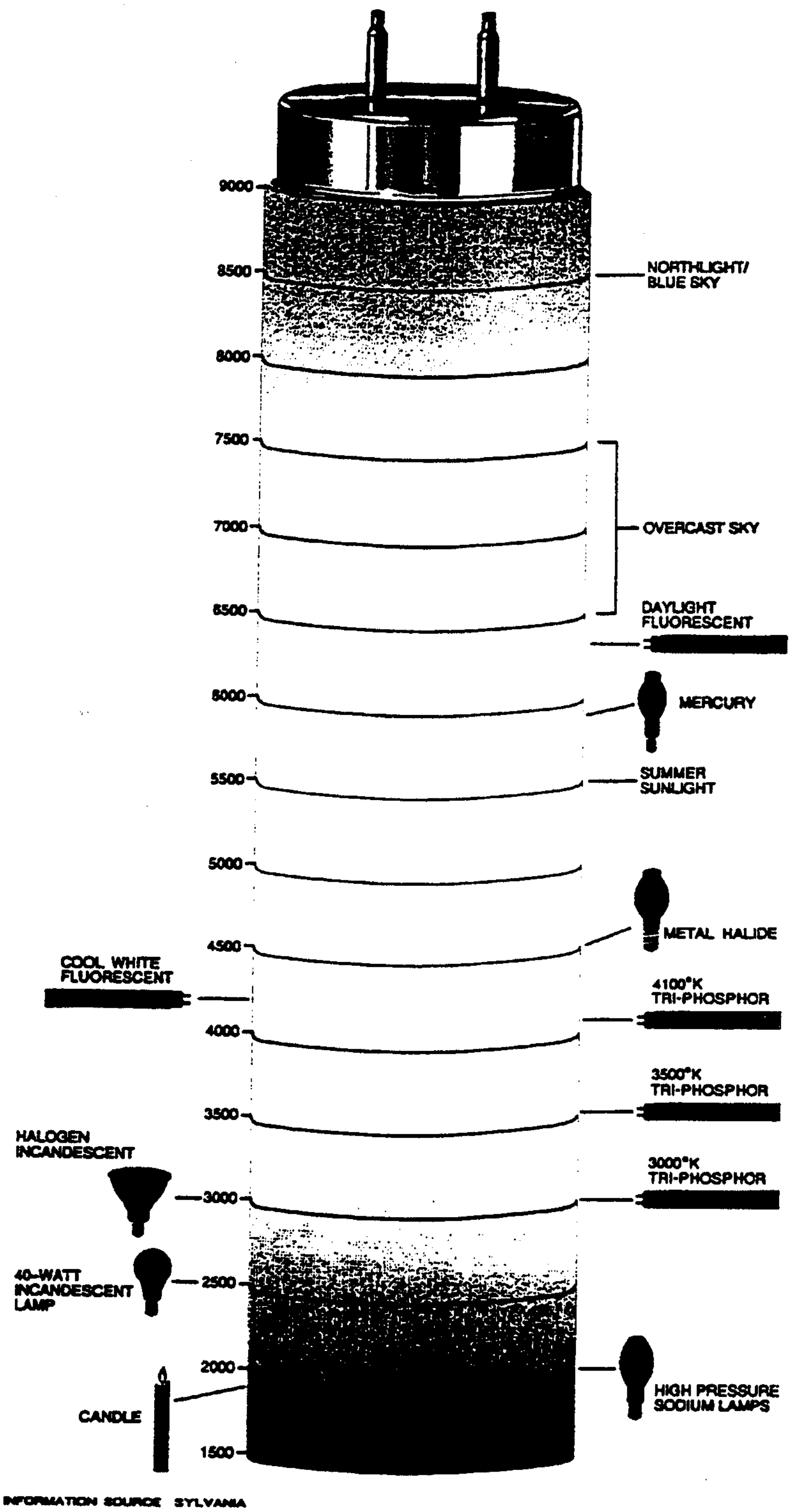
Color Rendering Index

The color rendering index (CRI) is a relative scale (ranging from 0 - 100) that indicates the degree to which the perceived colors of objects illuminated by a given light source, conform to the colors of those same objects when lighted by a reference standard light source. In general, the higher the color rendering index, the less the color shift or distortion.

The CRI number does not indicate which colors will shift or by how much; it is rather an indication of the average shift of eight standard colors. Two different light sources may have identical CRI values, but colors may appear quite different under these two sources.

LAMP CHARACTERISTICS

	Standard Incandescent	Tunsten Halogen	Fluorescent	Compact Fluorescent	Mercury Vapor	Metal Halide	High-Pressure Sodium	Low-Pressure Sodium
Wattages	3-1500	10-1500	4-215	5-40	40-1250	32-2000	35-1000	18-180
System Efficacy (lm/W)	6-24	18-33	50-100	50-80	25-50	40-100	40-140	120-175
Average Rated Life (hrs)	750-2,000	2,000-4,000	7,500-24,000	10,000-20,000	24,000+	6,000-20,000	16,000-24,000	12,000-18,000
Color Rendering Index	95+	95+	62-92	82-86	22-52	65-85	21-80	0
Life Cycle Cost	high	high	low	moderate	moderate	moderate	low	low
Fixture Size	compact	compact	extended	compact	compact	compact	compact	extended
Start to Full Brightness	immediate	immediate	0-5 seconds	0-1 minute	2-5 minutes	2-5 minutes	4-6 minutes	10-15 min.
Restike Time	immediate	immediate	immediate	immediate	3-10 min.	10-20 min.	1 minute	immediate
Lumen Maintenance	good/ excellent	excellent	good	good	poor/ fair	good	good/ excellent	excellent



COLOR TEMPERATURE

The absolute temperture (°K) of a black-body radiator having a chromaticity equal to that of the light source. The degree of warmth or coolness of the light source.

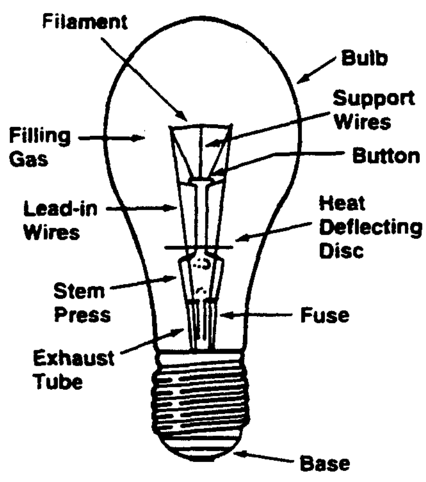
Incandescent Lamps

Standard Incandescent Lamp

The incandescent lamp is one of the oldest electric lighting technology available. With efficacies ranging from 6 to 24 lumens per watt, incandescent lamps are the least energy-efficient electric light source and have a relatively short life (750-2500 hours).

Light is produced by passing a current through a tungsten filament, causing it to become hot and glow. With use, the tungsten slowly evaporates, eventually causing the filament to break.

These lamps are available in a wide variety of shapes and finishes. The two most common types of shapes are the common "A-type" lamp (shown below) and the reflector-shaped lamps (R-lamps or PAR lamps).



Incandescent A-lamp

Tungsten-Halogen Lamps

The tungsten halogen lamp is another type of incandescent lamp. In a halogen lamp, the filament is contained inside a quartz capsule that contains a halogen gas. This gas allows the filament to operate at a higher temperature, which produces light at a higher efficacy than standard incandescents. The gas also combines with the evaporated tungsten, and re-deposits it back on the filament, which increases lamp life and keeps the bulb wall from blackening and reducing light output.

Because the filament is relatively small, this source is often used where a highly focused beam is desired. New compact halogen lamps are popular in retail applications for display and accent lighting. In addition, tungsten-halogen lamps generally produce a whiter light than other incandescent lamps, are more efficient, last longer, and have improved lamp lumen depreciation.

Fluorescent Lamps

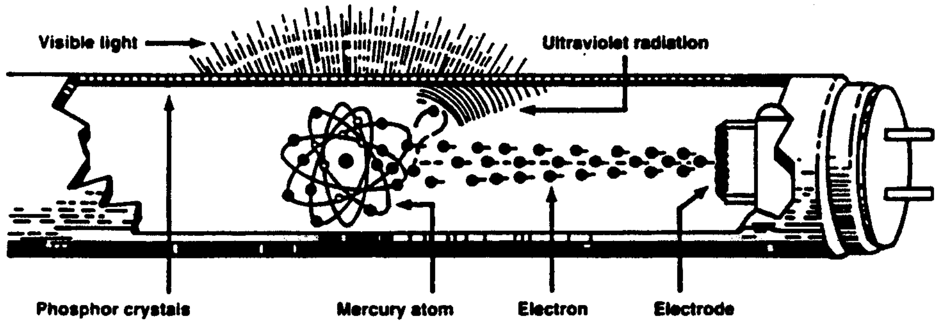
Fluorescent lamps are the most commonly used commercial light source in North America at this time. In fact, fluorescent lamps illuminate 71% of the commercial space in the United States. Their popularity can be attributed to their relatively high efficacy, light distribution characteristics, and long operating life.

Fluorescent lamp construction consists of a glass tube that is:

- filled with an argon or krypton gas and a small amount of mercury
- coated on the inside with phosphors
- equipped with an electrode at both ends

Fluorescent lamps provide light by the following process:

- An **electric discharge** (current) is maintained between the electrodes through the mercury vapor and inert gas.
- This current excites the mercury atoms, causing them to emit non-visible **ultraviolet (UV) radiation.**
- This UV radiation is converted into **visible light** by the phosphors lining the tube.



Fluorescent Lamp

Discharge lamps (such as fluorescent) require a ballast to provide correct starting voltage and to regulate the operating current after the lamp has started.

Full-Size Fluorescent Lamps

Full-size fluorescent lamps are available in several shapes, including straight, U-shaped, and circular configurations. Lamp diameters range from 1" to 2½". The most common lamp type is the four-foot (F40), 1½" diameter (T-12) straight fluorescent lamp.

Fluorescent lamps are available in colors ranging from warm (2700K) "incandescent-like" colors to very cool (6500K) "daylight" colors. "Cool white" (4100K) is the most common fluorescent lamp color. Neutral white (3500K) is becoming popular for office and retail use.

Improvements in the phosphor coating of fluorescent lamps have improved color rendering and made some fluorescent lamps acceptable in many applications previously dominated by incandescent lamps.

Compact Fluorescent Lamps

Advances in phosphor coatings and reductions of tube diameters have facilitated the development of compact fluorescent lamps. Manufactured since the early 1980s, they are a long-lasting, energy-efficient substitute for the incandescent lamp.

Various wattages, color temperatures, and sizes are also available. The wattages of the compact fluorescents range from 5 to 40 -- replacing incandescent lamps ranging from 25 to 150 watts -- and provide energy savings of 60 to 75 percent. While producing light similar in color to incandescent sources, the life expectancy of a compact fluorescent is about 10 times that of a standard incandescent lamp. Note, however, that the use of compact fluorescent lamps is very limited in dimming applications.

The compact fluorescent lamp with an Edison screw-base is a more recent development that offers an easy means to upgrade from an incandescent to compact fluorescent. Screw-in compact fluorescents are available in two types:

Integral Units. These consist of a compact fluorescent lamp and ballast in self-contained units. Some integral units also include a reflector and/or glass enclosure.

Modular Units. The modular type of retrofit compact fluorescent lamp is similar to the integral units, except that the lamp is replaceable.

A *Specifier Report* that compares the performance of various name-brand compact fluorescent lamps is now available from the National Lighting Product Information Program.

High-Intensity Discharge Lamps

High-intensity discharge (HID) lamps are similar to fluorescents in that an arc is generated between two electrodes. The arc in a HID source is shorter, yet it generates much more light, heat, and pressure within the arc tube.

Originally developed for outdoor and industrial applications, HID lamps are also used in office, retail, and other indoor applications. Their color rendering characteristics have been improved and lower wattages have recently become available -- as low as 18 watts.

There are several distinct advantages to HID sources:

- relatively long life (5,000 to 24,000+ hrs)
- relatively high lumen output per watt
- relatively small in physical size

However, this operating limitation must also be considered:

- HID lamps require time to warm up. The time varies from lamp to lamp, but the average warm up time is 2 to 5 minutes before the lamp will reach full output. If there is a momentary interruption of current, or if the voltage drops too low to maintain the arc, the lamp will extinguish. At that point, the gases inside the lamp are too hot to ionize, and time is needed for the gases to cool and pressure to drop before the arc will restrike. This process of restriking takes between 5 and 15 minutes depending on which HID source is being used. Therefore, good applications of compact HID lamps are areas where lamps are not switched on and off intermittently.

In increasing order of efficacy, HID sources are:

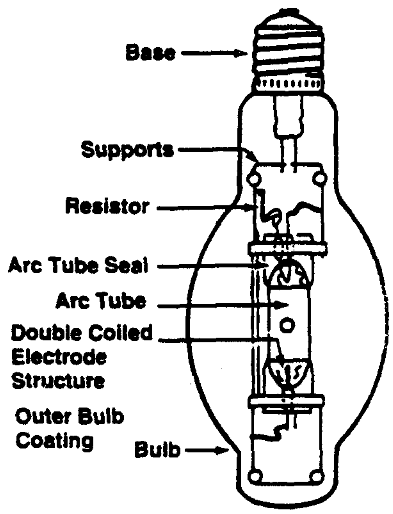
- Mercury-Vapor
- Metal Halide
- High Pressure Sodium
- Low Pressure Sodium

Mercury Vapor

Clear mercury vapor lamps, which produce a blue-green light, consist of a mercury-vapor arc tube with tungsten electrodes at both ends. These lamps have the lowest efficacies of the HID family, rapid lumen depreciation, and a low color-rendering index. Because of these characteristics, other HID sources have replaced mercury vapor lamps in many applications. However, mercury vapor lamps are still popular sources for landscape illumination because of their 24,000 hour lamp life and vivid portrayal of green landscapes.

The arc is contained in an inner bulb called the arc tube. The arc tube is filled with high purity mercury and argon gas. The arc tube is enclosed within the outer bulb, which is filled with nitrogen. (See the typical HID lamp below.)

Color-improved mercury lamps use a phosphor coating on the inner wall of the bulb to improve the color rendering index.



High Intensity Discharge Lamp

Metal Halide

These lamps are similar to mercury vapor lamps but use metal halide additives inside the arc tube along with the mercury and argon. These additives enable the lamp to produce more visible light per watt with improved color rendition.

Wattages range from 32 to 2,000, offering a wide range of indoor and outdoor applications. The efficacy of metal halide lamps ranges from 50 to 115 lumens per watt -- typically about double that of mercury vapor.

In short, the advantages of metal halide lamps are:

- high efficacy
- good color rendering
- wide range of wattages

There are some operating limitations of metal halide lamps that should be considered:

- the rated life of metal halide lamps is shorter than other HID sources; lower-wattage lamps last less than 7500 hours while high-wattage lamps last an average of 15,000 to 20,000 hours

- the color may vary from lamp to lamp, and shift over the life of the lamp

Because of the good color rendition and high lumen output, these lamps are good for sports arenas and stadiums. Indoor uses include large auditoriums and convention halls. These lamps are sometimes used for general outdoor lighting, such as parking facilities, but a high pressure sodium system is typically a better choice because of its higher efficacy and because good color rendition may not be a priority in such applications.

High Pressure Sodium

The high pressure sodium (HPS) lamp is widely used for outdoor and industrial applications. HPS lamps differ from mercury and metal-halide lamps in that they do not contain starting electrodes; the ballast circuit includes a high-voltage electronic starter. The arc tube is made of a ceramic material which can withstand temperatures up to 2372°F. It is filled with xenon to help start the arc, as well as a sodium-mercury gas mixture.

The efficacy of the lamp is very high -- up to 140 lumens per watt. For example, a 400-watt high pressure sodium lamp produces 50,000 initial lumens. The same wattage metal halide lamp produces 40,000 initial lumens, and the 400-watt mercury vapor lamp produces only 21,000 initially.

Sodium, the major element used, produces the "golden" color that is characteristic of HPS lamps. Although HPS lamps are not generally recommended for applications where color rendering is critical, HPS color rendering properties are being improved. Some HPS lamps are now available in "deluxe" and "white" colors that provide higher color temperature and improved color rendition. The efficacy of low-wattage "white" HPS lamps is lower than that of lower-wattage metal halide lamps (Lumens per Watt of low wattage metal halide is 75-85 LPW, while white HPS is 50-60 LPW).

Low Pressure Sodium

(Note: Although LPS lamps are low-pressure discharge systems -- similar to fluorescent systems -- they are commonly included in the HID family.) Low pressure sodium (LPS) lamps are the most efficient light sources, but they produce the poorest quality light of all the lamp types. Being a *monochromatic* light source, all colors appear black, white, or shades of gray under an LPS source. LPS lamps are available in wattages ranging from 18-180.

LPS lamp use has been generally limited to outdoor applications such as security or street lighting and indoor, low-wattage applications where color quality is not important (e.g. stairwells). However, because the color rendition is so poor, many municipalities do not allow them for roadway lighting.

Ballasts

All discharge lamps (non-incandescent) require an auxiliary piece of equipment called a ballast. There are three main functions of a ballast:

- Provide correct **starting** voltage. The lamps require a higher voltage to start than to operate.

- **Matches** the line voltage to the operating voltage of the lamp.

- **Limit** the lamp current. Once the arc is struck the lamp impedance decreases. Therefore, the current must be limited to prevent immediate destruction.

Because ballasts are an integral component of the lighting system, they have a direct impact on *light output*. The **ballast factor** is the ratio of a lamp's light output using a given ballast, compared to the lamp's rated light output on a laboratory standard ballast. General purpose ballasts have a ballast factor that is less than one; special ballasts may have a ballast factor greater than one.

Fluorescent Ballasts

There are two general types of fluorescent ballasts:

- **MAGNETIC ballasts** (known as magnetic, electromagnetic or core-coil ballasts)

  There are three sub-classes of **magnetic ballasts:**

  -- **standard core-coil** (no longer sold in the US for most applications)
  -- **high-efficiency core-coil**
  -- **cathode cut-out**

- **ELECTRONIC ballasts**

Magnetic Ballasts

Standard core-coil magnetic ballasts are essentially core-coil transformers that are relatively inefficient in operating fluorescent lamps. The high-efficiency ballast replaces the aluminum wiring and lower grade steel of the standard ballast with copper wiring and enhanced ferromagnetic materials. The result of these material upgrades is a 10 percent system efficiency improvement.

"Cathode cut-out" (or "hybrid") ballasts are high-efficiency core-coil ballasts that incorporate electronic components that cut off power to the lamp cathodes (filaments) after the lamps are lit, resulting in an additional 2-watt savings per standard lamp. Also, most hybrid magnetic ballasts provide approximately 8-15% less light output while consuming 17-32% less energy than energy-efficient magnetic ballasts.

Electronic Ballasts

In nearly every full-size fluorescent lighting application, electronic ballasts can be used in place of conventional magnetic "core-and-coil" ballasts. Electronic ballasts improve fluorescent system efficacy by converting the standard 60 Hz input frequency to a higher frequency, usually 25,000 to 40,000 Hz. Lamps operating at these higher frequencies produce about the same amount of light, while **consuming 12 to 25 percent less power**. Other advantages of electronic ballasts include less audible noise, less weight, virtually no lamp flicker, and dimming capabilities (with specific ballast models).

There are several electronic ballast designs available. The most common are:

- **Standard T-12 Electronic Ballasts (430 mA).** These ballasts are designed for use with conventional (T-12) fluorescent lighting systems. Some electronic ballasts that are designed for use with 4' lamps can operate up to four lamps at a time. Parallel wiring is another feature now available that allows all companion lamps in the ballast circuit to continue operating in the event of a lamp failure. Electronic ballasts are also available for 8' standard and high output T-12 lamps.

- **T-8 Electronic Ballasts (265 mA).** Specifically designed for use with T-8 (1-inch diameter) lamps, the T-8 electronic ballast provides the highest efficiency of any fluorescent lighting system. Some T-8 electronic ballasts are designed to start the lamps in the conventional rapid start mode, while others are operate in the instant start mode. The use of instant start T-8 electronic ballasts may result in up to 25% reduction in lamp life (at 3 hours per start) but produces slight increases in efficiency and light output. (Note: Lamp life ratings for instant start and rapid start are the same for 10 or more hours per start.)

- **Dimmable Electronic Ballasts.** These ballasts permit the light output of the lamps to be dimmed based on input from manual dimmer controls or from devices that sense daylight or occupancy.

Types of Fluorescent Circuits

There are three main types of fluorescent circuits. They are:

- rapid start
- instant start
- preheat

The specific fluorescent circuit in use can be identified by the label on the ballast.

The rapid start circuit is the most used system today. Rapid start ballasts provide continuous lamp filament heating during lamp operation (except when used with a cathode cut-out ballast or lamp). Users notice a very short delay after "flipping the switch," before the lamp is started.

The instant start system ignites the arc within the lamp instantly. This ballast provides a higher starting voltage, which eliminates the need for a separate starting circuit.

The preheat circuit was used when fluorescent lamps first became available. This technology is used very little today. A separate starting switch, called a starter, is used to aid in forming the arc. The filament needs some time to reach proper temperature, so the lamp does not strike for a few seconds. This low-cost circuit is used today mainly for low wattage applications such as compact fluorescent lamps and inexpensive task lights.

HID Ballasts

Like fluorescent lamps, HID lamps require a ballast to start and operate. The purposes of the ballast are similar: to provide starting voltage, to limit the current, and to match the line voltage to the arc voltage.

With HID ballasts, a major performance consideration is lamp wattage regulation when the line voltage varies. With HPS lamps, the ballast must compensate for changes in the lamp voltage as well as for changes in the line voltages.

If the wrong HID ballast is installed, it can:

- waste energy and increase operating cost
- severely shorten lamp life
- significantly add to system maintenance costs
- produce lower-than-desired light levels
- increase wiring and circuit breaker installation costs
- result in lamps cycling when voltage dips occur.

The chart on the following page describes the differences between the three types of HID ballasts. For definitions of these ballast types, please refer to the glossary in Appendix C.

Capacitive switching is available in new HID luminaires that can be controlled by occupancy sensors. Upon sensing motion, the occupancy sensor will send a signal to the bi-level HID system that will instantly bring the light levels from a standby reduced level to 80% of full output, followed by the normal warmup time between 80% and 100% of full light output. Depending on the lamp type and wattage, the standby lumens are roughly 15-40% of full output and the input watts are 30-60% of full wattage. Therefore, during periods that the space is unoccupied and the system is dimmed, savings of 40-70% are achieved.

Electronic ballasts for some types of HID lamps are beginning to become commercially available.

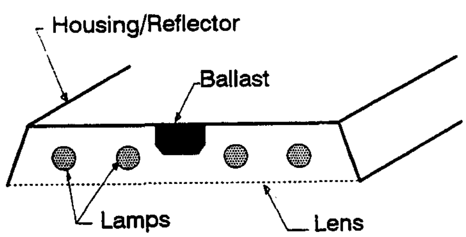
	NON-REGULATING (reactor, lag)	LEAD-TYPE REGULATOR (CWA)	LAG-TYPE REGULATOR (magn. regulator)
Line Voltage Variation	+/- 5%	+/- 10%	+/- 10%
Losses	Low	Med. to High	High
Power Factor	40-50%	90%+	90%+
Dip Tolerance	20-10%	50-10%	60-30%
Lamp Wattage Regulation	2-2.5% for each 1% change of line voltage	1-1.5% for each 1% change of line voltage	0.8% for each 1% change of line voltage

HID Ballast Selection Factors

D.3 LUMINAIRES

A luminaire, or light fixture, is a unit consisting of the following components:

- lamps
- lamps sockets
- ballasts
- reflective material
- lenses, refractors, or louvers
- housing



LUMINAIRE

The main function of the luminaire is to direct light using reflective and shielding materials. Many lighting upgrade projects consist of replacing one or more of these components to improve fixture efficiency. Alternatively, users may consider replacing the entire luminaire with one that is designed to efficiently provide the appropriate quantity and quality of illumination.

There are several different types of luminaires. The following is a listing of some of the common luminaire types:

- General illumination fixtures such as 2x4, 2x2, & 1x4 fluorescent troffers
- Downlights
- Indirect lighting (light reflected off the ceiling/walls)
- Spot or accent lighting
- Task lighting
- Outdoor area and flood lighting

Efficiency

The efficiency of a luminaire is the percentage of lamp lumens produced that actually exit the fixture. The use of louvers can improve visual comfort, but because they reduce the lumen output of the fixture, efficiency is reduced. Generally, the most efficient fixtures have the poorest visual comfort (e.g. bare strip industrial fixtures); conversely, the fixture that provides the highest visual comfort level is the least efficient. Therefore, a lighting designer must determine the minimum efficiency and visual comfort probability (VCP) needed for a space. Recently, some manufacturers have started offering fixtures with excellent VCP *and* efficiency. These so-called "superfixtures" combine state-of-the-art design and materials to provide the best of both worlds.

Surface deterioration and accumulated dirt in older, poorly maintained fixtures can also cause reductions in luminaire efficiency. Refer to Chapter 9 for more detail on lighting maintenance.

Directing Light

Each of the above luminaire types consist of a number of components that are designed to work together to *produce* and *direct* light. Because the subject of light production has been covered by the previous section, the text below focuses on the components used to direct the light produced by the lamps.

Reflectors

Reflectors are designed to redirect the light emitted from a lamp in order to achieve a desired distribution of light intensity outside of the luminaire.

In most incandescent spot and flood lights, highly specular (mirror-like) reflectors are usually built-in to the lamps.

In standard *fluorescent* troffers, however, the reflector surface usually consists of a white enamel painted surface that evenly reflects light away from the fixture. The reflectance of the white surface is typically 80-90%, but the light is evenly reflected and is not directionally controlled.

One energy-efficient upgrade option is to install a custom-designed mirror-like reflector to enhance the light control and efficiency of the fixture, which will allow a partial delamping of the fixture. Reflectors are available in anodized aluminum sheet (standard or enhanced reflectivity) or silver film laminate materials. Silver film laminate is generally considered to have the highest reflectance, while aluminum sheets are considered more durable.

Proper design and installation of reflectors can have more effect on performance than the reflector materials. In combination with delamping, however, use of reflectors may result in reduced light output and may redistribute the light, which may or may not be acceptable for a specific space or application. To ensure acceptable performance from reflectors, arrange for a trial installation and measure "before" and "after" light levels using the procedures outlined in Chapter 5. *Refer to Specifier Reports: Specular Reflectors, Volume 1 Issue 3, National Lighting Product Information Program for specific name-brand performance data.*

Lenses and Louvers

Most indoor commercial fluorescent fixtures use either a lens or a louver to prevent direct exposure to the lamps. Light that is emitted in the so-called "glare zone" (angles above 45 degrees from the fixture's vertical axis) can cause visual discomfort and reflections that reduce contrast on work surfaces or computer screens.

Lenses. Lenses made from clear ultraviolet-stabilized acrylic plastic deliver the most light output and uniformity of all shielding media. However, they provide less glare control than louvered fixtures. Clear lens types include prismatic, batwing, linear batwing, and polarized lenses. Lenses are usually much less expensive than louvers.

Louvers. Louvers provide superior glare control and high visual comfort than lens-diffuser systems. The most common application of louvers is to eliminate the fixture glare reflected on computer screens. So-called "deep-cell" parabolic louvers -- with 5-7" cell apertures and depths of 2-4" -- provide a good balance between visual comfort and luminaire efficiency. Although small-cell parabolic louvers provide the highest level of visual comfort, they reduce luminaire efficiency by 35-45% compared to clear lenses. For retrofit applications, both deep-cell and small-cell louvers are available for use with existing fixtures. Note that the deep-cell louver retrofit adds 2-4" to the overall depth of a troffer; verify that sufficient plenum depth is available before specifying the deep-cell retrofit. The chart on the following page shows the efficiency and VCP for various shielding materials.

Distribution

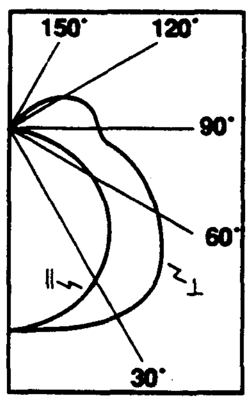
One of the primary functions of a luminaire is to direct the light to where it is needed. The light distribution produced by luminaires is characterized by the Illuminating Engineering Society of North America as:

- **Direct** -- 90 to 100 percent of the light is directed downward for maximum use;
- **Indirect** -- 90 to 100 percent of the light is directed to the ceilings and upper walls and is reflected to all parts of a room;
- **Semi-Direct** -- 60 to 90 percent of the light is directed downward with the remainder directed upward;
- **General Diffuse or Direct-Indirect** -- equal portions of the light are directed upward and downward; and
- **Highlighting** -- characterized by the distance of the beam of light and focusing ability

2'x4' TROFFER SHIELDING MEDIA

Shielding Material	Efficiency Range (%)	VCP Range
Clear Lens	60-70	50-85
Deep Cell Parabolic Louver	50-65	75-95
Opaque Diffuser	40-60	40-50
White Metal Louver	35-45	65-85
Small Cell Parabolic Louver	35-45	99

The lighting distribution that is characteristic of a given luminaire is described using the candela distribution provided by the luminaire manufacturer. The candela distribution is represented by a curve on a polar graph showing the relative luminous intensity 360° around the fixture -- looking at a cross-section of the fixture. This information is useful because it shows how much light is emitted in each direction and the relative proportions of downlighting and uplighting. See the figure at right. The cut-off angle is the angle, measured from straight down, where the fixture begins to shield the light source and no direct light form the source is visible.



Candela Distribution Curve (Sample)

32053b PJF

U.S. EPA Green Lights

Case Studies

EPA

7202 (5/93)

U.S. EPA Green Lights Program

Lighting Upgrade Case Study

Financial Services Industry

American Express
Shearson Lehman Brothers Headquarters
New York, New York
May, 1992

Equipment

Before Upgrade	After Upgrade
31,000 T-12 lamps	31,000 T-8 lamps
17,000 magnetic ballasts	17,000 electronic ballasts
58 incandescent lamps	58 compact fluorescents
manual switches	239 occupancy sensors

Facility Square Footage: 1,360,000
Total Project Cost: $710,000

Savings

Internal Rate of Return: 38% (excluding rebate)
Total Annual Savings: $280,000
Rebate/Grants: $450,000

Energy Savings

kW Avoided: 519.9
Lighting Electricity Reduction: 47%

Pollution Prevented

CO_2 5,072,403 lbs
SO_2 16,062,610 grams
NO_x 5,495,103 grams

For more information on this case study, please contact the Green Lights Hotline at (202) 775-6650.

U.S. EPA Green Lights Program

Lighting Upgrade Case Study

Waste Recycling Industry

Browning Ferris Industries
Office Facility
Houston, TX
October, 1992

Equipment

Before Upgrade	After Upgrade
10,000 T-12 lamps	6700 T-8 lamps
3,300 magnetic ballasts	3,300 electronic ballasts
350 incandescent lamps	350 compact fluorescents

Facility Square Footage: 545,000
Total Project Cost: $210,000

Savings

Internal Rate of Return: 51% (excluding rebate)
Total Annual Savings: $107,000
Rebate/Grants: $16,000

Energy Savings

kW Avoided: 221
Lighting Electricity Reduction: 50%

Pollution Prevented

CO_2	1,034,280 lbs
SO_2	1,436,500 grams
NO_x	1,436,500 grams

For more information on this case study, please contact the Green Lights Hotline at (202) 775-6650.

U.S. EPA Green Lights Program

Lighting Upgrade Case Study

Hotel Service Industry

WESTIN
HOTELS & RESORTS

Westin Hotels and Resorts
St. Francis Hotel
San Francisco, CA
May, 1992

Equipment

Before Upgrade	After Upgrade
1,600 incandescent lamps	1,600 compact fluorescents

Facility Square Footage: 1,500,000
Total Project Cost: $35,915

Savings

Internal Rate of Return: 186% (excluding rebate)
Total Annual Savings: $85,200
Rebate/Grants: $16,573

Energy Savings

kW Avoided: 66
Lighting Electricity Reduction: 82.3%

Pollution Prevented

CO_2 867,792 lbs
SO_2 3,355,462 grams
NO_x 1,446,320 grams

For more information on this case study, please contact the Green Lights Hotline at (202) 775-6650.

U.S. EPA Green Lights Program

Lighting Upgrade Case Study

Hospital Services Industry

ELKHART GENERAL HOSPITAL

Elkhart General Hospital
Elkhart, Indiana
September, 1992

Equipment

Before Upgrade	After Upgrade
7000 T-12 lamps	3200 T-8 lamps
2700 magnetic ballasts	1600 electronic ballasts
97 manual switches	82 occupancy sensors
	15 timed switches

Facility Square Footage: 430,000
Total Project Cost: $85,446

Savings

Internal Rate of Return: 33-50%
Total Annual Savings: $102,150

Energy Savings

kW Avoided: 270.6
Lighting Electricity Reduction: 70+%

Pollution Prevented

CO_2 3,064,488 lbs
SO_2 11,849,354 grams
NO_x 5,107,480 grams

For more information on this case study, please contact the Green Lights Hotline at (202) 775-6650.

U.S. EPA Green Lights Program

Lighting Upgrade Case Study

State Government

State of Maryland
Department of Education Headquarters
Baltimore, MD
May, 1992

Equipment

Before Upgrade	After Upgrade
10,600 T-12 lamps	5,600 T-8 lamps
5,300 magnetic ballasts	2,800 electronic ballasts
68 incandescent exit signs	68 fluorescent exit signs
28 incandescent lamps	28 compact fluorescents

Facility Square Footage: 180,000
Total Project Cost: $280,749

Savings

Internal Rate of Return: 48% (excluding rebate)
Total Annual Savings: $100,513
Rebate/Grants: $104,374

Energy Savings

kW Avoided: 317
Lighting Electricity Reduction: 64%

Pollution Prevented

CO_2 2,681,387 lbs
SO_2 11,932,175 grams
NO_x 4,022,081 grams

For more information on this case study, please contact the Green Lights Hotline at (202) 775-6650.

U.S. EPA Green Lights Program

Lighting Upgrade Case Study

Metal Products Industry

The Gillette Company
Manufacturing Facility
Santa Monica, CA
May, 1992

Equipment

Before Upgrade	After Upgrade
4300 T-12VHO lamps	496 metal halide lamps
10 manual switches	10 daylight switches

Facility Square Footage: 150,000
Total Project Cost: $176,534

Savings

Internal Rate of Return: 73% (excluding rebate)
Total Annual Savings: $128,608
Rebate/Grants: $27,000

Energy Savings

kW Avoided: 186.5
Lighting Electricity Reduction: 58%

Pollution Prevented

CO_2 2,411,393 lbs
SO_2 9,324,051 grams
NO_x 4,018,988 grams

For more information on this case study, please contact the Green Lights Hotline at (202) 775-6650.

U.S. EPA Green Lights Program

Lighting Upgrade Case Study

Aerospace Industry

BOEING

Boeing
Manufacturing Facility
Auburn, WA
February, 1992

Equipment

Before Upgrade	After Upgrade
11,000 T-12VHO lamps 5700 magnetic ballasts	4200 metal halide lamps

Facility Square Footage: 1,537,775
Total Project Cost: $2,858,558

Savings

Internal Rate of Return: 13%
Total Annual Savings: $131,000
Rebate/Grants: $2,011,790

Energy Savings

kW Avoided: 727
Lighting Electricity Reduction: 27%

Pollution Prevented

CO_2	1,192,280 lbs
SO_2	4,172,980 grams
NO_x	2,384,560 grams

For more information on this case study, please contact the Green Lights Hotline at (202) 775-6650.

U.S. EPA Green Lights Program

Lighting Upgrade Case Study

Pharmaceuticals Industry

Johnson & Johnson

Johnson & Johnson
Institutional Facility
San Diego, California
June, 1991

Equipment

Before Upgrade	After Upgrade
1386 T-12 energy saving lamps	734 T-8 lamps
693 efficient magnetic ballasts	367 electronic ballasts
	reflectors

Facility Square Footage: 35,000
Total Project Cost: $20,400

Savings

Internal Rate of Return: 59%
Total Annual Savings: $5,400
Rebate/Grants: $11,200

Energy Savings

kW Avoided: 21.5
Lighting Electricity Reduction: 52%

Pollution Prevented

CO_2	122,700 lbs
SO_2	474,440 grams
NO_x	204,500 grams

For more information on this case study, please contact the Green Lights Hotline at (202) 775-6650.

U.S. EPA Green Lights Program

Lighting Upgrade Case Study

Forest Products Industry

Union Camp
Office Facility
Wayne, New Jersey
April, 1992

Equipment

Before Upgrade	After Upgrade
7000 T-12 lamps	3600 T-12 lamps
3500 magnetic ballasts	1500 tandem-wired electronic ballasts
	reflectors

Facility Square Footage: 150,000
Total Project Cost: $280,000

Savings

Internal Rate of Return: 90%
Total Annual Savings: $100,000
Rebate/Grants: $186,000

Energy Savings

kW Avoided: 168.4
Lighting Electricity Reduction: 51.05%

Pollution Prevented

CO_2 674,895 lbs
SO_2 2,024,685 grams
NO_x 1,446,203 grams

For more information on this case study, please contact the Green Lights Hotline at (202) 775-6650.

U.S. EPA Green Lights Program

Lighting Upgrade Case Study

Toys, Sporting Goods Industry

Hasbro
Warehouse Facility
West Warwick, RI
February, 1992

Equipment

Before Upgrade	After Upgrade
260 metal halide lamps	260 high pressure sodium lamps

Facility Square Footage: 340,000
Total Project Cost: $186,000

Savings

Internal Rate of Return: 50% (excluding rebate)
Total Annual Savings: $63,000
Rebate/Grants: $154,000

Energy Savings

kW Avoided: 126
Lighting Electricity Reduction: 57%

Pollution Prevented

CO_2 1,500,000 lbs
SO_2 5,800,000 grams
NO_x 2,500,000 grams

For more information on this case study, please contact the Green Lights Hotline at (202) 775-6650.

United States Environmental Protection Agency
Air and Radiation 6202J
EPA 430-F-93-052
November 1993

EPA

Energy Star Programs

Energy Star Programs

EPA POLLUTION PREVENTER

Electricity generation is a source of air pollution, accounting for 35 percent of all U.S. emissions of carbon dioxide, 75 percent of sulfur dioxide, and 38 percent of nitrogen oxides. EPA has formed revolutionary, voluntary new partnerships with the private sector to encourage the production and use of energy-efficient equipment that reduce air pollution. The flagship Green Lights program helps businesses and other organizations cut their lighting electricity bills. It is also the first step in the comprehensive Energy Star Buildings program, which addresses heating, cooling, and air handling in commercial buildings. The Energy Star Computers program works with manufacturers and end users to bring more energy-efficient computers to market. These exciting public-private partnerships are changing the way the country consumes energy—and they're preventing pollution profitably!

Green Lights: A Bright Investment in Energy Efficiency

Lighting accounts for 20–25 percent of all electricity use in the United States. If everyone in the country used energy-efficient lighting, the nation could save—and reinvest—about $16 billion per year, and could reduce carbon dioxide, nitrogen oxides, and sulfur dioxide emissions from utilities by up to 12 percent.

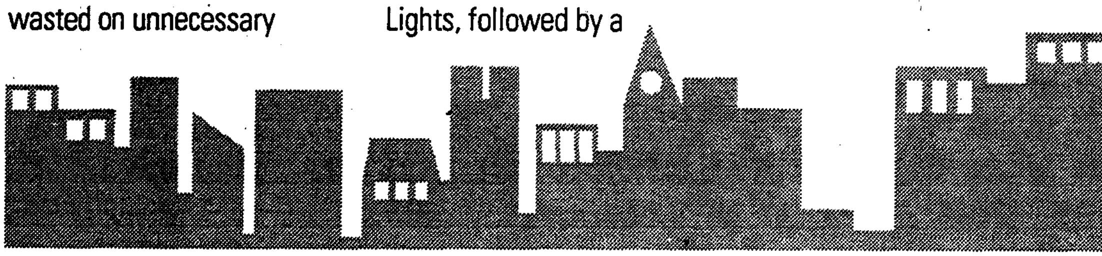
By forming voluntary working partnerships with over 1,150 businesses, institutions, and nonprofit organizations, the Green Lights program has taught these organizations to view lighting as an opportunity for investment, rather than as simply a fixed overhead cost. Green Lights works with participants to encourage the installation of energy-efficient lighting, only where profitable and where lighting quality is maintained or enhanced. EPA provides technical support to participants, as well as employee education and opportunities for public recognition for their environmental leadership. By applying the Green Lights formula for success, these organizations have realized average rates of return on their investments of 30 percent or more.

Recycled/Recyclable
Printed with Soy/Canola Ink on paper that

Energy Star Buildings: Maximizing Energy Efficiency—and Profits

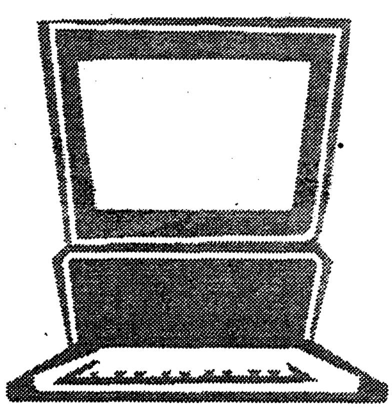
The United States spends approximately $70 billion annually to operate commercial and industrial buildings. Now, a wide variety of energy-efficient technologies can cut this energy use by more than 40 percent. That amounts to $28 billion that can be reinvested in the economy each year, rather than wasted on unnecessary electricity use. More important, this profitable and efficient use of energy means less air pollution!

The Energy Star Buildings program is a five-stage process in which EPA asks participants to perform energy-efficiency upgrades only where profitable. The program starts with membership in Green Lights, followed by a comprehensive building survey and tune-up. It then calls for reducing heating, ventilation, and air-conditioning (HVAC) loads and improving fans and air-handling systems. The program finishes with an improved HVAC plant, comprised of more efficient chiller and heating systems.



Energy Star Computers: Saving Money by Going to Sleep

Computers currently account for 5 percent of commercial electricity consumption. As the fastest-growing business electricity load, this could rise to 10 percent by the year 2000. As many as 30–40 percent of personal computers are left running at night and on weekends. Recognizing this significant, energy-saving opportunity, EPA has formed a partnership with leading computer manufacturers to develop desktop computers, monitors, and printers that can "sleep," or "power-down," when not is use. Now available to consumers and businesses, this sleep feature can cut a computer's electricity use by over one-half.



Look for computer products with the Energy Star™ logo. Together, we could save enough electricity each year to power Vermont and New Hampshire, to cut electricity bills by $2 billion, and to reduce carbon dioxide pollution equal to the emissions from 5 million automobiles.

The Energy Star programs offer the kind of tools pioneered by the Green Lights program—objective product information, expert decision-making capability, extensive technical support, and the ability to publicize progress in environmental protection. Energy Star Buildings and Energy Star Computers are adding to the momentum established by Green Lights, and already the air is cleaner!

EPA POLLUTION PREVENTER

For more information:

For more information contact:

Energy Star Programs
U.S. EPA (6202J)
401 M Street, SW
Washington, DC 20460
Fax: 202 775-6680

Or call: 202 775-6650

For more information by fax (available 24 hours a day), call 202 233-9659

United States Environmental Protection Agency | Air and Radiation 6202J | EPA 430-F-93-051 November 1993

EPA

Energy Star Buildings

Introducing... The Energy Star Buildings Program

The energy to run buildings in the United States costs about $70 billion a year. Besides being costly, producing the electricity to run these buildings contributes to a host of environmental problems: acid rain, smog, and global warming. EPA's Energy Star programs promote the use of profitable, energy-efficient technologies as a way to increase profits and competitiveness, while at the same time preventing pollution.

What Is the Energy Star Buildings Program?

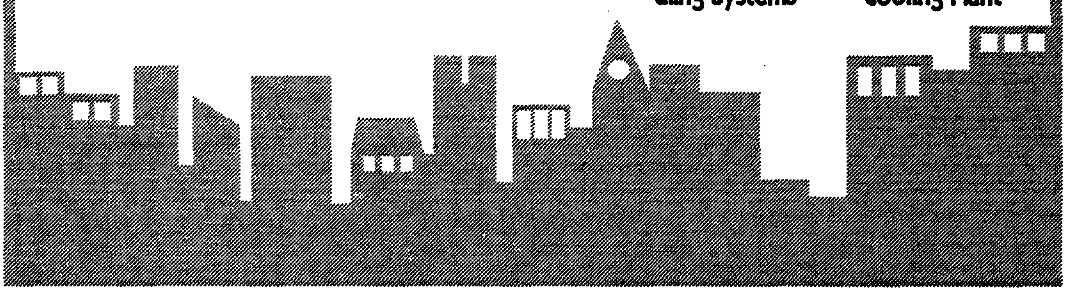
EPA's new Energy Star Buildings program is a voluntary energy-efficiency program for U.S. commercial buildings. Building on the successful Green Lights program, the program focuses on profitable investment opportunities available in most buildings, using proven technologies. A central component of the program is a step-by-step implementation process that takes advantage of the system interactions, enabling building owners to achieve additional energy savings while lowering capital expenditures.

The five-stage Energy Star Buildings upgrade strategy is shown below. One key advantage of this approach is that it reduces equipment cost. By implementing Green Lights (Stage 1), tuning up the building's systems (Stage 2), and investing in upgrades that reduce heating and cooling loads (Stage 3), building owners can significantly reduce the size and cost of equipment associated with Stages 4 and 5. Moreover, uncertainties about the proper sizing of upgraded cooling equipment (chillers and direct-expansion units) are reduced, leading to potential equipment downsizing and cost savings.

Partners are expected to follow this staged implementation strategy in upgrades of buildings they own. The Energy Star Buildings program will also seek to expand markets for emerging energy-efficient technologies, with the goal of reducing prices to make investments even more profitable.

This staged approach provides a broad strategic framework for making comprehensive efficiency upgrades in a range of commercial building types.

Stage 1	Stage 2	Stage 3	Stage 4	Stage 5
Green Lights	Building Tune-Up	HVAC Load Reductions	Improved Fans and Air-Handling Systems	Improved Heating and Cooling Plant



Energy Star Buildings: Maximizing Energy Efficiency (And Profit!)

EPA asks Energy Star Buildings participants to perform upgrades only where profitable. The five stages of the Showcase Buildings initiative are sequenced to maximize savings, prevent oversizing, and minimize equipment costs.

Stage 1: Green Lights	Stage 2: Building Tune-Up	Stage 3: HVAC Load Reductions	Stage 4: Fan System Upgrades	Stage 5: HVAC Plant Improvements
Install energy-efficient lighting technologies that maintain or enhance lighting quality. Green Lights will help reduce the cooling load in a building and will increase the savings from subsequent HVAC upgrades.	Check for the optimal operation of building systems, develop a preventative maintenance plan, and improve comfort and indoor air quality. A low-cost tune-up at this point could save 10–15 percent in overall energy costs.	Improve window and roof systems by installing such technologies as window films, a low-cost retrofit that will reduce peak cooling load; high-reflectance roof covers; and more effective insulation. When replacing existing PCs, replace them with Energy Star Computers.	Upgrade existing variable-air-volume (VAV) systems with variable speed drives (VSDs). Upgrade constant-air-volume (CAV) systems with VAV systems, saving energy by providing only the amount of air flow needed in a building. Reduce fan system oversizing, and replace existing motor with smaller, high-efficiency motor.	Prepare for 1995 CFC phaseout by replacing or upgrading chillers. Improve chiller system efficiency by retrofitting water pumps and compressors with VSDs. Improve heating system efficiency, and replace wasteful electric-resistance heat where possible. Save on equipment costs because of reduced load.

What Is a Showcase Building?

To qualify as a Showcase Building, a facility should contain at least 25,000 square feet of office space and should include energy-usage monitoring systems that allow for regular reporting of successful upgrades. The facility must be committed to installing Green Lights but not yet have performed the upgrade. A Showcase Building owner agrees to complete all upgrades in 1 to 2 years, with the goal of cutting electricity use by up to 50 percent.

Why Should I Be a Showcase Building?

In addition to the resulting energy and cost savings, by taking part in the first phase of the Energy Star Buildings program, Showcase Buildings tangibly demonstrate their concern for the environment. In return for helping EPA publicize and test its program, EPA provides Showcase Buildings with extensive technical support, such as objective technology information, savings analysis software, and survey and analysis guidance. And, as owners of multiple buildings choose just one to showcase, the potential savings from upgrading all the facilities is demonstrated.

Energy EPA POLLUTION PREVENTER

For more information about Showcase Buildings, please contact:

Manager
Energy Star Showcase Buildings
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United States Environmental Protection Agency | Air and Radiation 6202J | EPA 430-F-93-048 November 1993

EPA

Energy Star Buildings

Introducing... Energy Star Showcase Buildings

BUILDINGS

The U.S. Environmental Protection Agency (EPA) promotes energy efficiency because electricity generation contributes to air pollution, including 35 percent of all U.S. emissions of carbon dioxide. It also accounts for 75 percent and 38 percent of all U.S. emissions of sulfur dioxide and nitrogen oxides, respectively. By using more energy-efficient equipment in our homes, offices, and factories, we can reduce this pollution—while saving money!

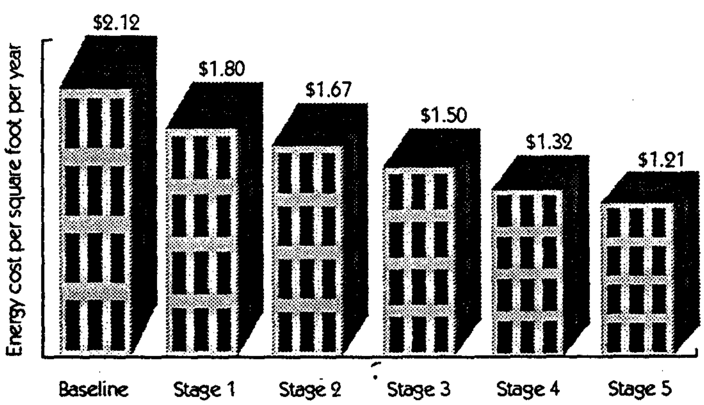
What Is the Showcase Buildings Program?

As part of its market-driven, nonregulatory Energy Star Buildings program, EPA is working to identify 20 to 30 buildings nationwide to "showcase" comprehensive energy-efficient upgrades. Showcase Building owners will work closely with EPA to demonstrate an upgrade process that maximizes energy savings through the appropriate use and sizing of energy-efficient heating, ventilating, and air-conditioning systems and other related building efficiency measures. The Showcase Buildings initiative will demonstrate the potential pollution prevention of cutting-edge, energy-efficient technologies, paving the way for a broader Energy Star Buildings program to be marketed nationwide.

How Can It Make a Difference?

Each year, about $70 billion is spent to operate commercial and industrial buildings in the United States. Fortunately, there is an array of readily available, energy-efficient technologies on the market that can profitably cut this energy use by more than 40 percent. That's $28 billion annually that can be reinvested in the economy rather than wasted on unnecessary electricity use. Moreover, less electricity use means cleaner air!

How Much Can I Save?



Costs will fall and energy savings will rise as each stage of the Showcase Buildings initiative is completed. (Data are based on the Energy Star Buildings upgrade of a 100,000-square-foot office building in Washington, DC.)

Savings Example: Variable Speed Drives

Variable speed drives (VSDs) control fan and pump motor speeds precisely, greatly improving the efficiency of HVAC systems. EPA recently completed a Variable Speed Drive Demonstration Study, in which EPA and a group of nine Green Lights Partners conducted a series of tests on existing installations of variable-speed-drive controls on HVAC fan systems. The purpose of these tests, which were held in several U.S. locations, was to monitor the energy savings relative to mechanical inlet-vane airflow controls. In most cases, the observed savings were significant, averaging 53 percent. In general, VSDs are expected to save from 30 to 60 percent in retrofit applications on existing variable-air-volume systems.

Energy Star Showcase Buildings

Over the next 2 years, EPA will work closely with a group of 20 to 30 Green Lights Partners to complete comprehensive and accelerated single-building efficiency upgrades. These Showcase Buildings will demonstrate that the comprehensive Energy Star Buildings strategy works to maximize energy savings at a profit. Furthermore, the Energy Star Showcase Building projects will offer an opportunity to field-test and refine EPA's technical support materials.

How Does EPA Help?

In addition to publicly recognizing an organization for its participation in the program and the energy savings it achieves, EPA provides a number of technical resources to help plan and implement building upgrades. These resources include:

- The *Building Retrofit Manual*, a step-by-step guide to a comprehensive commercial building upgrade.
- Software to calculate savings from upgraded fan systems.
- A data base of financing programs for building-efficiency upgrades.
- Case studies documenting monitored savings for specific technologies (such as variable speed drives or fan motors).
- Generic specifications for specific energy-efficient technologies.
- Information and guidance on indoor air quality issues.
- Guidance on how to use the CFC phaseout as an opportunity to increase building efficiency and reduce the cost of the transition to acceptable alternative refrigerants.

How Do I Join?

To participate in the Energy Star Buildings program, organizations must first agree to join EPA's Green Lights program, committing to identify and implement 90 percent of profitable lighting upgrades in their commercial and industrial space within 5 years. EPA offers its Partners extensive technical, organizational, and publicity support for lighting upgrades.

Green Lights Partners may become full Partners in the Energy Star Buildings program by signing an addendum to their existing Green Lights Memorandum of Understanding (MOU). As Energy Star Buildings Partners, they are expected to survey all owned U.S. commercial building space to identify profitable efficiency upgrades (rate of return greater than prime rate plus 6 percent), and to complete 90 percent of all profitable upgrades within 7 years.

EPA POLLUTION PREVENTER

For more information about the Energy Star Buildings program and the Green Lights program, please contact:

Manager
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Washington, DC 20460
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Or call: 202 775-6650

For more information by fax (available 24 hours a day), call: 202 233-9659.

EPA'S ENERGY STAR FAX-LINE MENU
(202) 233-9659

ENERGY STAR PROGRAMS GENERAL INFORMATION:

Item No.
1501 EPA's Voluntary Energy Star Programs: General Information Package
1511 Washington-Baltimore Energy Star Region Information Package
1701 Methane Programs General Information Package

GREEN LIGHTS PROGRAM INFORMATION:

General Information

1001 General Green Lights Information Package – contains new menu
5400 List of Green Lights Participants
4110 Lighting Upgrade Case Studies
1101 Ally Programs General Information

Joining Green Lights

2000 The Green Lights Partnership: Description of the Memorandum of Understanding (MOU)-Which MOU is Right For You?
2100 Green Lights Partner Sample MOU
2120 Green Lights Endorser Agreement-blank copy to fill in
4080 How do we make the Decision to Join Green Lights?

Specific Industry Information

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1021 Endorser Program Information Package
1031 Living Landmark Program Information Package

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3030 Green Lights in the Press: Recent Articles
3011 Perspectives on the Program: Press Releases by Current Partners

Lighting Upgrade Information

4000 Implementation Package: Getting Started with Upgrades & Staying on Schedule
4001 One-Page Lighting Upgrade Report Form & Instructions
4002 Lighting Upgrade Workshop Information & Registration Form
4100 Green Lights and the Environment: Measuring Your Pollution Prevention
4320 Product Information: National Lighting Product Information Program Specifier Report Order Form
4010 Energy-Efficient Lighting Technologies (lamps, ballasts, controls, etc.)
4020 Financing Your Green Lights Upgrades
4030 Lighting Disposal Information
4090 Working with Your Local Utility's Conservation Program

ENERGY STAR BUILDINGS PROGRAM INFORMATION:

1521 General Information Package
5112 Showcase Building Program Description (2 pgs.)
4120 Variable Speed Drive Pilot Study
2600 Joining the Energy Star Buildings Program: Sample Partnership Agreement (Addendum)
2605 Joining the Showcase Building Program: Sample Partnership Agreement (Addendum)

ENERGY STAR COMPUTERS PROGRAM INFORMATION:

1531 General Information Package
5103 Executive Order #12845: Federal Government Purchase of Energy-Efficient Computers
5502 List of Participating Manufacturers (PCs, Printers, and Allies)
5306 List of Available Energy Star Computers Products
4710 Product Testing Procedures
5305 How to Qualify Your Energy Star Product with EPA
2610 Purchasing Energy Star Computers: "Letter of Principal"
2611 Joining the Energy Star Computers program: the PC & Monitor Supplier MOU
2612 the Printer Supplier MOU
2613 the Ally MOU (related products)
3060 Energy Star Computers in the Press: Recent Articles (*by mail only*)

METHANE PROGRAMS INFORMATION:

1711 Natural Gas Star Program Information Package & Participants List
2550 Joining the Natural Gas Star Program: the MOU Agreement
6000 Implementation Guidelines
1721 Ag Star Program Information Package & Participants List
2560 Joining the Ag Star Program: the MOU Agreement

ENERGY STAR PROGRAMS MATERIALS *BY MAIL* ONLY:

5100 "The Climate is Right for Action:" Overview Brochure of Global Change Division's Programs
5000 Green Lights Update - a Monthly Newsletter
5001 Green Lights Second Annual Program Progress Report
5002 Green Lights Program Brochure (4-color)
5600 Introducing Green Lights by Video (12 minutes)
5601 Green Lights Program Technology Video: Occupancy Sensors (15 minutes)

circle desired item # above, complete the information below and fax to (202) 775-6680

Name **Title (required)**

Company

Address **Suite/Room No.**

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Energy Engineering

Anna Fay Williams, Ph.D., Editor-in-Chief

Vol. 89, No. 2

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1992

JOURNAL OF THE ASSOCIATION OF ENERGY ENGINEERS®

Published Since 1904 aee® DSMs ISSN: 0199-8595

A Spreadsheet-Based Microcomputer Application for Determining Cost-Effectiveness of Commercial Lighting Retrofit Opportunities

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Abstract

Lighting accounts for 20-25% of electricity use in the United States. With estimates of 50-70% potential reductions being made by energy engineers, lighting is a promising area for cost-effective energy conservation projects in commercial buildings. With an extensive array of alternatives available to replace or modify existing lighting systems, simple but effective calculation tools are needed to help energy auditors evaluate lighting retrofits.

This paper describes a spreadsheet-based microcomputer application for determining the cost-effectiveness of commercial lighting retrofits. Developed to support walk-through energy audits conducted by the Industrial Energy Advisory Service (IdEA$), the spreadsheet provides essential comparative data for evaluating the payback of alternatives. The impact of alternatives on environmental emissions is calculated to help communicate external costs and sell the project, if appropriate. The methodology and calculations are fully documented to allow the user to duplicate the spreadsheet and modify it as needed.

Introduction

The Industrial Energy Advisory Service conducts walk-through audits of business, industry and institutional sites in Alabama under the sponsorship of the Alabama Department of Economic and Community Affairs,

Science, Technology and Energy Division. In order to provide a calculation tool that would allow quick calculation of decision criteria for lighting opportunities, a spreadsheet was developed. Its simple, straightforward design allows changes to be easily made when necessary.

EPA, through the Green Lights program, has developed a computerized Decision Support System that identifies the lowest energy-using alternative that meets their "prime plus six" profitability hurdle.[1] However, it requires considerable time to enter information about the space and the lighting system and is currently limited to office buildings. Also, it is difficult to isolate a specific retrofit measure to determine payback for that particular project. Future releases will expand the building types which can be modeled and a spreadsheet program which allows specifying measures to be considered has been promised. When widely available, this system should greatly facilitate analyses of lighting retrofit projects. Meanwhile, this spreadsheet provides a simple, flexible analysis environment for a knowledgeable energy auditor to evaluate lighting alternatives.

Methodology

The energy engineer doing energy audits and lighting retrofit studies needs to quickly and accurately evaluate the alternatives and make appropriate recommendations. Detailed life cycle cost analysis resulting in net present value (NPV) or internal rate of return (IRR) is most precise but takes considerable time to setup, calculate and interpret the results. It has long been recognized that the proper application of direct, simple and understandable techniques is usually preferred over excessive detail that exaggerates the precision of the calculations given the accuracy of assumptions made in input data.[2] For this reason, decision statistics such as simple and discounted payback are used.

The spreadsheet model makes several simplifying assumptions. Costs and savings are annualized without respect to the time value of money or inflation. Lamp replacements are assumed to be uniformly distributed. No provision is made for costs associated with future ballast replacement or maintenance other than lamp replacement. The approach to tax implications is limited. Straight-line depreciation is assumed although other, more beneficial methods may be applicable. No input line for tax credits or expensing options is provided. While the cooling impact of lighting is

considered, no provision is made for calculating the additional heating that may be required in winter months. Since most commercial buildings have much greater cooling loads than heating loads, and since heating energy is frequently less expensive than cooling energy, this is usually not significant. However, where heating loads dominate, this impact should be considered. At a minimum, no credit should be taken for cooling impact in that situation.

The decision statistics used in this model are as follows:

Simple Payback: This is the time needed to recover the initial capital investment from net cash flows. It is simple and easy to understand. It is widely criticized because of what it does not consider such as the effect of cash flows after the payback period or the time value of money.

$$(1)\quad \textit{Simple Payback} = \frac{\textit{Net Investment}}{\textit{Net Annual Savings}}$$

Despite the fact that most engineering economy and finance texts either ignore simple payback or explain why it is not a valid decision statistic, it is still widely used. It is the required statistic for ranking energy conservation measures (ECMs) in an Institutional Conservation Program (ICP) technical assistance (TA) study.[3] Grant et. al.[4] note from one survey that 12% of U.S. multinational companies and 31% of non-U.S. multinational companies use payback as their primary capital budgeting evaluation tool. Longmore[5] summarizes several studies showing 53-74% of companies use payback as a primary or secondary decision criteria compared to only 10% using the NPV statistic. Longmore also develops a decision rule utilizing a payback statistic that results in decisions consistent with NPV analysis.

Simple Rate of Return: Simple rate of return is the reciprocal of simple payback and sometimes called the investor's rate of return.[6] It should not be confused with internal rate of return (IRR) which is based on a true life cycle cost analysis.

Net annual savings for calculating simple payback and simple rate of return should be after-tax savings, where appropriate. Frequently, analysts

$$(2)\quad \begin{aligned} \textit{Simple Rate of Return} &= \frac{\textit{Net Annual Savings}}{\textit{Net Investment}} \\ &= \frac{1}{\textit{Simple Payback}} \end{aligned}$$

fail to recognize the impact taxes have on lengthening payback periods for energy-saving investments. Payback periods are lengthened as the tax rate increases due to the tax deduction allowed for energy expenses.

Discounted Payback: Discounted payback modifies simple payback by considering the time value of money.[7] The discount rate is chosen to reflect the interest rate which could be earned on alternative, low-risk investments. It is sometimes referred to as an opportunity cost[8] because it is the return foregone by investing in the project. Discounted payback's shortcoming is that it still does not consider the effect of cash flows after the payback period or differing lives of alternatives.

$$(3)\quad \text{Discounted Payback} = \frac{\log \dfrac{1}{1-(\text{Simple Payback} * \text{Discount Rate})}}{\log(1 + \text{Discount Rate})}$$

Description of Spreadsheet

The spreadsheet is organized into two main blocks: input data and calculated data. Within each block, data is further segmented by categories, with each category having no more than six items. There is some data redundancy to make the spreadsheet more "self-documenting." The basic spreadsheet has four columns. One is devoted to item labels and descriptions, one to data related to the existing system, one to the proposed system and one for calculating the difference (where appropriate) between the existing and proposed system. Spreadsheet formula are designed such that the "proposed" column can be copied over the "difference" and adjacent columns to allow for multiple alternatives on a single spreadsheet.

The spreadsheet (Table 1) was created using Lotus 123 Version 2.2 with the Impress spreadsheet publishing add-in application. It is fully compatible with Lotus 123 Version 2.3 and its included add-in, WYSIWYG. It should be compatible with any popular spreadsheet without modification, except that spreadsheet publishing features may not be supported. It may be printed, without modification, using compressed print on any printer without use of a publishing add-in. Three named graphs, COSTS, EMISSIONS and PAYBACK, have been pre-defined to aid in data analysis.

Data categories and items are listed below with descriptions. Where appropriate, limitations or inherent assumptions are identified and references cited. Input and calculated data items are described in text while formulas are documented in spreadsheet form in Table 2.

Input Data

Fixture Characteristics:

Fixture Type --a label or code for the type fixture. For information purposes only, it is not used in any calculation.

Number of Fixtures --total number of fixtures being considered. If a retrofit involves changing the number of fixtures, then the number will be different, otherwise the default is the existing number.

Fixture Power, W/fixture --total power per fixture, including all lamps and ballasts.

Estimated Useful Life, yrs ---estimated life is used to calculate straight-line depreciation per year where tax effects are considered.

Lamp Characteristics:

Lamp Type --label or code for the lamp(s) used in the fixture. Not used in any calculations.

Lamps per Fixture--number of lamps in each fixture. Used to determine total lamps replaced in calculating annual replacement costs.

Lamp Life, hrs --average rated life of a lamp in hours. Manually vary this number as appropriate if strategy employed is expected to increase or decrease life based on hours per start or temperature. Used to calculate lamps replaced.

Lamp Output, lumens (initial) -initial rated lumens of a lamp. Used for calculating total light output for comparative purposes. Could be expanded to allow for calculation of light level of proposed projects if necessary room and fixture description inputs are added to spreadsheet model. For ideas on how to do this, refer to reference.[9]

Situation:

Daily Operation, hrs/day --hours per day lights are on.

Weekly Operation, days/wk --days per week lights are on.

Annual Operation, wks/yr --weeks per year lights are on. While these

three inputs could easily be combined into one input, they are listed separately to provide greater documentation. For example, the reduction in daily operation afforded by an occupancy sensor is easier to follow when daily operation is listed.

Area Served, ft² --gross building floor area served by lighting system being analyzed. Allows for calculation of lighting power density, a useful audit statistic.

Measured Light Level, fc --provides a place to document existing light levels and to estimate changes due to a proposed scenario. Not used in any calculation.

Quality of Light (subjective) --a subjective, descriptive entry indicating any relative change in light quality. Light quality is an important current issue. Although color temperature and color rendering index (CRI) can be quantified, numeric comparisons may not be meaningful without interpretation. Not used in any calculation.

Cooling Impact:

Cooling Operation, months/yr --months per year the facility is mechanically air-conditioned. Used to estimate lighting-dependent cooling energy. Mendelsohn and Rundquist [10] provide a useful tabulation of cooling season by geographic location as well as a discussion of methodology for determining lighting related HVAC energy.

Cooling SEER, Btuh/W --seasonal energy efficiency ratio (SEER) of the mechanical cooling equipment in Btu per hour per watt. If you prefer to think in terms of cooling season coefficient of performance (COP), multiply COP by 3.413 Btuh/W to get SEER.

Light Heat into Cooled Space, % --percent of heat generated by lighting system which is removed by mechanical air conditioning during the cooling season.

Installation & Replacement:

Fixed Installation Cost, $ --the fixed portion of the installation cost of a project. May include design, labor or equipment charges that are not variable based on the number of fixtures involved.

Variable Installation Cost, $/fixture - The variable installation cost of the project that is based on the number of fixtures involved.

Replacement Lamp Cost, $/lamp -- the cost of replacement lamps exclusive of labor to install them. The costs of lamps needed in the initial installation of the project should be included in the variable installation cost per fixture.

Replacement Labor, hrs/lamp --the average time required to replace one lamp. It should be chosen based on knowledge of the lamp replacement strategy to be used, whether individual or group.

Labor Cost, $/hr -- cost per hour of labor for replacing lamps that should represent total hourly cost including indirect and fringe as appropriate.

Energy:

Energy Cost Method (0=avg, 1=incr) --a flag to indicate the type energy cost method to be used.

Average Energy Cost, $/kWh --average energy cost in dollars per kilowatt-hour. Used if method flag is set to "0". Most commonly used method of estimating savings, but may overestimate savings under declining block rates.

Incremental Energy Cost, $/kWh --incremental energy cost in dollars per kilowatt-hour. Used if method flag is set to "1". Select based on utility rate schedule and knowledge of how proposed project affects energy use relative to that schedule. No provision is made for ratchet clauses. However, since lighting is normally baseload, ratchet should not affect results.

Incremental Demand Cost, $/kW/month --average incremental demand cost per kilowatt per month. Used if method flag is set to "1". Select based on knowledge of rate schedule and impact of proposed project. If rates vary seasonally, adjust to compensate.

Financial:

Incremental Income Tax Rate, % --the income tax rate that the organization would pay on additional income received. Typical values are 33% for individuals and partnerships, 34% for corporations. [11]

Depreciation Rate, %/yr --depreciation rate as a percent of initial investment per year. Default is straight-line depreciation over the "Estimated Useful Life" of the proposed system. Lighting im-

provements may qualify for seven year MACRS deduction. Straight-line is conservative and consistent with simple approach assuming uniform annual costs and benefits.

Discount Rate, % --the rate which the organization could earn on money invested in alternative, low-risk investments such as securities.

Calculated Data

Situation:

Total Light Output, lumens --total light output, product of number of fixtures, lamps per fixture and initial lamp output in lumens.

Lamp Efficacy, lumens/W --ratio of total fixture lumens to fixture power.

Total Connected Load, kW --total power of all fixtures.

Annual Operation, hrs/yr -- hours per year lights are on. Product of daily, weekly and annual operation inputs.

Power Density, W/ft² - Ratio of total connected load to area served, expressed in watts per square foot. Values in excess of 2 W/ft² suggest opportunities for reduction.

Installation & Replacement:

Total Installed Cost, $ --total project cost, sum of fixed and variable costs.

Average Lamp Replacements, lamps/yr--average number of lamps failing per year based on rated life, annual operating hours and total number of lamps. For a discussion of this subject, refer to reference.[12]

Replacement Costs, $/lamp --total cost to replace one lamp. Includes cost of the lamp and the labor to replace it.

Total Annual Replacement Cost, $ --total cost per year to replace lamps, the product of average lamp replacements and replacement costs.

Energy:

Lighting Energy Consumption, kWh/yr --annual energy use of the lighting system, the product of total connected load and annual operation.

Lighting-Related Cooling Energy, kWh/yr --annual electrical energy required for mechanical air-conditioning to remove lighting heat gain.

Total Energy Consumption, kWh/yr --total annual energy use, the sum of lighting energy consumption and lighting-related energy consumption.

Annual Energy Cost (avg or incr), $ --the total annual cost of energy, calculated based on average or incremental cost of energy as selected under energy cost method.

Financial:

Before-Tax Operating Cost, $/yr --the sum of total annual replacement cost and annual energy cost.

Depreciation, $/yr --annual depreciation assuming straight-line depreciation over estimated useful life with no salvage value, expressed as negative value.

Net Influence on Taxable Income, $/yr --used to determine the net tax effect of the measure, before-tax operating cost less depreciation.

After-Tax Cash Flow, $/yr --before-tax operating cost less the product of net influence on taxable income and incremental income tax rate. The difference between existing after-tax cash flow and proposed after-tax cash flow is the after-tax benefit to be used in calculating payback.

Environmental Emissions:

Carbon Dioxide, lbs/yr --Primary component of emissions from combustion of hydrocarbon fuels. Associated with "greenhouse effect." Default values for pounds of emissions per kilowatt-hour of electricity are as reported in reference [13] and are based on an assumed generation mix. For an extensive review of the environmental impact of electrical power generation, see reference.[14]

Sulfur Dioxide, lbs/yr - Linked with acid rain and snow.

Nitrous Oxides, lbs/yr --contributes to greenhouse effect.

Decision Statistics:

Simple Payback, yrs --total installed cost divided by the after-tax benefit (see after-tax cash flow).

Simple (Investor's) Rate of Return, % -- the reciprocal of payback,

expressed in percent.

Discounted Payback, yrs --payback time in years modified according to the discount rate.

Example Calculations

To demonstrate use of the spreadsheets, example printouts are shown for four possible lighting retrofits in a small professional office. In order to display results side-by-side, the "Proposed" column was copied to adjacent columns and columns labeled as "Proposed 1" through "Proposed 4." The spreadsheet formula were designed so that columns may be copied for as many alternatives as desired on a single spreadsheet.

The alternatives considered were:

Proposed 1 - Parabolic Reflector

Proposed 2 - T-8 Lamps/Electronic Ballast

Proposed 3 - Current Limiters (30%)

Proposed 4 - Occupancy Sensor.

The costs and inputs are based on information from personal experience, estimating guides and price quotes from local suppliers. They may not be representative for similar products in other areas. For help in estimating costs for lighting retrofits, obtain a copy of reference 15.

Printouts of the spreadsheet are contained in Tables 1-3. Table 1 shows results using incremental energy costs and 34% incremental tax rate. Graphs produced from this spreadsheet are shown in Figures 1-3. Table 2 shows the equations for Table 1. Table 3 shows the results for the proposed alternatives above. By varying income tax, it is possible to do a sensitivity analysis and see the impact on simple paybacks.

