Combined Heat & Power (CHP) for Colleges and Universities

Presentation to:
Midwest Buildings Technology Application Center Webinar Series
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Presented by:
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Midwest CHP Application Center
University of Illinois at Chicago
Outline

- Midwest CHP Application Center
- CHP the Concept & Technology Building Blocks
- Are Colleges & Universities a Good Match for CHP?
- CHP Regulatory & Financial Issues
- Next Steps to Evaluating CHP
- Alternative CHP Designs
Regional Application Centers

The regional application centers will promote combined heat and power (CHP) technology and practices, serve as a central repository and clearinghouse of CHP information, and identify and help implement regional CHP projects.
Midwest CHP Application Center “MAC”

- Established in 2001 and located at the University of Illinois at Chicago
- U.S. DOE Sponsored Center
  - With support from 12 Midwest States
- Service area includes:
  - Illinois - Minnesota
  - Indiana - Missouri
  - Iowa - Ohio
  - Michigan - Wisconsin
  - Nebraska - Kansas
  - North Dakota - South Dakota
“MAC” – Mission & Focus

Mission:
Develop Technology Application Knowledge and the Educational Infrastructure Necessary to:
- Foster CHP as a Viable Energy Option in the Midwest
- Reduce any Perceived Risks Associated with its Implementation

Focus:
Foster Project Identification and Implementation through:
- Targeted Education
- Unbiased Information
- Technical Assistance
Available Services

- Website with Extensive CHP Information
  www.chpcentermw.org
- Full Gamut of Targeted Workshops / Courses
- CHP Site Project Profiles (Case Studies)
- Technical Assistance
- Specialty Reports & Studies
Distributed Generation

DG is …
• An Electric Generator
• Located At a Substation or Near a Building / Facility
• Generates at least a portion of the Electric Load

DG Technologies …..
• Solar Photovoltaic
• Wind Turbines
• Engine Generator Sets
• Turbine Generator Sets
  • Combustion Turbines
  • Micro-Turbines
  • Steam Turbines
• Fuel Cells
Combined Heat & Power (CHP)  
A Form of Distributed Generation

CHP is …

- An Integrated System
- Located At or Near a Building/Facility
- Provides at Least a Portion of the Electrical Load and
- Recycles the Thermal Energy for
  - Space Heating / Cooling
  - Process Heating / Cooling
  - Dehumidification
  - Domestic Hot Water

Picture Courtesy of UIC
Combined Heat and Power

100% (fuel input)

Prime Mover

15% to 20%

Generator

30% to 35%

electricity

Heat Exchanger

40% to 45%

Thermal System

Natural Gas
Propane
Digester Gas
Landfill Gas
Steam
Others
District Energy Systems

- Produce Steam, Hot Water, and/or Chilled Water at a Central Plant Located on Campus
- Pipe the Energy to Buildings in the District (Campus)
- Provide Space Heating, Domestic Water Heating, and Air Conditioning
Option 1
- Gaseous Fuel into the Prime Mover
- Produce Electricity & Heat thru Prime Mover
- Distribute the Recycled Energy for Heating and/or Cooling via the District Energy System

Option 2
- District Energy System Produces Steam
- Steam Produces Electricity and Heating / Cooling
- Recycled Energy Supplements Heating / Cooling via the District Energy System
Types of CHP Systems – Technology Building Blocks
CHP Basic Components

- $Q_{in}$ (fuel input)
- $W_{out}$
- $Q_{out}$

Prime Mover → Generator: electricity

Steam Turbine (Bottoming Cycle)

- Steam Loop (Heating)
- Hot Water Loop (Heating)

Absorption Chiller (cooling)
Combined Heat and Power

**CHP Prime Movers**

- Reciprocating Engines
- Industrial Gas Turbines
- Micro-turbines
- Steam Turbines
- Fuel Cells
- Caterpillar
- Waukesha
- Cummins
- Wartzila
- Jenbacher
- Fairbanks-Morse
Gas Turbine

- Turbine Here is Roughly 2 feet in Diameter
- Output is 7 MW (~10,000 HP)
Microturbines

- Consist of a compressor, combustor, and turbine
Fuel Cell Stack

Internal fuel cell stack (similar in most systems) Individual fuel cells comprise a fuel cell stack
Which Prime Mover to Use

