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Development of a Pollution Prevention Factors Methodology Based on Life-Cycle Assessment

Lithographic Printing Case Study

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DEVELOPMENT OF A POLLUTION PREVENTION FACTORS METHODOLOGY BASED ON LIFE-CYCLE ASSESSMENT: LITHOGRAPHIC PRINTING CASE STUDY

by

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FOREWORD

Today's rapidly developing and changing technologies and industrial products and practices frequently carry with them the increased generation of materials that, if improperly dealt with, can threaten both public health and the environment. The U.S. Environmental Protection Agency is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. These laws direct the EPA to perform research to define our environmental problems, measure the impacts, and search for solutions.

The Risk Reduction Engineering Laboratory is responsible for planning, implementing, and managing research, development, and demonstration programs. These provide an authoritative defensible engineering basis in support of the policies, programs, and regulations of the EPA with respect to drinking water, wastewater, pesticides, toxic substances, solid and hazardous wastes, and Superfund-related activities. This publication is one of the products of that research and provides a vital communication link between researchers and users.

This report describes a preliminary pollution prevention (P2) factors methodology which was developed using a streamlined life-cycle assessment (LCA) approach. The lithographic printing industry was selected as the test industry. Two P2 activities associated with lithographic printing were selected for P2 factor calculation. These two activities were solvent substitution in blanket and press wash and waterless versus conventional dampening fountain system printing. Individual criterion scores and the total of all criteria scores were determined for impacts occurring both before and after implementation of the P2 activity. The P2 factor was determined to be the ratio obtained by dividing the total score after P2 implementation by the total score before P2 implementation, with a score higher than 1.0 indicating a reduction in environmental impacts. The results of applying the preliminary methodology to the two selected pollution prevention activities to identify reduced or increased environmental impacts are presented in the report.

E. Timothy Oppelt, Director
Risk Reduction Engineering Laboratory

ABSTRACT

A preliminary pollution prevention (P2) factors methodology was developed using a streamlined life-cycle assessment (LCA) approach. The lithographic printing industry was selected as the test industry due to the willingness of the Graphic Arts Technical Foundation (GATF) and seven of their member companies to provide data, as well as the availability of published information on a wide variety of P2 activities that have been undertaken by this industry. Scoring criteria were developed with five levels that indicate decreasing environmental impact by the numbers 1, 3, 5, 7, and 9, with the number 9 indicating the least environmental impact. Criteria for a given P2 activity were selected from a master list of possible criteria by using stressor/impact chains to indicate the environmental impact areas where a change is expected due to implementation of the P2 activity. A good understanding of LCA and environmental impact assessment, as well as an understanding of the industry and P2 activities under evaluation, are very important in selecting the appropriate criteria for scoring.

Two P2 activities associated with lithographic printing were selected for P2 factor calculation. These two activities were solvent substitution in blanket and press wash and waterless versus conventional dampening fountain system printing. Individual criterion scores and the total of all criteria scores were determined for impacts occurring both before and after implementation of the P2 activity. Each of the criteria was given equal weight in calculating the total score. The P2 factor was determined to be the ratio obtained by dividing the total score after P2 implementation by the total score before P2 implementation, with a score higher than 1.0 indicating a reduction in environmental impacts. However, improvement in one or more individual criteria should also be considered when selecting a P2 activity, even if the overall P2 factor score does not show a dramatic improvement.

It should be stressed that the preliminary P2 factors methodology described in this report still requires more development before it can be used as an accurate screening tool to provide direction in selecting P2 activities that provide the most environmental improvement. Therefore, the P2 factor numbers should only be used as an indicator of the general degree of environmental improvement for the entire life-cycle that has occurred, or might be expected to occur, as a result of implementing a particular P2 activity.

The methodology permitted calculating and comparing P2 factors for individual companies and averages for multiple companies. The accuracy of the P2 factor depends on better data collection than many companies have historically done, since most companies focus their data collection connected with implementing a P2 activity on cost savings and not on data needed to score environmental criteria. Potential problems with the methodology that can be resolved with additional testing include evaluation of the impact on the P2 score due to implementation of more than one P2 activity at the same time, and addition of criteria that give credit for reduction in the quantity of hazardous materials (e.g., solvents) used. Additional testing is also needed to see if the P2 factors methodology is applicable to other industries and to evaluate how much improvement in the P2 factor is necessary to make implementation of the new activity worthwhile from an environmental impact reduction standpoint.

This report was submitted in fulfillment of contract 68-C0-0003 by Battelle under the sponsorship of the U.S. Environmental Protection Agency. This report covers a period from July 1993 to December 1993, and work was completed as of January 1994.

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Battelle gratefully acknowledges the assistance of members of the Graphic Arts Technical Foundation (GATF) and Toray Corporation. Gary Jones, Manager, Office of Environmental Information at GATF, assisted in identifying cooperating printing companies and supplied comments on the impact/stressor diagrams for lithographic printing pollution prevention activities. Individual company data on pollution prevention activities was supplied through the assistance of the following employees who work at the lithographic printing companies indicated: David Hewitt, Dartmouth Printing; Jeff Adrian, The John Roberts Company; Kathleen Winters, Mack Printing Group; Bob Bade, Impressions, Inc.; Walter Bowles, James River Corporation; Bill Spencer, Intelligencer Printing Company; and Rob Sternau and Kevin Green, Merchants Press. John O'Rourke of the Toray Corporation provided the results of a survey of nine printers that switched from conventional to waterless printing.

Battelle also acknowledges the support and encouragement of the U.S. EPA Project Officer, Mary Ann Curran. Two Battelle staff, Jody A. Jones and Kenneth D. Pugsley, assisted with the data collection by visiting the printing facilities.

SECTION 1

INTRODUCTION AND OVERVIEW

P2 FACTORS DEFINITION

The basis for this Work Assignment is the idea that the Life-Cycle Assessment (LCA) approach can be used for the development of pollution prevention (P2) factors. A P2 factor is defined as a numerical or semi-quantitative ratio between alternative source reduction activities which indicates the magnitude of the resulting environmental effects. This methodology does not require conducting a "full LCA" which accounts for all emissions associated with energy use, resource extraction and environmental releases across the life-cycle system. It is anticipated that this type of an approach would require excessive effort and cost, resulting in the development of very few P2 factors. Therefore, the goal of this task is to develop a simplified LCA methodology involving a mix of life-cycle inventory and impact assessment scoring criteria that can be used to screen candidate P2 activities.

LIFE-CYCLE ASSESSMENT

LCA is a systematic method for identifying, evaluating, and minimizing the environmental consequences of resource usage and environmental releases associated with a product, process, or package. LCA takes a comprehensive approach by analyzing the entire life cycle, which includes the following four stages: raw materials acquisition, manufacturing, use/reuse/maintenance, and recycle/waste management (U.S. EPA, 1993). LCA has traditionally been used by industry to guide internal decision-making on product and process changes.

A complete LCA consists of several interrelated phases.

1) **Goal Definition and Scoping** - goal definition identifies the purpose for a particular LCA and its intended uses. Scoping defines the boundaries, assumptions, and limitations for a specific LCA (Fava et al., 1993).

2) **Inventory Analysis** - a technical, data-driven process of quantifying energy and raw material requirements, atmospheric emissions, water effluents, and solid waste for the entire life cycle of a product, process, or package, including all four of the life-cycle stages listed above.

3) **Impact Assessment** - a technical, quantitative, and/or qualitative process of characterizing and assessing the effects of the resource requirements and environmental loadings identified in the inventory component. The assessment should address ecological and human health impacts, as well as resource depletion.

4) **Improvement Assessment** - a systematic evaluation of the needs and opportunities to reduce environmental burdens associated with energy, raw materials use, and waste emissions throughout the life cycle of a product, process, or package (Fava et al., 1993; U.S. EPA, 1993).

The LCA methodology can provide valuable information to effect environmental improvements. Implementation of opportunities to reduce burdens to the environment can occur during any of the three components of LCA. For example, the inventory component alone may be used to show where an input or output is highest in a given process and, therefore, direct opportunities for reducing emissions, energy consumption, and material use. The impact assessment attempts to use information on environmental effects, moving beyond the numerical quantification of inputs and outputs of the inventory data.

Improvement analysis, though not well-developed from a methodological standpoint, provides information which helps ensure that environmental benefits are optimized and adverse impacts to human health and the environment are not created as improvement opportunities are implemented.