Table 1. Analysis of a single alternative

Filename: LIGHT1.WK1
Project: Example Office
Description: 12' x 15' x 8' Professional Office with four 2'x4' 4-tube troffers

INPUT DATA	EXISTING	PROPOSED	DIFFERENCE
Fixture Characteristics			
Fixture Type	F404T	F404T/Reflector	
Number of Fixtures	4	4	
Fixture Power, W/fixture	176	88	
Estimated Useful Life, yrs	15	15	
Lamp Characteristics			
Lamp Type	F40CW/T12	F40CW/T12	
Lamps per Fixture	4	2	
Lamp Life, hrs	20000	20000	
Lamp Output, lumens (initial)	3150	3150	
Situation			
Daily Operation, hrs/day	12	12	
Weekly Operation, days/wk	5	5	
Annual Operation, wks/yr	50	50	
Area Served, ft2	180	180	
Measured Light Level, fc	140	100	-29%
Quality of Light (subjective)	Acceptable	Same/Less glare	
Cooling Impact			
Cooling Operation, months/yr	7	7	
Cooling SEER, Btuh/W	9	9	
Light Heat into Cooled Space, %	90%	90%	
Installation & Replacement			
Fixed Installation Cost, $	$0.00	$0.00	
Variable Installation Cost, $/fixture	$0.00	$50.00	
Replacement Lamp Cost, $/lamp	$1.50	$1.50	
Replacement Labor, hrs/lamp	0.25	0.25	
Labor Cost, $/hr	$8.00	$8.00	
Energy			
Energy Cost Method (0=avg, 1=incr)	1	1	
Average Energy Cost, $/kWh	$0.0700	$0.0700	
Incremental Energy Cost, $/kWh	$0.0302	$0.0302	
Incremental Demand Cost, $/kW/month	$8.10	$8.10	
Financial			
Incremental Income Tax Rate, %	34.0%	34.0%	
Depreciation Rate, %/yr	6.7%	6.7%	
Discount Rate, %	6.0%	6.0%	

Table 1. Analysis of a single alternative (continued)

CALCULATED DATA		EXISTING	PROPOSED	DIFFERENCE
Situation				
Total Light Output, lumens		50400	25200	-25200
Lamp Efficacy, lumens/W		71.6	71.6	0.0
Total Connected Load, kW		0.704	0.352	-0.352
Annual Operation, hrs/yr		3000	3000	0
Power Density, W/ft2		3.91	1.96	-1.96
Installation & Replacement				
Total Installed Cost, $		$0.00	$200.00	$200.00
Average Lamp Replacements, lamps/yr		2.4	1.2	-1.2
Replacement Costs, $/lamp		$3.50	$3.50	$0.00
Total Annual Replacement Cost, $		$8.40	$4.20	($4.20)
Energy				
Lighting Energy Consumption, kWh/yr		2112	1056	-1056
Lighting-Related Cooling Energy, kWh/yr		420	210	-210
Total Energy Consumption, kWh/yr		2532	1266	-1266
Annual Energy Cost (incr), $		$144.96	$72.48	($72.48)
Financial				
Before-Tax Operating Cost, $/yr		$153.36	$76.68	($76.68)
Depreciation, $/yr		$0.00	($13.33)	($13.33)
Net Influence on Taxable Income, $/yr		$153.36	$90.01	($63.35)
After-Tax Cash Flow, $/yr		$101.22	$46.08	($55.14)
Environmental Emissions	lbs/kWh			
Carbon Dioxide, lbs/yr	1.48	3748.1	1874.0	-1874.0
Sulfur Dioxide, lbs/yr	0.016	40.5	20.3	-20.3
Nitrous Oxides, lbs/yr	0.007	17.7	8.9	-8.9
Decision Statistics				
Simple Payback, yrs			3.6	
Simple (Investor's) Rate of Return, %			27.6%	
Discounted Payback, yrs			4.2	

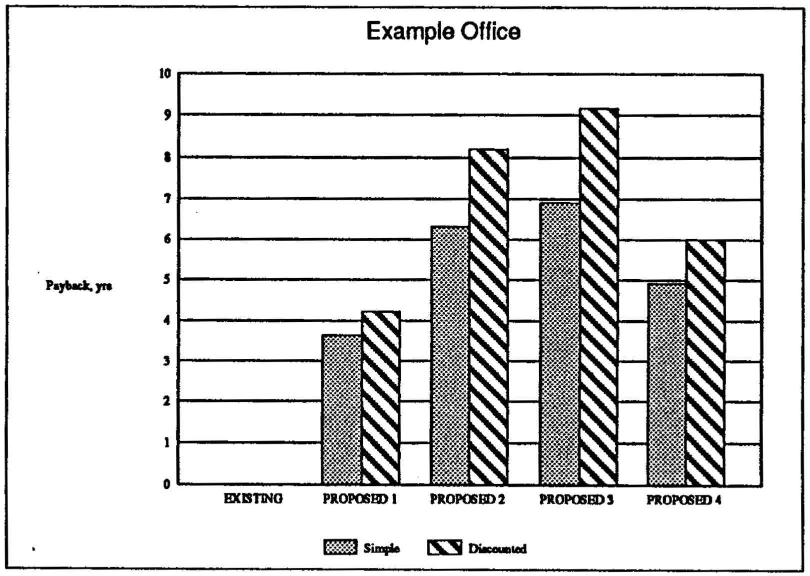

Figure 1. Graph of payback statisitcs

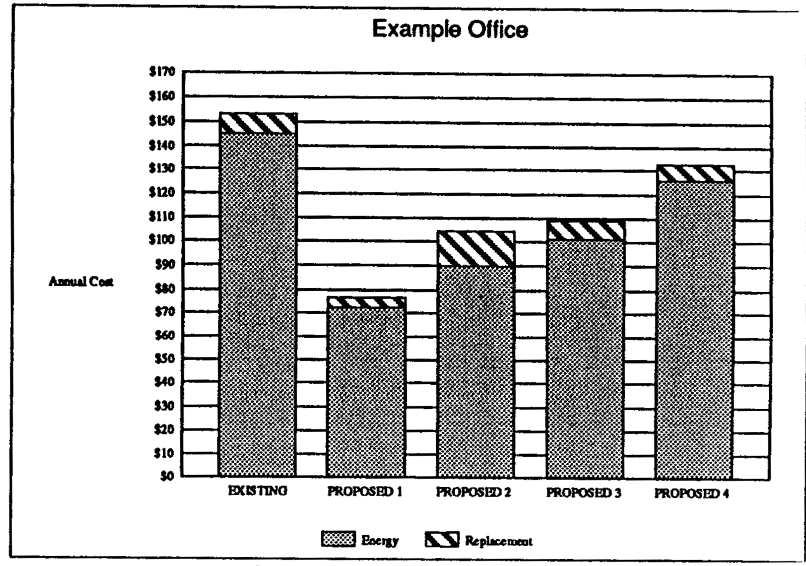

Figure 2. Graph of annual costs

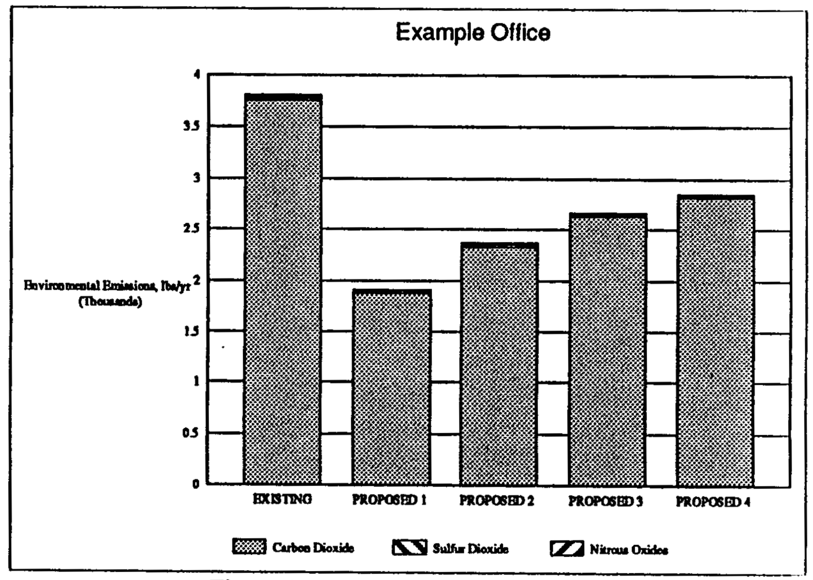

Figure 3. Graph of avoided emissions

Table 2. Examples of the formulas from table 1

	A	B	C	D	E	F
1		Filename:	LIGHT1.WK1			
2		Project:	Example	Office		
3		Description:	12' x 15'	x 8' Professional Office with four 2'x4' 4-tube troffers		
4						
5						
6		INPUT DATA		EXISTING	PROPOSED	DIFFERENCE
7	Fixture Characteristics					
8		Fixture Type		F404T	F404T/Reflector	
9		Number of Fixtures		4	+$D9	
10		Fixture Power, W/fixture		176	88	
11		Estimated Useful Life, yrs		15	15	
12	Lamp Characteristics					
13		Lamp Type		F40CW/T12	F40CW/T12	
14		Lamps per Fixture		4	2	
15		Lamp Life, hrs		20000	20000	
16		Lamp Output, lumens (initial)		3150	3150	
17	Situation					
18		Daily Operation, hrs/day		12	+$D18	
19		Weekly Operation, days/wk		5	+$D19	
20		Annual Operation, wks/yr		50	+$D20	
21		Area Served, ft2		12*15	+$D21	
22		Measured Light Level, fc		140	100	(E22-D22)/D22
23		Quality of Light (subjective)		Acceptable	Same/Less glare	
24	Cooling Impact					
25		Cooling Operation, months/yr		7	+$D25	
26		Cooling SEER, Btuh/W		9	+$D26	
27		Light Heat into Cooled Space, %		0.9	+$D27	
28	Installation & Replacement					
29		Fixed Installation Cost, $		0	0	
30		Variable Installation Cost, $/fixture		0	50	
31		Replacement Lamp Cost, $/lamp		1.5	+$D31	
32		Replacement Labor, hrs/lamp		15/60	+$D32	
33		Labor Cost, $/hr		8	+$D33	
34	Energy					
35		Energy Cost Method (0=avg, 1=incr)		1	+$D35	
36		Average Energy Cost, $/kWh		0.07	+$D36	
37		Incremental Energy Cost, $/kWh		0.03022	+$D37	
38		Incremental Demand Cost, $/kW/month		8.1	+$D38	
39	Financial					
40		Incremental Income Tax Rate, %		0.34	+$D40	
41		Depreciation Rate, %/yr		1/D11	1/E11	
42		Discount Rate, %		0.08	+$D42	

Table 2. Examples of the formulas from table 1 (continued)

	A	B	C	D	E	F
45		CALCULATED DATA		EXISTING	PROPOSED	DIFFERENCE
46	Situation					
47		Total Light Output, lumens		+D9*D14*D16	+E9*E14*E16	+E47-D47
48		Lamp Efficacy, lumens/W		+D16/(D10/D14)	+E16/(E10/E14)	+E48-D48
49		Total Connected Load, kW		+D9*D10/1000	+E9*E10/1000	+E49-D49
50		Annual Operation, hrs/yr		+D18*D19*D20	+E18*E19*E20	+E50-D50
51		Power Density, W/ft2		+D49*1000/D21	+E49*1000/E21	+E51-D51
52	Installation & Replacement					
53		Total Installed Cost, $		+D29+D30*D9	+E29+E30*E9	+E53-D53
54		Average Lamp Replacements, lamps/yr		+D9*D14*D50/D15	+E9*E14*E50/E15	+E54-D54
55		Replacement Costs, $/lamp		+D31+D32*D33	+E31+E32*E33	+E55-D55
56		Total Annual Replacement Cost, $		+D54*D55	+E54*E55	+E56-D56
57	Energy					
58		Lighting Energy Consumption, kWh/yr		+D49*D50	+E49*E50	+E58-D58
59		Lighting-Related Cooling Energy, kWh/yr		+D58*D25/12*3.413/D26*D27	+E58*E25/12*3.413/E26*E27	+E59-D59
60		Total Energy Consumption, kWh/yr		+D58+D59	+E58+E59	+E60-D60
61		Annual Energy Cost (incr), $		@IF(D35=1,D49*D38*12+D60*D37,D60*D36	@IF(E35=1,E49*E38*12+E60*E37,E60*E36)	+E61-D61
62	Financial					
63		Before-Tax Operating Cost, $/yr		+D61+D56	+E61+E56	+E63-D63
64		Depreciation, $/yr		-D53*D41	-E53*E41	+E64-D64
65		Net Influence on Taxable Income, $/yr		+D63-D64	+E63-E64	+E65-D65
66		After-Tax Cash Flow, $/yr		+D63-(D65*D40)	+E63-(E65*E40)	+E66-D66
67	Environmental Emissions		lbs/kWh			
68		Carbon Dioxide, lbs/yr	1.48	+D$60*$C68	+E$60*$C68	+E68-D68
69		Sulfur Dioxide, lbs/yr	0.016	+D$60*$C69	+E$60*$C69	+E69-D69
70		Nitrous Oxides, lbs/yr	0.007	+D$60*$C70	+E$60*$C70	+E70-D70
71	Decision Statistics					
72		Simple Payback, yrs			+E53/($D66-E66)	
73		Simple (Investor's) Rate of Return, %			1/E72	
74		Discounted Payback, yrs			@LOG(1/(1-E72*E42))/@LOG(1+E42)	

Table 3. Spreadsheet Analysis of the four alternatives

Filename: LIGHT2.WK1
Project: Example Office
Description: 12' x 15' x 8' Professional Office with four 2'x4' 4-tube troffers

INPUT DATA	EXISTING	PROPOSED 1	PROPOSED 2	PROPOSED 3	PROPOSED 4
Fixture Characteristics					
Fixture Type	F404T	F404T/Reflector	F404T	F404T	F404T
Number of Fixtures	4	4	4	4	4
Fixture Power, W/fixture	176	88	109	123	176
Estimated Useful Life, yrs	15	15	15	15	15
Lamp Characteristics					
Lamp Type	F40CW/T12	F40CW/T12	FO32/T8	F40CW/T12	F40CW/T12
Lamps per Fixture	4	2	4	4	4
Lamp Life, hrs	20000	20000	20000	22000	18000
Lamp Output, lumens (initial)	3150	3150	2900	2205	3150
Situation					
Daily Operation, hrs/day	12	12	12	12	9
Weekly Operation, days/wk	5	5	5	5	5
Annual Operation, wks/yr	50	50	50	50	50
Area Served, ft2	180	180	180	180	180
Measured Light Level, fc	140	100		100	140
Quality of Light (subjective)	Acceptable	Same/Less glare	Improved	Same	Same
Cooling Impact					
Cooling Operation, months/yr	7	7	7	7	7
Cooling SEER, Btuh/W	9	9	9	9	9
Light Heat into Cooled Space, %	90%	90%	90%	90%	90%
Installation & Replacement					
Fixed Installation Cost, $	$0.00	$0.00	$0.00	$0.00	$75.00
Variable Installation Cost, $/fixture	$0.00	$50.00	$60.00	$60.00	$0.00
Replacement Lamp Cost, $/lamp	$1.50	$1.50	$4.00	$1.50	$1.50
Replacement Labor, hrs/lamp	0.25	0.25	0.25	0.25	0.25
Labor Cost, $/hr	$8.00	$8.00	$8.00	$8.00	$8.00
Energy					
Energy Cost Method (0=avg, 1=incr)	1	1	1	1	1
Average Energy Cost, $/kWh	$0.0700	$0.0700	$0.0700	$0.0700	$0.0700
Incremental Energy Cost, $/kWh	$0.0302	$0.0302	$0.0302	$0.0302	$0.0302
Incremental Demand Cost, $/kW/month	$8.10	$8.10	$8.10	$8.10	$8.10
Financial					
Incremental Income Tax Rate, %	34.0%	34.0%	34.0%	34.0%	34.0%
Depreciation Rate, %/yr	6.7%	6.7%	6.7%	6.7%	6.7%
Discount Rate, %	6.0%	6.0%	6.0%	6.0%	6.0%

Table 3. Spreadsheet Analysis of the four alternatives (continued)

CALCULATED DATA		EXISTING	PROPOSED 1	PROPOSED 2	PROPOSED 3	PROPOSED 4
Situation						
Total Light Output, lumens		50400	25200	46400	35280	50400
Lamp Efficacy, lumens/W		71.6	71.6	106.4	71.7	71.6
Total Connected Load, kW		0.704	0.352	0.436	0.492	0.704
Annual Operation, hrs/yr		3000	3000	3000	3000	2250
Power Density, W/ft2		3.91	1.96	2.42	2.73	3.91
Installation & Replacement						
Total Installed Cost, $		$0.00	$200.00	$240.00	$240.00	$75.00
Average Lamp Replacements, lamps/yr		2.4	1.2	2.4	2.2	2.0
Replacement Costs, $/lamp		$3.50	$3.50	$6.00	$3.50	$3.50
Total Annual Replacement Cost, $		$8.40	$4.20	$14.40	$7.64	$7.00
Energy						
Lighting Energy Consumption, kWh/yr		2112	1056	1308	1476	1584
Lighting-Related Cooling Energy, kWh/yr		420	210	260	294	315
Total Energy Consumption, kWh/yr		2532	1266	1568	1770	1899
Annual Energy Cost (incr), $		$144.96	$72.48	$89.78	$101.31	$125.63
Financial						
Before-Tax Operating Cost, $/yr		$153.36	$76.68	$104.18	$108.94	$132.63
Depreciation, $/yr		$0.00	($13.33)	($16.00)	($16.00)	($5.00)
Net Influence on Taxable Income, $/yr		$153.36	$90.01	$120.18	$124.94	$137.63
After-Tax Cash Flow, $/yr		$101.22	$46.08	$63.32	$66.46	$85.97
Environmental Emissions	lbs/kWh					
Carbon Dioxide, lbs/yr	1.48	3748.1	1874.0	2321.2	2619.4	2811.1
Sulfur Dioxide, lbs/yr	0.016	40.5	20.3	25.1	28.3	30.4
Nitrous Oxides, lbs/yr	0.007	17.7	8.9	11.0	12.4	13.3
Decision Statistics						
Simple Payback, yrs			3.6	8.3	6.9	4.9
Simple (Investor's) Rate of Return, %			27.6%	15.6%	14.5%	20.3%
Discounted Payback, yrs			4.2	8.2	9.2	6.0

Summary

Cost-effective lighting energy conservation opportunities in commercial buildings are plentiful. It is more a problem of which project to select rather than if a project should be undertaken. Used with proper judgement and recognition of limitations and assumptions, this spreadsheet can assist the auditor in the selection process and help document results to the audit client.

Acknowledgments

I want to thank Robert E. Quick, C.E.M., IdEA$ Energy Auditor, for his assistance in reviewing the spreadsheet and compiling inputs for example purposes. I also want to thank the Alabama Department of Economic and Community Affairs, Science, Technology and Energy Division for their continued support of the IdEA$ program and other energy conservation programs in Alabama.

Program Availability

The lighting spreadsheets as shown in this paper are available on disk as Lotus 123 templates. To request a copy of the disk, call the Industrial Energy Advisory Service (IdEA$) at 1-800-VP-IDEAS (1-800-874-3327).

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Energy Engineering

Anna Fay Williams, Ph.D., Editor-in-Chief

Vol. 89, No. 1 — 1992

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JOURNAL OF THE ASSOCIATION OF ENERGY ENGINEERS®

Published Since 1904 aee® DSMs ISSN: 0199-8595

Energy Accounting Using Spreadsheet Forms

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Introduction

Energy managers need good information about energy use and cost in order to control costs and measure progress toward goals. An energy accounting system provides the necessary use and cost statistics which, when compared to a baseline or goal, indicate the success of cost control or conservation measures.

Although energy accounting is fundamental to energy management [1,2,3,4] and has been shown to result in energy cost savings,[5,6] relatively few organizations actually have an organized energy accounting system. Several companies offer software for energy accounting on a personal computer [7]. FASER [8] and Enact [9] are two examples of good, comprehensive energy accounting programs. Reference 10 provides a discussion of the essential characteristics of an energy accounting system from a management perspective.

Even with good software available at affordable prices, many companies still do not use energy accounting to monitor building energy use. With energy costs typically on the order of only 5 percent of total costs for most businesses, managers may not see the need to implement a sophisticated information system even though it has been shown to be profitable at that threshold.[11] A simple system can help sell the concept of energy accounting and then lead naturally into a more sophisticated system.

This paper outlines a simple forms-based energy accounting

This paper outlines a simple forms-based energy accounting system which can serve at least three purposes: (1) to illustrate the concept of energy accounting; (2) to provide the basis for a simple energy accounting system; and (3) to analyze and present billing data in conjunction with an energy audit. It was developed at the Industrial Energy Advisory Service (IdEA$). IdEA$ is operated by the Johnson Research Center at The University of Alabama in Huntsville under the sponsorship of the Alabama Department of Economic and Community Affairs, Science, Technology and Energy Division.

Description of Energy Accounting Forms

The energy accounting system consists of two forms: Energy Accounting Analysis (A-Form, Figure 1) and Energy Accounting Summary (S-Form, Figure 2). Each form has multiple uses and provides for a variety of statistics. While a computer is not necessary for use of the forms, electronic spreadsheets greatly simplify the calculations and allow graphical analysis of data.

The A-Form is used to track energy use and cost for one fuel source for one metered facility for one year. One A-Form would be required to track energy use for an all-electric facility with only one meter. If a building has multiple fuel sources, such as both electricity and natural gas, or multiple meters, then one A-Form is used for each fuel source (or meter).

The S-Form can serve several purposes. For a single facility with multiple fuel sources or meters, the S-Form is used to sum energy use and cost for the facility in common units of millions Btu (MMBtu). For multiple facilities, the S-Form is used to compare energy use during the current period with energy use for the same period in a baseline year. The S-Form may also be used to show avoided costs resulting from operations changes or energy conservation projects.

Case Example

To illustrate how the forms would be used, consider the hypothetical All-American Company. It has three facilities: an office building, a manufacturing facility and an executive gymnasium. Figure 3 shows an organization chart layout of the building, meter and submeter structure.

The office building is served by a single electric meter. Since only one fuel source is used, the manager of this facility would use a single A-Form to track energy consumption in this facility. Extended data to be tracked would include heating and cooling degree days as well as building operating hours because energy use would likely vary based upon weather extremes and changes in operating hours.

The manufacturing facility uses several different fuel sources. Electricity is used for electric motor drives for transportation, chillers, and air compressors. Natural gas is used to fuel boilers for process steam production as well as for direct drying of products. Fuel oil is used for boiler operation during periods of gas service interruption. Coal is used to fire a boiler also used for process steam energy.

The manager of this plant would use four separate A-Forms, one for each fuel source. To summarize total energy use, an S-Form would be used to total energy use for the plant. Submetering of electric energy by production areas provides a basis for cost-center allocation of energy expenses. Individual A-Forms could be used for each submeter of each energy source with an S-Form used to totalize the submeters. Extended data to be tracked might include the operating hours, number of products produced, and pounds of product produced. Weather fluctuations would probably have minimal impact on energy use.

The executive gymnasium is served by a single electric meter and a single natural gas meter. Electricity is used for lighting, cooling, ventilation and office equipment. Natural gas is used for a pool heater and a steam boiler supplying steam for the steam room, a hot water

generator, and steam radiators for space heating. An A-Form would be used for each meter with an S-Form used to sum energy use for the facility. Extended data for electricity should include cooling degree days and possibly building operating hours. Extended data for natural gas use should include heating degree days and perhaps operating hours.

The chief operations officer for the All-American Company would use a single S-Form to compare total energy use by facility for the whole company. Inputs to this form are taken from the A-Form submitted by the manager of the office building and the S-Forms submitted from manufacturing and the executive gymnasium.

At each facility, S-Forms are used to compare energy use during the current year with energy use for the same facility during a baseline year. Avoided energy costs are computed by multiplying the reduction in Energy Utilization Index (EUI) times the current period average cost of energy.

Using the A-Form

The most basic use of the A-Form is to enter consumption and cost data from the utility bill in the unshaded columns labeled accordingly.

Table 1 Energy Conservation Factors

Energy Type	Consumption Units	To convert to MMBtu multiply by
Electricity	kWh	0.003413
Natural Gas	ccf	0.103
Propane	gal	0.095475
Coal	ton	24.5
#2 Oil	gal	0.138690
#6 Oil	gal	0.149690

Energy consumption is converted to MMBtu using the appropriate conversion factor given in Table 1. The basic energy utilization statistics are the Energy Utilization Index in Btu per gross sq ft (gsf) of building area and the average cost of energy in dollars per MMBtu.

Shaded columns are for data that is non-essential or that may not be appropriate for every energy type or situation. Entering the date that a particular meter was read allows for calculation of number of days in a billing period to allow for unequal billing period lengths and per day statistics.

The Standard Data section has shaded columns for tracking billing demand and the load factor. Demand is usually metered for electricity but not for other energy sources. The load factor is an indication of the relationship of average energy use to peak or billing demand. It is calculated by dividing energy consumption by the product of demand times the hours in the billing period and is expressed in percent. A high load factor may indicate opportunities for energy savings by reducing equipment operating hours. A low load factor could indicate savings opportunities from peak-shaving strategies.

The Extended Data section is used to track variables such as degree days, operating hours and/or production data to provide a means of normalization for energy use with respect to uncontrollable changes. Based on the nature of energy use in the facility, extended data can help determine baseload and variable energy use. Spreadsheets typically have data regression functions to mathematically assess the relationship of energy use to the extended data. Graphs of energy use versus extended data will quickly show those trends.

A variety of energy utilization statistics are provided for at the bottom of the form. Space is allowed for most combinations of consumption units, energy units and "cost per" statistics. The most common statistics, EUI in Btu/gsf and energy cost per MMBtu are highlighted for emphasis.

Using the S-Form

The energy accounting summary form may be used for:

(1) combining multiple fuel types in a single facility,
(2) combining multiple meters for the same fuel type,
(3) combining multiple meters for a variety of fuel types,
(4) summarizing total energy use for a related group of facilities,
(5) comparing current period energy use and cost to a base period use and cost, and
(6) calculating avoided costs from energy management efforts.

The basic data to be tracked is entered in the unshaded columns. Space is provided at the bottom for calculating totals, averages and extremes as appropriate. Additional data may be entered such as base period EUI and average cost. Avoided cost is defined as the reduction in EUI times the current period average cost of energy.

Sample Analysis Using the A-Form

A sample analysis of energy use for the executive gymnasium of the All-American Company is shown to illustrate how the system might be used. For the analysis, a Lotus 123 template of the A-Form was used. This template automates the required calculations and has a series of graphs pre-defined to aid in the analysis.

Table 2 shows a printout of the A-Form for electricity use for 1988. The totals and statistics show that the company consumed 686 MMBtu of electrical energy at a cost $11,229 or an average cost of $16.36 per MMBtu ($0.0559 per kilowatt-hour). The EUI is 51,689 Btu/gsf.

Table 3 shows the A-Form for natural gas use. Since gas demand is not metered in this facility, the load factor is undefined (shown as 0%). Consumption was 3925 MMBtu at a total cost of $15,566. While the average cost of $3.97/MMBtu is low compared to average electricity cost, an EUI of 295,648 Btu/gsf seems excessive and suggests opportunity for conservation.

Table 4 - S-Form for Example Building

File ID: ALLAMER.WK1

ENERGY ACCOUNTING SUMMARY
Year 1988

Company/Division: All-American Company/Executive Gymnasium

Building Information				Current Period Jan-Dec 1988	
File ID	Bldg/Meter	Area gsf	Energy Type	EUI Btu/gsf	Avg Cost $/MMBtu
AFORMEX1.WK1	Gym Electric	13,276	Electric	51,689	$16.36
AFORMEX2.WK1	Gym Nat Gas	13,276	Nat Gas	295,648	$3.97
Totals		13,276		347,337	

Table 4 shows an example S-Form summary of energy use and cost for the building and could serve as the basis for comparisons of future years' energy use.

Figure 4 shows a series of eight pre-defined graphs in the spreadsheet which illustrate the power of graphics in energy accounting. The high demand and low load factor in November suggest a possible metering anomaly. The straight-line relationship of energy used versus extended variable 2, cooling degree days (CDD), quickly shows how much energy is used for space cooling versus lighting and equipment.

Figure 5 shows the linear relationship of gas energy use to extended variable 1, heating degree days (HDD) and provides a basis for separating space heating and weather-variable pool heating energy from baseload pool and domestic water heating use.

Figure 6 pie charts illustrate baseload and variable energy use and cost as determined from the A-Form analysis. The information provided by this analysis of one year's billing history for the building provides an excellent starting point for an energy audit and for future management attention to energy accounting.

Conclusions

Energy accounting is fundamental to energy management and auditing efforts. This forms-based system provides a flexible system for analyzing and summarizing energy use and cost in support of energy management objectives. It can service the energy accounting needs of many small organizations and help sell the concept of energy accounting in larger organizations needing a more sophisticated system. It can be a manual system using forms and a calculator or can easily be implemented in a spreadsheet environment.

Program Availability

The A-Form spreadsheet is available on disk as a Lotus 1-2-3 template or as a separate, stand-alone compiled version which does not require Lotus 1-2-3 to operate. The compiled version looks and acts like the original spreadsheet but will not allow modification or addition of new formula. To request a copy of the disk, call the Industrial Energy Advisory Service (IdEA$) at 1-800-VP-IDEAS (1-800-874-3327).

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File I.D. ________

ENERGY ACCOUNTING ANALYSIS
Year ________

Company/Division ________
Building ________
Building Area, gsf ________ Avg. Occupancy ________
Account No. ________ Meter No. ________
To convert ________ (Consumption Units) to MMBtu, multiply by ________ (Conversion Factor) Energy type ________

	Consumption ( )		Energy (MMBtu)	Cost $	

Energy Utilization Statistics

per gsf	EUI (Btu per gsf)	Cost per gsf
per occ	MMBtu per occ	Cost per occ
per day	MMBtu per day	Cost per day
per	MMBtu per	Cost per
Cost per	Cost per MMBtu	

Figure 1 Sample A-Form

File I.D. ________

ENERGY ACCOUNTING SUMMARY
Year ________

Company/Division ________

	Building Information			Current Period		Base Period		Avoided Cost		
File I.D.	Bldg/Meter	Area gsf	Energy Type	EUI Btu/gsf	Avg Cost $/MMBtu	EUI Btu/gsf	Avg Cost $/MMBtu	[illegible]	[illegible]	[illegible]
Totals										
Avg										
Max										
Min										

Figure 2 Sample S-Form

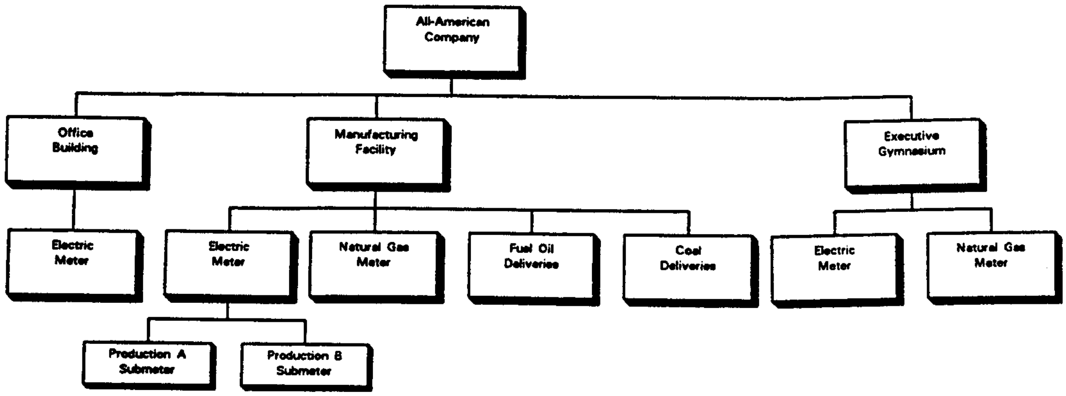


Figure 3 Energy Accounting Example
Building / Metering / Submeter Organization

File ID: AFORMEX1.WK1

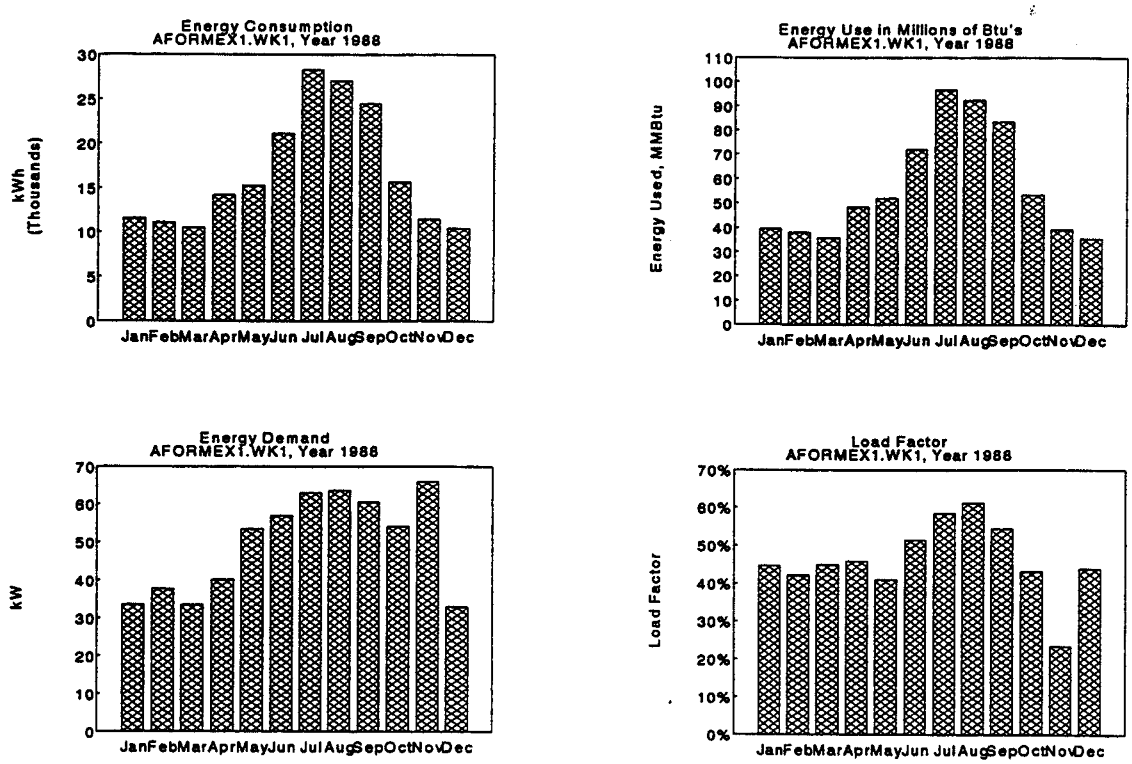


Figure 4 Graphs for Electric A-Form

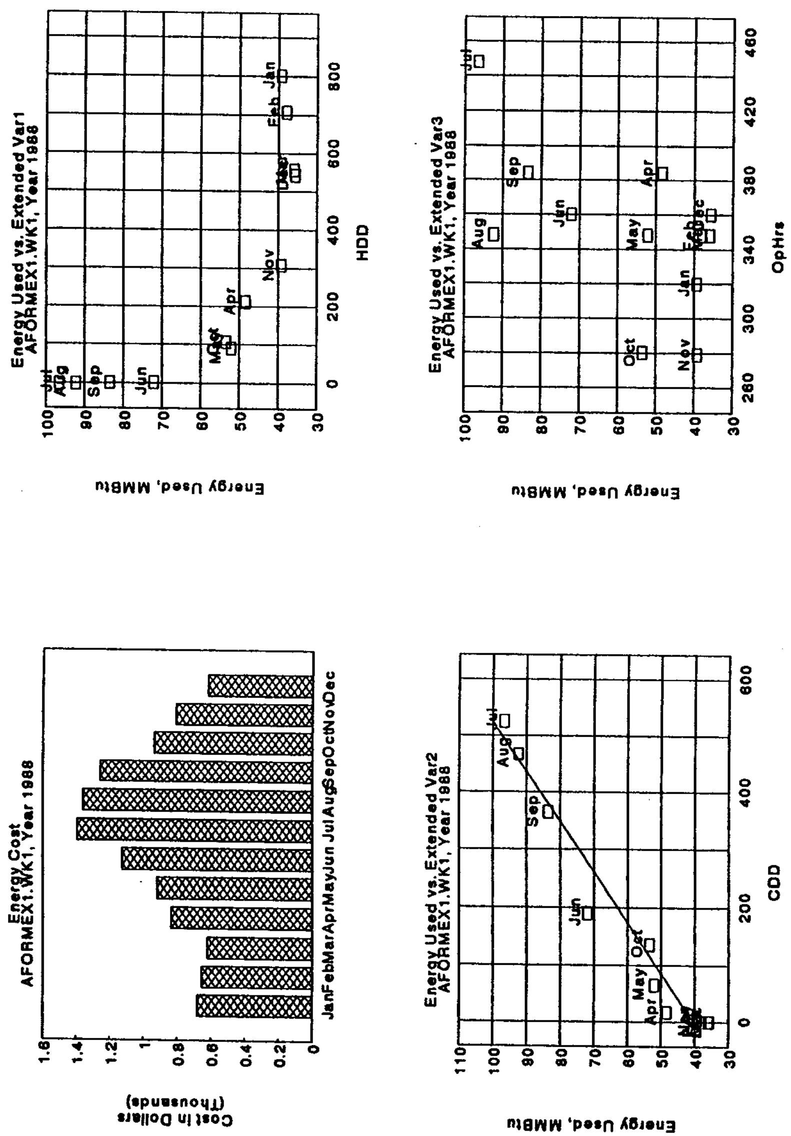


Figure 4 Graphs for Electric A-Form (continued)

File ID: AFORMEX2.WK1

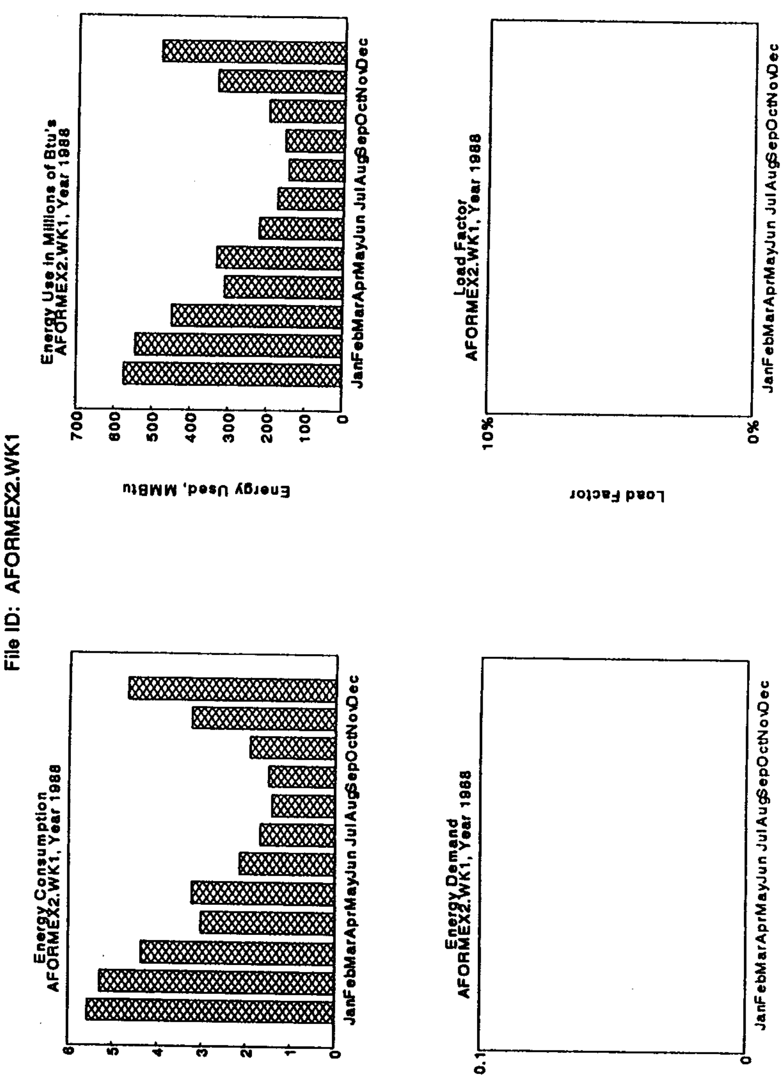


Figure 5 Graphs for Natural Gas A-Form.

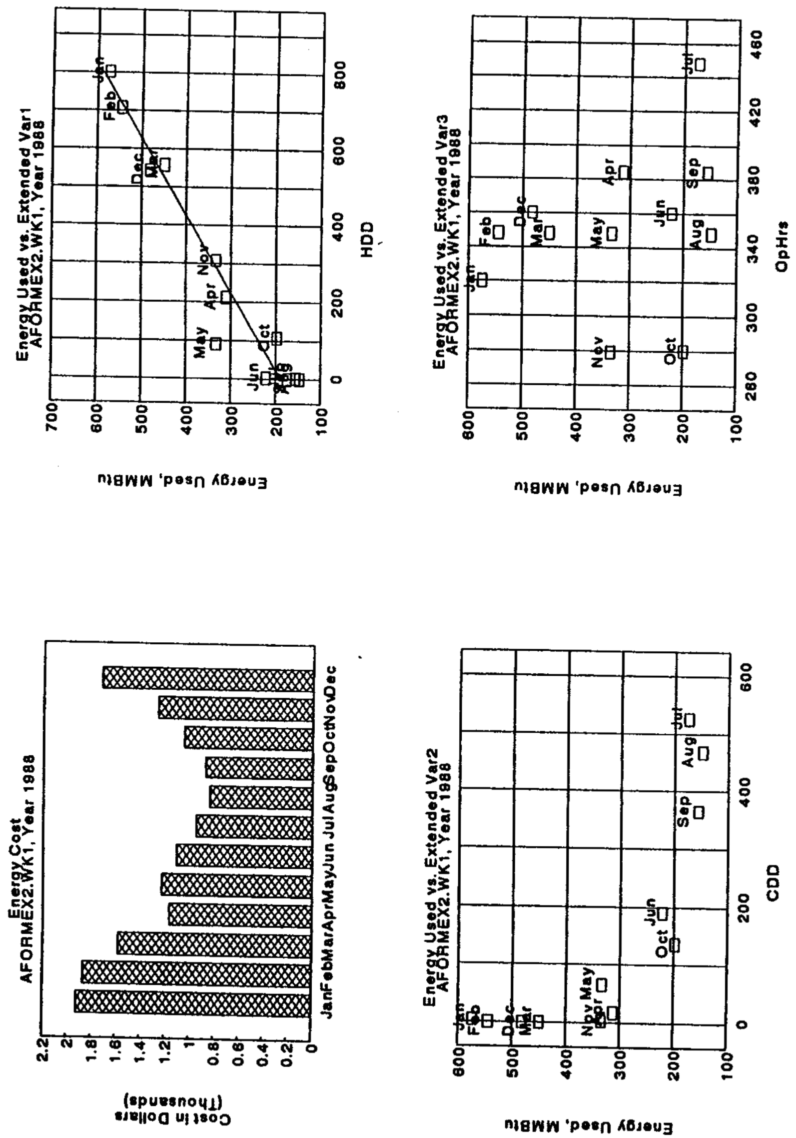


Figure 5 Graphs for Natural Gas A-Form (continued)

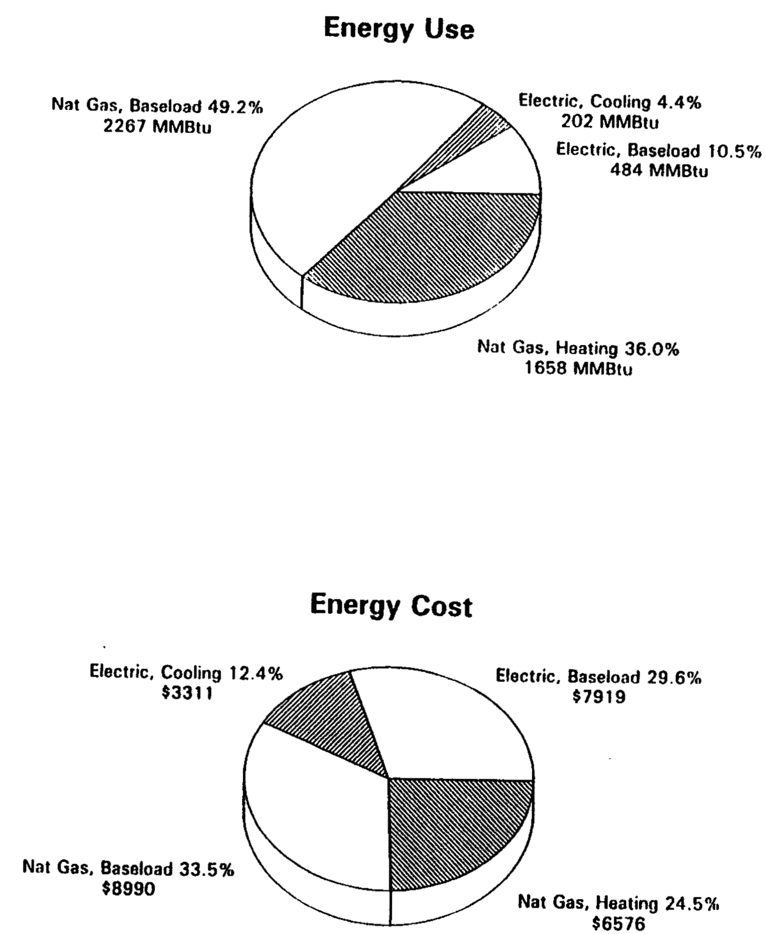


Figure 6 Energy Use and Energy Cost Breakdown

Table 2 Example of Electric A-Form

File ID: AFORMEX1.WK1

ENERGY ACCOUNTING ANALYSIS
Year 1988

Company: All American Company, Inc.   Division: Administration

Building: Executive Gymnasium

Building Area: 13276 gsf   Avg Occupancy: 100 persons

Account No: 002-0570-113   Meter No: E123-456-78

To convert kWh to MMBtu, multiply by 0.003413   Energy type: Electricity

Period			Standard Data					Extended Data		
	Current	No.	Demand	Consumption	LF	Energy	Cost	Var1	Var2	Var3
Month	Read Date	Days	(kW)	(kWh)	%	(mmBtu)	($)	HDD	CDD	OpHrs
	12/18/87									
Jan	01/19/88	32	33.6	11520	45%	39.32	682.42	801	4	320
Feb	02/17/88	29	37.8	11100	42%	37.88	657.81	707	0	348
Mar	03/17/88	29	33.6	10500	45%	35.84	622.65	557	0	348
Apr	04/18/88	32	40.2	14160	46%	48.33	837.13	212	17	384
May	05/17/88	29	53.4	15240	41%	52.01	921.14	91	65	348
Jun	06/16/88	30	57.0	21120	51%	72.08	1,128.00	3	190	360
Jul	07/18/88	32	63.0	28320	59%	96.66	1,394.18	0	526	448
Aug	08/16/88	29	63.6	27060	61%	92.36	1,360.96	0	468	348
Sep	09/16/88	31	60.6	24480	54%	83.55	1,258.70	2	365	384
Oct	10/14/88	28	54.0	15660	43%	53.45	938.70	107	136	280
Nov	11/14/88	31	66.0	11460	23%	39.11	808.51	308	3	279
Dec	12/14/88	30	33.0	10440	44%	35.63	619.13	543	0	360
Total		362		201060		686.22	$11,229.33	3331	1774	4207

Energy Utilization Statistics	kWh/gsf	Btu/gsf	Cost/gsf
	15.14	51,689	$0.85
	kWh/occ	mmBtu/occ	Cost/occ
	2010.60	6.86	$112.29
	kWh/day	mmBtu/day	Cost/day
	555.41	1.90	$31.02
	kWh/Hr	mmBtu/Hr	Cost/Hr
	47.79	0.1631	$2.67
	Cost/kWh	Cost/mmBtu	
	$0.0559	$16.36	

Table 3 Examples of Natural Gas A-Form

File ID: AFORMEX2.WK1

ENERGY ACCOUNTING ANALYSIS
Year 1988

Company: All American Company, Inc.   Division: Administration

Building: Executive Gymnasium

Building Area: 13276 gsf   Avg Occupancy: 100 persons

Account No: 002-0570-113   Meter No: G123-456-78

To convert ccf to MMBtu, multiply by 0.103000   Energy type: Natural Gas

Period			Standard Data					Extended Data		
	Current	No.	Demand	Consumption	LF	Energy	Cost	Var1	Var2	Var3
Month	Read Date	Days	( )	(ccf)	%	(mmBtu)	($)	HDD	CDD	OpHrs
	12/18/87									
Jan	01/19/88	32		5567	0%	573.40	1,924.00	801	4	320
Feb	02/17/88	29		5288	0%	544.66	1,870.62	707	0	348
Mar	03/17/88	29		4364	0%	449.49	1,581.41	557	0	348
Apr	04/18/88	32		3028	0%	311.88	1,163.24	212	17	384
May	05/17/88	29		3236	0%	333.31	1,228.35	91	65	348
Jun	06/16/88	30		2149	0%	221.35	1,105.52	3	190	360
Jul	07/18/88	32		1688	0%	173.86	948.24	0	526	448
Aug	08/16/88	29		1427	0%	146.98	840.97	0	468	348
Sep	09/16/88	31		1508	0%	155.32	874.26	2	365	384
Oct	10/14/88	28		1925	0%	198.27	1,045.65	107	136	280
Nov	11/14/88	31		3248	0%	334.54	1,261.34	308	3	279
Dec	12/14/88	30		4679	0%	481.94	1,722.12	543	0	360
Total		362		38107		3925.02	$15,565.72	3331	1774	4207

Energy Utilization Statistics	ccf/gsf	Btu/gsf	Cost/gsf
	2.87	295,648	$1.17
	ccf/occ	mmBtu/occ	Cost/occ
	381.07	39.25	$155.66
	ccf/day	mmBtu/day	Cost/day
	105.27	10.84	$43.00
	ccf/Hr	mmBtu/Hr	Cost/Hr
	9.06	0.9330	$3.70
	Cost/ccf	Cost/mmBtu	
	$0.4085	$3.97	

README 4-23-92

This disk contains files to supplement two papers by T. Kenneth Spain which were published in *Energy Engineering*, the Journal of the Association of Energy Engineers (AEE). These tools were developed to support activities of the Industrial Energy Advisory Service (IdEA$) at The University of Alabama in Huntsville. IdEA$ is sponsored by the Alabama Department of Economic and Community Affairs (ADECA), Science, Technology and Energy Division.

Your comments, critical review or suggestions for improvement are welcome. You may contact the author by calling IdEA$ at 1-800-VP-IDEAS (1-800-874-3327) or (205) 895-6707, by FAX at (205) 895-6668 or by mail at The University of Alabama in Huntsville, Johnson Research Center, Huntsville, AL 35899.

"Energy Accounting Using Spreadsheet Forms," T. Kenneth Spain, *Energy Engineering*, Vol. 89, No. 1, 1992, pp. 23-41.

AFORM.WK1 is a Lotus 123 spreadsheet template that produces an Energy Accounting Analysis (A-Form) for one year of utility data for one billing meter. AFORMEX1.WK1 and AFORMEX2.WK1 are templates that have example data entered as shown in the paper.

SEAS.EXE is a self-extracting ZIP file (produced using the PKZIP utility by PKWARE, Inc. of Glendale, WI) that contains all files necessary to RUN AFORM without requiring Lotus 123 or a compatible spreadsheet program. This is a fully functional application produced using the Baler spreadsheet compiler by Baler Software of Rolling Meadows, IL.

To install from the A: drive, place the diskette in drive and type **A:<Enter>** to make the A: drive the default drive. At the A:\> prompt, type **SEAS C:\pathname** to indicate the drive and subdirectory where you want the files installed. Note that the subdirectory you specify must already exist before you attempt to install the files.

The installation procedure places 12 files in the specified directory. Eight of these, RUN.EXE, AFORM.OVR, AFORM.PAT, AFORM.PR1, AFORM.PR2, BAFORM.WK1, CONST.400, and VIDEO.PAR, are required to run the program. SETCOLOR.EXE is used to customize colors, if desired. QBHERC.COM should be run before the program if you use a Hercules graphics card and plan to use on-screen graphics. EXAMPLE1.WK1 and EXAMPLE2.WK1 files contain example data which may be loaded into the program (for example, / File Get **EXAMPLE1**).

To run the standalone AFORM program, type **RUN AFORM**. The program functions like a typical spreadsheet with the exception that you cannot create new formula. A good general book on Lotus 123 can provide documentation for using the spreadsheet features of the program.

In either the Lotus template or the standalone version of AFORM, several pre-defined macros are available to help use the program.

<Alt-M> displays a Lotus-style main menu to assist in moving to different data ranges, viewing graphs, printing and saving files.

<Alt-D> prompts you to enter a date in the current cell; asks for month, date and year, then converts to a Lotus serial number to allow date arithmetic.

<Alt-G> displays a menu of predefined graphs.

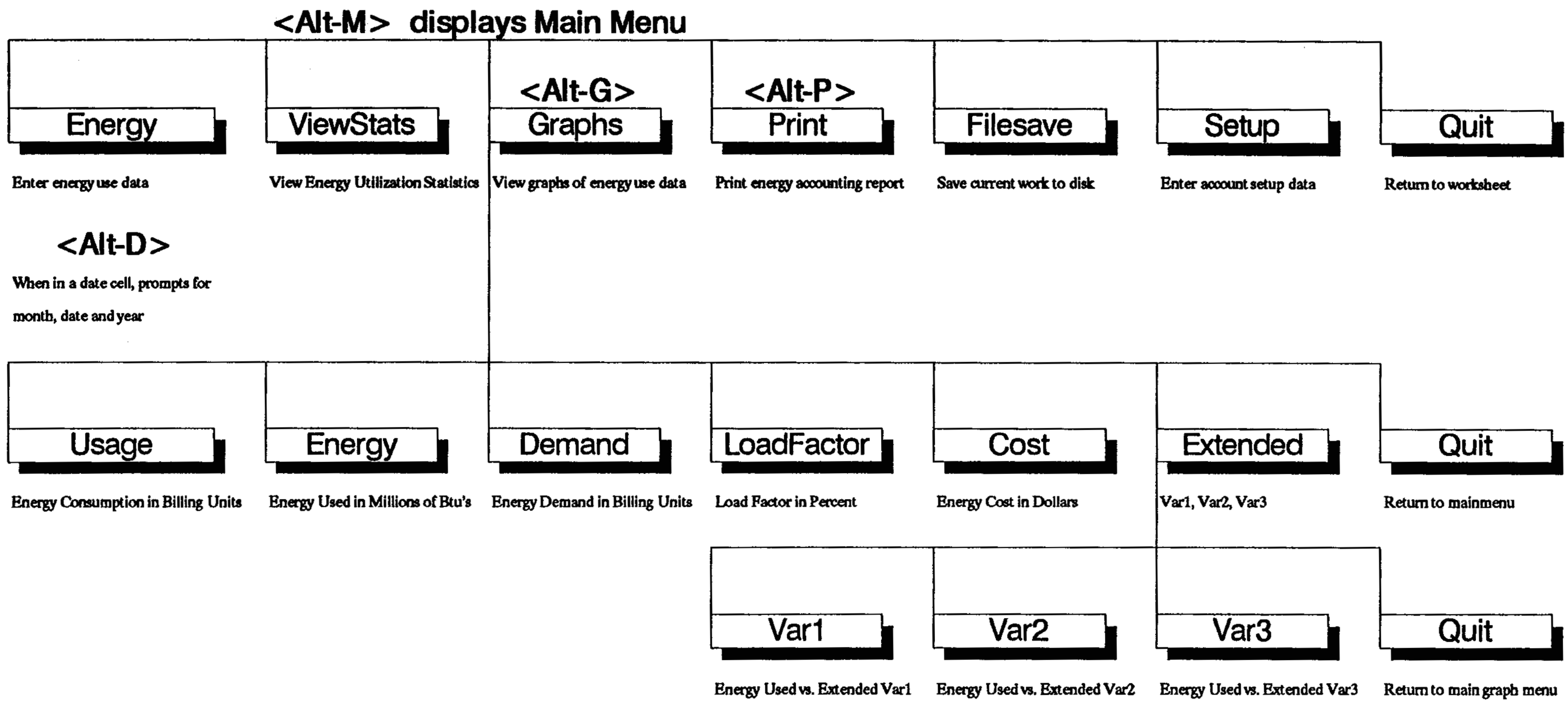
<Alt-P> prints the spreadsheet (on a single page, but from three data ranges).

The default print setup string selects the resident line printer font (compressed print) on an HP LaserJet Series II or compatible printer. If you have a different printer, consult your manual for the appropriate setup string for your printer and change by going to / **Print Printer Options Setup** (for example, use \015 for Epson FX80 printer).

"A Spreadsheet-Based Microcomputer Application for Determining Cost-Effectiveness of Commercial Lighting Retrofit Opportunities," T. Kenneth Spain, *Energy Engineering*, Vol. 89, No. 2, 1992, pp. 51-67.

LIGHT1.WK1 and LIGHT2.WK1 are Lotus 123 spreadsheet files that contain the lighting analysis spreadsheets shown in the paper. LIGHT1.FMT and LIGHT2.FMT are Impress or WYSIWYG add-in format files to provide spreadsheet publishing enhancements to the spreadsheets if you have the software to utilize them. These spreadsheets require Lotus 123 or a compatible spreadsheet to run.

AFORM Macro Menu Tree



Waste Reduction Guide to Electrotechnologies

published by

Tennessee Valley Authority
Waste Management

Waste Reduction Guide to Electrotechnologies

INTRODUCTION

This Guide serves as a handy reference to some of the Electrotechnologies that tend to reduce wastes in industrial processes.

The Guide is not intended to make the reader an expert in any of these areas. The Guide should give an appreciation of the types of applications in which use of these technologies are a viable option for reducing waste at the source.

SPECIAL THANKS

Most of this guide was reproduced or made available with permission by either:

1) The Electrification Council (TEC)
701 Pennsylvania Avenue, N.W.
Washington, DC 20004-2696

in association with

The UNIMAR Group, LTD
325 Market, P.O. Box 249
Alton, IL 62002

or

2) Electric Power Research Institute (EPRI)
3412 Hillview Avenue, P.O. Box 10412
Palo Alto, CA 94303
(800) 432-0267

YOU ARE URGED TO CONTACT THEM FOR ADDITIONAL DETAILS OF THESE TECHNOLOGIES OR ABOUT THEIR PROGRAMS.

Waste Reduction through *Electrotechnologies*

TECHNOLOGY	SAVES $$$	INCREASES QUALITY	REDUCES AIR EMISSIONS	REDUCES HAZARDOUS WASTE	REDUCES SOLID WASTE	REDUCES WASTE-WATER	REDUCES ENERGY USE
Direct Resistance	✓	✓	✓	✓	✓	✓	✓
EDM Electrical Discharge Machining	✓	✓	✓		✓		✓
Heat Pump	✓	✓	✓		✓		✓
Indirect Resistance	✓	✓	✓		✓		✓
Infrared	✓	✓	✓	✓			✓
Induction	✓	✓	✓	✓	✓	✓	✓
Laser	✓	✓	✓		✓	✓	✓
Membrane	✓	✓	✓	✓	✓	✓	
Microwave	✓	✓	✓				✓
Plasma Arc	✓	✓	✓		✓	✓	
Plasma Nitriding	✓	✓	✓	✓			✓
RF Radio Frequency	✓	✓	✓				✓
UV Ultraviolet	✓	✓	✓	✓	✓	✓	✓
Waterjet	✓	✓	✓		✓		
Emerging Techs ie electrophoresis freeze conc. infrared sand reclaim.	✓	✓	✓	✓	✓	✓	✓

Waste Reduction through *Electrotechnologies*

Technology / Process	Direct Resistance	EDM	Heat Pump	Indirect Resistance	Infrared	Induction	Laser	Membrane	Microwave	Plasma Arc	Plasma Nitriding	RF	UV	Waterjet
Heating - metals	✓			✓		✓	✓			✓				
Heating - nonmetals				✓					✓			✓		
Heating - in vacuum				✓										
Heating - brazing				✓			✓							
Heating (pre) - metals	✓			✓		✓								
Heating (pre) - plastics					✓				✓			✓		
Heating (post) - non-metals	✓			✓										
Heat treating	✓			✓		✓	✓			✓	✓			
Heating - space			✓	✓	✓									
Cooling - space			✓											
Kiln Drying - Lumber			✓	✓					✓			✓		
Drying, evap., distill. Concentration			✓	✓	✓			✓	✓			✓		
Drying - foundry sand core					✓				✓			✓		
Bonding - metal to plastic						✓								

Waste Reduction through *Electrotechnologies*

Technology / Process	Direct Resistance	EDM	Heat Pump	Indirect Resistance	Infrared	Induction	Laser	Membrane	Microwave	Plasma Arc	Plasma Nitriding	RF	UV	Waterjet
Curing - thermoset adhesive						✓			✓			✓		
Curing - textiles					✓				✓			✓	✓	
Curing - coatings and inks				✓	✓				✓			✓	✓	
Stripping - coatings														✓
Machining - tools, dies, molds		✓					✓				✓			
Fluid recovery or separation								✓						
Cutting							✓			✓				✓
Reuse - process fluid			✓	✓				✓					✓	
Food processing			✓		✓			✓	✓			✓	✓	✓
Papermaking			✓		✓				✓			✓		
Petrochemical			✓					✓	✓			✓		

Figure 4-1 ***Process Technology to SIC Application Matrix***

Applicability Key

- ○ None
- ◔ Limited
- ◑ Moderate
- ◕ Good
- ● Excellent

		TECHNOLOGY													
		Direct Resistance	EDM	Heat Pump	Indirect Resistance	Induction	Infrared	Laser	Membrane	Microwave	Plasma Arc	Plasma Nitriding	Radio Frequency	Ultraviolet	Waterjet
10	Metal Mining	○	○	○	◔	◔	○	○	○	○	○	○	○	○	○
12	Coal Mining	○	○	○	○	○	○	○	○	○	○	○	○	○	○
13	Oil & Natural Gas	○	○	○	◔	○	○	○	○	○	○	○	○	○	○
14	Non-Metal Mining	○	○	○	○	○	○	○	○	○	○	○	○	○	○
20	Food	◔	○	◕	◑	○	◑	◔	◕	◕	○	○	◑	●	◑
21	Tobacco	○	○	◔	◔	○	◔	○	○	◔	○	○	◔	○	○
22	Textiles	○	○	◑	◔	○	●	○	◑	◑	○	○	◑	◔	◑
23	Apparel	○	○	○	◔	○	◑	◔	◔	○	○	○	○	◑	◔
24	Wood	○	○	●	○	○	◔	◔	○	◔	○	○	◔	◕	◑
25	Furniture	◔	○	○	◔	◔	◑	◔	○	◔	◑	○	◔	●	◑
26	Paper	○	○	◑	◔	○	◕	○	◑	◔	○	○	○	●	○
27	Printing	○	○	○	◔	○	●	◔	○	◔	○	○	◔	●	○
28	Chemicals	○	○	◑	◔	○	◔	○	◕	◔	○	○	○	◕	○
29	Petroleum	○	○	◑	○	○	◔	○	◔	○	○	○	○	○	○
30	Rubber/Plastics	○	◔	◑	◕	◔	●	◔	○	◑	◔	○	◔	◑	◔
31	Leather	○	○	◔	◔	○	◔	●	◔	◔	○	○	◔	◑	●
32	Stone, Clay, Glass	◑	○	○	◑	◔	●	○	○	◔	○	○	◔	◑	◔
33	Primary Metal	◔	○	○	◑	●	◑	◔	◔	○	◔	◔	○	●	◔
34	Fabricated Metal	◑	◑	○	●	◕	●	●	◔	○	◕	◑	○	●	●
35	Industrial Machinery	◔	◑	○	◑	◑	○	◕	○	○	◑	◑	○	◑	◕
36	Electrical/Electronic	○	○	○	◔	◔	◔	◑	◔	○	◑	◔	○	◕	◕
37	Transport Equipment	◔	◔	○	◑	◑	◑	◑	◑	○	◑	◕	○	◑	◑
38	Instruments	◔	○	○	◔	○	○	◑	◑	○	◔	◑	○	◔	◑
39	Miscellaneous	◔	○	○	◔	◔	◑	◔	◔	○	◔	◔	○	◑	◑

Trade Associations

While Federal and State agencies can, and do, provide a wealth of information regarding environmental issues, there will be times when the organization constructing an environmental action program needs:

- More in-depth industry specific data than is available through other sources;
- Information on particular industry specific aspects of certain regulations;
- Information on industry segment responses to certain environmental challenges;
- Information on environmental strategies and success stories related to the particular industry segment.

In cases where highly focused data is essential, the industry trade association may be an especially valuable resource. Most companies in a given industry segment will be likely to belong to some sort of trade association relative to that segment but they may not have taken full advantage of services that might relate to an environmental effort.

Trade associations, of course vary markedly from industry to industry. Some may be extremely large, well funded organizations offering a wide range of valuable services while yet others may be little more than a one person shared office with responsibility for keeping up membership lists and sending out the occasional newsletter. Various trade association directories such as the National Trade and Professional Associations (NTPA) guide are readily available. These will normally list the associations by specialty and give some idea of staffing, membership and annual operating budget. These reference guides may usually be found in the reference section of your public library.

The following pages contain a listing of some of the major national trade associations for each of the mining and manufacturing SIC groups. Other associations within each industry segment or subsegment may also exist and should be listed in the previously referenced trade association directories.

SIC 10

American Mining Congress
1920 N Street, N.W.,
Suite 300
Washington DC 20036-1662
(202) 861-2800

Gold Institute
1112 16th Street, N.W.,
Suite 240
Washington DC 20036
(202) 835-0185

Silver Institute
1112 16th Street, N.W.,
Suite 240
Washington DC 20036
(202) 835-0185

Society for Mining, Metallurgy, and Exploration
P.O. Box 625002
Littleton, CO 80162-5002
(303) 973-9550

SIC 12

American Mining Congress
1920 N Street, N.W.,
Suite 300
Washington DC 20036-1662
(202) 861-2800

Nat'l Coal Association
1130 17th Street, N.W.
Washington DC 20036
(202) 463-2625

American Gas Association
1515 Wilson Blvd.
Arlington, VA 22209
(703) 841-8400

American Petroleum Institute
1220 L Street, N.W.
Washington DC 20005-8029
(202) 682-8000

Interstate Natural Gas Association of America
555 13th Street, N.W., Suite 300 W
Washington DC 20004
(202) 626-3200

Natural Gas Supply Association
1129 20th Street, N.W.,
Suite 300
Washington DC 20036
(202) 331-8900

SIC 14

American Mining Congress
1920 N Street, N.W.,
Suite 300
Washington DC 20036-1662
(202) 861-2800

The Clay Minerals Society
P.O. Box 4416
Boulder, CO 80306
(303) 444-6405

National Stone Association
1415 Elliot Place, N.W.
Washington DC 20007-2599
(202) 342-1100

SIC 20

American Association of Meat Processors
P.O. Box 269
Elizabethtown, PA 17022
(717) 367-1168

Beer Institute
1225 Eye Street, N.W.,
Suite 825
Washington DC 20005
(202) 737-2337

Biscuit and Cracker Manufacturers Association
1400 L Street, N.W.,
Suite 400
Washington DC 20005
(202) 898-1636

Food Processing Machinery & Supplies Association
200 Daingerfield Road
Alexandria, VA 22314
(703) 684-1080

Institute of Food Technologies
221 N. LaSalle Street,
Suite 300
Chicago, IL 60601
(312) 782-8424

National Food & Energy Council
409 Vandiver West, Suite 202
Columbia, MO 65202
(314) 875-7155

National Food Processors Association (NFPA)
1401 New York Avenue,
N.W., Suite 400
Washington DC 20005
(202) 639-5900

National Soft Drinks Association
1101 16th Street, N.W.,
Suite 700
Washington DC 22036-4877
(202) 463-6732

Snack Food Industry Association
1711 King Street, Suite 1
Alexandria, VA 22314
(703) 836-4500

United Dairy Industry Association
10255 W. Higgins
Rosemont, IL 60018-5616
(708) 803-2000

SIC 21

Cigar Association of America
1100 17th Street, N.W.,
Suite 504
Washington DC 20036
(202) 223-8204

Smokeless Tobacco Council
2550 M Street, N.W.,
Suite 300
Washington DC 20037
(202) 452-1252

Tobacco Institute
1875 Eye Street, N.W.,
Suite 800
Washington DC 20006
(202) 457-4800

Tobacco Merchants Association of the U.S.
P.O. Box 8019
231 Clarksville Road
Princeton, NJ 08543-8019
(609) 275-4900

SIC 22

American Association for Textile Technology
P.O. Box 99
Gastonia, NC 28053
(704) 824-3522

American Textile Manufacturers Institute
1801 K Street, N.W.,
Suite 900
Washington DC 20006
(202) 862-0500

American Textile Machinery Association
7297 Lee Highway, Suite N
Falls Church, VA 22042
(703) 533-9251

The Carpet and Rug Institute
P.O. Box 2048
310 S. Holiday Avenue
Dalton, GA 30722-2048
(706) 278-3176

SIC 23

American Apparel Manufacturers Association
2500 Wilson Boulevard,
Suite 301
Arlington, VA 22201
(703) 524-1864

Men's Fashion Association of America
475 Park Avenue South,
17th Floor
New York, NY 10016
(212) 683-5665

SIC 24

Hardwood Plywood and Veneer Association
P.O. Box 2789
Reston, VA 22090-2789
(703) 435-2900

National Hardwood Lumber Association
P.O. Box 34518
Memphis, TN 38184-0518
(901) 377-1818

National Lumber and Building Material Dealers Association
40 Ivy Street, S.E.
Washington DC 20003
(202) 547-2230

Timber Products Manufacturers
951 East Third Avenue
Spokane, WA 99202
(509) 535-4646

Wood Moulding & Millwork Producers Association
P.O. Box 25278
Portland, OR 97225-0278
(503) 292-9288

Wood Products Manufacturers Association
52 Racette Avenue
Gardner, MA 01440
(508) 632-3923

SIC 25

American Furniture Manufacturers Association
P.0. Box HP-7
High Point, NC 27261
(919) 884-5000

Business and Institutional Furniture Manufacturers Association
2335 Burton Street, S.E.
Grand Rapids, MI 49506
(616) 243-1681

National Home Furnishings Association
P.O. Box 2396
High Point, NC 27261
(919) 883-1650

SIC 26

American Pulpwood Assoc.
1025 Vermont Avenue, N.W., Suite 1020
Washington DC 20005
(202) 347-2900

Containerization and Intermodal Institute
P.O. Box 1593
North Caldwell, NJ 07007-1593
(201) 226-0160

National Paperbox Assoc.
1201 E. Abingdon Drive, Suite 203
Alexandria, VA 22314
(703) 684-2212

National Particleboard Association
18928 Premiere Court
Gaithersburg, MD 20879-1569
(301) 670-0604

Paperboard Packaging Council
1101 Vermont Avenue, N.W., Suite 411
Washington DC 20005
(202) 289-4100

Technical Association of the Pulp and Paper Industry
P.O. Box 105113, Technology Park
Atlanta, GA 30348-5113
(404) 446-1400

SIC 27

Association of American Publishers
220 East 23rd Street, 2nd Floor
New York, NY 10010-4606
(212) 689-8920

International Business Forms Industries
2111 Wilson Boulevard, Suite 350
Arlington, VA 22201-3008
(703) 841-9191

Magazine Publishers of America
575 Lexington Avenue, Room 540
New York, NY 10022
(212) 752-0055

National Association of Printers and Lithographers
780 Palisade Avenue
Teaneck, NJ 07666
(201) 342-0700

National Newspaper Association
1627 K Street, N.W., Suite 400
Washington DC 20006-1790
(202) 466-7200

Printing Industries of America
100 Daingerfield Road
Alexandria, VA 22314
(703) 519-8100

SIC 28

American Chemical Society
1155 16th Street, N.W.
Washington DC 20036
(202) 872-4600

Chemical Manufacturers Association
2501 M Street N.W.
Washington D.C. 20037-1303
(202) 887-1100

Chemical Specialties Manufacturers Association
1913 I Street, N.W.
Washington DC 20006
(202) 872-8110

Industrial Chemical Research Association
1811 Monroe
Dearborn, MI 48124
(313) 563-0360

National Agricultural Chemicals Association
Madison Building
1155 15th Street, Suite 900
Washington DC 20005
(202) 296-1585

National Paint and Coatings Association
1500 Rhode Island Avenue, N.W.
Washington DC 20005-5597
(202) 462-6272

Synthetic Organic Chemical Manufacturers Association
1330 Connecticut Avenue, N.W., Suite 300
Washington DC 20036-1702
(202) 659-0060

SIC 29

American Petroleum Institute
1220 L Street, N.W.
Washington DC 20005-8029
(202) 682-8000

National Lubricating Grease Institute
4635 Wyandotte Street
Kansas City, MO 64112-1596
(816) 931-9480

National Petroleum Refiners Association
1899 L Street, N.W., Suite 1000
Washington DC 20036
(202) 457-0480

SIC 30

Composites Institute
355 Lexington Avenue
New York, NY 10017
(212) 351-5410

Rubber Manufacturers Association
1400 K Street, N.W., Suite 900
Washington DC 20005
(202) 682-4800

Society of Plastics Engineers (SPE)
14 Fairfield Drive
Brookfield, CT 06804-0403
(203) 775-0471

Society of The Plastics Industry, Inc. (SPI)
1275 K Street, N.W.,
Suite 400
Washington DC 20005
(202) 371-5200

SIC 31

Footwear Industries of America
1420 K Street, N.W.,
Suite 600
Washington DC 20005
(202) 789-1420

Leather Industries of America
1000 Thomas Jefferson Street,
N.W., Suite 515
Washington DC 20007
(202) 342-8086

Luggage and Leather Goods Manufacturers of America
350 Fifth Avenue, Suite 2624
New York, NY 10118
(212) 695-2340

SIC 32

American Ceramic Society
735 Ceramic Place
Westerville, Ohio
43081-8720
(614) 890-4700

Flat Glass Marketing Association
3310 S.W. Harrison Street
Topeka, Kansas 66611-2279
(913) 266-7013

National Glass Association
8200 Greensboro Drive,
Suite 302
McLean, VA 22102
(703) 442-4890

National Stone Association
1415 Elliot Place, N.W.
Washington DC 20007-2599
(202) 342-1100

Primary Glass Manufacturers Council
3310 S.W. Harrison Street
Topeka, Kansas 66611-2279
(913) 266-3666

SIC 33

American Iron and Steel Institute
1101 17th Street, N.W.
Washington DC 20036-4700
(202) 452-7100

American Society for Metals
Metals Park, OH 44073
(216) 338-5151

Center for Metal Fabrication
Battelle Columbus Division
505 King Avenue
Columbus, OH 43201
(614) 424-7742

Center for Metals Production
Mellon Institute
4400 Fifth Avenue
Pittsburgh, PA 15213
(412) 578-3243

Forging Industry Association
Landmark Office Towers,
Suite 300-LTV
25 Prospect Avenue
West Cleveland, OH
44115-1040
(216) 781-6260

Society of Die Casting Engineers
2000 N. Fifth Avenue
River Grove, IL 60171
(312) 452-0700

Lead Industries Ass'n & Zinc Institute, Inc.
295 Madison Avenue
New York, NY 1017
(212) 578-4750

SIC 34

Fabricators and Manufacturers Association, International
833 Featherstone Road
Rockford, IL 61107
(815) 399-8700

National Association of Metal Finishers
401 N. Michigan Avenue
Chicago, IL 60611-4267
(312) 644-6610

National Ornamental and Miscellaneous Metals Association
804-10 Main Street, Suite E
Forest Park, GA 30050
(404) 363-4009

National Tooling and Machining Association
9300 Livingston Road
Fort Washington, MD 20744
(301) 248-6200

Precision Metalforming Association
27027 Chardon Rd.
Richmond Heights, OH
44143-1193
(216) 585-8800

SIC 35

Construction Industry Manufacturers Association
111 E. Wisconsin Avenue
Milwaukee, WI 53202-4879
(414) 272-0943

Farm Equipment Manufacturers Association
243 N. Lindbergh Boulevard
St. Louis, MO 63141
(314) 991-0702

Industrial Distribution Association
3 Corporate Square, Suite 201
Atlanta, GA 30329
(404) 325-2776

Manufacturers Alliance for Productivity and Innovation
1200 18th Street, N.W.,
Suite 400
Washington DC 20036-2506
(202) 331-8430

United States Cutting Tool Institute
1300 Sumner Avenue
Cleveland, OH 44115-2851
(216) 241-7333

SIC 36

Association of Home Appliance Manufacturers
20 North Wacker Drive
Chicago, IL 60606
(312) 984-5800

Battery Council International
401 N. Michigan Avenue
Chicago, IL 60611
(312) 644-6610

Electronic Industries Association
2001 Pennsylvania Avenue,
N.W.
Washington DC 20006-1813
(202) 457-4900

National Electrical Manufacturers Association
2101 L Street, N.W.
Washington DC 20037
(202) 457-8400

National Sound and Communications Ass'n
10400 S. Roberts Road,
Suite D
Palos Hills, IL 60465-1972
(708)598-7070

SIC 37

Aviation Distributors and Manufacturers Association International
1900 Arch Street
Philadelphia, PA 19103-1498
(215) 564-3484

Motor and Equipment Manufacturers Association
P.O. Box 13966
Research Triangle Park
Durham, NC 27709-3966
(919) 549-4800

Motor Vehicle Manufacturers Association of the United States
7430 Second Avenue,
Suite 300
Detroit, MI 48202
(313) 872-4311

National Association of Boat Manufacturers
401 N. Michigan Avenue,
Suite 1150
Chicago, IL 60611
(312) 836-4747

National Marine Manufacturers Association
401 N. Michigan Avenue,
Suite 1150
Chicago, IL 60611
(312) 836-4747

SIC 38

American Watchmakers-Clockmakers Institute
P.O. Box 11011
3700 Harrison Avenue
Cincinnati, OH 45211
(513) 661-3838

Analytical Instrument Association
225 Reinekers Lane, Suite 625
Alexandria, VA 22314
(703) 836-1360

Instrument Society of America
P.O. Box 12277
67 Alexander Drive
Research Triangle Park, NC 27709
(919) 549-8411

Measurement, Control and Automation Association
225 Reinekers Lane, Suite 625
Alexandria VA 22314-2875
(703) 836-1360

Photographic Manufacturers and Distributors Association
866 United Nations Plaza, Suite 436
New York, NY 10017
(212) 688-3520

SIC 39

Manufacturing Jewelers and Silversmiths of America
100 India Street
Providence, RI 02903-4300
(401) 274-3840

National Association of Band Instrument Manufacturers
38 West 21st Street, 5th Floor
New York, NY 10010-6906
(212) 924-9175

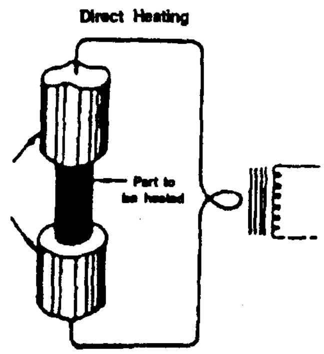
National Sporting Goods Association
1699 Wall Street
Mount Prospect, IL 60056-5780
(708) 439-4000

Toy Manufacturers of America
200 Fifth Avenue
New York, NY 10010
(212) 675-1141

Writing Instrument Manufacturers Association
2 Greentree Centre, Suite 225
P.O. Box 955
Marlton, NJ 08053
(609) 985-2878

Regulation Class: ◑ Clean Air ◔ Clean Water ◔ Haz. Waste ○ CERCLA ○ ______

Process Technology: *DIRECT RESISTANCE*



DIRECT RESISTANCE

Source: Maurice Orfeuil, Electric Process Heating, Batelle Press

Function/Theory

Direct resistance heating, sometimes called "conduction heating," involves connecting electrodes in contact with the workpiece and passing an alternating electrical current directly through the workpiece. The heat generated (I^2R) comes as a result of the electrical resistance (ohms) of the metal workpiece and the current flow (amperes).