- Recip. Engine --- Hot Water / Low Pressure Steam
- Industrial Gas Turbines --- High Pressure Steam, Usually over 3 to 4 MW in Capacity
- Steam Turbines --- Large District Energy Plant and/or Large Pressure Drop Requirements
- Micro-Turbines --- Fuel Flexibility, Relatively Small Capacities Required, Hot Water
- Fuel Cells --- Extremely Clean, Very Expensive
## Summary Table of CHP Prime Movers

<table>
<thead>
<tr>
<th></th>
<th>Diesel Engine</th>
<th>Natural Gas Engine</th>
<th>Gas Turbine</th>
<th>Microturbine</th>
<th>Fuel Cells</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Electric Efficiency (LHV)</strong></td>
<td>30-50 %</td>
<td>25-45 %</td>
<td>25-40 % (simple)</td>
<td>20-30 %</td>
<td>40-70 %</td>
</tr>
<tr>
<td><strong>Power Output (MW)</strong></td>
<td>0.05-5</td>
<td>0.05-5</td>
<td>3-200</td>
<td>0.025-0.25</td>
<td>0.2-2</td>
</tr>
<tr>
<td><strong>CHP installed cost ($/kW)</strong></td>
<td>800-1,500</td>
<td>800-1,500</td>
<td>700-900</td>
<td>500-1,300</td>
<td>&gt;3,000</td>
</tr>
<tr>
<td><strong>O&amp;M cost ($/kW)</strong></td>
<td>0.005-0.010</td>
<td>0.007-0.015</td>
<td>0.002-0.008</td>
<td>0.002-0.01</td>
<td>0.003-0.015</td>
</tr>
<tr>
<td><strong>Availability (uptime)</strong></td>
<td>90-95 %</td>
<td>92-97 %</td>
<td>90-98 %</td>
<td>90-98 %</td>
<td>&gt;95 %</td>
</tr>
<tr>
<td><strong>Hours between Overhauls</strong></td>
<td>25,000-30,000</td>
<td>24,000-60,000</td>
<td>30,000-50,000</td>
<td>5,000-40,000</td>
<td>10,000-40,000</td>
</tr>
<tr>
<td><strong>Start-up time</strong></td>
<td>10 sec</td>
<td>10 sec</td>
<td>10 min-1 hr</td>
<td>60 sec</td>
<td>3 hrs-2 days</td>
</tr>
<tr>
<td><strong>Fuels</strong></td>
<td>Diesel and residual oil</td>
<td>Natural gas, biogas, propane</td>
<td>Natural gas, biogas, propane, distillate oil</td>
<td>Natural gas, biogas, propane, distillate oil</td>
<td>Hydrogen, natural gas, propane</td>
</tr>
<tr>
<td><strong>NOx emissions (lb/MW-hr)</strong></td>
<td>3-33</td>
<td>2.2-28</td>
<td>0.3-4</td>
<td>0.4-2.2</td>
<td>&lt;0.02</td>
</tr>
<tr>
<td><strong>Uses for Heat Recovery</strong></td>
<td>Hot water, LP steam, district heating</td>
<td>Hot water, LP steam, district heating</td>
<td>Direct heat, hot water, LP-HP steam, district heating</td>
<td>Direct heat, hot water, LP steam</td>
<td>Hot water, LP-HP steam</td>
</tr>
<tr>
<td><strong>CHP output (Btu/kWh)</strong></td>
<td>3,400</td>
<td>1,000-5,000</td>
<td>3,400-12,000</td>
<td>4,000-15,000</td>
<td>500-3,700</td>
</tr>
<tr>
<td><strong>Useable Temp for CHP (8F)</strong></td>
<td>180-900</td>
<td>300-500</td>
<td>500-1,100</td>
<td>400-650</td>
<td>140-700</td>
</tr>
</tbody>
</table>
Generators

- **Induction:**
  - Requires External Power Source to Operate (Grid)

- **Synchronous:**
  - Self Excited, Does Not Need the Grid to Operate

- **Inverter:**
  - Converts DC to AC Power (micro-turbines & fuel cells)
Thermally Activated Technologies

- Steam or Hot Water Heating Loops
- Absorption Chillers
- Desiccant Dehumidification
CHP Equipment Summary

