EPA/742/R-95-008

Pollution Prevention
Educational Resource Compendium:

Industrial Engineering and Operations Research

NATIONAL POLLUTION PREVENTION CENTER FOR HIGHER EDUCATION

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Pollution Prevention Educational Resource Compendia
Goal Statement and Summary:

Education offers one of the greatest opportunities for achieving a more sustainable society. Today's students will be tomorrow's leaders. With them in mind, the NPPC offers pollution prevention compendia for faculty in a variety of disciplines. These compendia, developed by NPPC staff as well as university faculty nationwide, present multi-sector perspectives. They contain background materials, annotated bibliographies, course syllabi, selected readings, teaching tools, and lists of resources relevant to each discipline. The NPPC is producing and disseminating these compendia to help faculty incorporate the concepts and principles of pollution prevention into their courses; members of industry, government, and non-profit organizations may also find them useful when pursuing pollution prevention initiatives. As the scope of pollution prevention evolves, so will the compendia. The NPPC encourages contributions from business, industry, and academia.

This is the Industrial Engineering and Operations Research compendium. Other compendia-in-progress cover disciplines such as Accounting, Agriculture, Architecture, Business Law, Chemical Engineering, Chemistry, Corporate Strategy, Environmental Engineering, Environmental Studies, Finance, Industrial Ecology, and Operations Management. For more information, contact the NPPC directly.

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The mission of the NPPC is to promote sustainable development by educating students, faculty, and professionals about pollution prevention; create educational materials; provide tools and strategies for addressing relevant environmental problems; and establish a national network of pollution prevention educators. In addition to developing educational materials and conducting research, the NPPC also offers an internship program, professional education and training, and conferences.

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April 1995

Table of Contents

All documents can be ordered separately—see the NPPC Order Form. Short documents are free of charge; to cover the cost of photocopying, there is a small fee for longer documents.

Explanation of Compendium Contents

Introductory Materials

- **Overview of Environmental Problems.** This lengthy paper highlights major areas of environmental concern: energy use, global change, stratospheric ozone depletion, resource depletion, land use and development, waste, air quality, water quality and quantity, ecological health, and human health. It includes definitions of concepts and terms, current data and research findings on the state of the environment, tables, figures, and guidance on obtaining additional information.

  This document is designed to assist faculty members from all disciplines in preparing course materials and lectures. For faculty (and students) who may not have extensive knowledge of environmental issues, it provides background information; for people already familiar with environmental problems, it is a convenient, concise source of current data. The document is formatted so that individual topic areas can be easily reproduced for distribution to students; all figures and tables are provided in a full-page format suitable for overhead projection.

- **Pollution Prevention Concepts and Principles.** This short paper introduces the concepts, terminology, objectives, and scope of pollution prevention. It discusses how government and the private sector are currently perceiving and implementing pollution prevention and describes the barriers and benefits encountered in implementing pollution prevention activities.

- **Pollution Prevention: A Logical Role for the Industrial Engineer.** Describes the inherent and critical role industrial engineers must play in developing successful pollution prevention programs, explains regulatory and market factors for pollution prevention, and outlines a framework for pollution prevention within a firm. Further, it outlines how the materials provided by the NPPC relate to the various subdisciplines of the industrial engineering.

Pollution Prevention and IE/OR Resource List

This is a list of all relevant resources known to the NPPC, including materials that we produce and/or distribute. NPPC has strived to make this list as comprehensive as possible—we welcome your suggestions on what to include in future editions. Note that all NPPC Resources (see next section) appear in the Resource List.

- **Educational Tools.** Lists four case studies, three articles, one exercise, four course syllabi, and one video.
- **Reference Materials.** Lists 15 books and 42 articles, three organizations, and 11 faculty involved in pollution prevention education. Includes matrix showing how each document relates to each IE/OR subdiscipline.

NPPC Resources

The NPPC distributes all of these resources; in many cases, the NPPC has also developed them. All appear in the Resource List (see previous section).

- ☐ **Annotated Bibliography.** Alphabetically lists and describes all books, articles, and case studies listed in the Resource List. Includes matrix showing how each document relates to each IE/OR subdiscipline.
- ☐ **Selected Readings.**
  - Robert A. Frosch and Nicholas E. Gallopoulois. "Strategies for Manufacturing." *Scientific American* 261 (September 1989): 144–152.
  - H.C. Haynsworth and R. Tim Lyons. "Remanufacturing By Design." *Production and Inventory Management* (2nd Quarter 1987): 24–29.
  - Robert L. Kraft. "Incorporate Environmental Reviews into Facility Design." *Chemical Engineering Progress* 88 (August 1992): 46–52.
- ☐ **Course Syllabi:**
  - William Clark and Robert Frosch. *ESPP 98 / ENR 204: Reducing Industrial Wastes.* Harvard University, Spring 1994.
  - Rex T. Ellington. *HON 3993: Clean Fuels and Clean Technology: The Technical, Environmental, and Policy Issues.* University of Oklahoma, May 1994.
  - Robert B. Pojasek. *CE-194J: Pollution Prevention.* Tufts University, Spring 1994.
  - Wayne C. Turner. *INDEN 5943: Hazardous Material/ Waste Management.* Oklahoma State University, Spring 1994.
- ☐ **Article With Discussion Questions and Teaching Notes: "Pollution Prevention and Facilities Planning."** Discusses the need for facility planners to consciously include environmental considerations when locating and designing facilities. Provides accompanying questions and possible answers.

- ☐ **Article With Discussion Questions and Teaching Notes: "Total Quality Management: A Methodology for Pollution Prevention."** Discusses how the four elements of Total Quality Management — customer focus, continuous improvement, teamwork, and strong management commitment — can all be applied to prevent pollution. Provides questions and answers.

- ☐ **Case Study With Teaching Note: "Amoco and the Environmental Decision Analysis: Cases A and B."** Investigates the failure of the rational decision model under certain resource allocation conditions. Provides questions and answers.

- ☐ **Case Study With Teaching Note: "Pollution Prevention as Continuous Improvement at Ford Motor Company."** Describes Ford's successful use of continuous improvement techniques to reduce waste at its Livonia, MI, transmission plant. Discusses a cross-disciplinary team and the waste-prevention opportunities it developed as well as a pollution prevention guidebook that could be used for waste prevention at other Ford plants. Provides questions, answers, and discussion points.

- ☐ **Problem Set With Teaching Note: "The Tragedy of the Commons and the Rational Decision Maker."** Investigates the failure of the rational decision model under certain resource allocation conditions. Provides questions and answers.

- ☐ **Video: "Second Victory at Yorktown."** This 30-minute video documents the cooperative project between Amoco and the EPA to explore pollution reduction at a petroleum refinery. The results of the project have important implications for both engineering and business.

For the Instructor: Teaching Note on "Incorporating Pollution Prevention in Facilities Planning"

Purpose

When designing new facilities, planners must ask themselves, "Can this facility's environmental impact be reduced?" The accompanying article and exercise are designed to help future facilities planners address this question.

"Pollution Prevention and Facilities Planning" discusses the need for facility planners to consciously include environmental considerations when locating and designing facilities. The first section discusses pollution prevention considerations in the design process; the second examines modeling environmental variables into the facilities location problem.

These articles were designed for an introductory Facilities Planning course. The material requires 50 minutes of class time for discussion; the questions can be assigned as a homework. Students should be familiar with the basic concepts of both facilities design and facilities planning prior to the class. For those courses that do not teach facilities location, the facilities design component can be assigned alone.

Before assigning the accompanying article and exercises, you may want to have your students read this compendium's introduction, "A Logical Role for the Industrial Engineer." It discusses the inherent and critical role industrial engineers must play in developing successful pollution prevention programs, explains regulatory and market factors, and outlines a framework for preventing pollution within a firm.

Answers

1. Wastes are usually generated by productive use of an activity's components. Production waste has traditionally been seen as a necessary, if unwanted, by-product of an activity. Pollution prevention questions the necessity of waste and calls for activities to *prevent* it wherever possible (rather than merely controlling it as is common today).

2. As a facilities planner involved in *product design* review, apply value analysis techniques to the choice of materials or the method of manufacture to determine if pollution can be prevented.

   The *process selection* procedure offers significant opportunities to prevent pollution. Interacting with the process planner, the facilities planner can call for pollution prevention to be evaluated along with cost, flexibility, efficiency, reliability and maintainability.

   Good *schedule design* lends itself to pollution prevention — correct volume determinations will minimize excess inventory and possible waste. The same point applies to scrap estimates and machine fractions. When determining these values, minimizing waste is naturally a goal.

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3. x-axis

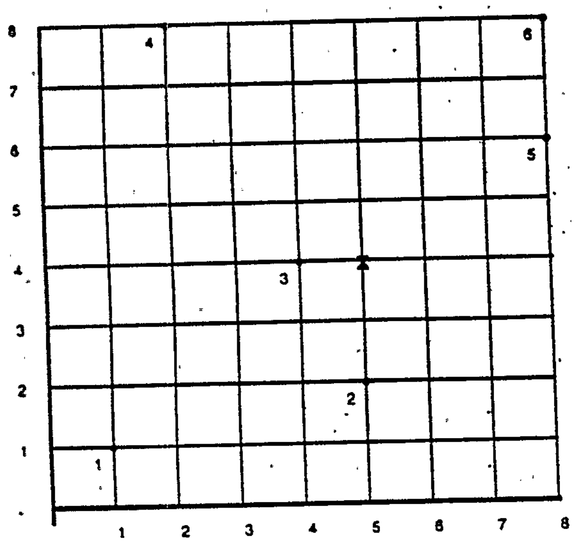
Location	a_i	w_i	Σw_i	
1	1	10	10	
4	2	4	14	
3	4	8	22	
2	5	12	34	> 56/2
5	8	16	50	
6	8	6	56	

$x^* = a^2 = 5$

y-axis

Location	b_i	w_i	Σw_i	
1	1	10	10	
2	2	12	22	
3	4	8	30	> 56/2
5	6	16	46	
4	8	4	50	
6	8	6	56	

$y^* = b^3 = 4$



4. x-axis

Location	a_i	w_i	Σw_i	
1	1	5	5	
4	2	4	9	
3	4	4	13	
2	5	6	19	
5	8	16	35	> 41/2
6	8	6	41	

$xe^* = a^5 = 8$

y-axis

Location	b_i	w_i	Σw_i	
1	1	5	5	
2	2	6	11	
3	4	4	15	
5	6	16	31	> 41/2
4	8	4	35	
6	8	6	41	

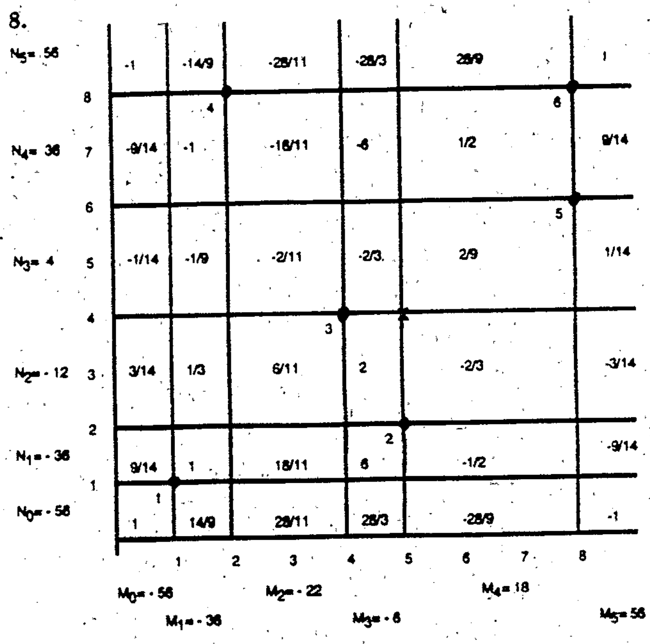
$ye^* = b^5 = 6$

5. The solution in problem #3 tends to "center" the facility with regard to all other facilities. In contrast, #4 tends to place the facility away from the populated areas.