Selection Criteria/Considerations

Acceptance: ☑ High ☐ Medium ☐ Low

- Used to heat long & slender, high resistivity workpieces, with higher than 6:1 length to diameter ratio.
- Applied to product runs of 200 - 2,000 pounds per hour.
- Glass melting (post heat only).
- Direct resistance welding is cost justified for spot, projection, seam, or flash buck welding of high volumes or parts.
- High frequency contact welding is particularly suited to pipe and tube 4" in diameter or more.

Environmental Benefits

- Low reject rates, resulting in less process waste.
- No combustion or fossil by-products.

Additional Benefits

- Uniform and fast heating.
- Low scale buildup.
- Selective or through heating.
- Very efficient heating.
- Small floor space requirements.
- Can be integrated into forging equipment (presses, upsetters).

Drawbacks

- Heating applications limited to Workpieces:
  - high length to diameter ratios > 6:1
  - uniform cross-sections
  - high resistivity metals
  - Isolation of unit from rest of the plant
  electronics may be needed in some cases (e.g. workpiece arcing)
- Workpiece overheating potential
- Workpiece ends must be clean and oxide free
- Frequent contact replacement required
- Essentially no reheat capabilities

Waste Stream Reduced

Air		*Water*		*Solid*
☐ Particulates	☑ Organics	☐ Particulates	☐ Organics	☑ Hazardous
☑ CO_2, NOx	☐ Toxics	☑ Metals, Ions	☐ Oil	☑ Non-Hazardous

SIC Potential

◔ 25% ◕ 75% ◑ 50% ● 100%

Mining

Metal	10	○
Coal	12	○
Oil & Gas	13	○
Mineral	14	○

Mfg.

Food	20	◔
Tobac	21	○
Textile	22	○
Apparel	23	○
Lumber	24	○
Furn	25	◔
Paper	26	○
Print	27	○
Chem	28	○
Petrol	29	○
Rubber	30	○
Leather	31	○
Stone, Glass	32	◑
Metals	33	◔
Metals Fabric.	34	◑
Mach	35	◔
Elect	36	○
Trans	37	◔
Instru	38	◔
Misc.	39	◔

P-1

Typical System Example

Size: Takes up about 50 sq. ft. of floor space {Forging/ Fabricated Metals}

Energy Requirement:

200 - 300 kW can typically heat around one ton of steel per hour in Forging

50 - 300 kW typically in forming

50 - 200 kW in welding

100 kW typically in metals fabrication

Efficiency: 85% in Fabricated Metals
80 - 90% in Forging

Economics

Capital Cost: $40,000 for Fabricated Metals
$165/kW in Forging

Payback: 1.67 years

Based on replacing a gas fired slot furnace with an electric resistance heating furnace. The application was based on heating 1" diameter x 14" long steel bars (3.1 lbs./bar) at a rate of 1500 lbs./hr to 2250 degrees F for a forging application.

Source: Pillar Industries

Service/Maintenance

Contacts and workpiece ends need to be clean and burr-free. Oxides and lubricants can impede the current flow. Contacts require dressing/ replacement on a periodic basis.

Vendors

New Cor Bay
Pillar Industries
Seco/Warwick
Taylor-Winfield
Thermatool
Thermtronix
TOCCO, Inc.

Notes

Major Vendors

DIRECT RESISTANCE

APV Crepaco
395 Fillmore Ave.
Tonawanda, NY 14150
(716) 692-3000

Newcor Bay
1846 Trumbell Drive
Bay City, MI 48707
(517) 893-9509

Pillar Industries
N92 W. 15800 Megal Dr.
Menomonee Falls, WI 53051
(414) 255-6470

Seco/Warwick
180 Mercer St.
Meadville, PA 16335
(814) 724-1400

Taylor-Winfield
1050 Mahonig Ave. NW
Warren, OH 44482
(216) 399-8862

Thermatool
31 Commerce St.
East Haven, CT 06512
(203) 468-4108

TOCCO, Inc.
30100 Stephenson Highway
Madison Heights, MI 48071
(313) 399-8601

EPRI Techcommentaries

Direct Resistance Heating
Direct & Encased Resistance Heating, EPRI CMF TechCommentary, Vol.3, No. 8, 1986
Direct Resistance Heating Blanks For Forging, EPRI CMF TechApplication, Vol.1, No.19, 1987

TECH COMMENTARY

DIRECT AND ENCASED RESISTANCE HEATING

Published by the EPRI Center for Materials Fabrication Vol. 3, No. 8, 1986

Putting the Heat Where It's Needed

Electric resistance heating offers manufacturers precise control and directed heat for applications such as preheating billets for forging, producing unique hardening patterns on metals, selectively heating forging dies and maintaining solutions at constant temperature. Direct resistance heating works only for electrically conductive workpieces, while any material, either solid or liquid can be heated with an encased resistance heater.

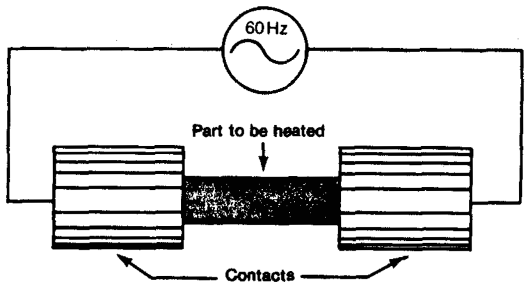
This issue of TechCommentary describes how these two heating techniques are used and the factors to consider in deciding whether one of them is appropriate for your application.

Direct Resistance Heating

By generating heat within the workpiece rather than in a furnace, direct resistance offers a number of benefits over fuel-fired furnaces including:

- Rapid heating
- Fast start up
- Energy savings
- Higher production rates
- Ease of automation
- Material saving as a result of reduced scale
- Improved working environment
- Reduced floor space requirements
- Low maintenance costs.

Direct Resistance Heating Overview



Any electrically-conductive material, metal or nonmetal, can be heated by direct resistance. Basically, the workpiece is clamped between two electrodes, or power connections, and current passed between them. Current flowing through the workpiece generates heat by the Joule effect.

The frequency of the AC current from the power supply determines the heating pattern. Low frequencies heat a product throughout its mass, so are used for through heating billets prior to forming, and for melting glass. Higher frequencies, on the other hand, flow only near the surface, so are used for surface hardening and seam welding.

Minimum equipment requirements for a direct resistance heating system are the current input electrodes and their attachment to the workpiece, and a power supply and power regulation equipment, as shown in the diagram. Automated systems require load handling equipment, and some systems include water-cooling to prolong electrode life.

Applications

The major metalworking applications of direct resistance heating are heating prior to forming, heat treating, and seam welding. Glass melting is the major nonmetals application. Other, less common, uses include heating concrete to accelerate setting, producing silicon carbide, and remelting metals in electroslag.

Heating prior to hot working— Direct resistance is used to preheat round or square metal bar stock prior to operations such as forging, stamping, extrusion, bending (for chains), and upsetting.

Workpiece material and shape are both important in determining the success of direct resistance heating. Materials with fairly high electrical resistivity, such as carbon and low-alloy steels and nickel alloys, are readily heated by direct resistance. With low resistivity materials like copper and aluminum, the process is often not cost-effective.

For most efficient heating the workpiece should have the following geometry:

- Diameter (or one side for square stock) less than 1.5 in.
- Length-to-diameter ratio at least 6:1. For smaller ratios, line and contact losses reduce efficiency (Figure 1).

Generally, to ensure even heating, the cross section of the workpiece should be uniform. Otherwise, the heating rate will be high where the cross section is small and low where it is large. However, workpieces with variations in their cross section, such as rivets, can sometimes be uniformly heated by pulsing the power during the heating cycle.

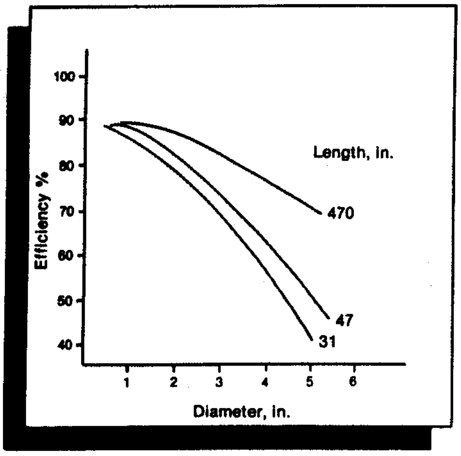


Figure 1. **Heating efficiency as a function of billet length and diameter.**

Recent improvements in electrode design have made the condition of the workpiece ends less critical. However, they should be fairly smooth and scale-free to ensure good contact with the power electrodes and maximize current flow. Finally, processing is most economical for loads of less than 2000 lbs/hr.

Traditionally, ferrous materials are preheated to around 2300 F (the exact temperature depends on the particular alloy) before hot working. However, there is a trend towards "warm forging," which is done at lower temperatures, (800-1700 F). Direct resistance heating works equally well for both since the final workpiece temperature depends only on heating time.

Through-heating equipment consists of the power input contacts and a line frequency power supply and controllers. The power electrodes are the critical component since they determine how much current can be passed to the workpiece, and heating rate depends on current flow. Contacts are often water-cooled to prolong their life. Contact design is generally done by the equipment manufacturer.

Technologies competing with direct resistance for heating prior to hot working include gas-fired furnaces and induction heating. The electric based methods, direct resistance and induction, offer several advantages over gas furnace heating including:

- Energy savings, because gas furnaces are inefficient at the temperatures required for preheating.
- Lower scale losses (½% rather than 2% of total workpiece weight) as a result of rapid heating. Besides material savings, reduced scale formation means less die wear and longer die life in hot working operations.
- Selective heating of ends or specific sections of bars by appropriate electrode placement.

Usually, direct resistance and induction are complimentary rather than competing heating techniques. However, for those workpieces of the right shape and size, direct resistance heating is more economical than induction. Equipment is less expensive and more energy efficient, so operating costs are also lower.

	Resistance	Induction
Power requirements	280 kWh/Ton	350 kWh/Ton
Efficiency	85%	65%

In addition, resistance heating is more versatile. Heating modules can be used in combination as necessary, and short-run jobs or die tryouts can be done without building new coils.

Direct resistance heated salt baths are often used for uniform through heating of workpieces. Two electrodes are mounted in the bath and a current is passed through the salt to melt it. Salt baths are more efficient than furnaces because heat transfer to the workpiece is by conduction rather than convection.

Heat treating applications — Direct resistance heating is an excellent method for selective surface hardening carbon and low-alloy steels and cast iron. Such hardening improves the wear resistance of products like automobile universal joints, engine piston rings, wrenches, leaf springs, and hedge clippers.

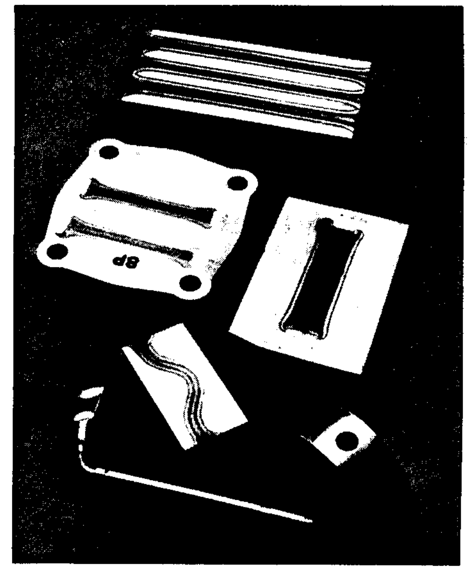
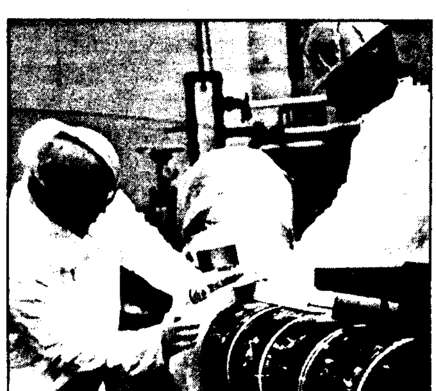


Figure 2. **Parts hardened by direct resistance heating.**

For hardening, two power contacts are attached to the workpiece just beyond the ends of the area to be hardened. A water-cooled "proximity conductor" is placed close to the workpiece surface, and connected between the electrodes. When high frequency current (usually radio frequency [RF], 400 kHz) is passed between the power contacts, the narrow strip of workpiece surface under the proximity connector heats up. Heating depth is about 0.03 in. The strip reaches hardening temperature (about 1600 F in steel) in about 0.5 sec, so the surrounding workpiece material remains cool. Thus, the process is self-quenching, so there is almost no part distortion. The hardening pattern produced mirrors the proximity conductor shape, and, with appropriately-designed conductors, many different, well-



This fuel oil pipe must be kept at 130 F even when the outside temperature is 0 F and there is a 20 mph wind.
The company chose constant-wattage heating cable, laid in parallel lengths along the pipe, even though steam was available as a plant byproduct. The cable is insulated with 2 in. of calcium silicate and covered by an aluminum jacket so that it retains its shape even when walked on. This system was easy to install, operates on their available 277 V supply, and requires little maintenance.

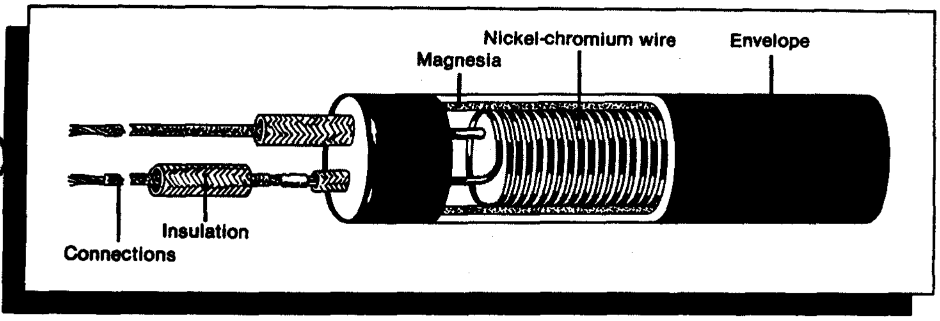


Figure 3. **A cartridge heater containing an encased resistance element.**

defined hardening patterns, on either flat or tubular workpieces, are possible. Some of these patterns are shown in Figure 2.

Direct resistance through heating and surface hardening differ in their power supply requirements. A line frequency supply works for through heating, whereas hardening requires an RF supply. Such high-frequency power supplies are expensive ($100,000-200,000 depending on size), so direct resistance hardening is economical only in high volume applications.

Other methods used for selective hardening include induction heating and laser and electron beam hardening. (Convection furnaces do not work because of the difficulty of controlling the hardening pattern.) All of these methods are fast and produce little heat distortion. However, laser and electron beam hardening are limited to case depths of less than 0.02 in. In addition, equipment is expensive and complex, both to operate and to maintain.

Induction hardening can produce greater case depths but is restricted to patterns for which a coil can be designed. However, direct resistance and induction hardening use the same power supply, so you can produce almost any pattern by selecting either a coil or a contact/proximity-conductor assembly.

Joining — High-frequency resistance heating is widely used for seam welding steel tubing, and occasionally copper and aluminum tubing. The tube is moved past two stationary electrodes that pass RF current through its edges. Heat generated by the current causes the edges to melt and fuse together. The process is always automated, making direct resistance welding fast and economical. Unlike induction welding, which is energy efficient only for small diameters, any size tube can be resistance welded.

Resistance welding is also used for many special joining applications, of both similar and dissimilar metals, which would be impossible with induction. These include structural shapes such as I- and H-beams and T-sections, and welding fins to cubes.

	Heating Cartridges	Immersion Heaters	Heating Collars	Heating Tapes
Materials and some uses	Metal dies, core boxes and welding tools	Plating, pickling, degreasing solutions; melting solder	Pumps, punches, presses, tubular ovens	Valves, pumps, pipes carrying chemicals, fuels or food
Operating temperature	To 1500 F	To 1600 F	To 1650 F	Depends on type
Attachment method	Inserted in holes drilled in product	Flanges, screw plugs, over-the-side brackets	Brackets or bolts	Wrapped or taped
Competing processes	Plasma torches, convection ovens	Gas immersion, gas-fired steam	Depends on application	Steam heating lines

Table 1. **Some Characteristics of Encased Resistance Heaters**

Encased Resistance Heaters

Resistance heating is not restricted to electrical conductors. Non-conductive materials can be heated by placing them in contact with encased resistance heaters. Heat is transferred from the heater by thermal conduction.

Encased resistance heaters come in an enormous range of "packages" and have a correspondingly wide range of applications. For example, they are used to heat fish tanks and household hot water, and are an integral part of electric blankets. However, we will limit this discussion to industrial applications.

Advantages

Because their uses are so varied, it is difficult to define benefits of encased resistance heaters independent of application. However, this diversity is an advantage in itself, since a heater can be found for practically any application. Other advantages include:

- Low cost. Heaters are fairly inexpensive, reliable, durable, and require little maintenance.
- Energy efficiency. Close to 100% of the applied energy is converted to useful heat.
- Precise temperature control. Thermostats ensure well-controlled heating.

An encased resistance heater consists of an electric wire or ribbon resistance element surrounded by an electrical insulator enclosed in an outer envelope. The outer covering provides mechanical and chemical protection (Figure 3). The heater is placed on or in the solid or liquid to be heated. Heat generated by current flow through the resistance element is transferred to the workpiece by conduction. These heaters almost always use line frequency, and they can be designed to operate at whatever voltage a plant has available.

Encased resistance heaters are classified by shape, maximum operating temperature, type of insulation, and application. Commonly used types include:

- Heating cartridges
- Immersion heaters
- Heating collars
- Heating tapes.

Some of the characteristics and a few common applications of each type are summarized in Table 1.

Technical Considerations

While application determines which particular heater is most appropriate, in all situations the heater power density and outer casing material must be carefully considered.

Power density is a function of the material from which the actual resistance element is made, the maximum temperature the case can withstand, and the shape of the heater and its cross section. While it is generally true that a higher power density heats faster, this is not necessarily desirable. Suppose, for example, that a liquid is to be held at a temperature below its boiling point. If the power density is too high, the fluid touching the heater will boil. To prevent this, the heater chosen should have a surface area sufficient to transfer enough heat, while maintaining a fairly small temperature difference between the heater surface and the fluid. Similarly, if a high-powered heater is used with a poorly conducting material, heat will not be removed from the heater fast enough, resulting in overheating and premature failure of the heater element. Equipment suppliers are experienced in determining the right heating element, and they will help you make the best choice.

Case material must be able to withstand the environment in which it will be used, both thermally and chemically. Plastic casing materials are only useful up to about 300 F, steels to around 950 F, nickel alloys to 1500 F, and some ceramics up to about 1800 F. The liquid in which they are immersed also influences the choice of outer sheath material. For example, copper or stainless steels work well for water heaters but PTFE-coated steel or nickel alloys may be required for highly corrosive liquids.

There is no average cost for encased resistance heaters because of the wide range of models available. However, they are frequently a more cost-effective solution to heating problems than are the competing processes.

In Summary

There are a number of non-furnace heating techniques which use resistance heating. Two of the most important are direct resistance and encased resistance heating. Direct resistance heating may well be the simplest and most economical method for through heating or heat treating workpieces of the appropriate material and geometry. Encased resistance heaters, available in a wide range of shapes, sizes, and electrical ratings, are generally used when reliable, long-term heating at low to medium temperatures is required.

The information in this issue of TechCommentary is an overview and is intended only to familiarize you with the basic aspects of special forms of resistance heating. For more information please contact CMF or one of the suppliers of resistance heating equipment.

The Center for Materials Fabrication (CMF) is operated by Battelle's Columbus Division. Basic funding is provided by the Electric Power Research Institute, a nonprofit institute that conducts research and development on behalf of the United States electric utility industry

The Center's mission is to assist industry in implementing cost- and energy-efficient, electric-based technologies in metals fabrication and related fields. TechCommentary is one communication vehicle that the Center uses to transfer technology to industry. The Center also conducts research in metal heating, metal removal and finishing, and fabrication.

This issue of TechCommentary was made possible through the cooperation of Battelle staff members Lee Semiatin, Senior Research Scientist, John Hallowell, Industry Applications Engineer, Laura Cahill, Manager, Marketing and Communications, and Denise Sheppard, Publications Coordinator; and Anne Moffat and Dorothy Tonjes of ProWrite. Technical review was provided by John Meek, Chromalox, Paul Miller, Inductoheat, and Humfrey Udall, Thermatool.

Sources used in this issue of TechCommentary were:

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Photographs courtesy of Fabricator (Figure 2), New England Power and Chromalox (Figure on page 2)

Applicable SIC Codes

34—23, 29, 52, 62, 82, 83, 89
35—23, 24, 31-33, 44, 45, 68
37—11, 13-15, 21, 24, 28, 43, 51, 61, 95, 99

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APPLICATION

Direct Resistance Heating Blanks for Forging

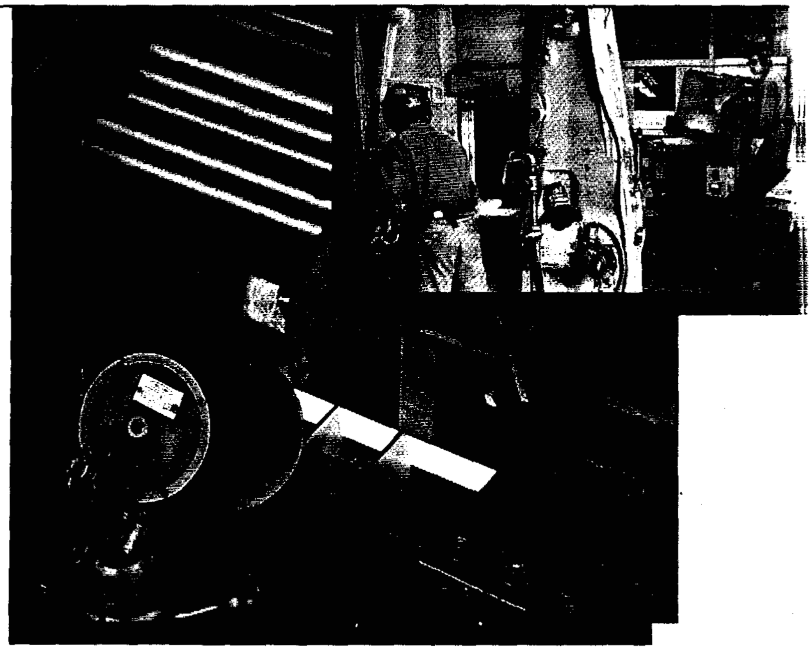
Published by the EPRI Center for Materials Fabrication Vol. 1, No. 19, 1987

The Challenge: Build a Modern Forging Plant

Modern Drop Forge of Blue Island, Illinois, manufactures forgings for such products as roof drills for mines, chain cutters, air conditioning flanges, connecting rods, idle arms and cam shafts. When it outgrew its present plant's capabilities, it decided to add an entire new plant. It wanted the new plant to

- Cope with rising energy costs
- Be close to its mining, automotive and railroad customers
- Improve product quality
- Reduce manpower requirements through automation
- Provide good working conditions.

It considered sites in Kentucky, Virginia, Tennessee and North Carolina before deciding to locate in Piney Flats, Tennessee. In 1978 the new facility, named Modern Forge/Tennessee, began producing custom-designed drop forgings in an efficient, all-electric facility that boasted a greatly improved forging environment. Much of the improvement can be credited to the electric resistance and induction heaters Modern Forge uses to heat blanks to forging temperatures. And with operating efficiencies close to 85%, direct resistance heaters have led the way in controlling energy costs.



A steel blank is dropped from the magazine, clamped with electrodes at each end, and consistently heated to forging temperature within seconds.
Inset: The heated blank is conveyed to the forging station.

The Traditional Way

In a typical forging plant using fossil-fueled furnaces, a worker would load a gas-fired furnace with 30 to 40 bars of steel that were 4 or 5 times as long as the material necessary to produce the forging. The ends of the bars would be heated to 2250 F for about 15 to 20 minutes until a worker determined that the proper temperature had been reached.

For the next 45 minutes the worker would remove a long bar from the furnace to the drop hammer and hold it in place. The hammer operator would work the end of the bar until a piece was forged into the desired shape and cut from the bar. The worker would then replace this bar in the furnace and place the heated end of the next bar into the forging hammer. The process was repeated until all the bars had been used up and it was time to reload the furnace.

The work was fatiguing and time consuming. The worker had to face an open furnace much of the day, and work stopped when waiting for the bars to heat.

The New Way

At Modern Forge/Tennessee the bars are cold sheared into individual blanks and cleaned by shot blasting to prepare them for direct resistance heating. The cleaned blanks are loaded into a magazine and fed one at a time into the heater, where each is automatically clamped between two electrodes and quickly heated by electric current passing through it. The current passes through the metal for a predetermined length of time or until an infrared sensor shuts it off.

The heated blank is conveyed directly into the drop hammer where it is forged as before. Forging continues uninterrupted throughout the day except for a morning, a lunch and an afternoon break. Since only 11 seconds is required to heat each blank from ambient temperature to 2250 F, there are no delays.

Modern Forge has 7 drop hammers in operation with hammers ranging from 1500 to 4000 pounds. Two are fed by direct resistance heaters and 5 by induction heaters. Modern Forge/Tennessee uses direct resistance heaters for bars up to $1\frac{1}{16}$-inch diameter and induction heating for larger diameter bars.

The Results: Improved Productivity and Better Working Conditions

Labor savings. Since loading the blanks into the magazine takes less time, 1 worker now can keep 2 drop hammer operators supplied with heated forging material rather than just 1.

Determining when the steel had reached the proper temperature required a skilled worker with experience and high visual acuity. Now the direct resistance heaters are calibrated with every new setup, and the steel is heated to the proper temperature automatically. Less-skilled labor can be used for the loading operation.

Higher quality product. Since direct resistance heating is so fast, scale formation is no longer a problem. Before, some bars would be in the furnace a long time and accumulate a great deal of scale. Now, with little or no scale formation, the finished product has a superior finish and appearance.

Energy usage. Electric resistance is extremely efficient in heating only the workpiece, without heating the surrounding furnace as in conventional operations. Because of its efficient energy usage, electric resistance costs about $33.80 to heat a ton of steel to 2250 F while using a fossil-fuel furnace would cost about $34.80.

Improved work environment. The ambient temperature of the building has been reduced, and the fumes and dirt inherent with fuel-fired furnaces have been eliminated.

Space savings. The direct resistance heating operation requires 15% to 20% less floor space.

Material usage. Each direct resistance heated blank requires about a 1-inch long tong hold which is cut off and discarded once the forging is completed. Each furnace-heated bar also requires a tong hold, but 4 or 5 forgings are made from each bar. Therefore the material discarded is 4 to 5 times greater for direct resistance heating.

Setup and calibration. Direct resistance heating requires up to a 2-hour setup and recalibration when changing from one product to another.

What Did It All Cost?

Modern Forge paid about $50,000 for each of its 2-unit direct resistance heating stations. Each heater typically requires 550 kVA at 480 V. Modern Forge's payback period was about 2½ years.

Alternatives and Competing Technologies

Indirect resistance heating can be used for heating metal prior to forging, but it is only 50% to 60% efficient. Oil-fired furnaces are difficult to control and cannot be used with better refractory materials so they are less energy-efficient. Natural gas is less destructive to furnace refractory materials than oil but shares many of its drawbacks:

- Not easily amenable to automation
- Large scale losses due to long heating times
- Thermal efficiencies of only 10% to 34%.

The Bottom Line: A Modernized Plant Well-Suited for Its Product

Determining the most cost-effective manufacturing method has no easy answers. Direct resistance heating has proven itself the best choice for Modern Forge/Tennessee's 1 1/16-inch-diameter stock because its lower labor and energy costs more than offset higher material costs.

Other Applications of Direct Resistance Heating

In addition to heating blanks for forging, direct resistance heating is used to produce unique hardening patterns on metals and to selectively heat forging dies. For more information on direct resistance heating, see *TechCommentary* Vol. 3, No. 8.

Company Profile

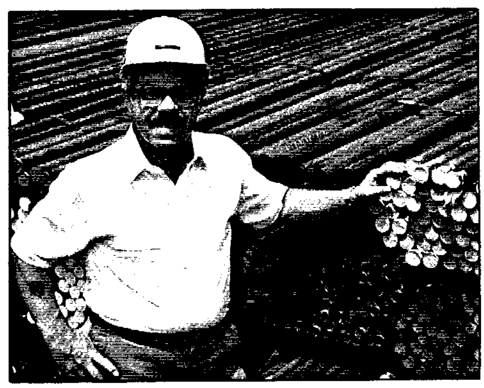
Modern Forge/Tennesse
Piney Flats, Tennessee

President and General Manager—Ron Shrum

Approximately 90 employees

A leading supplier of raw forgings for the automotive aftermarket and mining industries.

Company philosophy: Growth happens by performance and dedication to quality, service and economy.



Ron Shrum—General Manager of Modern Forge/Tennessee's efficient all-electric plant.

The Center for Materials Fabrication (CMF) would like to thank Tom Bartley of Modern Drop Forge for valuable contributions made to this issue.

Tennessee Valley Authority provides electric service for Modern Forge/Tennessee.

CMF is operated by Battelle's Columbus Division. Basic funding is provided by the Electric Power Research Institute, a nonprofit institute that conducts applications development on behalf of the United States electric utility industry. *TechApplication* is one of the ways the Center assists industry in implementing cost- and energy-efficient, electric-based technologies in materials fabrication and related fields. This issue was cofunded by a grant from the United States Department of Energy Office of Industrial Programs.

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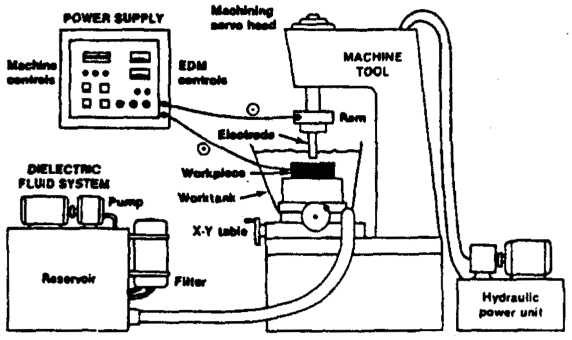
SIC Potential
◔ 25% ◕ 75%
◑ 50% ● 100%

Process Technology: *ELECTRICAL DISCHARGE MACHINING (EDM)*



EDM PROCESS

Source: EPRI - TECHCOMMENTARY, Vol. 3/No. 1

Function/Theory

- An electrode is placed near an electrically conductive workpiece which is submerged in a non-conductive fluid.
- Initiating a 40 - 80 volt potential in the electrode causes a small electrical discharge, eroding a small part of the workpiece (and part of the electrode).
- By pulsing the voltage at frequencies from 1 kHz to 1,000 kHz, the workpiece may be cut or milled as desired.

Selection Criteria/Considerations

Acceptance: ☑ High ☐ Medium ☐ Low

- Used in production of carbide tools, dies, and making long, small diameter holes or narrow slots in metal.
- Requires consistent, quality power.
- Used for difficult-to-machine metals and shapes.
- Fast accurate prototyping of parts, molds, and dies.

Environmental Benefits

- Lower process waste due to lower scrap rate.

Additional Benefits

- Fast response & dependable, easily automated.
- Can produce any shape: odd-shaped holes, deep slots or difficult cavities.
- Very high quality cutting, very little distortion, and very accurate, resulting in burr-free, precise shapes.
- Very flexible, can cut high length to diameter workpiece or drill at shallow angles.
- Can create solid dies eliminating sectionalizing, reducing labor requirements and grinding.

Drawbacks

- High capital costs
- Relatively slow for cutting mild steel
- Higher maintenance required to keep dielectric clean in "dirty" applications
- Workpiece must be conductive
- Slower material removal rate
- Electrodes near end of life may produce inaccuracies
- Cavities may be slightly tapered
- Leaves a very shallow, highly stressed layer
- Undesirable recast layer may need to be removed

Mining

Metal	10	○
Coal	12	○
Oil & Gas	13	○
Mineral	14	○

Mfg.

Food	20	○
Tobac	21	○
Textile	22	○
Apparel	23	○
Lumber	24	○
Furn	25	○
Paper	26	○
Print	27	○
Chem	28	○
Petrol	29	○
Rubber	30	◔
Leather	31	○
Stone, Glass	32	○
Metals	33	○
Metals Fabric.	34	◑
Mach	35	◑
Elect	36	○
Trans	37	◔
Instru	38	○
Misc.	39	○

Waste Stream Reduced

Air		*Water*		*Solid*
☐ Particulates	☐ Organics	☐ Particulates	☐ Organics	☐ Hazardous
☑ CO_2, NOx	☐ Toxics	☐ Metals, Ions	☐ Oil	☑ Non-Hazardous

P-2

Electrical Discharge Machining (cont.)

Typical System Example

Size: 10" x 12" up to 39" x 47" table for Fabricated Metals.

Energy Requirement:

2 - 20kW for Metals Fabrication

Efficiency: 70 - 80% in Fabricated Metals

Economics

Capital Cost: $120,000 plus $40,000 for computer & software

Source: The UNIMAR Group, Ltd.

Service/Maintenance

Change the filters and dielectric fluid. In vertical EDM, electrode wear requires resurfacing/ replacement, depending on surface quality requirements.

Vendors

Mitsubishi

Notes

Major Vendors

EDM

Mitsubishi
610 Supreme Dr.
Bensenville, IL 60106
(708) 860-4210

EPRI Techcommentaries

Electrical Discharge Machining

Electrical Discharge Machining, EPRI CMF TechCommentary, Vol.3, No.1, 1986
Electrical Discharge Machining, EPRI CMF TechApplication, Vol.1, No. 9, 1987

TECH COMMENTARY

ELECTRICAL DISCHARGE MACHINING

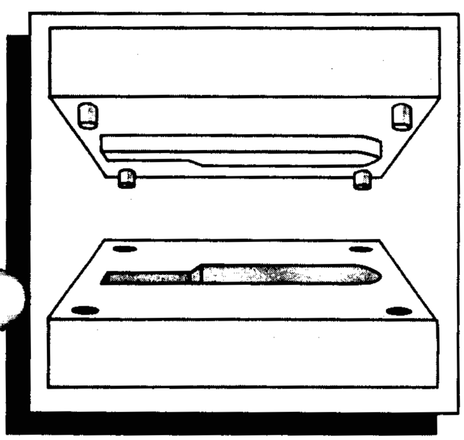
Published by the Center for Metals Fabrication Vol.3, No.1, 1986

EDM: The Metal-Removal Problem Solver

Today machine shops are being asked to machine hard materials into intricate and unusual shapes. In many cases traditional machining methods just don't measure up. Electrical Discharge Machining (EDM) fills this gap and produces high quality products.

While the basic EDM process has been around for over 40 years, only recently have advances in power supplies and computer control made it practical for many applications. An increasing number of companies find that they can save money and manpower by using EDM. For example, tools used in the manufacture of dies and punches previously took skilled craftsmen endless hours to produce by hand. Now they can be machined automatically—faster, more accurately, in a single piece, in hardened metal, and at a fraction of the cost. For many other companies EDM is the only way to get a job done, because EDM can create burr-free, intricate and precise shapes in materials that otherwise cannot be machined. In fact, the EDM process is so versatile that the shapes it creates are limited only by a designer's imagination. These shapes include workpieces with high length-to-diameter ratios, extrusion dies where difficult angles are required, and gears where repeatability of critical specifications is a necessity.

***Figure 1.* A punch and die that stamps blades for an electric knife.**



Applications

Because EDM is able to create this wide variety of difficult shapes, it has become popular for many different applications. EDM has found widespread use not only in the manufacture of punches and dies, but also in moldmaking, aerospace applications, making extrusion dies, and the production of small holes (larger than 0.015 inch) and micro-holes (0.015 inch and smaller). Creating small and/or deep slots is another important EDM application. However, its most popular application is in the making of blanking dies.

EDM can be used to advantage in many situations, and a few examples are given below. While none of the examples may exactly fit your type of work, they may give you ideas on how to use EDM to solve some of your more difficult machining problems.

- In 1973, a punch and die set used to stamp blades for an electric knife was made of carbide, without EDM, at a cost of $12,900. In 1984, it was produced in-house by wire-cut EDM at a cost of $4,000. The set was made of CPM-10V and has stamped more than 100,000 parts. (See Figure 1).
- A three-gang punch and die set took about 1,000 hours to manufacture using conventional methods and required sectionalization. Using EDM took 1/5 the time and the die was manufactured in a single piece. Machining with a solid die is more accurate because the die is more rigid than a die made in sections and bolted together. (See Figure 2).
- EDM was selected as the method to produce holes in a stainless steel medical cannula where no burrs could be tolerated. (See Figure 3).

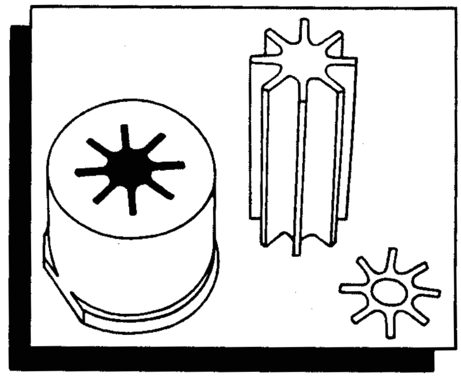


***Figure 2.* A punch and die that punches the small star-shaped fiber part in the lower right.**

A summary of representative parts produced by different industries is given in Table 1.

Advantages and Limitations

EDM is selected for a job because of the advantages it offers over conventional methods. The

Industry	Part
Tool and Die	Plastic molds Form tools Extrusion dies Blanking dies Punches
Automotive	Die shoes Trim dies Fuel injector nozzles Carburetors
Aerospace	Cooling holes in turbine blades Turbine blade root sections Combustor liners Turbine nozzle bands
Medical Supplies	Cannula tubes

***Table 1.* Representative Parts Produced in Various Industries by EDM**

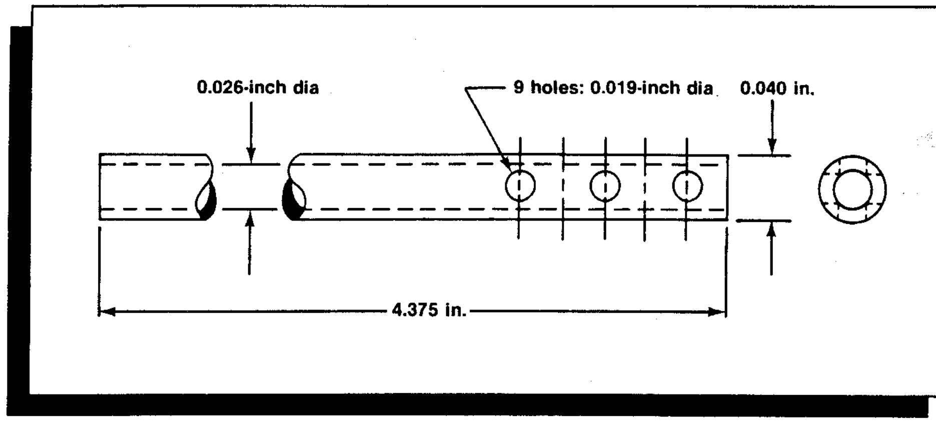


Figure 3.* This medical cannula was drilled by EDM. *Nine burr-free 0.019-inch-diameter holes were drilled in 304 stainless steel tubing.

advantages and the limitations of EDM are listed in Table 2.

To overcome its limitations, EDM is often used in conjunction with other processes. For example, the bulk of the material may be removed by conventional means before EDMing.

EDM Variations

Any material that conducts electricity can be EDMed, and the speed of the process is not affected by the hardness of the material. This makes EDM an ideal process for machining hard materials like hardened steel and carbides. EDM also is perfect for soft or delicate materials since EDM does not use force to remove the material, and there is no risk of mechanical distortion or damage by cutting tools.

There are two basic types of EDM machines, vertical and wire-cut. In both types material is removed from a workpiece by steadily bombarding it with controlled sparks of electricity. The workpiece never comes in contact with the electrode and thus no machining forces distort its shape.

Vertical EDM—It sometimes is called ram-type, plunge-type, sink, cavity, or conventional EDM. Despite its many names, the process is the same. An electrode is moved towards a workpiece submersed in a tank containing a dielectric. Electric sparks erode the workpiece so that eventually a mirror image of the electrode is formed. The shape of the electrode thus determines the shape of the cavity; for example, a star-shaped electrode creates a star-shaped cavity.

What has contributed greatly to the versatility of vertical EDM is the ability to program and move the electrode in three axes of motion, X, Y, and Z, plus rotation. In many cases the table holding the workpiece also can move in both the X and Y directions. These combinations of movements together with different shaped electrodes make possible the creation of virtually any shape; the machining method is not limited to surfaces of revolution as with conventional machining methods.

A vertical EDM system is composed of a pulse power supply, an electrode, a dielectric coolant, and ancillary equipment. Technological advances are improving the system capabilities—cutting rates are increasing and improvements are being made in other values.

A significant feature of EDM is electrode wear. Since some material is blasted off both the workpiece and the electrode with each pulse, the EDM tool wears—even though there is no cutting force or contact between it and the workpiece. There is considerable variation of electrode

***Table 2.* Advantages and Limitations of EDM**

Advantages	Limitations
Can EDM anything that conducts electricity	Workpiece must be conductive
Can create intricate and unusual shapes	Slower material removal rate
No tool force on machine, electrode, or workpiece	Electrode wear may require use of several tools
Easily automated	Electrode wear can produce inaccuracies
Great precision	Cavities may be slightly tapered
Repeatability	Undesirable recast layer may need to be removed
Can create solid dies eliminating sectionalizing and grinding	Leaves a very shallow, highly stressed surface layer
Frees skilled craftsmen for more productive work	Equipment is expensive
May eliminate secondary operations	
Drilling at shallow angles possible	

wear depending on the application. Several electrodes may be necessary to complete one job or a single electrode may be used for quite a few operations. Often, a partially worn electrode may be used to start a job and then a new one brought in to finish it. Fortunately, an electrode's wear is not related to its hardness, so that electrodes can be made of materials that are easily machinable such as graphite.

Wire-Cut EDM—Because it uses a constantly-moving wire as the cutting tool, it is also called traveling-wire EDM. The wire is threaded around the machine and through the material. This means wire-cut EDM cannot be used to machine blind shapes since the wire must go completely through the workpiece.

In wire-cut EDM the side of the wire acts like a bandsaw to cut through the workpiece material. Once the machine starts, the wire is in continuous motion so that the cutting is actually being done by a new electrode all the time, thus solving the problem of electrode wear. The used wire is then discarded. Wire-cut EDM is used with computer numerical control (CNC), and machines frequently work unattended throughout the night or weekend.

Numerical control has always been a part of wire-cut EDM. Today computers with sophisticated software packages have cut programming time and extended geometric capabilities. There have been hardware developments in the machines as well. Especially important is automatic rethreading which is vital for machines that work unattended.

A wire-cut EDM system is composed of a power supply, an electrode, a dielectric coolant and ancillary equipment. Like vertical EDM, technology is rapidly improving the systems' capabilities. Some of today's CNC wire EDM equipment can cut at speeds in excess of 20 square inches per hour (0.33 in.^{2}/min).

The workpiece typically is mounted on a table with two degrees of freedom. The movement of the table often is controlled by a computer which may be able to compensate for overcut, wire thickness, and known errors in the workpiece. By angling the workpiece with respect to the wire, conical shapes can be formed.

Wire-cut EDM is efficient because the wire erodes a thin line around the perimeter of the required cut rather than eroding the full volume of the cavity as with vertical EDM.

The dielectric fluid used with wire-cut EDM is usually deionized water. It is forced by pressure and/or vacuum into the cavity around the wire and is collected on the other side of the workpiece.

Other Types—Another form of EDM which should be mentioned is Electrical Discharge Grinding (EDG). A graphite wheel is used as a rotating electrode. This nonabrasive grinding eliminates costly diamond wheels and does not distort delicate parts.

Overview

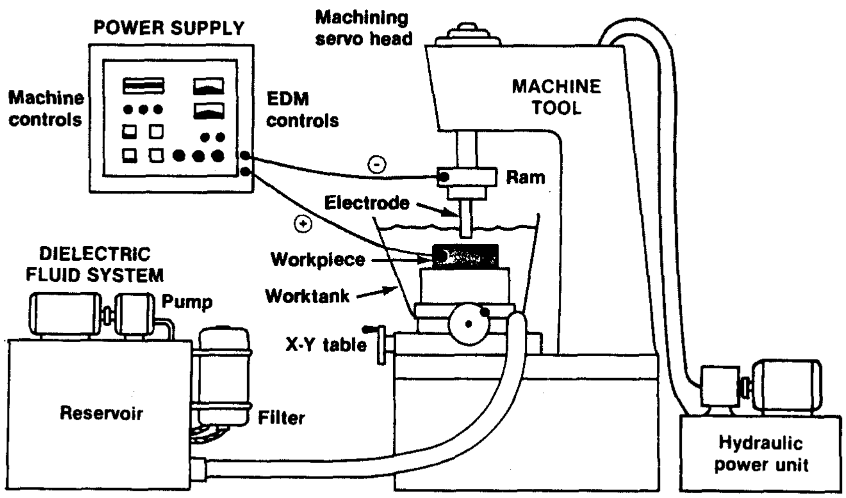
Process Description

In both vertical EDM and wire-cut, the actual metal-removal process is similar. The workpiece and the electrode are immersed in a dielectric fluid such as oil or deionized water. The electrode and workpiece are separated by a small gap and voltage is applied. When there is enough voltage, the dielectric breaks down. A spark jumps the gap, striking the workpiece and vaporizing part of the material. The intense heat also melts a small portion of the material. The current then is pulsed off, and the dielectric flows into the area carrying away most of the melted material in the form of small chips or cinders. The current is pulsed on and off at a rapid rate, typically at frequencies of from 500 to 1,000,000 pulses per second.

The chips absorb most of the heat produced by the sparks. The dielectric fluid that flushes away these particles also dissipates the heat enabling the tool and workpiece to remain relatively cool despite the very high, localized temperatures produced by the spark discharges.

The shape of the electrode creates a correspondingly shaped cavity in the workpiece that is always slightly larger than the dimensions of the electrode. This overcut reflects the size of the gap and can be as small as 0.001 inch with low cutting rates.

A small portion of the melted material is redeposited on the workpiece. The amount redeposited can be minimized by carefully controlling the pulsing of the current and the flow of the dielectric. In most applications this redeposited material is not a problem and can even be beneficial. In other applications, a finishing step is required to remove it. Other than the redeposits, EDM is a completely burr-free machining method.



Schematic of the EDM process

Power Supplies—These provide a train of unipolar pulses of adjustable width, height and repetition rate.

Advances in power supplies have improved the consistency and control of the pulses as well as increasing the power, and have greatly improved EDM operations. Fortunately, new power supplies are compatible with most systems, so older EDM systems can be upgraded by replacing the power supply.

In Summary

Electrical Discharge Machining has become a valuable tool for tool manufacturers and throughout the metalworking industry. As with other nontraditional processes, its specialized characteristics have enabled it to have a major impact on the manufacturing industry. Recent advances in controls and automation have secured EDM's position in today's factories. As with all processes, there are limits and drawbacks. However, EDM can be used to advantage in many applications, and shops which ignore EDM may find themselves no longer in a competitive position.

The information discussed in this issue of TechCommentary is an overview and intended only to familiarize you with the basic aspects of EDM. If you are interested in more detailed background, please contact CMF or an EDM equipment builder or supplier.

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The Center's mission is to assist industry in implementing cost- and energy-efficient, electric-based technologies in metals fabrication and related fields. TechCommentary is one communication vehicle that the Center uses to transfer technology to industry. The Center also conducts research in metal heating, metal removal and finishing, and fabrication.

This issue of TechCommentary was made possible through the cooperation of Battelle staff members Laura Cahill, Manager of Marketing and Communications; Denise Sheppard, Publications Coordinator; and William Scharenberg, Manager of Shop Services; William Garwick, The Master's Touch Technologies; Dorothy Tonjes of ProWrite; and Guy Bellows of Metcut. Technical reviewers were John Kohls, Institute for Advanced Manufacturing Sciences, Inc.; and Kempes Trager, Sr., Trager Research and Manufacturing.

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APPLICATION

Electrical Discharge Machining

Published by the Center for Metals Fabrication Vol. 1, No. 9, 1987

EDM cuts a production die.

The EDM-cut die stamps out the cage component of a fastener to exact specifications.

The Challenge: Winning on Delivery, Price and Quality

Aerospace fastener manufacturers must quickly meet their customers' demands for new designs and stringent delivery schedules or be willing to lose contracts to competitors. In 1984, Tridair Aerospace Fasteners Division (TAF) invested in wire-cut electrical discharge machining (EDM) to enable it to quickly produce inexpensive but reliable tooling and prototypes for the cage components of its fasteners. EDM permits TAF to compete aggressively on delivery, price and quality.

The Old Way

When a customer submitted a fastener request, TAF's research and development department would design the fastener and submit the design to the tool and die department. Working from a blueprint, a die maker would scribe the pattern onto steel, band saw it, and bend it up, a process that took a total of about 40 hours to make 12 to 15 prototypes. If the customer approved the sample, a die maker was assigned the task of making a production-quality die set. That same die maker was subsequently responsible for changing the tooling to meet reorder specifications, repairing worn dies, and supervising the production press.

Handmade die sets are slow to produce, expensive, inexact and unreliable, and a backlog had developed for the department. Because both are handmade, a production-quality die set might not meet specifications even though the prototype did. And reorders had similar problems. Therefore, when a handmade die was cutting parts to specifications, TAF would keep it running, building up inventory so that TAF could be assured of meeting shipping schedules. This inventory was an unproductive drain on TAF and a risk since the order might be cancelled or cut back.

The New Way

To streamline operations, TAF purchased a wire-cut EDM machine. Now, when TAF receives a part for bid, it immediately prepares a computer numerical control (CNC) program for its EDM machine to cut 12 to 15 prototypes. If TAF wins the contract, it uses information from the CNC program to quickly produce short-run production tooling. For large orders, more durable tooling can be made while the short-term tooling is meeting initial delivery schedules. And because of the repeatability of EDM, all prototypes and parts produced by the short-term and long-term tooling will meet specifications.

The Results: Fast Delivery and Streamlined Production

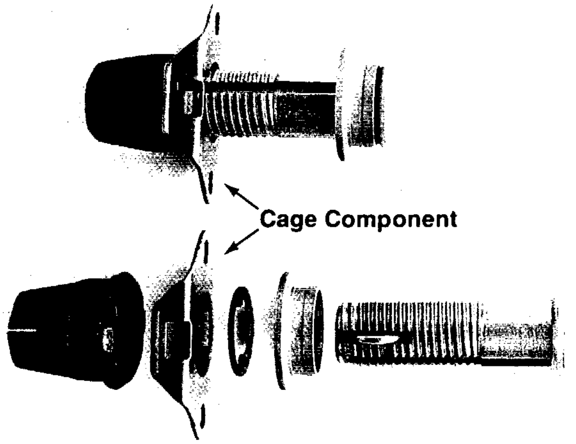
Fast response. The tool and die department has eliminated its backlog and responds quickly to changing customer requirements. The weak link in the production process has been eliminated. Time to produce a prototype has been reduced from 40 hours to 4 hours.

Lower production costs. Fewer hours are required to make production tooling, for much of the time the EDM machine can operate unattended. This translates into reduced production costs and lower costs per part.

Faster tooling production. It now takes an average of 125 hours to make a long-run production die set, instead of the 300–400 hours required with conventional machining which could mean an elapsed time of up to 6 months.

More reliable die sets. EDM'ed dies consistently manufacture to specification and run with fewer problems so that customers' delivery schedules can be met without significant inventories.

Longer die life. Since the EDM cutting rate is not affected by material hardness, dies can be made out of higher quality, tougher steel which lasts about 4 times longer and needs sharpening less frequently. EDM can produce more complex die components, reducing the number of die parts and further increasing die life, reliability and accuracy.



Aerospace fasteners are specifically designed to withstand vibration and remain locked in place. They are corrosion resistant and can withstand an average of 250 cycles of reuse. By using these long-lasting fasteners, an aerospace company can decrease the number of spare parts needed to keep its planes flying.

More accurate tooling. In an air-conditioned room, the wire-cut EDM machine cuts to an accuracy of 0.001 inch.

Dependability. The EDM machine runs 24 hours a day and after 7,000 operating hours in 3 years has never had a breakdown.

Improved use of die makers' time. Die makers no longer spend their time machining dies. They do only final assembly and fine tuning of the dies, so they have more time to spend on die design.

Lower scrap rate. Scrap rate for the dies is now 0.5% compared with 10–20% for conventional machining. For parts coming off the press, the scrap rate is now about 1%, compared with the old rate of 20–30%.

Energy usage and savings. Conventional machining uses a 2-horsepower motor for 6–8 hours per day for 6 days. The EDM machine runs 24 hours per day and is machining typically 12 hours per day, 7 days per week. It runs off 440 voltage. The significant reduction in scrap rates lowers the average energy usage per finished part. More modest energy savings result from producing dies more efficiently and reducing downtime for die repair.

Design experimentation. EDM allows the designer to go from ideas to physical parts in 3 or 4 hours. Now riskier designs can be tried without enormous expenses and developing a quality part is easier.

What Did It All Cost?

TAF spent about $196,000 to install wire-cut EDM. This cost included $120,000 for the wire-cut EDM machine itself, $30,000–40,000 for a computer and software, and additional expenses for setting up a special air-conditioned room for increased cutting accuracy. The payback period was about 6 months.

The Bottom Line: Fast Response Time and Improved Production Methods

Wire-cut EDM gives TAF the greater flexibility and faster turnaround time it needs. Now TAF can rapidly respond to changing customer demands and grow in a tough business environment.

Other Applications of EDM

EDM can be used on any material that conducts electricity. Wire-cut EDM is used by mold and die makers when they need precision, when they are working with hardened materials, or when no other method will do the job. Vertical EDM uses the same principle as wire-cut EDM but can be used to machine blind shapes. It is frequently used for drilling microholes and creating small and/or deep slots. For more information on EDM see TechCommentary Vol. 3, No. 1.

Company Profile

Tridair Aerospace Fasteners Division, Torrance, California.

Manufacturer of precision fasteners for the aerospace and defense markets.

Company philosophy:
We will make any fastener for any application.

Paul Hafeli, Tool and Die Design Supervisor, says "Manufacturers who are not using EDM won't be in business very long because the advantages of EDM are so great."

The Center for Metals Fabrication wishes to thank Southern California Edison for valuable contributions made to this issue

CMF is operated by Battelle's Columbus Division. Basic funding is provided by the Electric Power Research Institute, a nonprofit institute that conducts applications development on behalf of the United States electric utility industry. TechApplication is one of the ways the Center assists industry in implementing cost- and energy-efficient, electric-based technologies in materials fabrication and related fields. This issue was cofunded by a grant from the United States Department of Energy, Office of Industrial Programs

Applicable SIC Codes
34—23, 29, 49, 89 **35—**11, 19, 41, 44, 73, 79 **38—**11, 29 **39—**63, 64

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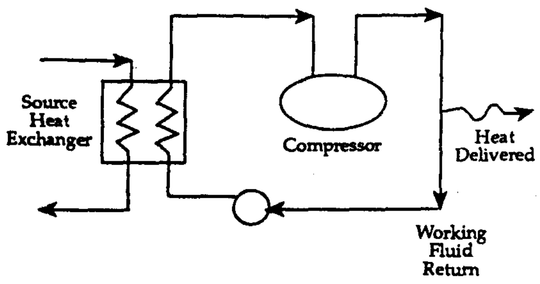
Regulation Class: ◑ Clean Air ◑ Clean Water ○ Haz. Waste ○ CERCLA ○ ______

Process Technology: *HEAT PUMP*



HEAT PUMP

Source: UNIMAR Research

Function/Theory

Heat pumps are compressors operating like refrigerators but with an inverted thermodynamic cycle. These withdraw energy from a low temperature source and transfer it at a higher temperature. Industrial heat pumps can amplify the temperature of the waste heat source stream, thereby heating a cold stream to a temperature higher than the waste heat source.

Selection Criteria/Considerations

Acceptance: ☐ High ☑ Medium ☐ Low

- Suitable for unit operations involving mass transfer (drying, concentration, evaporation, distillation, etc.) where latent heat loss can be recovered.
- Used for heat transfers, especially when there is need for both heating and cooling

Environmental Benefits

- Reduces need for cooling water (distillation).
- Conserves fuel by recovering what would otherwise be waste heat.
- Process control, quality, and cleanliness lead to reduced product waste and increased productivity.
- Cooling of waste water prior to discharge.

Additional Benefits

- Reduces the influence of the weather on the distillation process, by making barometric condenser of secondary importance.
- Energy cost reduction through heat recovery
- Relatively inexpensive way to add capacity by enhancing the current process.

Drawbacks

- Retrofits can be expensive, installations somewhat limited to new construction, or added capacity.
- Not cost effective for high temperature differential requirements.
- Future refrigerant availability and costs.
- Industrial heat pump installations are typically highly specialized which makes finding vendors difficult.

Waste Stream Reduced

Air	*Water*	*Solid*
☐ Particulates ☑ Organics	☐ Particulates ☐ Organics	☐ Hazardous
☑ CO_2, NOx ☐ Toxics	☐ Metals, Ions ☐ Oil	☑ Non-Hazardous

SIC Potential

◔ 25% ◕ 75%
◑ 50% ● 100%

Mining

Metal	10	○
Coal	12	○
Oil & Gas	13	○
Mineral	14	○

Mfg.

Food	20	◕
Tobac	21	◔
Textile	22	◑
Apparel	23	○
Lumber	24	●
Furn	25	○
Paper	26	◑
Print	27	○
Chem	28	◑
Petrol	29	◑
Rubber	30	◑
Leather	31	◔
Stone, Glass	32	○
Metals	33	○
Metals Fabric.	34	○
Mach	35	○
Elect	36	○
Trans	37	○
Instru	38	○
Misc.	39	○

Heat Pump (cont.)

Typical System Example

Size: 3' wide, 6-8' long, 3' high (excluding piping)

Energy Requirement: 206 kW - 700 kW

Economics

Capital Cost: $180,000 - $500,000

Payback: 2.17 years (includes 27% benefit of heat integration)

This payback is based on modifying a gas conveyorized dryer to utilize a heat recovery heat pump. The application includes a minor process modification and in using a MVR heat pump to provide additional heat exchange for the drying operation of cereal grain in the food industry. The heat savings from the heat pumping is 13.6 Mil BTU/hr and from the heat integration (process change) is 5 Mil BTU/hr.

Source: Frank Pucciano, Consultant

Service/Maintenance

- Strict EPA regulations on CFC refrigerant usage increase maintainance costs and time.

Vendors

APV Crepco (Distillation)

Drylime Systems

Vista Environment

Notes

Major Vendors

HEAT PUMP

APV Crepaco
395 Fillmore Ave.
Tonawanda, NY 14150
(716) 692-3000

Drylime Systems
2359 Royal Windsor
Unit #6
Mississauga, Ontario A5J
459
(416) 855-2331

Vista Environmental
2 Neshaming Interplex
Suite 202
Trevosa, PA 19053
(215) 245-5950

EPRI Techcommentaries

Industrial Heat Pumps

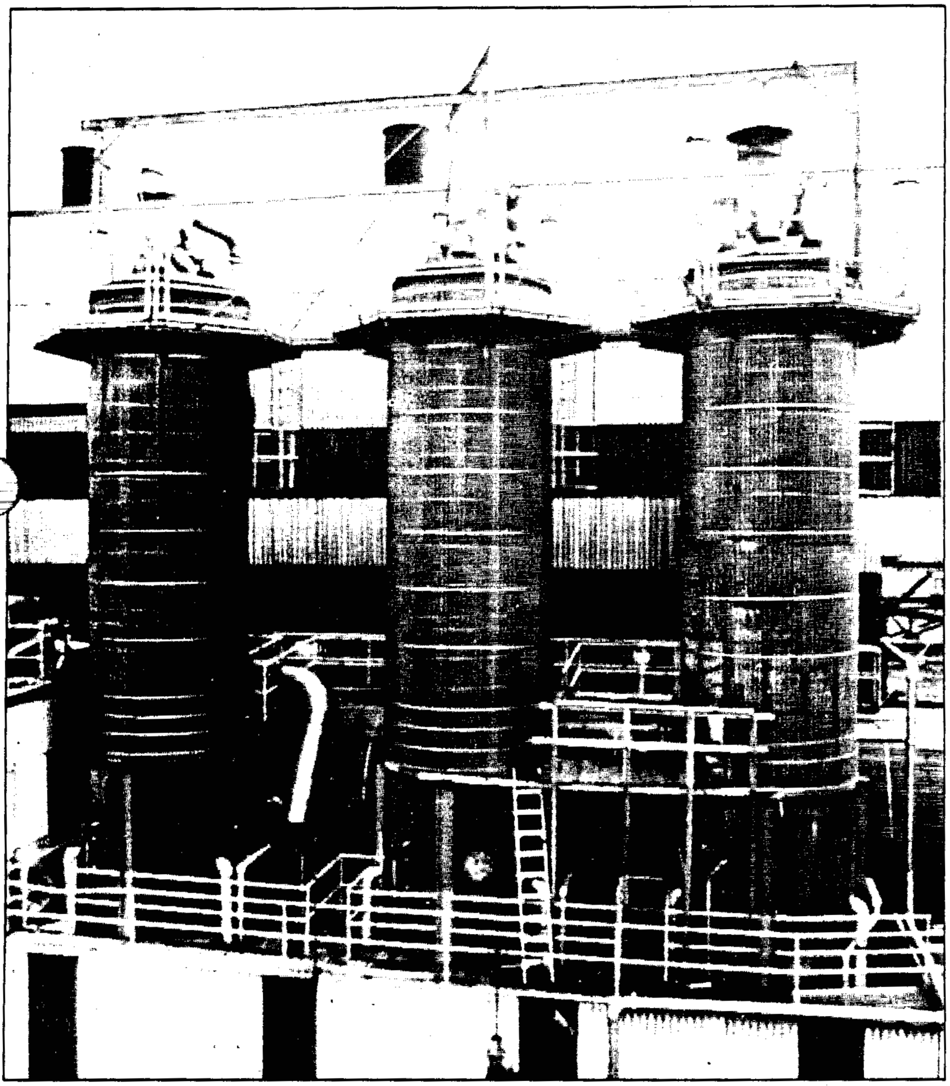
Industrial Heat Pumps, EPRI TechCommentary, Vol.1, No. 4, 1988
Drying with Electrical Heat Pumps, EPRI TechApplication, Vol.1, No. 1, 1988
Pinch Technology, EPRI TechCommentary, Vol.1, No. 4, 1988

TECH COMMENTARY

INDUSTRIAL HEAT PUMPS

Published by the EPRI Process Industry Coordination Office

Vol. 1, No. 4, 1988



An MVR heat pump conserves heat in this six-stage falling-film evaporator at a paper mill.

CAPTURING WASTED HEAT

There are often better ways to supply heat to industrial processes than burning fuel in steam boilers or process heaters. For many evaporation, distillation, and drying processes, industrial heat pumps represent a lower total energy cost alternative to fuel-consuming options.

For many industrial processes, energy costs represent over 25% of total manufacturing costs. Where applicable, industrial heat pumps can capture relatively low temperature waste heat and use a modest amount of mechanical energy to elevate the waste heat to a temperature that supplies process energy needs.

The unique heat recovery feature of heat pumps reduces energy costs for businesses such as

- Food processing
- Lumber drying
- Papermaking
- Chemical processing
- Petroleum refining.

Besides reducing costs, industrial heat pumps avoid gas discharge issues associated with direct fuel consumption.

ADVANTAGES

When properly applied and designed, heat pumps yield many benefits:

Lower energy costs—Heat pumps can substantially reduce energy costs, sometimes by 50% or more. Corresponding cooling requirements are also reduced, an important consideration when cooling water supply and treatment costs are high.

Reduced emissions—Unlike boilers and furnaces, electric-driven heat pumps do not produce pollutants. Installing heat pumps can help plants maintain or increase production capacity without violating ever-tightening restrictions on air and water emissions.

Increased capacity—Using a heat pump can overcome limitations in a plant's heating and cooling system. For example, using a heat pump may avoid the purchase of a steam boiler and cooling tower, which might have been required to evaporate and condense water in a product concentrator.

Improved product quality—Heat pumps generally provide heat at lower temperatures than other alternatives. As a result, heat-sensitive products avoid contact with localized hot spots, which degrade product properties and performance.

Less floor space—Heat pumps often require less space than competing energy supply systems. Heat pumps may be the solution to a tight layout design any industrial processes are complex collections of equipment, material flows, and temperatures. Evaluating the heat flows through these processes can be difficult, and incorrect conclusions regarding the best way to supply and recover heat often result. Consequently, these systems often use more equipment and more energy than is necessary. But if the system's heat flows are complex, identifying appropriate heat pump applications to cost-effectively reduce energy costs can be a tough job.

Pinch technology, a method that examines and optimizes the overall operating and capital costs of industrial processes, can help. The information obtained in a pinch analysis identifies if a heat pump should be used and determines the appropriate heat source, heat sink, temperature lift, and heat pump size. Pinch technology methods are explained in detail in *TechCommentary* Vol. 1, No. 3, and in the *Industrial Heat Pump Manual.*

problem, especially in retrofit applications.

ALTERNATE METHODS

Even when a heat pump is feasible, careful evaluation is needed to determine if it is the best option for the application. A heat pump is only one of several available options that help reduce process costs. Other options include passive heat recovery, modifications of the process itself, and using fuel-fired heaters. All options should be considered to ensure that the most cost-effective choice is made. Often, the right choice may be a combination of several measures.

APPLICATIONS

Industrial heat pumps are used for evaporation, distillation, and drying processes in many industries, as shown in Table 1. The principle motivating factors for using heat pumps include reduced energy and other operating costs and inexpensive debottlenecking.

Evaporation—When appropriately placed, heat pumps reduce energy usage and production costs. They can reduce equipment needs and floor space requirements. Heat pumps are used in evaporation processes for several products:

- Cheese and whey
- Skim milk powder
- Black liquor preconcentration
- Fruit juice concentration
- Starch/sugar.

Distillation—In the chemical and petroleum industries, heat pumps can be an important energy conservation tool for new or retrofit distillation columns. More than 25 distillation columns in the U.S. operate with MVR heat pumps. These operations include

- Propane–propylene splitting in fluid catalytic cracking operations
- Isobutane–normal butane splitting in alkylation
- Isopentane–normal pentane splitting in isomerization
- Specialty chemical purification.

In one distillation application, polymer-grade propylene is separated from a mixed propane/propylene stream using a heat pump. Rather than condensing the tower overhead vapor in a conventional condenser, the vapor is compressed to a higher temperature in a heat pump and piped to the tower's reboiler. In the reboiler, the vapor condenses in the exchanger, transferring heat to the base of the tower. The condensed overhead stream is then refluxed back to the tower's top tray.

Drying—Heat pumps reduce energy costs while improving product quality in industries such as lumber drying. Because the heat pump provides constant temperatures and controllable heat, the lumber dries without cracking or degrading. In addition to lumber, heat pumps also dry

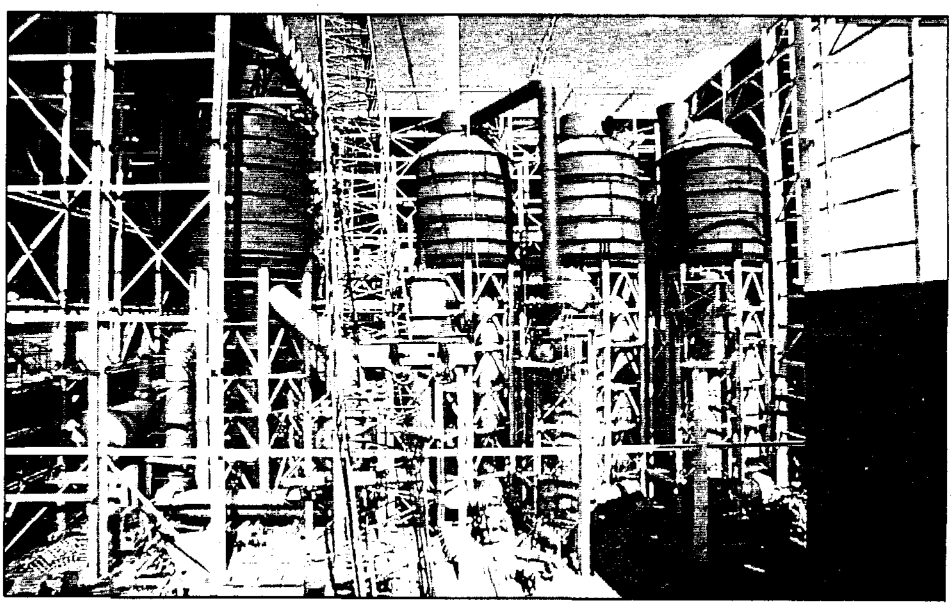
- Grain
- Fish
- Fine chemicals.

TECHNICAL CONSIDERATIONS

When evaluating heat pumps for a particular application, consider several factors that influence their cost-effectiveness.

Temperature differential—The temperature at the heat source should be only moderately lower than the temperature needed at the heat sink. This temperature difference affects the amount of power required to run the heat pump compressor. Power requirements increase proportionally with increasing temperature differential. The maximum practical temperature differential is approximately 60 F.

Temperature limitations—Refrigerant working fluids in closed cycle heat pumps are stable up to approxi-



This triple-effect evaporative-crystallizer uses an MVR to help produce sodium carbonate monohydrate. Appropriately placed heat pumps reduce production costs.

mately 250 F. Both open cycle and closed cycle heat pumps utilizing steam can operate up to approximately 320 F. Limitations in compressor equipment prevent operation above this temperature.

Size—A heat pump operates most ficiently at design capacity. Operating elow capacity decreases the heat pump's operating efficiency and effectively increases the capital cost. Where process requirements fluctuate, economic benefits are usually maximized by sizing the heat pump for base load heating needs and using another heat source to satisfy variable incremental needs.

Compressor materials—Each heat pump is custom engineered to meet the needs of a specific application, so materials used in the construction of heat pumps will vary. If corrosive liquids or severe operating environments are encountered, the heat pump must be corrosion resistant and suitably designed. These design requirements affect system cost.

Horsepower requirements—Heat pump efficiency is measured by the coefficient of performance, the heat output divided by the work input. It helps determine the horsepower (hp) requirements of the compressor needed for a specific application. Both temperature differential and throughput directly affect the horsepower needed. In general, doubling the temperature differential or the throughput doubles the horsepower requirements of the heat pump.

ECONOMIC CONSIDERATIONS

When considering the cost of a heat pump, you must evaluate capital, operating, and maintenance costs.

Capital costs—The installed heat pump costs range from $10,000 for a 50-hp unit in a small evaporator to $2,000,000 for a 5000-hp unit for a distillation operation with a throughput of 400 million pounds per year. The cost of stopping production during installation must also be considered.

Operating costs—Because operating requirements are specific for each application, actual operating costs vary greatly. For purposes of comparing heat pumps to other options, the operating

eat pumps take heat rejected at some point in the process, raise its temperature, and transfer it to another portion of the process. If the source of low-temperature heat is a noncorrosive vapor, the vapor may become the heat pump medium. Its heat can also be transferred across a heat-exchange surface to an intermediate fluid inside the heat pump. The heat pump compresses the fluid, increasing its temperature. The fluid is delivered to another part of the process, called the sink, where heat is transferred to the process either directly or through a heat exchanger.

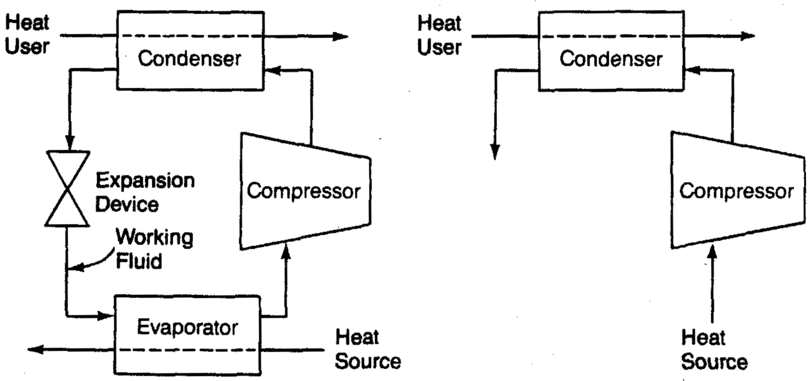
Four types of industrial heat pumps are in general use: closed cycle, open cycle, semi-open cycle, and thermocompressors. Closed and open cycle systems comprise more than 90% of the industrial heat pumps in operation.

Closed cycle—In a closed cycle heat pump, the working fluid is isolated from the process. Heat is transferred across a heat-exchange surface both at the source and at the sink. Closed cycle heat pumps are often used when processing corrosive or fouling materials. Special characteristics of the working fluid may yield benefits that justify the higher capital costs of a closed cycle heat pump.

Open cycle—In this type, the process stream acts as the working fluid and is compressed to raise the temperature.

Semi-open cycle—The semi-open or mechanical vapor recompression (MVR) cycle, uses a heat-exchange surface to transfer heat at either the source or the sink. MVR systems require fewer heat exchangers than closed-cycle systems, so they are less expensive.

Thermocompressors—With thermocompressors, the kinetic energy of a vapor jet, usually steam, compresses a process fluid initially at a lower pressure. Because large quantities of vapor are required to drive thermocompressors, they are best applied to systems with a small heat source and a large heat sink requiring only a small temperature boost.



CLOSED CYCLE

SEMI-OPEN CYCLE (MVR)

Table 1. **Industrial Uses of Heat Pumps**

General Utilities
Low-pressure steam thermocompression
Wastewater MVR evaporators
Food
Absorption chillers
Grain driers
Cheese and skim milk evaporators
Fruit juice concentrators
Forest Products
Lumber drying
Black liquor MVR evaporators
Chemicals
Chlor-alkali evaporation
MVR propylene splitters
Alcohol fermentation evaporators
Petroleum
Isobutane–normal butane distillation in alkylation
Isopentane–normal pentane distillation in isomerization

Operating heat pumps in distilleries, like this one distilling alcohol, often results in steam savings of 25%.

cost of each unit of heat (in BTUs) supplied by the heat pump can be established. This includes the cost of auxiliary equipment, the energy cost to drive the compressor, and any savings in cooling costs. The net operating cost may be compared against the net cost of the competing system. Heat pump compressors require typical maintenance procedures, including fluid changes, checks for oil leakage, and seal replacement.