- Prime Movers
  - Recip. Engines, Turbines, Fuel Cells
- Generators
  - Synchronous, Induction, Inverters
- Heat Recovery
  - Steam, Water, Air
- Thermal Equipment
  - Space/Process Heat, Absorption Chillers, Desiccant Dehumidifiers
Combined Heat and Power

CHP Is A Low Technical Risk

- Utilize Proven Technologies
- Employ Standard Design Practices
- Incorporate Good Maintenance Practices

CHP Is More a Financial and Regulatory Risk
CHP is a Good Match for Colleges and Universities
### Conventional Energy System vs. CHP

**Combined Heat and Power**

**Electric Effic:** \(\frac{35}{113} = 31\%\)  
**Heating Effic:** \(\frac{50}{59} = 85\%\)  
**Combined Effic:** \(\frac{85}{172} = 49.4\%\)

**Electric Effic:** \(\frac{35}{100} = 35\%\)  
**No Additional Fuel for Recycled Heat**  
**Combined Effic:** \(\frac{85}{100} = 85\%\)
Campus Energy Costs

Electricity is 38% of consumption
- Increased 13% 1995-2005

Natural Gas is 35% of consumption
- Increased 129% 1995-2005

College and University Energy Costs have risen from $5B to over $7B since 1995 – with most of the increase occurring in the last five years
Emerging Drivers for CHP on Campuses

- Rising & Volatile Energy Costs
- Energy Loads Growing - Driven by Building Construction
- Thermal Loads (heating & cooling) Tend to Match Well with Electric Power Requirements
- Existing District Energy Piping Systems Already Aggregate the Thermal Requirements
Easy Transfer of the Thermal Energy
Emerging Drivers

- Common Ownership and Able to Retain 100% Energy Savings
- Move Toward “Sustainability” and Green Campuses
- University Hospitals and Critical Care Research Labs – Reliability is Paramount
- Utilized as Emergency Centers During Disaster Situations
- History of Success
CHP & Campus Sustainability

- CHP higher efficiencies translate into less air pollutants & less greenhouse gases
- CHP higher efficiencies & environmental advantages can add 8 to 10 points on LEED certification

Over 100 College & University Presidents have committed their campuses to reversing climate change

American College & University Presidents Climate Commitment:  http://presidentsclimatecommitment.org/
Emerging Drivers

- Common Ownership and Able to Retain 100% Energy Savings
- Move Toward “Sustainability” and Green Campuses
- Energy Reliability is Paramount
  - University Hospitals
  - Critical Care Labs
  - Emergency Center in Disaster Situations
- History of Success
CHP can be an effective tool to keep critical facilities online during prolonged electric grid outages

- Hurricane Katrina – August, 2005
  - Mississippi Baptist Medical Center: 100% operation during 57 hour outage

- Blackout 2003
  - Norwalk Hospital … Connecticut
  - Cargill Salt Inc. … Michigan
  - North Shore Towers … New York
  - Millennium Chemicals … Ohio
  - South Oaks Hospital … New York
Installed CHP

- 82,400 MW at approx. 3000 sites (Nationally)
- Represents approx. 9% of total US generating capacity
- Saves an estimated 3 Quads of fuel per year
- Eliminates over 400 million tons of CO$_2$ emissions annually
History of Success

- Nationally
  - 210 Colleges & Universities with CHP Installed
  - Total Capacity --- 2,545 MW (3% CHP market)

- Midwest (12 States)
  - 48 Installations
  - Total Capacity: 790 MW

Source of Data: DOE CHP Database
### Midwest CHP Installations in Higher Education

- University Of Iowa
- Iowa State University
- University Of Northern Iowa
- University of Illinois
- Moose International
- Illinois Institute Of Technology
- Illinois Central College
- Univ. Of Illinois, Chicago-East Campus
- Northeastern Illinois University
- College of DuPage
- Chicago State College
- Univ. of Illinois, Chicago- West Campus
- Loyola University Medical Center
- Joliet Junior College
- Lewis University
- Sauk Valley Community College
- Triton College
- Elgin Community College
- Art Institute of Chicago
- University Of Notre Dame Power Plant
- Purdue University Physical Plant
- Indiana State University
- Culver Educational Foundation
- University Of Michigan
- Michigan State University
- Northwood Institute
- Albion College
- Ferris State College
- Central Michigan University
- Western Michigan University
- Eastern Michigan University
- Wayne State University
- Grand Valley State University
- Henry Ford Community College
- University Of Minnesota Plant Upgrade
- University Of Missouri
- Southeast Missouri State University
- Oberlin College
- Mccracken Power Plant
- Medical College Of Ohio
- College of Wooster
- Kent State University
- University of Cincinnati
- University Of Wisconsin At Whitewater
- University Of Wisconsin-Madison
Benefits of CHP