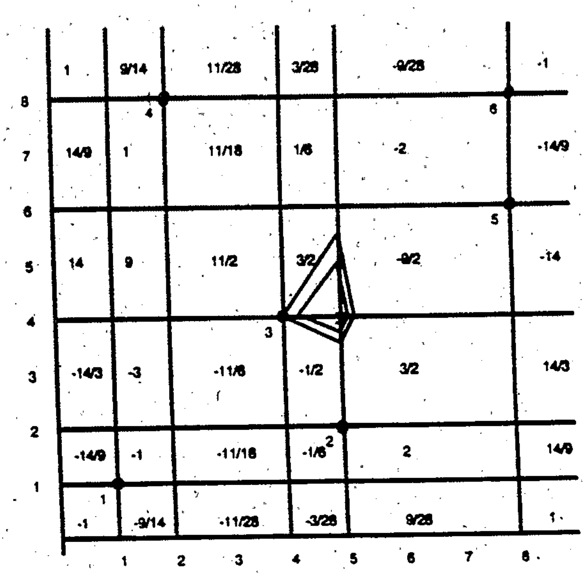
6. The environmental weights take on smaller values to force the model to place the facilities *away* from the populated areas. High positive values would drive the facility closer to the very places that need to be kept apart from the facility. In determining weights, the "costs" associated with the environmental issues should be *subtracted* from the traditional costs to reach the new w_{ei}s.

7. In this example, all the population areas are located in a certain quadrant of the area. If the population areas are more dispersed, the solutions will show a tendency toward the center which might be the worst possible solution.

8.

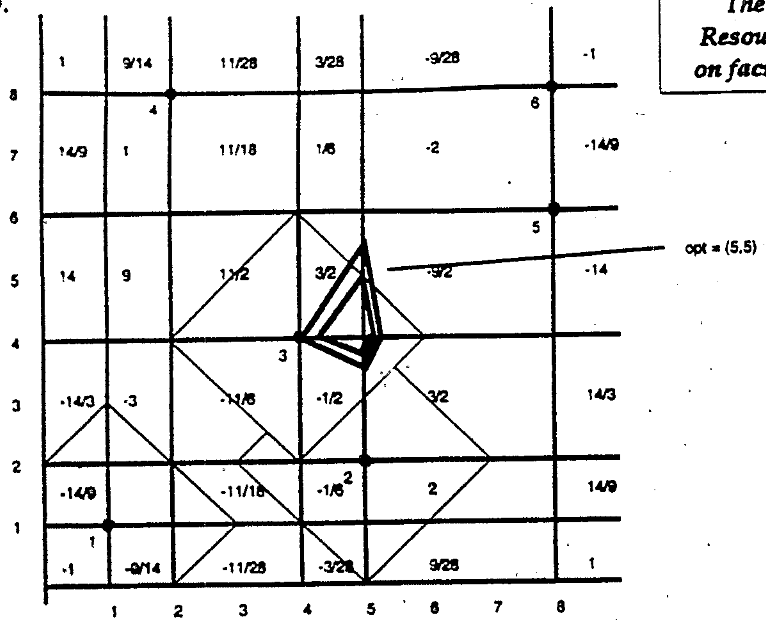


Forces



Contour lines

9.



Contour lines
with constraints

The matrix at the end of this compendium's Resource List indicates eight books and articles on facilities planning and industrial engineering.

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Incorporating Pollution Prevention in Facilities Planning

By Leith Harmon, NPPC Research Rssistant, under the supervision of Yavuz Bozer, Associate Professor of Industrial and Operations Engineering, University of Michigan.

Introduction

Facilities planning represents a significant economic activity. The U.S. Bureau of Census estimates that U.S. industry spends eight percent of the GNP on new facilities. As environmental concerns continue to grow, new facilities will have to be designed with pollution prevention in mind. It is important that the facilities planner ask the question, "Can this facility's environmental impact be reduced?" By considering pollution prevention, and including environmental variables in analytical models, that impact can indeed be reduced.

Facilities planning involves many disciplines. Civil, electrical, industrial and mechanical engineers; architects; consultants; general contractors; managers; real estate brokers; and urban planners all participate in facilities planning. Although all play an important role, this article will focus on the industrial engineer's role in preventing pollution in facilities planning. Because facilities planning is frequently divided into "facilities design" and "facilities location," this paper addresses pollution prevention in regards to both.

Facilities Design

Tompkins and White define facilities design as "the determination of how the components of an activity support achieving the activity's objectives." [1] These objectives usually take the form of generating profit, providing quality products, and providing quality service. Thus, the components are purchased and utilized to be as efficient and productive as possible. Wastes are usually generated by productive use of an activity's components, and it is then the responsibility of the environmental engineering department to get rid of the waste in a safe and legal manner. The traditional approach to production waste has been to view it as a necessary, if unwanted, by-product of an activity. Pollution prevention questions the necessity of waste and calls for activities to *prevent* pollution wherever possible, rather than merely controlling. Generally, pollution prevention is not explicitly defined as a means to meeting an activity's objectives. Yet, by consciously including pollution prevention in facilities planning, a more efficient and productive facility can result.

Tompkins and White stress that "the success of a firm is dependent on having an efficient production system." [2] Further, "it is essential that product designs, process selections, production schedules and facilities plans be mutually supportive." Thus, before a facility can be adequately designed, these other activities must be performed. While the facilities planner will not be involved in much of the detailed work in product design, process selection, or production scheduling, s/he will have the opportunity to review these functions as they relate to facilities planning *and* pollution prevention.

PRODUCT DESIGN

Within product design, value analysis is employed to determine the interaction between product function and cost. The facilities planner involved in product design review might ask if the choice of materials or the method of manufacturing best prevent product and process waste.

PROCESS SELECTION

The process selection procedure offers significant opportunities to prevent pollution. Interacting with the process planner, the facilities planner can ask that pollution prevention be evaluated along with cost, flexibility, efficiency, reliability and maintainability. Production Scheduling design call for scrap estimates, and it is during the process selection procedure that process and facilities planners must ask if and how much scrap is really necessary.

Step 1: Define elemental operations

Step 2: Identify alternative processes for each operation

Step 3: Analyze alternative processes

Step 4: Standardize processes

Step 5: Evaluate alternative processes

Step 6: Select processes[3]

PRODUCTION SCHEDULING

Good schedule design lends itself to pollution prevention — correct volume determinations will minimize excess inventory and possible waste. The same point applies to scrap estimates and machine fractions. When determining these values, minimizing waste is naturally a goal.

Once the product designs, process selections, and scheduling activities have been completed, the facilities planner can develop requirements for space, material handling, and personnel. Each of these activities provides opportunities for preventing pollution, and will be considered in turn.

SPACE REQUIREMENTS

Good space requirement design inherently prevents pollution. Efficient flow of material and personnel in and out of departments naturally reduces waste by reducing energy consumption and possible work-in-progress (WIP) losses. Within departments, space should be allocated to ensure stable flow of WIP. Too much space may allow WIP to accumulate, causing stress and possible waste for the downstream department. Too little space may cause employees to store WIP outside the department, where it can be lost.

Interdepartmental space allocations are even more important. A good layout minimizes the flow of material and energy through the facility. Not only are costs minimized, but waste is reduced when high-volume departments are in close proximity. As aisles provide the routes by which material is transferred between departments, good aisle arrangement also reduces waste.

MATERIAL HANDLING REQUIREMENTS

Material handling deals with moving raw material, work-in-progress, and finished goods within the facility. When determining "what to move," "where to move it," "how to move it," and "when to move it," good material handling design naturally minimizes waste. Not often asked however, is the question "what to move it in." Many parts and supplies are brought into a facility and moved through it in single-use packaging. This packaging can take the form of cardboard boxes, weak wooden pallets, or shrink-wrap plastic, all of which become waste after one use. Reusable materials, such as metal or plastic bins, can often replace disposable packaging. Ford Motor Company uses this "reusable dunnage" with both internal and external suppliers. When designing material-handling requirements, the facilities planner should investigate reusable dunnage as well.

PERSONNEL REQUIREMENTS

When defining the needs of employees, consider pollution prevention as well. For instance, the facilities planner can encourage alternatives to commuting in single-occupant vehicles. The state of California currently provides tax incentives to employers who develop transportation alternatives; other states may soon follow suit. Parking facilities can have secure, convenient bicycle storage; locker rooms can include showers for employees who cycle long distances to work. Employee shuttle services from home or a common "park-&-ride" area might also be viable. Because parking facilities can tie up large tracts of land, reducing them with these other alternatives might reduce real estate costs as well as gain tax breaks and improve the environment.

The facilities planner should also investigate the waste to be generated by the proposed food service facility. In facilities with less than 200 employees, vending machines are considered sufficient. However, this type of food service often results in a significant amount of packaging waste. As landfill costs soar, the removal of this waste can become a significant expense. The facilities planner should investigate the viability of reusable dishware and utensils — when weighed against disposal costs, they can save the firm money and prevent pollution.

Facilities Location

Traditional facilities location is concerned with placing the facility to best provide for the interactions with customers, suppliers, and other facilities. To determine the "optimal" location of the facility, planners often use analytical models that ignore environmental issues such as pollution prevention. However, simple awareness of environmental factors enable the planner to incorporate these issues into the models. Two commonly used models — minisum and minimax — can be modified to address environmental considerations.

Minisum seeks to find the value of the objective, X, which minimizes the weighted sum of distance traveled, or:

$$\text{Minimize } f(X) = \Sigma\, w_i\, d(X,P_i) \quad \text{for } i = 1 \text{ to } n$$

where $d(X,P_i)$ is the distance between X (the new location) and P_i (the existing location), and w_i is the "weight" between the new location and the existing location.

The objective function usually includes the minimization of cost or distance (cost would be assigned as part of the weight, w_i). By default, these values generally prove to benefit (or minimize the impact on) the environment: the shortest distance traveled will require the least amount of energy consumption. Sometimes, however, environmental considerations must be explicitly included in the model.