IN SUMMARY

When appropriately placed, industrial heat pumps can provide significant energy savings for many industries and products. By using heat that would otherwise be wasted, heat pumps significantly reduce energy consumption.

Improvements in heat pump compressor capacity and compression ratio are continuing, which will result in greater efficiency and reduce energy costs even further in many applications.

This issue of *TechCommentary* is intended to provide a basic understanding of industrial heat pumps. More detailed information is available in EPRI's *Industrial Heat Pump Manual*. For specific applications, talk to your electric utility marketing representative or an equipment supplier. For more information on pinch technology, see *TechCommentary* Vol. 1, No. 3, and EPRI's *Pinch Technology Primer*. An industrial heat pump application in lumber drying is featured in *TechApplication* Vol. 1, No. 1.

Basic funding for this *TechCommentary* is provided by the Electric Power Research Institute (EPRI), a nonprofit institute that conducts applications development on behalf of the United States electric utility industry. *TechCommentary* is one of the ways EPRI assists the process industries in implementing cost- and energy-efficient, electric-based technologies.

This issue of *TechCommentary* was written by Battelle Columbus Division. Information on industrial heat pumps and pinch technology was made available to Battelle by Linnhoff March, Inc.

Sources used in this issue of *TechCommentary* were

Industrial Heat Pump Manual, EPRI Report No. EM-6057, October 1988

Heat Pumps in Evaporation Processes, EPRI Report No. EM-4693, November 1986

Heat Pumps in Distillation Processes, EPRI Report No. EM-3656, August 1984.

Hybrid Heat Pump Application Study, EPRI Report No. EM-4654, July 1986.

APLUS Software (Analysis of Plant Utility Systems), available from EPRI Software Center.

HPSCAN Software (Heat Pump Screening Analysis), available from EPRI Software Center.

Linnhoff, B. et al *User Guide on Process Integration for the Efficient Use of Energy*, Institution of Chemical Engineers: Rugby, England.

Centre for Process Integration, a program of basic and applied research in pinch technology at the University of Manchester Institute of Science and Technology supported by EPRI and 16 major industrial companies.

Photos courtesy of Swenson Process Equipment, Inc. and Linnhoff March.

Applicable SIC Codes
13—11 **20—**11, 13, 16, 17, 21–24, 32–35, 37, 38, 41, 43–48, 51, 52, 61–63, 65–67, 74–77, 79, 82–87, 91, 92, 95, 97–99 **21—**11, 21, 31, 41 **22—**11, 21, 23, 24, 27, 31, 57, 58, 81, 83 **26—**11–13, 16, 43, 47, 51–55 **28—**13, 19, 21, 22, 24, 31, 33, 34, 41–44, 65, 69, 73, 74, 79, 91, 95 **29—**11

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TECHAPPLICATION

Drying With Electric Heat Pumps

Published by the EPRI Process Industry Coordination Office

Vol. 1, No. 1, 1988

The Challenge: Custom Hardwood Lumber Drying

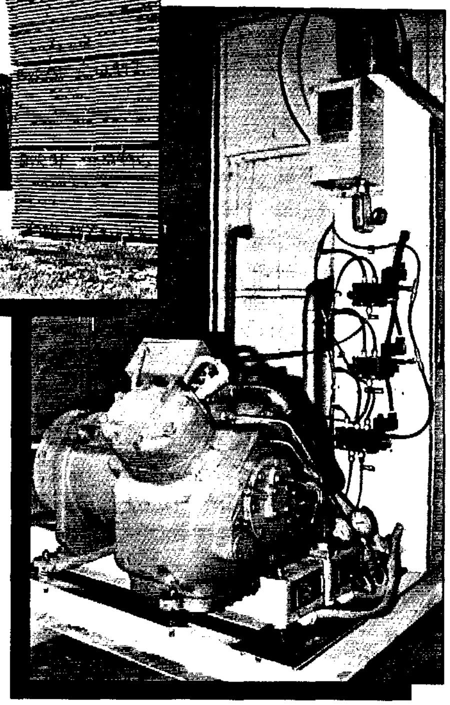
Lumber companies, wholesalers, and end users who own high-quality hardwood lumber want to maintain that quality for its ultimate use in products such as cabinets, furniture, molding, and flooring. However, conventional drying processes often crack or warp the lumber. And this degradation significantly lowers the value of expensive hardwoods such as oaks, hickory, ash, and pecan.

GPS Lumber Services, in Carlisle, Arkansas, sought a lumber-drying process that would

- Minimize potential for wood degrade
- Efficiently dry lots of less than 100,000 board feet
- Yield low energy costs.

After working for over a year to find the right process, Vern Gilmartin, President of GPS, together with his local electric utility, Arkansas Power and Light (AP&L), discovered that electric heat pumps could meet demands for high quality with low energy costs. In February 1987, GPS became the first custom hardwood lumber-drying operation in Arkansas to use heat pumps.

GPS' customers protect their valuable hardwoods by relying on electric heat pumps to dry the lumber without damage.



Electric heat pumps remove moisture from the wood at low energy costs.

Before lumber is dried, it is graded to determine its monetary value. It is extremely important to use a reliable drying process for high-grade hardwoods because lumber damaged during drying can lose 30% to 50% of its value for each drop in grade.

GPS evaluated several drying methods, including

- Fuel furnaces
- Waste wood boilers
- Fuel-fired steam boilers
- Electric heat pumps.

Sample Grades and Values for 4/4 Red Oak

Grade	Value/1000 board feet*
Firsts and Seconds (FAS)	$1000
#1 Common	$ 550
#2 Common	$ 275
3A	$ 180
3B	$ 100

*Value in June 1988.

Fuel furnaces and waste wood boilers were quickly eliminated because the capital costs were too high for GPS' small drying operation. The choice narrowed to the electric heat pump and the more conventional fuel-fired steam boiler.

The drying process begins by stacking lumber outside to air dry for 3 to 4 months. When the moisture content is less than 25%, the wood is placed in a drying building or kiln. In the steam heat method, fuel-fired boilers create steam to heat the air. The hot air draws moisture from the wood. When the air becomes saturated, it is vented. Cool air flows in, is heated, and collects more moisture from the wood. Circulating air blowers try to maintain a constant temperature in the kiln for the 6- to 12-day drying cycle. Once the wood reaches a moisture content of 6% to 8%, it is conditioned with steam for 12 to 24 hours to relieve stresses built up during drying then removed from the kiln to cool.

The steam heat method had several drawbacks:

- Heating the cool air that is systematically drawn in results in higher energy costs.
- Frequent temperature and humidity fluctuations harm the wood.
- The air blowers require 50% more horsepower than those used with heat pumps.

Because of the higher potential for wood degrade and the high energy costs, GPS rejected the steam heat process. With AP&L's help in predicting electricity usage and demand, GPS found that electric heat pumps operate at low energy costs with a minimal degrade potential.

For drying with heat pumps, lumber is handled in the same way as in the steam heat method. Only the drying process differs. The dehumidification process takes moisture out of the wood by heating air so it will collect moisture. As the air becomes saturated, ceiling fans circulate it through ducts to the heat pumps in the adjacent equipment room. Here it passes over cold coils in the pump, condensing and removing the moisture. The air is then reheated over hot coils and passes back over the wood to collect more moisture. Because the same air recirculates over the wood, the temperature does not drastically fluctuate. The desired temperature and humidity levels are maintained by precise electronic controls—housed in the equipment room with the heat pumps. The wood dries in the kiln for 10 to 14 days. When it reaches a moisture content of 6% to 8%, it is conditioned with steam and removed from the kiln.

GPS has achieved significant benefits from using heat pumps for drying lumber.

Energy savings. GPS estimates that its energy costs are 50% lower than if it used the steam boiler. The dehumidification process is about 20% slower than conventional processes, but the substantial energy savings offset the longer drying times.

Minimal degrade. The heat pumps' constant and lower temperatures and precise control of the drying environment contribute to an 80% to 90% lower potential for degrade during drying.

Flexibility. The heat pumps' precise controls enable GPS to accurately maintain the proper kiln conditions. GPS can bring green wood with 70% to 100% moisture content directly into the kiln without previous air-drying—a procedure nearly impossible with conventional methods.

High customer satisfaction. Although a relatively new process, drying lumber with heat pumps is becoming recognized for high quality. The wood maintains a better color and appearance, so GPS' customers protect their investment and get a better price for their wood.

The two heat pumps and electronic controllers at GPS cost $75,000. A building or kiln that houses the lumber while it dries is also required. GPS expects a payback period of less than 2 years. GPS's two heat pumps, each controlling a kiln of 30,000 board feet capacity, greatly increase the flexibility of the drying operation.

According to Vern, "the word is getting out" that GPS can dry expensive hardwoods without risking damage and loss in value. GPS plans to expand its drying operation—double its current capacity by adding two more heat pump units. By giving the consumer high quality, GPS gains an edge over its competitors and keeps a loyal customer base.

Heat pumps are known primarily for their use in heating and air conditioning. However, many applications exist in evaporation processes, such as citrus juice concentration and chemical distillation processes. Heat pump applications can also be found in the dairy, petroleum, pulp and paper, and textile industries.

Company Profile

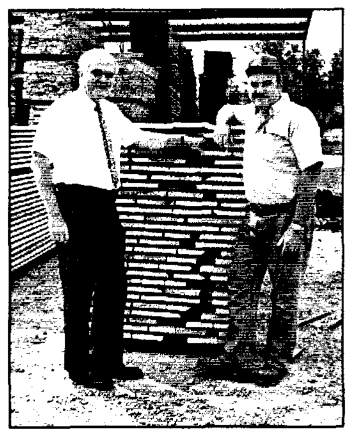
GPS Lumber Services, Carlisle, Arkansas

President—Vern Gilmartin

6 employees

A custom drying operation for hardwood lumber used in furniture, cabinets, molding, and other household products.

Company philosophy: We provide quality-oriented services to meet our customers needs.



Ed Barry, of AP&L (left), and Vern Gilmartin, President of GPS, worked together to find an effective method for drying lumber.

Ed Barry of Arkansas Power and Light Company, which provides electric service for GPS Lumber Services, made valuable contributions to this issue.

Basic funding for this *TechApplication* is provided by the Electric Power Research Institute (EPRI), a nonprofit institute that conducts applications development on behalf of the United States electric utility industry. *TechApplication* is one of the ways EPRI assists the process industries in implementing cost- and energy-efficient, electric-based technologies.

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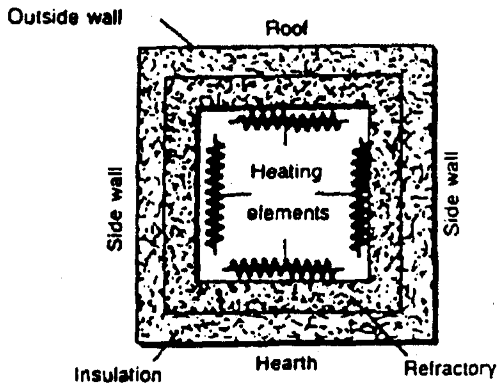
Process Technology: *INDIRECT RESISTANCE*



INDIRECT RESISTANCE

Function/Theory

Indirect resistance represents the oldest form of electric heating. Electric current passes through a special resistive heating element causing heating, as in an electric toaster. The workpiece is heated by convection, conduction, and in some cases, radiation emitted from the element. Temperature can range from ambient to nearly 5,000° F, depending on the application and the elements.

Selection Criteria/Considerations

Acceptance: ☑ High ☐ Medium ☐ Low

- Most efficient in small and/or high temperature furnaces.
- Used for heating high cost metals where very precise temperature control is required, and/or high reliability applications (eg. aerospace).
- Applied where oxidation and scale cannot be tolerated thus calling for a controlled furnace atmosphere.
- Found where high material purity required.
- Where vacuum chamber is required, indirect resistance is the predominant heating method.

Environmental Benefits

- Atmospheric gases eliminated with vacuum furnace
- Elimination of combustion products

Additional Benefits

- Full range of configurations; many sizes, watt densities, temperature control ranges.
- Large equipment manufacturer/distribution infrastructure.
- Flexibility, controllability, compact.
- Quieter, cleaner, and less waste heat emitted than with fossil furnace.
- Generally low maintenance.
- Easy to incorporate into existing processes.

Drawbacks

- Higher capital costs
- Susceptibility to power outages and interruptions
- Reduced efficiency with larger, low temperature or "loose seal" furnaces
- Demand charges
- Resistive elements require occasional replacement

Waste Stream Reduced

Air	*Water*	*Solid*
☐ Particulates ☑ Organics	☐ Particulates ☐ Organics	☐ Hazardous
☑ CO_2, NOx ☐ Toxics	☐ Metals, Ions ☐ Oil	☑ Non-Hazardous

SIC Potential

◔ 25% ◕ 75% ◑ 50% ● 100%

Mining

Metal	10
Coal	12
Oil & Gas	13
Mineral	14

Mfg.

Food	20
Tobac	21
Textile	22
Apparel	23
Lumber	24
Furn	25
Paper	26
Print	27
Chem	28
Petrol	29
Rubber	30
Leather	31
Stone, Glass	32
Metals	33
Metals Fabric.	34
Mach	35
Elect	36
Trans	37
Instru	38
Misc.	39

P-4

Typical System Example

Size: (2' x 3' x 2') to (5' x 6' x 5')
(2" x 6" x X")

Energy Requirement:

Component heaters (e.g. cartridge, band, strip) - typically .2 - 2.0 kW each in plastics.

50 - 2,000 kW in forming.

50 - 200 kW for joining in metals fabrication

Efficiency: 60 - 80% in Fabricated Metals
90% plus in Plastics

Economics

Capital Cost:

Typically \$50 - \$100/kW(e.g. 0.850 kW 6" OD x 1/2" W band heater \$40 to \$60) {Plastics}
\$14,000 - \$350,000, \$25,000 - \$35,000 (forming), \$10,000 - \$100,000 (joining) {Fabricated Metals}

Payback: 2.07 years

The payback is based on replacing a gas-fired box furnace with an electric resistance radiant heating furnace. Typical applications include sintering ceramics or tempering glass with furnace operating temperatures of 1500 - 3000° F.

Source: Lindbergh

Service/Maintenance

Element life is affected by operating temperatures and furnace environment (atmosphere). Element life varies from 1 year to 15 years or more. Generally, the higher the temperature, the shorter the element life.

Vendors

C.I. Hayes

Can-Eng

Dyna Rad Corp.

Lindberg

Pillar Industries

Seco/ Warwick

Surface Combustion Inc.

Notes

Major Vendors

INDIRECT RESISTANCE

Abar-Ipsen Industries
905 Pennsylvania Blvd.
Feasterville, PA 19047
(215) 355-4900

C. I. Hayes, Inc.
811 Wellington Ave.
Cranston, RI 02910
(401) 467-5200

Can Eng
P.O. Box 628
6800 Montrose Rd.
Niagra Falls LZE 6Y5
(416) 356-1327

Fostoria Industries
P.O. Box E
Fostoria, OH 44830
(419) 435-9201

Lindberg
304 Hart St.
Watertown, WI 53094
(414) 261-7000

Seco/Warwick
180 Mercer St.
Meadville, PA 16335
(814) 724-1400

Surface Combustion, Inc.
1700 Indian Wood Circle
Maumee, OH 43537
(419) 891-7150

EPRI Techcommentaries

Indirect Resistance Heating
Indirect Resistance Heating, EPRI CMF TechCommentary, Vol. 3, No. 7, 1986
Electric Resistance Melting, EPRI CMP TechCommentary, CMP-1188-036, 1988
Resistance Melting for Low Capital Investment, EPRI CMP TechApplication, CMP-045,1989

TECH COMMENTARY

INDIRECT RESISTANCE HEATING

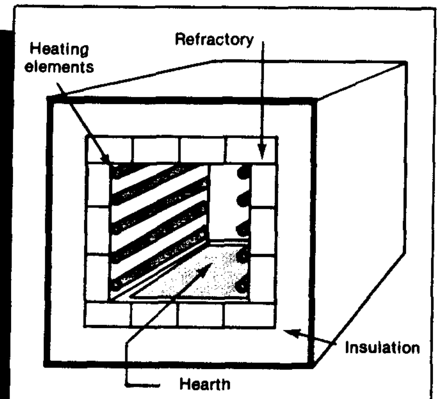
Published by the Center for Metals Fabrication

Vol. 3, No. 7, 1986

Clean, Controlled Heating

Electric resistance furnaces offer a safe, efficient, reliable and clean method for heat treating, melting, heating prior to forming, and brazing metals. Electric furnaces are also easy to control, and operate over a wide temperature range. In addition to heating metals, they are used for melting glass, sintering ceramics, and curing coatings. And the number of applications continues to grow as technological developments broaden the operating temperature range of electric furnaces, and the demand for automatic process control increases.

Resistance heating is based on the principle that, when a current is passed through an electrical resistor, electrical energy is converted to thermal energy. The thermal energy then is transferred to the part by convection, radiation and/or conduction. This issue of TechCommentary describes indirect resistance heating and discusses the technical and economic factors to consider when deciding if the process could benefit a particular application or product. Direct resistance heating and encased resistance heaters are discussed in TechCommentary, Vol. 3, No.8.



Schematic diagram of an indirect resistance heating furnace showing the arrangement of the heating elements on the walls.

Below about 1250 F, heat transfer to the workpiece is primarily by convection, sometimes with the aid of fans, as in "forced" convection furnaces. Radiation is the major mode of heat transfer at temperatures above about 1250 F and in vacuum furnaces where there is no atmosphere to support convection.

Advantages

Often, an electric resistance furnace and a gas-fired furnace are equally appropriate for a particular application, and the choice is based on economics. However, several characteristics of electric resistance furnaces may make them the better choice for your application. The advantages of electric resistance furnaces include:

- Flexibility. Both operating temperature and furnace atmosphere can be varied. Resistance heating elements are available for all temperatures of importance in industrial processing, whereas the maximum temperature of gas-fired furnaces is limited to approximately 2400 F. Heating in a controlled atmosphere or a vacuum is easily achieved with an electric furnace. Such control is more difficult in a gas furnace unless radiant tubes or protective muffles are used.
- Automatic temperature control. Microprocessors and solid-state switches can control furnace temperature automatically. Gas-fired furnaces are less amenable to automatic control.
- Improved working conditions. Electric furnaces are quiet because there is no combustion or blower noise (except in forced air furnaces, where there is some fan noise). The absence of smoke and hot flue gases makes the plant both cleaner and cooler, thus minimizing concerns for worker safety and environmental pollution.
- Cost savings. For some applications resistance furnaces are more energy efficient and save space. Resistance furnace efficiency is relatively independent of temperature, whereas the efficiency of gas-fired furnaces drops sharply with increasing temperature. Waste heat is minimized since there are no hot flue gases in an electric furnace. Space is saved because there is no need to store or pipe in flammable fuel or remove exhaust gases.
- Safety. There is little explosion hazard with an electric resistance furnace.

Applications

Indirect resistance heating is used primarily in the metals, ceramics, electronics and glass industries. The more frequently used processes that incorporate this heating technique include:

- Heat treatment of metals
- Metal melting
- Heating prior to forming
- Brazing
- Sintering ceramics
- Curing coatings
- Glass tempering.

Heat treatment of metals — Indirect resistance heating is used for annealing, austenitizing, normalizing,

Temperature Range	Heat Treatment
300-600 F	Age hardening light metals e.g. aluminum alloys Blueing steels Tempering ultrahigh-strength steels and carburized components
600-1000 F	Nitriding Annealing copper Solution treating aluminum alloys
700-1400 F	Tempering steels Annealing and stress relieving wrought steels and steel welds Annealing copper alloys
1300-1700 F	Carbonitriding Carburizing
1600-2000 F	Austenitizing low and medium alloy steels Annealing specialty steels Sintering nonferrous powdered metals
1900-2400 F	Heat treating tool steels Sintering ferrous powdered metals Solution treating nickel-based alloys

***Table 1.* Common Heat Treatments and Their Temperature Ranges**

hardening, tempering, nitriding, carburizing, and sintering a wide range of ferrous materials. It is also used for annealing, solution treating, and aging nonferrous metals. These processes are carried out at temperatures ranging from 300 to 2400 F, as shown in Table 1.

Both gas-fired and indirect resistance furnaces can be used at low temperatures and where there are no special atmosphere demands. However, aerospace alloys and tool steels often have to be treated in a controlled atmosphere. For example, titanium alloys, which are prone to contamination, particularly hydrogen pickup, must be processed in a vacuum or an inert atmosphere. Similarly, tool steels often must be heat treated in a vacuum or special atmosphere to prevent vaporization of important alloying elements at the surface. These special conditions are easily arranged in an indirect resistance furnace but difficult to achieve in a gas furnace.

Induction is occasionally used if rapid heating is required. However, the cost of coils and power supplies makes it economical only in high volume applications.

Metal melting — Indirect resistance furnaces for melting and holding metals, especially nonferrous alloys, have become popular in the casting industry in the last ten years. The reason for this popularity is the increased availability of light-weight refractory materials for building indirect-resistance-heated crucible furnaces. The low thermal mass of these materials makes the furnaces very energy efficient.

In modern aluminum foundries there is often an electric resistance crucible furnace at each casting machine to hold the molten aluminum at the optimal casting temperature (1100-1200 F depending on the alloy). Gas furnaces can be used, but it is more difficult to maintain their contents at a constant temperature. In addition to allowing excellent temperature control, electric heating minimizes gas pickup by the molten metal, or oxidation of the surface. Together, these factors can reduce metal loss by half. Electric heating also limits hot spots and thermal stresses in the furnace; and, because there are no combustion products, the crucible is not eroded by hot gases.

The capital cost of an electric crucible furnace is somewhat higher than that of a gas-fired furnace ($14,000 versus $10,000 for 500 lb capacity) but the extra cost can be quickly paid back by decreased material loss.

Some materials, especially reactive or refractory metals like titanium and molybdenum, must be melted in a vacuum. While this can be done in a resistance heated furnace, vacuum melting is usually done with induction, arc or electron beam heating since these methods result in faster melting and a more homogeneous product.

Heating prior to forming — In the forging industry, electric-based heating is gaining in popularity for billet preheating. The reason is that electric furnaces are considerably more efficient than gas-fired furnaces, even those with recuperators, at preheating temperatures (around 2100 F, the exact temperature depending on the specific material).

Direct resistance and induction heating are two other methods used for preheating materials. Both heat faster than indirect resistance because the heat is generated within the workpiece. However, they only work efficiently for simply-shaped blanks, such as rods and bars, made of fairly high-resistivity metals. There are essentially no restrictions on the materials or workpiece shapes that can be heated in an indirect resistance furnace. And a single furnace can be used to heat a wide variety of parts.

Brazing — Metal components are often brazed in indirect resistance furnaces because of the need for a controlled atmosphere (or vacuum) or a carefully controlled thermal cycle. Induction brazing is also done, but is economical only for high volume applications because the complex coils required are so expensive.

Sintering ceramics — Ceramic materials are widely used in the production of various electronic components including capacitors, resistors and piezoelectric elements. They are also being developed for use in internal combustion engines. These ceramic materials must often be fired, or sintered, at temperatures as high as 3000 F, and both temperature and furnace atmosphere have to be precisely controlled. The electronics industry also uses indirect resistance furnaces for growing, purifying and processing the silicon and germanium crystals and wafers used in many semiconductor devices.

Curing coatings — Resistance furnaces are used in the finishing industry for baking vitreous enamel coatings onto metal substrates and for drying and curing organic coatings, such as paints and varnishes, on a variety of materials. The main competitors to indirect resistance furnaces are medium and short wave infrared ovens.

Glass tempering — Glass is tempered by heating to a carefully controlled temperature (usually around 1100 to 1200 F) followed by rapid but uniform cooling. Tempering results in residual compressive stresses on the surface that provide greater resistance to fracture and damage. Typical products include automobile and architectural glass. Tempering is almost always carried out in resistance furnaces.

Technical Considerations

Indirect resistance furnaces are usually designed for a particular application, although modifying an existing furnace to operate at a different temperature range is quite feasible.

Important factors to consider in selecting an indirect resistance furnace are:

- Heating element characteristics
- Form and arrangement of heating elements
- Material handling
- Power requirements.

Heating element characteristics — The choice of furnace heating elements is influenced by both the temperature required and the furnace atmosphere. Commercially available resistance heating elements are broadly characterized as metallic or nonmetallic. Common metallic elements, made of alloys containing various percentages of iron, nickel, chromium and aluminum, work up to approximately 2400 F. For temperatures above about 2200 F, however, noble or refractory metals, such as platinum, molybdenum, tantalum, or tungsten, or ceramic elements, including silicon carbide, molybdenum disilicide and graphite, are used.

The specific heating process and the workpiece material determine whether the furnace should have an air, inert, oxidizing, or reducing atmosphere, or whether a vacuum is appropriate. Many metallic heating elements can be used in air. However, molybdenum, tantalum, and tungsten elements cannot be exposed to oxygen. Molybdenum and tungsten work well in hydrogen or inert gas and in a vacuum. Tantalum absorbs hydrogen as it cools below 1200 F and also absorbs residual oxygen in an atmosphere. Therefore, tantalum elements are best used only in a vacuum. Because they oxidize rapidly, graphite elements must also be used only in an inert or vacuum environment. However, silicon carbide and molybdenum disilicide can be used at high temperatures and in air. Maximum operating temperatures and environments for various heating element materials are shown in Table 2.

Element Material	Maximum Operating Temperature F	Operating Environment
Metal-sheathed elements	1300	Air
*Fe-Ni-Cr alloys	1850	Air
*Ni-Cr alloys	2000	Air
*Fe-Cr-Al alloys	2400	Air
Platinum	2900	Air
Platinum-rhodium alloys	3250	Air
Molybdenum	3400 4080	Hydrogen Vacuum
Tantalum	4000 4710	Helium/argon Vacuum
Tungsten	5425	Vacuum
*Silicon carbide	3100	Air
*Molybdenum disilicide	3275	Air
Carbon/graphite	5450	Helium/argon

*These elements can also be used in a protective atmosphere. The maximum operating temperature will depend on the composition of the atmosphere. Consult heating element manufacturers for further details.

Table 2. **Operating Characteristics of Various Heating Element Materials**

Heating element life is influenced by both operating temperature and furnace environment. However, average values are:

Operating Temperature F	Element Life Years
Below 1200	More than 4
1400-1600	2-4
2000	1-2

Form and arrangement of heating elements — Metallic heating elements come in a variety of forms, most commonly wires, rods, strips, ribbons, sheets, plates, and bars (Figure 1). Nonmetallic elements are usually rod-shaped. Element form, as well as placement of elements within the furnace, is generally determined by the furnace manufacturer. A variety of factors influence the final choice. They include volume and shape of the furnace enclosure and the area available for the heating elements, and ease of installation and replacement of elements. Also considered are the types of treatment to be performed, the mode of heat transfer (radiation or convection), furnace insulation, the method of transporting material through the furnace, and the mechanical strength of the heating elements.

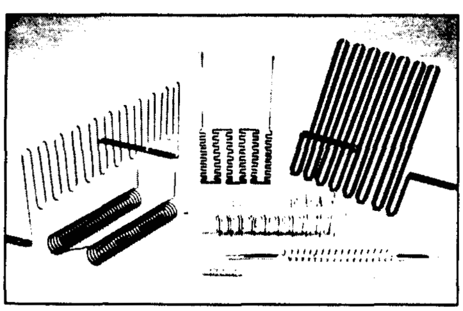


Figure 1. **Common shapes and forms of metallic elements.**

Element strength determines whether heating elements are arranged horizontally or vertically in the furnace. Horizontally mounted metallic elements tend to sag at high temperatures. Suspending them vertically relieves this problem. Element strength also determines to a certain extent whether radiant heat is transferred directly or indirectly from the elements to the charge. A "muffle" or tube furnace is used for indirect radiant heating. Heat passes by radiation from the heating element to the walls of the tube and then to the workpiece within the tube; such a design protects the heating elements and evens out temperature gradients and hot spots.

Material handling — Indirect resistance furnaces are available with both batch and continuous material handling. Batch furnaces can be used for a wider variety of products and parts, and have more flexible cycle times. In continuous furnaces, the charge is moved through at a constant rate, either on a high temperature mesh conveyor belt or by a mechanical pusher.

Power requirements — Because of the many material and processing parameters involved, precise estimates of power requirements for indirect resistance furnaces are best left to experienced furnace manufacturers or utility experts.

Economic Considerations

The following factors should be taken into consideration in determining the economic feasibility of indirect resistance furnaces:

- Equipment cost
- Energy cost
- Maintenance costs.

Equipment cost — The cost of an indirect resistance furnace is determined mostly by size and operating temperature. A 2x3x1.5 ft. furnace operating up to about 2000 F would cost around $35,000. Increasing the size to 5x6x5 ft. would increase the cost to $150,000. Furnaces operating to higher temperatures are more expensive because of increased material costs.

Energy cost — Energy cost is determined by fuel cost and the operating efficiency of the furnace. On a per BTU basis, natural gas usually costs about one-third as much as electricity. However, at 1800-2200 F a gas-fired furnace without a recuperator is only about 20% efficient. Adding a recuperator increases efficiency to 35-40%. But electric furnaces are typically 60-70% efficient. Thus, increased efficiency can often compensate for higher energy costs. The actual utilization break point at which electric resistance furnaces are more economical than gas-fired furnaces depends on the relative costs of electricity and gas.

Maintenance costs — Indirect resistance furnaces require no burner adjustment or other special maintenance. The major tasks are replacing burned out elements, which is usually easy, and cleaning out the furnace when necessary.

In Summary

Indirect resistance heating is appropriate for a variety of heat treating, preheating, sintering, and brazing processes. The ease of temperature control, atmosphere control, and maintenance, combined with high energy efficiency, make it an attractive technique in the metals, ceramics, electronics, and glass industries, among others.

The information discussed in this issue of TechCommentary is an overview and intended only to familiarize you with the basic aspects of indirect-resistance heating. If you are interested in more detailed information, please contact CMF or an equipment manufacturer.

The Center for Metals Fabrication (CMF) is operated by Battelle's Columbus Division. Basic funding is provided by the Electric Power Research Institute, a nonprofit institute that conducts research and development on behalf of the United States electric utility industry.

The Center's mission is to assist industry in implementing cost- and energy-efficient, electric-based technologies in metals fabrication and related fields. TechCommentary is one communication vehicle that the Center uses to transfer technology to industry. The Center also conducts research in metal heating, metal removal and finishing, and fabrication.

This issue of TechCommentary was made possible through the cooperation of Battelle staff members Lee Semiatin, Senior Research Scientist, John Hallowell, Industry Applications Engineer, Laura Cahill, Manager, Marketing and Communications, and Denise Sheppard, Publications Coordinator; and Anne Moffat and Dorothy Tonjes of ProWrite. Technical review was provided by Tom Groeneveld, Battelle, and Robert Watson, The Kanthal Corporation.

The source used in this issue of TechCommentary was:

Orfeuil, M. *Electric Process Heating: Technology/Equipment/Applications,* Battelle Press (in press).

Photograph courtesy of The Kanthal Corporation, Bethel, CT.

Applicable SIC Codes

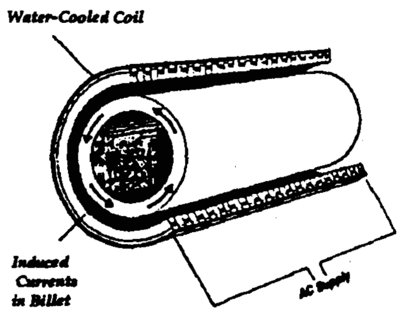
34 — 21, 23, 25, 29, 41-43, 49, 51, 52, 62, 63, 82-84, 89, 93, 96, 97
35 — 11, 19, 23, 24, 31-33, 41, 42, 44-46, 49, 51, 62, 63, 66, 68, 72-74, 76, 79, 92, 99
36 — 12, 21, 43-46, 91
37 — 11, 13-15, 21, 24, 28, 31, 32, 43, 51, 61, 64, 95, 99
38 — 11, 41-43, 61
39 — 11, 14, 15, 44, 61, 64

For further information on Center programs, write or call

Center for Metals Fabrication
505 King Avenue
Columbus, Ohio 43201-2693
(614) 424-7737

Regulation Class: ◑ Clean Air ◔ Clean Water ◔ Haz. Waste ○ CERCLA ○ ______

Process Technology: *INDUCTION*



INDUCTION HEATING COIL

Function/Theory

The workpiece is placed inside/next to a custom designed, water cooled coil (copper tube) called the "inductor." The inductor coil carries alternating current at 60 to 450,000 hertz (cycles per second), depending on specified hardening depth. The inductor coil creates an electromagnetic field that cuts through the workpiece and generates a circulating current in it. The resistance of the metal to the induced currents (I^2R) heats the workpiece.

Selection Criteria/Considerations

Acceptance: ☑ High ☐ Medium ☐ Low

- Melting and holding ferrous metals in foundries.
- Transformation hardening (selective or through) on ferrous metals having greater than .3% carbon content.
- Heating metal bars prior to forming in forge shops and metals fabricating operations.
- Joining/welding small diameter workpieces (.5" - 7" outside diameter).
- Drying/curing for inline processes (i.e. strip & tube/pipe application)
- Other continuous heating applications of similar sized products.
- Bonding plastics in automotive, packaging, construction, and office equipment.

Environmental Benefits

- No combustion by-products as with fossil fuel furnaces.
- Eliminates hazardous waste salts in heat treating.
- Reduced scale/slag/dress.
- Fewer rejects & less post-treatment mach. scrap

Additional Benefits

- Rapid, uniform heating; ideal for high production, in-line processes with throughput from 500 to 10,000 lbs/hr.
- Considerably less space required than fossil furnaces.
- Doesn't generate room heat like fossil furnaces.
- Very precise temperature control.
- Extremely fast, efficient and accurate heating for transformation hardening and selective in-line annealing/stress relieving.
- Can perform either selective or through heating.

Drawbacks

- Higher capital costs.
- Customized coils required for irregular shaped parts.
- Not suitable for frequent product changes.
- Inefficient for small volumes.
- High kW ratings impact on "demand charges."

Waste Stream Reduced

Air		Water		Solid
☑ Particulates	☑ Organics	☐ Particulates	☐ Organics	☑ Hazardous
☑ CO_2, NOx	☐ Toxics	☑ Metals, Ions	☑ Oil	☑ Non-Hazardous

SIC Potential

◔ 25% ◕ 75%
◑ 50% ● 100%

Mining

Metal	10	◔
Coal	12	○
Oil & Gas	13	○
Mineral	14	○

Mfg.

Food	20	○
Tobac	21	○
Textile	22	○
Apparel	23	○
Lumber	24	○
Furn	25	◔
Paper	26	○
Print	27	○
Chem	28	○
Petrol	29	○
Rubber	30	◔
Leather	31	○
Stone, Glass	32	◔
Metals	33	●
Metals Fabric.	34	◕
Mach	35	◑
Elect	36	◔
Trans	37	◑
Instru	38	○
Misc.	39	◔

Typical System Example

Size: 3 - 5 ft. of coil length per ton/hr. in forming {Fabricated Metals}. 375 kW, 1.25 tons/hr = 4' wide x 11' long heater line. 1,100 kW, 3.50 tons/hr = 4' wide x 25' long heater line {Forging}

Energy Requirement:

Heating/melting applications can range from 50 - 5,000 kW.

200 kW for typical Heat Treating installation.

300 - 400 kW for each ton/hr. throughput in forging and other forming.

450 - 550 kW hrs/ton for melting operations in foundries.

30 - 50 kW hrs/ton for holding hot metals in foundries.

10 - 150 kW for joining metals in fabrication.

Economics

Capital Cost: $50,000 - $1,000,000, depending on system size and type. $50,000 - $500,000, typical Heat Treating. $500,000 = 5 tons/hr to melt. $300,000 = 10 tons/hr for holding. $250/ kW for forging & other forming. $1,000/ kW (joining). $500/ kW (heat treating)

Payback: 1.09 years

The payback is based on replacing a gas fired slot furnace with an electric induction billet heating system. This hot metal working application is based on heating 3,000 lbs/hr of steel bars to 2250 degrees F for a forging process.

Source: Pillar Industries

Service/Maintenance

Very low maintenance; cooling water system requires chemical to mitigate scaling and corrosion. Coil life depends on usage (range is from weeks to years). Replacing the coil typically takes 20 - 40 minutes.

Vendors

ABB Metallurgy, Inc.

Ajax Magnethermic Corp.

Inductoheat

Pillar Industries

TOCCO, Inc.

Notes/

Major Vendors

INDUCTION

ABB Metallurgy, Inc.
Induction Furnace Division
North Brunswick, NJ 08902
(908) 932-6134

Ajax Magnethermic Corp.
1745 Overland Ave.
Warren, OH 44482
(216) 372-8511

Inductoheat
32251 N. Avis Dr.
Madison Heights, MI 48071
(313) 585-9393

Pillar Industries
N92 W. 15800 Megal Dr.
Menomonee Falls, WI 53051
(414) 255-6470

TOCCO, Inc.
30100 Stephenson Highway
Madison Heights, MI 48071
(313) 399-8601

EPRI Techcommentaries

Induction Melting

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cmp TECHAPPLICATION

Induction Melting For Higher Productivity

Published by the EPRI Center for Metals Production

THE CHALLENGE:
Modernizing Melting Operations to Lower Production Costs and to Develop a Reliable Source of Specialty Aluminum Alloy for a Captive Die-Casting Operation

In 1982, Mercury Marine, a division of Brunswick Corporation headquartered in Fond du Lac, Wisconsin, sought an alternative to melting aluminum alloy in gas reverberatory furnaces. The company's goals were to:

- Increase the energy efficiency of melting operations
- Give the foundry a make-or-buy option for the highly corrosion-resistant aluminum required for the cast parts used in marine motors
- Lower the cost of casting production
- Improve the foundry's operating environment.

The choice was to replace the gas furnaces with coreless induction units.

Mercury Marine, Fond du Lac, WI, uses a low-cost light scrap aluminum charge in its Brown Boveri induction furnaces. Induction melting holds metal losses to a low 2-3%, compared to 10-15% that would occur with reverb melting.

The Old Way

The gas-fired reverberatory furnaces, which range in capacity from 15,000 to 90,000 pounds, were operating at only 15 to 20 percent energy efficiency. "They used 2,500 to 3,000 Btu per pound of molten metal, and we were producing in excess of 30 million pounds of alloy per year," says Tom Schmidt, Manager of Foundry Operations.

Schmidt says that an eight to ten percent melt loss was another reason to look for a better method. "Stirring in the gas furnaces — it was either manual or with graphite pumps — was poor, so the chemical and metallurgical properties of the metal weren't consistent."

A key corporate goal in modernizing foundry operations was to ensure the foundry a dependable supply of high-quality metal. The company had been buying its specialty alloy ingots from primary and secondary smelters, but decided to develop options for its growing needs. A flexible internal melter such as an induction unit would allow recycling of its own scrap, as well as melting of low-cost purchased scrap.

Another reason for replacing the gas furnaces was that they produced environmentally undesirable particulates and noxious gases.

The New Way

Central to the foundry's modernization were two Brown Boveri coreless induction melters. Each is rated at 6,600 lbs., 900 kW, giving the plant a production capability of 25 million lbs/yr.

Coreless induction furnaces consist of a refractory chamber which holds the metal, surrounded by an electric heating coil and refractory insulation. The furnaces operate on the transformer principle — the charge acting as a single secondary turn, producing heat when power is applied to the multiturn primary coil.

Schmidt notes that there was a certain risk involved in the switch to induction melting. "Aluminum casting foundries have a long history of gas-fired furnaces. We were among the first to use electric induction furnaces in aluminum melting, but we had been using them with positive results in the gray iron foundry and were confident of their success."

The Results: Improved Energy Efficiency, Lower Metal Loss, Higher Quality Castings

The induction furnaces are operating at 55 percent energy efficiency and have cut melt energy consumption 40 to 50 percent. Additional energy savings have come from the interruptable rate the local utility has given the company.

Melt losses have been reduced substantially — to two to three percent. "We get consistently high yields on light-gauge scrap — turnings and borings, which have high surface area and low mass. Due to the controlled stirring of

continued page 2

the induction melters, the turnings are submerged immediately," remarks Schmidt.

Another benefit of the induction furnaces' controlled stirring action is chemical and thermal homogeneity, which results in improved product uniformity. According to the foundry manager, the furnaces are excellent at dissolving silicon, a continuous problem with the gas units. "Although we melt at 1300°F instead of 1500°F as before, the high agitation in the furnaces eliminates the silicon problem."

The electric furnaces' output has surpassed expectations. Designed to produce 1.25 tons per hour, they have yielded as much as 1.75 to 2.25 tons per hour at a melt rate of roughly 50 percent of bath capacity, as opposed to the gas furnaces' ten percent of bath capacity melt rate.

The foundry is enjoying improved labor utilization as well. The gas furnaces had to run seven days a week, even though they were in use only five. Induction furnaces, however, heat quickly and efficiently from a cold start and require only three workers per shift.

Greater operator comfort is another benefit cited by Schmidt. "The induction furnaces have a higher depth-to-surface ratio than do our gas furnaces, so there is much less radiant heat."

Further Advantages of Induction Furnaces

Cold Start with Limited Scrap. No molten metal is necessary with medium-frequency induction melting. Induction furnaces operate reliably with repeated cold starts.

Fast melting time. Efficient, controlled heating results in one to two hour melt cycles for faster operations and easier, more convenient scheduling.

Variable Metal Composition. Induction furnaces allow the metal's composition to be altered in the middle of a heat, a significant benefit for foundries producing a variety of products to different specifications.

Automatic Operation. Precise regulation of solid state power with modern controls requires furnace attendance only for charging, tapping and metallurgical measurements. These controls also contribute to improved product quality.

Long Refractory Life. Medium-frequency furnaces require minimum maintenance because of greatly reduced lining erosion.

Quiet Operation. Since there is no combustion process, induction furnaces run steadily and quietly, minimizing noise pollution.

The Bottom Line: Increased Operating Efficiency, Future Expansion

Four years after commissioning its induction melters, Mercury Marine is still enjoying the benefits of lower energy costs and improved product yield: a 55 percent furnace energy efficiency; melt energy consumption cut 40 to 50 percent; and melt losses reduced to two to three percent.

Currently running three shifts, six or seven days a week, the company is installing another identical furnace to keep up with the demand for marine motors.

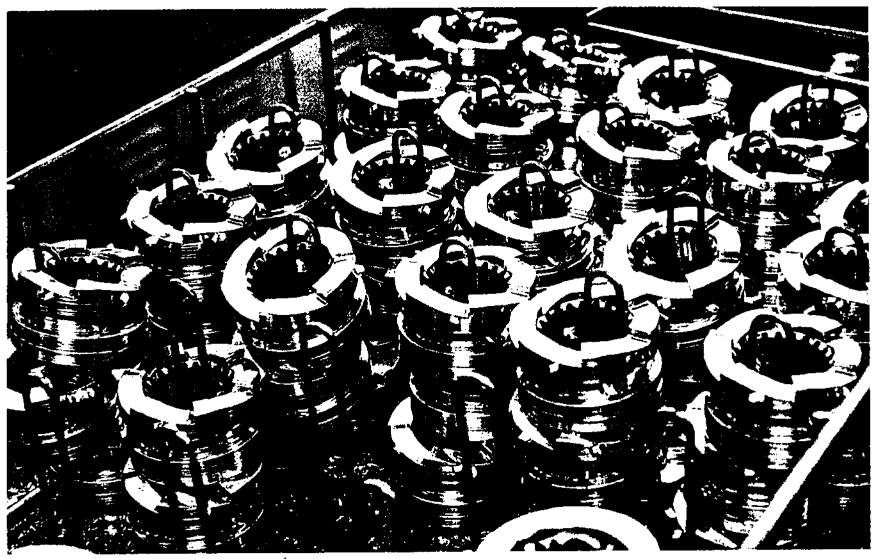
"We've looked at alternative gas technologies and we don't see anything promising," says Schmidt. "We're very strong on electric melting."

Other Applications of Induction Melting Furnaces

Induction furnaces are used in a variety of melting applications. Some include:

- Melting brass, bronze, zinc, and other nonferrous metals
- Melting iron
- Holding metals before casting
- Melting and superheating steel for subsequent refining in basic oxygen furnaces

COMPANY PROFILE



High quality aluminum from induction melters permits Mercury Marine to offer the industry's only three-year corrosion warranty on critical marine engine parts.

Mercury Marine, the world's largest manufacturer of marine engines, began when Carl Kiekhafer Corporation bought a defunct outboard motor plant in 1939 and found itself with hundreds of outboard motors rejected by the buyer. Although the company did not intend to go into the outboard motor business, the need for capital led it to rebuild and improve the motors. The original purchaser not only accepted them, but ordered more.

Kiekhafer was soon asked to design a new motor, and his success led him to design entirely new and more advanced motors, introducing innovations that became standard to the industry.

During World War II, the company's production facilities were diverted to producing engines for portable chain saws. By the end of the War it was the largest chain saw engine builder in the world.

The company has expanded dramatically, adding production plants, distribution centers, and testing stations in the United States, Canada, Australia, and Belgium, and continuing its engineering innovations. The purchase of the Brown Boveri induction furnaces is only one aspect of a $100 million, five year project initiated in 1984 and aimed at improving manufacturing efficiency and ensuring Mercury Marine's position as the world's largest producer of marine engines.

The Center for Metals Production (CMP), is an R&D application center sponsored by the Electric Power Research Institute (EPRI) and administered through Mellon Institute of Carnegie Mellon University. CMP's goal is to develop and transfer technical information that improves the productivity and energy efficiency of U.S. primary metals producing companies (SIC 33). Efforts are concentrated in three areas: (1) melting and casting, (2) rolling and finishing, and (3) eletrolytic processing.

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CMP TECH APPLICATION

Induction Melting for Business Building

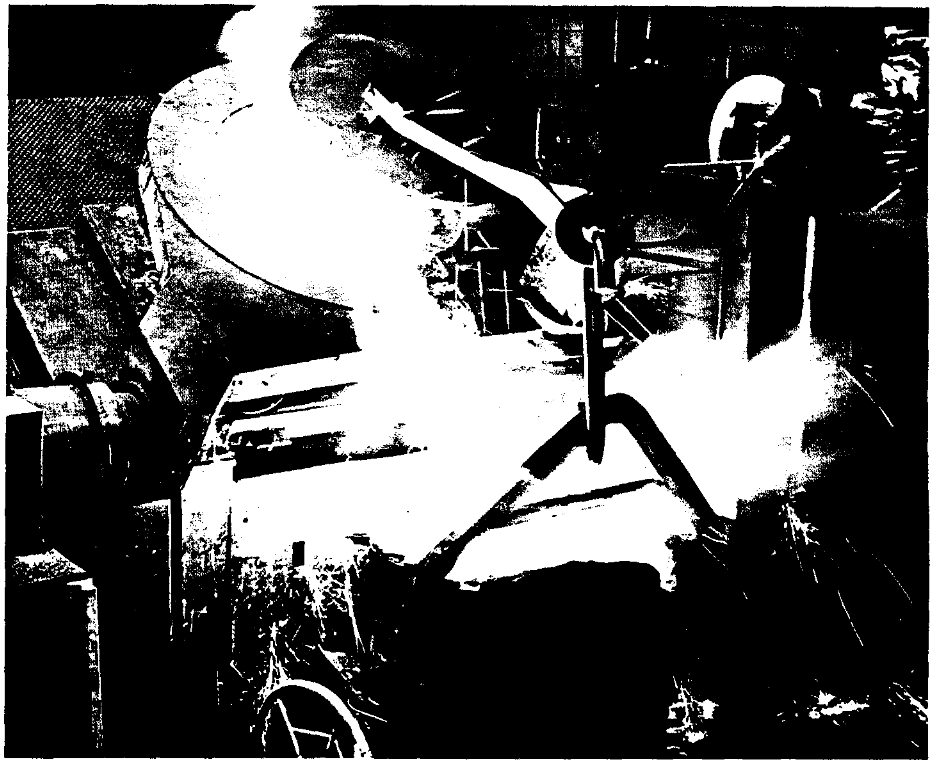
Published by the EPRI Center for Metals Production

THE CHALLENGE:
Increasing Foundry Production Flexibility and Lowering Energy Costs to Better Serve the Water Control Equipment Marketplace

Over the past two decades, production requirements at Rodney Hunt Company in Orange, Massachusetts have gradually changed. The foundry, which specializes in the production of sluice gates used in water control, found itself pouring an increasing quantity of Ni-resist and other alloyed irons.

Through careful study and analysis, it was determined that to meet this changing production scenario, and to reduce energy costs, conversion to electric induction melting was in order.

Jim Hodson, Foundry Manager, explains: "We pour about 6½ million pounds of clean castings a year. After considering all the alternatives, we found coreless induction furnaces more precisely fit our operations' needs, giving us the flexibility required to meet our customers' demands."



Until the early '70s, Rodney Hunt Company used coke-fired cupolas for iron melting, but with increasing production of alloyed-iron, the foundry converted to induction melting.

The Old Way

Up until the early '70s, Rodney Hunt used coke-fired cupolas to melt their iron.

The cupolas satisfied heavy production demands, but they created a number of environmental problems ... including atmospheric pollution, hazardous wastes (resulting from high-lead content scrap), and noisy operation.

Rather than spend heavily on expensive scrubber systems, the foundry then purchased channel induction furnaces.

Channel induction furnaces consist of an inductor— a water-cooled coil— which is the energy source. A channel is formed in the refractory through the coil, creating a continuous loop with the metal in the main part of the furnace. The hot metal in the channel circulates into the main body of metal in the furnace envelope and is replaced by colder metal.

The channel induction furnaces satisfied Rodney Hunt Company's production demands at that time.

The New Way

The key to the foundry's more flexible operations and energy savings was one medium-frequency, 1750kW induction power supply with two 4-ton, steel shell coreless induction furnaces and a third 12-ton, steel shell coreless induction furnace— all supplied by Inductotherm Corp. of Rancocas, New Jersey.

Coreless melting furnaces consist of a crucible, which holds the metal, surrounded by an electric heating coil and refractory insulation. The furnaces operate on the transformer principle, with the charge acting as a single secondary turn, producing heat when power is applied to a multiturn primary coil.

Energy-efficient coreless induction allows Rodney Hunt Company to batch melt their iron. Batch melting represents a major advance in induction furnace technology, offering foundries added flexibility and improved operating efficiencies.

Batch melting is a process in which the furnace volume is emptied after the melt has reached the proper temperature. Successive melts are started using either unheated or preheated charge materials. No hot heel needs to be maintained in the furnace as required with channel melting.

The New Way (cont.)

The energy savings that result from batch melting are significant. The ease of starting the empty furnaces allows Rodney Hunt, now a single-melt operation, to take advantage of the lower off-peak rates by melting at night.

The resulting energy savings are significant.

The Results: Pollution-Free, Flexible, Cost-Efficient Melting

Pollution control is a major problem facing American foundries today. The coke-fired cupolas previously used at Rodney Hunt required cost-prohibitive pollution control equipment. According to Hodson, "From an operations standpoint, cupolas are filthy ... and they're very expensive to maintain."

Electric heating, on the other hand, practically eliminates pollution control equipment because it does not require combustion air. And expensive gas cleaning devices are not needed.

Also, the scrap melted in induction furnaces does not contain the high lead content of the scrap that sometimes was used in cupolas, eliminating the problem lead-containing waste.

As Hodson states, "These induction furnaces give us far more flexibility. We're now able to produce the whole gamut of alloy grades, on demand, without any costly turnovers."

Further Advantages of Induction Melting Include:

Fast startup from cold. Full power is instantly available significantly reducing the time it takes to reach working temperatures.

Cold start with limited scrap. No molten metal is necessary with medium-frequency induction melting. Induction furnaces operate reliably with repeated cold starts.

Fast melting time. Efficient, controlled heating results in one-to-two hour melt cycles for faster operations and easier, more convenient scheduling.

Natural stirring action. Medium-frequency units provide a strong stirring action, resulting in a homogenous melt.

Automatic operation. Precise control of solid-state power with modern controls requires furnace attendance only for charging and metallurgical measurements. These controls also contribute to improved product quality.

Long refractory life. Medium-frequency furnaces require minimum maintenance due to greatly reduced lining erosion.

Quiet operation. Induction furnaces run steadily and quietly, minimizing noise pollution.

The Bottom Line: Saving On Energy Costs While Meeting Customers' Demands

Less than a year after the new furnaces were installed, the Rodney Hunt Foundry realized over a 50% reduction in energy costs. Hodson says, "The cost of the furnaces is justified by the reduction in energy consumption alone."

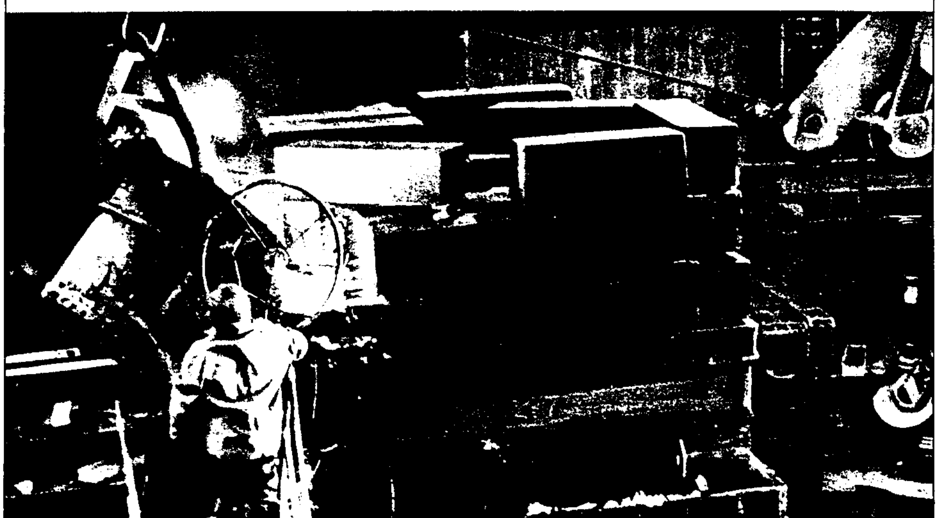
But, more significantly, Rodney Hunt Company is better able to provide customers with the grades of iron they require. Says Hodson, "Increasingly, customers are buying high alloy iron that is more corrosion-resistant. Rodney Hunt Company has always focused on customer service ... our response time now is quicker than ever!"

Other Applications of Induction Melting Furnaces:

Induction melting furnaces are used in a variety of applications. Some include:

- Melting aluminum, brass and bronze, zinc, and other nonferrous metals
- Holding furnaces for the casting industry
- Melting and superheating of steel for subsequent refining in basic oxygen furnaces

COMPANY PROFILE



Foundry worker operates a ladle pour for a 96" diameter valve with a body weight of 22,000 lbs.

Rodney Hunt Company's beginnings go back 142 years when Rodney Hunt started his business making plows for farmers.

Later, due to the growth of textile mills in the area, Hunt found a stronger market for water wheels. In the 1900s, the company specialized in the manufacturing and selling of turbines for generating power in many of the area's waterways.

For the past 50 years, the foundry's primary business has been the design and manufacture of cast iron/bronze-mounted sluice gates used in sewage treatment plants and dams. Rodney Hunt is the leading sluice gate manufacturer in the world.

The company employs approximately 300 people, 55 of whom work in the foundry and pattern shop.

The Center for Metals Production (CMP), located at Carnegie Mellon University in Pittsburgh, Pennsylvania, is a research and development applications center sponsored by the Electric Power Research Institute (EPRI). EPRI is a nonprofit institution that conducts R&D on behalf of the United States electric utility industry.

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TECHCOMMENTARY

INDUCTION HEAT TREATMENT

Published by the EPRI Center for Materials Fabrication Vol. 2, No. 2, 1985 Reprinted March, 1990

Using Induction Heat Treatment to Obtain Special Properties Cost Effectively

Heat treatment is often one of the most important stages of metal processing because it determines the final properties that enable components to perform under such demanding service conditions as high load, high temperature, and adverse environment. This **TechCommentary** illustrates how you can use the special features of induction heat treatment, such as its speed and selective heating capability, to produce quality parts cost effectively. It will answer such questions as: What are the advantages of induction heat treatment? What heat treatments can I conduct with induction? What are some typical parts and materials that are induction heat treated? What properties can I obtain with induction heat treatment?

The differences between induction and conventional furnace-based heat treating processes and some advantages of induction heating are discussed in **TechCommentary** Vol. 2, No. 1. Advantages specific to induction heat treating are:

Speed — In heat treatment, the higher heating rates play a central role in designing rapid, high-temperature heat treating processes. Induction heat treating of steel may take as little as 10 percent or less of the time required for furnace treatment. Short heating times also lead to less scaling for materials such as steels that oxidize readily at high heat treating temperatures.

Selective Heating — Controlling the heating pattern by selecting the right induction equipment allows surface and selective heat treatments that yield an attractive blend of properties (e.g., high strength and toughness). Such treatments are not feasible with furnace processes, which are slow and heat the entire workpiece.

Energy Savings — In addition to eliminating dwell periods, induction heat treating techniques put energy only where needed, improving energy efficiency.

Increased Production Rates — Rapid heating often increases production and reduces labor.

Heat treatment is the controlled heating and cooling of a solid metal or alloy to obtain desired properties. Depending on the material and its intended use, heat treatment can improve such characteristics as formability, machinability, and service performance. Typical heat treating operations include:

- Annealing — used to soften metals to improve formability and machinability.
- Hardening — used to increase the strength and deformation resistance of metals (such as steels).
- Tempering — used to increase the toughness of hardened metals and thereby improve their resistance to brittle, catastrophic failure in high-stress, high-integrity applications.

A glossary at the end of this **TechCommentary** precisely defines these and other important heat treating terms.

There are two broad categories of heat treating processes — those involving **indirect** heating and those using **direct** heating. With indirect methods, heat is produced in a furnace by burning a fuel or by converting electrical energy into heat by passing a current through resistance heating elements. This energy is then transferred to the workpiece by radiation, convection, or conduction. By contrast, direct heating methods, including induction, direct resistance, and flame heating, supply heat directly to the workpiece. An in-depth discussion of how induction heating works is included in **TechCommentary** Vol. 2, No. 1.

Types Of Induction Heat Treatments

You can utilize the speed and selective heating characteristics of induction processes for:

Hardening of Steels — Steels are hardened by heating to austenitizing temperatures and then quenching. The speed of induction heating and minimal soak time mandate higher austenitizing temperatures than those used with furnace processes (Table 1). Depth of austenitization is

Percent Carbon	Furnace Heating, F (C)	Induction Heating, F (C)
0.30	1550 to 1600 (845 to 870)	1650 to 1700 (900 to 925)
0.35	1525 to 1575 (830 to 855)	1650 (900)
0.40	1525 to 1575 (830 to 855)	1600 to 1650 (870 to 900)
0.45	1475 to 1550 (800 to 845)	1600 to 1650 (870 to 900)
0.50	1475 to 1550 (800 to 845)	1600 (870)
0.60	1475 to 1550 (800 to 845)	1550 to 1600 (845 to 870)

Table 1 Austenitizing Temperatures For Carbon Steels

easily controlled so that parts can be surface or through hardened.

Tempering of Steels—Tempering of hardened steels is a function of both time and temperature. Induction tempering uses shorter heating times (usually only seconds) and higher temperature to produce results equivalent to furnace tempering treatments that often require hours.

Normalizing—Since normalizing requires heating to a high temperature followed by air cooling, it is an ideal application of induction heating. Induction normalizing treatments are often used for products that can be processed on a continuous basis, such as pipe.

Weld Seam Annealing—The speed and selectivity of induction heating can be called on for local stress relief annealing of welds in sheet metal, tubular, and other kinds of products.

Recrystallization Annealing—Annealing treatments for sheet metal have been carried out successfully using a new process called "transverse flux" (TFX) induction heating, in which sheet is fed continuously through a specially designed coil. Total heating time is only a few seconds, compared to many hours for conventional furnace or batch annealing of coils of sheet metal. Moreover, the fine temperature control with induction heating permits partial as well as full recrystallization annealing, depending on the annealing temperature chosen. Thus, a range of properties, not obtainable with batch annealing, is possible.

Induction Heat Treating Applications And Materials

You can use induction heat treatment for a wide range of parts. The brief list of common applications that follows is only representative of its potential use.

Surface Hardening and Tempering of Steels:

- Transportation—crankshafts, camshafts, axle shafts, transmission shafts, splined shafts, universal joints, gears, valve seats, wheel spindles, bearings.
- Machine tools—lathe beds, transmission gears, shafts.
- Metalworking, hand tools—rolling mill rolls, pliers, hammers.

Through-Hardening and Tempering of Steels:

- Oil-country tubular products, structural members, spring steel, chain links.

Annealing:

- Longitudinally welded steel tubes, nonferrous sheet metals, ferrous and nonferrous wire, steel pipes, tanks.

Induction heat treating is also useful for a wide range of materials, but steel parts comprise the largest portion of induction heat-treated components. Some typical induction heat-treated steels are

- Medium-carbon steels, such as 1030 and 1045, used for welded tubing, automotive shafts, and gears
- High-carbon steels, such as 1070, used for hand tools
- Alloy and stainless steels used for bearings, automotive valves, and machine tool components
- Tool steels, such as M2 and D2, used for cutting tools and metalworking dies.

The induction annealing of aluminum and its alloys is certainly feasible, but, at present, nonferrous alloys are induction heat treated less often than steels. Pending the development of an information base on process economics, heat treatments for titanium and nickel-base alloys, which are readily heated by induction, could become a reality in the future.

Technical And Economic Considerations

Determining whether induction heat treatment is suited to your needs requires evaluation of such technical factors as:

Workpiece Size and Shape—These influence the shape of the induction coil to be used. It is easiest to design coils for symmetric parts. However, induction heat treating is readily applied to irregularly shaped components by using special coil designs.

Subsequent Processing—Should permit easy integration of induction heat treating. This includes, for example, the design of quench stations following steel hardening operations. The high speed of induction heating may accommodate machining operations on the same processing line.

Metallurgical Condition—Must the part meet special service requirements that induction heating can provide, such as a blend of high strength and toughness? Some of the properties and characteristics of induction heat treated parts are discussed below.

In addition to evaluating technical feasibility, you must also determine if induction heating is cost effective when compared to other techniques. Important economic factors in your decision should include production lot size, equipment and energy costs, labor requirements, scale and scrap losses, and floor space requirements. The way each of these elements figure in an overall cost analysis is discussed in detail in **TechCommentary,** Vol. 2, No. 1.

Properties Of Induction Heat Treated Parts

The largest amount of property information on induction heating is for hardened and tempered steel parts. Such data indicate that induction through heat-treated parts have mechanical properties similar to

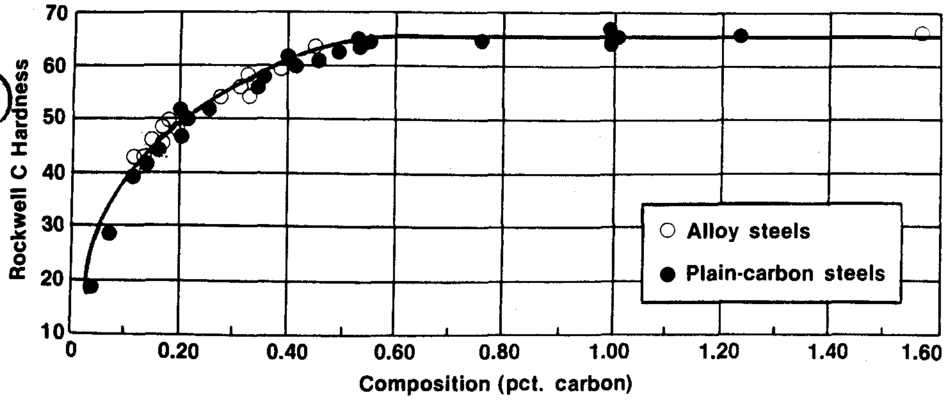

Figure 1 Hardness Of As-Quenched Martensite As A Function Of Its Carbon Content

those heat treated in furnaces.

In many applications, however, surface hardened and tempered steel parts surpass their furnace treated counterparts. This is because surface induction heating leads to:

- A hard case and a soft core, which provide a good blend of strength and toughness not attainable with furnace through heating. Further, because the hardness of as-quenched steels depends only on carbon content (Figure 1), this combination of properties can be obtained in inexpensive carbon steels. Induction heat-treated carbon steel parts can be used in many applications that require alloy steels with good toughness, which are through heat treated in furnaces.
- Compressive residual stresses at the surface, which are important in combination with the surface hardness. These residual stresses arise primarily from the density difference between the hard martensite layer and the softer interior layer of pearlite or bainite in surface hardened parts.

The combination of a hard surface, compressive residual stresses, and a soft core results in excellent wear and fatigue resistance. Improvement in bending fatigue when compared to furnace treatments is shown in Figure 2 for axle shafts. The attributes of induction treatment are particularly attractive in bending fatigue in which high levels of tensile stress are generated at the surface, and no stresses are imposed at the center. Here, the property distribution in the surface hardened part is well matched with the demands placed on it in service. Another example is the wear resistance afforded gear teeth by selective surface hardening. Properties of induction surface hardened parts are discussed further in **Tech-Commentary** (Vol. 2, No. 3).

Heat Treating Processes That Compete With Induction

Considerations of speed, selective heat treating requirements, and process economics are often sufficient to establish whether you should use induction or conventional furnace-based methods for through heat treatment. On the other hand, if you've determined that surface hardening is necessary, there are a number of other processes to consider. These include conventional **carburizing** and **nitriding, ion-nitriding, laser hardening** and **electron beam hardening.**

Carburizing and nitriding are well established technologies in which surfaces are alloyed with carbon or nitrogen by placing parts in a gaseous or liquid environment. The alloying results in surface hardening. Cost data from commercial heat treaters indicates that the overall cost for induction hardening is much less than for carburizing, salt bath nitriding, or gas nitriding. (The cost ratio for the 4 processes in the order listed is 0.11:2.5:1.75:8.) Thus, if your part geometry and production volume allow the use of induction, it is the preferred surface hardening method from a cost standpoint.

Ion-nitriding, laser hardening, and **electron-beam (EB) hardening** are emerging technologies that are

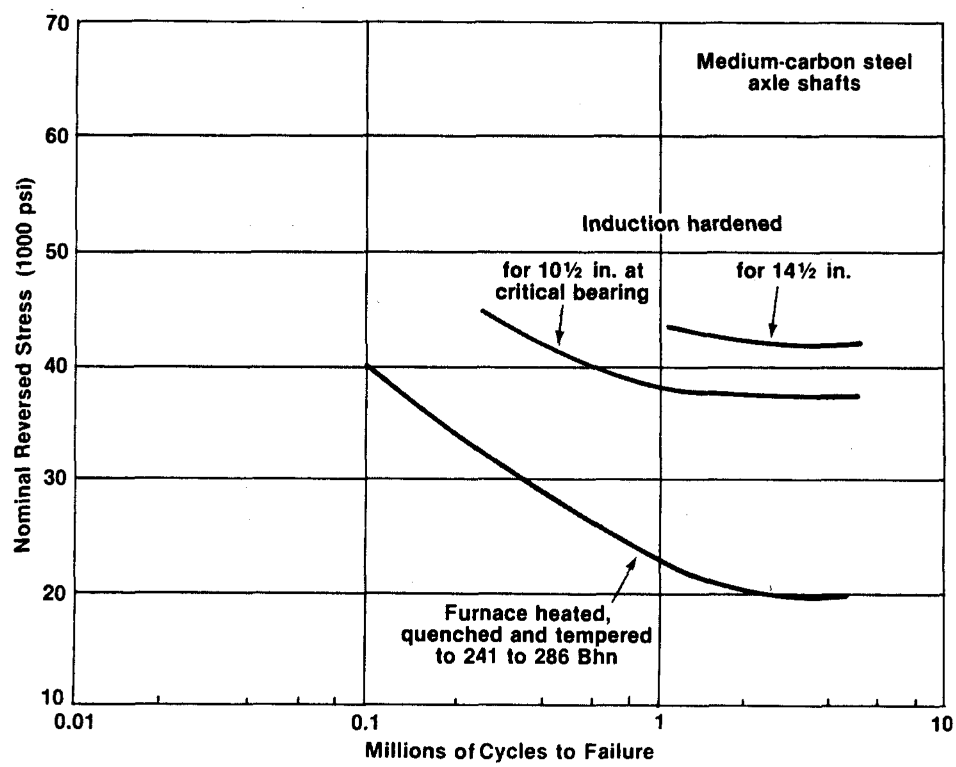

Figure 2 Bending Fatigue Response Of Medium-Carbon Steel Tractor Axles Which Were Either Furnace Hardened Or Induction Hardened

used to obtain shallow case-hardened depths (0.02 in. or less). Ion-nitriding is similar to other nitriding processes except that a glow-discharge method is employed.

Laser and EB techniques both use extremely high-energy input rates that austenitize a very thin surface layer in a fraction of a second. The bulk of the substrate remains cool and provides an adquate heat sink for "self-quenching". Advantages include:

- Minimal workpiece distortion
- Ability to selectively harden portions of a surface and to control the process in general
- Ability to harden areas inaccessible to conventional induction techniques
- Repeatability
- High speed.

According to a recent American Society for Metals (ASM) survey, ion-nitriding offers the greatest challenge to induction heating for purposes of surface hardening. Laser and EB processes are also expected to satisfy some of the applications now handled by induction, particularly those for which induction coils are difficult to design. Nevertheless, in situations in which case depths of 0.02 to 0.04 in. are required, induction systems that produce very high-power inputs per unit of surface area (i.e., "high intensity" induction setups) can compete effectively because of lower equipment cost, higher productivity, less maintenance, and lower floor space requirements. For example, in typical industrial applications, a 2 to 3 kilowatt laser, costing approximately $250,000 is required. This is about 3 times the cost of comparable induction equipment. Electron-beam hardening also has some important limitations, such as the need for a vacuum atmosphere.

Design Of Induction Heat Treatment Processes

To make induction heat treatment work for you, carefully select equipment and understand the metallurgical variables that control heat treating response. The most important equipment parameters are **coil design, generator frequency,** and applied **power density.**

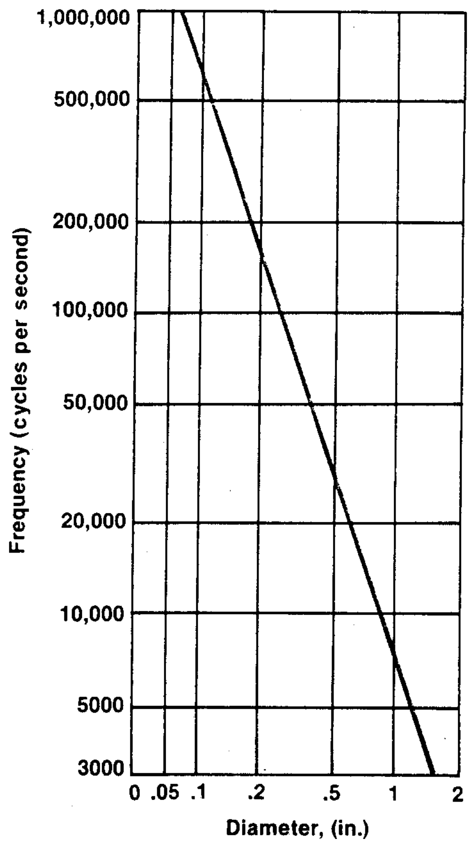

Figure 3
Relation Between Diameter Of Round Steel Bars And Minimum Generator Frequency For Efficient Austenitizing Using Induction Heating

Coil Design — Solenoidal coils are easily designed for round parts. For more complex parts, design procedures are described in induction heating textbooks or can be provided by equipment manufacturers.

Generator Frequency — This is determined by the material, part size, and the need for through or surface heating. Low frequencies, which provide large "penetration" depths of the induced eddy currents, are used for through heat treating. High frequencies are used for surface heat treating. The minimum frequencies for efficient through austenitizing of steel bars are shown in Figure 3. Frequencies for surface hardening of steels are chosen to ensure penetration depths of about twice the required hardened depth. Other variables, such as power density, are important in selecting frequency in these instances as well and are discussed in **TechCommentary,** Vol. 2, No. 3.

Power Density (or power per unit of surface area) — The same power input can lead to a low heating rate for a large part but a high heating rate for a small part. As with frequency, power density level is selected based on the need for through or surface heat treating. The schematic diagram in Figure 4 illustrates the typical temperature versus time behavior for an induction heated part and is useful in explaining power density effects. Because the magnitude of the eddy currents are greatest at the surface and least at the center, the surface heats more rapidly. After an initial transient, the difference in temperature remains fixed. This difference represents an equilibrium between heat input via induction and heat transfer between the surface and center by conduction. As such, it is a function of the applied power density and workpiece electrical and thermal properties. For through heating and heat treating, lower power densities of 0.1 to 0.5 kW/in.^{2} are recommended to ensure a more or less uniform heating pattern. High power densities (approximately 10 to 20 kW/in.^{2}) are needed for surface heating and heat treatments of steel.

Using data on coil design and power supply requirements, you can figure out where the heating power is going to be located in your heat treating process. To ensure success, however, it is important to understand the metallurgical properties of the workpiece and how these interact with your heating cycle. Of utmost importance is the design of the necessary time-temperature cycles, which are typically quite different from those for furnace heat treatments.

The data in Table 1 reveal that higher temperatures are employed for induction austenitizing of steels. You need these to compensate for short or zero soak times. Similarly, short-time tempering treatments involving short or zero soak time can be designed around induction heating processes by using the so-called tempering parameter,

$$\mathbf{T}(14.44 + \log_{10}\mathbf{t}),$$

where **T** is the tempering temperature in degrees Rankine and **t** is the tempering time in seconds. An induction tempering treatment

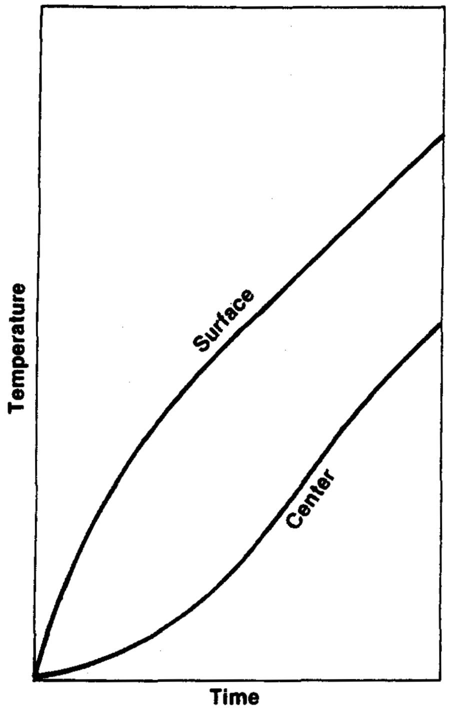

Figure 4
Schematic Illustration Of The Surface And Center Temperature Histories Of A Bar Heated By Induction (Note that, following an initial transient, the surface-to-center temperature difference is constant during the heating cycle.)

whose tempering parameter is equivalent to that for a longer-time, lower-temperature treatment will give a part with equivalent properties. The application of this concept is discussed further in **TechCommentary,** Vol. 2, No. 4.

A final factor that warrants consideration in process design is the starting condition of the workpiece. This is particularly important for steels that are to be hardened. In these cases, austenitizing behavior will be affected greatly by the starting microstructure. An example of this microstructure effect is seen in Figure 5. As shown here, when using the same induction heating parameters, the case hardened depth for a 1070 steel bar increases as the starting structure becomes finer: quench and tempered = fine martensite structure, normalized = fine pearlite with thin lamellar carbides, and annealed = structure with coarse, difficult-to-dissolve spheroidal carbides.