EPA'S LIFE-CYCLE ASSESSMENT RESEARCH PROGRAM

The P2 Factors research project is one of several life-cycle related projects being conducted under the auspices of the Life-Cycle Assessment Research Program. This program was established in 1990 by the EPA's Pollution Prevention Research Branch (PPRB) in Cincinnati, Ohio. Through the LCA Research Program, PPRB is investigating LCA-related issues through a series of case studies on various products, processes, and activities. The results of these studies will be used to advance current understanding of the methodology and encourage wider adoption of the life-cycle concept by industry and government. In 1993, PPRB published a guidance manual on LCA, entitled "Life-Cycle Assessment: Inventory Guidelines and Principles" (EPA/600/R-92/245). The procedural guidance described in the manual is being used to conduct demonstrations to measure the effectiveness and utility of the LCA manual. Life-cycle inventory and impact assessment methodology will continue to develop as PPRB conducts real-world applications in close cooperation with industry, academia, and other federal agencies.

In a related field, PPRB is working with universities and other federal agencies, including the Departments of Defense and Energy, to identify opportunities for product and process re-design through life-cycle assessments. A series of life-cycle design demonstrations is being conducted with industry and government partners.

PPRB continues to investigate life-cycle assessment methodology (inventory, impact assessment, and improvements analysis) and its many applications in order to provide a wide audience with the necessary tools and data that are needed to evaluate the environmental impacts of products, processes and activities from cradle to grave so that risks to human health and the environment can be identified and minimized or eliminated.

SECTION 2

PRELIMINARY P2 FACTORS FRAMEWORK

A preliminary P2 factors methodology has been developed that accommodates calculation of both an industry average for an entire industry and a site-specific value for an individual company, in order to determine which P2 activities result in the greatest environmental improvement. This section describes potential P2 factors users and limitations of the method. Section 3 demonstrates how the calculations would be used for a specific industry (lithographic printing).

POTENTIAL USERS OF P2 FACTORS

It is expected that the users of this P2 factors methodology will include both industry and government. The method can be used by an entire industry, or a single company in that industry, to identify which P2 activities result in the greatest overall environmental improvement. This information can be used along with other factors, such as cost, manufacturability, and performance, to choose among similar P2 alternatives. It can also be used by government agencies to justify policy decisions regarding preferred P2 activities.

LIMITATIONS OF THE P2 FACTORS METHODOLOGY

P2 factors are designed to quantify the environmental improvement in the form of a ratio, where the denominator is the summed score for criteria before application of a specific P2 activity, and the numerator is the summed score for the same criteria after implementation of that P2 activity. A P2 factor calculated for a specific P2 activity in a given industry can be compared on a relative basis with other P2 factors calculated for the same industry to see which activity provides the greatest environmental improvement. However, a P2 factor should not be used to claim that a specific alternative is good or bad for the environment. Each factor is only scored for selected criteria within certain life-cycle stages that are expected to be effected by the implementation of the P2 activity. P2 factors are not based on all activities and do not represent all possible impacts in all life-cycle stages, and thus do not represent a full LCA.

It should be stressed that this preliminary P2 factors methodology is still being developed as a screening tool to provide direction in selecting P2 activities that provide the most environmental improvement. Therefore, the P2 factor should only be used as an indicator of the general degree of environmental improvement for the entire life-cycle that has occurred, or might be expected to occur, as a result of implementing a particular P2 activity. At this point in development of the methodology, sensitivity analysis has not been calculated for each factor. That is to say, in comparing two P2 factors we need to determine how much of a difference is needed between the factors in order to be able to say that one is clearly superior. For example, if a factor of 1.01 is compared to a factor of 1.05 and each is described as ± 0.5 through sensitivity analysis, then these factors would be essentially equivalent.

CRITERIA SELECTION

The first step in developing P2 factors is to identify which criteria are likely to change as a result of implementing a P2 activity. This is accomplished with the help of stressor/impact chains as discussed in the impact framework document prepared by the Society of Environmental Toxicology and Chemistry (Fava et al., 1992). The impact/stressor concept has also been developed by The Scientific Consulting Group, Inc. (1993) for the Environmental Resource Guide (ERG) under a contract with the American Institute of Architects (AIA) and with cooperative funding from the U.S. Environmental Protection Agency (EPA). The ERG constructs general materials flow diagrams, which focus on the most important environmental considerations at each stage of the life cycle and connects these with one or more impacts that could occur.

Thus, the ERG concentrates on the elements that appear to be most significant in terms of their volume, toxicity, or potential environmental damage.

As defined by SETAC (Fava et al., 1993), stressors are conditions that may lead to human health or ecological impairment or to resource depletion. Stressor/impact chains can be developed by considering the energy, water, and raw material inputs to life-cycle stage, as well as the air, water and solid waste emission outputs from each life-cycle stage. The inputs and outputs can then be compared against lists of potential impacts (e.g., Fava et al., 1993 and Heijungs et al., 1992), in order to develop stressor/impact chains. The development of stressor/impact chains prior to calculating P2 factors is designed to focus the P2 evaluation only on those stressors and associated impacts that are expected to change in one or more life-cycle stages as a result of implementation of a P2 activity. Development of the stressor/impact chains and selection of the impact criteria for analysis should be done by someone who is trained in life-cycle or impact assessment and who has a reasonably good understanding of the industry and P2 activities under evaluation.

CRITERIA SELECTION FOR INDUSTRY-AVERAGE OR SITE-SPECIFIC P2 CALCULATION

Depending on whether the P2 factors are going to be used for making general recommendations applicable to an entire industry or whether the use of the P2 factors is specific to a single company at a single location (site-specific), the criteria selected for determining the P2 factor may be slightly different. Table 1 lists the criteria that may be selected to develop industry-average or site-specific P2 factors for any industry. The life-cycle stages where these criteria may be relevant are indicated by an "x". However, during the calculation of a specific P2 factor for a particular industry, only a subset of the criteria will be relevant. Furthermore, the stressor/impact chains discussed above may indicate that significant changes resulting from implementation of a P2 activity are only likely to occur during selected stages for a certain criterion. In addition, some criteria are relevant from a industry-average standpoint (i.e., when the entire industry is evaluated), and other criteria may only be appropriate when the P2 factor is determined from a site-specific standpoint (i.e., a single company at one location).

Table 1. List of Potential Scoring Criteria for Determining P2 Factors, with Relevant Life-Cycle Stage Indicated by an "X".

SCORING CRITERIA	RMA[(a)]	MAN[(b)]	U/R/M[(c)]	R/WM[(d)]
Habitat Alteration	x			
Industrial Accidents	x	x		
Resource Renewability	x			
Energy Use	x	x	x	x
Net Water Consumption	x	x	x	x
Preconsumer Waste Recycle Percent		x		
Airborne Emissions	x	x	x	x
Waterborne Effluents	x	x	x	x
Solid Waste Generation Rate		x		
Recycle Content		x		
Source Reduction Potential		x		
Product Reuse		x		
Photochemical Oxidant Creation Potential (POCP)	x	x	x	x
Ozone Depletion Potential (ODP)	x	x	x	x
Global Warming Potential (GWP)	x	x	x	x
Surrogate for Energy/Emissions to Transport Materials to Recycler		x	x	
Recyclability Potential (Postconsumer)				x
Product Disassembly Potential				x
Waste-to Energy Value				x
Material Persistence				x
Toxic Material Mobility after Disposal				x
Toxic Content		x		x
Inhalation Toxicity		x		x
Landfill Leachate (Aquatic) Toxicity				x
Incineration Ash Residue				x

(a) RMA = Raw Material Acquisition
(b) MAN = Manufacturing
(c) U/R/M = Use Reuse and Maintenance
(d) R/WM = Recycle/Waste Management

SECTION 3

EVALUATION OF PRELIMINARY P2 FACTORS METHODOLOGY USING LITHOGRAPHIC PRINTING

SELECTION OF INDUSTRY AND P2 ACTIVITIES FOR CASE STUDY

In order to demonstrate the use of this preliminary framework for developing P2 factors, the lithographic printing industry has been selected for the first case study. This decision was based in part on the willingness of the Graphic Arts Technical Foundation (GATF) and seven of their member companies to provide data. Selection of the printing industry as the first case study was also based on the availability of published information on a wide variety of P2 activities that have been undertaken by this industry.

Many different P2 activities have been implemented by one or more of the seven lithographic printers that agreed to provide information for this project. Two P2 activities, solvent substitution for blanket or press wash (Figure 1) and use of waterless versus conventional printing (Figure 2), were selected for more detailed analysis, because data needed for analysis were readily available, and the criteria used for evaluation were expected to be different. Thus, criteria for the two P2 activities on solvent substitution in blanket and press wash and waterless versus conventional printing were scored and the P2 factors were calculated.