For example, a facilities planner is responsible for siting a manufacturing facility that generates toxic waste. While developing a process that does not generate the waste at all should be a goal, it might not be technologically or financially feasible at the time. Siting the facility upstream from a town might affect the town more adversely than siting it downstream. These adverse affects can translate into financial liabilities. To address this issue, the environmental consideration can be incorporated into the weights for the minisum model. An industrial engineer probably doesn't have the expertise to assess these weights independently. However, just as accountants provide necessary cost data, environmental experts should be available to provide guidance on environmental issues. The facilities planner should understand how the weights were determined and question the viability of those values before incorporating them into the model. As a facility planner, it is important to ask the questions, even if one is not necessarily able to provide the answers.

The other model, **minimax**, seeks to find the value of the objective, X, which minimizes the maximum distance between the new location and any existing location, or:

$$\text{Minimize } f(X) = \max\ d(X,P_i) \quad \text{for } i = 1 \text{ to } n$$

Minimax models are often used when transaction time cannot exceed a defined value (firehouse siting, for example). A variation — maximin (maximizing the minimum distance between the new location and any existing location) — can be used in certain environmental applications. For example, a hazardous waste facility must be sited. No one can live closer than X miles from the facility. Further, the more remote the facility the better. Thus, the minimum distance is maximized for any neighbor.

Conclusions

Environmental concerns *are here to stay*. Facilities planners will have to take these concerns into account when designing new facilities, now and into the foreseeable future. Again, it is important that a facilities planner ask the question, "Can this facility's environmental impact be reduced?" By considering pollution prevention, and including environmental variables in analytical models, the facilities planner will be addressing these growing environmental concerns.

ENDNOTES

[1] James A. Tompkins and John A. White. *Facilities Planning*. New York: Wiley & Sons, 1984, p 2.

[2] Ibid, p 33.

[3] Ibid, p. 42.

Questions

1. What has been the traditional approach to an activity's waste, and how does pollution prevention change that approach?

2. When interacting with product, process, and schedule design, how can the facilities planner introduce pollution prevention considerations?

3. Consider the location of a manufacturing facility where the costs (w_is) of traveling between the plant and existing suppliers and customers (P_is) are shown below. Solve and graph the minisum facility location problem.

Location	Coordinates	Weights
1	1,1	10
2	5,2	12
3	4,4	8
4	2,8	4
5	8,6	16
6	8,8	6

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4. A new weighting table includes the adverse affects of locating the facility closer to populated areas (P_1, P_2, P_3). Solve and graph the minisum facility location problem with the environmental consideration weights.

Location	Coordinates	Weights
1	1,1	5
2	5,2	6
3	4,4	4
4	2,8	4
5	8,6	16
6	8,8	6

5. Discuss the differences between the solutions in #3 and #4.

6. Why do the environmental weightings take on smaller "cost" values?

7. If the population areas are more dispersed how will the model place the manufacturing facility?

8. Using the data from #3, develop and graph minisum contour lines for the rectilinear distance problem.

9. Now assume that a constraint is placed on the new facility whereby its location cannot be within two rectilinear units of locations 1, 2, and 3 (represented populated areas). On the graph developed for #8, show the optimal location.

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For the Instructor: Amoco Case Teaching Note

Purpose

Increasingly, decision-analysis techniques are being applied to decisions outside the traditional engineering and business spheres. These are designed to show students that decision analysis is an effective tool for complex environmental issues.

"Amoco and the Environmental Decision Analysis" is composed of two case studies. **Case A** briefly discusses the Analytical Hierarchy Process and presents criteria and option information on a pollution prevention project at Amoco's Yorktown refinery; included are discussion questions and exercises that allow students to develop a hierarchy and perform AHP computations. **Case B** investigates Amoco's use of the AHP in a pollution prevention project at its Yorktown refinery.

This material was designed for inclusion in an introductory Decision Analysis or Management Science course; it is appropriate for both MBA and industrial engineering students. It is recommended that you allow 50–80 minutes over two class periods, assigning Case A prior to the first class and Case B prior to the second class. Students should have some familiarity with the Analytical Hierarchy Process before undertaking this assignment.

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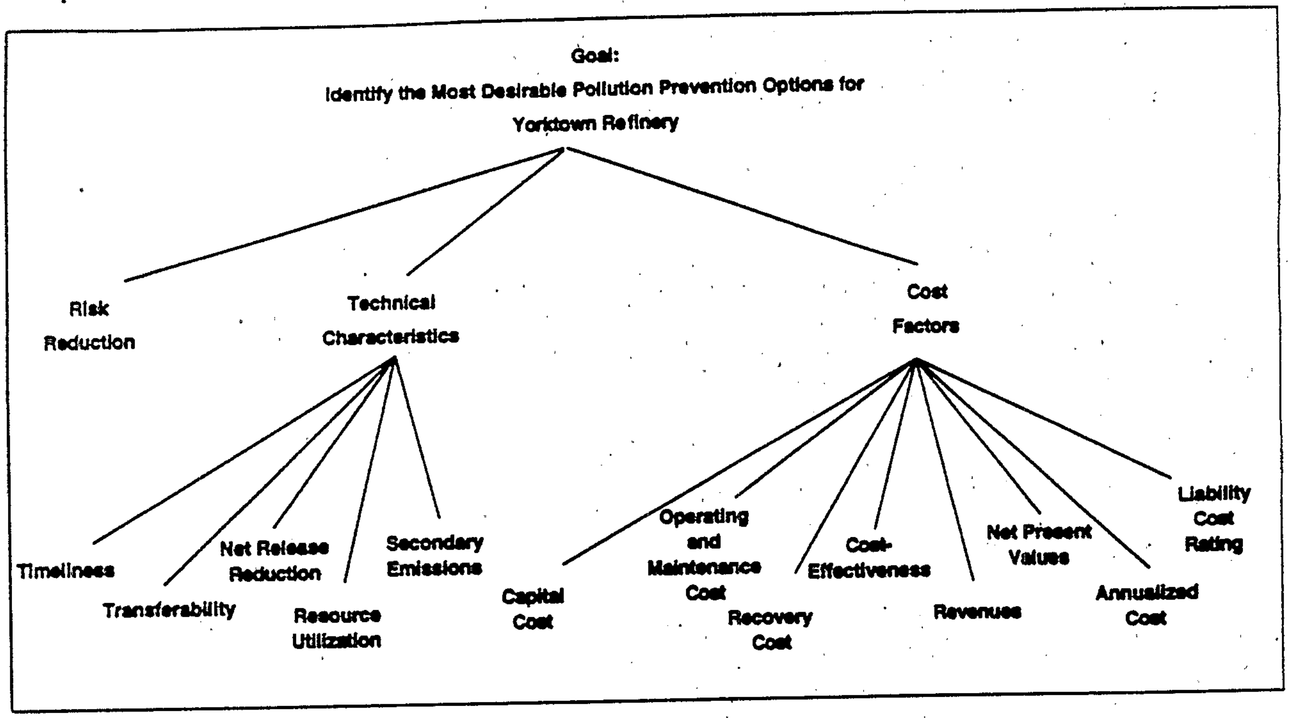
Case A Exercise Answers

1. One possible criteria hierarchy:



2. Workshop member #1 developed the following priority weights.

   Risk Reduction: .763
   Cost: .063
   Technical Characteristics: .173

   Workshop member #2 developed the following priority weights.

   Risk Reduction: .111
   Cost: .333
   Technical Characteristics: .561

3. Assuming that students develop the following priority scores (and any weighting is acceptable),

	Risk	Cost	Tech
5c	.333	.204	.140
9	.069	.739	.287
11b	.598	.057	.564

and use the workshop members' priority weights, the following results:

.763 (.333) + .063 (.204) + .173 (.140) = .289
.763 (.069) + .063 (.739) + .173 (.287) = .149
.763 (.598) + .063 (.057) + .173 (.564) = .557

Therefore, choose 11b.

.111 (.333) + .333 (.204) + .561 (.140) = .183
.111 (.069) + .333 (.739) + .561 (.287) = .415
.111 (.598) + .333 (.057) + .561 (.564) = .402

Therefore, choose 9 or 11b.

4. One party viewed the reduction of risk as all-important, almost to the exclusion of the other factors, while the other viewed cost considerations as most important. Yet, even with these seemingly disparate perspectives, given the technical and financial attributes of Option 11b (quarterly LDAR program with a 10,000 ppm hydrocarbon leak level), an agreement can be reached to develop a pollution prevention alternative.

Case Study: Amoco and the Environmental Decision Analysis

The major part of this document is excerpted, with modifications, from the executive summary and project summary of Amoco–U.S. EPA Pollution Prevention Project, Yorktown, Virginia, *by Amoco Corporation and the U.S. Environmental Protection Agency. The Analytical Hierarchy Process subsection is by Leith Harmon, NPPC research assistant. The Case A discussion questions are by Martin Young, assistant professor at the U-M School of Business Administration. Harmon and Young collaborated on the Case A exercises. The NPPC thanks Amoco for granting permission to reproduce the text of this case.*

Introduction

Environmental issues are playing an increasing role in many firms' strategic, tactical, and operational activities. Regulatory pressure and public concern demand that manufacturing process wastes be dealt with effectively. Historically, industry has dealt with pollution using increasingly sophisticated and expensive methods of control, adding an ever-increasing, non-value-added component to a product's cost. In many cases, however, it may be more economical to *prevent* pollution, rather than try to control it after the fact.

To this end, in late 1989, Amoco Corporation and the United States Environmental Protection Agency began a voluntary, joint project to study pollution prevention opportunities at an industrial facility. EPA, Amoco, and Commonwealth of Virginia staff formed the Amoco/EPA Workgroup. This group conducted a multimedia assessment of releases to the environment at Amoco Oil Company's refinery at Yorktown, Virginia, and then developed and evaluated options to reduce those releases. To evaluate these options, the Workgroup used a decision analysis technique called the Analytical Hierarchy Process (AHP).

Case A discusses AHP and presents the Amoco/EPA criteria and options; Case B discusses the results of Amoco/EPA's application of AHP. Much of the work done in assessing releases (defining the Refinery Release Inventory), developing options, and reviewing implementation obstacles and incentives is beyond the scope of this case, and will not be covered as such.

Amoco/EPA Project Background

At the time the Amoco/EPA project began, pollution prevention was a concept predicated on reducing or eliminating releases of materials into the environment rather than managing the releases later. The Workgroup adopted this concept and agreed to consider all potential management opportunities: source reduction, recycling, treatment, and environmentally sound disposal. Since then, Congress (in passing the Pollution Prevention Act of 1990) and other organizations have put greater emphasis on source reduction as the primary, if not exclusive, means to prevent pollution.

A central goal of this project was to identify criteria and develop a ranking system for prioritizing environmental management opportunities that recognized a variety of factors: release reduction, technical feasibility, cost, environmental impact, human health risk, and risk reduction potential. Due to the inherent uncertainties in risk assessments, the project focused on relative changes in risk compared to current levels, rather than establishing absolute risk levels. Because of difficulties in quantifying changes in ecological impact from airborne emissions, changes in relative risk were based primarily on human health effects indicated by changes in exposure to benzene. The risk assessment did not quantitatively analyze volatile organic compounds (VOCs) due to limited information on their health effects. This Project focused on pollution and potential risks posed by normal operation of the Refinery and chronic exposure to its releases into the environment.