Such variations in induction heat treatment results can be overcome

Glossary Of Heat Treating Terms*

Alloy Steel — Steel containing significant quantities of alloying elements (other than carbon and the commonly accepted amounts of manganese, silicon, sulfur, and phosphorous) added to effect changes in the mechanical or physical properties.

Annealing — Heating to and holding at a suitable temperature and then cooling at a suitable rate for such purposes as reducing hardness, improving machinability, facilitating cold working, producing a desired microstructure, or obtaining desired mechanical, physical, or other properties. Specific types of annealing processes include:

Recrystallization annealing — Annealing cold or hot worked metal to produce a new grain structure without phase change.

Spheroidization annealing — Heating and cooling to produce a spheroidal or globular form of carbide in steel.

Stress relief annealing — Heating to a suitable temperature, holding long enough to reduce residual stresses, and then cooling slowly enough to minimize the development of new residual stresses.

Austenitizing — Forming of the face-centered-cubic austenite phase in steel by heating above the transformation temperature range. Process forms the basis of hardening of steels.

Bainite — A decomposition product of austenite consisting of an aggregate of ferrite and carbide. In general, it forms at temperatures lower than those where very fine pearlite forms and higher than that where martensite begins to form on cooling. Its appearance is feathery if formed in the upper part of the temperature range; acicular, resembling tempered martensite, if formed in the lower part.

Carbon Steel — Iron alloy containing carbon up to about 2 percent and only residual quantities of other elements except those added for deoxidation, with silicon usually limited to 0.60 percent and manganese to 1.65 percent. Also termed plain-carbon steel.

Cementite — A compound of iron and carbon found frequently in steels known chemically as iron carbide and having the approximate chemical formula Fe_3C.

Ferrite — A solid solution of 1 or more elements in body-centered cubic iron; the solute is generally assumed to be carbon unless designated otherwise.

Hardenability — In steels, the property that determines the depth and distribution of hardness induced by austenitizing and quenching. Hardenability is a function of alloy composition and quenching medium.

Hardening — Increasing the hardness by suitable treatment, usually involving heating and cooling. For steels, this typically consists of austenitizing followed by cooling to form pearlite, bainite, or martensite, or a combination of these constituents.

Martensite — A metastable phase of steel formed by a transformation of austenite below the M_s temperature and composed of a body-centered tetragonal lattice. Its microstructure is characterized by an acicular, or needle-like, pattern.

Microstructure — The structure of polished and etched metals as revealed by a microscope at a magnification greater than 10 diameters.

Normalizing — Heating a ferrous alloy to a suitable temperature above the transformation range and then cooling in air to a temperature substantially below the transformation range.

Pearlite — A lamellar aggregate of ferrite and cementite, often occurring in steel and cast iron.

Quench Hardening — Hardening a ferrous alloy, such as a steel, by austenitizing and then cooling rapidly enough so that some or all of the austenite transforms to martensite.

Tempering — Reheating a normalized or quench-hardened ferrous alloy such as a steel to a temperature below the transformation range and then cooling at any rate desired.

Transformation Temperature — The temperature at which a change in phase occurs. The term is sometimes used to denote the limiting temperature of a transformation range.

*Source: *Metals Handbook*, Vol. 1, Eighth Edition, American Society For Metals, 1961.

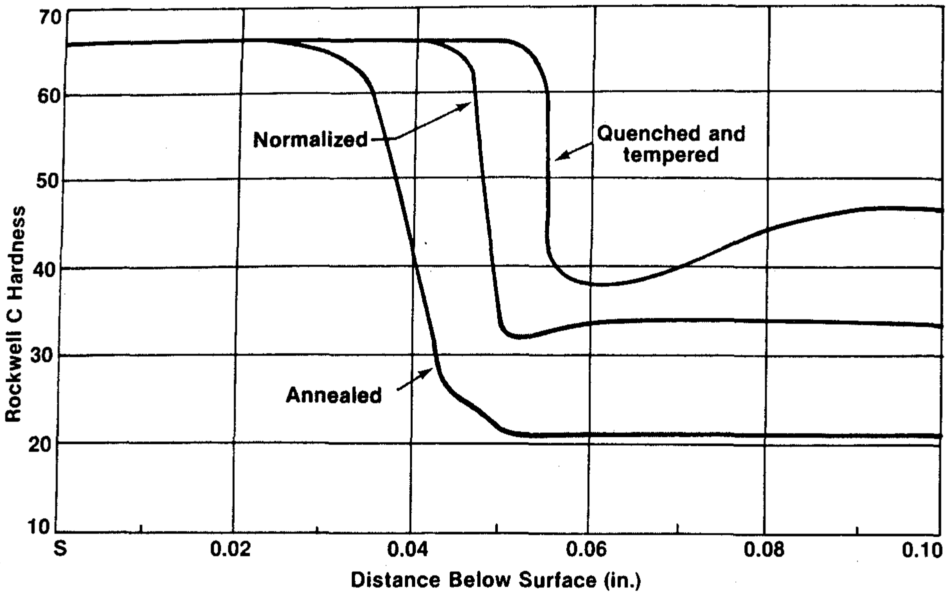

Figure 5 Effect Of Starting Microstructure In 1070 Steel Bars On Surface Hardening Response Using A 450 kHz Induction Generator Operated At A Power Density Of 2.5 Kilowatts Per Square Centimeter (15.9 kilowatts per square in.)

by determining (on a trial-and-error basis) modified peak temperatures or heating rates for your particular alloy and expected variations in starting condition.

In Summary

Induction heat treatment is applicable to hardening, tempering, normalizing, and annealing a wide range of parts, particularly in ferrous alloys — medium- and high-carbon steels, alloy and stainless steels, and tool steels. It is also finding increasing application in the nonferrous metals industry. Advantages include high heating rates, selective heating capability, improved production rates, and energy savings. Induction heat treatment can produce surface hardened parts with soft cores that exhibit excellent wear and fatigue resistance. However, satisfactory heat treatment requires careful selection of equipment and good understanding of the metallurgical variables involved. For surface hardening applications, there are a number of competing processes to consider. □

This **TechCommentary** provides an overview. It is intended to familiarize you with the important applications of induction heat treatment. If you are interested in a more detailed background, please refer to subsequent issues of **TechCommentary** on "Surface and Selective Heat Treatment" (Vol. 2, No. 3), "Induction Tempering" (Vol. 2, No. 4), and the sources listed below.

The Center for Materials Fabrication (CMF) is operated by Battelle's Columbus Division. Basic funding is provided by the Electric Power Research Institute, a nonprofit institute that conducts research and development on behalf of the United States electric utility industry.

The Center's mission is to assist industry in implementing cost- and energy-efficient electric-based technologies in the metals fabrication and related fields. **TechCommentary** is one communication vehicle that the Center uses to transfer technology to industry. The Center also conducts research in metal heating, metal removal and finishing, and fabrication.

This issue of **TechCommentary** was made possible through the cooperation of Battelle staff members Lee Semiatin, author; Jack Mortland, editor; Laura Cahill, publications coordinator.

Sources used in this issue of **TechCommentary** were:

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Applicable SIC Codes

33— 12, 15, 16, 17, 21, 34, 41, 51, 53, 54, 55, 56, 98, 99
34— 11,12, 21, 23, 25, 29, 41, 43, 49, 52, 62, 63, 71, 79, 83, 84, 89, 93, 95, 99
35— 23, 24, 31, 32, 33, 36, 41, 42, 44, 45, 46, 47, 62, 66, 67, 68, 92, 99
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APPLICATION

Induction Hardening with a Flux Field Concentrator

Published by the EPRI Center for Materials Fabrication Vol. 1, No. 11, 1987

The Challenge: Obtaining Superior Heat-Treating Patterns

The gear teeth and hubs in differentials and transaxles manufactured by Peerless Gear and Machine Division of Tecumseh Products Company for use in riding mowers, small garden tractors, and snow blowers are now induction hardened using a flux field concentrator. The flux field concentrator enables the induction heating to achieve more consistent hardness patterns in less time and with less energy.

Before going to the new method in 1986, Peerless Gear was dissatisfied with the results it was obtaining. It sought a technique that would

- Consistently produce hardness to the desired depth
- Reduce rework and scrap
- Increase the production rate
- Not distort the workpiece.

The Old Way

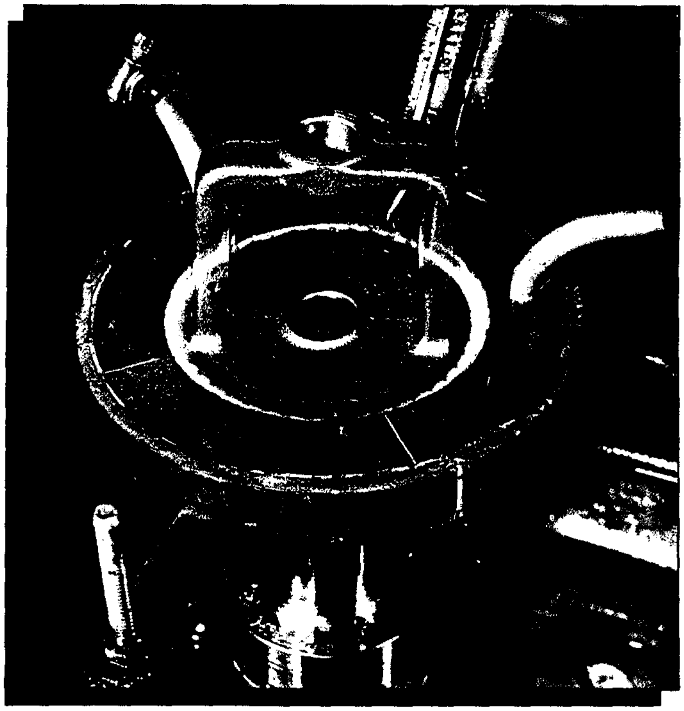
Peerless began its gear manufacturing process with purchased rough pearlitic malleable iron castings that were then turned on a chucker, broached, drilled, and pot broached. Following machining, gear teeth were induction hardened and tempered in a gas-fired furnace, and random samples were inspected. Sampled gear teeth had to withstand a striking force of 12 pounds from 16 inches. In addition to passing the impact test, the parts had to have a minimum hardness of HRC 47 and meet case depth specifications when sectioned. If a part failed a test, all parts made since the last successful test were rejected and sent for rework.

The induction coils Peerless had been using to harden the gear teeth and hubs created variations from specification in hardness depth so that many parts had to be sent back to be reworked. The problem was so bad that sometimes an entire shift's production was rejected.

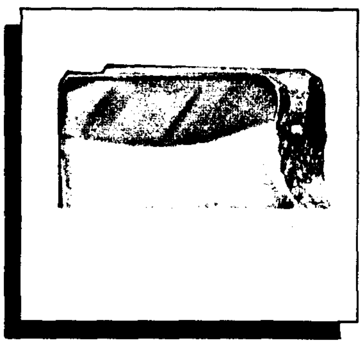
The New Way

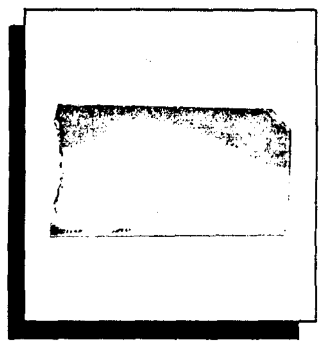
Peerless kept the rest of the production process the same but centered its efforts on finding a better way to induction harden the parts. After experimenting with different coil designs and heating patterns, Peerless ordered a new coil that was enveloped with a flux field concentrator. The flux field concentrator material concentrates more energy into the part, gives superior hardening and creates a new hardness pattern. Now, almost all parts pass quality testing and are ready for subsequent operations without rework.

The improvements the flux field concentrator brought are a major factor in Peerless Gear's streamlined operations.



Induction hardening with a flux field concentrator directs more energy into the gear teeth, giving superior hardening. Below, a cross-sectional view shows gear tooth hardness patterns: at left is the new pattern, which is deep in the center and shallower at the outside, while at right is the old pattern, shallow in the center.





The Results: Faster, Deeper and More Consistent Hardening

Increased production savings. The cycle time has been reduced from 30 to 20 seconds. The total number of parts produced, about 172,000 per year, remained the same. However, now the quota is met without overtime or weekend work. By eliminating rework, 2 shifts can do the work of 3.

About Flux Field Concentrators

Flux concentrators surround the induction coil with a material that keeps the magnetic field within the confines of the coil so it is not lost into space or adjacent machinery. Examples of magnetic flux concentrator materials include silicon-steel laminations, ferrites and iron powder composites. Different applications may call for different flux concentrator materials.

The use of flux concentrator material not only reduces the amount of energy lost but also allows only selected areas of the part to be heated, depending on the placement of the material around the coil. Flux concentrator materials can be used to direct, redirect or block either low frequencies (60 Hz–10 kHz) or radio frequencies (50 kHz–500 kHz).

Material and labor savings. With better quality and consistency, the number scrapped due to destructive testing was reduced from 7% to 1.5%. By reducing the number of rejects from 12,040 to 2,508 parts annually, Peerless projects its material and labor savings to be about $38,000. Additional savings are achieved through reduction of scale during heat treating.

Reduced production cost. Costs are reduced through

- The elimination of overtime and extra shifts
- The reduction in rejected parts and reduced rework
- The decrease in energy used.

Less work in process. Previously, parts had to be tagged and inventoried before they were taken to the grinders. Now there is a constant flow, and the assembly line stays supplied.

Energy savings. Because of the flux concentrator, power usage was reduced from 24.5 kW to 22.5 kW. Heat cycle time was reduced from 9.7 sec to 6.1 sec. This amounted to an overall energy savings of 42%. Further energy savings result from the drastic reduction in rework.

More consistent hardness depth. The hardness depth of 0.130–0.200 inch and pattern are consistently achieved.

Equipment savings. Before, induction coils had to be replaced every month. At time of publication, the flux concentrator has been in use for 7 months with no downtime and no maintenance. It seems to have an indefinite lifetime.

What Did It All Cost?

The redesigned coil, enveloped with the flux concentrator material, cost $2800. The payback period was 1 month.

The Bottom Line: Better Quality Products at a Lower Cost

By trying a new technology, Peerless came up with a winner—a process that increases quality while decreasing costs, time, and rework. Now production proceeds smoothly with less wasted effort and rework.

Other Applications of Flux Field Concentrators

Any part that requires hardening or heat treating is a potential candidate for induction heating with a flux field concentrator. Originally, flux concentrators were reserved for difficult applications—about 5% of the induction hardening market. But today, with the superior materials available, about 90% of the induction heating applications could benefit from using the concentrators. Induction heating for tempering, annealing, softening or brazing can also benefit from the use of flux concentrator materials to modify the flux pattern available from a particular coil.

Company Profile

Peerless Gear and Machine Division, Tecumseh Products Company, Clinton, Michigan

General Manager—H. Orrin Pease

Over 500 employees in the Division

Peerless makes transaxles, transmissions, differentials and other power train components for lawn, garden and recreational vehicles.

Company philosophy: Be the premier manufacturer of lawn and garden drive components by providing superior customer service at the most competitive price.

Bill Fetzer, Peerless Gear's Chief Metallurgist and Heat Treat Manager, was responsible for implementing the flux field concentrator.

The Center for Materials Fabrication (CMF) would like to thank John Minnema of Peerless Gear and Bob Ruffini of R.S. Ruffini and Associates for valuable contributions made to this issue.

Detroit Edison Company provides electric service for Peerless Gear.

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APPLICATION

Post-Grinding Induction Hardening

Published by the EPRI Center for Materials Fabrication Vol. 1, No. 2, 1987

The Challenge: Finding a More Efficient Method of Producing Steel Camshafts

Creative implementation of forging and induction hardening techniques has enabled the Buick-Oldsmobile-Cadillac (BOC) Powertrain Division of General Motors to develop a cost-effective production technique for large numbers of steel camshafts. The result is a high-performance steel camshaft produced cost-competitively with standard cast iron camshafts.

BOC Powertrain's incentive for developing a new camshaft production process was a desire to increase automobile fuel economy. Company officials knew this could be done by replacing their standard valve lifters with roller lifters, thereby reducing engine friction. But using roller lifters posed a challenge:

- The camshaft had to be steel rather than cast iron to withstand the higher stress.

But there was no efficient method for producing steel camshafts. Therefore, BOC Powertrain had to develop a process which would:

- Eliminate the material wastage and high scrap rates inherent in conventional pre-hardening processes
- Be cost-effective at high production rates.

The Traditional Way

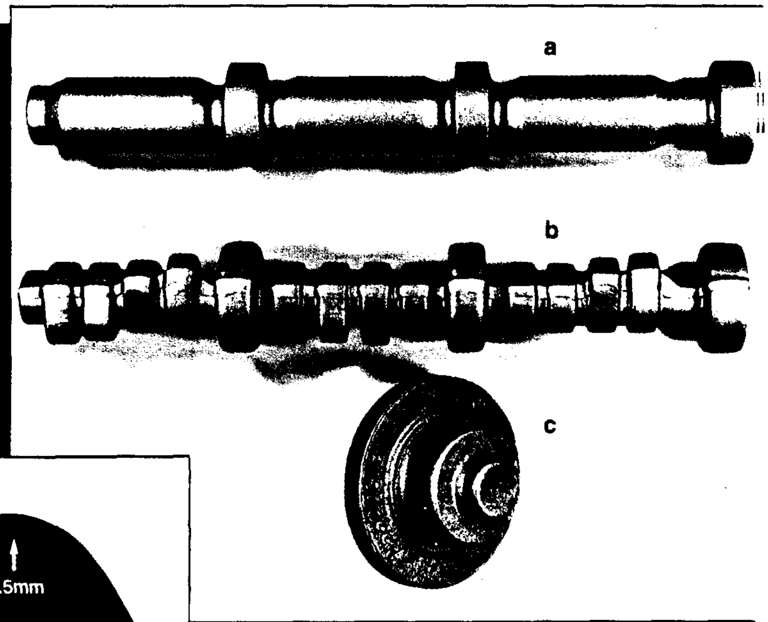
In general, steel camshafts are made by machining a forging, flame or induction hardening the whole shaft and, finally, grinding the lobes on the hardened camshaft. But for BOC Powertrain this process has numerous disadvantages, including:

- Approximately 50% flash and machining loss
- Low production rates because of the time taken to grind off hardened material
- Scrap parts due to burning and cracking from stresses induced by grinding hardened material.

The New Way

BOC Powertrain's Product Development Team determined that, for cost effective production, the new camshaft should:

- Be made from a blank that required minimal machining, to decrease material loss
- Have the lobes ground before hardening, to eliminate the problems associated with grinding hardened material
- Experience minimal distortion during heat treatment.



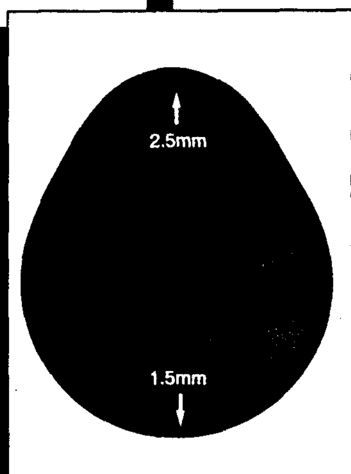


***Figure 1.* To minimize machining, a cross-rolled preform is made first (a), then the lobes are forged (b). This shaft is friction welded to a hub-flange component (c) that has been forged separately.**

***Figure 2.* Cross section of a cam lobe showing hardness pattern after selective hardening.**

To meet these criteria, BOC Powertrain developed a production technique that applies both forging and hardening technologies in new ways. It has replaced machined rough forgings with a friction-welded assembly consisting of two forgings—a hub-flange component and a shaft made from a precision cross-rolled preform. The camshaft lobes are ground, then selectively hardened—one at a time—using induction heating. After hardening the lobes are cleaned, polished and gauged.

Forging. To minimize machining, the main section of the camshaft and the end hub-flange component are made separately and friction welded together after forming. In addition, the main shaft is made from a precision preform, and only the lobes are formed in a conventional forge press (Figure 1). Using a precision preform results in significant material savings.

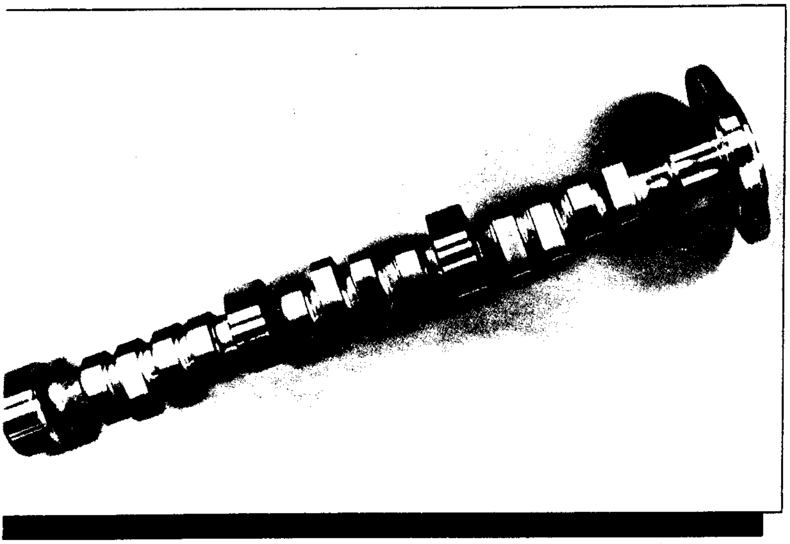


Figure 3. **Completed camshaft after cleaning lobes.**

Selective hardening. The lobes are ground before hardening so hardening must be done without producing any distortion. This meant selecting a low heat input method for hardening only the lobes. Options were laser, electron beam or induction hardening. Test parts made from SAE 5150 steel were hardened satisfactorily by all three methods. Induction hardening was selected (Figure 2) for use on the production line because it was simplest to implement, equipment cost only 25-33% as much as the other methods, and maintenance costs were lower.

BOC Powertrain uses a vertical induction hardening unit with an auxiliary quench coil to cool the hardened lobes during heating of adjacent lobes. Power to the coil is approximately 40 kW at 10 kHz, and each lobe is heated for about 2.5 seconds.

The Results: A Better Product at a Reasonable Cost

The success of BOC Powertrain's new camshaft is a result of new applications of both forging and selective hardening methods. Among the benefits of using precision preforms and post-grinding selective hardening are:

Material savings. Flash is reduced by 17% and machining loss by 13%. And two preforms can be made in one rolling.

Reduced die costs. Using precision preforms means less forging time and pressure are required.

Reduced scrap. Because there is no post-hardening grinding there are no grinding defects.

Energy savings. Only about 50% as much energy is required to grind and then harden to a depth of 60 thousandths of an inch as to harden to 240 thousandths and then grind off the excess hardened material.

Lower capital investment. By grinding before hardening instead of after, the capital investment in equipment, for comparable production rates, is reduced by 67%. Only half as many grinding machines are needed and there is no need for equipment to check for grinding-induced part defects.

Labor savings. There are fewer grinding machines and no inspection equipment to operate.

Product reliability. There have been no camshaft failures.

The Bottom Line: A Reliable Product that Does the Job

So far, BOC Powertrain has produced 500,000 steel camshafts, at a rate and cost comparable to cast iron camshafts. And its new, high-quality camshaft (Figure 3), together with the roller lifters, has enabled the company to meet its original goal. Fuel efficiency in automobiles using the new camshaft has increased by 1 mpg and reliability has been excellent.

Other Applications of Induction Hardening

Induction heating can be used for selectively hardening a variety of parts subject to load or excessive wear. About 90% of the applications are in the transportation industry, but use is not confined to large companies. With the increasing trend towards using outside suppliers, induction heating units are also being installed by small, parts-manufacturing companies. Among products typically hardened by induction are automobile gear teeth, valve seats and wheel spindles, and hand tools such as hammers and pliers. To learn more about selective hardening by induction, see TechCommentary Vol. 2, No. 3.

CMF would like to thank Charlie Lusher of BOC Powertrain and Mike Wiezbowski of Welduction for the valuable contributions made to produce the TechApplication. Additional information was obtained from SAE Technical Paper 860231.

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Applicable SIC Codes

34—23, 62 **35**—19, 31, 42, 46, 52, 66, 69, 99 **37**—14, 28, 51 **38**—43

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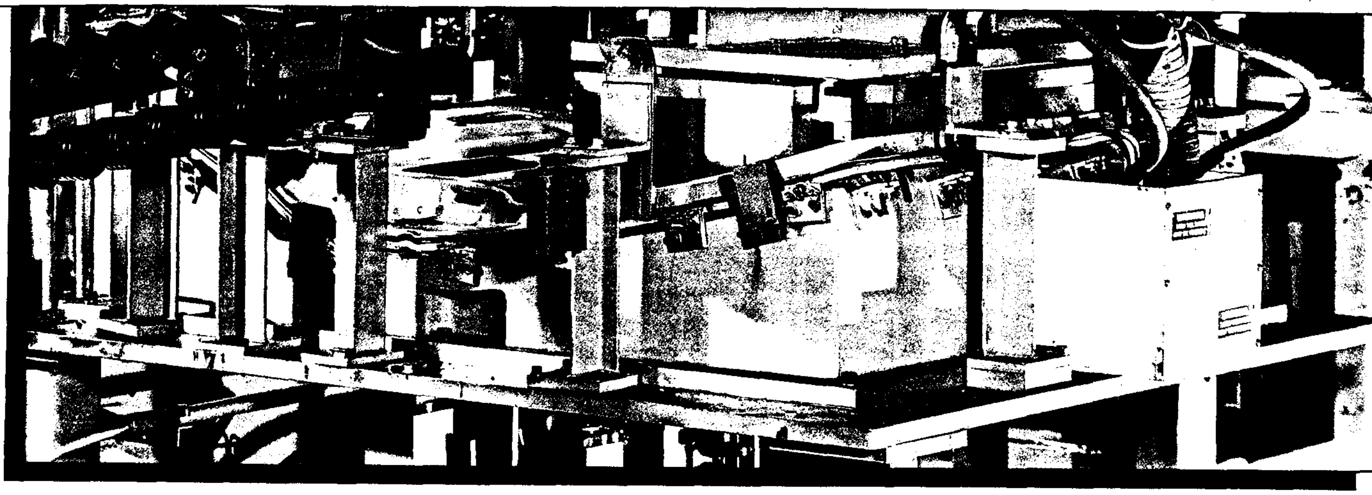
APPLICATION

Induction Heating of Thermoset Adhesives

Published by the EPRI Center for Materials Fabrication Vol. 1, No. 12, 1987



The door panel assembly is lowered onto the induction heating coil fixture, where heat generated in the metal partially cures the adhesive.

The Challenge: Better Joining of Galvanized Metal Panels

By taking advantage of recent developments in heat-curing epoxies and the speed and flexibility of induction heating, Chrysler Corporation now produces automobile door panels that are both more corrosion resistant and better looking than its former resistance spot-welded doors.

About 5 years ago Chrysler replaced cold-rolled steel with galvanized steel because of its superior corrosion resistance. This caused the hem series resistance spot welding operations to become unfeasible. Chrysler needed to find a better way of joining galvanized metal panels.

To meet this challenge, Chrysler pulled together a team of staff members—experts from the different fields of Advanced Manufacturing, Joining, and Structural Engineering.

The Old Way

Chrysler manufactures automobile doors by stamping an upstanding flange in the outer door panel, setting the inside panel in position, and "hemming" the door in 2 stages. After hemming, the doors used to be held together by resistance spot welds placed at intervals around the door edge, a method suitable for cold-rolled—but not galvanized—steel. The hem series resistance spot welding of galvanized steel has a number of drawbacks, including

- Weld quality is inconsistent
- Electrode depressions caused by the welding operation require additional finishing steps
- A seam with discrete welds is open to moisture and requires sealing to prevent corrosion.

To overcome these drawbacks, a substitute for hem series resistance spot welding needed to be found.

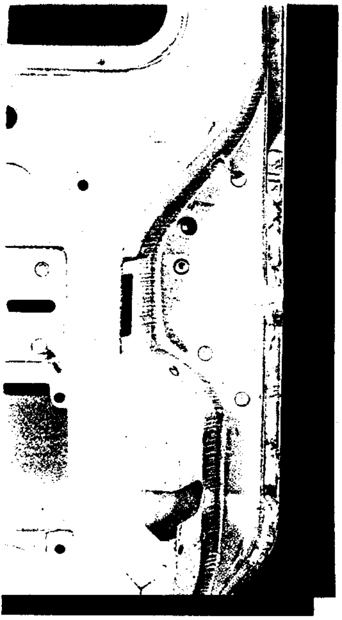
The Requirements

Since resistance spot welding is part of the door assembly line, Chrysler's new method had to fit into the same assembly-line slot. Thus, it required a method which could

- Maintain the line speed
- Work on metal coated with lubricant
- Give a suitable bond strength
- Provide a bond that was stable over the entire temperature range to which automobiles are exposed (−40 to +250 F)
- Have no corrosive effects on the galvanized metal
- Withstand subsequent operations
- Substitute completely—there could be no backup welding.

Initially, Chrysler tried a paste adhesive that was cured in the assembly plant concurrently with the electrodeposition coating (E-coat) in the E-coat oven. However, the uncured bond was not strong enough to withstand transportation from the stamping plant to the assembly plant and through car assembly. In addition, when the automobiles were dipped in various pretreatment and E-coat tanks, some adhesive flushed out of the joints and was visible on the bottom of the doors. This required an additional cleanup operation.

Further research led Chrysler to an induction-curable epoxy adhesive compatible with current manufacturing schedules. Such an adhesive is pasty and wet to touch at room temperature. With increasing temperature it passes through a gel stage in which it is still flexible but adheres to the substrate. At this stage excess adhesive is easily removed. When the adhesive is heated to a higher temperature, it reaches its final hardened state and increased bond strength.



The door panel edge has a continuous seam, sealed by induction bonding, while the recessed area for the locking mechanism exhibits spot welds.

The New Way

A new way was developed that gives Chrysler the results it wanted.

- Prior to the mating of the inner panel to the outer panel, a robot applies a ⅛-inch bead of adhesive to the inside surface of a door outer panel.
- The inner panel is positioned and hemmed, and the assembly is placed on an induction heating coil fixture.
- Current flow in the coil induces eddy currents in the door hem, and heat generated by the eddy current flow cures the adhesive to the gel stage.
- Final cure of the adhesive takes place in the E-coat curing oven.

Chrysler wanted a bond strong enough to prevent slippage through assembly and finishing but flexible enough to allow the door to be "fitted" into shape during assembly if necessary. To obtain the required bond, the adhesive had to be held at about 375 F for 3 seconds. However, the metal temperature could not exceed 400 F because above that temperature the lubricant on the surface bakes, becomes difficult to remove, and adversely affects the quality of the paint job. Fortunately, induction heating can be carefully controlled. Varying the frequency of the supply voltage to the induction coil allows the depth and rate of heating to be optimized for a particular application and the proper bond to be achieved.

The Results: Improved Corrosion Resistance and Appearance

With its new induction bonding technique Chrysler maintains the 300-400 parts per hour production rate and enjoys added benefits:

Excellent performance. Bonded joints stand up at least as well as welded joints in crash tests.

Improved corrosion resistance. There is a continuous adhesive seal around the inside of the entire panel hem so moisture cannot penetrate, thereby decreasing the opportunity for corrosion.

Material flexibility. Adhesives can join metal and plastic parts, a distinct advantage given the trends towards plastic automobile parts.

Decreased labor costs. Doors bonded with cured adhesive need much less refitting and surface finishing during assembly so employees are freed to do other jobs. Cured adhesive does not flush out in the E-coat bath so no cleanup is required, a further labor savings.

Energy savings. Induction bonding uses less than half as much energy as resistance spot welding—a decrease from 0.11 kWh per door to less than 0.05 kWh.

Further savings are expected since induction bonding is being implemented in other areas.

What Did It Cost?

The equipment cost approximately $140,000 to $200,000 including fixture, station, power source and fluid recirculator. Equipment was received 4 months after the order was placed and fine tuning took less than 2 weeks.

The Bottom Line

The team effort and 1½-year development period paid off for Chrysler. It is now making high-quality automobile panels from a corrosion-resistant material, and induction bonding was the only way it could get the job done.

Chrysler's first induction bonding line, in its Warren stamping plant, was so successful that it is now using the technique in 14 additional lines and in all 3 of its stamping plants. In fact, by 1988 Chrysler will be using induction-bonded lift gates and doors on all its vehicles.

Other Applications of Induction Bonding

Induction bonding is used in plastic fabrication, caskets, aircraft parts, plumbing fixtures, kitchen utensils with plastic handles, and bonding rotors to shafts in small motors.

Company Profile

Chrysler Corporation, Highland Park, Michigan

A manufacturer of automobiles and trucks.

Company philosophy: We have one and only one ambition: to be the best. What else is there?

The Center for Materials Fabrication (CMF) wishes to thank Garry DeFrayne, Materials Joining Laboratory, and Tony Vanraaphorst, Advanced Manufacturing, Chrysler Corporation, for valuable contributions to this issue. Additional material came from SME Technical Paper Number AD86-364.

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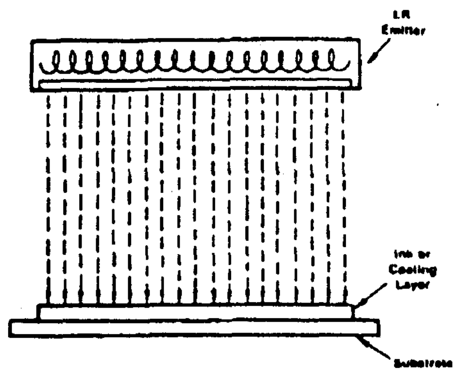
Regulation Class: ● Clean Air ○ Clean Water ◔ Haz. Waste ○ CERCLA ○ ______

Process Technology: *INFRARED*



ELECTRIC INFRARED

Function/Theory

Infrared radiation occurs when a material (called the "emitter") is heated, usually in the range of 800 - 4,000° F. Electromagnetic radiation then passes from the emitter through space and is converted to heat when it encounters an object in its path. Electric IR emitters can be glass bulbs, quartz or metallic tubes, or ceramic panels. There are three wavelength classifications, long, medium, and short wave - which determine temperature. Long wave IR generates lower temperatures(< 800°F), while short wave generates higher temperatures (>2000°F).

Selection Criteria/Considerations

Acceptance: ☐ High ☑ Medium ☐ Low

- Browning cookies, precooking pizza prior to packaging.
- Used as a "booster" before gas oven to enhance drying/curing.
- Replacement or additional oven for water dry-off and as cure oven for paints/coatings/dyes (ind. product furnishing).
- Used for sand reclamation in foundries (profile elsewhere).
- Preheating plastics prior to forming.
- Heating/setting designs on textiles.
- Localized space heating in manufacturing workplace.

Environmental Benefits

- Eliminates combustion by-products when replacing gas convection.
- Reduces/eliminates VOCs when used with consumable change to waterborne or powder coatings.

Additional Benefits

- Adaptable to automation (flexibility).
- Rapid start-up and standby, precise control, fast response time.
- Retrofittable, easily integrated into existing lines.
- Capable of working in conjunction with fossil technologies.
- Simple technology.
- Can be zoned to exact production configuration.
- Efficiency, high productivity and consistent product quality.
- Floor space conservation.

Drawbacks

- Limited applications - not appropriate for all situations (requires some line of sight contact).
- Configuration time can make frequent product changes difficult.
- Cost of energy.
- Frequent cleaning of certain types of IR tubes, bulbs reflectors.
- Color sensitivity with some emitters.
- Not as effective with reflective or thin coatings which can reflect the heat.
- May affect heat sensitive substrates.

SIC Potential

◔ 25% ◕ 75% ◑ 50% ● 100%

Mining		
Metal	10	○
Coal	12	○
Oil & Gas	13	○
Mineral	14	○

Mfg.		
Food	20	◑
Tobac	21	◔
Textile	22	●
Apparel	23	◑
Lumber	24	◔
Furn	25	◑
Paper	26	◕
Print	27	●
Chem	28	◔
Petrol	29	◔
Rubber	30	●
Leather	31	◔
Stone, Glass	32	●
Metals	33	◑
Metals Fabric.	34	●
Mach	35	○
Elect	36	◔
Trans	37	◑
Instru	38	○
Misc.	39	◑

Waste Stream Reduced

Air		*Water*		*Solid*
☐ Particulates	☑ Organics	☐ Particulates	☐ Organics	☑ Hazardous
☑ CO_2, NOx	☐ Toxics	☐ Metals, Ions	☐ Oil	☐ Non-Hazardous

Infrared (cont,)

Typical System Example

Size: 105 sq. ft.
40" - 60" width most common in Printing

Energy Requirement:

10 - 100 kW, 60 kW average in Food Manufacturing

25 - 60 kW normal range for Printing

100 - 500 kW in Fabricated Metals, Power Coating and Surface Film Drying

0.5 - 50 kW, plus for printing applications

2 - 100 kW, plus for thermoforming of Plastics

Efficiency: 80% or better in Printing
50-75% in Finishing

Economics

Capital Cost:

$200 - $700/kW for systems, less for modules in Food Manufacturing.
$30,000 - $100,000 for IR ovens in Fabricated Metals.
$8,000 - $10,000 for basic system to $35,000 - $50,000 for a 4 color 44"- 48" system in Printing.

Payback: 1.2 years
Payback is based on installing a 12 foot long infrared tunnel oven for a finishing system. The infrared replaces 60 feet of gas convection. The application is based on curing a polyester powder in 2 to 3 minutes.

Source: Casso-Solar Corp.

Service/Maintenance

Bulbs and reflectors should be cleaned and lamps and reflector should be replaced regularly to maintain high efficiency of the oven. The average bulb life is 3,000 - 5,000 hours, tube life is 15,000-20,000 hrs, and flat panel life is 20,000-25,000 hrs.

Vendors

BGK Finishing Systems

Casso-Solar Corp.

Commerce Controls, TDM

Fostoria Industries, Inc.

Industrial Heating & Finishing Co., Inc.

Notes

Major Vendors

INFRARED

BGK Finishing Systems
4131 Pheasant Ridge Drive
North
Blaine, MN 55434
(612) 784-0466

Casso-Solar Corp.
P.O. Box 163
US Route 202
Pomona, NY 01970
(914) 354-2500

Commerce Controls, TDM
41069 Vincenti Ct.
Novi, MI 48375
(313) 476-1442

Fostoria Industries
P.O. Box E
Fostoria, OH 44830
(419) 435-9201

Industrial Heating and Finishing Co., Inc.
P.O. Box 129
Pelham Industrial Park
Pelham, AL 35142
(205) 663-9595

EPRI Techcommentaries

Infrared Drying

Infrared Processing of Coatings, EPRI CMF TechCommentary, Vol. 3, No. 6, 1986, 1990r
Infrared Drying in Papermaking, EPRI ICO TechCommentary, Vol.2, No. 1, 1989
Medium & Short Wave Infrared Curing, EPRI CMF TechApplication, Vol.1, No.3, 1987
Short Wave Infrared Curing, EPRI CMF TechApplication, Vol.1, No.1, 1987
Infrared Drying of Paint, EPRI CMF TechApplication, Vol. 3, No.1, 1989

TECHCOMMENTARY

INFRARED PROCESSING OF COATINGS

Published by the EPRI Center for Materials Fabrication Vol. 3, No. 6, 1986

IR Brings New Light to Manufacturing

Consumers of coated metal, wood, paper, glass, plastic and textile products are demanding attractive, long-lasting, wear-resistant surfaces. At the same time, stricter safety and environmental standards are forcing manufacturers to look at new types of finishes, e.g., water-based and powder coatings, and at different technologies to process them. Among the technologies well suited to both drying and curing the newer finishes is electric infrared (IR) process heating.

Electric infrared has actually been used by industry since the mid 1930's, when the Ford Motor Company developed and adopted it for curing paint on auto bodies. However, early users often became disillusioned with electric IR because the technology was oversold. But emitter design and process control have been improved to such an extent that there is now essentially a "new IR" technology. And, unlike many traditional coatings, the new coating systems being developed are extremely tolerant of high levels of IR energy. Innovative manufacturers are capitalizing on these developments to obtain higher quality products for a lower unit cost.

This TechCommentary discusses current and potential applications of electric IR, as well as the technical and economic factors to consider in selecting a processing unit.

Advantages/Drawbacks

Companies in the automotive, plastic, paper converting, graphics, packaging, home appliance, textile and wood products industries find numerous advantages in using electric IR to process coatings. Many of these advantages translate into better product quality, increased productivity and lower costs.

Electric IR processing offers:

Energy efficiency — In a properly designed system, radiant heat acts directly on the surface to be treated, resulting in faster product heating and lower energy costs.

Space savings — Faster heating means shorter ovens, so equipment occupies less floor space. IR ovens can be added to an existing production line without difficulty, and, since units are modular, ovens can be easily enlarged or reconfigured.

Clean products — Since IR heats the product directly, there is no need to blow hot air, and dust, through the treatment area.

Precise control — Electric IR emitters respond quickly, can be controlled by microprocessors and can follow process changes with little lag.

Flexibility — Emitters can be zoned and adjusted to suit product width and processing requirements.

Low maintenance — Electric IR emitters have a very long life and require little routine maintenance.

Adaptability — Any heat-treatable coating can be processed with IR.

IR does have some drawbacks. On poorly conducting substrates such as fiberboard or plastic, there must be a direct line of sight between the radiation source and the surface to be treated. This largely restricts its use to flat

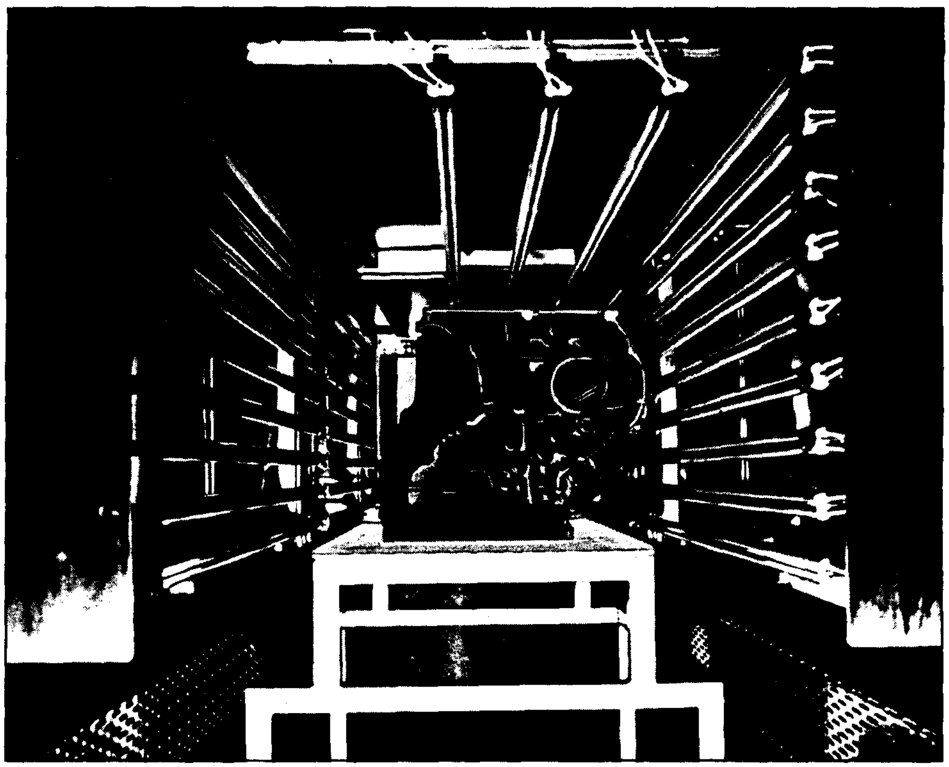


Figure 1. **IR curing of powder coating on an engine block.**

products like wood panels. With metal parts, which conduct heat well, enough energy is absorbed by the metal substrate that areas not directly in the IR beam are heated by conduction. Therefore, even complex parts like engine blocks can be properly treated.

Applications

A major use of IR processing is drying both water- and solvent-based paints and inks. In a conventional oven, paints must be dried slowly to prevent the formation of a surface skin. If a skin forms before the underlying paint has dried, the remaining carrying agent will produce surface blisters as it evaporates, resulting in a less attractive and less durable finish. IR radiation passes through the outer surface and dries the paint from the inside out, so skinning is not a problem. The result is a better-looking, more durable surface, produced in less time.

IR is also an ideal method for curing powder coatings, which are being used increasingly for consumer products such as venetian blinds and appliances, and for automotive parts like oil filters. Electrostatically-charged powder is sprayed over the workpiece and heated until it melts. It flows over the surface and is cured in an even layer. A major problem in convection ovens is that moving air can blow the powder around before it melts, leading to uneven coating. With IR curing there is no need for air flow so this problem does not arise.

Another growing use of electric IR is for booster ovens in front of existing convection ovens. For example, on auto body production lines an IR oven at the start of the line rapidly heats the paint and sets the body finish. The car then moves into a forced air convection oven where the underparts, on which surface finish is less critical, are dried more slowly. Initial rapid setting of the topcoat eliminates concerns about dust damage in the convection oven. With a booster oven, conveyor speed is increased significantly without much increase in oven length.

IR processing has been used successfully in many applications including drying and/or curing:

- Paint on car bodies and home appliances
- Paint and powder coatings on light fixtures
- Paints and varnishes on sheets of hardboard, particleboard and chipboard
- Coatings on steel and aluminum coil
- Epoxy powder coatings on oil filters and irrigation pipes
- Polyvinyl chloride waterproofing on automobile rocker panels
- Printing ink on paper.

Success Stories

A company that manufactures coated steel strap replaced 180 feet of gas-fired convection ovens with 17 feet of IR heating units. They increased their line speed from 800 to 1000 feet/min and decreased their energy costs from $9.92 to $6.92 per hour.

Adding a 7-foot IR booster oven to a convection oven enabled a light fixture manufacturer to double line speed, double production, reduce energy cost per part by 25% and improve product quality. Payback time was six months.

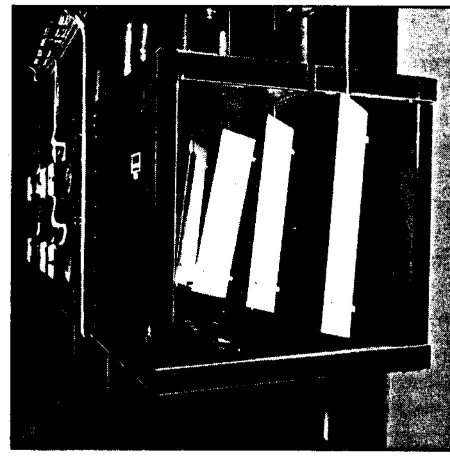


Figure 2. **An IR booster oven curing a water-based coating on light fixtures.**

Alternate Technologies

Electric IR competes with both traditional methods, such as air or gas-oven drying, and with gas IR. Other types of radiation, such as electron beam (EB) and ultraviolet (UV), are used to cure specially-formulated, non-heat-treatable coatings that cannot be treated with IR.

Air-drying is slow and the coated surface is exposed to dust, insects and other airborne contaminants. Gas-fired convection ovens are costly, slow, cumbersome and energy inefficient. A large volume of air is heated and the heat is then transferred to the coating. This process is slow and difficult to control since oven heating and cooling takes a long time. Therefore, if a conveyor stops, the product can be ruined by overheating.

Heating a ceramic surface with a gas flame also produces IR radiation. However, heat transfer is mainly by convection, and gas IR is limited to bulk water removal applications.

Technical Considerations

A number of factors have to be considered when tailoring IR to a specific situation. They include:

Emitters — Electric IR sources produce primarily either short or medium wavelength IR. Short wave IR is intense and easy to focus, and penetrates coatings well. It is used where intense, directed heat is required, such as in curing thick coatings, or in high speed conveyor lines for curing coatings on steel

Glossary

Curing involves heating or irradiating a polymeric material so that it forms a new, three-dimensional network structure with improved physical and chemical properties. As a result of the structural changes, the coating usually bonds better to the substrate and is more durable.

Drying involves removing the carrying agent, either an organic solvent or water, from a liquid-coating mixture. The structure of the coating materials is not changed.

Heat treating involves heating a workpiece for any of a variety of reasons including drying, curing, hardening, tempering, etc.

Powder coating involves spraying an electrostatically-charged powdered polymer onto an oppositely-charged substrate. There is no solvent—the spray is 100% coating. The coating is heated until it melts and flows over the substrate and is cured in an even layer.

Substrate is the material to which the coating is applied.

straps and wood products.

Medium wave radiation is less intense, so heating with medium wave emitters takes longer. This can be an advantage for treating materials not tolerant to high heat levels. Medium wave IR is usually used where a lower temperature, more diffuse source of heat is required, such as in drying water from metal or plastic surfaces or curing inks on paper or screen-printed fabrics.

The number of emitters required will depend on product size, line speed and exposure time. Since emitters usually come in modular units, it is not difficult to add or remove them as necessary.

Reflectors — Emitters radiate in all directions, so reflectors are placed behind them to redirect as much of the radiation as possible onto the product. Appropriately placed reflectors can radiate the whole product uniformly, or focus radiation on a section that needs extra heating.

Reflector materials include ceramics, polished aluminum or stainless steel, and gold-plated aluminum or steel. Gold is the most efficient reflector material. It reflects approximately 98% of the IR energy, whereas polished metals reflect only 70-75%. These values apply only to clean reflectors. Dirt severely degrades their performance, so reflectors should be cleaned regularly.

Reflectors come in different forms. Often, they are separate panels mounted behind the emitters. However, one emitter design uses a twin bore tube with the filament in one bore and a thin layer of gold plated on the inside of the second bore. Thus, the reflector is an integral part of the emitter.

It may be necessary to cool reflectors to protect them and the lamps and wiring they shield. Usually, air is blown over them (from behind to eliminate blowing dust). The hot air can be recycled to heat other parts of the work area, or to augment a convection oven if the IR unit is being used as a booster oven.

Coating material — The color, thickness, reflectivity, and absorption chemistry of the coating being treated all affect the amount of heat required. For example, it may take longer to cure an automobile panel if the finish is a highly reflective metallic silver than if it is matte black.

Carrying agents — Some organic solvent vapors become explosive at certain concentrations. Thus, with solvents like toluene, hexane, or methanol it is essential that there be adequate air flow in the oven to prevent vapor accumulation. (This applies to any type of oven in which organics are treated, not just IR ovens.) The contaminated air must then be properly treated. With water-based coatings, the accumulated water vapor must be removed.

Substrates — IR can treat coatings on a wide variety of substrates including metals, wood products, most plastics, fabrics, ceramics, glass and paper.

If you think that IR may be appropriate for treating coatings you use, talk to manufacturers about doing pilot tests. This service, which is often free, helps you determine the size and type of equipment you need. It also gives you an opportunity to evaluate both a company and its equipment before making any commitments.

Economic Considerations

When deciding on the economic feasibility of IR heating, the following items should be considered.

Capital costs — IR ovens are custom-designed, so it is difficult to give exact costs. However, an oven

Process Description

Infrared (IR) is the name given to the part of the electromagnetic spectrum between visible light and radio waves. IR wavelengths range from 0.8 and 1000 microns, but we will consider only the 0.8 to 3.3 micron band since these wavelengths work best for treating coatings.

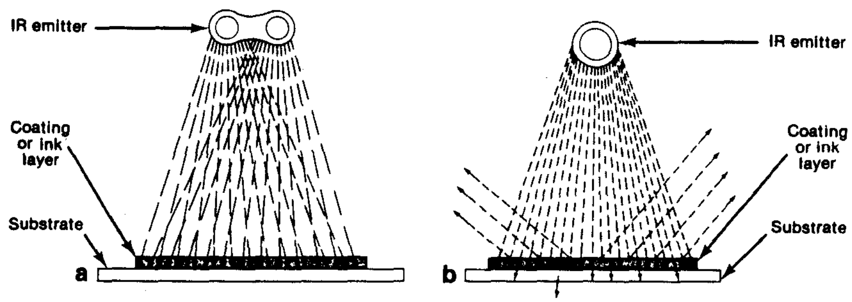
When a material absorbs infrared radiation, the motion of its molecules increases and it gets hotter — this is the basis of infrared process heating.

Electric IR is used for both drying and curing surface coatings. Drying is used by metals fabricators to remove the carrying agent, be it water or an organic solvent, from wet coatings on armature windings, inexpensive metal furniture or other products. These articles do not need a high-performance, long-lasting finish, but must be "dry to the touch" before subsequent handling. However, many products require a higher quality, more durable finish, so the coatings on them must be polymerized, or thermally cured, as well as dried.

IR radiation is produced by heating the filament of a source, or emitter. All emitters produce radiation over a range of wavelengths, with the peak of the output spectrum determined by the maximum temperature to which the filament is heated.

Commonly used IR emitters fall into two major categories. One type consists of a non-oxidizing wire coil in an open-ended glass or quartz tube. Such emitters can be heated up to about 1800 F, and they emit predominantly medium wave IR (2.3-3.3 microns). Medium wavelengths are absorbed very efficiently by most organic materials. The second type is a tungsten filament in a sealed quartz tube, which is either evacuated or filled with an inert gas. When tungsten filament emitters are heated to their maximum temperature, 3000-4000 F, they emit primarily short wavelength IR (0.8-2.2 microns). Short wave IR tends to penetrate deeper and to heat faster than medium wave. If the applied voltage is reduced, the filament does not get as hot and tungsten filament emitters become primarily medium wave IR sources.

Processing is usually done in an IR oven, consisting of a bank of IR emitters and a conveyor belt or web that carries the product through the oven. Oven design is best left to a manufacturer who should carefully study your application and provide you with the optimal design.



Schematic representations of (a) medium and (b) short wave IR radiation

with a heating area about 10 feet long and 4 feet wide would likely cost between $50,000 and $100,000. About half the cost is for the oven and reflectors and the other half is for the rather sophisticated control equipment. Although the control system is complex, it is designed to be easy to use, so highly skilled operators are not necessary.

Operating costs — This category includes costs for energy, maintenance, and replacement emitters.

Short wave emitters require more electric power (the filaments are heated to a higher temperature) but conversion to radiant energy is more efficient — 85-90% compared with 60-65% for medium wave lamps. Generally, 50-70% of the radiant energy is actually absorbed by the product. In gas IR ovens only about 25% of the input energy reaches the product, and in gas convection ovens it is only 15%. Thus, electric IR is significantly more efficient.

Maintenance is limited to cleaning the reflectors regularly and replacing burned out emitters. Emitter life is long. Short wave emitters should last 5,000 hours, or about two years with one shift a day, when operated at full power. Decreasing the power input to 80-90% of maximum extends emitter life to more than 30,000 hours. Medium wave emitters last even longer. Replacement emitters cost between $15 and $300, depending on size and whether or not they have an integral reflector.

Payback — Electric IR ovens are about four times as efficient as convection ovens. Therefore, if electricity costs less than four times as much as gas, electric IR may be justified in terms of energy costs alone. However, with electric IR ovens there is also faster product throughput, a higher quality finish, and less wastage than with convection ovens. IR ovens also save space, which can be a major advantage. With all these savings, the payback period for electric IR equipment is often less than a year.

In Summary

Electric infrared heating is an excellent method for treating many kinds of coatings, both new and traditional, on a wide variety of substrates. The process is easy to implement and control and is much more efficient than gas convection ovens and gas IR.

European manufacturers have been aware of the benefits of electric IR process heating for many years and the technology is well established there. The number of IR processing systems in the US is likely to grow substantially in the coming years as manufacturers here, too, begin to recognize the advantages this technology offers for producing long-lasting, durable and high-quality finishes on a variety of products.

The information in this issue of TechCommentary is intended only to introduce you to the many applications of IR heat treating. More information is available from the Center for Metals Fabrication and from the many suppliers of IR equipment.

The Center for Metals Fabrication (CMF) is operated by Battelle's Columbus Division. Basic funding is provided by the Electric Power Research Institute, a nonprofit institute that conducts research and development on behalf of the United States electric utility industry.

The Center's mission is to assist industry in implementing cost- and energy-efficient, electric-based technologies in metals fabrication and related fields. TechCommentary is one communication vehicle that the Center uses to transfer technology to industry. The Center also conducts research in metal heating, metal removal and finishing, and fabrication.

This issue of TechCommentary was made possible through the cooperation of Battelle staff members Vince McGinniss, Research Leader, John Bush, Principal Research Engineer, John Hallowell, Industry Applications Engineer, Laura Cahill, Manager, Marketing and Communications, and Denise Sheppard, Publications Coordinator; and Anne Moffat and Dorothy Tonjes of ProWrite. Technical review was provided by Nick Fusilli, Hereaus Amersil, John Harvey, Epner Technology, and George Krahn, BGK Finishing Systems, Inc.

Sources used in this issue of TechCommentary were:

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Hereaus Amersil Product Literature, Sayreville, NJ.

McGinniss, V.D. "Radiation Curing: State-of-the-Art Assessment." *EPRI Report,* No. EM-4570, 1986.

Photos courtesy of Hereaus Amersil, Sayreville, NJ.

Applicable SIC Codes

24 — 35, 36
26 — 49
27 — 51, 52
30 — 79
All 34-39 SICs are applicable.

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CENTER FOR MATERIALS FABRICATION
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TECH COMMENTARY

INFRARED DRYING IN PAPERMAKING

Published by the EPRI Process Industry Coordination Office Vol. 2, No. 1, 1989

QUALITY PAPER, HIGH YIELDS

By uniformly drying paper during production, electric infrared (IR) helps paper mills and converting operations produce paper with superior smoothness, gloss, and printability. The uniform drying also gives the paper a consistent thickness, reduces feeding breaks, increases machine speeds, and produces higher yields. Paper products dried by IR include

- Newspapers
- Magazines
- Tissues
- Envelopes
- Books
- Stationery
- Lightweight packaging.

Printers and wholesale customers are becoming more quality conscious. They expect excellent smoothness, gloss, and printability as well as uniform moisture, caliper (or thickness of a single sheet), and coatings—and they hold the papermaker accountable for maintaining these characteristics. Drying paper and coatings with IR processes helps papermakers meet their customers' expectations.

In the papermaking process, paper is formed on a paper machine from a slurry of fibers then pressed and steam-dried to remove moisture. For added strength and printability, clay or latex coatings containing binders are applied to the paper. IR drying is applicable in two areas of papermaking: On paper machines (see Figure 1), IR lamps are automatically turned on over wet spots, drying the paper sheet to a uniform moisture content in a process called moisture profiling. In coating processes, IR sets the coatings instantly, preventing binder migration and producing a smoother coating with improved printability and uniform coating weight. Of approximately 2000 paper machines in the United States, about 400 have electric IR units. Approximately 80% of the remainder could realize significant benefits from adopting IR processes.

ADVANTAGES

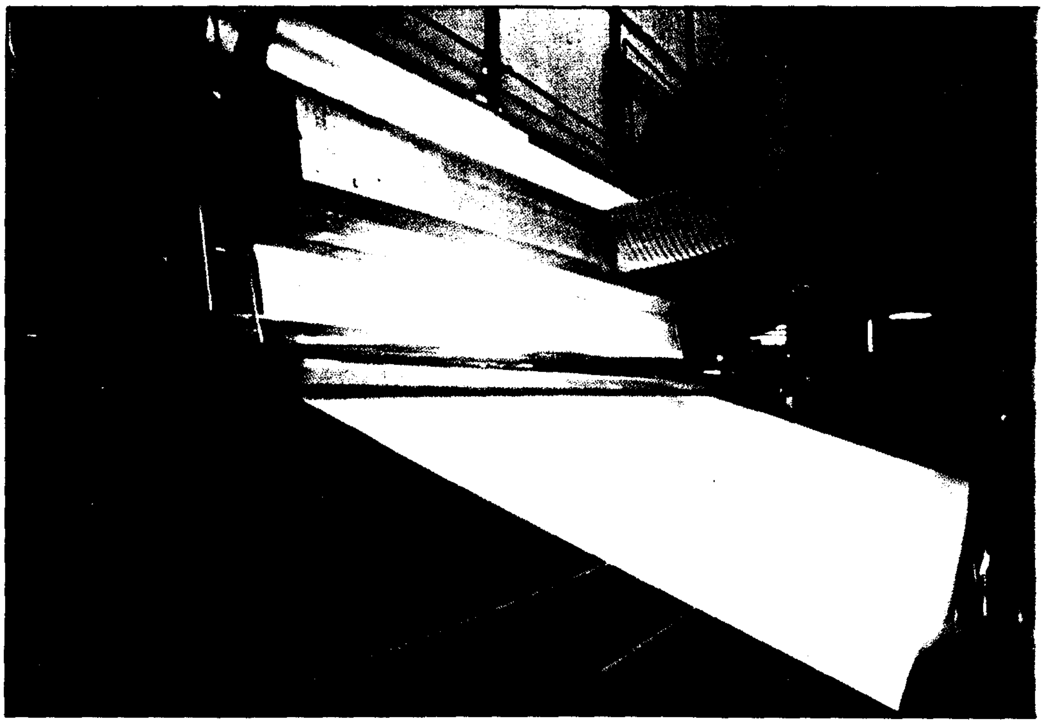
For both papermaking and binder-coating applications, IR drying provides many benefits:

Improved paper quality—IR improves the overall paper quality, strength, and printability by enhancing coating uniformity. IR sets the coating quickly and evenly, so the binder concentrates on the paper surface instead of migrating into the base paper. In both papermaking and coating, IR processes also reduce moisture variations to produce more uniform cross-direction (CD) caliper and smoothness. Improvements of 50% to 75% can be expected.

Increased productivity—Paper machine yields increase because IR maintains a consistently low CD moisture level, resulting in uniform thickness, fewer breaks, and 5% to 15% faster production speeds. Reducing moisture by 1% can result in a 4% to 5% increase in machine speed.

Waste reduction—IR moisture profiling can reduce waste on the paper machine as much as 50% per year. Increased moisture uniformity results in fewer caliper rejects, fewer machine breaks, less "off-spec" paper, and reduced machine rethreading. IR drying also reduces rejects by heating the sheet as it comes out of the wet press; this helps prevent the sheet from sticking to the dryer cans—a problem known as "picking."

When coatings are applied, one IR unit can be used to set the coating and another to automatically level moisture variations. IR controls binder migration, reducing rejects by 30% to 50% for



Electric IR penetrates the sheet as it passes through the second dryer section.

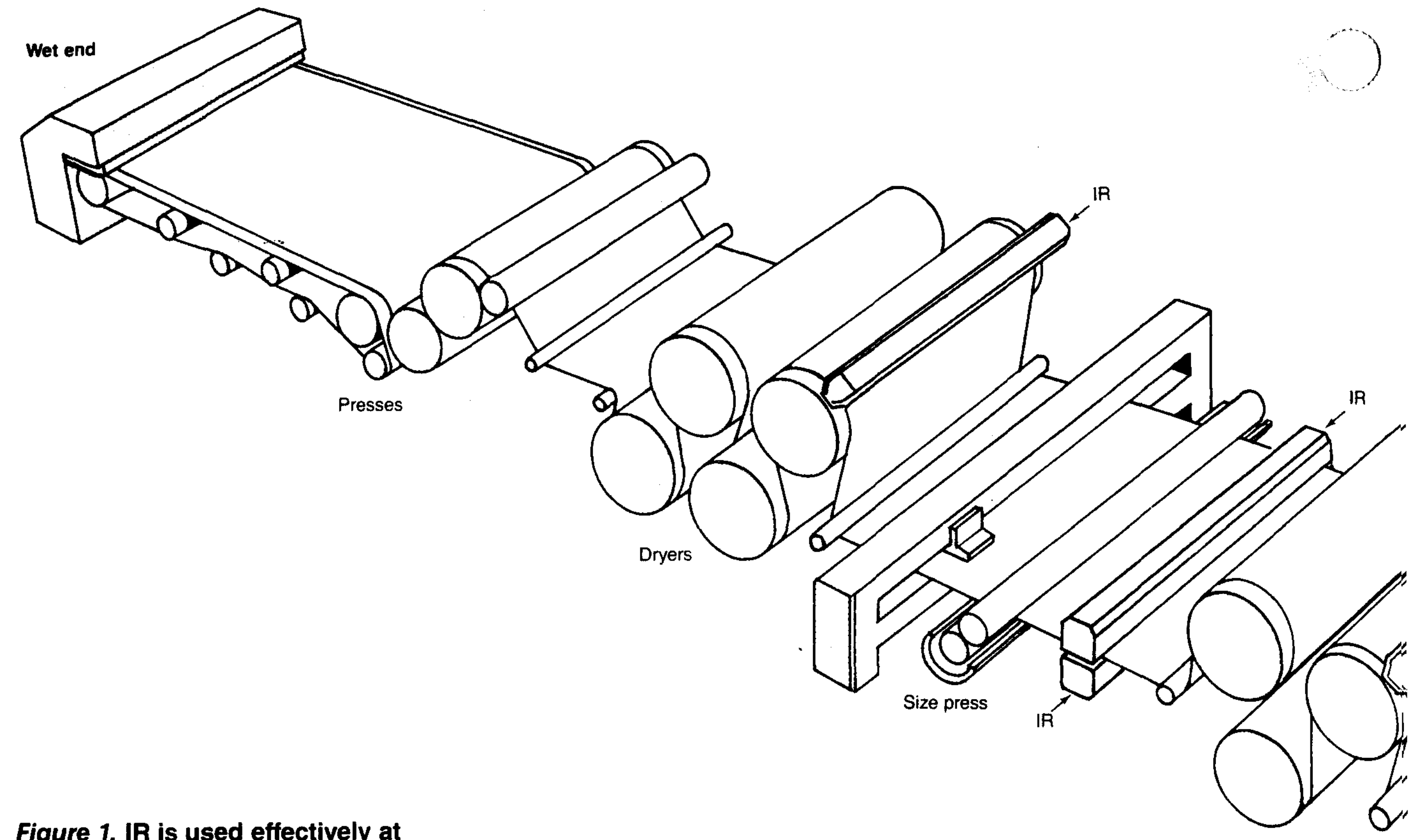


***Figure 1.* IR is used effectively at many points during the papermaking process.**
(Sources: Impact Systems and Combustion Engineering Company brochures)

yearly savings of $200,000 to $300,000, and possibly even more.

Improved process control—IR microprocessing controls react quickly to precisely level moisture variations. The controls also respond to changes in paper grade, so the paper machine returns to optimum speed and quality production within minutes, reducing waste by 1% to 2%. IR lamps are turned on only where energy is needed to reduce moisture variations. Moisture streaks as small as 3 in. wide can be leveled, minimizing energy usage.

Safe operation—Electric IR operates at lower temperatures than other systems and responds with immediate cool-down. When a paper break occurs, there is no fire or charred paper—two problems associated with gas IR drying.

APPLICATIONS

IR is used in two general areas of papermaking:

Moisture profiling—On the paper machine, IR levels the moisture profile across the sheet (see Figure 2). Achieving moisture uniformity is more important than just reducing the moisture levels. The typical goal in moisture

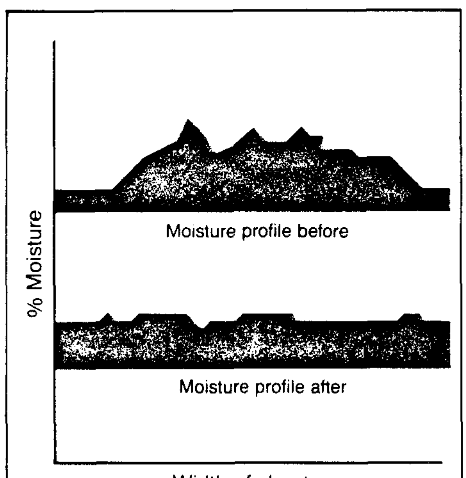


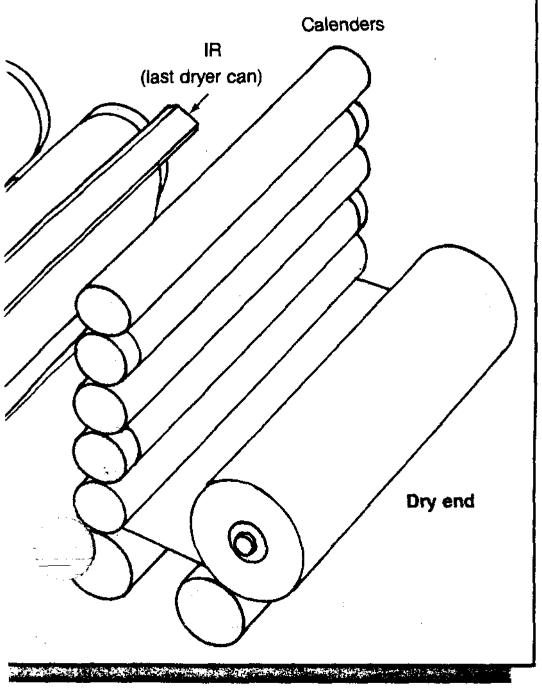
***Figure 2.* IR eliminates moisture streaks, improving sheet uniformity.**
(*Source:* Impact Systems Company brochure)

profiling is to reduce the peak-to-peak moisture variation to 0.5% to 1%.

Typically in a paper machine, the paper at the wet end of the press contains up to 40% water. Dryer cans and steam boxes then reduce the moisture level to about 6%. Throughout this process, it is important to maintain a uniform moisture level across the sheet to avoid uneven caliper and mottling. These problems can be controlled by IR profiling at the last dryer can before the reel, before or after the size press, or at the coating stations.

Process controls monitor the thickness, weight, and moisture levels of the paper and actuate the IR lamps to react immediately to moisture variations. Improving the moisture profile can increase production speeds 5% to 15% and reduce caliper, reel building, and converting problems by 30% to 80%. Profiling also reduces steam requirements.

IR's high-intensity energy is well suited for the dry end of the paper machine, where moisture removal and control are easier and more cost efficient than at the wet end.



n addition to electric IR discussed in this *TechCommentary,* gas IR units are also available.

Gas IR is often chosen for incremental drying and coating drying rather than moisture profiling. Incremental drying adds additional drying capability at the wet end of the press. Incremental drying with gas IR provides improvements in paper quality over air caps and dryer cans in many situations.

In contrast, gas IR is not as suitable for moisture profiling as electric IR because its broader wavelength range does not penetrate the sheet as deeply. With electric IR, up to 80% of the energy is absorbed directly into the paper, as compared with approximately 50% for gas IR processes. Electric IR units are compact and can fit easily into the existing machine configuration, unlike larger gas IR units. If paper breaks occur, the electric IR unit shuts down and immediately reduces the temperature of the unit, greatly minimizing fire hazards. Gas and electric IR systems can be used in combination when both incremental drying and moisture profiling are desirable.

Coatings—Applying coatings to paper rewets the sheet from 6% to nearly 30% moisture. A high-intensity IR unit can quickly dry and set the coating immediately following application. The binder remains concentrated in the coating, producing a strong, uniform surface without mottle. IR penetrates uniformly through the sheet, driving moisture from the center. This penetration prevents warp or curl caused when only one side is heated.

A second IR unit at the end of the coater produces uniform CD moisture levels in the final sheet and aids sheet processing for a higher quality final coating.

ALTERNATE TECHNOLOGIES

Other processes used for moisture profiling in papermaking include water sprays and steam boxes.

Water sprays—Whereas IR dries wet spots in the sheet, water sprays wet the dry spots to achieve a level moisture profile. This process can be beneficial on machines where tension and curl are a concern, because additional moisture helps alleviate these problems. Adding moisture to the sheet, however, may reduce production speeds.

Steam boxes—Used for drying, steam boxes often complement IR processes rather than compete with them. Steam boxes reduce large amounts of water at the wet end of the paper machine where water removal with IR is not economically feasible. They reduce moisture streaks down to about 6%; then an IR unit can complete the moisture profiling process.

TECHNICAL CONSIDERATIONS

IR processing is applicable in most moisture-profiling and binder-coating situations. However, many aspects must be evaluated when considering IR processes for a specific application.

Weight—IR effectively profiles paper with weights up to 96 lb/1000 ft^2. But the amount of IR energy needed to profile weights above 42 lb/1000 ft^2 may not be economical.

Moisture levels—The difference between the present moisture level and the target level can determine whether IR processing is cost effective to implement. This difference is obtained by analyzing existing moisture profiles and determining the minimum IR processing required to obtain the desired improvement in quality. For example, reducing a moisture profile from 2% to 0.5% peak to peak should result in substantial quality and production increases, without a considerable capital investment or sizable increase in operating costs.

Production increase—An IR system can often be justified by its increased production capacity. In general, production increase is proportional to the quantity of IR energy added to the existing drying capacity of the paper machine or coating line.

Electricity requirements—In papermaking, the average energy consumption of an IR unit is 180 to 200 kW. The electricity demand depends on the drying capacity needed.

When considering IR implementation, the existing process must be evaluated carefully to determine specific needs and the optimal placement of the IR unit. The IR requirements best suited for the application can be determined by discussing the following factors with an equipment supplier:

- Process type
- Moisture variations
- Machine configuration
- Process speeds
- Sheet weight, composition, moisture content, and temperature ranges.

Analyzing this information allows estimates to be developed for energy requirements, waste savings, caliper improvements, and the amount of moisture profiling expected for the cost incurred.

ECONOMIC CONSIDERATIONS

Capital costs—A typical IR unit costs $400,000 and includes one frame and a CD or profile control package. This cost includes the necessary software and operator interface for measuring and controlling moisture. One frame is 18 in. (machine direction) by 21½ in. (high) stretching across the width of the sheet (typically 15 ft wide), and has up to 24 lamps per foot. Installation costs are usually an additional $60,000 to $100,000. The unit's compact size allows it to fit into the existing machine configuration with minimal modifications. With careful planning, the unit may be installed in 16 to 36 h during a routine shutdown. Payback periods are typically 3 to 12 months.

Operating costs—Average yearly maintenance cost for an IR unit is $10,000 to $15,000, primarily for lamp replacements; incidentals include air filters and electrical components. Lamps usually last two to three years or 12,000 to 15,000 h; replacements cost about $70 each. Routine maintenance can easily be handled by plant staff during regular shutdowns—no additional shutdowns are required. Training to operate an IR unit typically requires only about 3 h; complete maintenance training may take up to one week. The IR unit does not require additional labor for operation and should actually reduce the machine operator's workload, because constant adjustments are no longer required to maintain a high-quality sheet.

The IR Drying Process

IR energy is produced by heating the tungsten filament of an IR lamp. The emitters operate at 3900°F to produce peak energy at 1.2 microns. This wavelength is effectively absorbed by paper fiber and water. Heat from the lamps is directed at the paper by a series of ceramic reflectors. On the paper machine, the lamps and reflectors are mounted next to each other in a module configuration with quartz plates in front of the lamps to prevent mechanical damage to them (see Figure 3). Blowers circulate air around the lamps to keep the temperature in the module below 400°F for maximum lamp life. The sheet is 1 to 2 in. away from the IR lamps. IR penetrates the paper, resulting in uniform temperature distribution through the paper. IR controls moisture in sections as small as 3 in. across the width of the sheet—which can be as wide as 30 ft.