SELECTION OF SCORING CRITERIA FOR SPECIFIC P2 ACTIVITIES

Based on the stressor/impact chains shown in Figures 1 and 2, 11 scoring criteria were selected in three life-cycle stages (Table 2) using the process described in Section 2. These criteria were selected from the larger list of scoring criteria in Table 1, because these specific stressors were expected to change from the conditions before versus after implementation of the two P2 activities. In addition, a twelfth scoring criterion is available as a fall-back option for scoring stressors that can not be readily quantified with available data. Some criteria, such as global warming potential (GWP), ozone depletion potential (ODP), and photochemical oxidant creation potential (POCP) were applied to printing, but not to manufacture of petrochemicals. These potentially applicable criteria were not scored for petrochemical manufacture, in order to keep the process as simple as possible, and because existing data on petrochemical manufacture do not indicate which emissions result from manufacture of individual chemicals. If refinements in the Toxic Chemical Release Inventory (TRI) request information on emissions of chemicals with ODP, GWP, or POCP, these criteria can be (and should be) included later.

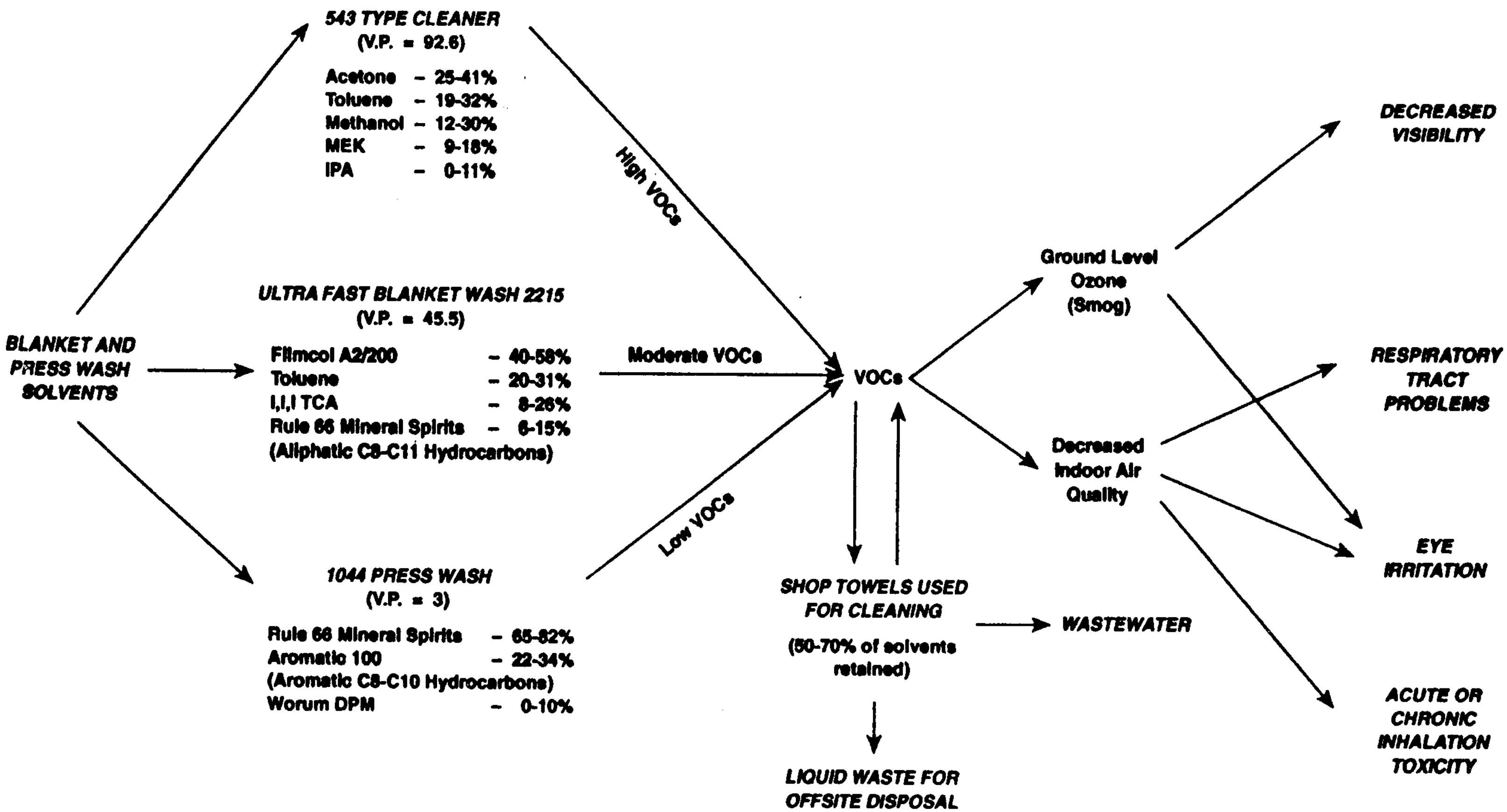


FIGURE 1. STRESSOR/IMPACT DIAGRAM FOR SOLVENT SUBSTITUTION IN BLANKET OR PRESS WASH

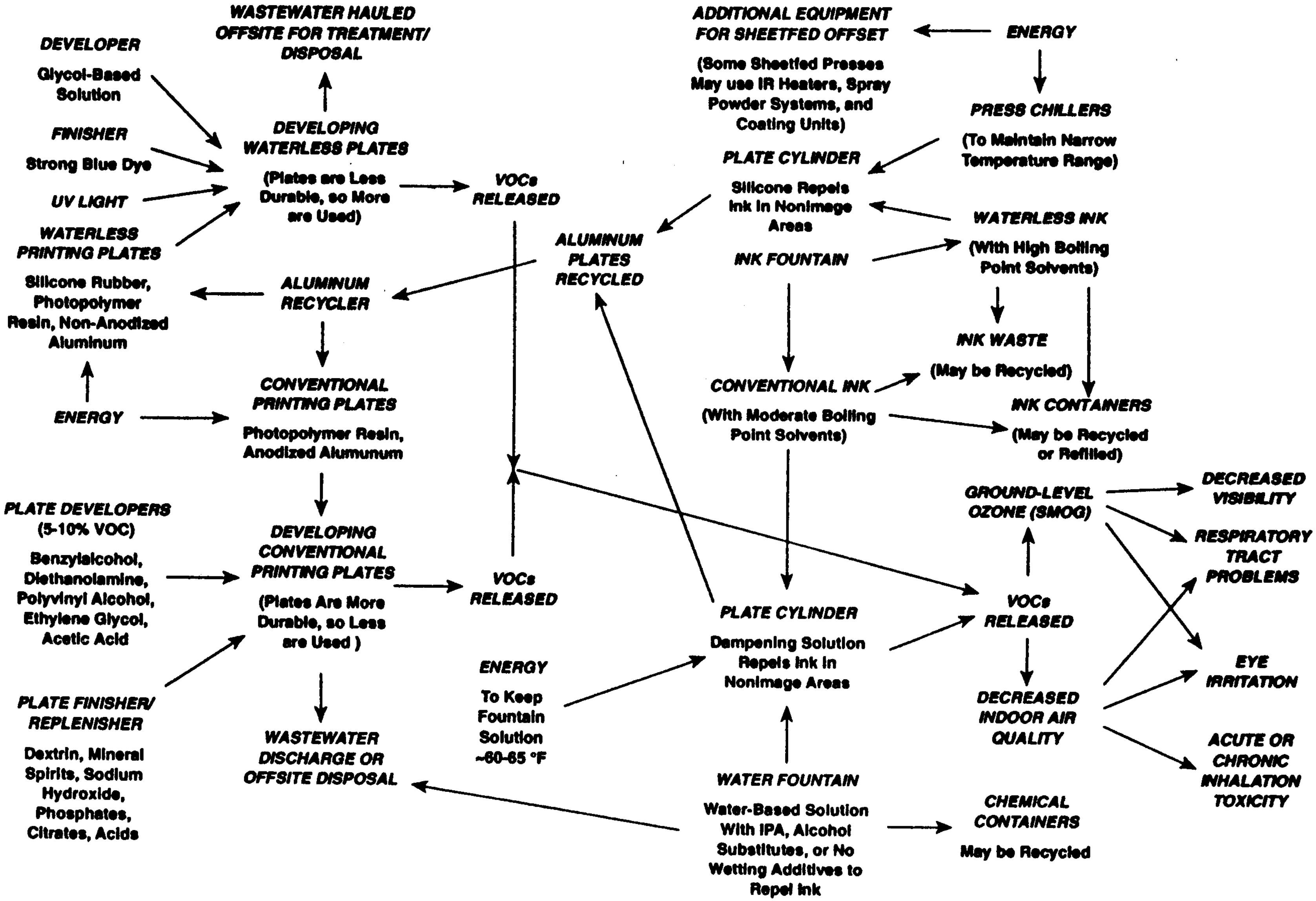


FIGURE 2. STRESSOR/IMPACT DIAGRM FOR WATERLESS PLATES VERSUS CONVENTIONAL PLATES FOR PRINTING AND ALUMINUM PLATE RECYCLING

Table 2. Evaluation Criteria and Scoring Ranges for Calculation of P2 Factors for Two P2 Activities Used by Lithographic Printers