Case A: The Analytical Hierarchy Process, Selection Criteria, and Options

The Analytical Hierarchy Process

The Analytical Hierarchy Process addresses the issue of how to structure a complex situation in five steps.

1. Identify the overall goal and the important decision criteria. For the Amoco/EPA Project, the goal was to select the most effective pollution prevention options for the Refinery.
2. Organize the criteria into a hierarchical structure based on the relationships among criteria and the project objective.
3. Establish the relative significance (weight) of each criterion. This usually is accomplished by choosing pairs of criteria on the same hierarchical level and directly comparing them. The decisio-maker (in this case, the Workgroup) establishes the importance of one criteria relative to the other. All possible combinations of unique pairs at each level are compared. AHP then translates the pairwise comparison results into a relative weight for each criterion.
4. Evaluate each option within the context of the proposed hierarchy. Base the overall score for each option on its performance on the criteria in the hierarchy—this establishes a comparative ranking of options among themselves.
5. Adjust and/or revise the hierarchy on the basis of information acquired during the preceding steps in the decision-making process. Using sensitivity analyses, decision-makers can review the overall contributions of specific criteria and judgments to the final decision; how changes in criteria weights affect outcomes; or how changes in the hierarchical structure influence the decision. This review may lead to altered judgments and/or revised hierarchy.

AHP has been used in a variety of complex decisions. Examples include use by the U.S. Department of Energy to prioritize hazardous waste remedial efforts at federal energy facilities, use by the Regional Advisory Committee of the National Health Care Management Center to identify problem areas for research affecting health care in the U. S., and use for setting priorities in development of a transportation system for the Sudan.

The Analytical Hierarchy Process has been found to be a flexible model for solving problems — it allows individuals or groups to shape ideas and define problems by making their own assumptions and deriving the desired solution from them.

The Yorktown Refinery

Exhibit 1 shows a schematic diagram of the Refinery, potential release sources, and a number of pollution prevention options identified in this Project. **Exhibit 2** describes specific options to reduce releases.

Project Definitions

WORKGROUP

Monthly Workgroup meetings provided project oversight, a forum for presentations on different project components, and an opportunity for informally discussing differing viewpoints about environmental management. Although attendance varied, each meeting included representatives from various EPA offices, the Commonwealth of Virginia, and Amoco.

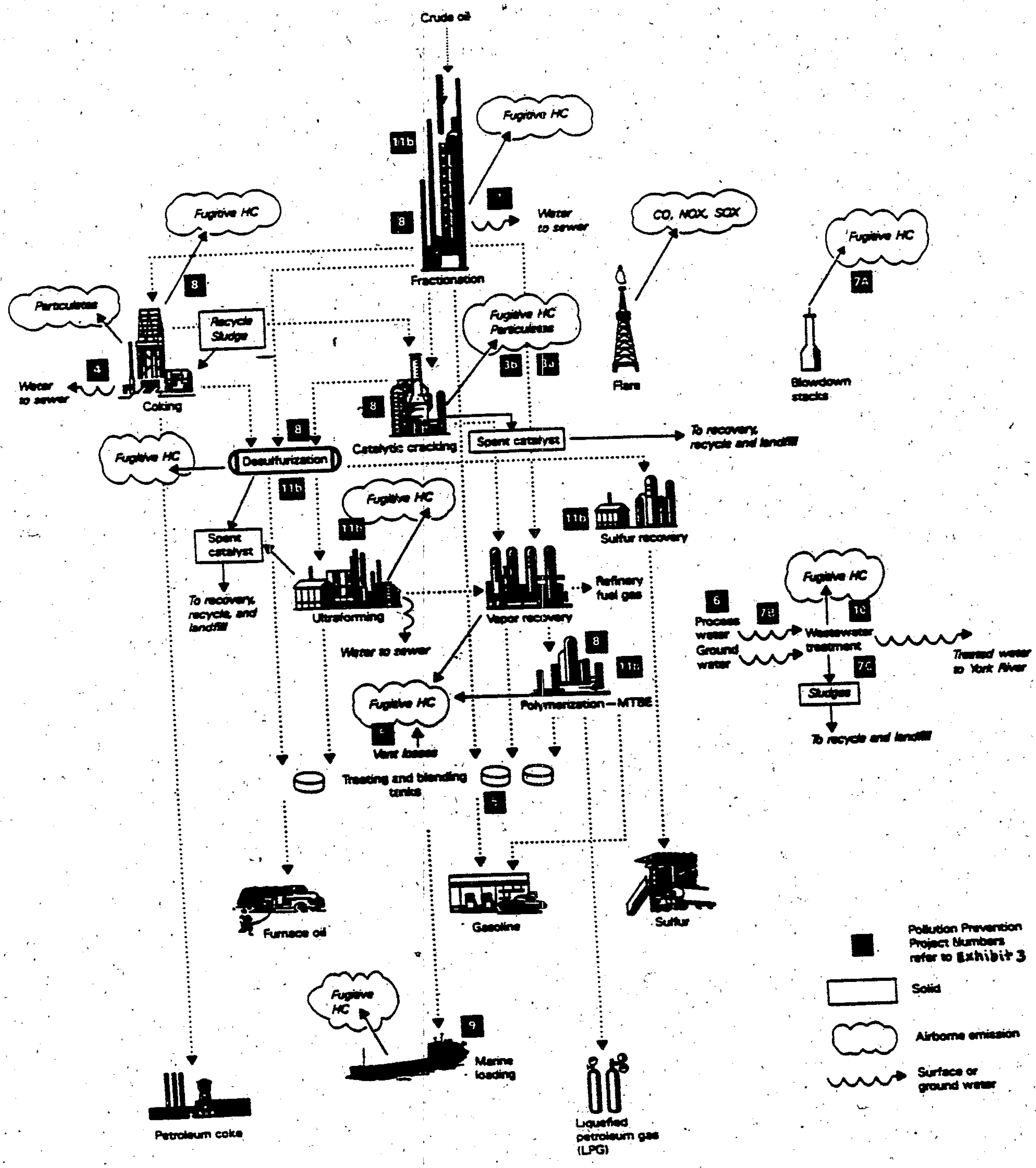
WORKSHOP

In March 1991, more than 120 representatives from EPA, Amoco, the Commonwealth of Virginia, and academic, environmental, and consulting organizations met for a three-day brainstorming Workshop in Williamsburg, Virginia. Workshop sessions included both a structured review of process synthesis techniques and a more free-wheeling discussion of ideas, resulting in suggestions that further refined and directed Project activities. Participants reviewed sampling data and considered ranking criteria, permitting issues, and obstacles and incentives for implementation. They developed a variety of release reduction options and proposed more than 50 concepts for further consideration, covering energy conservation (affecting criteria pollutant releases), volatile hydrocarbon controls, solid waste, groundwater, and surface water streams.

PEER REVIEW

At the Workgroup's request, Resources for the Future organized a group of outside scientific and technical experts. This Peer Review Group provided evaluation and advice on the project workplan, sampling, analytical results, and conclusions. The EPA paid members of this group small honoraria for their participation and reimbursed them for travel expenses to Washington.

EXHIBIT 1: SIMPLIFIED FLOW DIAGRAM OF AMOCO'S YORKTOWN REFINERY



PARTICIPANTS

More than 200 people, 35 organizations, and many disciplines have been involved in this project.

COST

Total cost for this project was approximately $2.3 million. Amoco Oil Company provided 70 percent of the funding and EPA the remainder.

Criteria

The Workshop participants identified and organized the following criteria into an analytical hierarchy:

- **Risk Reduction:** Changes in relative risk were based primarily on human health effects indicated by changes in exposure to benzene.
- **Capital Cost:** Cost estimates with a ±25 percent accuracy were made for these scoping studies. Additional engineering effort would be required to prepare an estimate with the ±10 percent accuracy typically needed for management approval.
- **Operating and Maintenance Cost:** Costs were estimated as a percentage of total capital cost and option complexity. Depending upon the option, this cost varied between three and six percent of total capital. It also includes depreciation, taxes, insurance, and other indirect costs.
- **Recovery Cost:** For liquid hydrocarbons or VOC emissions, the equivalent annual cost was divided by the net release reduction volume to determine an average $/gallon for each option. This number is equivalent to the price which would have to be charged per gallon of recovered material to recover capital, operating, maintenance, and distribution costs.
- **Cost-Effectiveness:** The equivalent annualized cost was divided by the net release reduction to determine a $/ton cost effectiveness for all options.
- **Revenues:** Revenues were estimated for those options where salable materials were recovered. The quantity of recovered material was equivalent to the emissions reduction. All recovered hydrocarbons were valued as gasoline at $0.75/gallon, with an average density of 6.5 lbs/gallon.
- **Net Present Values:** Present value of all cash flow, including initial capital, operating expenses, taxes, depreciation, indirect costs, revenues, etc.
- **Annualized Cost:** These costs were estimated as the sum of annualized capital costs and all variable expenses. Future costs were discounted at 10 percent (or 15 percent) to determine their present value, assuming a option life of 15 years.
- **Liability Cost Rating:** Each option was evaluated qualitatively for its potential to affect future remediation, catastrophic, and product-quality liability concerns.
- **Timeliness:** The number of years needed to complete each option was estimated, subject to current equipment maintenance schedules and operating limitations.
- **Transferability:** Qualitative assessment of the ability to use the option technology within other refineries and other industries was made.
- **Net Release Reduction:** Estimates of emissions reduction (tons/year) vary in accuracy. Additional emissions sampling and more detailed engineering analysis would be needed to improve these estimates. Where possible, generation and transfer of releases in other media were included in estimating the "net" change in release. Within the release reduction criteria, one or more of the pollution prevention modes in the pollution prevention hierarchy was assigned based on review, discussion, and consensus among Workgroup members. These classifications were not obvious in several cases and required extended debate.
- **Resource Utilization:** Qualitative estimates were developed for each option's effect on raw materials and utilities requirements.
- **Effects on Secondary Emissions:** The impacts of each option on other emissions were judged qualitatively. For example, increased power requirements would normally increase emissions in utility systems.

Ranking and prioritizing these options required specific, quantitative (and sometimes qualitative data) about each choice.

EXHIBIT 2: SELECTED POLLUTION PREVENTION PROJECT OPTIONS

The following options were identified for further study as a result of the March 1991 Workshop and subsequent Workgroup meetings.

1. **Reroute Desalter Effluent.** Hot desalter effluent water currently flows into the process water drainage system at Combination unit. This option would install a new line and route this stream directly to the API Separator. This process lowers sewer temperature and oil content. Volatile losses at the API Separator increase slightly.

3a. **Replace FCU Cyclones.** Assess potential for reducing emissions of catalyst fines (PM10) by adding new cyclones in the regenerator.

3b. **Install Electrostatic Precipitator at FCU.** Assess the potential of electrostatic precipitator in reducing catalyst fines (PM10) emissions.

4. **Eliminate Coker Blowdown Pond.** Change operating procedures for coke drum quench and cooldown so that an open pond is no longer needed. This reduces volatile losses from the hot blowdown water.

5a. **Secondary Seals on Gasoline Tanks.** Install secondary rim-mounted seals on tanks containing gasoline.