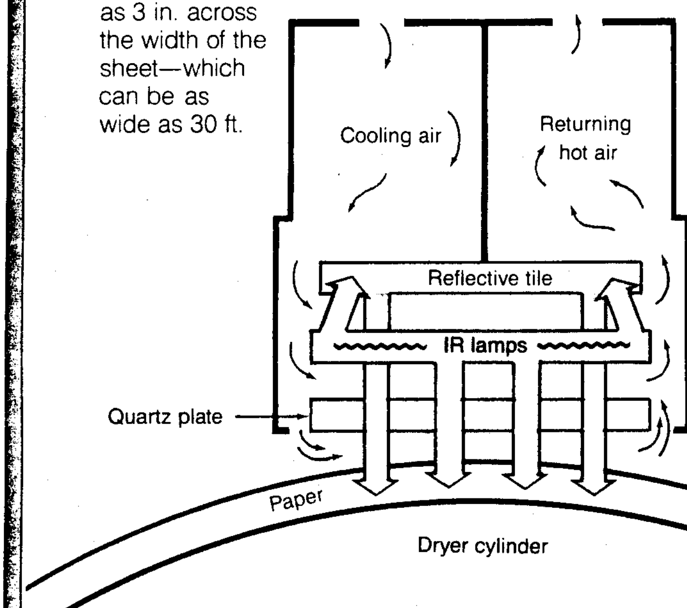


***Figure 3.* Schematic of electric IR equipment.** (*Sources:* Impact Systems and Combustion Engineering Company brochures)

OUTLOOK

IR processing can provide significant improvements in paper quality and process control and can increase yield and production speeds in both papermaking and binder-coating processes. Equipment suppliers continue to (1) improve the design of IR units to make them more universally applicable and economical and (2) provide better integration and system control. A 10% to 15% yearly growth in IR installations is predicted for the papermaking industry as more papermakers become informed of the substantial benefits IR can provide.

Basic funding for this *TechCommentary* is provided by the Electric Power Research Institute (EPRI), a nonprofit institute that conducts applications development on behalf of the United States electric utility industry. *TechCommentary* is one of the ways EPRI assists the process industries in implementing cost- and energy-efficient, electric-based technologies.

This issue of *TechCommentary* was written by ProWrite with the cooperation of Andrew Bukovinsky, Combustion Engineering; Rick Ricks and Susan Heinlein, Impact Systems; and Richard Smith, EPRI Center for Materials Fabrication.

Sources used in this issue of *TechCommentary* were:

Stephansen, E. W. "New Applications of High Intensity Infrared To Reduce Binder Migration on Coating," presented at the TAPPI Coating Conference, 1985.

Stephansen, E. W. "Infrared Drying of Coated Paper," presented at the TAPPI Coating Conference, 1986.

Electric Infrared Process Heating: State-of-the-Art Assessment, EPRI Report No. EM-4571, March 1987.

Photograph courtesy of Combustion Engineering.

Applicable SIC Codes
26—11, 21, 31, 41–43, 47–49, 51

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APPLICATION

Medium and Short Wave Infrared Curing

Published by the Center for Metals Fabrication Vol. 1, No. 3, 1987

The Challenge: Meeting the Demand For Quality Finished Light Standards

Doug MacVoy, President, United Lighting Standards, Inc., (ULS) knew that "the market for finished steel light standards is extremely competitive. To increase our market share we had to offer a higher-quality product. We also knew that our customers would not accept a price increase, so our only option was to increase productivity."

ULS did just that when it replaced the air-dried, acrylic finish on the light standards with a powder coating cured with medium and short wave infrared (IR). As a result, the poles now supplied, for street and athletic field lighting and for traffic sign and signal supports, have one of the most attractive and durable finishes available in the industry.

ULS's goals for the new finishing line were to:

- Increase productivity, without an increase in cost per part
- Produce standards with a colorfast coating that will last about 20 years
- Eliminate costs of removing noxious fumes and hazardous waste
- Optimize use of available floor space.

The Old Way

ULS cleaned rust from steel poles with a volatile solvent, then hand-sprayed them with a primer. After the primer air-dried, an acrylic enamel finish was sprayed on and also allowed to air-dry. Each coat required between 2 and 8 hours to dry, depending on the weather.

Although customers seemed satisfied with poles finished in this way, from ULS's standpoint the procedure had a number of drawbacks, including:

- Low productivity—only 30 finished poles a day.
- Poor materials utilization and high maintenance costs—only about 40% of the paint was actually applied to the poles. The remainder was waste and the paint area had to be scraped and scrubbed once a week.
- EPA requirements—paint and cleaner had to be stored, handled and disposed of according to strict regulations, and a powerful ventilation system was required to remove solvent fumes.

Finding a Better Way

Based on more than a year of research, ULS chose to replace liquid paint with a dry, powder coating because of the superior appearance and abrasion resistance of powder finishes.

Since powder coatings are applied by spraying electrostatically-charged powder onto the poles, thickness and uniformity are easily controlled. The powder is cured by heating to about 400 F, which causes it to melt and bond to the underlying substrate. Traditionally, powder coatings are cured in gas convection ovens. However, convection heating is slow and difficult to control, and the large ovens are energy-inefficient. Since ULS was trying to avoid such problems, the research included finding a better curing method. The choice was medium and short wave electric infrared heating.

An overhead conveyor transfers a light standard from the powder coating booth to a bank of medium wave IR emitters (above). The IR cure takes 2-5 min. depending on length and diameter of the standard.

ULS's New Finishing Line: Fast, Efficient and Automated

ULS's light standards actually consist of two parts—the pole itself, made of 7- to 11-gauge steel, and the heavier base plate, usually of ¾- to 2-inch steel.

The welded assembly is loaded onto an overhead conveyor, cleaned by shot blasting, then powder coated. The coating booth has 4 automatic spray guns and 2 manual guns for coating odd-shaped parts.

Coated poles are conveyed to a two-stage IR oven for curing. The first stage is 19 feet long and has 3 zones of 2500 watt medium wave IR emitters. There are 38 emitters in zone 1 and 18 each in zones 2 and 3. Each zone has its own 220 volt power supply. Cure time in the medium wave oven is from 2-5 minutes, depending on the length and diameter of the poles.

The second stage of the oven is used to complete the curing of the much thicker coating on the bases. This section is 10 feet long and has 2 zones each with 7 short wave IR emitters. These emitters produce 3000 watts at 440 volts, and cure the coated base in 2-4 minutes.

The Results: The Best Finish in the Industry

With its new finishing line, ULS has met its major goal of:

Increased production. The same work crew now produces up to 120 finished poles a day, rather than 30.

Among the benefits of using a powder coating rather than liquid paint are:

Materials savings. Now 95% of the powder is actually applied to the poles, rather than 35-40% of the liquid paint.

Lower maintenance. Since almost all the powder coating adheres to the light standards, very little cleanup is required.

Safer and cleaner operation. The coating contains no solvent, so there are no toxic fumes to remove and no problems meeting EPA requirements.

Flexibility. There is only 45 minutes down-time in switching coating colors.

Curing the powder coating with IR radiation has resulted in:

Energy savings. Curing the powder coating with electric IR costs only $0.86 per pole. Curing in a gas oven would have cost $1.59 per pole.

Space savings. The electric IR ovens occupy only 105 square feet of floor space. A gas oven would have required about 2000 square feet and a much larger conveyor system. Based on ULS's cost of $6 per sq ft, this translates into a saving of $11,370 per year.

Faster curing. It takes 4-9 minutes to cure the coatings in the infrared oven compared with 4-16 hours for air-drying. A convection oven would require 25-40 minutes.

Fast response. The IR oven reaches operating temperature within 12 seconds of power on. A gas convection oven requires about 1 hour and must be held at temperature even when empty.

Better control. The emitter banks can be moved in and out and controlled individually to optimize curing different-sized poles.

What Did it All Cost?

Total cost of ULS's new powder coating application and curing line was approximately $500,000, with the IR oven accounting for about $100,000. A gas convection oven capable of the same production rate would have cost about $150,000, and it would have required much more floor space and a more expensive conveyor system.

The Bottom Line: An Industry Leader

As a result of the new finishing line, ULS can offer its customers a superior product at a competitive price. In fact, ULS is so confident of the quality of its finish that it feels it could set a new standard.

Other Applications of IR

Infrared heating can be used to dry and cure a variety of wet and dry coatings on many different substrates. Among products treated are:

- Appliances, car bodies and light fixtures
- Steel and aluminum strap and coil
- Flat wood products
- Glass, fabrics and paper.

More information on IR treating of coatings can be found in TechCommentary Vol. 3, No. 6.

Company Profile

United Lighting Standards, Inc., Warren, Michigan

- Founded 1970
- Manufacture steel light standards
- President—Douglas MacVoy, General Manager—Bernie Jenkins
- 28 employees
- Company philosophy: Let's be a standard setter, not a standard follower.

Bernie (left) and Doug (right) setting new standards.

Detroit Edison Company made valuable contributions to this TechApplication.

The Center for Metals Fabrication (CMF) is operated by Battelle's Columbus Division. Basic funding is provided by the Electric Power Research Institute, a non-profit institute that conducts applications development on behalf of the United States electric utility industry. TechApplication is one of the ways the Center assists industry in implementing cost- and energy-efficient, electric-based technologies in metals fabrication and related fields. This issue was cofunded by a grant from the United States Department of Energy Office of Industrial Programs.

Applicable SIC Codes
24—35,36 **26**—49 **27**—51,52 **30**—79 All **34-39** SICs

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APPLICATION

Short Wave Infrared Curing

Published by the EPRI Center for Materials Fabrication Vol. 1, No. 1, 1987

The Challenge: Keeping the Charm of the South Made in the USA

The beautiful white wooden columns that grace southern mansions and other neoclassical buildings were expensive to buy and to maintain. But Moultrie Manufacturing's Bill Smith, Sr., changed all that. In 1967, he developed a method for joining long sections of aluminum. This breakthrough enabled Moultrie to introduce extruded aluminum columns that are both less expensive and more durable than wood.

In 1983, Bill learned that a foreign company was planning to offer columns which they claimed were less expensive than Moultrie's. This threat of competition, combined with the need to comply with strict EPA regulations, convinced Bill and his son Bill Smith, Jr., that it was time to modernize their entire finishing line. Their goals were to:

- Increase production without an increase in labor costs
- Improve utilization of coating material
- Comply with EPA regulations
- Improve product quality.

The Old Way

Column sections were placed on a conveyor and sprayed with two coats of liquid paint. Caps and bases were hand-painted. Only 40% of the paint actually adhered to the columns. The other 60% was wasted. In fact, there was so much excess paint that the entire line had to be shut down for a half day each week for cleaning.

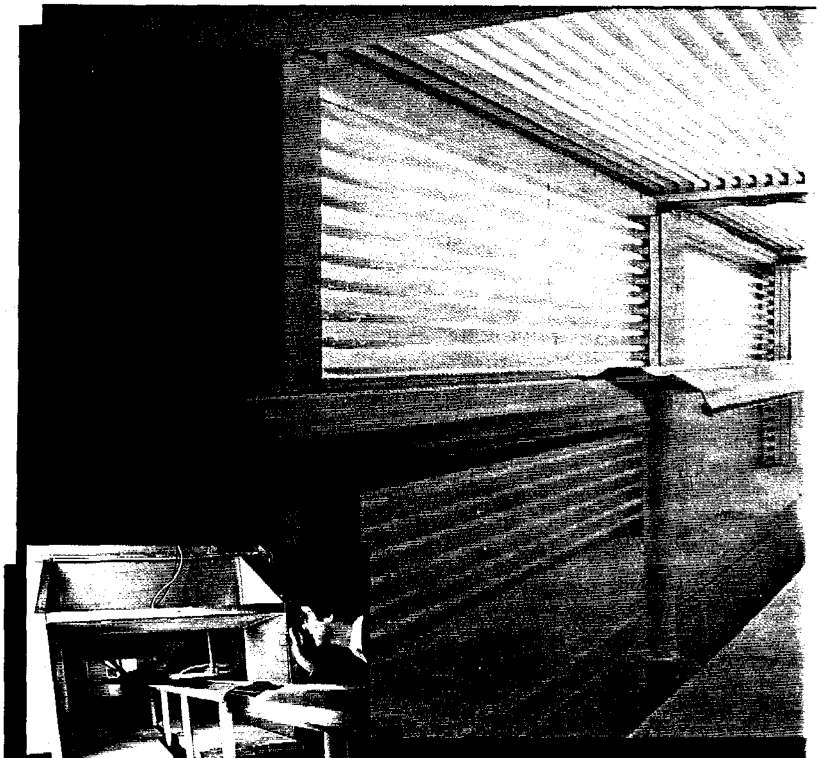
After spraying, the columns were placed in a 40-foot-long, gas-convection batch oven where the paint solvent was removed—and released into the atmosphere. So much solvent was released that Moultrie was in danger of being closed down by the EPA.

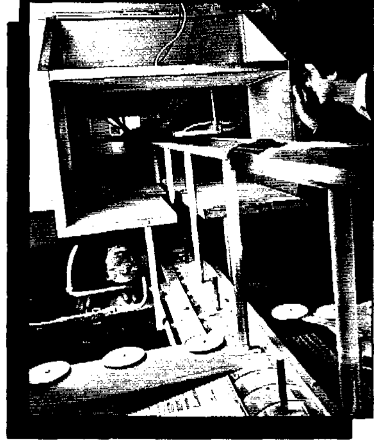
Paint drying took 1-1½ hours and only 300 parts could be processed per shift — not enough to fill all their orders.

The New Way: A Totally Different Approach

To meet all the challenges, Moultrie completely restructured their cleaning, coating and finishing system. They replaced their liquid paint with a 100% solids powder coating, which is applied electrostatically. In place of the convection oven they installed a high-intensity, short wave infrared (IR) curing oven with 6 heating zones, each with an independent 3 phase 480V power controller. And the entire line, except for part loading and unloading, is under computer control.

While each component offers certain benefits, these benefits can only be realized as part of a totally integrated system. IR is an ideal method for curing powder coatings. Because heating is so fast, the process works best under computer control.





A powder coated column section is cured in the infrared oven (above). A section of aluminum column passes through the powder paint booth then enters the infrared oven behind for curing (left).

The Results: Everything Moultrie Hoped For and More

Increased production. The same two-man, eight-hour shift now produces 10,000 rather than 300 pieces. And the finishing line is run for only half a day. The operators spend the other half of the day packaging the columns for shipping.

Material savings. Powder overspray is trapped and recycled, so that eventually over 99% of the powder is actually applied to the columns. Moultrie's powder coating material costs are the same as their paint costs in the 1960s, and 25% less than paint would cost today.

Lower maintenance. Since all the powder is applied to the columns, there is no need to close the line for cleaning.

No pollution. Because the powder is all coating material, there are no toxic fumes or solid wastes to remove, so there are no problems in complying with current EPA regulations, and Moultrie foresees no problems in meeting future standards.

Flexibility. The powder application system is designed to make it quick and easy to switch coating color.

Space savings. The IR oven itself is only 7 feet wide and 30 feet long. A gas oven with comparable capacity would have been 40 feet wide and 200 feet long, or about 40 times as large.

Faster heating. It takes only 34 seconds, at 55 ft/min, in the IR oven to cure the powder coating, whereas the old method took 1-1½ hours.

Energy savings. After installing all their new equipment, Moultrie's monthly energy costs decreased from $2,400 to $1,100.

Process control. IR emitters turn on and off very fast, so as soon as the product has left the oven, the power can be reduced. This is not possible with gas ovens because they take so long to come to temperature. In addition, sensors detect any changes in line speed and, if necessary, automatically reduce or turn off power to prevent the coating from burning.

Improved product quality. Moultrie can now offer a one year guarantee on its finishes.

Improved work environment. The IR oven concentrates the heat on the product and doesn't heat up the surrounding area.

What Did It All Cost?

Moultrie's new coating and curing equipment cost about $450,000 and their entire new installation about $1,000,000. It would have cost about 2½ times as much had they not done much of the site preparation and installation work themselves. With the increased productivity and lower operating costs, Moultrie expects the new line to pay for itself in only 3 years.

The Bottom Line: A Stronger Company and No Competition in Sight

With their new finishing line, Moultrie has improved the quality and appearance of their columns while still offering them at the 1980 price. Customers clearly appreciate this, and sales in 1985 were 25% higher than in pre-automation 1983. And the foreign competition? It is nowhere to be seen.

Other Applications of High-Intensity IR

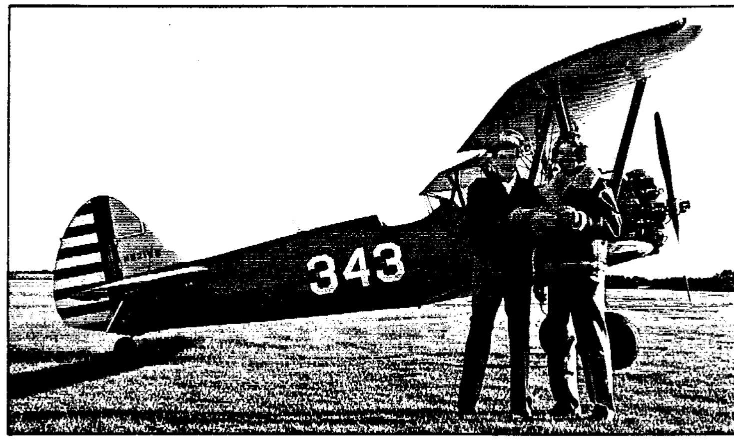
Infrared treating is not restricted to powder coatings on metals. It is also used to treat liquid or dry coatings on:

- Appliances, car bodies and light fixtures
- Steel and aluminum strap and coil
- Flat wood products
- Glass, fabrics and paper.

You can find more information on IR treating of coatings in TechCommentary Vol. 3, No 6.

Company Profile

The Moultrie Manufacturing Company, Moultrie, Georgia



The Smiths reach great heights not only in implementing new technology but also in their World War II PT Boeing Stearman.

Moultrie always welcomes visitors.

Chairman — Bill Smith, Sr.; President — Bill Smith, Jr.

Approximately 50 employees

The country's leading producer of coated aluminum architectural columns and accessories, and cast aluminum furniture

Company philosophy: Stretch your mind to the ridiculous to find solutions, move fast.

The Center for Materials Fabrication (CMF) is operated by Battelle's Columbus Division. Basic funding is provided by the Electric Power Research Institute, a non-profit institute that conducts applications development on behalf of the United States electric utility industry. TechApplication is one of the ways the Center assists industry in implementing cost- and energy-efficient, electric-based technologies in metals fabrication and related fields.

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Reprinted 3905

APPLICATION

Infrared Drying of Paint

Published by the EPRI Center for Materials Fabrication Vol. 3, No. 1, 1989

The Challenge: The Perfect Finish

Chrysler Motors implemented electric infrared (IR) drying at its Belvidere, Illinois, automobile assembly line to achieve superior high gloss, durable paint finishes—and to position the line for paint technologies of the future.

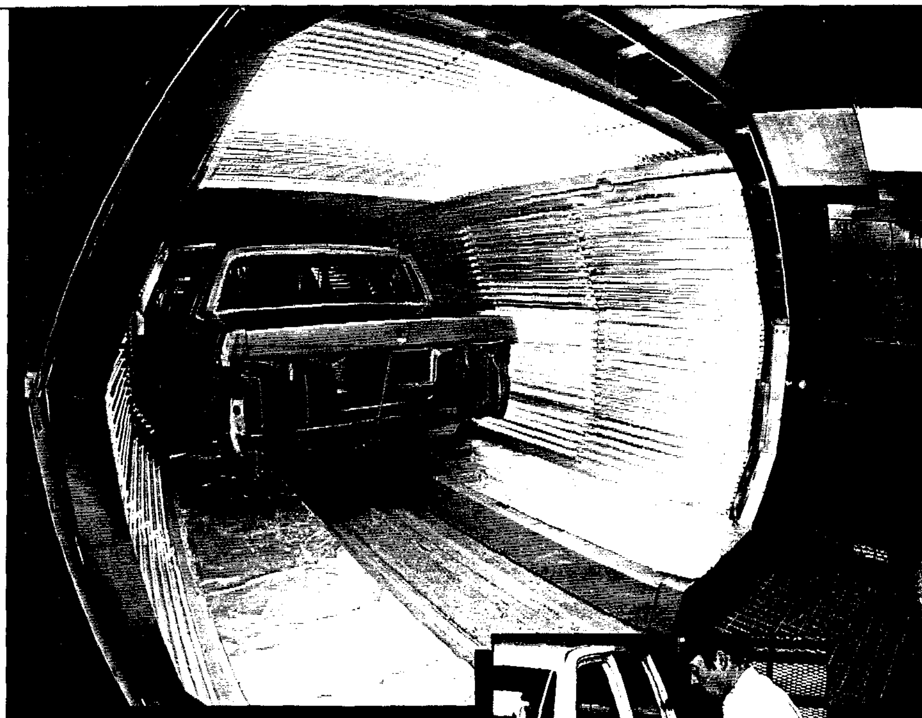
Chrysler officials believe the New Yorker and Dodge Dynasty models produced at the Belvidere plant have the highest reflective finishes of any mass-produced U.S. cars.

Implementing IR drying together with newly developed color- and clear-coat paints provides outstanding hardness, durability, and a mirror-like finish. IR dries the color-coat quickly and

- Improves gloss and durability because a thicker (25% more) clear-coat can be applied
- Reduces defects caused by paint sags or trapped solvent.

Before choosing IR, Chrysler evaluated several drying methods, including convection, hot air, and radiant methods. IR was selected because

- High-flow paints can be dried at current production line speeds
- Oven temperatures can be precisely controlled
- IR drying adapts well to water-borne paints, now in the development stage
- The 16-foot IR oven fit into the existing production line without modification.



Above: The IR unit drives out color-coat solvents, reduces defects, and improves the finish.

Right: A worker uses a Tension meter to measure finish reflectance.

From Cleaning to Clear-Coat

The automobile shell, once assembled, is conveyed through the paint line. The shell undergoes a nine-step cleaning and phosphating process to eliminate dust and lubricants that can blemish a painted surface. For corrosion resistance, the shell is conveyed through a bath that electrolytically coats all surfaces. The electrocoat is cured in a black-body radiant and convection oven. Robots then apply joint sealers which are cured in a gel oven.

The shell is conveyed into the spray booth. Anti-chip coating is sprayed on rocker panels and underbody areas. Workers enter the desired color code into a Manual Input Station (MIS) computer. The MIS directs which of nine selected colors the car is painted; colors can be sprayed in any sequence. Now that the IR unit has been added, the MIS also controls the IR drying cycle for each car body. Three different programs (the unit is infinitely variable)—one for white and light metallics, one for dark metallics, and one for black—set the power changes for each lamp in the IR unit throughout the drying cycle.

Workers spray color-coat on the interiors, inside the trunk and hood, and on the wheel wells and other recessed areas. Spray bells and reciprocating spray equipment then automatically spray the top and sides with the new high-flow color-coat, a paint that reduces blemishes and is compatible with the new two-component clear-coat. Before IR, the old color-coats were dried in ambient air for approximately four minutes. Now the car bodies are conveyed immediately into the IR oven, where the color-coat is dried in 31 seconds.

The glossy clear-coat is sprayed in the same manner as the color-coat and is cured in a long-wave gas IR/convection oven. Quality checks are performed for smoothness, blemishes, and dirt—any defects are repaired.

The computer-operated IR unit at Chrysler utilizes sophisticated exhaust and cooling air systems. The IR unit contains 400 lamps across five zones. The IR heat warms the car body, driving out solvents and setting the paint. Currently, only two zones (68 lamps) are used. The additional zones will be needed when water-borne coatings are implemented.

The Results: Higher Quality/Reliability

Chrysler continues to achieve measurable improvements:

High gloss. Chrysler measured substantial improvements in smoothness and gloss after implementing IR. The automotive industry uses a Tension meter to measure reflectance of the finish. A reading of 20 is the standard achieved only on polished black glass. With IR and new paints, Tension readings on metallic colors at the Belvidere assembly plant have increased from 16 to 18 on horizontal surfaces and from 10 to 14 on vertical surfaces. On black and white finishes, horizontal readings are up to 19 and vertical readings are 16 to 17.

Energy usage. Quality has improved at Belvidere with a minimal increase in energy costs. The output and usage of the IR unit is precisely controlled; the energy cost is only $0.08 per car.

No downtime. The IR unit is tied to the entire spray line—if the unit goes down, the entire line goes down. This illustrates Chrysler's commitment to the IR drying process. The IR unit has demonstrated impressive reliability; it has caused no downtime since production began in March 1988.

Meets future requirements. IR drying will meet Chrysler's future needs as well. When water-borne coatings are implemented, IR will be the critical factor in removing 95% of the water from the color-coat.

What About Cost?

One IR drying unit, computer programs, exhaust and cooling systems will cost from $500,000 to $1,500,000, according to the manufacturer, BGK Finishing Systems, Inc., Minneapolis, Minnesota. The cost is dependent on line speed and installation complexity.

EPRI/CMF Sponsorship

The Electric Power Research Institute (EPRI) Center for Materials Fabrication (CMF) cosponsored the field trials for the IR unit through the CMF Electrotechnology Implementation Program (EIP). EIP encourages innovative applications in electrotechnologies (such as induction, IR, and microwave heating) to prove their economic and technical feasibility in production settings.

Other Applications of IR

Chrysler's success has led it to explore IR for other production processes, such as two-tone paints. And, together with CMF, it is researching IR curing the electrocoat.

The IR technology utilized at Chrysler can be implemented in a wide variety of industries and applications; for example:

- To coat continuous strip, cans, and other metal containers in the metal strip, sheet, coil, and decorating industries
- To cure coatings on refrigerators, freezers, cooking equipment, laundry equipment, and small appliances
- To dry lumber and wood products, paper and allied products, and printing.

For more information on infrared drying and curing, see CMF *TechCommentary* Vol. 3, No. 6, and CMF *TechApplication* Vol. 1, Nos. 1 and 3.

Company Profile

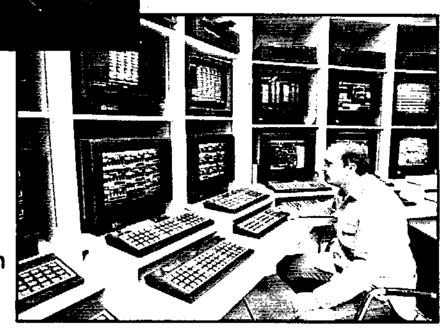
Chrysler Motors
Belvidere, Illinois

Plant Manager: S. T. Rushwin

Employees at the Belvidere plant: 4000

The Belvidere plant assembles Chrysler New Yorker and Dodge Dynasty automobiles.

Company philosophy: To be the best.



Above: Greg Bartos, paint operations manager, behind a Chrysler New Yorker. Right: The control room for the Belvidere plant paint line.

The Center for Materials Fabrication (CMF) recognizes Garry Good of PPG Industries, Belvidere, Illinois, for his assistance.

Commonwealth Edison Company provides electric service for Chrysler Motors Belvidere Plant.

CMF is operated by Battelle, Advanced Materials, Columbus, Ohio. Basic funding is provided by the Electric Power Research Institute, a nonprofit institute that conducts applications development on behalf of the United States electric utility industry. *TechApplication* is one of the ways the Center assists industry in implementing cost- and energy-efficient, electric-based technologies in the fabrication of metals, plastics, ceramics, composites, and wood.

Applicable SIC Codes
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All **34–39** SICs are also applicable

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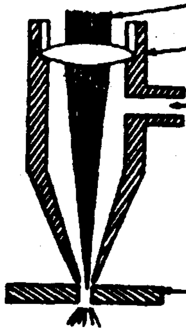
Regulation Class: ◑ Clean Air ◔ Clean Water ◔ Haz. Waste ○ CERCLA ○ ______

SIC Potential
◔ 25% ◕ 75%
◑ 50% ● 100%

Process Technology: *LASER*



LASER

Source: Maurice Orfeuil, Electric Processing Heating, the Battelle Press

Function/Theory

LASER stands for Light Amplification by Stimulated Emission of Radiation. In simplest form, the system makes use of focused high intensity light pulses that are directed to strike the workpiece surface "target" areas causing localized and rapid heating. Thermal energy is generated by absorption of laser radiation (extremely intense light beam) at the workpiece surface. Automated optical systems scan and focus the laser beam on predetermined areas of the workpiece. When used for cutting, LASER energy vaporizes the workpiece material at the cutting site. Absorption of the beam by the workpiece results in localized heating for welding applications.

Selection Criteria/Considerations

Acceptance: ☐ High ☑ Medium ☐ Low

- Cutting as an alternative to current technologies, such as punching, nibbling, or drilling.
- Applied for heat treating high quality/performance parts requiring precision localized hardening not achievable by induction.
- Heat treating large and irregular shaped parts; difficult to reach surface areas.
- Most cost efficient for numerous small runs where quick changeover is critical for reduced downtime.
- Used for selective surface hardening without heating the entire workpiece.
- Best suited for special application welding, including deep narrow welds of thick material, or joining foil, where precise control is needed.

Environmental Benefits

- No special atmospheric gases required.
- Usually self-quenching, so no waste oil is generated in heat treating.
- No combustion by-products as generated with fossil energy sources.
- Reduced reject rate, resulting in less process waste.

Additional Benefits

- Precision control of beam shape and high power density achieves rapid selective hardening at specified depths and hard to reach surface areas with minimal workpiece distortion.
- Rapid, clean, and precise cutting resulting in improved product quality, reduced rejection rate, increased productivity, and improved design flexibility.
- Flexible to accommodate a variety of workpiece sizes
- Rapid, clean and precise welding, able to accommodate unusual joint geometry; air tight seals if necessary.
- Accommodates parts requiring tight dimensional tolerances/stability.

Drawbacks

- High equipment capital cost.
- Low "user comfort level".
- Heat affected zones (HAZ) in the cut area may require heat treating to restore desired metal characteristics (2% of applications).
- Limited thickness on conductive materials.

Mining

Metal	10	○
Coal	12	○
Oil & Gas	13	○
Mineral	14	○

Mfg.

Food	20	◔
Tobac	21	○
Textile	22	○
Apparel	23	◔
Lumber	24	◔
Furn	25	◔
Paper	26	○
Print	27	◔
Chem	28	○
Petrol	29	○
Rubber	30	◔
Leather	31	●
Stone, Glass	32	○
Metals	33	◔
Metals Fabric.	34	●
Mach	35	◕
Elect	36	◑
Trans	37	◑
Instru	38	◑
Misc.	39	◔

Waste Stream Reduced

Air
☐ Particulates ☑ Organics
☑ CO_2, NOx ☐ Toxics

Water
☐ Particulates ☐ Organics
☐ Metals, Ions ☑ Oil

Solid
☐ Hazardous
☑ Non-Hazardous

Typical System Example

Size: 48" x 98" x 4" to
60" x 120" x 4"

Energy Requirement:

0.5 - 25 kW; 5 kW (typical)
Beam power densities of 3,000 to 30,000 watts per sq. in. on workplace surface area for Heat Treating.

0.5 - 2.5 kW in Fabricated Metals Welding.

0.5 - 5 kW; 1-3 kW typical in Fabricated Metals Cutting.

Efficiency: 8 - 12% in Heat Treating

Economics

Capital Cost: $200,000 to $1,500,000 = Total system (laser, optics, material handling, controls).

$500,000 for 5 kW system and
$1,500,000 for 25 kW system in Heat Treating.

$300,000 to $700,000 = Total system (laser, optics, material handling, controls).

$30,000/kW (roughly) Fabricated Metals Welding.

$85,000 - $100,000 (Laser only).

$250, 000 - $500,000 plus (with automation and positioning equipment) Fabricated Metals Cutting.

$80,000 for single beam to $400,000 for multiple beams in Plastics.

Payback: 1.5 to 2 years

Source: Trumpf, Inc.

Service/Maintenance

Clean and align optics, and service vacuum system and electronics regularly. Replace optics every 9 - 12 months, depending on use in Fabricated Metals Cutting.

Vendors

Amada

Cincinnati, Inc.

Coherent General

Mazak Nissho-Iwai

Mitsubishi

Trumpf, Inc.

Notes

Major Vendors

LASER

Amada
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EPRI Techcommentaries

Laser

Laser Hardening, EPRI CMF TechApplication, Vol.1, No. 18, 1987
Laser Cutting, EPRI CMF TechCommentary, Vol.3, No. 9, 1986
Laser Cutting og Metal, EPRI CMF TechApplication, Vol.1, No. 6, 1987
Laser Cutting & Scribing of Ceramics, EPRI CMF TechApplication, Vol.1, No. 5, 1987

APPLICATION

Laser Hardening

Published by the EPRI Center for Materials Fabrication

Vol. 1, No. 18, 1987

The casting, machined to final blueprint dimensions, is held in a simple fixture and moved in the laser beam for hardening.

The Challenge: Selectively Harden While Minimizing Distortion and Cost

Replacing gas carburizing with laser hardening enabled Garrett Turbine Engine Company (GTEC) to produce superior torque load arms for turboprop airplane engines while reducing manufacturing costs by 61%. The small, steel torque load arms are part of a sensing system that manages the engine's power. They must have a low core hardness for ductility and a high surface hardness on the contact pads for wear resistance. But the gas carburizing method used to achieve this selective hardening was time-consuming and costly—and often distorted the part beyond repair.

In 1984 a GTEC team sought to reduce costs, save time, and find a better way to harden the torque load arm. In addition, the new method had to

- Simplify machining operations
- Reduce distortion
- Create quality products
- Meet all blueprint hardness and case depth requirements.

The Old Way

GTEC had been manufacturing the torque load arms from SAE 9310 bar stock rough machined to slightly oversize. Since selective hardening was required, the part was plated with copper, selectively masked, stripped and cleaned—all in preparation for gas carburizing.

The gas carburizing was done in batches in a sealed furnace in which an endothermic atmosphere surrounds the parts and, under heat, increases their surface carbon content. The parts were held in the carburizing oven for about 3 hours at 1650 F and then allowed to cool. After cooling, the parts went through additional processing steps to achieve the desired hardness including deep freeze treatment, tempering and additional cleaning and stripping.

Parts passing inspection were further machined to correct distortion produced by the carburization cycle and to achieve the desired shape. If the distortion was so great that it could not be corrected, the part had to be scrapped.

Since gas carburizing involved so many steps, it was expensive and afforded many chances for error. The GTEC team appraised several alternative processes including induction hardening, nitriding and laser hardening. Induction hardening could not selectively harden the contact pads, leave the core soft, and obtain the HRC 58+ requirement. Nitriding could give a very hard surface but could not create a deep enough case. But laser hardening met specification with minimum costs.

The New Way

GTEC takes advantage of the laser's selective and nondistorting nature to surface harden the torque load arms. Now the load arms begin as an investment casting of AISI 4340 Mod., a steel containing sufficient carbon to respond to the laser and achieve the desired hardness.

The investment castings are furnace heat treated to provide a core hardness of HRC 34-38 and machined to final blueprint dimensions. The castings are then spray painted with an absorptive paint. This makes heating more efficient by overcoming the bare metal's inherent tendency to reflect the laser light.

A defocused CO_2 laser beam traverses the work surface, rapidly heating the surface without melting it. Due to the mass of unheated material, the hot surface metal quickly self-quenches. This intense heating and cooling results in a hard martensitic microstructure (HRC 58+) being formed only near the surface. Since the remainder of the part stays cool, distortion is minimized, and the core remains soft. After laser hardening, the parts are tempered and then cleaned with a fine wire brush.

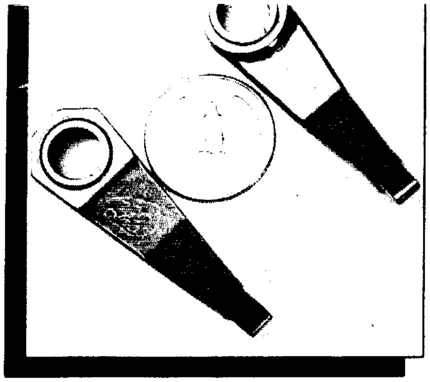
The Results: Simpler Production and Decreased Costs

Reduced production costs. Changing to the laser hardening process reduced costs by 61%. This includes savings in labor, machining, material, and all processing.

Time savings. Simple and fast, laser hardening reduced the hardening time from 6 hours for a 100-piece lot to about 50 minutes.

Reduced scrap rate. Scrap rate has been reduced from 15% to less than 1%.

A superior torque load arm is made with less cost and time: The top part is a laser-hardened investment casting. The bottom part is gas-carburized machined bar stock.



Elimination of steps and equipment. The use of investment castings reduces the number of surfaces that require subsequent machining from 17 to only 8. Eliminated are plating, masking, stripping, and cleaning operations as well as carburizing furnaces, sub-zero freezers, hardening furnaces, quench presses, salt baths, and other related equipment.

Faster turnaround—Less work in process. Lead time has been reduced by eliminating posthardening operations and because the hardening operations can be performed on the shop floor without transporting hardware to remote carburizing facilities.

Lower maintenance and space savings. With less equipment needed, maintenance and floor space requirements have been reduced.

Less pollution. Solutions used to strip copper from the part are no longer used, eliminating disposal concerns.

Energy usage. The major energy reduction comes from the elimination of the high-temperature gas carburizing and hardening operations. Energy used to carburize a 100-piece lot has been reduced from 800 kWh to only 1.1 kWh. More modest savings come from the elimination of other unit operations such as plating, freezing, and machining steps. Finally energy usage per finished part is also significantly reduced by reduction in scrap rate.

What Did It All Cost?

The laser equipment cost about $250,000 and can be used for a variety of parts, not just torque load arms. GTEC expects a payback period of about 2 years. In addition to the laser, a numerical-controlled method is needed to move the part through the laser beam. GTEC uses a 5-axis milling machine although generally only 1 or 2 axes are needed for laser hardening.

A person familiar with heat treating can operate the laser with only a few hours of instruction in its operation and safety procedures.

The Bottom Line: High-Quality Products at Reduced Cost

Using laser hardening for torque load arms and other parts has enhanced GTEC's ability to maintain high standards in production and output. It has expanded capacity without additional carburizing facility.

Fewer manufacturing steps and other reduced costs allow GTEC to stay competitive.

Other Laser-Hardening Applications

Laser surface hardening is used primarily in the automobile industry for axle shaft housings and power-steering gear housings. It is also used for selectively hardening typewriter keys, farm implements, and parts of hand tools, such as saw teeth and hammer heads. Process refinement is continuing on gears, splines and shafts. For more information on laser hardening, see *TechCommentary* Vol. 3, No. 9 on Laser Cutting.

Company Profile

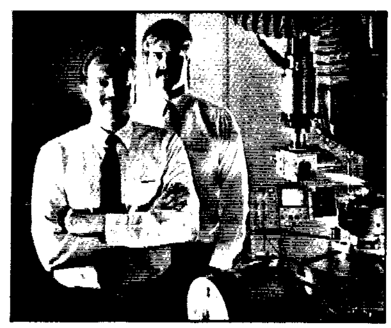
Garrett Turbine Engine Company, Phoenix, Arizona

President—Mal Craig

Approximately 7000 employees

Garrett turbine engines are used in commercial, industrial and military applications including propulsion engines for aircraft, auxiliary power systems and industrial gas turbines.

Company philosophy: Doing the job right the first time.



Gary Benedict (left) and Larry Ciolek are part of the team that made GTEC's laser hardening operation successful.

The Center for Materials Fabrication (CMF) would like to thank Larry Ciolek and Gary Benedict of GTEC for valuable contributions made to this issue.

Arizona Public Service provides electric service to Garrett Turbine Engine Company.

CMF is operated by Battelle's Columbus Division. Basic funding is provided by the Electric Power Research Institute, a nonprofit institute that conducts applications development on behalf of the United States electric utility industry. *TechApplication* is one of the ways the Center assists industry in implementing cost- and energy-efficient, electric-based technologies in materials fabrication and related fields. This issue was cofunded by a grant from the United States Department of Energy, Office of Industrial Programs.

Applicable SIC Codes

34—21, 23, 25, 29, 62, 84, 89
35—11, 19, 23, 24, 31-33, 41, 42, 44-47, 49, 62, 66, 68
37—14, 24, 28, 43, 51, 64 **38**—41, 42

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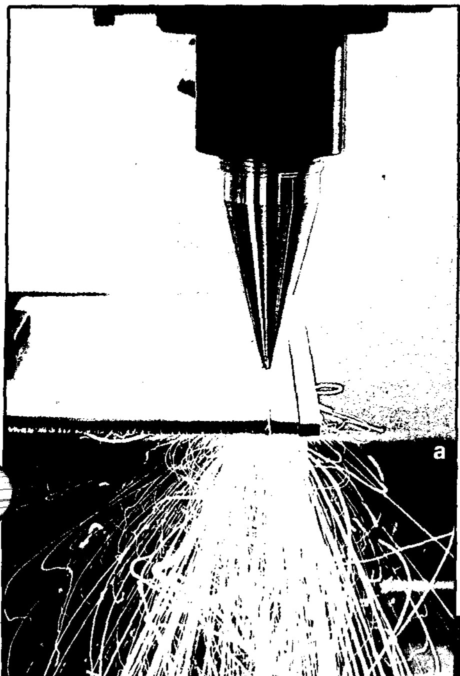
TECH COMMENTARY

LASER CUTTING

Published by the Center for Metals Fabrication Vol. 3, No. 9, 1986



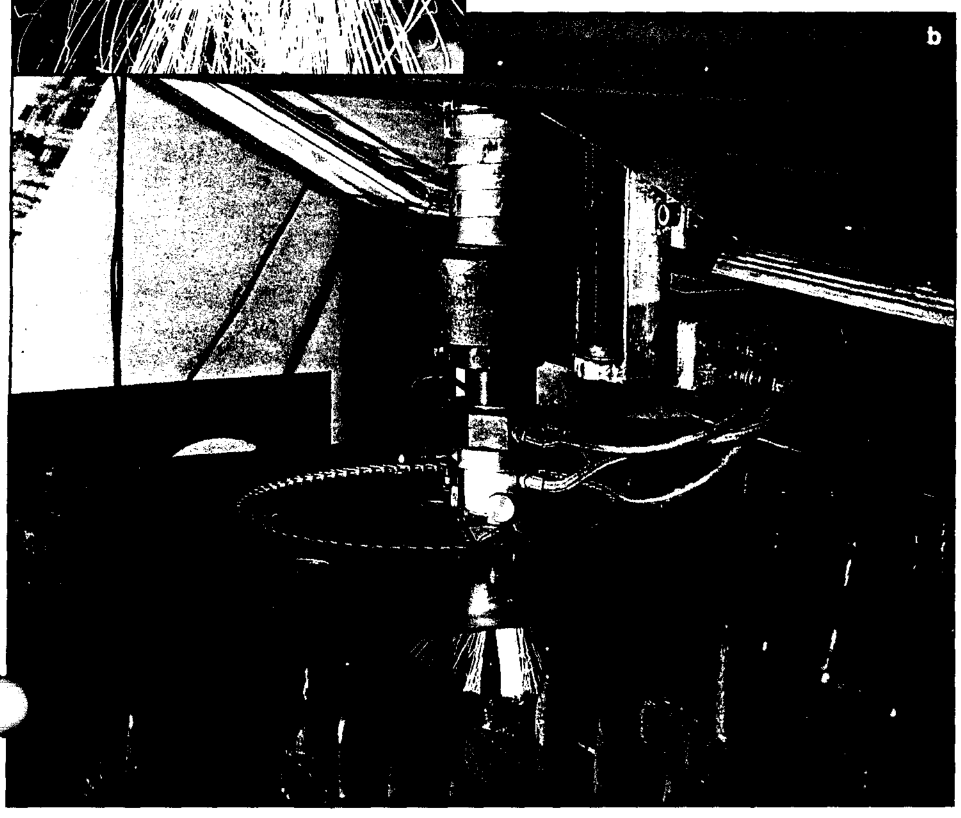
A Versatile, High-Speed Cutting Technique

Companies producing parts for the transportation, aerospace, electronics, and consumer products industries, among many others, are facing demands for:

- Instantly available prototypes
- Small production runs of precise parts
- Rapid delivery of many different kinds of parts.

To meet these demands, without tying up large amounts of capital in tooling and parts inventory, some manufacturers are turning to laser-based systems to cut, drill, weld, mark and selectively heat-treat a variety of materials. Laser systems cut many different materials both fast and accurately, with no tool wear and minimum heat affected zone (HAZ). However, their biggest advantage over other cutting techniques is that new parts can be created by simply changing the computer numerical control (CNC) program—there is no need to wait for dies or other hard tooling. Enterprising manufacturers have capitalized on the speed and versatility of laser systems to increase productivity, improve product quality and expand their range of products (Figure 1).

***Figure 1.* With CNC, a laser can (a) cut straight lines or (b) make intricate cuts as in this saw blade.**



This issue of TechCommentary describes the advantages and drawbacks of laser systems in metal cutting and hardening applications and points out the factors to consider in determining whether a laser system is right for your shop.

Advantages/Drawbacks

Several characteristics distinguish laser-based cutting systems from other metal-cutting techniques, and each has specific advantages. The laser beam's small size and high energy density offer:

- Rapid cutting
- Cutting accuracy of 0.005 in. or better
- Ability to cut a variety of materials, including most metals, ceramics, plastics, wood, fabrics and glass
- Little heat-induced distortion
- Minimal kerf (0.01 in.) and HAZ (0.008 in.)
- Clean, straight-sided cuts with minimum dross.

The fact that cutting is always done under computer control means:

- Ease of cutting complex shapes in sheet stock

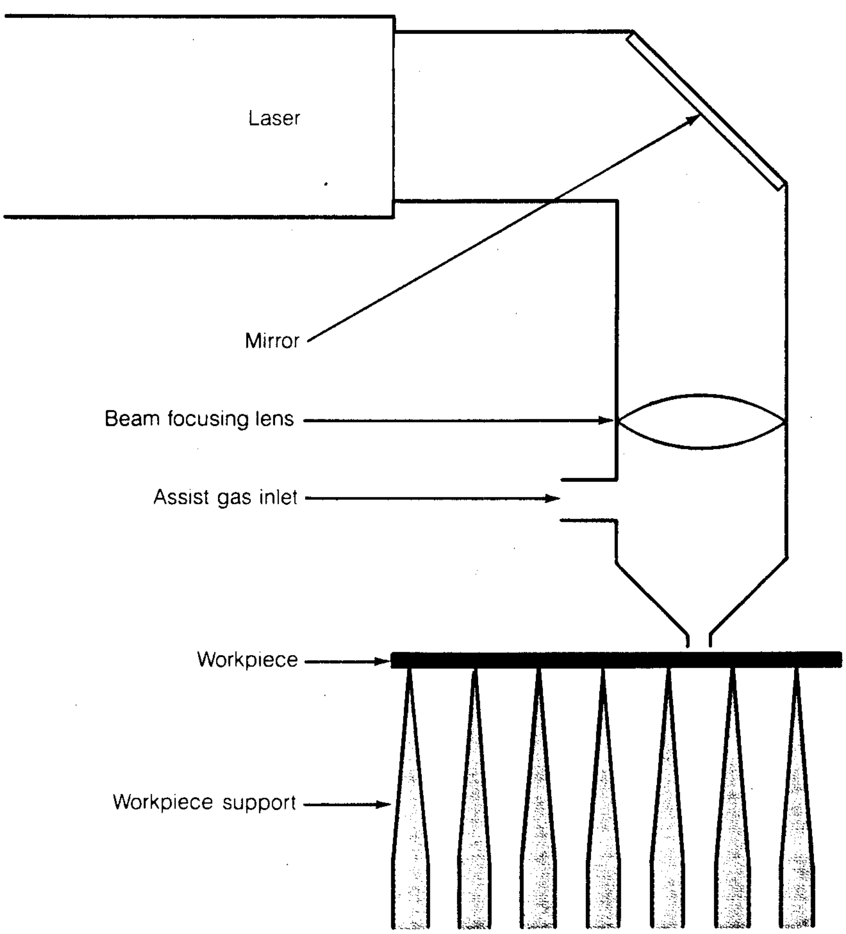
Lasers—What they are

A laser is essentially a source of high-intensity light, which is produced by passing electrical energy through a lasing medium. Two different types of lasers—gas and solid state—are used for metalworking. The lasing medium in gas lasers is carbon dioxide (CO_2) mixed with helium and nitrogen. In solid state lasers it is an yttrium-aluminum-garnet (YAG) crystal containing neodymium ions. The two types are generally referred to as CO_2 and YAG lasers, respectively.

Laser light waves travel in only one direction, unlike light waves from an ordinary light bulb which spread out in all directions. The unidirectional, or coherent, laser beam can be focused into a spot only 0.005 inches in diameter (about the size of a human hair) with an energy density of megawatts/square inch. When this tiny, high-energy beam strikes a surface, the material is vaporized almost immediately, resulting in a clean, sharp cut.

Laser cutting systems—What they are

The laser is only one part of a laser cutting system. Other essential components include beam-focusing optics to direct the beam to the workpiece, and equipment for moving either the laser beam or the workpiece, or both, to obtain the desired cutting pattern. Beam and workpiece motion are always under computer control. Also necessary is a heat exchanger to cool the laser and the optical components, gas delivery systems, and an exhaust system for removing vaporized material. While programming can be done at the control computer, it is more efficient to have an off-line CAD/CAM system for designing parts and preparing part programs. This is especially true for shops producing small lots of many different parts, where the control program must be changed frequently.



- Optimal material utilization
- Ability to switch rapidly to different parts
- Short lead times
- Economical low-volume production
- Excellent pattern reproducibility.

Laser cutting uses no physical tool, only a high-energy light beam. This has several advantages including:

- No tool-induced distortion or tool wear
- Three-dimensional cutting
- Machining in areas inaccessible to regular tools
- Hole drilling as close as 5° to the horizontal.

Finally, with a laser cutting system there is little down time.

There are, of course, a few drawbacks to laser cutting systems, including:

- High initial equipment cost
- Materials restriction—cutting is most efficient for nonreflective materials less than about 0.5 in. thick
- In drilling, maximum hole diameter is limited to the beam diameter unless trepanning is used.

Applications

Laser cutting systems are generally used for cutting prototypes or small production runs from sheet stock. Hard tooling is usually more economical for high volumes. However, one high volume application in which lasers have found a niche is trimming automobile parts. These are now being made of thinner materials, and trim dies capable of cutting to the required tolerances are so expensive that laser cutting is cost-competitive even for the large lot sizes involved.

Lasers are used in place of traditional punching or nibbling to cut:

- Jet engine combustion chamber liners
- Elevator and escalator panels
- Heat exchanger plates
- Electrical and office equipment enclosures
- Air-conditioning ductwork
- Saw blades.

Laser beams are used to drill:

- Car door lock holes
- Oil holes in engine and transmission parts
- Cooling holes in turbine engine vanes and blades
- Mounting holes in printed circuit boards

The Center for Metals Fabrication (CMF) is operated by Battelle's Columbus Division. Basic funding is provided by the Electric Power Research Institute, a nonprofit institute that conducts research and development on behalf of the United States electric utility industry.

The Center's mission is to assist industry in implementing cost- and energy-efficient, electric-based technologies in metals fabrication and related fields. TechCommentary is one communication vehicle that the Center uses to transfer technology to industry. The Center also conducts research in metal heating, metal removal and finishing, and fabrication.

This issue of TechCommentary was made possible through the cooperation of Gregg Simpson, Peerless Saw Company; Battelle staff members John Hallowell, Industry Applications Engineer, Laura Cahill, Manager, Marketing and Communications, and Denise Sheppard, Publications Coordinator; and Anne Moffat and Dorothy Tonjes of ProWrite. Technical review was provided by Gary Brockman, Diversified Manufacturing, and Bill Shiner, Dana Elza and Tony Mastey, Coherent General.

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Photos courtesy of Peerless Saw Company, Columbus, OH and The Electrification Council, Washington, DC.

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Applicable SIC Codes

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35—11, 19, 23, 31-34, 36, 37, 41, 45, 46
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38—11
39—93

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Material	Thickness (in.)	Speed (in./min)	Power (kW)
Aluminum	0.005	32	3.0
Aluminum	0.250	78	3.0
Aluminum	0.125	40	1.0
Aluminum	0.050	230	2.0
Aluminum	0.063	50	0.5
Stainless Steel	0.375	75	3.0
Stainless Steel	0.250	85	2.0
Stainless Steel	0.125	100	1.0
301 Stainless Steel	0.025	630	0.5
410 Stainless Steel	0.250	60	1.2
Hastalloy	0.060	360	1.0
Titanium	0.140	20	2.0*
Titanium	0.250	120	0.5
Nickel Alloy	0.125	125	4.0
Invar	0.030	162	2.0
Zinc	0.020	180	2.0
Rene 41	0.060	330	1.0
17-4 ph	0.080	100	0.6
Inconel 718	0.180	45	2.0
Inconel 718	0.016	530	1.0

*With argon assist gas

***Table 1.* Cutting Rates For Various Materials**

- Holes in timed-release medication capsules.

Switching to laser cutting systems has produced significant time/cost savings for a number of manufacturers.

- Seven-foot long aircraft wing sections were trimmed by hand at a rate of three parts per operator per shift. Switching to laser-robot trimming reduced process time to 10 minutes and resulted in greater dimensional accuracy and consistency.
- By replacing its punch presses with laser cutters, a company increased production of steel and aluminum chassis tenfold, and paid for the new machines in only eight months.
- Switching from plasma arc to laser cutting reduced by 90% the time needed to cut a galvanized steel part for refrigerated display cases.

Technical Considerations

Among the technical factors to consider in evaluating laser cutting systems are the laser itself, workpiece materials, beam/workpiece motion, auxiliary equipment, and safety.

The laser—Lasers are classified by their lasing medium (CO_2 or YAG) and by the amount of power in the output beam. Beam power of most materials-processing lasers is between 50W and 5kW. Generally, cutting rate increases with increased beam power.

The energy distribution, or pattern, across the width of the beam is not the same for all lasers. The pattern is determined by the "mode" in which the laser is operating. Lasers operating in the fundamental, or TEM_{00}, mode have a Gaussian energy pattern, which is ideal for cutting. Gaussian means that energy density is highest in the center of the beam and drops off smoothly towards the edges. There are many other modes, each of which has its own energy distribution.

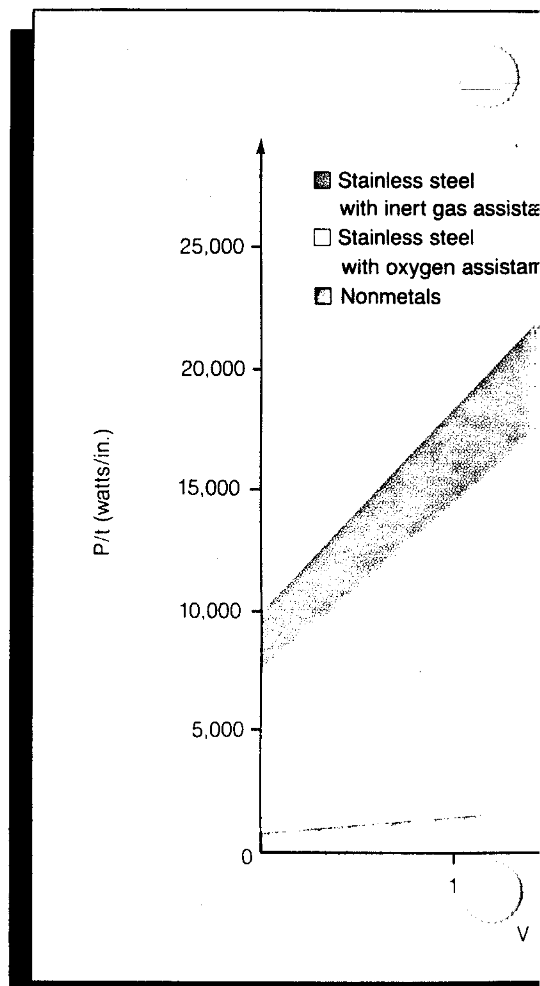
The quality of a cut is determined by beam focus, and lasers operating in the TEM_{00} mode can be most sharply focused. YAG lasers cannot be focused as well as CO_2 lasers, and their average output power is limited to about 400W. Because of this, they are used only for very thin materials and when minimal HAZ is more important than cutting rate. About 90% of cutting is done with CO_2 lasers, and Table 1 shows the beam power required for different cutting rates in a number of materials. For CO_2 lasers it also has been found that the power per unit thickness (P/t) is proportional to the cutting speed (V); i.e., P/Vt is approximately constant (Figure 2).

Important characteristics for a cutting laser are:

- Overrated power output. A laser with slightly more power than you think you need will give you flexibility to expand your product range.
- True TEM_{00} mode. Not all lasers can operate in this mode.
- Proven reliability. A laser model that is known to function consistently and accurately in a shop floor environment probably provides the best return on investment.

Workpiece materials—Laser cutting works best for materials less than about 0.5 in. thick. With enough laser power and a low cutting rate, thicker materials can be cut, but cost increases significantly.

Carbon and low-alloy steels can be cut fast, and edge finish is excellent. With stainless steels, and nickel, chromium and aerospace alloys, there is sometimes some slag or dross at the bottom of the cut. Alumi-



num and copper are more difficult to cut because they reflect the laser light unless coated or anodized to improve absorption. In addition, there are usually burrs on the bottom of the cut, which must be removed.

Laser cutting also works well with many plastics, composites, vinyls, ceramics, and easily-deformed materials like rubber.

Beam/workpiece motion—High cutting rates require efficient beam/workpiece motion. This can be achieved by:

- Moving the workpiece under a stationary laser beam
- Moving the laser beam over the stationary workpiece
- Moving both the beam and the workpiece.

Auxiliary equipment—Two tools that increase laser cutting efficiency are height sensing devices and assist gas jets.

The computer that controls beam position uses information about workpiece irregularities, obtained from height sensing devices, to keep the beam focused on the workpiece surface. This ensures optimal cutting efficiency.

An assist gas directed with the beam onto the workpiece surface "blows away" the molten or vaporized metal from the work area, ensuring uninterrupted cutting and preventing material from spattering onto the beam-focusing optics. It also cools the workpiece and minimizes the heat affected zone. Oxygen is generally used for cutting metals, although argon is substituted with oxygen-sensitive materials like titanium. Oxygen enhances the exothermic reaction and produces additional heat, which results in cutting rates up to five times higher than with an air or inert gas jet.

Safety—Intense laser beams can cause eye damage and burns. Operators should wear safety glasses, and the work cutting area should be enclosed to prevent accidental exposure. When cutting toxic materials like plastics and lead, fumes must be trapped and properly handled.

Economic Considerations

A 1 kW CO_2 laser costs between \$85,000 and \$100,000. Adding computer controls, a system for moving the laser and/or workpiece, and the other necessary equipment increases the cost to between \$250,000 and \$500,000.

While the initial cost of a laser cutting system is high, improved productivity and product quality, combined with low tooling and maintenance costs, make a system economical, especially for companies that produce a wide range of parts. In addition, the beam from a single laser can be shared by several workstations, so expansion may require adding only new workstations rather than an entire new system.

To decide whether a laser cutting system would be cost-effective, you must know your real cost per part, including all overhead and benefit costs, not just shop rate. If you cannot justify your own system, there are many job shops willing to do contract laser cutting.

Operating expenses include the cost of laser gases, assist jet gases, dry compressed air, and power, all of which vary with application. Average costs for all of these components together are \$6-10/hr. Another operating cost is replacement of the

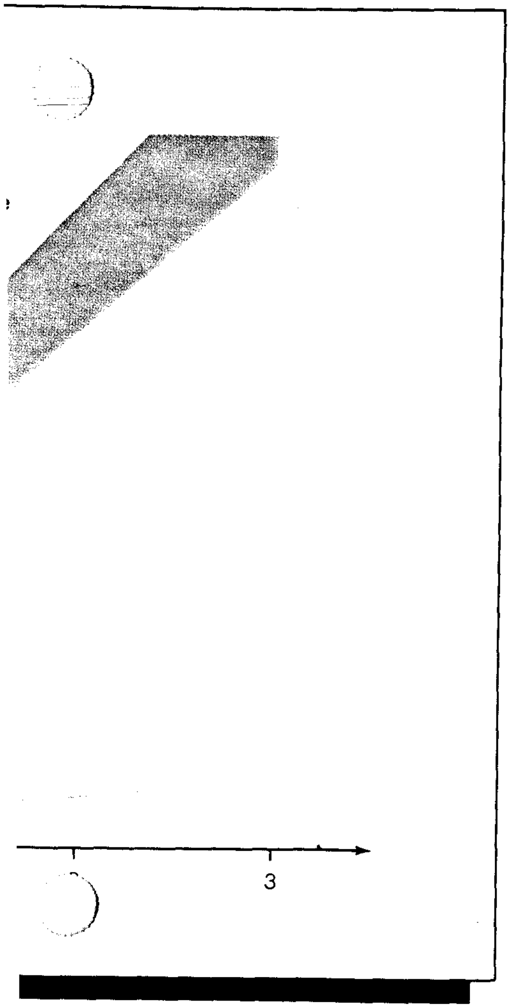


***Figure 2.* Relationship between power per unit thickness (P/t) and cutting speed (V) for stainless steel and various nonmetals.**

Laser Hardening

High wear areas of parts such as gears and gear housings often are selectively hardened to prolong the life of the entire part. Selective hardening is usually done by induction, but this method heats such a large area that further machining is often needed to correct part distortion.

Laser hardening heats only a small area and the rest of the part acts as a heatsink. There is essentially no part distortion, so no costly post-hardening machining.

Since a sharply focused beam would melt the surface, hardening is done with a defocused laser beam. Usually, the part is coated with a thin layer of a light-absorbing material to enhance energy absorption.

Equipment for surface hardening includes a 1-5 kW CO_2 laser, beam shaping lenses, and computer controlled beam movement to produce the desired hardening pattern. Case depths of up to 0.02 in. are obtainable.

Other selective hardening methods include induction and electron beam (EB) hardening. Induction is restricted to fairly simple part shapes because of the need for specially-designed coils. But, for case depths greater than about 0.03 in., it is still the preferred method.

Both laser and electron beam hardening can produce complex hardening patterns and reach inaccessible areas. However, electron beam hardening equipment is more expensive, and the procedure more complex, because it must be done in a partial vacuum.

Laser surface hardening is used primarily in the automobile industry for parts such as gears, camshafts, cylinder liners, and power-steering gear housings. It is also used for selectively hardening parts of hand tools, such as saw teeth and hammer heads.

optical components in the laser, because they tend to deteriorate with time and use. They are usually replaced every 9-12 months at a cost of about $1500.

Maintenance is usually done by the system operators, who must learn to clean and align optical components and to service vacuum, NC and electronic systems. Laser manufacturers offer training courses, lasting from three days to three weeks, for system operation and maintenance. Local technical societies sometimes also have useful courses.

Competing Processes

Processes competing with laser cutting include conventional mechanical cutting and drilling, oxyacetylene, plasma arc and water-jet cutting, stamping and punching, and electric discharge machining (EDM). Some characteristics of the different methods are listed in Table 2.

Method	Material Thickness	Advantages	Drawbacks
Oxyfuel flame	Unrestricted	Low cost, easy to use, portable	Accuracy limit 0.03 in., fumes
Plasma arc	Up to 6 in.	Easy to use, fairly portable	Accuracy limit 0.03 in., fumes
Laser	< 0.5 in.	High speed and accuracy	High equipment and maintenance costs, materials restrictions, fumes
Water jet	Up to 6 in.	Can cut any material: wood, glass, stone, metals, food products	Needs settling tanks, cost and disposal of abrasive, tool wear
Fixed die stamping	< 0.5 in.	Lowest cost/piece for high volumes, can be very accurate	Edge distortion, requires fixed tooling, needs dies
Turret punch	<0.250 in.	General purpose tooling, accurate, reliable	Noisy, must "nibble" arcs
Wire EDM	Up to 4 in.	Most accurate, can cut irregular tapers, best for punches and dies	Slow

***Table 2.* Characteristics of Different Cutting Methods**

In Summary

With a laser cutting system a manufacturer is guaranteed quality cuts and high cutting rates in many different materials, both metals and nonmetals. A variety of parts can be produced with little lead time, since a new part requires only a new program to direct the cutter—and it is much faster to write a program than to make or wait for new tooling. This flexibility reduces inventory requirements and makes possible product and material diversification. With the increasing trend towards nonmetal parts, especially in automobiles, the ability to work with a range of materials is a definite competitive advantage. Laser systems also work well for selective hardening a variety of heat-treatable parts.

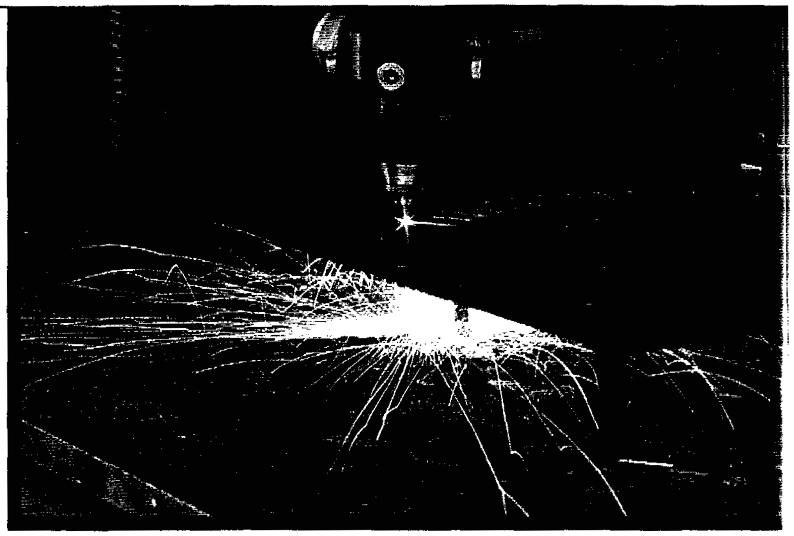
The information in this issue of TechCommentary gives you an overview of the capabilities of laser processing systems. If you think your company could use such a system, look at the sources used in this TechCommentary and talk with equipment vendors or job shop owners.

APPLICATION

Laser Cutting of Metal

Published by the Center for Metals Fabrication

Vol. 1, No. 6, 1987



Laser cutting of motor end plates offers increased flexibility to meet changing customer demands.

The Challenge: More Custom Parts at Reduced Costs

By finding an innovative way to decrease manufacturing costs, Westinghouse Canada, Inc., is now supplying a wider variety of electric motors to its customers but without the extra cost usually inherent in manufacturing small orders. In the spring of 1986 Westinghouse Canada, Inc., accomplished this feat by taking advantage of the expertise of a high-quality job shop and the flexibility of laser cutting to manufacture the end plates, an important motor component. Now it supplies electric motors tailored to a variety of specifications while actually reducing the manufacturing cost of machining short runs of end plates.

Westinghouse Canada, Inc., builds 150-600 horsepower motors that are used for pumps, blowers, and conveyors in a variety of industrial and commercial applications. Each application has somewhat different requirements, in terms of motor efficiency, torque, and full load speed. Different requirements result in different end plate designs but only a few of each design will be manufactured.

Westinghouse Canada, Inc., knew that to continue offering design flexibility and control costs it had to find a new manufacturing method that would:

- Cut the cost of tooling—a costly portion of short run end plate manufacture
- Require little capital investment
- Permit the manufacture of a variety of motor end plates out of thicker materials.

The Old Way

The cores of electric motors are made from a series of laminations, tightly bolted together by an end plate on either end. Made from 0.125- to 0.25-inch thick mild steel, the end plates add structural stability and prevent flaring of the thin laminations from which the motor is made.

Until 1970, Westinghouse Canada, Inc., made its motor end plates in a 3-stage stamping process, using a special, high-tonnage punch press and purchased tooling. In the first press, sheets of 0.125-inch thick mild steel were cut into circular blanks from 14 to 22 inches in diameter. A second press formed the slots in the end plates, and the final press cut the shaft and vent holes.

While each pressing operation took less than a minute, the turnaround time for an end plate was about a week, partly because it took approximately 3 hours to set up the punch press for each operation resulting in a 1- or 2-day delay between operations. In addition, tooling for each end plate design cost around $4000.

From 1970 to 1986 Westinghouse Canada, Inc., looked at a variety of solutions before it decided to turn to laser cutting. It tried brazing standard laminations together to create the end plate. While this was fairly quick in elapsed time, the process was labor intensive and thus expensive. Gas cutting the end plates was tried, but it was not accurate enough.

Glass banding was used to hold the laminations together instead of end plates, but this restricted the motor's ventilation. However, this process is still being used for larger motors.

The New Way: Work Together with an Innovative Job Shop

In 1986 Westinghouse's Buffalo plant found its cost-effective solution by switching to an entirely different method for making end plates. Instead of stamped or gas cut, the end plates are now laser cut.

Rather than investing in its own laser equipment, Westinghouse Buffalo chose to contract with Diversified Manufacturing, Inc., of Lockport, New York, a job shop experienced in laser cutting a variety of materials. This arrangement was so efficient that the technology has been transferred to the Westinghouse Canada, Inc., location. Now, Westinghouse Canada, Inc., engineers simply send Diversified a part drawing. From the drawing, Diversified takes about 4 hours to produce a CNC (Computer Numerical Control) tape for its 1.5 kW metal-cutting laser; it then cuts the parts.

Results: Lower Costs and a Diverse Product Line

Lower tooling costs. Instead of paying about $4000 for hard tooling for the punch press, Westinghouse Canada, Inc., now pays about $250 for the CNC tape.

Lower labor costs. Rather than punch press operators spending 5-6 hours setting up the presses, the laser cutter operators simply load the CNC tape, insert the end plate blank and start the machine. The actual cutting time is about 15 minutes per part.

Faster turnaround time. Diversified usually cuts the parts within a day of receiving the drawing because set up is minimal. For stamping, turnaround time was about a week, not including the time to build tooling.

Reduced capital investment. Westinghouse Canada, Inc., reduced the need for its high-tonnage punch presses. This also made floor space available for other uses.

Lower cost per part. A run of 25 end plates of 20-in. diameter are considerably cheaper using laser cutting:

	Cutting Cost			
	Per Part	25 Parts	Fixed Cost	Total Cost
Old Way	$12	$300	$4000 tooling	$4300
New Way	$32	$800	$ 250 CNC tape	$1050

The total cost per part has thus been reduced from $172 to $42.

Energy costs. Now that no tooling is required, the energy used to manufacture the tooling is conserved. In addition, the power to drive the punch press is also conserved. The total savings offsets the laser's energy use. By finding ways to decrease cost and increase quality, Westinghouse Canada, Inc., has improved its industrial competitiveness.

Fast design changes. Laser cutting enables Diversified to readily change designs for smaller runs. A new job is started by simply changing the CNC tape and inserting another workpiece. Minor design changes are easily made without additional charge to Westinghouse Canada, Inc. When Westinghouse Canada, Inc., calls with a rush job, it can be shipped within 48 hours.

What Did it All Cost?

Westinghouse Canada, Inc., would have had to spend about $250,000 for a laser and computer control if it had decided to buy one. The services of a job shop were much more economical, especially since Westinghouse Canada, Inc., had no other use for the laser. Westinghouse Canada, Inc., has avoided capital costs and has allowed production costs to be fully expensed as incurred.

The Bottom Line: A More Competitive Company, Better Able to Meet its Customers' Needs

Switching to laser cut end plates has put Westinghouse Canada, Inc., in a more flexible position to design motors which meet exactly its customers' specifications. For example, Westinghouse Canada, Inc., recently accepted an order for a new motor design, even though the customer wanted only 4 motors. Without laser cutting, each motor would have over $1000 in end plate costs alone.

Other Laser Applications

Lasers can cut a variety of thin materials. Laser cutting lends itself well to producing instantly-available prototypes, small production runs of precise parts, and rapid delivery of many different kinds of parts. For more information about laser cutting, see TechCommentary Vol. 3, No. 9.

Company Profile

Westinghouse Canada, Inc., Hamilton, Ontario

320 employees at site; 5500 in Westinghouse Canada

Company philosophy: Industrial achievements are made to happen by committed resourceful people who match vision and talent with the needs of the day.

Bohdan Solilo, Buyer, (above left) and Douglas Stafford, Product Specialist, of Westinghouse Canada, Inc., work together with Gary Brockman, Laser Operations Manager, (below left) and David Few, Sales Manager, of Diversified to supply quality electric motors.

The Center for Metals Fabrication (CMF) wishes to thank Grant Neal of Westinghouse Canada, Inc., and Gary Brockman of Diversified Manufacturing, Inc., for their valuable contributions to this TechApplication.

CMF is operated by Battelle's Columbus Division. Basic funding is provided by the Electric Power Research Institute, a nonprofit institute that conducts applications development on behalf of the United States electric utility industry. TechApplication is one of the ways the Center assists industry in implementing cost- and energy-efficient, electric-based technologies in materials fabrication and related fields. This issue was cofunded by a grant from the United States Department of Energy, Office of Industrial Programs.

Applicable SIC Codes
34 - 23, 62 **35** - 19, 31, 42, 46, 52, 66, 69, 99 **37** - 14, 28, 51 **38** - 43

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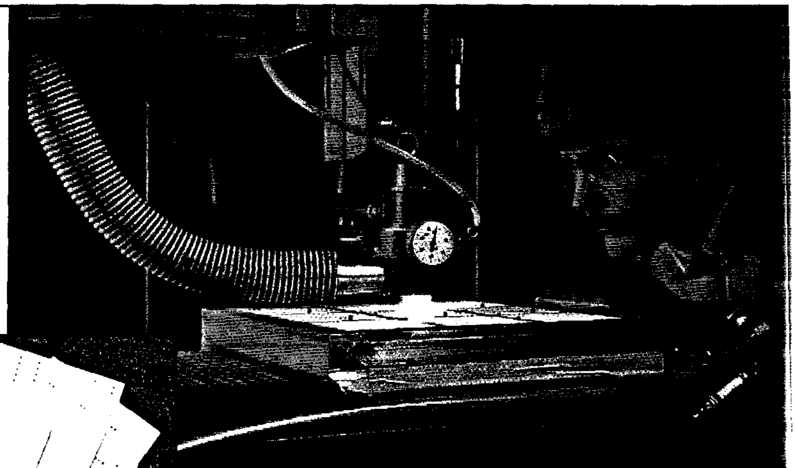
505 King Avenue
Columbus, Ohio 43201-2693
(614) 424-7737

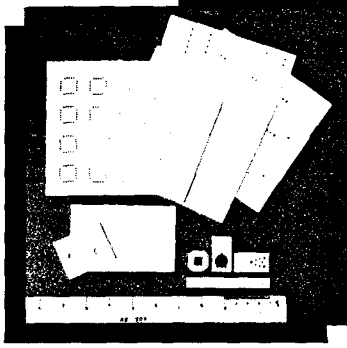
TechApplication Vol. 1 No. 6

APPLICATION

Laser Cutting and Scribing of Ceramics

Published by the Center for Metals Fabrication Vol. I, No. 5, 1987





The laser is an ideal tool for cutting sheets of ceramic substrate because it produces no mechanical stress. After the parts (left) are scribed and/or cut by DMI, the customer can solder wires to the electronic component and trim the part by snapping along the scribe lines.

The Challenge: Keeping Ahead of Customers' Tightening Specifications

The electronics industry is rapidly developing new uses for ceramic materials and demanding shapes that meet increasingly stringent specifications. A company that scribes and machines ceramics for the electronics industry hears a clear message from its customers: either meet the new specifications or get out of the business.

But Diversified Manufacturing, Incorporated, (DMI) of Lockport, New York, has no intention of getting out of a growing market. In 1986 when its current laser equipment could not make the higher quality cuts that customers were demanding, DMI opted to invest in a new laser system which could give:

- Faster scribing and deeper penetration
- Higher-quality machining with clean edges
- Better pulse control
- Improved equipment reliability and less downtime.

The Old Way

A customer would describe the needed design to DMI by a blueprint, a sketch or a phone call. DMI produced a CNC (computer numerical control) tape for its laser cutting system and then made the part. Lot sizes ranged from 1 or 2 prototype parts to production runs of thousands of parts.

The ceramic alumina sheet would be held in place on a computer-controlled XY table with a vacuum chuck. For scribing, the laser was pulsed on and off to produce a row of holes. A pulsed beam was also used for cutting.

DMI was using a 150 watt slow axial flow CO_2 laser (SAF) which had shortcomings including:

- The equipment needed to be recalibrated frequently, and tight specifications could not be met.
- A 2-hour daily start up.
- Uneven heating from the unstable beam sometimes caused microcracks on the machined edges.

Diamond cutting was an alternative technology to meeting customers' demand for high quality cuts. However, diamond blades wear out, and the process is slower and more expensive than laser cutting.