- **Economic**
  - Reduces fuel & electricity costs

- **Environmental**
  - Reduces amount of fuel burned per unit of energy output – reducing air pollutants & greenhouse gases

- **Reliability**
  - Reduces impact of grid outages (disaster response) & grid congestion

- **Resources**
  - Requires less fuel per energy output, thus reducing the demand for our finite natural resources
Combined Heat and Power

CHP – Regulatory and Financial Issues
CHP Regulatory Requirements

- Grid Interconnection --- Lack of Standards
- Utility Standby / Backup Rates
- Environmental Permitting (over 1 MW)
  - Air Permitting
  - Water Permitting
- Other Permitting Requirements
  - Local Codes
  - OSHA
Normal CHP Configuration

- CHP Systems are Normally Installed in Parallel with the Electric Grid (CHP does not replace the grid)
- Both the CHP and Grid Supply Electricity to the Customer
- Recycled Heat From the Prime Mover Used for:
  - Space Heating (Steam or Hot Water Loop)
  - Space Cooling (Absorption Chiller)
  - Process Heating and/or Cooling
  - Dehumidification (Desiccant Regeneration)
  - Domestic Hot Water
# Two Types of Generators

<table>
<thead>
<tr>
<th>Induction</th>
<th>Synchronous</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Requires External Power Source to Operate (Grid)</td>
<td>• Self Excited (Does Not Need Grid to Operate)</td>
</tr>
<tr>
<td>• When Grid Goes Down, CHP System Goes Down</td>
<td>• CHP System can Continue to Operate thru Grid Outages</td>
</tr>
<tr>
<td>• Less Complicated &amp; Less Costly to Interconnect</td>
<td>• More Complicated &amp; Costly to Interconnect (Safety)</td>
</tr>
<tr>
<td>• Preferred by Utilities</td>
<td>• Preferred by CHP Customers</td>
</tr>
</tbody>
</table>
System Operation

- CHP systems often times are sized for the thermal load of the facility (potential for highest efficiency)
- Additional electricity needs purchased from the grid
- Excess power can be sold to the grid
- Black Start Capability Recommended
  - Should the grid and the CHP go down, the CHP system can be restarted without grid support.
Grid Interconnection

- Any CHP Interconnection Must Address
  - Safety of customers, line workers, general public
  - Integrity of the grid & quality of service
  - Protection of equipment
  - System Control by the utility
Grid Interconnection Standards

- Institute of Electrical and Electronic Engineers (IEEE) has developed standardized technical interconnection protocols (IEEE 1547)
- Underwriters Laboratory (UL) has developed interconnect equipment standards (UL 1741)
- Left to individual states to develop standard rules, protocols and procedures based on the above standards
- If no State standard, must follow individual Utility rules and protocols
• Interconnection – Not a Technical Issue
  – Technology exists to safely connect to any type grid
  – Most utilities provide example “tie ins”

• Interconnect – Cost & Utility Acceptance Issue
  – True cost varies with interconnect complexity
  – Utility resistance can add significant cost
    • Studies
    • Hardware
Financial Considerations

In a recent IDEA survey, 90% of the respondents identified $$ as the obstacle to CHP implementation

- Spark Spread: Difference between the cost of purchasing electricity from the grid versus the cost of the CHP Fuel
- Cost differential between a conventional system and a CHP system
- Economic value placed on power reliability and other benefits (beyond reduced energy costs)
- Understanding and availability of financial options
Financial Options

- **Vendor Financing** - Generally Suitable for smaller projects

- **Leasing**
  - Operating lease
  - Leverage lease
  - True lease
  - Municipal lease
  - Capital lease