5b. **Secondary Seals on Gasoline and Distillate Tanks.** Install secondary rim-mounted seals on tanks containing gasoline and distillate material.

5c. **Secondary Seals in <u>all</u> Floating Roof Tanks.** Install secondary rim-mounted seals on all floating roof tanks.

5d. **Option 5c + Internal Floaters Fixed Roof Tanks.** Install secondary rim-mounted seals on floating roof with a primary seal in all fixed roof tanks.

5e. **Option 5d + Secondary Seals on Fixed Roof Tanks.** Install secondary rim-mounted seals on all floating roof tanks and then install a floating roof with a primary and secondary seal on all fixed roof tanks.

6. **Keep Soils out of Sewers.** Use road sweeper to remove dirt from roadways and concrete areas which would otherwise blow or be washed into the drainage system. Develop and install new sewer boxes designed to reduce soil movement into sewer system, particularly from Tankfarm area. Estimate cost for installation on a Refinery-wide basis. Both items reduce soil infiltration, in turn reducing hazardous solid waste generation.

7a. **Convert Blowdown Stacks.** Replace existing atmospheric blowdown stacks with flares. This reduces untreated hydrocarbon losses to the atmosphere but creates criteria pollutants.

7b. **Drainage System Upgrade.** Install above-grade, pressurized sewers, segregating storm water and process water systems.

7c. **Upgrade Process Water Treatment Plant.** Replace API Separator with a covered gravity separator and air floatation system. Capture hydrocarbon vapors from both units.

8. **Modify Sampling Systems.** Install flow-through sampling stations (speed loops) where required on a refinery-wide basis. These replace existing sampling stations and would reduce oil load in the sewer or drained to the deck.

9. **Reduce Barge-Loading Emissions.** Estimate cost to install a marine vapor loss control system. Consider both vapor recovery and destruction in a flare.

10. **Sour Water System Improvements.** Sour water is the most likely source of Refinery odor problems. Follow up on options previously identified by Linnhoff-March engineering to reduce sour water production, and improve sour water stripping.

11. **Institute LDAR Program.** Institute a leak detection and repair (LDAR) program for fugitive emissions from process equipment (valves, flanges, pump seals, etc.). Consider costs and benefits of the following configurations:

    a. Annual LDAR Program with a 10,000 ppm hydrocarbon leak level

    b. Quarterly LDAR Program with a 10,000 ppm hydrocarbon leak level

    c. Quarterly LDAR Program with a 500 ppm hydrocarbon leak level

Options Identification and Analysis

After assembling the Refinery Release Inventory, the Workgroup identified potential process and operating changes that might impact these releases.

To meet option schedule and budget constraints, the Workgroup later selected 12 options for more detailed analysis. The options chosen were felt to: (1) be feasible with current technology, (2) offer significant potential for release reductions, (3) have manageable (or no) impact on worker safety concern, (4) be amenable to more quantitative analysis in the time available, and (5) address concerns in different environmental media.

Preliminary material balances and engineering designs were used to analyze each potential option. Some of this work was completed specifically for this option. Other portions were completed as part of environmental engineering work at Amoco for the Refinery.

Important characteristics of the 12 options, and their alternatives, are summarized in **Exhibit 3**. For three options — 3, 5, and 11 — only one of the several alternatives considered would be implemented.

Two options reduce solid wastes (catalyst fines and listed hazardous wastes), while the remaining 10 focus on air emissions (VOC, HC, H_2S, and NH_3); five employ source reduction to reduce releases. Capital costs range from a low of $10,000 to a high of $22,500,000. Annual costs, based on discounting capital, operating, and maintenance costs at a 10-percent discount rate, range from $30,000 to $7,400,000.

EXHIBIT 3: IMPORTANT CHARACTERISTICS OF THE 12 OPTIONS AND THEIR ALTERNATIVES

#	Project	Pollutant	PP Mode	Rel. red'n. (tons/yr)	Cap. Inv. ($MM)	An. Cost ($MM)	Cost-effect. ($/ton)	Recov. Cost ($/gal)	Benz Expos. Red'n %	Cost-effect. BER $M/% Expos. Red'n	Statutory Program	Exp. Year Compl.	Impl. time (yrs)
1	Reroute desalter effluent	VOC	R	52	1.00	0.33	6,279	21.00	1	329			1–3
3a	Replace FCU cyclones	catalyst fines	R, D	245	8.30	3.03	12,363	-	0				4–7
3b	Install FCU ESP	catalyst fines	D	442	9.10	3.58	8,106	-	0	-			4–7
4	Eliminate blowdown coker	VOC	SR	130	2.00	0.63	4,862	16.00	2	316	RCRA/CAA	1994	1–3
5a	Secondary seals on gas tanks	VOC	SR	475	0.26	0.09	190	0.65	18	5	MACT, ozone	1994	>7
5b	Secondary seals on gas & distribution tanks	VOC	SR	482	0.32	0.11	232	0.74	18	6	MACT, ozone	1994	>7
5c	Secondary seals on floating roof tanks	VOC	SR	541	0.45	0.16	287	0.93	18	9	MACT, ozone	1994	>7
5d	5c + fixed roof tank internal floaters	VOC	SR	592	1.83	0.64	1,077	3.51	18	35	MACT, ozone	1994	>7
5e	5d + fixed roof tank secondary seals	VOC	SR	592	2.00	0.70	1,179	3.34	20	35	MACT, ozone	1994	>7
6	Keep soils out of sewers	Listed HW	SR	530	0.34	0.20	383	-	0				4–7
7a	Upgrade blowdown	VOC	T	5,096	5.10	1.63	320	1.04	11	148	BzNE-SHAP	1993	4–7
7b	Upgrade drainage system	VOC	T	113	18.80	5.94	52,809	171.00	5	1,188	ozone	1994	1–3
7c	Upgrade process water treatment	VOC	T	58	22.50	7.40	127,638	415.00	5	1,481	BzNE-SHAP	1993	1–3
8	Modify sampling system	VOC/HC	SR	63	0.08	0.03	429	1.39	0		ozone	1995	4–7
9	Reduce barge loading losses	VOC	R	768	4.70	1.61	2,094	7.00	55	29	BzNE-SHAP	1994	1–3
10	Improve sour water system	H_2S, NH_3	R,T	18	0.06	0.20	11,056	-	0		ozone		1–3
11a	Annual LDAR (10,000 ppm)	VOC	R, T	320	0.01	0.09	288	0.94	2	46	MACT or HON	1994	<1
11b	Quarterly LDAR (10,000 ppm)	VOC	SR	511	0.01	0.14	270	0.88	3	46	MACT, ozone	1994	<1
11c	Quarterly LDAR (500 ppm)	VOC	SR	706	0.01	0.20	276	0.90	3	46	ozone	1994	<1

D=disposal, R= recycle, SR=source reduction, T=treatment
NESHAP=National Emission Standards for Hazardous Air Pollutants

Case A Exercises

1. Structure the criteria discussed in the case into a sensible hierarchy.

2. Two workshop members developed pairwise preferences for the following criteria:

Workshop member 1:

Criteria	Risk	Cost	Tech
Risk	1	9	7
Cost	1/9	1	1/4
Tech	1/7	4	1

Workshop member 2:

Criteria	Risk	Cost	Tech
Risk	1	1/7	1/3
Cost	7	1	1/4
Tech	3	4	1

Compute the priority weights for each criterion.

3. Using Options 5c, 9, and 11b from Exhibit 2, and information from Exhibit 3, develop pairwise comparison matrices for the options. Compute the overall scores for each decision alternative (using the workshop members' priority weights).

4. Draw conclusions from the computations.

Case A Discussion Questions

What decision does the AHP analysis suggest?

What are the numbers to which the analysis is most sensitive? (e.g., if the estimate of cost for option 5c is increased by $1,000, does the final conclusion change?)

What do you think are the major criteria and why?

Case B: Results of Applying AHP to the Amoco/EPA Project

Single Criterion Ranking Methods and Results

This section describes the process the Amoco/EPA team used to rank pollution prevention options. Important characteristics of the 12 options, and their alternatives, are summarized in **Exhibit 3**. For three options — 3, 5, and 11 — only one of the several alternatives considered would be implemented.

As mentioned in Case A, two options reduce solid wastes (catalyst fines and listed hazardous wastes), while the remaining 10 focus on air emissions (VOC, HC, H_2S, and NH_3); five employ source reduction to reduce releases. Capital costs range from a low of $10,000 to a high of $22,500,000. Annual costs, based on discounting capital, operating, and maintenance costs at a 10-percent discount rate, range from $30,000 to $7,400,000.

Members of the Peer Review Committee suggested that the options be ranked according to a single criterion, such as risk reduction. In addition to risk reduction, two other single criterion rankings are of interest: total release reduction and cost.

EXPOSURE REDUCTION

Since the risk assessment is still being conducted, a risk proxy of benzene exposure at a nearby residence was used to finish ranking the options. Benzene concentrations calculated at a nearby residence were assumed to reasonably indicate population exposure and the exposure reactions achievable by implementing a particular option. Several rankings were produced using this measure and the option characteristics developed by Amoco engineers (**Exhibit 3**).

The second set of columns in **Exhibit 4** shows the ranks resulting from using benzene exposure reduction as the sole criterion for valuing the options. Reducing barge-loading emissions is the outstanding option using this criterion — no other option comes close. The other ranking values provide insight into which options generally provide greater exposure reduction. For example, all secondary seal alternatives achieve significant exposure reduction, and the blowdown system upgrade also performs effectively in this regard. Four options achieve no benzene exposure reduction because these options deal with release sources that do not emit benzene.

EXHIBIT 4: SINGLE CRITERION RANKINGS BASED ON RELEASE AND EXPOSURE REDUCTION

Release Reduction			
Rank	#	Project	ton/yr
1	7a	Upgrade blowdown system	5,096
2	9	Reduce barge loading losses	768
3	11c	Quarterly LDAR (500 ppm)	706
4	5e	5d + fixed roof tank sec. seals	592
5	5d	5c + fixed roof tank int. floaters	592
6	5c	Sec. seals on floating roof tanks	541
7	6	Keep soils out of sewers	530
8	11b	Quarterly LDAR (10,000 ppm)	511
9	5b	Sec. seals on gas & dist.tanks	482
10	5a	Sec. seals on gas tanks	475
11	3b	Install FCU ESP	442
12	11a	Annual LDAR (10,000 ppm)	320
13	3a	Replace FCU cyclones	245
14	4	Eliminate blowdown coker pond	130
15	7b	Upgrade drainage system	113
16	8	Modify sampling system	63
17	7c	Upgrade proc. water treatment	58
18	1	Reroute desalter effluent	52
19	10	Improve sour water system	18

Exposure Reduction			
Rank	#	Project	%
1	9	Reduce barge loading losses	55
2	5e	5d + fixed roof tank sec. seals	20
3	5a	Sec. seals on gas tanks	18
3	5b	Sec. seals on gas & dist.tanks	18
3	5c	Sec. seals on floating roof tanks	18
3	5d	5c + fixed roof tank int. floaters	18
7	7a	Upgrade blowdown system	11
8	7b	Upgrade drainage system	5
8	7c	Upgrade proc. water treatment	5
10	11b	Quarterly LDAR (10,000 ppm)	3
10	11c	Quarterly LDAR (500 ppm)	3
12	4	Eliminate blowdown coker pond	2
12	11a	Annual LDAR (10,000 ppm)	2
14	1	Reroute desalter effluent	1
15	6	Keep soils out of sewers	0
15	8	Modify sampling system	0
15	10	Improve sour water system	0
15	3a	Replace FCU cyclones	0
15	3b	Install FCU ESP	0

The rankings are intended to provide an approximate guide to which options rank near the top with regard to certain criteria and which rank near the bottom. On this basis, the preferred options are those that consistently rank near the top across all criteria felt by the decision-maker to be important. Options that receive comparable scores during the ranking process should be considered equivalent independent of their rank. For example, from an exposure reduction perspective, **Exhibit 4** indicates that (a) controlling barge-loading emissions is the best single action; (b) installing secondary seals and implementing an upgrade of the blowdown stacks also will achieve beneficial exposure reductions; and (c) the remaining options achieve minimal or no reduction in benzene exposure.