The New Way

Since a laser is the preferred tool for processing ceramics, DMI sought a replacement for its SAF CO_2 laser. Options were another SAF laser or one of the new, fast axial flow lasers (FAF) developed within the last 4 years.

The basic difference between SAF and FAF lasers is the amount of power that each can output. The FAF lasers can achieve higher output powers due to the way that each disposes of the excess heat that is a natural byproduct of lasing.

After consulting laser manufacturers, DMI purchased a 600 watt FAF CO_2 laser mainly because of its improved pulsed beam. In addition, a FAF laser was about 30% less expensive than a SAF laser which would have given the same cutting rate. Fortunately, DMI did not need to buy any new computer or support equipment. Thus, within 2 months of purchase, the new laser was in operation.

Results: Increased Production and Improved Quality

Fewer rejects. Scrap rate has been reduced from 10% to 0.5%.

Higher quality cuts. The laser beam is stable, so heat input to the workpiece is constant. Thus, microcracking is less of a problem.

Round, clean holes when scribing. Material is vaporized thoroughly, so there is no redeposition. And precise on-off gating of the high voltage discharge means sides of holes are perpendicular.

Even scribing. The pulse frequency of the new laser can be changed instantaneously ("on the fly") under computer control so decreasing the pulse rate to match a decreased table speed as it changes direction is no longer a concern.

Labor efficiency. Warm-up time for beam stabilization is now 10 minutes per day, and alignment only takes 10 minutes per week. Since less time is spent on start up, the staff can produce more parts.

Faster processing. Scribing rate has increased from 5 to 10 in./sec and cutting rate from 0.500 to 1.7 in./sec on 0.025-in. thick substrate.

Thicker substrates. DMI can now cut ceramic alumina up to 100 thousandths of an inch versus 50 thousandths with the old system.

Fast turnaround and flexibility. Because of the new laser's increased power and reduced maintenance requirements, DMI can quickly produce to its customers' specifications.

Lower production cost. Faster processing and decreased downtime mean a lower cost per part.

Space saving. DMI's new laser is 10% smaller than the old one and 10% of the size of a SAF laser of equivalent power.

Energy usage. With 1 hour for warm-up and 1 hour for beam alignment, the old SAF only could be productive 75% of an 8-hour day. A newer 600 watt SAF laser takes 20 minutes for warm-up and 30 minutes for beam alignment and could be productive 85% of the day. With 12 minutes for start up, the FAF laser could be productive 98% of the day.

The old SAF laser consumed 6 kW while both newer lasers consume 12 kW. Although the energy consumption doubled, the new scribing rate doubled and the cutting rate more than tripled. When combined with the overwhelming reduction in scrap rate and increased productivity, the overall energy usage per part was reduced tremendously.

Low operating expenses. Only a small volume of laser gases are required, and the small closed-loop system it uses minimizes gas consumption.

Improved safety. Because of design improvements, maintenance technicians are not exposed to the dangers of high voltage while adjusting the cavity mirrors.

New markets. With higher peak powers from the FAF laser, DMI can now scribe and drill a greater variety of substrates as well as new composite materials.

What Did it All Cost?

DMI's new laser cost about $70,000. A complete laser processing system, including an XY table and a control computer, would cost around $200,000. DMI expects a payback period of about 2 years on its new laser.

The Bottom Line

DMI's product quality now meets or exceeds that of its competitors, so there is no problem in meeting customers' increasingly stringent specifications, and business is increasing.

Other Applications of Laser Cutting

Laser cutting is not restricted to ceramics—lasers are also used to cut thin metals, paper, cloth and a variety of synthetic materials. You can find more information on laser cutting in TechCommentary Vol. 3, No. 9.

Company Profile

Diversified Manufacturing, Inc., Lockport, New York

President—Jack Tillotson
Vice President—Gordon Bald

Approximately 75 employees

A job shop with a broad range of capabilities in design and production. DMI uses lasers also for cutting metals and nonmetals, welding, heat treating, and drilling.

Company philosophy: We will accept any challenge.

Co-owners, Gordon (left) and Jack, continually diversify their manufacturing operations to meet the needs of a dynamic marketplace.

The Center for Metals Fabrication (CMF) wishes to thank Gary Brockman, DMI, and Scott White, Spectra-Physics, for their valuable contributions to this TechApplication.

CMF is operated by Battelle's Columbus Division. Basic funding is provided by the Electric Power Research Institute, a nonprofit institute that conducts applications development on behalf of the United States electric utility industry. TechApplication is one of the ways the Center assists industry in implementing cost- and energy-efficient, electric-based technologies in materials fabrication and related fields. This publication was cofunded by a grant from the United States Department of Energy, Office of Industrial Programs.

Applicable SIC Codes
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37—14,24,28,99 **38**—11 **39**—93

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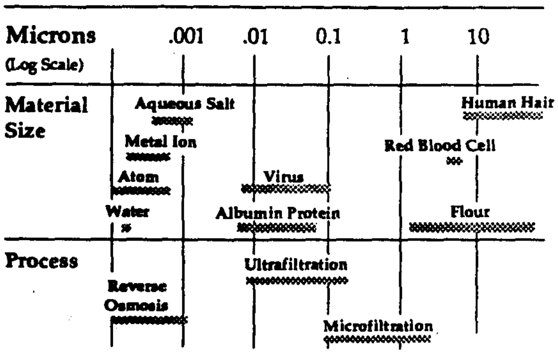
TechApplication/Vol. I/No. 5
Battelle Memorial Institute
Columbus, Ohio

Regulation Class: ◔ Clean Air ● Clean Water ◑ Haz. Waste ○ CERCLA ○ ______

Process Technology: *MEMBRANES*



THE FILTRATION SPECTRUM

Source: Osmonics, Inc.

Function/Theory

The membrane process uses a semi-permeable material to separate/concentrate compounds from a liquid feed stream. Electric pumps force liquid through the membrane. The components which are small enough to pass through the membrane are referred to as "permeates," and the larger particles that remain constitute the "concentrate." Membranes can be made of polymers, ceramics, or metals. There are three types of processes, determined by the size of the particles allowed the pass through the membrane:

Microfiltration: removes particles larger than .1 micron

Ultrafiltration: Filters particles as small as .001 microns

Reverse Osmosis: uses very small membrane openings, under .001 microns, along with very high pressure to pass nearly pure water through the membrane.

Selection Criteria/Considerations

Acceptance: ☑ High ☐ Medium ☐ Low

- Clarification of apple juice, beer and other beverages.
- Separation of whey and particulates from milk.
- Recovery of metal salts from waste streams and concentration of diluted oil for reuse in metal grinding, drilling, and cutting machines.
- Separation of pollutants in liquid stream in chemical processing, petroleum in waste water.
- Recovery of dyes, bleaches and other contaminants.
- Useful for thermally sensitive products.

Environmental Benefits

- No combustion by-products when replacing evaporation/distillation processes.
- Enables recirculation/reuse of process water.

Additional Benefits

- High separation efficiency.
- Continuous production capability.
- Requires much less room than evaporation columns, stills.
- Water can be stored and treated off-peak when electricity is less expensive.
- Non-thermal separation requires less energy than thermal separation such as steam evaporation or distillation.

Drawbacks

- High maintenance needs for membrane backflushing, which can slow down production.
- Capital cost of equipment.
- Cost of energy.
- High membrane replacement costs.
- Chemicals in water such as chlorine accelerate membrane deterioration, lowering the removal efficiency and shortening the membrane's life.

Waste Stream Reduced

Air		*Water*		*Solid*
☐ Particulates	☐ Organics	☑ Particulates	☑ Organics	☑ Hazardous
☑ CO_2, NOx	☐ Toxics	☐ Metals, Ions	☐ Oil	☑ Non-Hazardous

SIC Potential

◔ 25% ◕ 75% ◑ 50% ● 100%

Mining		
Metal	10	○
Coal	12	○
Oil & Gas	13	○
Mineral	14	○

Mfg.		
Food	20	◕
Tobac	21	○
Textile	22	◑
Apparel	23	◔
Lumber	24	○
Furn	25	○
Paper	26	◑
Print	27	○
Chem	28	◕
Petrol	29	◔
Rubber	30	○
Leather	31	◔
Stone, Glass	32	○
Metals	33	◔
Metals Fabric.	34	◔
Mach	35	○
Elect	36	◔
Trans	37	◑
Instru	38	◑
Misc.	39	◔

P-8

Typical System Example

Size: (5' x 4' x 4') to (50' x 15' x 8')
9 sq. ft. floor space to 60 sq. ft.

Energy Requirement: 2 - 250 kW
2 - 100 kW for concentration/clarification of various beverages in the Food Industry.

116.5 kW (155 hp) for 20 hrs and 86.25 kW (115 hp) for last 4 hrs. during cleaning in the Dairy Industry.

2 - 300 kW, depending on process and liquid flow rate for cleaning waste liquids in Fabricated Metals and Plastics.

Efficiency: 80%

Economics

Capital Cost: Ranges from $50,000 - $1,500,000, a very large system could cost up to $3.5 million. Typical dairy installation would cost $275,000 for equipment, and around $20,000 to prepare the site for installation.

Payback: 2.55 years

The payback is based on replacing a multi-effect steam evaporation/distillation process with a reverse osmosis system. Both systems are based on purifying 20,000 gallons/hr of brackish water with 20,000 part/million (1.5 - 2%) salt concentration.

Source: The UNIMAR Group, Ltd.

Service/Maintenance

Maintenance is dependent on the process. Generally, back flushing to clean clogged membranes every 60 - 100 hours. Replacement of membranes every 1 - 2 years.

Vendors

ACS Environmental

Dedert Corporation

Ionics, Inc.

Koch Membrane Systems, Inc.

Memtek

Niro Atomizer

Notes

Major Vendors

MEMBRANES

ACS Environmental
303 Silver Springs Rd.
Conroe, TX 77303
(409) 865-4515

Dedert Corporation
20000 Governors Dr.
Olympia Fields, IL 60461
(708) 747-7000

Ionics, Inc.
Water Systems Div.
65 Grove St.
Watertown, MA 02172
(617) 926-2500

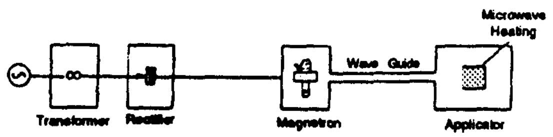
Koch Membrane Systems, Inc.
850 Main St.
Wilmington, MA 01887
(508) 657-4250

Memtek
28 Cook St.
Bellerica, MA 01821
(508) 747-7000

Niro Atomizer
1600 Country Rd. F
Hudson, WI 54016
(715) 386-9371

Regulation Class: ◑ Clean Air ○ Clean Water ○ Haz. Waste ○ CERCLA ○ ______

Process Technology: *MICROWAVE (DIELECTRIC)*



MICROWAVE HEATING SYSTEM

Source: Strayfield International

Function/Theory

Microwave drying and heating are variants of dielectric heating. Dielectric materials contain polar molecules that "vibrate/rotate" when "excited" by selected portions of the electromagnetic spectrum. The "excited" molecules create molecular friction (heat). Dielectric heating heats the material from the "inside out."

Selection Criteria/Considerations

Acceptance: ☐ High ☑ Medium ☐ Low

- Is effective in removing the last percentage of moisture from a product.
- Used when uniform drying at low temperatures is required.
- Tempering /thawing meats, pre-cooking and post-baking foods prior to packaging.
- Drying grains and nuts, partial dehydration of fruit.
- In the Plastics industry, used for preheating thermoset slugs (preforms) prior to forming, curing adhesives, bonding plastic pieces.
- Drying chemicals, yarn skeins, carpet, or finished wood products.
- Drying sand cores for foundry molds.
- Heating liquids, such as chemicals for reacting, dyes and coatings in textiles.

Environmental Benefits

- No combustion by-products as in fossil fueled ovens.

Additional Benefits

- Small space requirements.
- Adaptable to automation.
- Increased productivity due to rapid and uniform heating.

Drawbacks

- High capital costs.
- Limited number of high value added applications.

Waste Stream Reduced

Air		*Water*		*Solid*
☐ Particulates	☑ Organics	☐ Particulates	☐ Organics	☐ Hazardous
☑ CO_2, NOx	☐ Toxics	☐ Metals, Ions	☐ Oil	☐ Non-Hazardous

SIC Potential

◔ 25% ◕ 75% ◑ 50% ● 100%

Mining		
Metal	10	○
Coal	12	○
Oil & Gas	13	○
Mineral	14	○

Mfg.		
Food	20	◕
Tobac	21	◔
Textile	22	◑
Apparel	23	○
Lumber	24	◔
Furn	25	◔
Paper	26	◔
Print	27	◔
Chem	28	◔
Petrol	29	○
Rubber	30	◑
Leather	31	◔
Stone, Glass	32	◔
Metals	33	○
Metals Fabric.	34	○
Mach	35	○
Elect	36	○
Trans	37	○
Instru	38	○
Misc.	39	○

Typical System Example

Size: Ranges from 30" high x 12" deep x 24" wide to 72" high x 36" deep x 65 3/4" wide.

Energy Requirement:

5 - 100 kW for Food Processing applications.

Efficiency: 50%

Economics

Capital Cost: Rule of thumb: $3,000 - $4,000 per kW.

Payback: 1.51 years

The payback period is based upon replacing the final drying area in a gas convection oven with a post-drying dielectric unit. In this application, the through-put is increased by 15% using the dielectric unit to remove 250 lbs./hr. of moisture (remaining 12%) of bakery products.

Source: The UNIMAR Group, Ltd.

Service/Maintenance

Replace magnetron as required (2,500 - 10,000 hours) and routine cleaning of heating chamber.

Vendors

Berstorff, Inc.

Microdry

PSC, Inc.

Thermex-Thermetron, Inc.

Notes

Major Vendors

MICROWAVE

ABB Sanitec*
Wayne Interchange Plaza II
155 Route 46 West
Wayne, NJ 07470
(800) 551-9897

Berstorff, Inc.
P.O. Box 240357
Charlotte, NC 28224
(704) 523-2614

Microdry
7450 Highway 329
Crestwood, KY 40014
(502) 241-8933

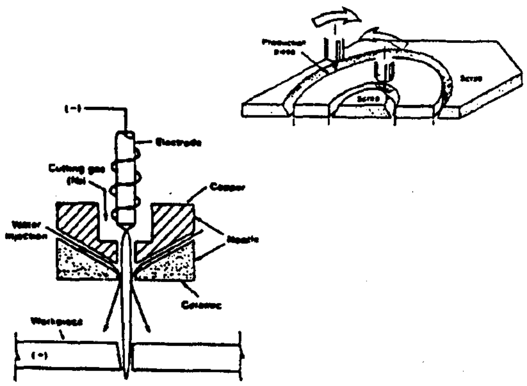
PSC, Inc.
21761 Tungsten Rd.
Cleveland, OH 44117
(216) 531-3375

Thermex-Thermetron, Inc.
60 Spence St.
Bayshore, NY 11706
(516) 231-7800

* for medical waste applications

Regulation Class: ◑ Clean Air ◔ Clean Water ◔ Haz. Waste ○ CERCLA ○ ______

Process Technology: *PLASMA ARC*



PLASMA ARC

Source: Philip S. Schmidt, Electricity and Industrial Productivity

Function/Theory

Plasma is an extremely hot, ionized or electrically conductive gas. The gas is first introduced to a torch, where a DC current is struck between the electrode and the torch tip. This current partially ionizes the gas, creating plasma, which passes through the torch to the workpiece.

Selection Criteria/Considerations

Acceptance: ☑ High ☐ Medium ☐ Low

- Plasma is used for very high quality welding of thin sections of metals or alloys.
- Fast, cost effective, and relatively accurate technology for cutting metal less than 1 inch thick.
- Used as the heat source for plasma incineration of waste in the chemicals industry (profile elsewhere).
- Plasma heat source furnaces used for melting in foundries.

Environmental Benefits

- Self quenching so no waste oil.
- No combustion by products as generated with fossil energy sources.
- Reduced reject rate, resulting in less process waste.

Additional Benefits

- Increased efficiency and productivity due to close tolerance and clean cutting at higher speeds than oxyfuel cutting.
- Can be automated.
- Able to cut a wide range of materials and thicknesses up to 6" thick, but more economical for thicknesses less than 1".
- Minimal training required.
- Faster than laser cutting.

Drawbacks

- High capital equipment costs.
- Plasma cutting is loud, messy, and creates fumes; however, underwater cutting is often used to minimize these effects.
- Cannot cut as precisely as LASER, although "high definition" plasma is approaching LASER capabilities.

Waste Stream Reduced

Air		*Water*		*Solid*
☐ Particulates	☑ Organics	☐ Particulates	☐ Organics	☐ Hazardous
☑ CO_2, NOx	☐ Toxics	☐ Metals, Ions	☑ Oil	☑ Non-Hazardous

SIC Potential

◔ 25% ◕ 75% ◑ 50% ● 100%

Mining

Metal	10	○
Coal	12	○
Oil & Gas	13	○
Mineral	14	○

Mfg.

Food	20	○
Tobac	21	○
Textile	22	○
Apparel	23	○
Lumber	24	○
Furn	25	◑
Paper	26	○
Print	27	○
Chem	28	○
Petrol	29	○
Rubber	30	◔
Leather	31	○
Stone, Glass	32	○
Metals	33	◔
Metals Fabric.	34	◕
Mach	35	◑
Elect	36	◑
Trans	37	◑
Instru	38	◔
Misc.	39	◔

Typical System Example

Size: Hand-held tool to a full-size piece of equipment, which is smaller than those used by more conventional technologies.

Energy Requirement:

20 - 300 kW in cutting, joining and heat treating.

100 - 5,000 kW in waste treatment and melting.

Efficiency: 40 - 80%

Economics

Capital Cost: $1,200 - $40,000, although accompanying automation system can cost up to $350,000 (cutting, joining, heat treating). $50,000 - $2,000,000 (waste treatment, melting).

Source: The UNIMAR Group, Ltd.

Service/Maintenance

Part replacement is typically every 4-8 hours if using nitrogen as the cutting gas. The nozzle and electrode may need to be replaced every 1 - 2 hours if using an air plasma system. Replacement time is generally less than 5 minutes. Ion processes work in a vacuum and require standard vacuum seal maintenance.

Vendors

Thermal Dynamics

Weldcraft Products, Inc.

Notes

Major Vendors

PLASMA ARC

Thermal Dynamics
Industrial Park #2
West Lebanon, NH 03784
(603) 298-5711

Weldcraft Products, Inc.
119 E. Graham Pl.
Burbank, CA 91502
(818) 846-8181

EPRI Techcommentaries

Plasma Arc

Plasma Arc Cutting, EPRI CMF TechCommentary, Vol.4, No. 5, 1987
Plasma Cutting, EPRI CMF TechApplication, Vol.1, No. 14, 1987

TECHCOMMENTARY

PLASMA ARC CUTTING

Published by the EPRI Center for Materials Fabrication Vol. 4, No. 5, 1987

Lightning Fast Metal Cutting

Plasma arc cutting can increase the speed and efficiency of both sheet and plate metal cutting operations. Manufacturers of transportation and agricultural equipment, heavy machinery, aircraft components, air handling equipment, and many other products have discovered its benefits. The high-temperature plasma arc cuts through a wide variety of metals at high speeds. Although plasma arc cutting can cut most metals at thicknesses of up to 4 to 6 in., it provides the greatest economical advantages, speed, and quality on carbon steels under 1 in. thick and on aluminum and stainless steels under 3 in. thick.

Plasma arc cutting has gained approval in both hand-held and automated cutting operations. This *TechCommentary* focuses on the advances in automated systems. Advances in computer numerical controls (CNC), robots, and other automation have encouraged manufacturers to take advantage of the high cutting speeds attainable with plasma arc cutting. Improved torch designs and more efficient power supplies have made plasma arc cutting an increasingly popular choice for cutting metal.

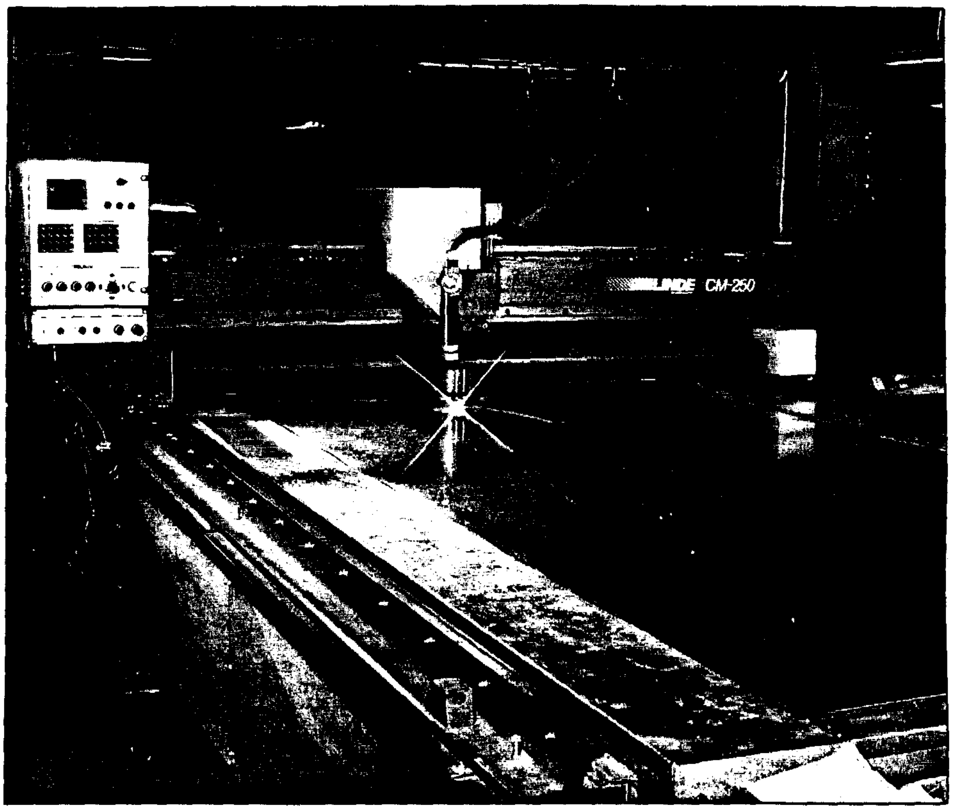


***Figure 1.* Automated plasma arc cutting systems increase efficiency and productivity for cutting duct work.**

Advantages

Automated plasma arc cutting systems provide several advantages over other cutting methods such as oxyfuel and laser.

Rapid cutting speeds — Plasma arc cutting is faster than oxyfuel for cutting steel up to 2 in. thick and is competitive for greater thicknesses. Plasma cutting achieves speeds greater than those of laser cutting systems for thicknesses over ⅛ in. CNC controls allow speeds of up to 500 in. per minute (ipm) to be achieved on gauge thicknesses. These fast cutting speeds result in increased production, enabling systems to pay for themselves in as little as 6 months for smaller units.

Wide range of materials and thicknesses — Plasma cutting systems can yield quality cuts on both ferrous and nonferrous metals. Thicknesses from gauge to 3 in. can be cut effectively.

Easy to use — Minimal training is required for plasma cutting. The torch is easy to operate, and new operators can make excellent cuts almost immediately. Plasma cutting systems are rugged, are suitable for production environments, and do not require the complicated adjustments associated with laser cutting systems.

Economical — Plasma cutting is more economical than oxyfuel for thicknesses under 1 in., and costs are comparable up to about 2 in. For example, for ½-in. steel, plasma cutting costs are about half those of oxyfuel.

Plasma cutting is compared in detail with laser and oxyfuel in Table 1.

Applications

Plasma cutting's high speeds and versatility make it attractive to manufacturers cutting metals in pro-

***Table 1.* Comparison of Plasma Arc Cutting with Competing Processes**

	Plasma Arc	Laser	Oxyfuel
Material type	Most metals	Most metals and many nonmetals	Limited to metals that oxidize easily
Material thickness, in.	Up to 6	Under 0.5	Unlimited
Equipment costs, $	1,200–40,000	100,000–500,000	1,000–5,000
Cutting speed, ipm	200	75	25
Kerf width,* in.			
Top	0.27	0.010	0.10
Bottom	0.08	0.010	0.05
Amount of bevel,* deg	2–4	<1	<1
Tolerance,* in.	0.03	0.001	0.06
HAZ,* in.	0.03	0.01	0.1

* Comparisons made on ¼-in. steel.

duction environments for both sheet and plate thicknesses. Automated systems are often used to increase the speed and accuracy of cuts, reduce scrap, and gain more control over the cutting operation.

Automated plasma cutting systems are being chosen over oxyfuel, hand tools, and lasers in the following areas:

Sheet metals — Plasma cutting is commonly used to cut sheet metals from 24 gauge up to ⅛ in. thick at high speeds on carbon steels, aluminum, and stainless steels. Plasma cutting is widely used in the transportation industry to form the outer skins of tractor trailers, buses, and agricultural equipment. Plasma cutting systems are also used in the heating, ventilating, and air conditioning industry to cut complex duct work.

Plate thicknesses — Industries involved in cutting plate thicknesses also find many applications for plasma cutting. Plasma systems cut plate thicknesses from ⅛ to 3 in., but the most common applications are for carbon steel plate ¼ to ¾ in. thick. Steel service centers cut large plates of steel down to size with plasma. Makers of large construction machinery, mining equipment, and material handling equipment utilize plasma cutting to produce cranes, bulldozers, and other large equipment. Plasma cutting also produces structural steel framework for railroad cars, trucks, and other heavy equipment. Other applications include cutting metal for ship building and the production of pressure vessels.

Other applications — Plasma cutting is not limited to flat sheets of metal. Plasma torches placed on robots are being used increasingly for contour cutting of pipes and vessels, removal of sprues and risers from castings, and cutting of formed shapes, angles, and curves in various planes.

Technical Considerations

Although plasma cutting is desirable for many metal-cutting applications, you must analyze your specific application before choosing a cutting method. This decision depends primarily on the material you are cutting, its thickness, the cutting speeds desired, and the cut intricacy and quality.

Material type — Carbon steels, aluminum, and stainless steels are most commonly cut with plasma arc. Many other metals may be cut with plasma including nickel alloys, brass, bronze, tungsten, copper, cast iron, titanium, and zirconium.

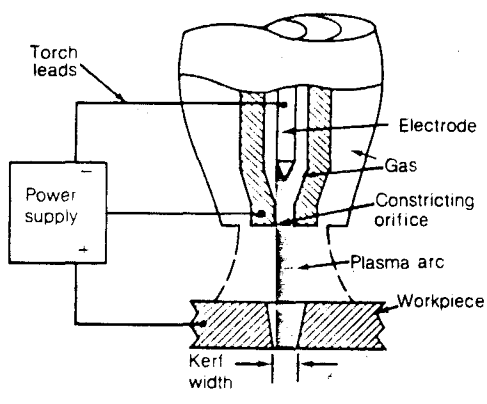
Material thicknesses and cutting speeds — Workpiece thickness determines whether plasma's cutting speeds will be cost effective for your application. However, the maximum cutting speed depends not only on thickness but also on power supply and material type. Figure 2 illustrates representative cutting speeds on

plasma is an ionized or electrically conductive gas. Plasma arc cutting utilizes the extremely high temperature of a constricted electric arc in the form of a high-velocity plasma jet to melt metal and expel it from the cut.

The basic process begins by introducing a gas into the torch. Imposing a small dc current between the electrode and the tip of the torch creates a pilot arc. The pilot arc partially ionizes the gas, creating a plasma that passes through the torch. This plasma establishes a path for the main arc, which is struck between the electrode and the workpiece. The combined main arc and pilot arc are forced through a constricting nozzle orifice, increasing the temperature and power density of the plasma jet. The plasma jet heats the metal workpiece to its molten state, and the high velocity and momentum of the plasma expel the metal from the cut.

The equipment needed for plasma arc cutting includes a power supply, a torch, torch leads (which carry the current from the power supply to the torch), and cutting gases. Automated systems also require a motion control device, a cutting table, and a control console. Plasma arc systems can be placed on almost any type of motion device, from simple *X/Y* machines to complex computer-controlled equipment that controls several torches at once.

Schematic of plasma arc cutting equipment



various thicknesses of aluminum, stainless steels, and carbon steels.

Cut quality — Cut quality is affected by type of metal and cutting speed. Process variables, such as cutting gas, power, and cutting speed are adjusted to provide the optimum cut for each metal type. Although the size of the power supply is also a factor, cuts in metals up to 2 in. thick tend to be smooth while cuts in thicker sections may be rougher but still clean.

Cutting specifications — For applications where high-quality cuts are needed, you should determine your requirements for

- Tolerances
- Amount of bevel
- Dross
- Heat-affected zone.

Plasma cuts to closer **tolerances** than flame processes like oxyfuel because the faster cutting speeds heat the workpiece less, resulting in less distortion. Plasma is capable of tolerances to 1/32 in. in materials under 1/2 in., but the tolerances achieved depend on material type, thickness, and power supply.

Plasma cutting produces a **beveled cut,** forming a wider cut at the top of the workpiece than at the bottom. The bevel can easily be corrected or reduced with special techniques or equipment. Generally the amount of bevel is less for thinner materials.

The amount of **dross** or oxidation on the surface of the workpiece depends mainly on cutting speed, type of gas, and arc voltage. Using the manufacturer's guidelines for these variables can produce dross-free cuts.

The high speeds of plasma cutting minimize the amount of distortion and **heat-affected zone** (HAZ). HAZ width is affected by material type and thickness, conductivity, and torch design.

Cutting gases — The cutting gas selected depends on the speeds and quality of cut desired. Several cutting gases can be used in a plasma system to improve cut quality and speed. Nitrogen is widely used because it is relatively inexpensive and can be used on many materials and thicknesses. Special mixtures of argon and hydrogen can improve cutting speed and quality on thicker metals and those other than carbon steels. Oxygen is used in combination with other gases to improve cut quality by increasing heat, improving cutting speed, and/or reducing power requirements. Compressed shop air is popular for many applications

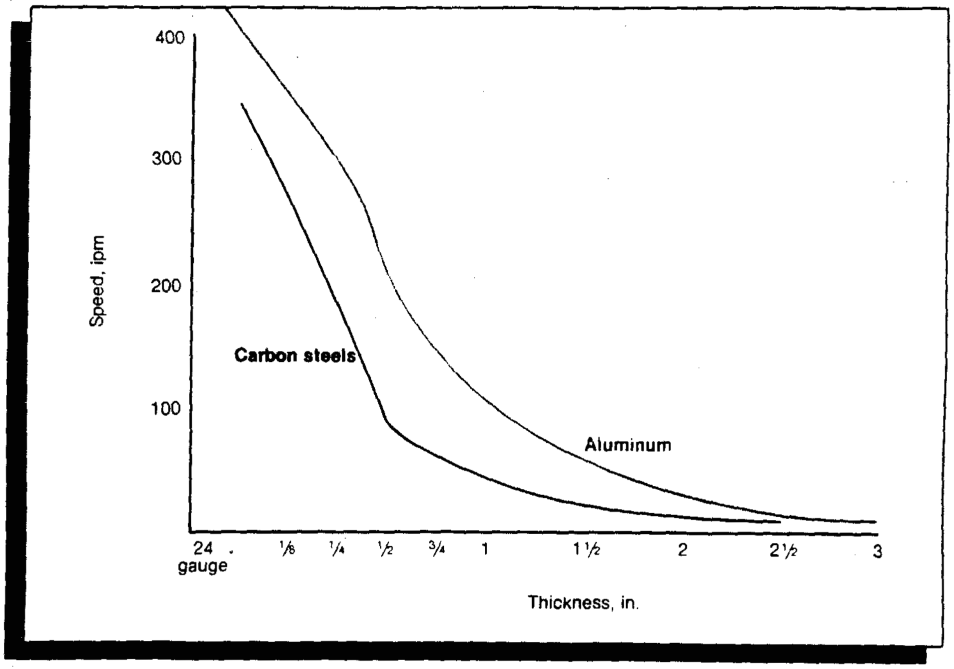


Figure 2. **Plasma arc cutting speeds on various thicknesses of aluminum, stainless steels, and carbon steels.**

because it is inexpensive and provides good quality cuts on thicknesses under 1 in., especially on carbon steels.

Power supply — The power supply required depends on the material thickness and cutting speeds desired. Increasing the power increases the cutting speed or enables thicker metals to be cut without slow down. Power ratings, commonly between 20 and 200 kW, are listed in Table 2.

Environmental concerns — Ultraviolet radiation, particle matter, and noise are hazards of plasma arc cutting, but these are manageable with the proper equipment. Water is often used to control these hazards, in the form of a water table, a water muffler, or underwater cutting. One of these devices is recommended for most automated applications.

Economic Considerations

When considering the cost of a cutting system, you must evaluate capital, operating, and maintenance costs.

Capital costs — Equipment needed for plasma cutting includes a power supply, torch, and torch leads. Table 2 compares costs of several plasma cutting systems. Equipment costs are greater than for oxyfuel cutting but are offset by the ability to cut aluminum and stainless steels and to achieve high speeds on carbon steels.

Additional equipment needed to automate a cutting operation can range from $3000 for a simple *X/Y* machine to $350,000 for an entire automated system.

Operating costs — Operating costs for plasma cutting on 1/4-in. steel are approximately 7 cents per foot. This includes power costs, labor costs, and the cost of plasma gases.

The nozzle and the electrode in the plasma torch are consumed in the cutting process. The life of these parts varies greatly. When using nitrogen as the cutting gas, part replacement is typically required every 4 to 8 hours of arc time. For air-plasma systems, the nozzle and electrode may need to

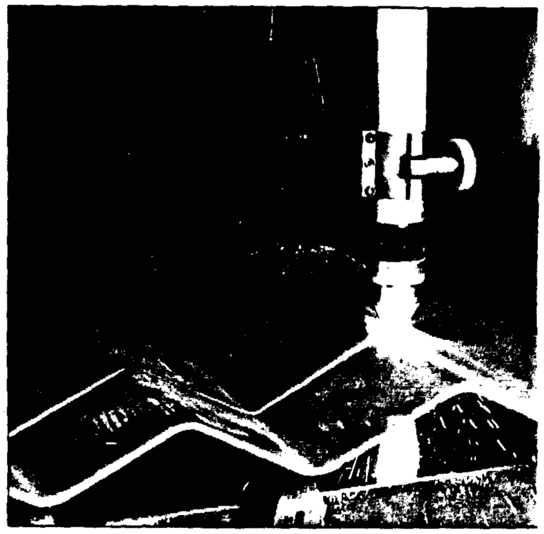


Figure 3. **Plasma arc systems can cut contours and uneven surfaces at high speeds.**

be replaced approximately every 1 to 2 hours of arc time. The cost of these replacement parts is typically under $15 for low-power, 40-amp systems and up to $40 for high-power, 1000-amp systems. Replacement parts can be installed in minutes by the operator.

In Conclusion

New areas of technology in plasma arc cutting systems are constantly being explored. One area of development includes nontransferred arc plasma, which allows plastics and other nonconductive materials to be cut. Research on cutting plastics is continuing and at least one commercial process is currently available.

The use of plasma arc cutting systems under CNC controls likely will increase as more manufacturers turn to computers to automate production and track the flow of materials through their operation. High cutting speeds, flexibility, and ease of use continue to increase plasma arc cutting's popularity.

The information in this issue of *TechCommentary* gives you an overview of the capabilities of plasma arc cutting systems. If you think your company could use such a system, talk with your electric utility marketing representative, equipment vendors, or job shop owners. A specific plasma arc cutting application is detailed in *TechApplication* Vol. 2, No. 14.

Table 2. **Cost Comparison of Various Sizes of Plasma Arc Cutting Systems**

Power, kW	Power Supply, amps	System Cost,* $	Maximum Cut Thickness,** in.
4.6	20	1,200	$\frac{3}{16}$
20	100	5,000	1
80	400	14,000	3
200	1000	30,000	6

* Includes torch, torch leads, and power supply.

** On steel, stainless steel, and aluminum.

and-held plasma arc cutting systems are useful for many applications, both in job shops as a production tool and on site for repair and maintenance. These units provide an effective cutting method for metals from gauge to 1 in. thick. Applications include

- Plant maintenance to install new equipment and make repairs and modifications to existing plant facilities
- Autobody repair to remove spot welds, remove damaged parts, and cut new pieces to fit
- Duct work for heating and air conditioning to adapt new fittings
- Job shop environments for low-volume production.

Hand-held plasma arc units range in size from 20-amp systems that can cut metals up to $\frac{3}{16}$ in. to 100-amp systems that can be used for both hand-held and automated applications for cutting metals up to 1 in. thick. The systems are relatively inexpensive—as low as $1200, have low power input requirements, and usually use inexpensive compressed air as the cutting gas. Where once air chiseling, shearing, or nibbling was required, plasma arc cutting now greatly improves cutting speed and accuracy.

The EPRI Center for Materials Fabrication is operated by Battelle's Columbus Division. Basic funding is provided by the Electric Power Research Institute (EPRI), a nonprofit institute that conducts research and development on behalf of the United States electric utility industry.

The Center's mission is to assist metals, plastics, ceramics, and composites fabricators in implementing cost- and energy-efficient, electric-based technologies. *TechCommentary* is one communication vehicle that the Center uses to transfer technology to industry through an electric utility network. The Center also conducts applications development projects that demonstrate innovative uses of electrotechnologies.

This issue of *TechCommentary* was made possible through the cooperation of Jack Barton and Roger Wertz, Hypertherm; Don Domina and Steve Corbeil, Thermal Dynamics Corp.; and Harvey Castner, Edison Welding Institute.

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Photos courtesy of R.W. Mead and Thermal Dynamics Corp.

Applicable SIC Codes
16—29 **34**—33, 43, 44, 89, 94, 99
35—11, 23, 24, 33, 37, 49, 64, 67, 85, 99
36—21, 99 **37**—21, 24, 28, 31, 95

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APPLICATION

Plasma Cutting

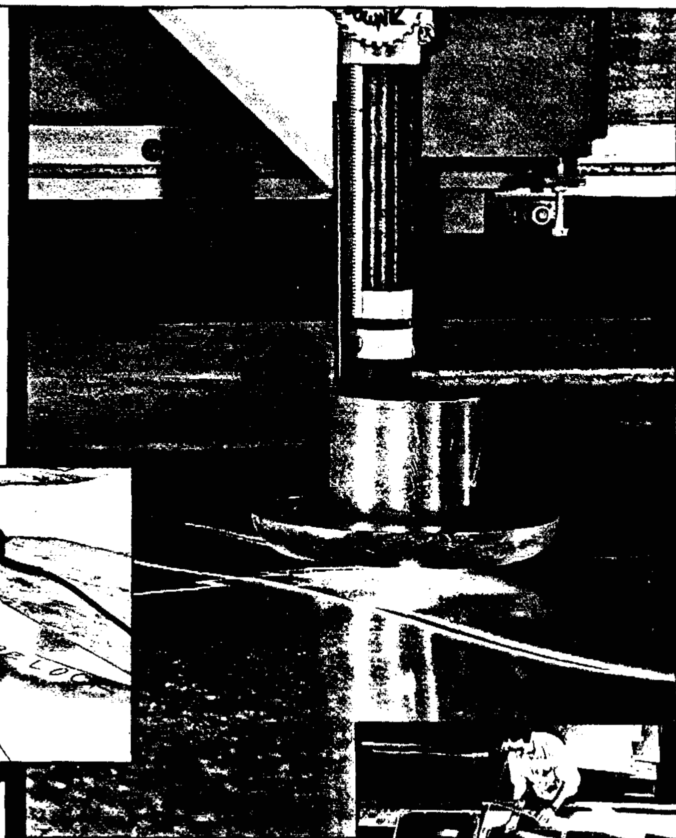
Published by the EPRI Center for Materials Fabrication Vol. 1, No. 14, 1987

The Challenge: Computerize a Duct-Making Operation

At the heart of R. W. Mead's heat and air duct manufacturing operation is a computer-controlled plasma cutter that lays out and cuts sheet metal into duct work fittings faster than Mead's field crews can install them. Vice President of Construction Mark Mead was able to computerize his entire operation when this plasma cutter went into production in 1986. And by computerizing the entire operation, Mead has improved efficiency and productivity manyfold.

Mead's shop was having trouble keeping the field crews supplied with cut materials. Therefore, Mark Mead sought a solution that would

- Increase output from the shop floor
- Reduce part handling
- Be more responsive to workload demand
- Streamline Mead's entire operation.



Fittings used to be cut by hand, a slow and wasteful process.

The plasma cutter works on 1 of 2 tables to cut parts to exact specification. The parts layout is very efficient, significantly reducing the scrap rate.

The Old Way

Mead manufactures and installs heat and air conditioning ducts for commercial, industrial and residential buildings. When Mead receives a request from a general contractor, one of its field engineers goes to the building to confirm the measurements and sketch out the duct work.

Before its new system was installed, an engineer would take the field sketches, design the system and create part drawings. After the dimensions were confirmed in the field, the part drawings would be sketched onto the sheet metal and the parts cut with hand tools such as electrically powered sheers, slitters and snips. This was slow, difficult work with danger from burrs and sharp edges. In an effort to maximize material usage, usable pieces of scrap would be sorted into piles and scavenged when smaller pieces needed to be cut.

The cut parts would then be assembled and shipped to the job site where field crews would install the duct work. Sometimes, because of errors in part layout and design, a fitting did not come together properly and a new part was needed. This slowed down installation.

The New Way

Today, field data is entered into Mead's CAD/CAM system. The part drawing is created electronically by adding dimensions to a part shape stored in the computer's memory, thus freeing the designer from tedious calculations and eliminating human errors. All the parts for the day's cuttings are entered before cutting begins, and the system specifies what size sheets are needed.

The computer-controlled plasma cutter then cleanly cuts the parts to within a pencil line of exact specifications, much more rapidly and accurately than is possible with hand tools. And the plasma cutter can make longitudinal and transverse cuts with equal ease. The computer-generated layout is so efficient that the scrap material now resembles ribbons and wires and is discarded. In addition, labels are generated that are affixed to the parts for identification by part number, size and application, as well as for sorting and tracking of cost estimates.

Without a way for the computer to control the cutting, most of the benefits of the CAD system would be lost. The plasma cutter is rugged and simple to operate, making it well-suited for the shop-floor environment. Lasers could be used to cut the metal, but they do not have the necessary durability. Lasers were not considered for this job because of their expense and their cutting precision far exceeds that needed for duct work.

The Results: More Versatility and Increased Productivity

The benefits from the plasma cutter and computerized operation are many:

Labor efficiency. Previously, 3 or 4 workers generated work for 30 installers. Now 2 workers in the shop generate work for up to 50 in the field. And no worker spends time sorting through piles for usable scrap.

Material savings. The capability of the computer-controlled cutter to nest parts has resulted in a decrease in scrap rate from about 20% to 10%.

Increased production. The plasma cutter can work off 2 parallel tables. While it is cutting a sheet of metal on one table, the other table can be set up and the cutter can be in use continuously.

Cutting rates have been increased from 15 to 20 fittings per day per worker to as high as 250 fittings per day for 1 worker using the plasma cutter.

Fewer rejects. The plasma cutter has abolished human cutting errors so rejects have almost totally been eliminated.

Energy costs. Although more energy is used with the plasma cutter, productivity has greatly increased. This added industrial competitiveness strengthens Mead's position in the marketplace.

Product improvement—New product line. The plasma cutter has increased the gauge of metal that can be cut from less than ⅛ inch to ¼ inch.

Production flexibility. Now Mead handles at least 4 or 5 jobs at one time.

Process control. Since a job's price depends on the weight of the metal installed, Mead used to weigh the parts by hand. Now the computer calculates the weight of the job automatically.

What Did It All Cost?

Mead's 2-table system cost about $100,000 installed. An exhaust system and installation added another $30,000. Mead incurred some additional expenses to make its floor level, a requirement it was unaware of when it purchased the system.

The payback period was about a year. It took 3 workers a week to assemble and install the system. Training took 2 days.

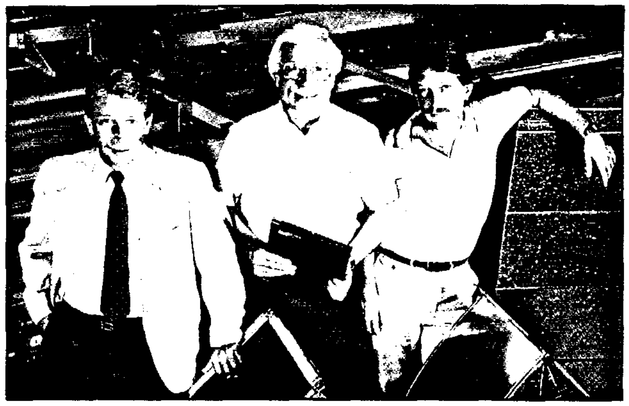
The Bottom Line: An Efficient, Versatile Operation

Mead workers are versatile and can work in the shop cutting out and fabricating parts or in the field. Now because of the plasma cutter more workers are out in the field and Mead can more quickly respond to customer needs.

Other Applications of Plasma Cutting

Plasma cutters are used in place of traditional sawing, drilling, machining, punching, and cutting. A computer-controlled plasma cutter is capable of consistently cutting to close tolerances a variety of metals into many geometric shapes.

Company Profile



Vice President of Construction Mark W. Mead, President Robert W. Mead, and Vice President of Service Richard M. Mead computerized their operation to improve productivity.

R. W. Mead & Co., Fraser, Michigan
President—Robert W. Mead
Approximately 70 employees
R. W. Mead is a complete heating, ventilating, and air conditioning contracting company
Company philosophy: To be the best in the industry.

The Center for Materials Fabrication wishes to thank Detroit Edison Company, which provides electric service for R. W. Mead and Co., for valuable contributions made to this issue.

CMF is operated by Battelle's Columbus Division. Basic funding is provided by the Electric Power Research Institute, a nonprofit institute that conducts applications development on behalf of the United States electric utility industry. *TechApplication* is one of the ways the Center assists industry in implementing cost and energy-efficient, electric based technologies in materials fabrication and related fields. This issue was cofunded by a grant from the United States Department of Energy, Office of Industrial Programs.

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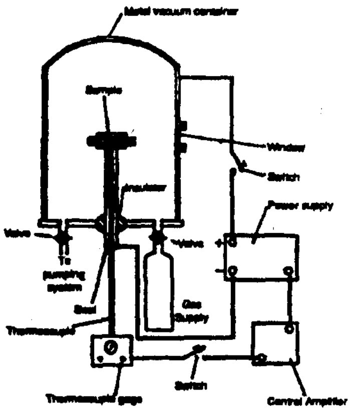
Process Technology: *PLASMA NITRIDING*



PLASMA NITRIDING

Source: ASM (Heat Treating Source Book)

Function/Theory

Plasma nitriding is also called "ion nitriding" and "glow discharge nitriding". Nitrogen gas introduced into a vacuum chamber is ionized by a DC. voltage. The workpiece becomes the "cathode" and the vacuum chamber walls the "anode." The workpiece is surrounded and bombarded by ionized gas, creating a purple glow. Nitrogen is absorbed by and diffused into the workpiece surface. The kinetic energy of "ion bombardment" heats the workpiece; sometimes additional heating used.

Selection Criteria/Considerations

Acceptance: ☐ High ☑ Medium ☐ Low

- Used for treating high value added, high reliability parts (e.g. transmission parts, reduction gears, hot-forging dies) requiring extremely hard, uniform, denser surfaces with "hard" layer ductility.
- Effective with complicated workpiece geometries.
- When batches of mixed/varied workpiece sizes and shapes must be treated together.

Environmental Benefits

- No combustion by-products usually associated with fossil furnaces.
- Eliminates hazardous waste salts from other types of heat treating.

Additional Benefits

- Shorter processing times at lower temperatures than conventional nitriding.
- Denser/harder surfaces than obtained with conventional nitriding/carbonitriding methods.
- Microprocessor controlled.

Drawbacks

- High capital costs.
- Vacuum chamber required.
- Fixturing and set-up time longer than competitive process (gas nitriding).
- Impracticality of liquid quenching (Heat Treating).
- Requires clean, smooth, workpiece surface for effective heat treating.

Waste Stream Reduced

Air

☐ Particulates ☑ Organics
☑ CO_2, NOx ☐ Toxics

Water

☐ Particulates ☐ Organics
☐ Metals, Ions ☐ Oil

Solid

☑ Hazardous
☐ Non-Hazardous

SIC Potential

◔ 25% ◕ 75% ◑ 50% ● 100%

Mining

Metal	10	○
Coal	12	○
Oil & Gas	13	○
Mineral	14	○

Mfg.

Food	20	○
Tobac	21	○
Textile	22	○
Apparel	23	○
Lumber	24	○
Furn	25	○
Paper	26	○
Print	27	○
Chem	28	○
Petrol	29	○
Rubber	30	○
Leather	31	○
Stone, Glass	32	○
Metals	33	◔
Metals Fabric.	34	◑
Mach	35	◑
Elect	36	◔
Trans	37	◕
Instru	38	◑
Misc.	39	◔

Typical System Example

Size: Varies by application.

Energy Requirement:

25 - 400 kW, depending on the chamber size.

80 - 200 kW, typical, heat treating.

Efficiency: 70 -80% for heat treating

Economics

Capital Cost: $100,000 - $1,000,000 range for 50 to 500 kW sizes.
$200,000 to $400,000 typical for 80 -200 kW sizes heat treating.

Payback: 1.60 years

The payback is based on replacing a conventional electric-fired nitriding salt bath with a plasma (ion nitriding) heat treating system. The application using either system is for hardening 1000 lb. batches of steel parts for a depth up to .020."

Source: Plasma Energy Corp.

Service/Maintenance

Vacuum chamber seals require periodic replacement.

Vendors

Abar Ipsen Industries

Metal Plasma Technology

Surface Combustion

Notes

Major Vendors

PLASMA NITRIDING

Abar-Ipsen Industries
905 Pennsylvania Blvd.
Feasterville, PA 19047
(215) 355-4900

Metal Plasma Technology
7950 Georgetown Rd.
Suite 300
Indianapolis, IN 46268
(317) 875-7380

Surface Combustion, Inc.
1700 Indian Wood Circle
Maumee, OH 43537
(419) 891-7150

EPRI Techcommentaries

Ion Nitriding
Ion Nitriding, EPRI CMF TechCommentary, Vol.2, No. 5, 1985
Ion Nitriding Injection Molds, EPRI CMF TechApplication, Vol.1, No. 13, 1987

TECHCOMMENTARY
ION NITRIDING

Vol. 2, No. 5, 1985 Published by the Center for Metals Fabrication

IMPROVE METALLURGICAL PROPERTIES AND INCREASE PRODUCTIVITY USING ION NITRIDING

Heat treaters use a number of surface hardening processes to enhance the wear and fatigue resistance of metal components. The most popular are carburizing and nitriding. In carburizing, carbon is diffused into the surface layers of the workpiece using a special atmosphere or a pack of carbonaceous material in a high-temperature furnace. Similarly, in nitriding, the workpiece surface is alloyed with nitrogen. Conventionally this has been done in an ammonia atmosphere or a special nitrogen-containing salt bath.

A welcome innovation has been ion nitriding which offers many advantages over conventional processes. Ion nitriding produces **more uniform cases**, enables the operator to exercise **greater control** over the process, and is **cost effective**.

This issue of TechCommentary describes the basic concept and advantages of ion nitriding as well as technical and economic factors to consider when deciding if the process could benefit a particular application or product.

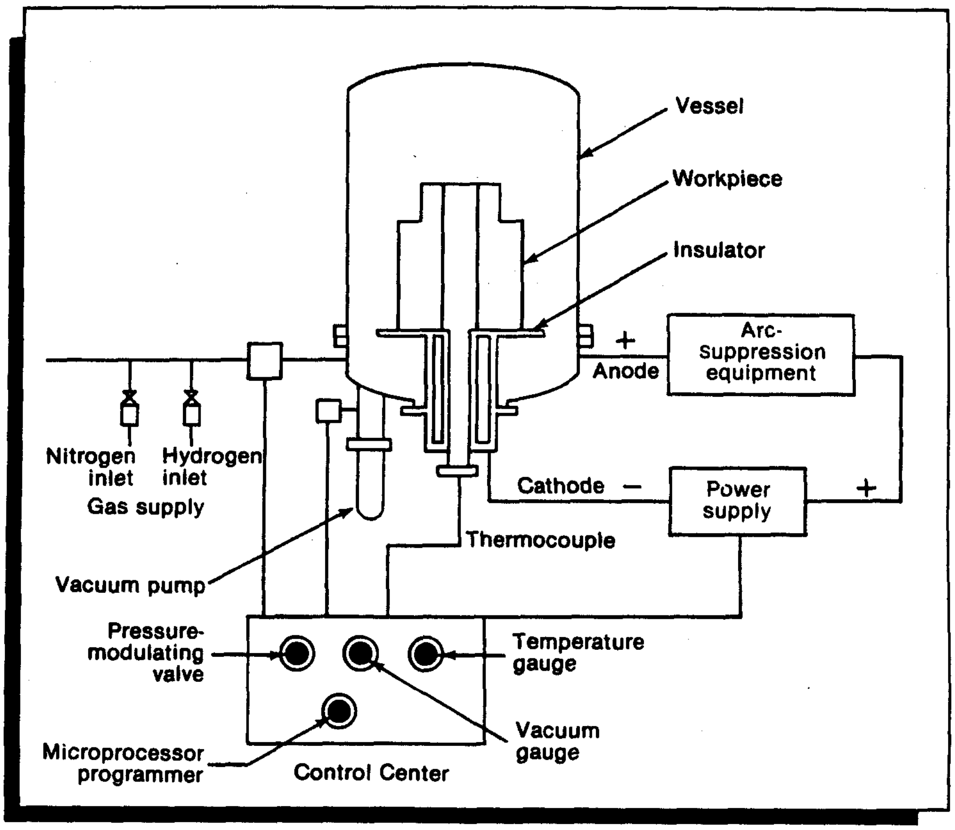


Figure 1. **Schematic arrangement of an ion-nitriding system.**

The Process

The ion nitriding process uses an electrically charged gas of ions to alloy metal surfaces with nitrogen. The process requires a vacuum vessel in which the workpiece becomes the cathode in a dc circuit. The vessel wall becomes the anode. (Figure 1). The vessel is evacuated to remove oxygen and other contaminants, and backfilled with a reactive gas such as an atmosphere containing nitrogen.

When the electric power is turned on, the gas becomes ionized. Positive ions strike the workpiece surface and electrons are emitted to the anode producing a glow discharge around the workpiece.

In steel this process forms a solid solution of nitrogen in the surface or develops a compound layer containing either a gamma prime (Fe_4N) or an epsilon ($Fe_{2\text{-}3}N$) crystal structure. The hardness, thickness, and composition of the cases formed can be controlled by varying the temperature, time, gas composition, pressure, voltage and current.

Frequently the vessel is initially filled with an inert gas. When power is applied, only sputtering occurs and the workpiece is cleaned. Since parts can be sputter cleaned in the ion nitriding vessel itself, the need for separate cleaning equipment is often eliminated.

Advantages

Ion nitriding offers numerous advantages over conventional nitriding and carburizing processes including:

Increased Control and Improved Properties — In a conventional nitriding process the furnace is set

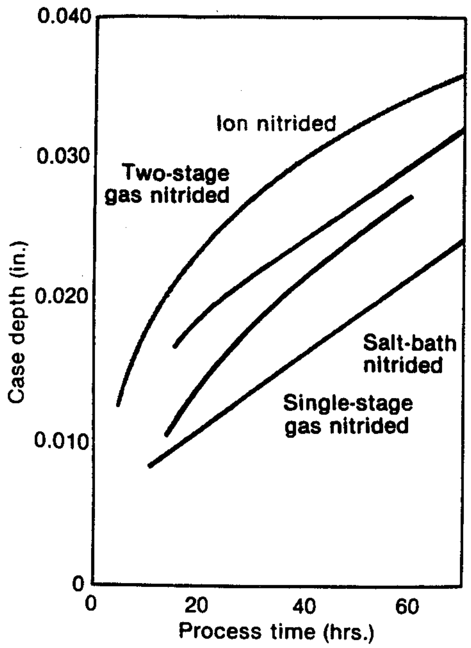


Figure 2. **Rates of case development for AISI 4340 steel.**

at 975 F and the operator controls only the length of time the workpiece is in the furnace. The compound layer formed often contains a mixture of the gamma prime and epsilon crystals. It is brittle and tends to spall or chip off during service.

By contrast, in ion nitriding other parameters such as temperature, time, gas composition, pressure, voltage and current can be controlled. The process can be used to create a diffusion zone of nitrogen dissolved in the surface layers of the workpiece. The result is surface toughness.

By varying the parameters a diffusion zone and a compound layer of either gamma prime or epsilon crystal structures can be achieved resulting in a surface that has both toughness and resistance to wear.

More Uniform Cases — The glow discharge surrounds the part forming a more uniform case and making the process ideal for complex parts such as gears, splines and shafts.

Negligible Thermal Shock and Distortion — Parts are heated to the desired temperature at a preset rate thus avoiding the thermal shock and distortion prevalent in a salt bath process. Since ion nitrided parts do not require quench hardening, as in carburizing, another source of distortion and cracking is eliminated.

Broader Treatment Range — The treatment range is 700 to 1200 F. The workpiece is heated to the desired temperature using the glow discharge and, in some cases, auxiliary electric-resistance heating elements. Lower temperatures help maintain workpiece dimensions during heat treatment. Keeping the temperatures 50 F or more below the tempering temperature of the steel maintains the core hardness of the parts and eliminates the need for any final heat treatment.

Faster Cycle Times — Heat treatment cycle times can be 20 to 50 percent shorter (Figure 2) and can favorably affect productivity.

Lower Energy Consumption— Lower temperatures and faster cycle times reduce energy consumption.

Easier Masking—Mechanical masks are used to leave chosen areas untreated. This avoids masking by electroplating and subsequent stripping procedures.

Increased Safety—Safety problems attendant with the toxic, flammable, or explosive salts or gases used in conventional processes are eliminated.

Typical Applications

The range of products which can be ion nitrided is broad because the process can impart either hardness, toughness or both while maintaining dimensional accuracy. Some typical products which are ion nitrided are listed in Table 1.

Improvements in the service life of the part are often dramatic. (Figure 3). In some reports the service life of hot forging dies has been increased 30 to 50 percent, and cutting tools by a factor of 2 or 4. The spindles for many machine tools require a high degree of dimensional accuracy, making them prime candidates for low treatment-temperature ion nitriding.

Technical Considerations

There are a number of technical factors to consider before deciding to invest in ion-nitriding equipment.

Table 1. **Typical applications of ion nitriding.**

Part	Attributes Required From Surface Heat Treatment	Optimum Surface Treatment By Ion Nitriding
Plastic molding equipment	Wear resistance	Diffusion zone + gamma prime layer
Machine tools	Wear resistance, dimensional accuracy	Diffusion zone
Drive gears for heavy machinery	Wear and fatigue resistance, nonadhesion properties	Gamma prime layer
Rotary engine housings	Wear resistance, nonadhesion properties	Epsilon layer
Hot forging dies	Wear resistance, toughness	Diffusion zone + gamma prime layer
Cold forging dies, sheet metal stamping dies	Toughness, nonadhesion properties	Diffusion zone
Cutting tools (e.g., drills, taps, end mills, etc.)	Toughness	Diffusion zone
Automotive components (e.g., gears, crankshafts, lifters, valves, rocker-arms, camshafts, etc.)	Fatigue resistance, wear resistance, antigalling resistance	Diffusion zone + epsilon or gamma prime layer

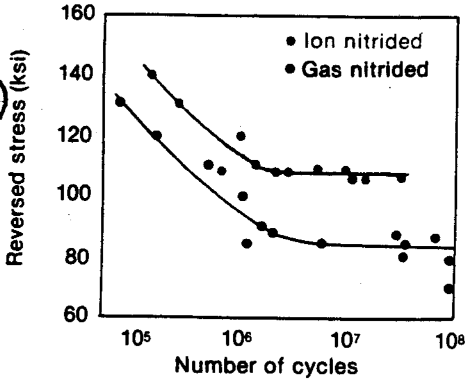


Figure 3. **Fatigue strength of AISI 4340 surface hardened via conventional gas nitriding or ion nitriding.**

Use—How the part is used determines the case depth, type of compound layer, layer thickness and areas to be hardened. See again Table 1.

Previous Processing—The processing steps that the part has already been subjected to determine whether or not additional steps such as stress-relief annealing or re-tempering are necessary prior to ion nitriding. When deciding on the ion nitriding process, all prior treatments must be considered.

Surface Condition—As with other processes, prior to nitriding, excessive scale or foreign matter must be removed by grit blasting, degreasing, or other methods. Otherwise arcing, which is common during the sputtering operation, can cause equipment damage.

Material Composition—Almost all irons and steels can be ion nitrided. These include:

- Plain-carbon steels and cast irons
- Low-alloy and microalloyed steels
- Tool steels (high speed and hot and cold work die steels)
- Stainless steels (ferritic, austenitic, martensitic, and precipitation hardening)
- Maraging steels.

Depending on the particular material and application, a diffusion zone alone (0.025 in. max.) or in combination with either an epsilon (0.001 in. max.) or a gamma prime (0.0005 in. max.) compound layer is imparted to the workpiece. Steels containing certain alloying elements such as chromium, vanadium, aluminum, silicon, and molybdenum will also form other types of nitrides which increase surface hardness and wear resistance.

Some nonferrous materials can also be ion nitrided. These include titanium alloys which are treated at temperatures of approximately 1600 F.

Geometric Restrictions—To permit adequate development of the glow seam around the workpiece, parts should not be densely packed into the nitriding vessel. Likewise, parts with small crevices or holes cannot be ion nitrided.

Economic Considerations

Extensive cost analyses have yet to be performed for this new process. However, the following factors are important when comparing ion nitriding to conventional nitriding:

Equipment Costs—Ion nitriding equipment is generally more expensive. However auxiliary equipment needed in conventional nitriding such as ammonia dissociators and cooling pits are not required. Floor space requirements can be reduced 50 percent.

Energy Costs—Energy requirements are lower because of reduced process time and temperature. Also the equipment is shut down completely when not in use and need not be maintained at idling temperatures.

Gas Costs—The inert and reactive gas consumption is negligible.

Labor Costs—Handling and stacking prior to treatment is similar in all nitriding processes. However masking and stripping is easier, and ion nitriding requires no washing, grinding to remove a brittle layer, or other handling of parts following treatment. Eliminating washing reduces water and waste disposal costs.

Other Competitive Processes

Before deciding on ion nitriding, there are a number of other surface hardening processes that you should evaluate. The advantages and disadvantages of some other processes are discussed below.

Induction, Laser and Electron Beam Hardening—These methods harden iron and steel surfaces without the use of additional alloying elements or surface coatings. In all cases, the surface is rapidly heated to temperatures of approximately 1500 to 1700 F and is water or self quenched. The final surface hardness is determined by the carbon content of the workpiece material. Because equipment costs are high, such processes are of greatest use in high production operations such as in the automotive industry.

Conventional Processes—Gas and salt bath carburizing, nitriding and carbo-nitriding are economical processes for many applications. Typically they produce case depths of 0.003 to 0.030 in. Ion nitriding is generally selected over these processes when shallow cases (0 to 0.005 in.) are needed, or when distortion or non-uniform case depth must be avoided.

Hard Chromium Plating—Ion nitrided surfaces yield better fatigue properties because of the absence of surface cracks and porosity. They are also harder (Vickers hardness of 1200 vs 830 for hard chromium plating).

Ion Implantation—It can produce very thin cases (0.0003 in. or less) that are quite hard. A focussed high-energy beam of ions penetrates the surface and combines with the part's surface atoms. The maximum temperature rarely exceeds 400 F. The major disadvantage is that only those portions of the workpiece in line with the beam are hardened.

Chemical Vapor Deposition (CVD) and Physical Vapor Deposition (PVD)—These methods apply a thin hard surface coating (less than 0.0003 in.) such as titanium carbide or titanium nitride. CVD uses a chemical reaction and subsequent vapor deposition. PVD uses a sputtering reaction. Process temperatures are 1700-2000 F (CVD) and 500-900 F (PVD). Drawbacks include the need for high processing temperature (CVD) and for ultraclean starting surfaces (PVD).

Ion Nitriding Process Variables

Several parameters must be controlled during processing:

Gas Composition—This determines the composition and

Gas Composition	Type of Surface Layer Obtained
5% Nitrogen, balance inert gas	Diffusion zone only
15 to 30% Nitrogen, balance inert gas	Gamma prime layer, (short times)
	Gamma prime layer + diffusion zone (longer times)
60 to 70% Nitrogen, 1 to 3% methane, balance inert gas	Epsilon layer + diffusion zone

Table 2. **Typical gas compositions used in ion nitriding.**

properties of the case hardened layer on the part. Table 2 gives typical selections.

Time and Temperature — Higher temperatures require shorter times to achieve a given case depth. Temperatures below 930 F are usually used to produce diffusion zones without a compound layer.

Voltage and Current — A minimum voltage is required for consistent results. The minimum voltage depends on the type and pressure of the gas, electrode spacing, and workpiece material but usually does not exceed 700 volts.

The amount of gas which is ionized and which strikes the workpiece is primarily controlled by the current. Current also affects the workpiece temperature. In general one milliamp per square centimeter of workpiece surface area is used for parts heated by the glow discharge. When auxiliary heating is used, values as low as 0.2 milliamps per square centimeter can be used. Newer systems use computers to control voltage and current.

Pressure — Pressure determines the thickness of the glow discharge seam. Pressure does not influence case depth but only its uniformity. Typical operating pressures are between 1 and 10 torr (1 to 10 mm of mercury). Higher pressures are used to penetrate blind holes and to develop uniform cases on parts such as gear teeth and complex injection molding dies.

In Summary

Ion nitriding is an attractive method for surface hardening steel parts. Its advantages over conventional nitriding and carburizing treatments include better control of surface structure and properties, less distortion, and shorter cycle times. The process is used for machine tools, heavy equipment, automobiles, and injection molding dies for forming plastics.

The information discussed in this issue of TechCommentary is an overview and intended only to familiarize you with the basic aspects of ion nitriding. If you are interested in more detailed background, please contact CMF or one of the manufacturers of ion nitriding equipment. Please refer to the sources listed below for additional information. ☐

The Center for Metals Fabrication is operated by Battelle's Columbus Division. Basic funding is provided by the Electric Power Research Institute, a nonprofit institute that conducts research and development on behalf of the United States electric utility industry.

The Center's mission is to assist industry in implementing cost- and energy-efficient electric-based technologies in metals fabrication and related fields. TechCommentary is one communication vehicle that the Center uses to transfer technology to industry. The Center also conducts research in metal heating, metal removal and finishing, and fabrication.

This issue of TechCommentary was made possible through the cooperation of Battelle staff members Dr. S. Lee Semiatin, author, and Laura Cahill, publications coordinator; and ProWrite. Technical reviewers were Raj Verma and Bill Kovacs.

Sources used in this issue of TechCommentary were:

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Metals Handbook, Vol. 4, Ninth Edition, American Society of Metals, Metals Park, Ohio, 1981.

Taylor, A.M. and Tookay, K.M. "Ion Nitriding — A Process With a Future." *Metallurgia*, Vol. 48, No. 2, 1981. Page 64.

Tools and Dies for Industry, The Metals Society, London, 1977.

Verma, R. Technical Data and Reports, GloTech, Inc. P.O. Box 527, Southhampton, PA 18966.

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35—23,24,31,32,33,37,41,42,45,46,47
37—11,13,14,15,21,24,28,43,51,61,64, 69,95,99

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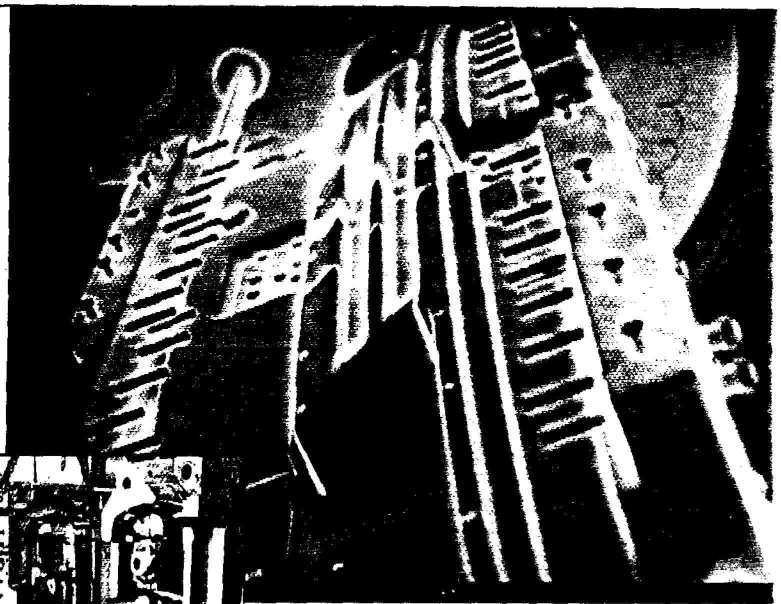
APPLICATION

Ion Nitriding Injection Molds

Published by the EPRI Center for Materials Fabrication Vol. 1, No. 13, 1987



The mold for an automobile grill opening panel is bombarded with nitrogen ions inside the ion nitriding chamber. These ions combine with the metal surface to harden it.

Ion nitrided molds produce parts with a top-quality appearance.

The Challenge: Gaining a Longer Mold Life

A high-visibility product demands a flawless appearance. Goodyear Tire and Rubber Company expects just that for its fiberglass products, such as outboard motor covers, basketball backboards, and front ends of automobiles and trucks. Since 1983, all its injection-molded products have been made from molds with ion-nitrided surfaces, and Goodyear can count on them having a smooth product appearance.

Goodyear has injection molded its products since 1981 but found that the mold surface would quickly become eroded or scarred, producing parts with a poor appearance. Hardening the mold's surface is the best way to reduce wear and keep the molds at work longer. Goodyear decided its surface-hardening method would need several characteristics:

- Reliably create a smooth, uniform surface
- Give the greatest surface hardness to each mold, especially in grooves and recessed areas
- Be repairable
- Be cost effective.

The Old Way

Fiberglass products are injection molded at Goodyear because that method produces better quality parts more quickly than other methods. But fiberglass is abrasive and quickly erodes steel molds, creating washed-out channels. As a mold erodes, it presents manufacturing problems: the quality of the part removed from a deteriorating mold is often unacceptable and requires sanding or other finishing to bring it up to standard. Sanding increases the porosity on the part, which can lead to paint pops and other surface imperfections unless additional finishing steps are performed. And all these additional finishing steps require more manpower.

Goodyear chromium plated the molds, which does not increase hardness but gives a mold life of 20,000–40,000 shots. But chromium plating had its own set of problems:

- Eroded molds had to be sent out for stripping, welding to repair the pits and channels, and rechroming—a 6-week process.
- A second mold, and sometimes a third, was needed for use when the first was in repair—an expense of $200,000–$300,000 for each mold.
- Extreme care must be taken in mold repair or the repaired mold would erode more quickly than a new mold.

Goodyear looked at other methods to increase mold life:

- Dies hardened to higher levels could not be used because they were brittle.
- The high temperatures required by heat treating cause mold warpage or cracking.

Other surface-hardening methods could not be applied: induction, laser, and electron beam hardening are not effective for complex mold shapes; gas carburizing and carbonitriding may distort the mold metal at the high temperatures they require; ion implantation and chemical and physical vapor deposition would not provide a hardened layer with sufficient thickness.

The New Way

Ion nitriding's benefits made Goodyear decide that it was the best method to harden the molds. Ion nitriding produces a smooth, uniform surface. It increases the surface hardness so that an injection mold now produces 5 times as many parts before it shows any signs of erosion. Recessed areas not able to be chromium plated can be hardened, allowing more complex designs to be molded. Four to six weeks are still needed to refurbish a mold and ion nitride it, but now the time between refurbishings is much longer.

Since many more parts are made before mold repair is needed, production savings are significant. And fewer spare molds are needed. This saves money, time and storage space for Goodyear.

The Results: Less Downtime and Higher Quality Products

Increased surface hardness. Ion nitriding increases mold surface hardness to HRC 65–70. Normal mold surface hardness is only HRC 32–34.

Increased mold life. A typical chromium plated mold could make 20,000–40,000 pieces before refurbishing. The same mold ion nitrided now can make 150,000–200,000 pieces.

Material savings. Fewer pieces are rejected because the molds do not erode as quickly. The need for extra molds is reduced because they are refurbished less often.

Reduced production cost. Goodyear experienced many cost reductions:

- 80% fewer refurbishings at $25,000–$40,000 each
- Smaller inventory of extra molds at $200,000–$300,000 each
- Less manpower to perform additional finishing.

Elimination of steps. Molds are replaced less frequently, improving the overall work flow. And workers do not have to spend time refinishing the products of eroded molds.

Energy usage. Electricity costs to ion nitride a typical mold is about $220 including solvent vapor degreasing. Electricity for chromium plating the same mold 5 times to get an equivalent number of shots would cost about $60 including the necessary stripping.

Greatly reduced mold maintenance and the decrease in rejections due to surface imperfections lead to modest savings in energy usage. The elimination of product reworking represents an additional savings in energy usage and significantly contributes to Goodyear's industrial competitiveness.

Product improvement. Ion nitriding provides release qualities similar to chromium plating, so little or no release agents are required.

Space savings. Inventory space is saved by both the reduction of extra molds and the reduction of parts warehoused to cover customer demand when the mold was being reworked.

Long-term results. Ion nitriding the molds results in harder surfaces which last longer, require less maintenance, and produce better quality products.

What Did It All Cost?

The initial cost for ion nitriding was about twice as expensive as chromium plating. The payback period was less than a year because of the much longer mold life.

The Bottom Line: Innovation Pays Dividends

Goodyear was one of the first companies in the U.S. to use ion nitrided molds for thermoset, fiberglass reinforced plastic. The increased number of quality parts produced between mold refurbishings gives Goodyear an edge in a competitive market.

Other Applications of Ion Nitriding

Ion nitriding is an excellent method for increasing abrasive wear resistance of a wide variety of parts including machine tools, dies, molds, drive gears and automobile and aerospace components. To find out more about ion nitriding, see *TechCommentary* Vol. 2, No. 5.

Company Profile

Goodyear Jackson Plant, General Products Division
Jackson, Ohio

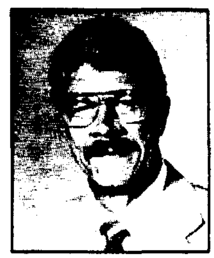
Plant Manager—Ken Seals

About 500 employees

The plant makes such fiberglass products as outboard motor covers, basketball backboards, engine covers and front ends of automobiles and trucks.

Company philosophy: To manufacture products which are recognized as world leaders in quality with lower cost than any world competitor.

Ken Seals
Plant Manager



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Section Head Tooling

The Center for Materials Fabrication (CMF) wishes to thank Gary Sharp of Advanced Heat Treat Corp. for valuable contributions made to this issue.

Columbus and Southern Ohio Electric Company provides electric service for the Goodyear Jackson Plant

CMF is operated by Battelle's Columbus Division. Basic funding is provided by the Electric Power Research Institute, a nonprofit institute that conducts applications development on behalf of the United States electric utility industry. *TechApplication* is one of the ways the Center assists industry in implementing cost- and energy-efficient, electric-based technologies in materials fabrication and related fields. This issue was cofunded by a grant from the United States Department of Energy, Office of Industrial Programs.