RAW MATERIAL ACQUISITION STAGE

Habitat Alteration

Score	Criteria Ranges for Habitat Alteration
9	Few acres altered; habitat recovery <5 years (e.g., natural gas or oil extraction)
7	Moderate number of acres altered; recovery 5-25 years (e.g., temperate forestry, underground mining)
5	Moderate number of acres altered; recovery 25-100 years (e.g., tropical forestry)
3	Many acres (hundreds) altered; recovery 25-100 years (e.g., strip mining)
1	Many acres altered; recovery 100+ years
*	Insufficient information

Resource Renewability

Score	Criteria Ranges for Resource Renewability
9	Renewability < 1 year (e.g., biomass feedstocks)
7	Renewability 1 - 25 years (e.g., temperate softwoods)
5	Nonrenewable, sustainability > 500 years (e.g., coal, oil, natural gas)
3	Nonrenewable, sustainability 50 - 500 years (e.g., aluminum)
1	Nonrenewable, sustainability < 50 years
*	Insufficient data

MANUFACTURING STAGE

Material Manufacture

Energy Usage

Score	Criteria Ranges for Energy Usage Per Unit Output
9	<5,000 BTU/lb
7	5,000 - 10,000 BTU/lb
5	10,000 - 20,000 BTU/lb
3	20,000 - 30,000 BTU/lb
1	>30,000 BTU/lb
*	Insufficient data

Table 2. (continued)

Toxic/Hazardous Airborne Emissions

Score	Criteria Ranges Based on Applicable Airborne Pollutant Emissions Regulatory Limits at Material Manufacturing Facility
9	Airborne pollutant emissions consistently >50% below limits
7	Airborne pollutant emissions frequently >25-50% below limits
5	Airborne pollutant emissions frequently >10-24% below limits
3	Airborne pollutant emissions typically at the limits
1	Airborne pollutant emissions often exceed one or more of limits
*	Insufficient information

Waterborne Effluents

Score	Criteria Ranges Based on Applicable Water Pollutant Emissions Regulatory Limits at Material Manufacturing Facility
9	Water pollutant emissions consistently >50% below limits
7	Water pollutant emissions frequently >25-50% below limits
5	Water pollutant emissions frequently >10-24% below limits
3	Water pollutant emissions typically at the limits
1	Water pollutant emissions often exceed one or more of limits
*	Insufficient information

Product Fabrication (Printing)

Energy Usage

Score	Criteria Ranges for Energy Usage Per Unit Output
9	<5,000 BTU/lb
7	5,000 - 10,000 BTU/lb
5	10,000 - 20,000 BTU/lb
3	20,000 - 30,000 BTU/lb
1	>30,000 BTU/lb
*	Insufficient data

Table 2. (continued)

Photochemical Oxidant Creation Potential (POCP)

Score	Potential for Ground-Level Ozone (Smog) Formation (The POCP of an emission is based on the ratio between the change in the ozone concentration due to a change in the emission of that VOC and the change in the ozone concentration due to a change in ethylene emissions)
9	≤0.005 (e.g., methane, tetrachloroethylene)
7	0.050-0.006 (e.g., average halogenated hydrocarbons, methylene chloride)
5	0.500-0.051 (e.g., average alcohols, methanol, average ketones, acetone, methyl ethyl ketone, average non-methane hydrocarbons, average alkanes, average esters)
3	0.999-0.501 (e.g., average aromatic hydrocarbons, toluene, o-xylene, m-xylene, p-xylene, average olefins)
1	≥1.000 (e.g., ethylene, propylene)
*	Insufficient information [see Heijungs (1992a) for POCP of additional chemicals]

Score Modifier: The score should be modified if more than 500 gallons of solvent are released (total used minus amount recovered for recycle or fuel blending) per year due to blanket cleaning activities and if the printer is located in an air quality non-attainment area for ozone. Decrease the calculated score by two or four points for areas with ozone non-attainment classifications considered, respectively, "marginal-to-serious" or "severe-to-extreme" (see maps on Figures 3 and 4).

Ozone Depleting Potential (ODP)

Score	ODP (for Stratospheric Ozone) Relative to CFC-11
9	<0.01 (all non-halogenated chemicals, HFC-125, HFC-134a, HFC-143a, HCFC-152a)
7	0.01-0.39 [HCFC-22, HCFC-123, HCFC-124, HCFC-141b, HCFC-142b, HCFC-225ca, HCFC-225cb, 1,1,1-trichloroethane (HC-140a)]
5	0.40-0.69 (CFC-115)
3	0.70-0.99 (CFC-114)
1	≥1.00 (CFC-11, CFC-12, CFC-113, Carbon Tetrachloride, Halon-1301, Halon-1211, Halon-1202, Halon-2402, Halon-1201 HC-10)
*	Insufficient information

Score Modifier: The score should be modified based on the quantity of solvent released (total used minus amount recovered for recycle or fuel blending) per year times the ODP. Decrease the score by two points if the product of ODP times solvent quantity released per year is greater than 100 gallons. For calculation purposes, assume an ODP of 0.01 for all non-halogenated hydrocarbons.

Table 2. (continued)

Global Warming Potential (GWP)

Score	GWP: Equal Mass Relative to CO_2 over 100 Years
9	<1 (H-2401, H-2311)
7	1-99 (CO_2, HCFC-123, H-1211, H-1202, H-2402, H-1201, Methane, HCFC-141b)
5	100-499 (Nitrous Oxide, HCFC-124, HFC-152a, Methyl Chloroform)
3	500-4999 (CFC-11, CFC-113, Carbon Tetrachloride, HCFC-22, HFC-125, HFC-134a, HCFC-142b, HFC-143a)
1	>5000 (CFC-12, CFC-114, CFC-115)
*	Insufficient information

Score Modifier: The score should be modified based on the quantity of solvent released (total used minus amount recovered for recycle or fuel blending) per year times the GWP. Decrease the score by two points if the product of the vapor pressure of the solvent times the length of evaporation time results in a number greater than 500. The evaporation time is the number of minutes the solvent is uncovered and available for rapid evaporation during one press cleaning operation (e.g., the amount of time the solvent is on shop towels or automatic blanket roller wash).

Surrogate for Energy/Emissions to Transport Material to Recyclers

The quantity of printing plates or wastepaper in pounds is a surrogate for the amount of energy and air emissions required to transport each material to the aluminum smelter or paper mill where the materials are finally recycled into new aluminum or paper. The units are expressed as the change in pounds of plates or wastepaper recycled for before minus after the P2 activity implementation. The score for before implementation of the P2 activity should be given a 5 and the score for after implementation should be determined as indicated below.

Score	
9	Decrease in pounds recycled by >25%
7	Decrease in pounds recycled by 10-25%
5	Change in pounds recycled ± 10%
3	Increase in pounds recycled by 10-25%
1	Increase in pounds recycled >25%
*	Insufficient data

Table 2. (continued)

Inhalation Toxicity

Score	Air Concentration Criteria Ranges for Major Component, Additives, or Degradation Products: NOAEL or OSHA Standard
9	NOAEL >1,000 mg/m^3 in air
7	NOAEL 10-1,000 mg/m^3 in air
5	NOAEL 0.1-10 mg/m^3 in air
3	NOAEL 0.01-0.1 mg/m^3 in air
1	NOAEL <0.01 mg/m^3 in air or carcinogen
*	Insufficient information
Score Modifier	The score should be modified based on the presence of toxic trace constituents that are present in such low (< 5 %) concentrations in a formulation that their contribution from a percentage standpoint would not effect the overall formulation score. In these cases, if the trace constituent would receive a score of 1 when considered alone, the score for the overall formulation should be lowered by two points.