RELEASE REDUCTION

The results obtained when pollution prevention options are ranked by extent of release reduction are shown in the first set of columns of **Exhibit 4.** Upgrading the blowdown stacks is a clear winner, reducing releases more than six times as much as the nearest competitor; the remaining options diminish gradually in terms of release reduction. All of the highest ranked release reduction options — blowdown stack upgrade, barge loadings, quarterly LDAR program (500 ppm), and double seals on tanks — also rank at the top in terms of exposure reduction.

COST

It is interesting to compare the exposure reduction and release reduction results with the ranking based on cost, shown in the first set of columns of **Exhibit 5.** In this case, modifying the sampling procedure is the best option, costing three times less than its closest competitor. Comparing this result with the results based on exposure reduction and release reduction, modifying sampling ranked near the bottom with respect to these other criteria. On the other hand, two options ranked highly with regard to exposure reduction and release reduction — (secondary seals and quarterly LDAR 500 ppm) — also rank well with respect to costs. Barge loading and blowdown system upgrade, which rank near the top from the exposure reduction and release reduction respectively, rank near the bottom from the cost perspective. Based on these three single criterion rankings, the secondary seals and quarterly LDAR options look promising, and, if sufficient funding is available, barge loading and the blowdown system upgrade may be promising as well.

EXHIBIT 5: SINGLE-CRITERION RANKINGS BASED ON ANNUALIZED COSTS AND NET ANNUAL CASH FLOW

Annualized Costs					Net Cost			
Rank	#	Project	Annualized cost (in $MM)		Rank	#	Project	Net ann. cash flow (in $/T)
1	8	Modify sampling system	0.03		1	11b	Quarterly LDAR (10,000 ppm)	-4
2	5a	Sec. seals on gas tanks	0.09		2	11a	Annual LDAR (10,000 ppm)	-2
3	11a	Annual LDAR (10,000 ppm)	0.09		3	5a	Sec. seals on gas tanks	-1
4	5b	Sec. seals on gas & dist.tanks	0.11		4	11c	Quarterly LDAR (500 ppm)	-1
5	11b	Quarterly LDAR (10,000 ppm)	0.14		5	8	Modify sampling system	5
6	5c	Sec. seals on floating roof tanks	0.16		6	5b	Sec. seals on gas & dist.tanks	10
7	6	Keep soils out of sewers	0.20		7	6	Keep soils out of sewers	17
8	10	Improve sour water system	0.20		8	5c	Sec. seals on floating roof tanks	30
9	11c	Quarterly LDAR (500 ppm)	0.20		9	10	Improve sour water system	110
10	1	Reroute desalter effluent	0.33		10	1	Reroute desalter effluent	131
11	4	Eliminate blowdown coker pond	0.63		11	5d	5c + fixed roof tank int. floaters	242
12	5d	5c + fixed roof tank int. floaters	0.64		12	4	Eliminate blowdown coker pond	246
13	5e	5d + fixed roof tank sec. seals	0.70		13	5e	5d + fixed roof tank sec. seals	281
14	9	Reduce barge loading losses	1.61		14	9	Reduce barge loading losses	568
15	7a	Upgrade blowdown system	1.63		15	7a	Upgrade blowdown system	734
16	3a	Replace FCU cyclones	3.03		16	3a	Replace FCU cyclones	1,158
17	3b	Install FCU ESP	3.58		17	3b	Install FCU ESP	1,548
18	7b	Upgrade drainage system	5.94		18	7b	Upgrade drainage system	2,467
19	7c	Upgrade process water	7.40		19	7c	Upgrade process water	3,120

Exhibit 5 provides annualized cost and net annual cash flow information for each option. The two numbers differ because the net annual cash flow includes revenue generated through product recovery; the annualized cost values do not.

In viewing these rankings, it is important to remember that the capital cost estimates are within 25 percent. Thus, values in the table are a best estimate, but have an unstated probable range. For example, the $90,000 annualized cost shown for modifying sampling systems (Option 8) has a range of $73,000 to $107,000. Similarly, the $632,000 annualized cost shown for eliminating the coker blowdown pond (Option 4) is the average of a range between $500,000 and $764,000. While it is possible to rank the options in the order shown, to find a distinction would be difficult, if not foolish, in practice.

Options 10 through 19 are ranked identically in both columns. These options have small or no product recovery revenues. Thus, no differences in ranking would be expected. The same group of options fall in the top half of both lists, although the order does change within each list. This is not unexpected, since a ranking based on the lowest cost would not necessarily coincide with a ranking based on the highest net annual cash flow. Options that generate income (primarily the LDAR programs and adding secondary seals to gasoline tanks) rank near the top of the list on a cash-flow basis. The top seven options that require least annualized cost to implement include modifying sampling systems and adding secondary seals to gasoline tanks (options that are also ranked near the top in the Net Cost column). This indicates that options that minimize annualized costs either generate income or minimize negative net annual cash flow.

Again, this ranking process provides a rough screen on the basis of one criteria, highlighting options that may merit further consideration and more detailed analysis.

OTHER CRITERIA

The decision-maker typically will augment rankings of the type established in this section by considering other criteria that have not been quantitatively evaluated. For example, institutional factors were originally included in the multiple criteria ranking process discussed below. When taking such institutional factors into account, a lower ranked option that significantly improves refinery odor or visibility performance might be elevated in rank if odor or visibility are of significant public concern in the region. Resource constraints are another important consideration. For example, some options may be precluded by their cost, or a group of options in the middle rank may, taken together, achieve better results at lower cost than the top ranked option. Such resource constraints may initially be addressed elsewhere, and a composite option then included in the multiple criteria ranking process as discussed below.

Multiple Criteria Ranking

Conducting a set of single criteria rankings and comparing results, as was done in the preceding section, lets the decision-maker quickly identify the more promising and least promising options. Often this provides sufficient perspective to proceed with in-depth evaluation of the more promising options.

In some cases, however, a more integrated multiple-criteria process is desired to help with selection. For example, the importance attributed to each criterion may be in dispute, and a systematic process may be needed to enable the decision makers to resolve these differences. In such cases, it is helpful to have a conceptual and computational framework for assessing the effect that alternative viewpoints have on the rankings. Usually, some differences can be put aside because they have limited effect on the rankings, and attention can be focused on those differences that do significantly affect the end result.

The Workgroup considered a number of multiple-criteria decision-making techniques for ranking options. The three approaches given greatest attention were: (1) the Analytical Hierarchy Process or AHP (Saaty, 1988 and 1990); (2) the Kepner-Tregoe approach (Kepner and Tregoe, 1979 and 1981), which Amoco has used in reviewing selected corporate decisions; and (3) Computation of Alternative Equivalents (Stokey and Zeckhauser, 1978), which a member of the Peer Review Committee suggested.

Ultimately, the Workgroup selected AHP as the ranking methodology, because it has proven useful in making decisions involving a large number of diverse criteria and options. As its name implies, AHP devotes a great deal of attention to the process by which the decision is made. Since the Amoco/EPA project involved a diversity of viewpoints at the federal, state, and industrial levels, a systematic process was needed for reaching a consensus or for identifying where and to what extent viewpoints differed. AHP provides such a framework:

it proceeds by using group discussion to identify criteria, organize them into a hierarchy that embodies relationships among the criteria, and establish priorities (i.e., criteria weights) with respect to an overall goal.

An initial list of criteria was generated from the project workplan and two brainstorming sessions at the Williamsburg Workshop. The project workplan provided overall perspective for criteria selection. Criteria identified at the Workshop provided a "base" list that was refined at subsequent Workgroup meetings. Initial criteria lists, broad in scope, were made more specific as the Workgroup gained knowledge about the characteristics of the options and the availability of data.

Through a process of elimination and refinement, the following criteria ultimately were selected for ranking options based on quantitative (and sometimes qualitative) assessment of the following characteristics:

Risk
- Relative benzene exposure reduction

Technical Characteristics
- Release reduction (mass)
- Status in pollution prevention management hierarchy (e.g., source reduction versus treatment)
- Transferability of option to other refineries/industries
- Timeliness of option implementation
- Secondary emissions

Cost Factors
- Resource utilization (raw materials and utilities)
- Capital, operating, and maintenance costs
- Effects of option implementation on potential remedial, product, and catastrophic liabilities.

Hierarchy structure was developed in parallel with refining the criteria list. The Workgroup identified relationships among criteria and constructed a hierarchy to represent these relationships. Within the hierarchical structure, each level is influenced only by the next higher level and can influence only the next lower level. The most general criteria contributing to achievement of the overall goal were identified as primary criteria or subgoals; these form the first level of hierarchy under the primary goal. Remaining criteria were grouped within these subgoal areas. Over the course of three iterations, the hierarchy evolved as Workgroup members gained information. **Exhibit 6 presents** the hierarchy used to rank options.