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34—11, 21, 23, 25, 29, 41, 44, 46, 49, 51, 52, 62, 63, 65, 66, 69, 82–84, 89, 96
35—23, 24, 31–33, 37, 41, 42, 45–47
37—11, 13–15, 21, 24, 28, 43, 51, 61, 64, 69, 95, 99

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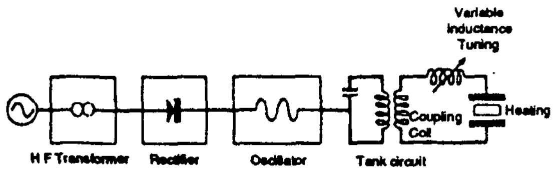
505 King Avenue • Columbus, Ohio 43201-2693
(614) 424-7737

Regulation Class: ◕ Clean Air ○ Clean Water ○ Haz. Waste ○ CERCLA ○ ______

Process Technology: *RADIO FREQUENCY (DIELECTRIC)*



RADIO FREQUENCY HEATING SYSTEM

Function/Theory

Also called "macrowave", a type of dielectric heating which heats the material from the "inside out." Dielectric materials contain polar molecules that "vibrate/rotate" when excited by a selected portion of the electromagnetic spectrum. The excited molecules create molecular friction (heat). Radio frequencies are in the 3 to 300 megahertz range; industrial radio frequencies operate at 13.56 MHz and 27.12 MHz. Radio frequency penetrates dielectric materials deeper than microwaves and have lower energy density.

Selection Criteria/Considerations

Acceptance: ☐ High ☑ Medium ☐ Low

- Has many of the same uses as microwave.
- Used when uniform drying at low temperatures is required.
- Drying "green" ceramics prior to firing.
- Selective joining of materials with poor thermal conductivity (e.g. plastics).
- Joining similar and dissimilar materials (e.g. plastic to paper, mesh materials) and emboss "decorating" plastic with special dies.
- Preheating thermoset slugs prior to forming in plastics industry.
- Post-baking cookies and crackers, dehydrating fruits and vegetables prior to packaging.
- Tempering/thawing of frozen food.
- Baking of resin bonded sand cures & molds for castings.
- Drying multiple layers of paper and adhesives (e.g. multi-layer business forms).

Environmental Benefits

- Less fossil fuel usage.

Additional Benefits

- Product moisture reduction without causing browning on the outside.
- Increased processing speed and volume.
- Uniform and controllable heating.
- Reduces weight loss common to conventional thawing (Food Processing).
- Compatible with conventional gas ovens/ dryers as a "post-dryer" (Food Processing).

Drawbacks

- High capital cost of equipment.
- Highly limited applications.

Waste Stream Reduced

Air: ☐ Particulates ☑ Organics ☑ CO_2, NOx ☐ Toxics

Water: ☐ Particulates ☐ Organics ☐ Metals, Ions ☐ Oil

Solid: ☐ Hazardous ☐ Non-Hazardous

SIC Potential

◔ 25% ◕ 75% ◑ 50% ● 100%

Mining		
Metal	10	○
Coal	12	○
Oil & Gas	13	○
Mineral	14	○
Mfg.		
Food	20	◑
Tobac	21	◔
Textile	22	◑
Apparel	23	○
Lumber	24	◔
Furn	25	◔
Paper	26	○
Print	27	◔
Chem	28	○
Petrol	29	○
Rubber	30	◔
Leather	31	◔
Stone, Glass	32	◔
Metals	33	○
Metals Fabric.	34	○
Mach	35	○
Elect	36	○
Trans	37	○
Instru	38	○
Misc.	39	○

Typical System Example

Size: Varies by application.

Energy Requirement:

1 - 25 kW for plastics applications.

50 kW avg. when used in Food Processing.

Efficiency: 55 - 60 % in Plastics

Economics

Capital Cost:

$20,000 - $30,000 for a 10 kW unit (depending on dies and automation) in the Plastics Industry.

$2,000 - $3,000 per kW (depending on automation) in Food Processing.

Source: The UNIMAR Group, Ltd.

Service/Maintenance

Replace oscillator tube (10,000 - 20,000 hours).

Vendors

Raytheon Corporation

PSC Inc.

Thermex/ Thermetron

Notes

Major Vendors

RADIO FREQUENCY

Microdry
7450 Highway 329
Crestwood, KY 40014
(502) 241-8933

PSC, Inc.
21761 Tungsten Rd.
Cleveland, OH 44117
(216) 531-3375

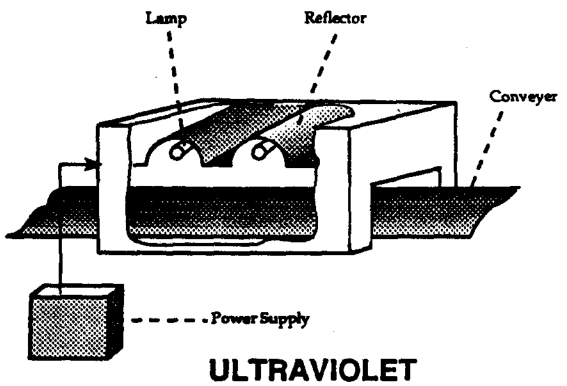
Thermex-Thermetron, Inc.
60 Spence St.
Bayshore, NY 11706
(516) 231-7800

EPRI Techcommentaries

Electromagnetic Forming
Electroforming, EPRI CMF TechApplication, Vol.3, No. 5, 1986

Regulation Class: ● Clean Air ◑ Clean Water ◔ Haz. Waste ○ CERCLA ○ ______

Process Technology: *ULTRAVIOLET*



ULTRAVIOLET

Source: UNIMAR Research

Function/Theory

The typical UV system makes use of a medium pressure mercury vapor lamp to generate UV light. A fluid or material passes under ultraviolet lamps emitting light at ultraviolet frequencies. When used for sterilization, this radiation attacks and decomposes microrganisms present in the stream, resulting in clean water liquid. When used for curing, specially formulated inks and coatings bond, or "crosslink", when exposed to the ultraviolet radiation. UV is considered a "cold" radiation electrotechnology because it produces no heat.

Selection Criteria/Considerations

Acceptance: ☑ High ☐ Medium ☐ Low

- Used for water sterilization in beverage processing, production of pharmaceuticals or other chemicals requiring pure water.
- Used to kill bacteria on meat surfaces, and for Sterilization/detoxification of food storage lockers.
- Curing inks and coatings on exterior surfaces of food cans/containers.
- Destruction/detoxification of contaminants in waste.
- Curing inks/coatings for high quality printing/converting applications, and on thermally sensitive substrates.
- Curing coatings and adhesives on wood paneling, cabinets, and high quality flooring.

Environmental Benefits

- Removes need for dangerous sterilization chemicals (chlorine, fluorine).
- No residual contamination left after treatment.
- Eliminates VOCs in curing applications.
- Eliminates combustion by-products when replacing a gas convection oven.

Additional Benefits

- Very short cure time, increased line speed, high production rate.
- Relatively low capital cost; very efficient.
- Superior product quality in printing applications - durable, abrasion resistant, high gloss finish.
- Can be used with heat sensitive materials.

Drawbacks

- Perceived health hazards of ultraviolet radiation.
- UV tubes need to be replaced every 1,800 - 2,500 hours.
- Requires special UV inks and coatings.

Waste Stream Reduced

Air		*Water*		*Solid*
☐ Particulates	☑ Organics	☐ Particulates	☑ Organics	☑ Hazardous
☑ CO_2, NOx	☑ Toxics	☐ Metals, Ions	☐ Oil	☑ Non-Hazardous

SIC Potential

◔ 25% ◕ 75% ◑ 50% ● 100%

Mining

Metal	10	○
Coal	12	○
Oil & Gas	13	○
Mineral	14	○

Mfg.

Food	20	●
Tobac	21	○
Textile	22	◔
Apparel	23	◑
Lumber	24	◕
Furn	25	●
Paper	26	●
Print	27	●
Chem	28	◕
Petrol	29	○
Rubber	30	◑
Leather	31	◑
Stone, Glass	32	◑
Metals	33	●
Metals Fabric.	34	●
Mach	35	◑
Elect	36	◕
Trans	37	◑
Instru	38	◔
Misc.	39	◑

Typical System Example

Size:
40" - 50" wide for metal deco applications .
65" - 70" wide for flat line wood applications.
8" - 100" width in printing/converting.

Energy Requirement:
10 - 200 kW for water.
2 - 100 kW for air systems.
75 - 125 kW in Metal applications.
150 - 200 kW in Wood applications.

Efficiency: 60 - 90% (flat line products).
50 - 70% (3D products).

Economics

Capital Cost: Sterilization: $5,000-$225,000.
$10,000 - $18,000 for beverages.
$25,000 - $27,000 in meat industry
$30,000 - $35,000 for a unit treating a million gal/day.

Curing: $5,000- $1,000,000 (depends on product size, line speed, number of lamps).
$5,000 - $10,000 for small units.
$50,000 - $60,000 for typical printing installation.
$250,000 plus, for large applications.

Payback: 1.05 years

This payback is based on replacing a gas convection oven (wet coating) with an ultraviolet curing system. The application is for curing inks of .00002" thickness and a clear varnish coating of .0002" thickness on 20" wide business forms at a rate of 800 ft./min.

Source: Fusion UV Systems

Service/Maintenance

Routine cleaning of tubes and reflector housing. Replace tube every 1,800 - 2,500 hours.

Vendors

Aetek International

Eye Ultraviolet

Fusion UV Systems

OnLine Energy, Inc.

Notes

Major Vendors

ULTRAVIOLET

Aetek International
1750 N. Van Dyke Rd.
Plainfield, IL 60544
(815) 436-2304/6299

Eye Ultraviolet
42 Industrial Way
Wilmington, MA 01887
(508) 694-9060

Fusion UV Systems
7600 Standish Pl.
Rockville, MD 28055
(301) 251-0300

Industrial Heating and Finishing Co., Inc.
P.O. Box 129
Pelham Industrial Park
Pelham, AL 35142
(205) 663-9595

OnLine Energy, Inc.
6701 E. Sierra Ct.
Dublin, CA 94568
(415) 828-1290

EPRI Techcommentaries

Ultraviolet Curing
Ultraviolet Curing Technology, EPRI CMF TechCommentary, Vol. 4, No. 4, 1987, 1990r
UV Curing of Coatings on Metals, EPRI CMF TechApplication, Vol.1, No. 16, 1987
UV Curing in the Label Industry, EPRI CMF TechApplication, Vol.1, No. 17, 1987

TECHCOMMENTARY

Ultraviolet Curing Technology

Published by the EPRI Center for Materials Fabrication Vol. 4, No. 4, 1987

Unlimited Curing Opportunities

Opportunities for tougher, glossier finishes on products from vinyl flooring to magazines to metal cans abound with ultraviolet (UV) curing technology. The UV process improves wear and scratch resistance and gives a higher quality appearance for virtually any coated, printed, or bonded product, such as

- Electronic components
- Plastic cups and tubes
- Printed labels and tags
- Wood furniture.

In addition, pollution-free UV curing technology allows manufacturers of these products to eliminate emissions, an action mandated by tightening EPA regulations.

Great strides have been made in UV-curable materials over the past 10 years. Many UV coatings, inks, and adhesives are now less toxic than their conventional counterparts yet meet strict specifications for a wide variety of products.

Advantages

UV technology has several advantages over water- or solvent-based coatings and inks cured by gas or electric forced-air ovens or by infrared.

Improved quality — UV-curable materials can provide improved hardness, gloss, wear resistance, compressive strength, adhesion, or elasticity for nearly any application.

Increased production rates — Curing time is nearly instantaneous, permitting higher line speeds.

Reduced pollution — UV materials contain no solvents, which evaporate during curing and require incineration. So, air pollution is reduced, and conformance to environmental regulations is easier.

Energy savings — Energy savings of up to 90% are possible by switching from fuel-fired ovens. Energy use is always more efficient, since all energy is directed toward curing the coating, not heating the substrate and surroundings.

Space savings — UV curing equipment occupies 10 to 50% of the space of fuel-fired curing ovens.

Streamlined operation — UV materials' fast curing rate may eliminate time-consuming secondary steps. For example, when metal sheet is printed in several colors, it traditionally must be stacked and cooled after each coating/curing step. But several UV stations can be set up in one continuous line, saving material handling, space, and time.

Increased flexibility — UV curing is ideal for heat-sensitive substrates such as plastics, which could be affected by heat processes.

Material savings — Because a UV material imparts greater strength and durability, cheaper substrate materials can sometimes be substituted.

Reduced cleanup — Cleanup of application equipment is simplified because UV materials do not dry in the applicator or cure prematurely during handling operations.

UV curing technology has two limitations that prospective users should consider:

- Custom-engineered curing and handling equipment for completely

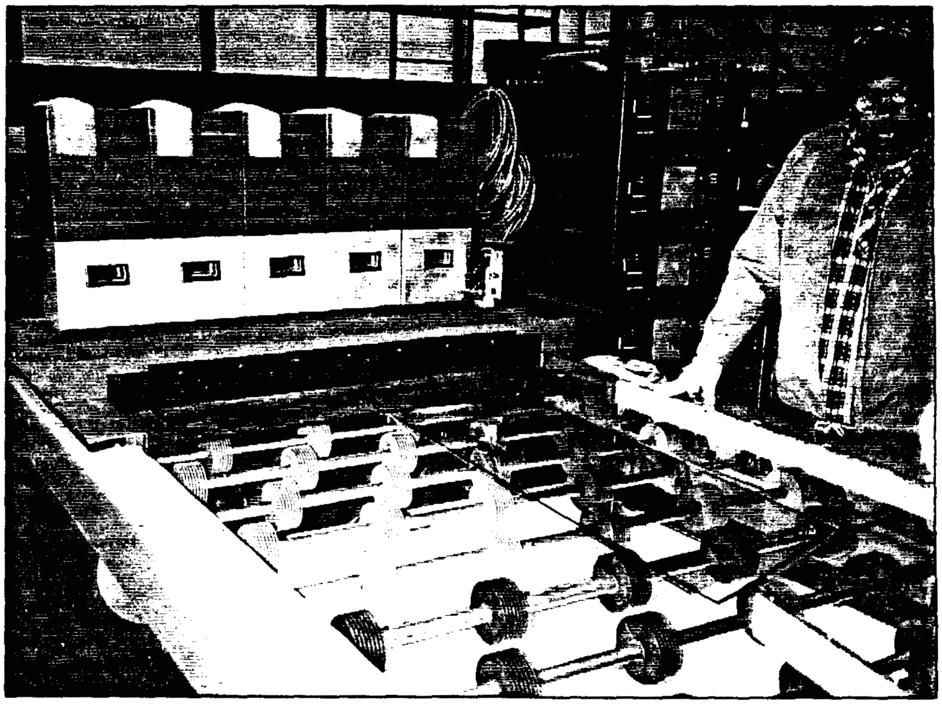


Figure 1. **The black frit border around this auto glass window is being cured by UV. The border protects the glue used during assembly from sunlight and eliminates the need for a rubber gasket to seal the window.**

curing three-dimensional objects is an added expense.

- UV materials are not FDA approved for use on food-contact surfaces.

Alternate Technologies

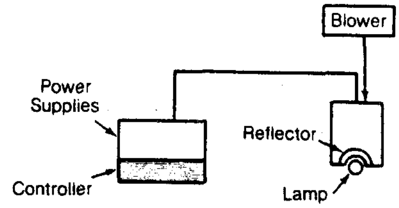
Instead of UV or water- or solvent-based coatings, manufacturers sometimes choose high-solids coatings, which also cure by gas or electric forced-air ovens or by infrared. High-solids coatings cure as slowly as solvent-based coatings but require less incineration.

Another option chosen by some manufacturers is a powder coatings/infrared combination. This combination is more cost effective than UV technology for applications requiring thick, pigmented coatings cured at high speeds.

Electron beam curing (EB), a highly specialized, capital-intensive method, competes with UV only for high-throughput (greater than 400 feet per minute) or wide printing/curing lines. EB also has specialized applications in areas that UV curing is not well suited, such as curing the heavily pigmented coatings on magnetic recording and video tape.

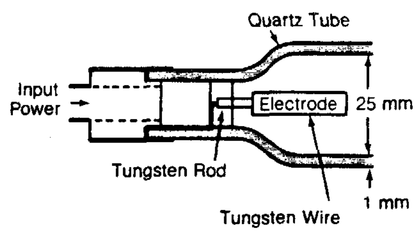
ltraviolet (UV) light is the part of the electromagnetic spectrum with wavelengths of 200 to 450 nanometers (nm), between visible light and X-rays. UV light is absorbed into UV materials by a photoinitiator additive. The photoinitiator converts UV light into energy and starts a cross-linking reaction in the UV material, which cures into a hard, solid film.

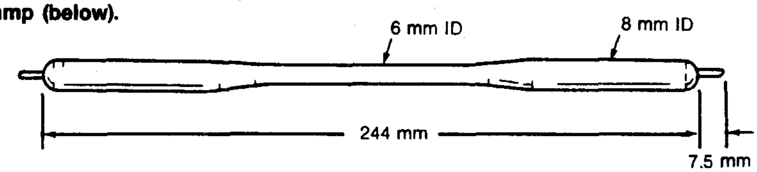
UV lamps emit light over specific wavelength ranges. The most common sources of UV light are medium-pressure mercury vapor lamps. Either microwave energy or an electrode arc excites the mercury, which then emits UV light. All light emitted is directed to the product by the reflectors housing the lamp assembly. The entire housing is cooled with air blowers or circulating water for optimum operating efficiency and life expectancy. Each lamp has an individual power supply linked to a single control panel.



A commercial UV processor unit

UV curing technology is most efficiently integrated into a continuous production line. The product is conveyed from the coating or printing station directly to the UV curing station. For proper curing, handling equipment at the curing station must expose the entire surface to UV light. UV curing a flat surface is straightforward, but three-dimensional objects require a custom-engineered curing and handling system to cure the entire surface.





Medium-pressure mercury vapor lamps activated by an electrode arc (above) and a microwave-powered lamp (below).

Applications

UV technology is rapidly overtaking applications for many types of products. Continuing developments in UV chemistry and handling equipment have opened opportunities for UV applications for products with strict performance specifications and complex shapes.

Industrial coatings/finishes — UV curing enables manufacturers to satisfy customer demands for more durable decorative or protective coatings while increasing throughput. Within this market, most UV applications are for coated wood, metal, and plastic products:

- Galvanized steel tubing
- Metal cans
- Vinyl flooring
- Wire
- Wood furniture.

Printing — Printers increasingly find their customers specifying brightly colored UV inks and high-gloss UV varnishes for high-quality printing projects. In addition, tightening EPA regulations on emissions force printers away from water- or solvent-based inks and thermal curing. These pressures have caused over 300 printers in the United States to switch to UV technology.

Letterpress, lithography, flexography, and screen printing are the four printing methods most adaptable to UV curing. The following products are commonly printed with UV curing technology:

- Books and periodicals
- Labels and tags
- Magazine covers.

Packaging — The glossy, high-quality appearance of UV inks and varnishes is in demand in the extremely competitive packaging industry. First used on upscale packaging items such as cosmetic cartons, UV technology is now popular for commodity items such as laundry soap boxes. The following packages are commonly printed and cured with UV technology:

- Folding cartons — for medications, cosmetics
- Plastic cups and tubes — for toothpaste, salves
- Bottles — for shampoo, lotions.

Electronics/Communications — UV technology is vital to the manufacture of electronic components because it enhances production capabilities, provides superior product performance, enables faster line speeds, and eliminates distortion of heat-sensitive materials. Many electronic components, such as optical fibers, integrated circuits, and printed circuit boards, were developed with UV technology.

For example, optical fibers, a new communications technology replacing copper telephone cable, uses a UV-curable coating that protects the glass fiber from mechanical and chemical damage and preserves the optical transmission characteristics.

Adhesives — The need for quick-bonding adhesives that cure without heat has made UV adhesives valuable for applications such as bonding electronic components and printed circuit boards and splicing optical fibers. Prebonding handling is simplified because the UV adhesive cures only on exposure to UV light.

Technical Considerations

UV curing can be adapted to nearly any coating, printing, or bonding process. Although the technology is flexible, the design of a successful curing system depends on a coordinated effort of the manufacturer with both a UV materials and an equipment supplier. The appropriate UV line design is determined from the manufacturer's system expectations and information furnished by materials and equipment suppliers.

The UV materials supplier needs certain information to provide a UV material that will meet your specifications.

- What properties are important for your product? For example, must the coating be glossy or wear resistant or meet a color specification?
- What is the substrate? A material/substrate/lamp combination providing good adhesion can only be determined after the substrate is identified.
- With what equipment will you apply the material? The application method may determine how viscous your UV material must be. On occasion, the material may dictate the application method.

The equipment supplier will test the UV material at its use thickness and pigmentation level to determine the most effective UV wavelength for curing. The following information is also needed to provide optimum curing: the product, the UV material and its response to UV light, the film thickness, and the required line speed. This information determines the size, type, positioning, and number of the UV lamps. Some UV equipment suppliers provide only the lamp and related components, while others help you design the entire system including handling equipment.

The following technical factors are also important when planning a UV process line:

UV materials — Upon exposure to UV light, 100% of the UV material reacts. Because there is no solvent medium to evaporate, UV materials cover more area than the same volume of water- or solvent-based coating. Most common UV applications have a film thickness between 0.3 and 1 mil, although thicknesses up to 20 mils may be UV cured.

UV lamps — The UV wavelength output of the lamp is designed to interact with the material's photoinitiator. The most common output has a major peak at 365 nm and is produced by both electrode arc and microwave-powered UV lamps. Unusual photoinitiators, thick coatings, or pigmented materials may require other peak wavelengths, which are obtained by introducing other substances, called dopants, into the lamp. A comparison of the features of electrode arc and microwave-powered UV lamps is presented in Table 1.

Safety — UV light is harmful to skin and eyes, so all UV curing equipment must be shielded. Shields to contain the UV light waves are part of the system installed by the equipment manufacturer. Microwave-powered UV lamps are interlocked with a detector to ensure that no microwave radiation leaks occur.

Economic Considerations

A thorough cost analysis is necessary when considering any new technology. The following costs should be considered when analyzing a UV curing operation:

Capital costs — The capital cost for UV equipment depends on the number of lamps needed for the curing process. A microwave-powered

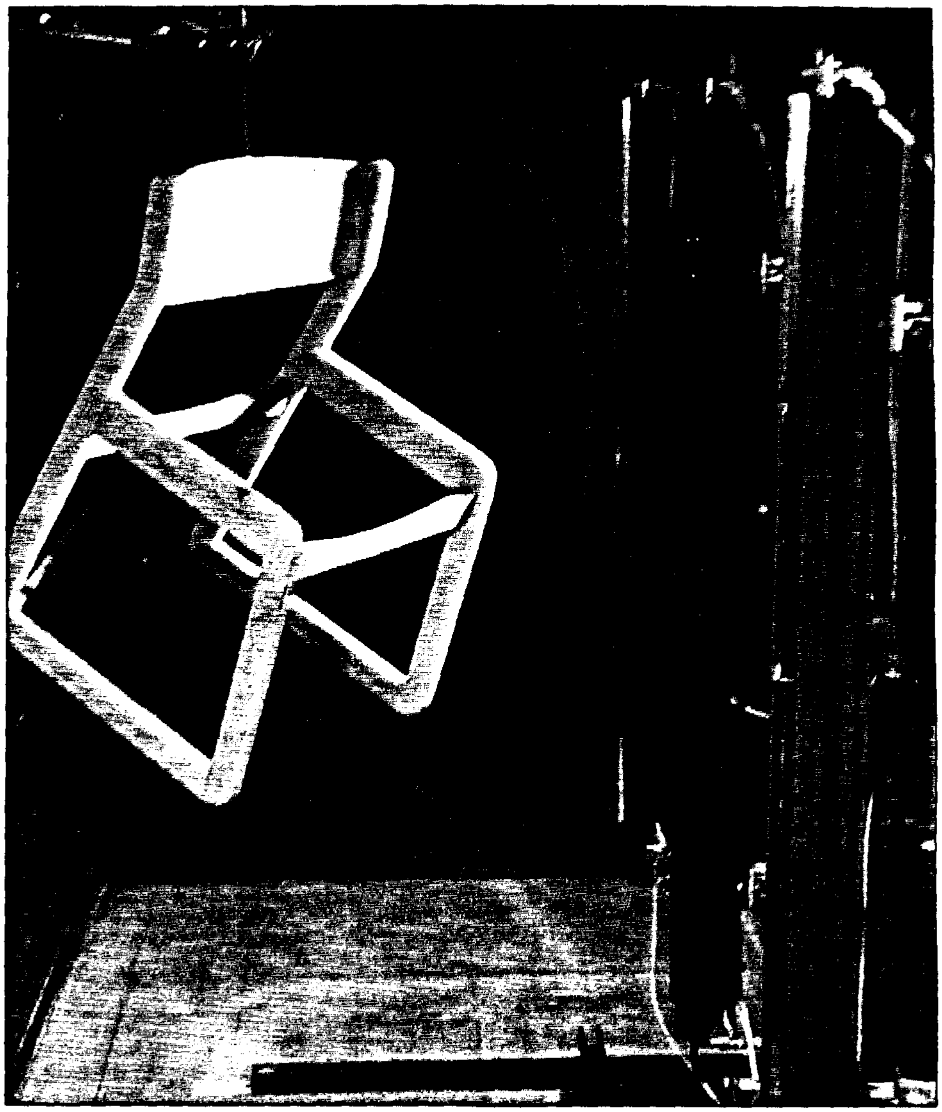


Figure 2. **The coating on wood furniture is UV cured. This inside view of the curing unit shows the UV lamps to the right of the chair.**

***Table 1.* Comparison of UV Light Sources**

Parameter	Electrode Arc	Microwave Powered
System cost	$6000–14400	$7500
Lamp replacement cost	$150–375	$150
Other replacement cost	none	$170 magnetron
Length	6–77 in.**	10 in.
Width	6–15 in.	8 in.
Height	6 in.	12–18 in.
Power	100, 200, 300, 400 W/in.	100, 200, 300, 375 W/in.
Guaranteed lifetime	1000 hrs	3000 hrs
Dopants available	unlimited	unlimited
Cold start-up time	45–180 sec	2–4 sec
Restart time	10–240 sec	10 sec

*System cost depends on lamp length.
**A variety of lengths from 6 to 77 inches is available.

UV curing system including one lamp, the power supply, the air cooling system, cable, and detector costs approximately $7500. Microwave-powered lamps are available in a standard length; lamp modules placed end to end provide any length required. An electrode arc UV curing system includes one lamp, shielding, reflectors, shutters, power supply, and air cooling fan. Its cost depends on the length of lamp needed. A system with a 10-in. lamp costs $6400, and one with a 34-in. lamp costs $9600. Several other lengths are also available, up to 77 inches. Additional lamps or customized conveyors increase costs.

Operating costs — A UV curing system requires regular maintenance, including lamp replacement and periodic cleaning of the reflectors and cooling system. UV material costs vary greatly with application, but higher costs are usually offset by increased coating coverage per unit volume.

All the above costs should be weighed against potential savings when determining the economic feasibility of UV curing. Along with the benefits mentioned earlier, other considerations include downtime or scrap loss decreases, line speed—and therefore throughput—increases, the elimination of air pollution and incineration, and the reduction or elimination of process steps.

In Conclusion

UV curing technology has gained acceptance in industry within the past 15 years. The next 2 to 3 years will see more manufacturers switching to UV curing because of its potential for large production savings. More UV curing applications for three-dimensional shapes will become commercial as manufacturers seek to improve product quality and throughput. The use of UV technology in identification marking and assembly of electronic and automotive parts will expand rapidly. The development of UV curing technology will advance for pressure-sensitive adhesives and produce less expensive tapes and labels with improved performance properties.

The information contained in this issue of *TechCommentary* is intended only to introduce you to the many applications of UV curing technology. For more information on UV curing of coatings on metals, see *TechApplication* Vol. 1, No. 16. UV curing in the printing industry is highlighted in *TechApplication* Vol. 1, No. 17. For help with specific applications, talk to your electric utility marketing representative or UV materials and UV curing equipment suppliers.

The EPRI Center for Materials Fabrication is operated by Battelle's Columbus Division. Basic funding is provided by the Electric Power Research Institute (EPRI), a nonprofit institute that conducts research and development on behalf of the United States electric utility industry.

The Center's mission is to assist metals, plastics, ceramics, and composites fabricators in implementing cost- and energy-efficient, electric-based technologies. *TechCommentary* is one communication vehicle that the Center uses to transfer technology to industry through an electric utility network. The Center also conducts applications development projects that demonstrate innovative uses of electrotechnologies.

This issue of *TechCommentary* was made possible through the cooperation of Vincent McGinniss, Battelle; Elinor Midlik, RPC Industries, Inc.; Kathy Miller and Dick Stowe, Fusion UV Curing Systems; and Bill Tasker, Acme Printing Co.

The source used in this issue of *TechCommentary* was McGinniss, V. D. "Radiation Curing: State-of-the-Art Assessment" *EPRI Report* No. EM-4570, 1986.

Photos courtesy of Fusion UV Curing Systems and RPC Industries, Inc.

Applicable SIC Codes
25 — 11, 12, 14, 17, 19, 21, 22, 31, 41, 99
26 — 31, 41, 45, 48, 51
27 — 11, 21, 31, 32, 41, 51-53, 71
28 — 21, 51, 91, 93 **30** — 79 **33** — 57
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APPLICATION

UV Curing of Coatings on Metals

Published by the EPRI Center for Materials Fabrication Vol. 1, No. 16, 1987

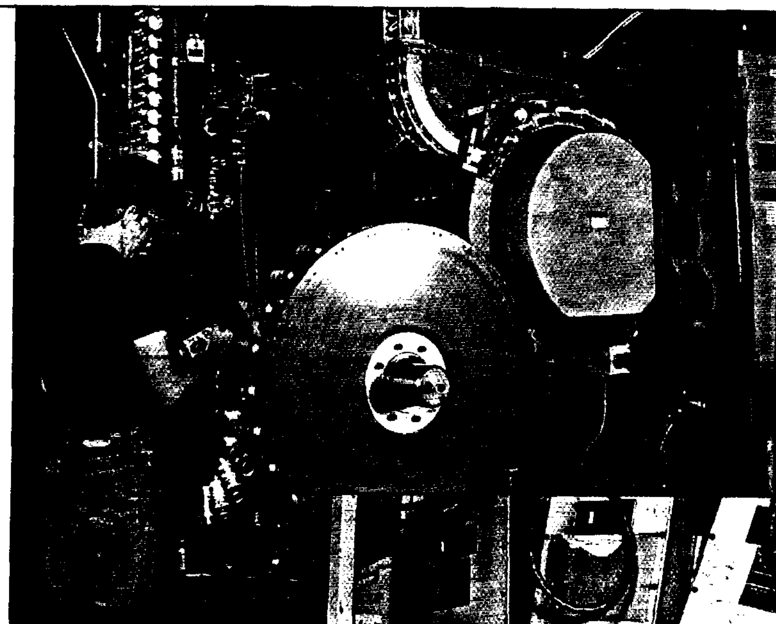
The Challenge: Increase Production Speeds

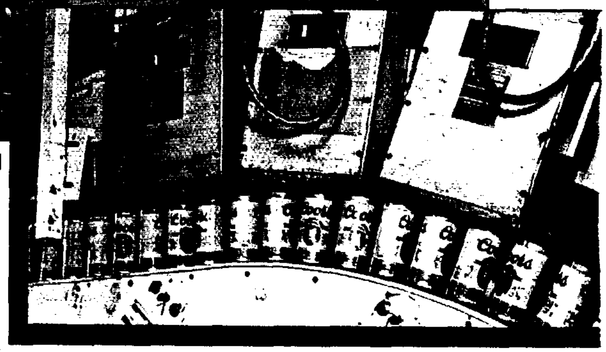
Shipping cold beer over long distances requires a good abrasion-resistant coating to maintain a high-quality appearance. When Adolph Coors Company enlarged its sales territory, its beer can production facility sought to not only increase its production rates but also improve the can's finish.

Coors investigated several can coating curing methods before deciding on and beginning to implement ultraviolet (UV) in 1975, a system that is now unique in the industry. Infrared curing is too inefficient because the thin coating film reflects radiation instead of absorbing it, and electron beam curing proved to be uneconomical. Changes in 1986 induced Coors to further innovation in its coating lines. Coors had several requirements for an updated UV system:

- Significantly increase production rates
- Reduce costs
- Maintain the can's high-quality appearance
- Require less line maintenance
- Provide greater production flexibility.

With UV's added flexibility, the plant produces 15 million cans per day on the largest can lines in the world.





Above: The UV inks and varnish are laid on the can in the printer.

Right: Exposure to UV light causes the can coatings to cure within 500 milliseconds.

Conventional Production Method

Coors still has in use a line that typifies can production before UV. The can exterior is printed by four-color offset; an inked printing blanket lays the image as the can spins on a mandrel. The decorative inks and varnishes are cured in a gas convection oven. Pin chains convey the can through the oven, which cures the coatings in 12 seconds at 400 F. The interior coatings are then applied and cured in another gas oven.

The thermal coating and curing system has several disadvantages:

- Length and speed of pin chain conveyor limit speed of decorator.
- Energy costs for gas ovens are high.
- Cans will be damaged if overheated in the convection oven.

In addition, a minimum amount of lubricant is used on the pin chain to prevent getting lubricant into the can and contaminating the contents. Lack of lubricant causes the pin chain to wear excessively and break frequently, and any repair of the conveyor or oven is time-consuming: 20 minutes is spent waiting for the oven to cool before repair can even begin.

The New Way: A More Efficient Method

Coors chose a UV curing and coating system for its high-quality, high-quantity beer can lines. The can undergoes the same operations as in the conventional line except for the UV coatings and the curing and conveying systems.

Wet UV inks are applied to the can on a conventional printer with the clear UV overvarnish as the final layer. The inks and varnish contain a photoinitiator and cure in about 500 milliseconds on exposure to UV radiation. Because the cure is so quick, line speeds are no longer restricted by the coating system, and there is no possibility of damaging cans due to overheating. The pin chain has been replaced by a vacuum system that touches only the can bottom, reducing the chance of damage to the can interior.

The Results: Faster Line Speeds with Significant Savings

Faster production rates. Both systems can operate at up to 1400 cans per minute, but the conventional system is at its limit. The UV curing/vacuum conveying system can handle much higher speeds and, as technology to increase printer and other equipment speeds is implemented, is expected to run at 2000 cans per minute.

High-quality appearance. The UV overvarnish provides the can with a tough, abrasion-resistant coating.

Less damage to can interior. Since the cans do not ride on a pin, the can's interior is not subject to scratching and nicks, which can affect the interior coating performance. After elimination of the pin chain a standard test for measuring interior coating performance has shown a tenfold improvement.

Less downtime. Coors estimates the beer can line is down about 20 min/week, while the average weekly downtime for the beverage can line is 2-3 hours. The UV oven contains 11 modular lamps and reflectors, and the nearby power supply is also modular. When a problem occurs or a lamp burns out, that module can be replaced in less than a minute. The reliable vacuum conveyor also needs less time for repairs.

Less energy use. Coors eliminated the 650 cubic feet per hour of gas a conventional oven consumes. The 35 kW of electricity needed to power the UV lamps is comparable to that used to run the fans for a gas oven with the same capacity. For comparable line speeds, the energy would be reduced by 92%. Since Coors significantly increased line speeds, the actual savings are even greater.

No emissions. The UV system emits no fumes and poses virtually no environmental threat, while the conventional oven's exhaust gases require incineration to minimize emissions.

Less floor space needed. The UV oven occupies 40 square feet, while the gas convection oven occupies 500.

Lower capital costs. Because the UV oven requires less space and no incineration to perform the same function, capital costs are about half that of the thermal cure/pin chain conveying system.

Less cleanup. Coors discovered an extra bonus in its cleanup procedures. Since the UV coatings do not cure by evaporation, they do not dry in the printing presses, making press cleanup quicker and simpler.

What Does It All Cost?

The cost of a UV system for a 2-piece can line running 1500-1600 cans per minute is $200,000-$225,000 without bottom-cure equipment. This price includes the UV lamps, power supply, shield enclosure, transport mechanism and the cooling and exhaust fans.

The Bottom Line: A Faster, More Efficient Can-Making Line

Coors can now produce high-quality decorated and coated cans at a faster rate and with fewer production worries. Ultraviolet curing adds flexibility to its operation, and the vacuum transfer system has increased line speeds. The final result is a faster, more efficient can-making line.

Other Applications of UV

Ultraviolet is currently being used in many areas:

- Coatings on cans, paper, cups and tubes
- For paper, metal, wood and glass products
- In medical and automotive applications
- For electronics, graphic art film and optical fibers
- For fabrication of semiconductor wafers.

For more information on UV curing, see *TechApplication* Vol. 1, No. 17.

Company Profile

Adolph Coors Company, Golden, Colorado

President—Jeffrey H. Coors

Approximately 9000 employees

Founded 1863

Corporation with operations in brewing, ceramics, aluminum, transportation, energy, food products, packaging and biotechnology. Coors holds several patents on technology developed in-house to improve operations. It pioneered the development of the 2-piece beverage can and implemented the first aluminum recycling program.

Company philosophy: Quality in all we are and all we do.

Bob Schultz, Mechanical Engineer, and Maurice Bryant, Director, Can Manufacturing, admire Coors' high quality.

The Center for Materials Fabrication (CMF) would like to thank Bob Schultz, Mike Lane, and Lowell Whitney of Adolph Coors Co., Fusion UV Curing Systems, and Georgia Power Company for valuable contributions made to this issue.

Public Service of Colorado provides electric service for Adolph Coors Company.

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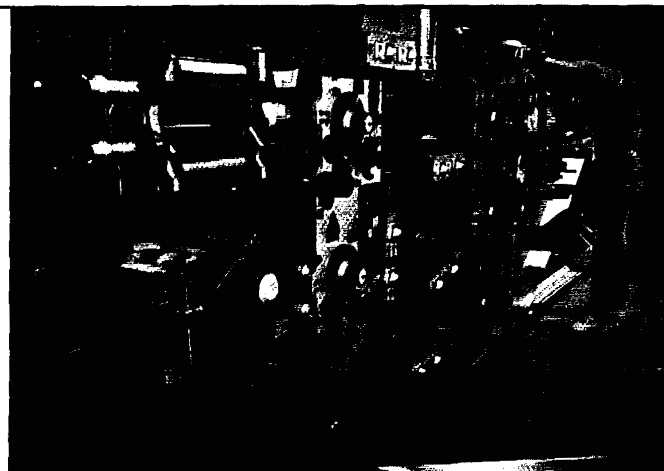
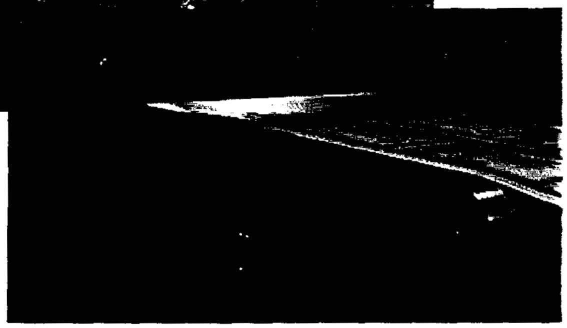
APPLICATION

UV Curing in the Label Industry

Published by the EPRI Center for Materials Fabrication Vol. 1, No. 17, 1987





Above: The rotary letterpress prints and cures the UV inks and varnishes at up to 6 stations.

Right: The UV station at the end of the flexographic press cures the UV varnish.

The Challenge: Produce High-Quality Specialty Printing

Voxcom Web Printing switched to ultraviolet (UV) curing technology to enable it to run unique, exotic print jobs at a competitive speed. Now, because of UV technology, Voxcom can produce labels, coupons and tags with durable finishes at lower prices than when expensive overlaminates are used.

After experimenting with UV on an existing press, Voxcom purchased rotary letterpress systems with UV curing capabilities. It was so impressed with the UV systems in action that it retrofitted 2 of its flexographic presses with UV stations. Voxcom now runs its presses with UV capabilities near capacity and utilizes the flexibility of UV to meet specifications and schedules previously not possible.

The Old Way

Until 1985, flexographic presses were Voxcom's workhorses. Rolls of card stock, paper and vinyl substrate unwound through the press. Cylinders surrounded by photopolymer plates with the inked image in relief rolled against the substrate, printing various colors at either 4 or 6 stations, depending on the job requirements. Then the printed stock traveled through forced-air electric ovens, drying the ink in 2 seconds at 180 F. The operation's morning startup took approximately 2 hours and several hundred feet of stock because fitting the design registration and controlling the color were difficult tasks.

Color was controlled by controlling ink viscosity, but since the inks were either water or solvent based, viscosity changed as the medium evaporated. Several problems were associated with water- and solvent-based ink use:

- Color consistency was poor, as viscosity continually changed.
- Flexographic inks could not provide the high gloss and bright colors that Voxcom needed for pharmaceutical and other upscale applications.
- Dried ink had to be removed from the presses every evening.
- Flammable ink solvents required special storage and handling.

Labels requiring protection from chemicals or fading needed an overlaminate to protect the inks. Overlaminate use also had drawbacks:

- Press speed was limited by the curing time of the inks and the rate of application of the overlaminate.
- The overlaminate was expensive.
- The overlaminate's thickness and tensile strength caused the rotary cutting dies to wear quickly.
- Difficulty in achieving the proper tension balance between face stock and overlaminate often resulted in curl of the finished label.

The New Way

UV capability on Voxcom's flexographic presses does not change the basic operation. The printing method is the same as before, but for most jobs a UV varnish is applied at the last station. The UV varnishes cure in 30% of the time of solvent-based varnishes, may replace the overlaminate in many cases, and are much less expensive than either.

Voxcom also owns 2 rotary letterpresses with UV capability. Rotary letterpresses offer greater capacity than flexographic presses, with tight registration for long runs. Printing on a rotary letterpress is similar to that on a flexographic press, except for the ink transfer. Because UV inks are paste instead of fluid, 16–18 transfer rolls are required to lay the inks on the plate.

The UV inks are available in a myriad of bright colors. Because they contain no solvents, the color does not drift out of specification as solvents evaporate. Less operator skill is needed since the color is no longer controlled by solvent addition.

The Results: Brighter, More Exotic Labels

UV's added production flexibility has enabled Voxcom to remain a strong source of quality labels. It can print a greater

What Is UV Curing?

Ultraviolet curing works by a combination of UV radiation and UV-sensitive chemicals. The UV inks contain liquid prepolymers, photoinitiators, and pigments when desired. When the inks are exposed to UV radiation, they polymerize almost instantaneously into hard, dry films. UV radiation is supplied by special lamps that emit radiation in the UV range.

Arc lamps rely on electrical discharge to excite mercury vapor to emit UV. These lamps typically have a lifetime of 1000 hours and must rest at 50% power when on standby. Recently, lamps that use microwave energy to excite the mercury vapor have been introduced. The microwave-powered lamps have a lifetime of 5000 hours and can be shut off when not needed. These lamps are available with the bulbs and reflectors housed in separate modules for easy replacement and repair.

variety of labels than ever before, with brighter colors and on many different substrates. And there are many other benefits:

Faster production rates. The UV lines run at 250 feet per minute, compared with 150 feet per minute for a conventional line.

Material savings. The UV varnish costs $36 per gallon, while air-dried varnishes cost $54-$108 per gallon and the equivalent overlaminate material to cover the same area costs $124. Less ink is required to run a job because UV inks are denser. Because daily startup time is reduced, several thousand feet of stock is saved each day.

Faster daily cleanup. Because UV inks and varnishes do not dry in the press overnight, 1 hour of cleanup is not needed every evening. Startup time each day is reduced from 2 hours to 15 minutes.

Fewer rejects. Because the inks are easier to control, fewer pieces are rejected due to poor color adjustment.

Safer operation. Voxcom has greatly reduced the amount of solvent stored, thereby reducing fire hazard and safe-storage concerns.

Double savings. Voxcom bought 2 microwave-powered lamps to retrofit 1 press. Instead, it found the lamps and reflectors so efficient that each was fit to a separate press.

Energy usage. While Voxcom's energy usage increased, its line speeds nearly doubled. Since a 2-hour daily startup is no longer necessary, all press time and therefore energy is used productively. The increased line speed and added capabilities improved Voxcom's industrial competitiveness.

What Did It All Cost?

Voxcom added UV stations to 2 of its flexographic presses for $10,000 per press. The equipment needed for the conversion was modular microwave-powered lamps and reflectors and a separate modular power supply.

The Bottom Line: Increased Capability at Significant Savings

Voxcom remains competitive in a demanding market because it committed to UV: a faster, cheaper, and more efficient printing system. It now uses UV for most upscale jobs, such as cosmetic, pharmaceutical, and specialty labels, while the conventional system produces food labels and other low-cost labels.

Other UV Applications

UV curing is effective for many products including cans, folding cartons, cups, tubes, flooring products, plastic film and glass as well as semiconductor devices, printed circuits, graphic art media, and furniture coatings. For more information on UV curing, see *TechApplication* Vol. 1, No. 16.

Company Profile

Voxcom Web Printing, Peachtree City, Georgia

President—David Good
Production Manager—Mark Shadle

40 employees

Printer of specialty labels, coupons, and tags

Company philosophy: The corporate attitude reflects service and meeting commitments: "The Personal Touch." Each customer's need is translated into product by a group of dedicated professionals.

Mark Shadle (left) and David Good inspect high-quality labels made with UV inks and varnishes.

The Center for Materials Fabrication (CMF) would like to thank Georgia Power Company, which provides electric service to Voxcom Web Printing, and Fusion UV Curing Systems for valuable contributions made to this issue.

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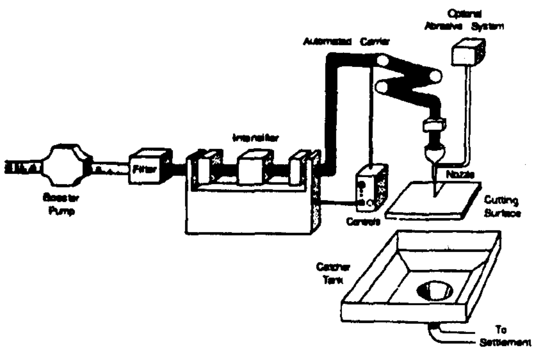
Process Technology: *WATERJET*



WATERJET CUTTING SYSTEM

Source: EPRI TECHCOMMENTARY Vol. 5/No. 1

Function/Theory

Waterjet uses a high pressure stream of water to erode the workpiece. A waterjet cutting system uses an intensifier to pressurize water up to 60,000 psi. To cut metals, an abrasive such as silica or garnet is introduced in the water stream just before it is forced through the .02 inch diameter nozzle. The water and abrasive jet leaves the nozzle and strikes the workpiece at speeds up to 3,400 ft./sec. Computer controls are used to move the nozzle or the workpiece to cut different shapes.

Selection Criteria/Considerations

Acceptance: ☐ High ☑ Medium ☐ Low

- Suitable for a wide range of materials requiring accurate, complex cuts with minimal distortion.
- Used to some extent for cutting (splitting, drilling, marking, machining) metal with thicknesses of less than 1".
- Emerging as a cutting technology for various food products, e.g. fish processing.
- Used in the Plastics Industry for cutting workpieces, and for cutting prototypes.
- Developed as an alternative method of stripping paint coating.

Environmental Benefits

- No combustion by-products.

Additional Benefits

- Clean smooth edges, reducing or eliminating the need for further finishing.
- No heat distortion on the workpiece.
- Can be used on highly reflective materials.
- Omnidirectional, able to cut complex shapes and patterns with great accuracy.
- Automatable.
- Can cut steel up to 6" thick.

Drawbacks

- Acquisition and disposal of abrasives used in waterjet is costly.
- Slower cutting speeds on thicker materials.
- Requires settling tanks to collect metal fragments and abrasives rinsed off of the workpiece during cutting.
- Not capable of partial-penetration of the workpiece - only able to cut or drill completely through the material.

Waste Stream Reduced

Air		Water		Solid
☑ Particulates	☑ Organics	☐ Particulates	☐ Organics	☐ Hazardous
☑ CO_2, NOx	☐ Toxics	☐ Metals, Ions	☐ Oil	☑ Non-Hazardous

SIC Potential

◔ 25% ◕ 75% ◑ 50% ● 100%

Mining

Metal	10	○
Coal	12	○
Oil & Gas	13	○
Mineral	14	○

Mfg.

Food	20	◑
Tobac	21	○
Textile	22	◑
Apparel	23	◔
Lumber	24	◑
Furn	25	◑
Paper	26	○
Print	27	○
Chem	28	○
Petrol	29	○
Rubber	30	◔
Leather	31	●
Stone, Glass	32	◔
Metals	33	◔
Metals Fabric.	34	●
Mach	35	◕
Elect	36	◕
Trans	37	◑
Instru	38	◑
Misc.	39	◑

Major Vendors

WATERJET

Ingersoll-Rand
Waterjet Cutting Systems
634 West 12th Street
Baxter Springs, KS 66713
(316) 856-2151

Trumpf, Inc.
Farmington Industrial Park
Farmington, CT 06032
(203) 677-9741

EPRI Techcommentaries

Waterjet,
Waterjet Cutting, EPRI CMF TechCommentary, Vol.5, No. 1, 1988

TECH COMMENTARY

WATERJET CUTTING

Published by the EPRI Center for Materials Fabrication Vol. 5, No. 1, 1988

Clean Cuts on Difficult Materials

Manufacturers cutting plastics, glass, metals, and even food seeking to improve productivity and quality are often thwarted by the slow and inexact cutting of knives, shears, saws, and other cutting technologies. Manufacturers find that some materials, including fiberglass, graphite/epoxy composites, and other new materials, cannot be cut to required tolerances even by faster methods such as plasma arc or laser cutting. But waterjets can cut to near-net shape on complex configurations and produce h-quality, dust-free cuts in virtually material.

Waterjet cutting uses a highly pressurized stream of water, sometimes with an added abrasive, to erode the workpiece. The waterjet stream, moving at nearly three times the speed of sound, can penetrate almost any material and thickness. Waterjets are often used on composites and plastics that cannot tolerate heat, mechanical damage, or delamination. And because the jet of water is constricted to a small diameter at such high pressures, the workpiece does not get wet.

Waterjets are widely used in aerospace, automotive, electronics, and other industries to cut products as wide ranging as

- Titanium aircraft components
- Printed circuit boards
- Automobile dashboards
- Diapers
- Cake and candy.

Waterjets were first used in production in the early 1970s to cut cardboard forms. Since then, its capabilities have grown, partially due to the use of abra- waterjet systems. A variation of waterjet, abrasive waterjet routinely cuts metals and harder, denser composites at greater thicknesses.

Automated waterjet cutting systems offer power, accuracy, and repeatability, making them an attractive cutting alternative. Currently there are 1500 waterjet systems in use worldwide, with an expected growth of 20% per year as more manufacturers seek the benefits of waterjet cutting for their applications.

Advantages

Waterjet cutting provides many advantages when traditional cutting methods prove inadequate.

Improved product quality—Waterjet cutting does not generate heat in the material being cut, so the product has no heat affected zone (HAZ), dross, or heat warpage, eliminating thermal and mechanical distortion. It cuts with a very narrow cutting width, or kerf, leaving a clean, finished edge.

Flexibility—Waterjet can cut a wide range of materials including

- Metals—titanium, lead, aluminum, steel
- Plastics
- Composites—fiberglass, graphite/epoxy
- Engineering materials—Kevlar®, Kapton®, Duroid®, Teflon®
- Paper
- Glass.

Waterjets can cut materials of varying thicknesses and densities without complicated adjustments.

Adaptable to automation—Nearly all waterjet systems utilize some type of automated carrier device. From *x-y* motion tables to CAD/CAM and 5-axis robotic systems, automated waterjets increase accuracy and cut complex shapes, contours, and configurations. Unlike conventional processes, waterjet cutting is omnidirectional, enabling accurate cuts to be made at any angle, even a tight inside radius. Waterjet can easily cut starter holes in the center of a workpiece, a task extremely difficult with

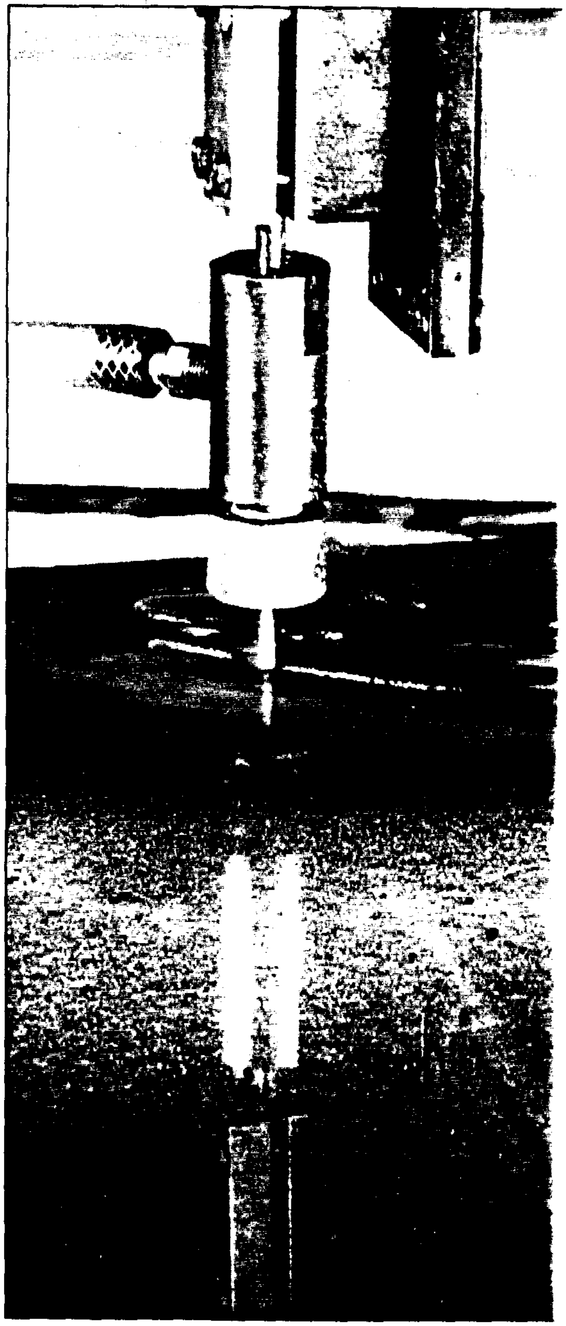


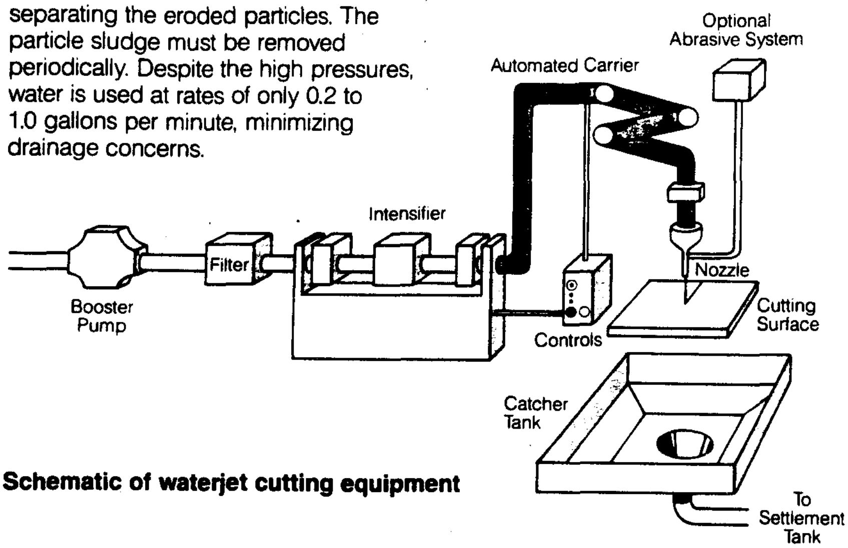
Figure 1. **Waterjet cuts difficult shapes and contours on glass quickly and accurately—a slow, difficult task using saws.**

Cutting with Water

Waterjet cutting uses a highly pressurized stream of water to erode the workpiece. Abrasive waterjet is a variation that introduces an abrasive such as garnet, silica, or zirconium into the stream to erode the workpiece. A waterjet system can quickly be converted to an abrasive system to cut thicker, harder materials.

Water is initially filtered to remove impurities, then pumped through an intensifier, a high-pressure pump that generates pressures as high as 60,000 pounds per square inch (psi). The water is forced through a constricting orifice, usually a synthetic sapphire ranging from 0.003 to 0.020 in. in diameter. The pressurized water exits the orifice (at velocities up to 3400 feet per second) in a coherent jet, yielding clean cuts with a kerf often no wider than the stream itself. Abrasive systems require a carbide insert inside the nozzle. This creates a vacuum and draws the abrasive into the stream and directs it to the orifice.

As the jet passes through the workpiece, a catcher traps the still-powerful stream and eroded particles. Large catching tanks under the cutting table are used with vertical waterjet systems. For omnidirectional systems, compact tube-like catchers move with the nozzle. The water then flows to a settlement tank, separating the eroded particles. The particle sludge must be removed periodically. Despite the high pressures, water is used at rates of only 0.2 to 1.0 gallons per minute, minimizing drainage concerns.



Schematic of waterjet cutting equipment

most methods. And waterjet integrates well into existing manufacturing systems.

Fewer production steps—Waterjets produce a clean edge cut, even on dense or hard materials, often eliminating finishing steps. The waterjet does not burn the cut edge so cleaning is not required.

Reduced dust and pollutants—The waterjet carries away the eroded material, practically eliminating dust, pollutants, and toxic fumes associated with other cutting methods.

Waterjet does have cutting limitations that should be considered. Due to the power of the jet, waterjet cuts all the way through a workpiece, making closed angles and enclosed sections difficult to cut. For example, you could not cut 2 in. deep into a 4-in.-thick workpiece. Current research in waterjet cutting systems addresses these limitations.

Alternate Technologies

Many manufacturers are still using traditional cutting methods, like band saws, knives, diamond-tipped tools, shears, and punch presses. When looking to convert to a more efficient system—one that can cut complex shapes with greater accuracy—the choices narrow to three methods: plasma, laser, and waterjet cutting.

Waterjets are likely to be chosen when a cut causing no heat distortion is required. Waterjet is often used when accurate cuts with minimal kerfs, no HAZ, and a finished quality edge are needed. Waterjet can be used on most materials and thicknesses but is slow on some materials.

Plasma cutting provides high speeds at great thicknesses but is primarily used on metals. Plasma can cause a wide kerf and heat distortion and generally cannot achieve the tolerances capable with waterjet systems. Plasma cutting systems are discussed in *TechCommentary* Vol. 4, No. 5.

Laser cutting achieves high speeds with minimal kerfs on thin materials. Primarily used for metals and composites under ½ in. thick, lasers can cause heat distortion, delamination of composites, and even toxic fumes on epoxy-based materials. Lasers are described in *TechCommentary* Vol. 3, No. 9.

Applications

The versatility of waterjet cutting makes it attractive to manufacturers in almost any industry. Automated waterjet systems can increase cutting speed and accuracy to improve production in many applications.

Automotive—The automotive industry is rapidly switching to composites, plastics, and new materials for automotive components. The industry now relies on waterjet to cut to near-net shapes for many components, including

- Plastic and fiberglass dashboards
- Wood fiber composite door panels
- Carpet and headliner fabrics
- Plastic gas tank shields
- Interior plastic trim for vans.

In automotive foundries, waterjet cuts gates and risers from iron and aluminum castings.

In another application, cutting asbestos brake linings for passenger cars, an automotive manufacturer switched from conventional sawing to waterjet. The switch increased cutting speeds and accuracy. The waterjet system uses a bank of six nozzles and cuts 30 to 50% faster than conventional sawing. The kerf was 0.155 in. with sawing and is only 0.010 in. with waterjet, reducing material usage. Dust was eliminated with waterjet—an important factor when cutting asbestos. The increased cutting speeds and other advantages result in savings of about $25,000 per year.

Electronics—Waterjets are often used in the electronics industry to cut loaded and unloaded circuit boards. The hairlike size of the kerf and the omnidirectional, sharp corner cutting capabilities of the waterjet permit precise cuts on composites without separating the composite layers. While lasers are also used for this application, some composites contain fibers that conduct heat and cause delamination.

Aerospace—The aerospace and aircraft industries must utilize hard, dense metals and composites that can

***Figure 2.* Waterjet cutting composite aircraft parts for the interior cabin eliminates costly trimming and finishing steps.**

withstand impact and drastic temperature changes. However, these characteristics also make them difficult to cut. Waterjet cuts exact shapes to meet strict tolerance specifications on

- Graphite/epoxy composites in structural wing components of military transport planes
- Fiber-reinforced composites for skin sections of helicopters and walls inside airplanes
- Contour trimming of advanced composite structures made from graphite, Kevlar®, and titanium
- Titanium for aircraft skins and ducts, landing gear, and turbine blades.

Other applications—Because waterjet is capable of cutting nearly any material at almost any thickness, its applications are widely varied and include cutting

- Vegetables and frozen foods
- Corrugated boxes
- Rock and concrete for excavation
- Astroturf®
- Stained glass.

Technical Considerations

When a manufacturer decides to convert from conventional tools to increase production, the primary choices are plasma, laser, and waterjet cutting systems. Although waterjet systems can cut most any material, their feasibility should be evaluated for each application. Many factors must be considered to determine if waterjet is right for your operation.

Material type—Waterjet is primarily used to cut materials for which plasma and lasers cause too great a kerf or HAZ. Composites, titanium, and food products are most often cut with waterjet because other methods are ineffective on these materials. Table 1 lists some of the materials and their thicknesses commonly cut with waterjet as well as cutting speeds.

Material thicknesses and cutting speeds—Waterjet is capable of cutting steel up to 3 in. thick and concrete slabs up to 12 in. thick. However, for practical applications, cutting speeds are the limiting factor. Thinner, softer materials, such as cardboard and rubber can be cut at speeds up to 3600 inches per minute (ipm). Achievable cutting speeds depend on the complexity of the cutting pattern, the nature and thickness of the material, and the capabilities of the carrier device.

Kerf—The amount of kerf depends on the material being cut, its thickness, and the diameter of the nozzle orifice. Typical kerfs range between 0.005 and 0.03 in.

Tolerances—The tolerance, or cutting accuracy, achievable with waterjet depends on the same factors as does the kerf. Generally, the tolerance achieved corresponds to the diameter of the nozzle orifice. Tolerances to 0.015 in. can often be obtained without further machining.

Abrasives—Abrasives are usually needed to cut metals and hard or dense composites. A grit, often garnet, silica, or zirconium, is pulled into the waterjet for greater erosive action. Abrasives can slightly increase kerf width.

Operating parameters—Operating parameters include water pressure, orifice diameter, and standoff distance. These parameters are set to optimum levels for each material, thickness, and desired cutting speed. The equipment supplier will help you determine the proper parameters for your application.

Power requirements—Most waterjet systems operate on 25 to 100 horsepower intensifiers, but some as large as 500 horsepower are used when many nozzles are required. One to twelve nozzles or cutting stations can be run from each intensifier pump. Power requirements range from 19 to 75 kW depending on the size of intensifier required.

Safety—Although there are inherent dangers when working with high-pressure equipment, safety concerns are minimal with waterjet cutting systems. Multiaxis systems are totally enclosed to reduce the pressure hazard and noise. Fire hazards associated with flame processes are eliminated. Dust, pollution associated with mechanical

***Table 1.* Waterjet Cutting Speeds on Representative Materials and Thicknesses**

	Material	Thickness, in.	Speed, ipm
Waterjet	ABS plastic	0.087	40–80
	Cardboard	0.055	240
	Graphite composite	0.06	36
	PC boards	0.06	118
	Plexiglas®	0.118	35
	Rubber	0.050	3600
Abrasive Waterjet	Aluminum	3.0	1.5
	Carbon steel	0.750	8
	Glass	0.50	15
	Kevlar®	0.56	12
	Stainless steel	1.0	2
	Titanium	0.12	18

Table 2. **Comparison of Waterjet Cutting with Competing Processes**

	Waterjet[a]	Laser[b]	Plasma Arc[b]
Material type	Any material	Most metals and many nonmetals	Metals only
Material thickness, in.	Up to 12	Under 0.5	Up to 6
Equipment costs, $	65,000–100,000	100,000–500,000	1,200–40,000
Kerf width, in.	0.003–0.125	0.010	0.027
HAZ	none	0.01	0.03
Tolerance	0.015	0.001	0.03

a) Ranges for a variety of materials.
b) Values for 1/4-in. steel.

methods, and dangerous fumes produced by lasers on some materials are also nearly nonexistent.

Economic Considerations

When evaluating a cutting method, consider both capital and operating costs.

Capital costs—A typical waterjet cutting system can be purchased for $65,000 to $100,000 and includes pumps, nozzles, and intensifier. The cost varies depending on the number of nozzles required, as additional intensifiers may be needed. Adding a relatively simple 3- and 5-axis system adds about $100,000. Some highly accurate robotics can cost as much as $500,000 but increase the complexity of shapes and configurations that can be cut. Special nozzles and the abrasive flow system add about $8,000 for abrasive cutting systems.

Operating costs—Operating costs include nozzles (possibly abrasives and carbides), electricity, water, and labor. Operating costs are estimated at $3 per hour for waterjet and $11 per hour for abrasive systems.

Abrasives, required for abrasive waterjet systems, are consumed at rates of 0.5 to 3 pounds per minute. Garnet, a commonly used abrasive, costs 25 to 30 cents per pound. Parts life varies greatly depending on pressure, water quality, and whether an abrasive is used. For waterjet systems, the constricting sapphire orifice lasts at least 50 hours and sometimes up to 300 hours, depending on water purity. For abrasive systems, the carbide is replaced every 4 to 6 hours, the orifice itself every 50 hours. An orifice costs $16 and a carbide costs $11. Both can be replaced in less than a minute. Labor costs are often reduced because only one operator may be required. The training time is approximately 3 days to operate the automated equipment but can take much longer if parts design is involved.

Outlook

Future developments in waterjet cutting systems focus on increasing attainable pressures and creating more accurate nozzles. These developments are expected to result in more efficient use of abrasives, further improvement in automated systems, and the use of portable waterjet systems for the construction industry.

The use of engineering plastics and composites demands the accurate cutting obtainable with automated waterjet cutting systems. As the use of these types of materials increases and as more manufacturers discover the many ways waterjet can benefit their cutting operations, the popularity of waterjet cutting continues to grow.

The information in this issue of *TechCommentary* gives an overview of the capabilities of waterjet cutting systems. If you think your company could use such a system, talk with your electric utility marketing representative and equipment vendors.

The EPRI Center for Materials Fabrication is operated by Battelle's Columbus Division. Basic funding is provided by the Electric Power Research Institute (EPRI), a nonprofit institute that conducts research and development on behalf of the United States electric utility industry.

The Center's mission is to assist metals, plastics, ceramics, and composites fabricators in implementing cost- and energy-efficient, electric-based technologies. *TechCommentary* is one communication vehicle that the Center uses to transfer technology to industry through an electric utility network. The Center also conducts applications development projects that demonstrate innovative uses of electrotechnologies.

This issue of *TechCommentary* was made possible through the cooperation of Carl Billhardt and John Bush of Battelle; and George Reinbold, Mitch Wade, and Bob Chellevold of Ingersoll-Rand.

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Kitagawa, T. "Future of Waterjet Cutting", *Metalworking*, March, 1986.

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"Waterjet and Laser Cutters Take on Tough Materials", *Plastics Technology*, Jan, 1987.

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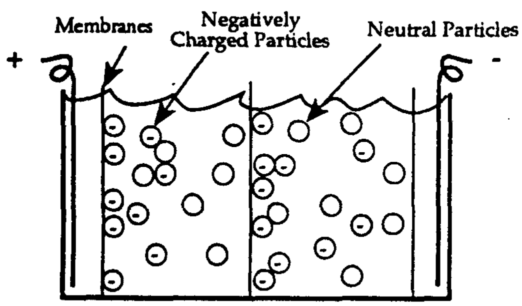
Photos courtesy of Ingersoll-Rand and BBDM Public Relations.

Applicable SIC Codes
17—71, 95 **20**—37, 65, 66
22—71, 72, 79, 93 **23**—96 **24**—92
26—53 **30**—79 **32**—31, 81, 92
33—16, 21-25, 51, 53-55, 61, 62, 69
34—11-99 **35**—11-99 **36**—12-99 **37**—11-99
39—31, 42, 44, 49, 93, 95, 96, 99

CENTER FOR MATERIALS FABRICATION
An EPRI R&D Applications Center
505 King Avenue • Columbus, Ohio 43201-2693
(614) 424-7742

Regulation Class: ○ Clean Air ◐ Clean Water ○ Haz. Waste ○ CERCLA ○ ______

Emerging Technology: *ELECTROPHORESIS*



BASIC ELECTROPHORETIC REACTOR

Source: EPRI

Function/Theory

Electrophoresis may be used to separate almost any type of charged particulate from either water or solid waste streams. In the process, feed materials are placed between layers of membranes contained in a cell and are then subjected to a DC potential. Oppositely-charged electrodes situated at each end of the cell attract the particles, and dialyzing membranes which permit only small ions and water to pass prevent further movement.

Likely SIC's

- 23 Apparel
- 28 Chemical
- 30 Rubber
- 32 Stone, Glass
- 33 Metals
- 34 Metals Fabric
- 36 Electrical
- 38 Instruments
- 39 Miscellaneous

Likely Industrial Applications/Considerations

Acceptance: ☐ High ☐ Medium ☑ Low

- Dye removal from industrial wastewater.
- Deposition of ceramics, metals, cements, and high polymers (i.e. rubber and paints).
- Separation of emulsions.

Environmental Benefits

- Any form of electrically-charged particles, whether living cells, inert material, or complex macromolecules, may be concentrated by this process.

Additional Benefits

- Cost of membranes is less than ion exchange membranes (used in electrodialysis).

Drawbacks

- When processing organic material, more voltage is required, thus producing higher costs.
- Organic processing using electrophoresis may produce toxicity and recovery problems.
- Creates concentrated solutions which are more hazardous than less concentrated solutions.
- Waste = solutions and membranes

Vendors

Backman Instruments, Inc.

Waste Stream Reduced

Air		*Water*		*Solid*
☐ Particulates	☐ Organics	☐ Particulates	☑ Organics	☐ Hazardous
☐ CO_2, NOx	☐ Toxics	☑ Metals, Ions	☐ Oil	☐ Non-Hazardous

Regulation Class: ○ Clean Air ◐ Clean Water ◔ Haz. Waste ○ CERCLA ○ ______

Emerging Technology: *FREEZE CONCENTRATION*

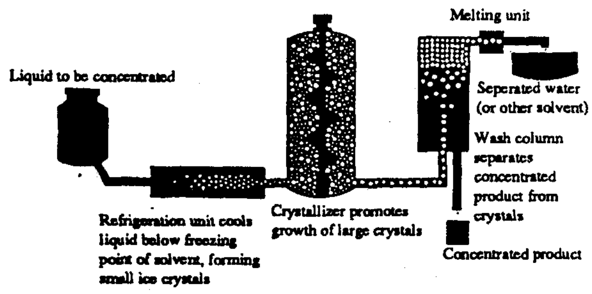
Likely SIC's

20 Food

26 Paper

28 Chemical

29 Petroleum



Freezing ⟶ Crystallization ⟶ Separation

FREEZE CONCENTRATION

Source: Grenco

Function/Theory

Freeze concentration uses the "refrigeration cycle" to lower the temperature of a mixed liquid to the freezing point of the constituents. Pure "crystals" (frozen constituents) are separated from mixtures mechanically or by use of compressed air.

Likely Industrial Applications/Considerations

Acceptance: ☐ High ☐ Medium ☑ Low

- Concentration of juice and dairy products.
- Crystalization of coffee and processing of beer, wine and vinegar.
- Chemicals processing including pharmaceuticals, industrial alcohols, and caustics.
- Treatment of waste water and hazardous waste.

Environmental Benefits

- Compared to other separation technologies, freeze concentration has lower criteria pollutant emissions.
- Zero discharge operation in hazardous waste water.

Additional Benefits

- End product is of higher sensory quality than obtainable with other methods of concentraion, primarily because no heat is involved.
- Reduced energy consumption.
- Due to the very low temperatures, corrosion is essentially eliminated.
- Lower microbiological contamination and lower cleaning requirements than with traditional fossil systems.
- Capable of continuous, long term processing.
- Losses of extract, alcohol and volatiles are negligible.
- Flavor and analytical differences between original and reconstituted products are minimal.
- The low temp. give immediate and effective chill stabilization thus removing the need for extended cold storage and, in most cases, the use of establishing aids.
- Concentrates have greatly extended flavor and physical shelf lives when stored for lengthy periods prior to final processing/packaging.

Drawbacks

- Limited to large volumes of liquid mixtures.
- High cost of equipment.
- Higher maintenance costs than traditional methods.
- Long shutdown, start-up times (24 hrs.).
- More labor intensive than traditional technology.
- Only one company is making commercially viable units.
- Not applicable for wastes which freeze with water, such as certain salts.
- Difficult to adapt to changing stream conditions.

Vendors

Grenco Technology

Waste Stream Reduced

Air		*Water*		*Solid*
☐ Particulates	☐ Organics	☑ Particulates	☑ Organics	☑ Hazardous
☐ CO_2, NOx	☐ Toxics	☐ Metals, Ions	☐ Oil	☐ Non-Hazardous

Regulation Class: ◔ Clean Air ◔ Clean Water ◑ Haz. Waste ○ CERCLA ○ ______

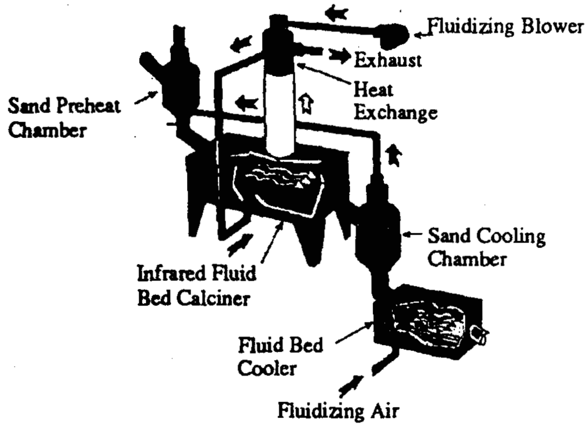
Likely SIC's

33 Metals

34 Metals Fabric.

37 Transportation

Emerging Technology: *INFRARED SAND RECLAMATION*



INFRARED SAND RECLAIMER

Source: Innovators - EPRI

Function/Theory

Infrared sand reclamation helps to cleanse the large amounts of sand used at foundries in the casting process so it can be recycled. The system uses high intensity infrared electricity to heat used sand to at least 1,500 degrees F. The heat burns away the chemicals and clay, leaving sand that can be reused to make more molds.

Likely Industrial Applications/Considerations

Acceptance: ☐ High ☑ Medium ☐ Low

- Recovery of spent sand in foundries and metals industries.
- Used where the volume of sand purchases and disposal costs exceed potential capital costs.

Environmental Benefits

- Helps foundry comply to environmental restrictions.
- Reduces the spent sand dumped in landfills.
- Does not require dewater like the wet reclamation process.
- Reduces carbon dioxide emissions.

Additional Benefits

- Cuts production costs by reducing new sand purchases and disposal fees.

Drawbacks

- Capital cost of reclamation system.
- Cost of maintenance, repair, and replacement of equipment.
- Some sand losses during reclamation.
- Some air emissions.

Vendors

BGK Industries

Waste Stream Reduced

Air		*Water*		*Solid*
☐ Particulates	☐ Organics	☑ Particulates	☐ Organics	☑ Hazardous
☑ CO_2, NOx	☐ Toxics	☑ Metals, Ions	☐ Oil	☐ Non-Hazardous

Major Vendors

EMERGING
TECHNOLOGIES

Electrophoresis

Beckman Instruments, Inc.
2500-T Harbor Blvd.
P.O. Box 3100
Fullerton, CA 92634
(714) 871-4848

Freeze Concentration

Grenco Technology
1101 N. Governor St.
Evansville, IN 47711
(812) 465-6603

Infrared Sand Reclamation

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