Fall-Back Option for any Criteria where Data are Unavailable

Score	Estimated Status for xxxxxx Criterion Relative to Industry Norm
9	Much better than industry norm (roughly ≥ 50% better)
7	A little better than industry norm (roughly 25-50% better)
5	Roughly equal to industry norm (status quo ± 25%)
3	A little worse than industry norm (roughly 25-50% worse)
1	Much worse than the industry norm (roughly ≤ 50% worse)

Classifed Ozone Nonattainment Areas

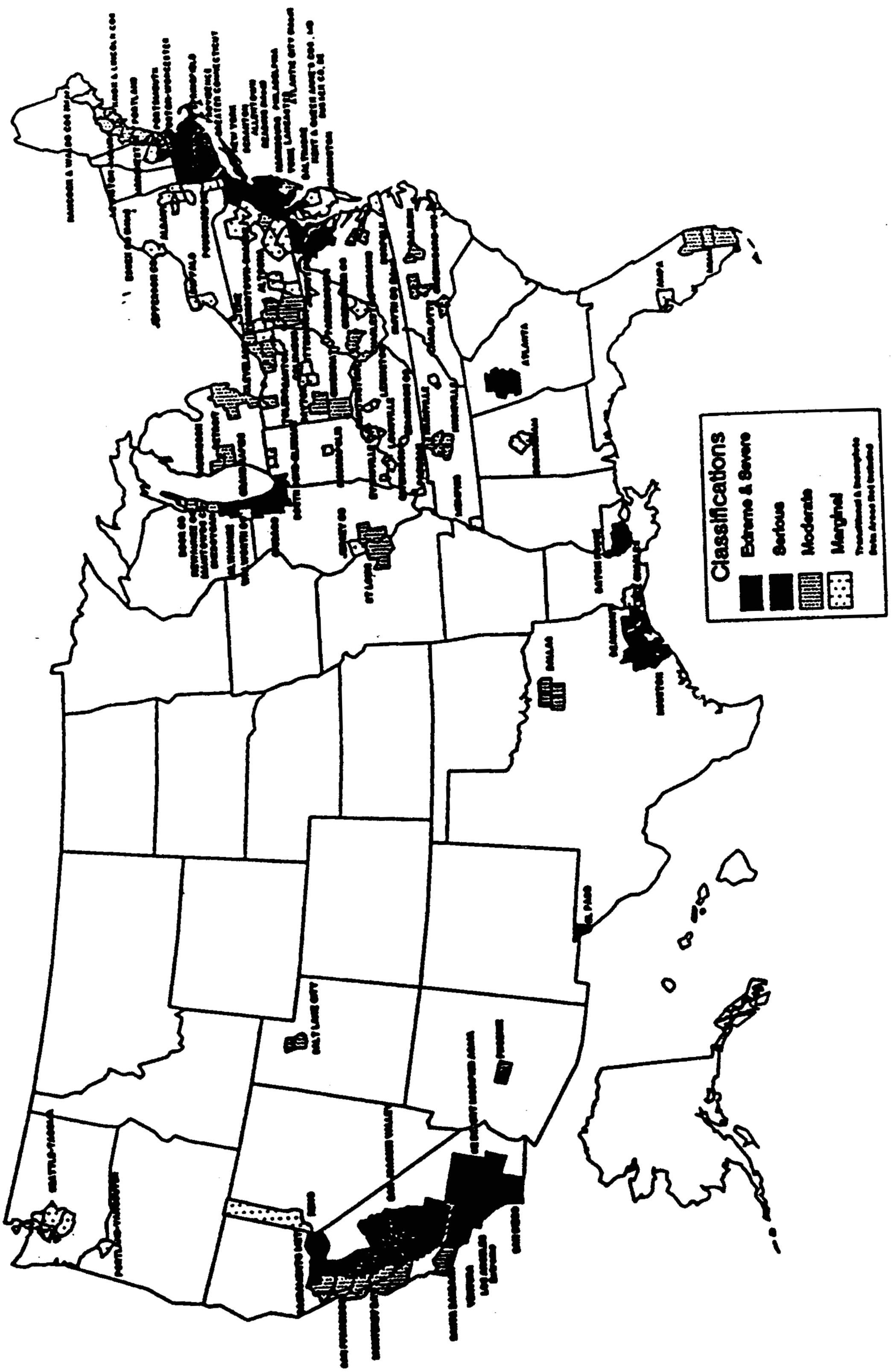
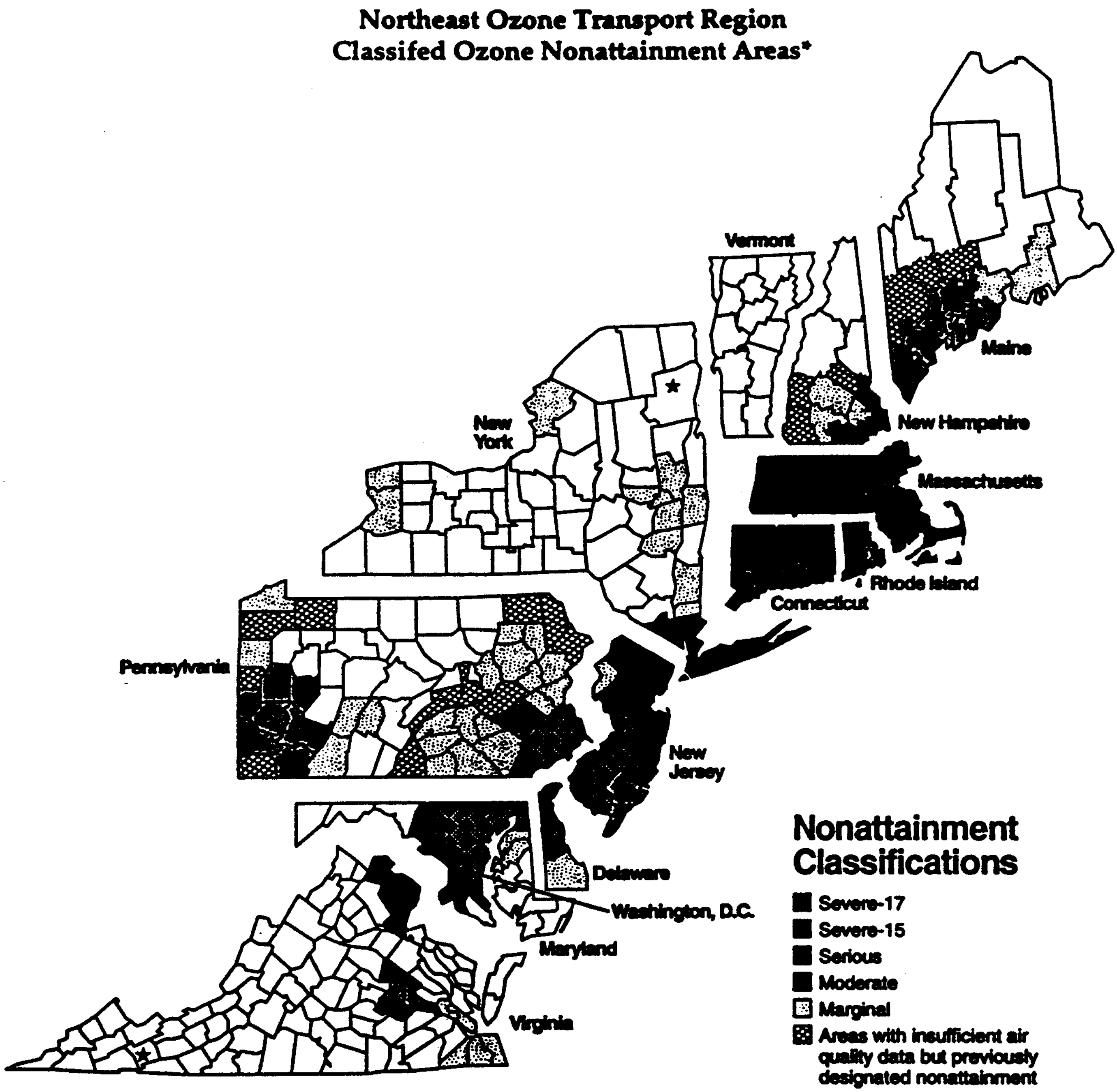


FIGURE 3. OZONE NON-ATTAINMENT CLASSIFICATIONS FOR THE UNITED STATES (Thompson Publishing Group, Inc., 1993)



Only the portion of Virginia falling within the Washington, D.C., CSMA (the portion shaded Serious) is part of the Ozone Transport Region.

Stars indicate Rural Transport Areas. These small, mountaintop areas are classified as Marginal.

FIGURE 4. OZONE NON-ATTAINMENT CLASSIFICATIONS FOR THE NORTHEASTERN U.S. OZONE TRANSPORT REGION (Thompson Publishing Group, Inc., 1993)

PETROCHEMICAL CLASSIFICATIONS

Many P2 activities involve the use of chemicals derived from petroleum and natural gas. Evaluating energy consumption and emissions for producing these materials is an important part of a life-cycle methodology. Pollution prevention assessments would typically involve either comparing two options where one set of chemicals was substituted for another or where a non-chemical alternative was substituted for a chemical one. To maintain the practical usability of the P2 factors approach, it was necessary to develop a scoring system that did not require detailed analysis of the life-cycle of each individual chemical.

Petrochemical production involves taking a complex mixture of aliphatic and aromatic compounds through a series of thermal and chemical reactions to separate them into marketable fractions and to upgrade their economic value. This suggested that a simple basis for categorizing the chemicals into groups would be the type and extent of processing. In each category chemicals were grouped together if the number and character of the processing steps were similar. Then, energy estimates were made for one or two members of the group in order to obtain the group score. This yields a simple tabulation of the basic slate of petrochemicals that should be suitable for scoring most P2 activities involving these materials (Table 3).