To rank options, each criterion on the hierarchy must be assigned a relative weight. Developing weights

EXHIBIT 6: HIERARCHY AND CRITERIA WEIGHTS USED FOR RANKING

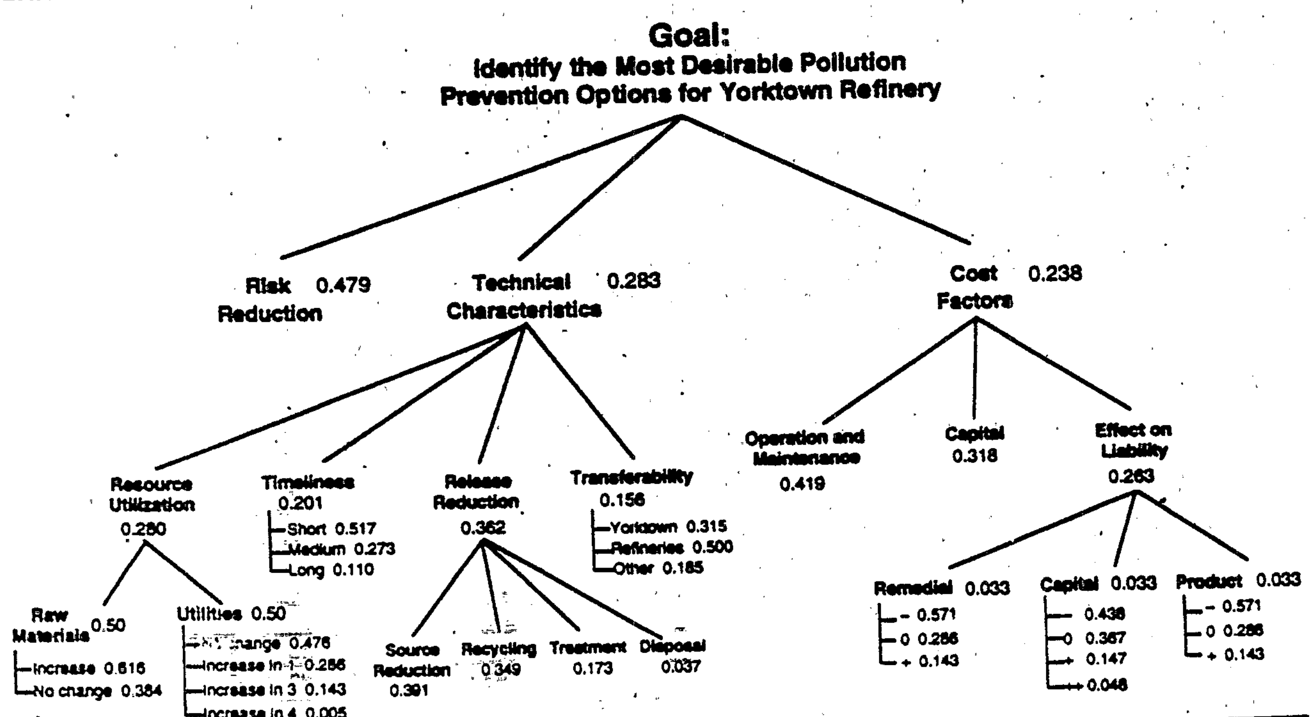
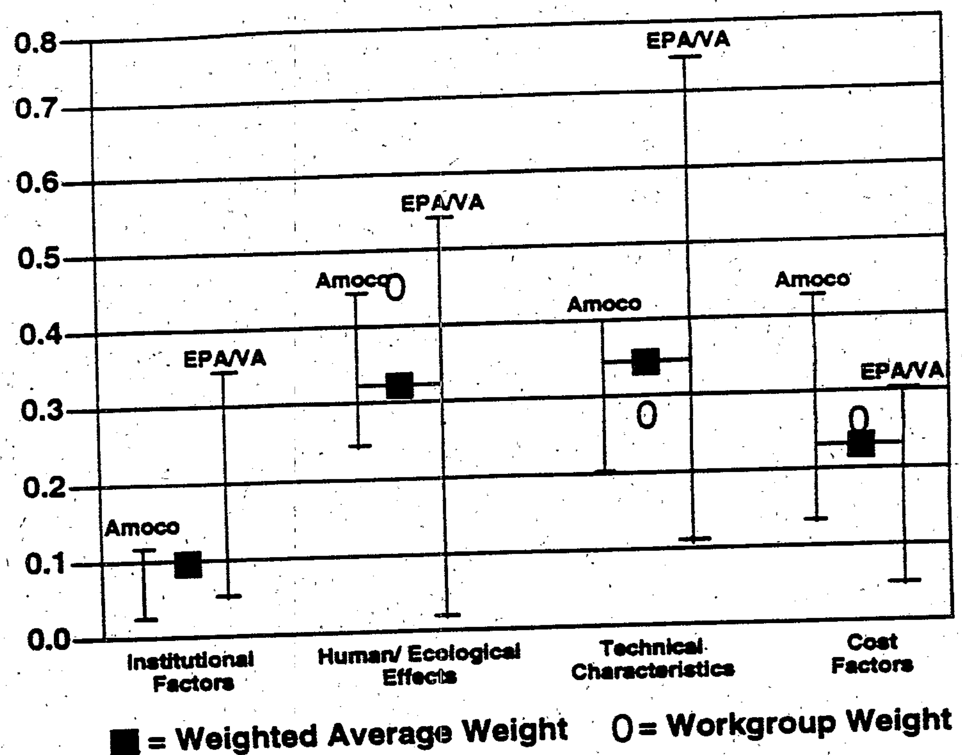


EXHIBIT 7: COMPARISON OF CRITERIA WEIGHTS



involved two steps: completing a survey of pairwise comparisons for each set of criteria, and convening an all-day session to review survey results and revise the criteria weights and hierarchy structure.

It is interesting to compare the weights proposed by the Amoco representatives with those proposed by EPA and state regulatory personnel. In three of four areas, the variability of proposed weights is much greater for the EPA/state personnel than for the Amoco representatives, and the spread of weights proposed by Amoco is nearly entirely encompassed within the spread of weights proposed by EPA and the state. **Exhibit 7** shows the weights proposed by each group and compares the weights obtained via the survey of individual respondents with weights established via extended discussion at a full-day Workgroup meeting, which were the principal weights used in the AHP analysis. The Workgroup placed greater emphasis on human/ ecological (risk) effects, less emphasis on technical characteristics and comparable weight on cost factors. Institutional factors were deleted as a ranking criterion, with the intent that these considerations be addressed external to the completed AHP ranking.

AHP Ranking Results

Exhibit 8 presents the results of the AHP ranking using the Workgroup's hierarchy and criteria weights. There appear to be three distinct groupings of options: most preferred, least preferred and a middle ground where no strong preference exists for one choice over another. Two major factors influenced the overall ranking of options — exposure reduction and cost. Technical characteristics determine the rankings within the mid- and low-performance groups.

The option of reducing barge-loading emissions, which achieves a 55 percent benzene exposure reduction, receives a ranking score more than two times greater than the next best option. The five mid-performance options (double seals, quarterly LDAR, sampling, blowdown system, and annual LDAR) have low to moderate costs and (except for sampling) a positive exposure reduction. The eight projects ranked lowest (drainage upgrade, treatment upgrade, reroute desalter, sour water improvements, soils out of drain, coke blowdown pond, install FCU ESP, and replace FCU cyclones) all have minor or no impact on the benzene exposure to the surrounding human population.

As discussed above, Amoco and EPA personnel proposed somewhat different weights for the AHP ranking criteria. AHP analyses were conducted to compare the results obtained using the criteria weights proposed by EPA and state Workgroup members to those suggested by Amoco. The results are presented in **Exhibit 9.** This analysis suggests how the options might be ranked from an industry outlook as compared with the ranking from a regulator's viewpoint. Despite differences in perspective, the results show that reducing barge-loading emissions is the preferred choice for both groups. In addition, while other options change order, the readjustments are minor. The average weights proposed by each group are shown at the bottom of the exhibit. Workgroup members from Amoco assigned nearly equal weights to all three categories, while EPA/state members assigned the highest weight to risk reduction, next highest weight to technical factors, and the lowest weight to cost.

Project Options and Regulatory Requirements

As indicated in **Exhibit 3**, eight of the 12 project options would, if implemented, contribute to meeting current or anticipated regulatory and statutory program requirements. The characteristics of these eight options are summarized in **Exhibit 10** (listed by compliance year). Legal requirements dictate that these options or equivalent be undertaken at the Refinery. The eight options, at an annual cost of $17,500,000, achieve a release reduction of 7,280 tons per year and a benzene exposure reduction equaling 99 percent of that associated with all 12 options.

For purposes of comparison, analyses were conducted to assess what options might be selected to achieve comparable release and exposure reduction objectives in the absence of the existing regulatory constraints. To avoid double-counting, a specific alternative was arbitrarily selected for those options involving multiple alternatives. The alternatives selected were 3b for FCU fines recovery, 5c for secondary seals, and 11b for LDAR. The goal in this analysis was to attain the desired environmental targets — release reduction or exposure reduction — at a lesser cost.

The 12 options are ranked in **Exhibit 11** with respect to cost-effectiveness of release reduction, expressed in dollars per ton. The results indicate that five options — 11b, 5c, 7a, 6, and 8 — are significantly more cost-effective with regard to release reduction. Taken together, these five options attain a release reduction of 6,741 tons per year at an annual cost of $2,160,000. When compared to the regulatory requirement options, the cost-effectiveness options attain more than 90 percent

EXHIBIT 8: AHP RANKING USING WORKGROUP WEIGHTS

Rank	#	Project	Score
1	9	Reduce barge loading losses	100
2	5a	Sec. seals on gas tanks	43
2	5b	Sec. seals on gas & dist.tanks	43
2	5c	Sec. seals on floating roof tanks	43
2	5e	5d + fixed roof tank sec. seals	43
6	5d	5c + fixed roof tank int. floaters	40
7	7a	Upgrade blowdown system	29
8	11c	Quarterly LDAR (500 ppm)	19
9	11b	Quarterly LDAR (10,000 ppm)	18
10	11a	Annual LDAR (10,000 ppm)	16
11	7b	Upgrade drainage system	13
12	4	Eliminate blowdown coker pond	12
12	7c	Upgrade proc. water treatment	12
14	1	Reroute desalter effluent	11
14	6	Keep soils out of sewers	11
14	8	Modify sampling system	11
17	10	Improve sour water system	10
18	3a	Replace FCU cyclones	5
18	3b	Install FCU ESP	5

EXHIBIT 9: COMPARISON OF AHP RANKING USING WORKGROUP WEIGHTS VS. AMOCO AND EPA WEIGHTS

WORKGROUP WEIGHTS				AMOCO WEIGHTS				EPA WEIGHTS			
Rank	#	Project	Score	Rank	#	Project	Score	Rank	#	Project	Score
1	9	Reduce barge loading losses	100	1	9	Reduce barge loading losses	100	1	9	Reduce barge loading losses	100
2	5a	Sec. seals on gas tanks	43	2	5a	Sec. seals on gas tanks	53	2	5e	5d + fixed roof tank sec. seals	44
2	5b	Sec. seals on gas and dist. tanks	43	2	5b	Sec. seals on gas and dist. tanks	53	2	5a	Sec. seals on gas tanks	43
2	5c	Sec. seals on floating roof tanks	43	2	5c	Sec. seals on floating roof tanks	53	2	5b	Sec. seals on gas and dist. tanks	43
2	5e	5d + fixed roof tank sec. seals	43	5	5e	5d + fixed roof tank sec. seals	49	2	5c	Sec. seals on floating roof tanks	43
6	5d	5c + fixed roof tank internal floaters	40	6	5d	5c + fixed roof tank internal floaters	46	6	5d	5c + fixed roof tank internal floaters	40
7	7a	Upgrade blowdown system	29	7	7a	Upgrade blowdown system	37	7	7a	Upgrade blowdown system	32
8	11c	Quarterly LDAR (500 ppm)	19	8	11c	Quarterly LDAR (500 ppm)	31	8	11c	Quarterly LDAR (500 ppm)	20
9	11b	Quarterly LDAR (10,000 ppm)	18	9	11b	Quarterly LDAR (10,000 ppm)	30	9	11b	Quarterly LDAR (10,000 ppm)	19
10	11a	Annual LDAR (10,000 ppm)	16	10	11a	Annual LDAR (10,000 ppm)	28	10	11a	Annual LDAR (10,000 ppm)	17
11	7b	Upgrade drainage system	13	11	4	Eliminate blowdown coker pond	21	11	7b	Upgrade drainage system	14
12	4	Eliminate blowdown coker pond	12	11	6	Keep soils out of sewers	21	12	4	Eliminate blowdown coker pond	13
12	7c	Upgrade process water treatment	12	11	8	Modify sampling system	21	12	7c	Upgrade process water treatment	13
14	1	Reroute desalter effluent	11	14	1	Reroute desalter effluent	20	14	1	Reroute desalter effluent	12
14	6	Keep soils out of sewers	11	15	10	Improve sour water system	19	14	6	Keep soils out of sewers	12
14	8	Modify sampling system	11	16	7b	Upgrade drainage system	16	14	8	Modify sampling system	11
17	10	Improve sour water system	10	16	7c	Upgrade process water treatment	16	17	10	Improve sour water system	10
18	3a	Replace FCU cyclones	5	18	3a	Replace FCU cyclones	10	18	3a	Replace FCU cyclones	6
18	3b	Install FCU ESP	5	19	3b	Install FCU ESP	9	18	3b	Install FCU ESP	6
CRITERIA WEIGHTS											
Risk reduction			0.479				0.30				0.421
Technical characteristics			0.283				0.376				0.394
Cost factors			0.238				0.324				0.185

of the release reduction at less than 15 percent of the annual cost. Adding Barge Loading Emission Reduction to the five most cost-effective options achieves 103 percent of the required tonnage reduction for just over a quarter of the annual cost.