- **Bonds**
  - General obligation bonds
  - Revenue bonds
Financial Options

- **Energy Savings Performance Contracts**
  - Guaranteed Savings
  - Stipulated Savings

- **Bank Loan**

- **Partnerships**

- **Utility Programs**

- **Capital Appropriations**

More information is available from the “CHP on Campus Online Guidebook” at [http://www.districtenergy.org/guidebook/chp.webdoc.homepage.htm](http://www.districtenergy.org/guidebook/chp.webdoc.homepage.htm)
Next Steps -- Educate

- Resource Guide & Tech. Profiles
  - MAC Website @ www.chpcentermw.org

- U.S. Department of Energy
  - www.eere.energy.gov/de/

- EPA – CHP Partnership
  - www.epa.gov/chp

- International District Energy Assoc.
  - www.districtenergy.org
### Next Step – Initial Screens

<table>
<thead>
<tr>
<th>STEP 1</th>
<th>Please check the boxes that apply to you:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Do you pay more than $.06/ kWh on average for electricity (including generation, transmission and distribution)?</td>
</tr>
<tr>
<td></td>
<td>Are you concerned about the impact of current or future energy costs on your business?</td>
</tr>
<tr>
<td></td>
<td>Is your facility located in a deregulated electricity market?</td>
</tr>
<tr>
<td></td>
<td>Are you concerned about power reliability? Is there a substantial financial impact to your business if the power goes out for 1 hour? For 5 minutes?</td>
</tr>
<tr>
<td></td>
<td>Does your facility operate for more than 5000 hours/ year?</td>
</tr>
<tr>
<td></td>
<td>Do you have thermal loads throughout the year (including steam, hot water, chilled water, process heat, etc.)?</td>
</tr>
<tr>
<td></td>
<td>Does your facility have an existing central plant?</td>
</tr>
<tr>
<td></td>
<td>Do you expect to replace, upgrade or retrofit central plant equipment within the next 3-5 years?</td>
</tr>
<tr>
<td></td>
<td>Do you anticipate a facility expansion or new construction project within the next 3-5 years?</td>
</tr>
<tr>
<td></td>
<td>Have you already implemented energy efficiency measures and still have high energy costs?</td>
</tr>
<tr>
<td></td>
<td>Are you interested in reducing your facility’s impact on the environment?</td>
</tr>
</tbody>
</table>

Questionnaire Provided by EPA CHP Partnership
Next Step – Initial Screen

If you have answered “yes” to 3 or more of these questions, your facility MAY be a good candidate for CHP.

- **Step 2:**
  - Contact Qualified Engineering Firm
  - Contact Midwest CHP Application Center (John Cuttica @ 312-996-4382)
  - Contact EPA CHP Partnership (Kim Crossman @ 202-343-9388)
Next Step – Level Two Engineering Analysis

- Contact Qualified Engineering Company
- Make Sure the Company has done CHP Analyses
- Capable of hour by hour Load Profile Simulation
- Do not use Average Rates or Costs
- Get the Local Utility Involved Early
Examples – Alternative Designs
University of Iowa – Biomass

- 24.9 MW Coal Steam CHP Plant
- 50% Biomass Co-firing - Oat hulls - byproduct of breakfast cereal
- Displace 23,000 tons of coal annually
- Reduce emissions by nearly 50%
- Fuel Savings of $500,000 to $700,000 annually
UCLA – Landfill Gas for CHP

- 43 MW Combined Cycle CHP Facility
- 21,900 ton Cooling Plant
- Landfill gas for 30% of annual plant fuel
- Reduced emissions 34% and water use 70 million gal/year
- Eliminated 4,000,000 ft³ flareoff of LFG/day
Elgin Community College - Illinois

- 4.1 MW Recip. Engine System
- Low Pressure Steam (11,200 MMBtu/hr)
- Absorption Cooling (1,350 RT)
- Emergency Center during Grid Outages – Black Start Capability
Antioch Community High School - Illinois

- 360 kW Capstone Microturbine System
- Landfill Gas Project
- Heat Recovery Space Heating
Where To Obtain More Information
- Midwest CHP Application Center
  www.chpcentermw.org

- U.S. Department of Energy
  http://www.eere.energy.gov/de/

- U.S. EPA CHP Partnership
  www.epa.gov/chp

- International District Energy Association
  www.districtenergy.org