The use of categories for partitioning the compounds is a simplification of the actual operations within a petrochemical complex (Table 4). In some cases energy recovered from exothermic reactions is used to offset the requirements of reactions requiring energy. Further, as one moves from Category A, where the operations are applied to the entire mixture of materials, to categories E and F, where the starting materials may be subjected to individual reaction sequences to produce the final compounds, the potential for a given chemical not falling into the range of energy scores for the class increases. Resources for this effort did not permit individually checking additional chemicals to estimate the magnitude of the error and to determine whether it is systematic or random. (Random errors for a larger number of chemicals would increase the overall uncertainty of the method, but would result in equal probability of high and low scores.) In the future it is recommended that additional individual compounds be used to check the validity of the recommended P2 methodology.

SOLVENT SUBSTITUTION IN BLANKET OR PRESS WASH

The first P2 activity used to demonstrate calculation of a P2 factor was substitution of the solvents for blanket or press wash formulations. Data for this P2 activity were obtained from three of the cooperating lithographic printers. The main reason for implementing this P2 activity is to reduce the quantity of volatile organic compounds (VOCs) released to the air. Based on the stressor/impact chain shown in Figure 1, the following seven scoring criteria were selected in two life-cycle stages: energy use, airborne emissions, and waterborne effluents for the materials manufacturing (petroleum refining) step of the manufacturing stage; and photochemical oxidant creation potential, ozone depletion potential, global warming potential, and inhalation toxicity for the product fabrication (printing) step of the manufacturing stage. These criteria were selected from the larger list of scoring criteria in Table 1, because these seven stressors were expected to change due to the decreased volatility of the blanket/press wash mixture.

Table 3. Determination of Energy Use, Air Emissions, and Waterborne Effluent Criteria Scores for Manufacture of Petrochemicals in Classification Categories[a].

CLASS[a]	CRITERIA[b]	SCORE
A Examples: Rule 66 Mineral spirits or Solvent 140 (aliphatic C8-C11 hydrocarbons), Aliphatic Petroleum Distillates(C9-C11), VM&P (complex mixture of aliphatic C7-C9 and toluene)	Energy Use (Aliphatic C8-C11 - 30,000 BTU) Refs: 1, 4, 5, 7	3
	Air Emissions[c] Based on a 98% efficiency of the air pollution control equipment. Refs: 1, 4, 5, 8	7
	Waterborne Effluents Refs: 1, 4, 5, 7	5
B Examples: Aromatic Hydrocarbons, Xylene, Cumene, Naphthalene, Ethyl Benzene	Energy Use (Cumene - 22,500 BTU; Ethylbenzene - 20,000 BTU) Refs: 1, 4, 5, 7	3
	Air Emissions[c] Refs: 1, 4, 5, 8	5
	Waterborne Effluents Refs: 1, 4, 5, 7	5
C Examples: Acetone, Methanol, MEK, Isopropyl Alcohol, Filmcol, MIK, 2-Butoxy Ethanol	Energy Use (Acetone - 20,000 BTU) Refs: 1, 4, 5, 6, 8	5
	Air Emissions[c] Based on a 98% removal efficiency of the air pollution control equipment. Refs: 2, 4, 5, 7	7
	Waterborne Emissions Refs: 1, 4, 5, 7	7
D Examples: Toluene, 1,2,4-Trimethylbenzene	Energy Use (Trimethylbenzene - 35,059 BTU) Refs: 1, 4, 5, 7	1
	Air Emissions[c] Refs: 2, 3, 4, 5, 7	5
	Waterborne Effluents Refs: 4, 5, 7, 8	5
E Examples:1,1,1 Trichloroethane, Dipropylene Glycol Monomethyl Ether, 1,4-Dioxane, Methylene Chloride	Energy Use (1,1,1 Trichloroethane - 35,000 BTU) Refs: 1, 4, 5, 6, 7	1
	Air Emissions[c] Refs: 4, 5, 7, 8	3
	Waterborne Effluents Refs: 4, 5, 7	5
F Examples:Diisononyl Phthalate, 2,6-Di-Tert-Butyl-p-Cresol	Energy Use (Diisononyl Phthalate - >30,000 BTU) Refs: 1, 4, 5, 6, 7	1
	Air Emissions[c] Refs: 4, 5, 7, 8	3
	Waterborne Effluents Refs: 4, 5, 7	5

(a) Petrochemical Classification Categories are described in Table 4.
(b) References: 1) PWMI (1993), 2) Heylin (1979), 3) Kronsoder (1976), 4) McKetta (1993), 5) Nelson (1958), 6) Froment and Bischoff (1979), 7) Kirk and Othmer (1984), and 8) Farrauto et al. (1992).
(c) Air emissions do not include CO_2 emissions.

Table 4. Definitions of Petrochemical Classification Categories Used in Table 3.

Category A:	contains simple aliphatic molecules and distillate fractions obtained from the petroleum source with minimal processing effort.
Category B:	contains simple aromatic molecules and distillate fractions obtained from the petroleum source with minimal processing effort.
Category C:	contains more complex aliphatic molecules obtained from the petroleum source with moderate processing effort.
Category D:	contains more complex aromatic molecules obtained from the petroleum source with moderate processing effort.
Category E:	contains the most complex aliphatic molecules obtained from the petroleum source with high processing effort. These should be evaluated separately when possible.
Category F:	contains the most complex aromatic molecules obtained from the petroleum source with high processing effort. These should be evaluated separately when possible.

Individual solvents used in one or more blanket wash or fountain solution mixtures for any of the printing facilities used in P2 factor calculations have been scored in Table 5. The scores for energy use, air emissions, and waterborne effluents were obtained for the material manufacture step of the manufacturing life-cycle stage by using the scores for the appropriate petrochemical classification in Table 3. The scores for the criteria on POCP, ODP, and GWP were determined directly from the examples listed for each criterion range in Table 2. The POCP, ODP, and GWP intensity values for the chemicals listed as examples in the scoring ranges for these criterion in Table 2, as well as additional individual chemicals not used in the solvent formulas evaluated, are available in Heijungs (1992a). The score for the criterion on inhalation toxicity [i.e., the time-weighted average (TWA) in mg/m^3] was determined from the OSHA (1990) standards or from toxicity data in the material safety data sheet (MSDS). In Table 6, the raw scores for the individual chemicals were proportionally (based on % composition of the mixture) used to calculate the combined score for each mixture used in a blanket or press wash by one of the three printing companies evaluated.

John Roberts Company

The stressor/impact chain in Figure 1 shows the two changes made by the John Roberts Company in their blanket and press wash over a 5 year period. They started with 543 Type Cleaner in 1988, changed to Ultra Fast Blanket Wash 2215 in 1990, and made another switch to 1044 Press Wash in 1993. Records were kept of the quantity of solvent used for each year, and the total sales increased by 61 percent over the five year period.

For the John Roberts Company, the solvent mixture combined scores for each of the three blanket/press wash formulations were as follows: 543 Type Cleaner - 45.1, Ultra Fast Blanket Wash - 37.0, and 1044 Press Wash - 43.8. Based on the scores for the solvent mixtures, the first solvent switch was calculated as a P2 factor of 0.82, and a P2 factor of 1.18 was calculated for the second solvent switch. In each case the solvent mixture combined score after the solvent switch is divided by the solvent mixture combined score before the solvent switch. Since there were two solvent mixture changes in this example, the P2 factor can also be determined by dividing the solvent mixture combined score after the second solvent switch by the solvent mixture combined score before the first solvent switch, which results in a P2 factor of 0.97 for switching from the first to the last solvent mixture. These P2 factors can then be compared with P2 factors for other solvent substitutions (e.g., the other two companies described below) or with other types of P2 activities for the lithographic printing industry. The higher the P2 factor, the lower the environmental impacts.

Impressions, Inc.

Impressions, Inc. was initially using 555 Typewash and 70 Press Wash and switched to 1066 Press Wash. The combined score for the 555 Type wash and 70 Press Wash, which is proportionally based on the quantities of each solvent mixture used, is indicated as 43.7 in Table 6. The combined solvent mixture score for 1066 Press Wash is 42.5. Thus, a P2 factor of 0.97 was calculated for the switch.

Table 5. Criteria Scores for Individual Solvents Used in Press or Blanket Wash Mixtures or Dampening Fountain Solutions

	Chemical	CAS Number	Energy Use	Airborne Emissions	Waterborne Emissions	Photo-chemical Oxidant Creation Potential	Inhalation Toxicity	Ozone Depleting Potential	Global Warming Potential
1	Acetone	67-64-1	5	7	7	5	9	9	9
2	Aliphatic Petroleum Distillates (C9-C11)	64742-48-9	3	7	5	5	7	9	9
3	Aromatic 100 or WC100 (aromatic C8-C10 hydrocarbons)	64742-95-6	3	5	5	3	7	9	9
4	Aromatic 150 (aromatic hydrocarbons)	64742-94-5	3	5	5	3	7	9	9
5	2-Butoxy ethanol	111-76-2	5	7	7	5	7	9	9
6	Cumene	98-82-8	3	5	5	3	7	9	9
7	Diisononyl phthalate	28553-12-0	1	3	5	3	1	9	9
8	1,4-Dioxane	123-91-1	1	3	5	5	1	9	9
9	Dipropylene glycol monomethyl ether	20324-32-7	1	3	5	5	7	9	9
10	2,6-Di-tert-butyl-p-cresol	128-37-0	1	3	5	1	5	9	9
11	Ethyl benzene	100-41-4	3	5	5	3	7	9	9
12	Ethlyene glycol	107-21-1	1	3	5	5	7	9	9
13	Filmcol A2/200		5	7	7	5	7	9	9
14	Isopropyl alcohol	67-63-0	5	7	7	5	7	9	9
15	Methanol	67-56-1	5	7	7	5	7	9	9
16	Methyl ethyl ketone	78-93-3	5	7	7	5	7	9	9
17	Methyl isobutyl ketone (hexone)	108-10-1	5	7	7	5	7	9	9
18	Methylene chloride	75-09-2	1	3	5	7	1	9	7
19	Monocyclic terpene hydrocarbon	5989-27-5	3	5	5	7	7	9	9
20	Napthalene (10% by weight Aromatic 150)	91-20-3	3	5	5	3	7	9	9
21	Nonylphenoxypoly(ethyleneoxy)ethanol	9016-45-9	1	3	5	3	7	9	9
22	Rule 66 Mineral Spirits or Solvent 140 (aliphatic C8-C11 hydrocarbons)	64742-88-7	3	7	5	5	7	9	9
23	Toluene	108-88-3	1	5	5	3	7	9	9
24	1,1,1-trichloroethane (Methyl chloroform)	71-55-6	1	3	5	5	9	7	5
25	1,2,4-Trimethylbenzene (2% Aromatic 150)	95-63-6	1	5	5	3	7	9	9
26	VM&P (aliphatic C7-C9 hydrocarbons & toluene)		3	7	5	5	7	9	9
27	Worum DPM	34590-94-8	5	7	7	5	7	9	9
28	Xylene	1330-20-7	3	5	5	3	7	9	9

Table 6. Combined Solvent Mixture Scores Based on Percent Composition of Individual Chemicals

COMPANY Combined Solvent		Energy Use	Airborne Emissions	Waterborne Emissions	Photo-chemical Oxidant Creation Potential	Inhalation Toxicity	Ozone Depleting Potential	Global Warming Potential	Individual Solvent Mixture Score	Average Concurrent Solvent Mixture Score	Intermediate P2 Factor	Overall P2 Factor
THE JOHN ROBERTS COMPANY, MINNEAPOLIS, MN												
534 Type Cleaner	raw score	4.0	6.5	6.5	4.5	7.7	9.0	9.0				
	modified score	4.0	6.5	6.5	4.5	7.7	9.0	7.0	45.1			
	Based on 9% of 1, 23% of 14, 24% of 15, 25% of 16, and 33 % of 23*.											
	Modifications: Global Warming Potential −2 due to high vapor pressure.											
											0.82	
Ultra Fast Blanket Wash	raw score	3.0	5.6	5.9	4.6	7.5	8.5	8.0				
	modified score	3.0	5.6	5.9	4.6	5.5	6.5	6.0	37.0			0.97
	Based on 0.5% of 8, 43.5% of 13, 1.9% of 15, 0.4% of 17, 7.8% of 22, 21.3% of 23, and 24.8% of 24*.											
	Modifications: Inhalation Toxicity −2 due to 1,4−Dioxane, Ozone Depletion Potential −2 due to 1,1,1−trichloroethane, and Global Warming Potential −2 due to high vapor pressure.										1.18	
1044 Press Wash	raw score	2.9	6.4	5.1	4.4	7.0	9.0	9.0				
	modified score	2.9	6.4	5.1	4.4	7.0	9.0	9.0	43.8			
	Based on 15% of 3, 0.5% of 6, 66.2% of 22, 12% of 25, 5.2% of 27, and 1.1% of 28*.											
IMPRESSIONS, INC., ST. PAUL, MN												
585 Typewash	raw score	2.9	4.9	5.5	4.5	5.4	9.0	8.5				
	modified score	2.9	4.9	5.5	4.5	5.4	9.0	6.5	38.7			
	Based on 23% of 21, 26% of 18, and 51% of 28*.											
	Modifications: Global Warming Potential −2 due to high vapor pressure.											
										43.7		
70 Press Wash	raw score	3.0	7.0	5.0	5.0	7.0	9.0	9.0				
	modified score	3.0	7.0	5.0	5.0	7.0	9.0	9.0	44.9			0.97
	Based on 52% of 22, 2% of 23, and 46% of 26*.											
1066 Press Wash	raw score	2.8	5.7	5.0	4.0	7.0	9.0	9.0				
	modified score	2.8	5.7	5.0	4.0	7.0	9.0	9.0	42.5	42.5		
	Based on 45.3% of 3, 6.9% of 9, 43.3% of 22, 2.4% of 25, and 2.1% of 28*.											
INTELLIGENCER PRINTING COMPANY, LANCASTER, PA												
VT3−A	raw score	2.7	5.9	5.9	3.9	7.7	9.0	9.0				
	modified score	2.7	5.9	5.9	1.9	7.7	9.0	7.0	40.0			
	Based on 33.3% of 1, 5% of 17, 4.7% of 14, and 57% of 23*.											
	Modifications: Photochemical Oxidant Creation Potential −2 due to estimated quantity released and Global Warming Potential −2 due to high vapor pressure.									39.4		
Power Kleen XF Plus	raw score	2.8	5.8	5.1	4.0	6.8	9.0	8.9				
	modified score	2.8	5.8	5.1	2.0	4.8	9.0	8.9	38.6			1.05
	Based on 39% of 1, 36% of 2, 7% of 5, 3% of 18, 2% of 21, and 13% of 25*.											
	Modifications: Photochemical Oxidant Creation Potential −2 due to estimated quantity released and Inhalation Toxicity −2 due to methlyene chloride.											
IP Wash	raw score	3.0	6.0	5.0	4.4	7.0	9.0	9.0				
	modified score	3.0	6.0	5.0	2.4	7.0	9.0	9.0	41.4	41.4		
	Based on 38.1% of 2, 40.4% of 3, 2% of 6, 0.5% of 11, 9% of 19, 8% of 25, and 2% of 28*.											
	Modifications: Photochemical Oxidant Creation Potential −2 due to estimated quantity released.											
											AVERAGE P2 RATIO:	1.00

* Individual chemicals are designated by the numbers used in Table 5.

Intelligencer Printing Company

Intelligencer Printing Company was initially using VT3-A and Power Kleen XF Plus and switched to IP Wash. The combined score for the VT3-A and Power Kleen XF Plus, which is proportionally based on the quantities of each solvent mixture used, is indicated as 39.4 in Table 6. The combined solvent mixture score for 1066 Press Wash is 41.4. Thus, the P2 factor for the switch is 1.05.

P2 Factor Average for Three Printers

Since data were only readily available to determine P2 factors due to solvent substitution for three lithographic printing companies, the average P2 factor of 1.00 indicated in Table 6 does not represent a true industry average. However, this average P2 factor is a reasonably good indicator of the level of environmental improvement that might be expected due to implementation of this P2 activity by other lithographic printers. Basically, very little overall environmental improvement was achieved, on average, by solvent substitutions made by the three companies. The most individual company improvement was made by the John Roberts Company in their second solvent switch, which had a P2 score of 1.18. A very small net environmental improvement was also made by Intelligencer Printing Company, which had a P2 score of 1.05 for their solvent switch.

Although the goal of the printers to limit the quantity of VOCs to the atmosphere is important, the criterion on photochemical oxidant creation potential (POCP) does not always reflect a decrease in VOC release. As noted in Table 2, the POCP criterion is based on the potential for ground-level ozone ("smog") creation relative to ethylene. To get a more accurate estimate of the quantity of a solvent that might become part of smog, the POCP could be multiplied by the amount of solvent actually released to the air. The amount of solvent released to air could be calculated using the vapor pressure of that solvent, or simply assuming that the amount of solvent released to air is equal to the total solvent used minus the amount of solvent recycled or recovered for fuel blending. The concentration of VOCs in indoor air was not used as a criterion for this analysis, due to the difficulty in getting the data needed to make these calculations. The quantity of solvent released to the environment was not included in determining the POCP score, but instead was used as a score modifier for companies located in ozone non-attainment areas (see Figures 3 and 4). Contributions of ozone precursors to areas that are in ozone attainment (e.g., Minneapolis and St. Paul, MN) were not considered to be a serious environmental problem.

One possible improvement to calculation of a P2 factor for solvent substitution would be to add a criterion that gave credit for decreasing the quantity of solvent required per year or per ton of printed product by switching to a solvent formulation with a lower vapor pressure. However, addition of this new criterion would be unlikely to improve the P2 factor for solvent substitution in any significant amount, since the P2 factor is determined by many criteria and several criteria need to be increased in order to improve the P2 factor. It should be noted that improvement in one or more individual criteria are important, so gains in an individual criterion should also be considered when selecting a P2 activity, even if the overall P2 factor score does not show a dramatic improvement.

WATERLESS VERSUS CONVENTIONAL PRINTING

The second P2 activity used to evaluate the P2 factors methodology is switching a nonheatset, sheetfed offset press from conventional dampening system printing to waterless printing. Although detailed data for individual companies that have made this switch were not readily available, the results of a survey for nine individual printing companies that switched to waterless were provided by John O'Rourke from Toray Corporation. The results were presented in a qualitative rather than quantitative manner, so scoring of criteria required use of the "fall-back" scoring method shown at the end of Table 2 for the criterion on energy use during printing. Based on the stressor/impact chain shown in Figure 2, the 11 scoring criteria associated with three life-cycle stages/steps shown in Table 7 were selected from the larger list of scoring criteria in Table 1.

Scores for individual criteria associated with both conventional and waterless, nonheatset, sheetfed offset printing are indicated in Table 8. For dampening fountain solvents, it was assumed that most of the companies converting to waterless were using either 2-butoxy ethanol or ethylene glycol in the fountain solution before switching. Thus, individual criteria scores for these two chemicals were averaged. Energy use and emission scores due to manufacturing these two fountain solvents are based on the petrochemical classification system shown in Table 3. Waterless printing received a score of nine for all of the criteria associated with fountain solution solvents, since no fountain solution is required for waterless printing, and environmental impacts associated with these solvents are eliminated.

A potential difference between waterless and conventional nonheatset, sheetfed offset printing is the energy used by the press chillers required for waterless printing. However, some conventional nonheatset, sheetfed offset presses may have IR heaters, spray powder systems, and coating units requiring electric energy that would be eliminated when switching to waterless. Since data on energy use for these press accessories were not available, the "fall-back" scoring criterion described at the end of Table 2 was used. Thus, each printing method was given a score of five for energy use during printing. The energy use scores for the two printing methods may be significantly different, if a specific company did not use IR heaters, spray powder systems, and coating units on their conventional press before switching to waterless.

Two important differences between waterless and conventional nonheatset, sheetfed offset printing from a life-cycle impact standpoint are the differences in the amount of aluminum printing plates and paper used. According to the survey by Toray of nine printers that switched from conventional to waterless printing, waterless printing plates generally do not last as long as conventional printing plates. Printers who typically have long press runs will end up using more printing plates for waterless printing than for conventional printing. On the other hand, the absence of the dampening fountain and tighter control on the press temperature with the chiller added, means that the makeready time is shorter for waterless than for conventional printing. This translates into fewer lost impressions and a decrease in the amount of wastepaper available for recycle. Since nearly all printers recycle both their aluminum plates and their wastepaper, the transport emissions to get recycled aluminum plates or wastepaper to the recycler is expected to differ between the two printing methods. Thus, scoring criteria were evaluated in both the material manufacture and product fabrication steps of the manufacturing life-cycle stage, as shown in Tables 7 and 8. The quantity of printing plates or wastepaper in pounds is a surrogate for the amount of energy and air emissions required to transport each material to the aluminum smelter or paper mill where the materials are finally recycled into new aluminum or paper. Thus, conventional printing was scored as five for the quantity of aluminum plates and wastepaper recycled and waterless printing was given scores of three and seven, respectively for the quantity of aluminum plates and wastepaper recycled. Data for energy use needed to make virgin and recycled aluminum was taken from AIA (1992). Data for energy use needed to make virgin and recycled paper was taken from raw data supplied to Battelle by paper mills.

The final P2 factor for switching from conventional to waterless nonheatset, sheetfed offset printing is 1.25 (Table 8). This assumes that the quantity of aluminum plates needed for waterless is over 10 percent more than if conventional printing was used. As explained above, some printers have consistently short press runs, so the fact that waterless plates do not last as long as conventional plates may not make any difference. If the score for transport of aluminum scrap from waterless printing to recycle is changed to 5 (i.e., no more than a 10% change from conventional printing), than the P2 factor increases from 1.23 to 1.25.

Table 7. Scoring Criteria Selected for P2 Factor Calculation Due to Switching from Conventional Dampening System to Waterless Printing Plates.

Raw Materials Acquisition Stage	Manufacturing Stage: Material Manufacture Step (Petroleum Refining and Material Recycling)	Manufacturing Stage: Product Fabrication Step (Printing)
Paper, Aluminum, and Petroleum Habitat Alteration Resource Renewability	Dampening Solvents Energy Use Airborne Emissions Waterborne Effluents	Press Accessories (e.g. chillers) Energy Use
	Recycled Aluminum and Wastepaper Energy Use	Dampening Solvents Photochemical Oxidant Creation Potential (POCP) Inhalation Toxicity Ozone Depletion Potential (ODP) Global Warming Potential (GWP)
		Transport of Recycled Aluminum and Paper Surrogate for Transport Energy/ Emissions Due to Recycling

Table 8. Scores for Individual Criteria and Combined Scores for Conventional Versus Waterless Sheetfed Printing Systems

	Raw Material Acquisition		Material Manufacture Step			Product Fabrication Step (Printing)						
Material	Habitat Alteration	Resource Renewability	Energy Use	Airborne Emissions	Waterborne Emissions	Energy Use	Photo-chemical Oxidant Creation Potential	Inhalation Toxicity	Ozone Depleting Potential	Global Warming Potential	Transport for Scrap	TOTAL
CONVENTIONAL SYSTEM												
Paper	7	7	5								5	
Aluminum Plates	3	3	1								5	
Fountain Solution (balance of water and trace process additives)												
2-Butoxy ethanol (3-5%)			5	7	7		5	7	9	9		
Ethylene glycol (3-5%)			1	3	5		5	7	9	9		
Press Accessories*						5						
AVERAGE	5.0	5.0	3.0	5.0	6.0	5.0	5.0	7.0	9.0	9.0	5.0	64
WATERLESS PLATE SYSTEM												
Paper	7	7	5								7	
Aluminum Plates	3	3	1								3	
Fountain Solution			9	9	9		9	9	9	9		
Press Accessories**						5						
AVERAGE	5.0	5.0	5.0	9.0	9.0	5.0	9.0	9.0	9.0	9.0	5.0	79

*Traditional sheetfed systems may include IR heaters, spray powder systems, and coating units.
**Waterless sheetfed systems include chillers.

P2 RATIO: 1.23

Interpretation of the Results

As indicated in Section 2, this preliminary P2 factors methodology still requires additional development/refinement. Ultimately, it can serve as a screening tool to provide direction in selecting P2 activities that provide the most environmental improvement. For now, the P2 factor should only be used as an indicator of the general degree of environmental improvement for the entire life cycle that has occurred, or might be expected to occur, as a result of implementing a particular P2 activity. If the P2 score is multiplied by 100, the amount over 100 is roughly the percent of reduction in environmental impacts over conditions before implementation of the P2 activity. Thus, the overall P2 factors for solvent substitution in blanket and press wash determined for the the three cooperating printers (i.e., 0.97, 0.97, and 1.05) are probably not far enough from 1.00, or from any of the P2 factors for the same P2 activity, to say that the implementation of this P2 activity resulted in a significant overall reduction in environmental impacts, or that one printer's switch resulted in a greater improvement than for another printer's switch. On the other hand, if more accurate data indicate that the switch from conventional to waterless printing typically results in an average P2 score of 1.25, it is likely that this represents greater environmental improvement than the average P2 score of 1.00 determined for the three printers switching their blanket or press wash solvent formulation.

It should be noted that this preliminary P2 factors methodology gives equal weight to each of the environmental scoring criterion. There are methods for applying differential weights to the criteria, so that an improvement in one score has a greater impact on the overall P2 factor. In either case, an improvement in one or more individual criteria should be considered when selecting a P2 activity, even if the overall P2 factor score does not show a dramatic improvement.

The accuracy of the P2 factor depends on better data collection than many companies have historically done, since most companies focus their data collection connected with implementing a P2 activity on cost savings and not on data needed to score environmental criteria. Potential problems with the methodology that can be resolved with additional testing include evaluation of the impact on the P2 score due to implementation of more than one P2 activity at the same time, and addition of criteria that give credit for reduction in the quantity of hazardous materials (e.g., solvents) used. Additional testing is also needed to see if the P2 factors methodology is applicable to other industries and to evaluate how much improvement in the P2 factor is necessary to make implementation of the new activity worthwhile from an environmental impact reduction standpoint.

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