The cost-effectiveness values in **Exhibit 11** do not include the potential revenue stream that could result from product recovery associated with source reduction and recycling activities. Including potential revenues in calculating a net cost effectiveness, results in the option ranking are shown in **Exhibit 12**. Because the revenue streams are relatively small for most options, the ranking changes very little: the option ranked highest — the Quarterly LDAR Program (Option 11b), which generates a positive cash flow and an estimated 19 percent rate of return —is the same in both tables, as are the options ranked 6 through 12. However, the ranking order for Options 2 through 5 does change somewhat. Installing secondary seals on all floating roof tanks (Option 5c) moves from the second choice to third. Upgrading blowdown stacks (Option 7A moves from third to fifth. Reducing soil intrusion into the sewer system (Option 6) moves from fourth to second.

EXHIBIT 10: REGULATORY REQUIREMENT OPTIONS

#	Project	Material	PP mode	Release reduct. ton/yr	Annualized cost $MM	Benzene Expos. Red'n %	Statutory Program	Expect Compliance Year
7a	Blowdown Upgrade	VOC	treatment	5,096	1.63	11	BzNESHAP, non-at.	1993
7c	Treatment Pit Upgrade	VOC	treatment	58	7.40	5	BzNESHAP	1993
4	Elim. coker pond	VOC	s. red'n	130	0.63	2	RCRA/CAA	1994
5c	Sec. seals-all fltRfTk	VOC	s. red'n	541	0.16	18	MACT, Oz non-at.	1994
7b	Drainage Upgrade	VOC	treatment	113	5.94	5	BzNESHAP/stmwtr.	1994
9	Barge Loading	VOC	rec/treat	768	1.61	55	MACT, non-at.	1994
11b	Quart LDAR (10,000 ppm)	VOC	s. red'n	511	0.14	3	Oz non-at	1994
8	Modify Sampling	VOC/HC	s. red'n	63	0.03	0	MACTor HON	1995
	Total			7,280	17.54	99		

EXHIBIT 11: COST-EFFECTIVE RELEASE REDUCTION RANKING

#	Project	Material	PP mode	Release reduct. ton/yr	Cum. Rel. Red'n (tons/yr)	Annualized Cost $MM	Cum. Ann. Cost $M	Cost effective $/ton
11b	Quart LDAR (10,000 ppm)	VOC	s. red'n	511	511	0.14	0.14	270
5c	Sec. seals-all fltRfTk	VOC	s. red'n	541	1,052	0.16	0.3	287
7a	Blowdown Upgrade	VOC	treatment	5,096	6,148	1.63	1.93	320
6	Soils Control	listed HW	s. red'n	530	6,678	0.20	2.13	383
8	Modify Sampling	VOC/HC	s. red'n	63	6,741	0.03	2.16	429
9	Barge Loading	VOC	rec/treat	768	7,509	1.61	3.77	2,094
4	Elim. coker pond	VOC	s. red'n	130	7,639	0.63	4.4	4,862
1	Reroute desalter	VOC	recycle	52	7,691	0.33	4.73	6,279
3b	Install FCU ESP	Cat. fines	disposal	442	8,133	3.58	8.31	8,106
10	Sour water improvement	H2S, NH3	rec/treat	18	8,151	0.20	8.51	11,056
7b	Drainage Upgrade	VOC	treatment	113	8,264	5.94	14.45	52,809
7c	Treatment Pit Upgrade	VOC	treatment	58	8,322	7.40	21.85	127,638
	Total			8322		21.85		2626

A similar analysis is shown for exposure reduction in **Exhibit 13**. In this case, six options — 5c, 9, 11b, 7a, 4, & 1 — are much more cost-effective in terms of benzene exposure reduction, collectively attaining 90 percent benzene exposure reduction at an annualized cost of $4,500,000, which is about one-fifth the annualized cost of the regulatory requirements options.

The regulatory requirements shown in **Exhibit 10** have been or will be developed using administrative procedures. The regulatory development process includes review and comment opportunities for the public and for industry organizations. It is not the intent of the analysis presented here to critically assess all of those regulatory requirements, because the level of evaluative detail here is considerably less. The results presented above merely indicate the possibility that when the collective requirements of the regulations imposed on a given facility are taken into account, granting the industrial organization greater flexibility in how to achieve the designated standards may enable a facility attain standards at a significantly reduced cost.

EXHIBIT 12: COST-EFFECTIVENESS VS. NET CASH FLOW EFFECTIVENESS

Cost-Effectiveness				Net Cash Flow Effectiveness			
Rank	#	Project	$/ton	Rank	#	Project	$/ton
1	11b	Quart LDAR (10,000 ppm)	270	1	11b	Quart LDAR (10,000 ppm)	-8
2	5c	Sec. seals-all fltRfTk	287	2	6	Soils Control	32
3	7a	Blowdown Upgrade	320	3	5c	Sec. seals-all fltRfTk	56
4	6	Soils Control	383	4	8	Modify Sampling	86
5	8	Modify Sampling	429	5	7a	Blowdown Upgrade	144
6	9	Barge Loading	2,094	6	9	Barge Loading	740
7	4	Elim. coker pond	4,862	7	4	Elim. coker pond	1,886
8	1	Reroute desalter	6,279	8	1	Reroute desalter	2,500
9	3b	Install FCU ESP	8,106	9	3b	Install FCU ESP	3,502
10	10	Sour water improvement	11,056	10	10	Sour water improvement	6,114
11	7b	Drainage Upgrade	52,809	11	7b	Drainage Upgrade	21,933
12	7c	Treatment Pit Upgrade	127,638	12	7c	Treatment Pit Upgrade	53,793

EXHIBIT 13: COST-EFFECTIVE BENZENE EXPOSURE REDUCTION RANKING

#	Project	Material	PP mode	Annualized Cost $MM	Cum. Ann. Cost $M	Bz Expos. Red'n %	Cost Eff. BzExRed $T/%BzE
5c	Sec. seals-all fltRfTk	VOC	s. red'n	0.16	0.16	18	9
9	Barge Loading	VOC	rec/treat	1.61	1.77	55	29
11b	Quart LDAR (10,000 ppm)	VOC	s. red'n	1.14	2.91	3	46
7a	Blowdown Upgrade	VOC	treatment	1.63	4.54	11	148
4	Elim. coker pond	VOC	s. red'n	0.63	5.17	2	316
1	Reroute desalter	VOC	recycle	0.33	5.50	1	329
7b	Drainage Upgrade	VOC	treatment	5.94	11.44	5	1,188
7c	Treatment Pit Upgrade	VOC	treatment	7.40	18.84	5	1,480
3b	Install FCU ESP	Cat. fines	disposal	3.58	22.42	0	
6	Soils Control	Listed HW	s. red'n	0.20	18.24	0	
8	Modify Sampling	VOC/HC	s. red'n	0.03	21.85	0	
10	Sour water improvement	H2S,NH3	treatment	0.20	18.04	0	
	Total			22.85		100	

EXHIBIT 14: OPTION SCORES BY RANKING TECHNIQUE

#	Project	Release reduction	Exposure Reduction	Cost	Cost-Effective Rel Red'n	Cost-Effective Exp Red'n	AHP
1	Reroute desalter				M	M	
3a	Replace FCU Cyclones						
3b	Install FCU ESP	M			M		
4	Elim. coker pond				M	M	
5a	Sec. seals-gas tks*	M	M	M	H	H	M
5b	Sec. seals-das/dist tks*	M	M	M	H	H	M
5c	Sec. seals-all fltRfTk*	M	M		H	H	M
5d	Opt 5c &flt on FixTk*						
5e	Opt 5d &S.seal FixTk*						
6	Soils Control	M		M	H		
7a	Blowdown Upgrade	H	M		H	M	M
7b	Drainage Upgrade						
7c	Treatment Pit Upgrade						
8	Modify Sampling			H	H		M
9	Barge Loading	M	H		M	H	H
10	Sour water improvement			M	M		
11a	Ann. LDAR (10,000 ppm)			M	H	H	M
11b	Quart LDAR (10,000 ppm)*	M		M	H	H	M
11c	Quart LDAR (500 ppm)*	M		M	H	H	M

Summary of Ranking Results

The scores achieved by each pollution prevention option under each of the ranking methods are summarized in Exhibit 14. Disregarding minor differences between option scores, the scores achieved under each method are grouped into high, medium, or low categories. Only the high (H) and medium (M) scores are shown; the absence of a score under a particular ranking method indicates that option received a low score for that method.

Those options (or alternatives) that received at least a high or medium score under all but one of the rankings are marked with an asterisk (*). These include all five double-seal alternatives, the blowdown system upgrade, barge loading emission reduction, and the two quarterly LDAR alternatives. By virtue of their consistently favorable ranking under a variety of perspectives, the Workgroup concluded that these four options show the most promise among the 12 considered. The three options faring next best across the ranking protocols are annual LDAR, sampling system modification, and soil control.

Several options also ranked consistently low and were thus least preferred. These included replacing the FCU cyclones (3a) and upgrading the drainage system (7b) and treatment plant (7c). None of these received a medium or high score. Just above this group, a third tier included Options 1, 2, 3b, 4, and 10. The table below separates the options into preference categories.

Most Preferred

5	Install secondary seals
7a	Upgrade blowdown system
9	Reduce barge-loading losses
11b, 11c	Quarterly LDAR program

Next Most Preferred

11a	Annual LDAR program
8	Modify sampling system
6	Keep soils out of sewers

Next Least Preferred

1	Reroute desalter effluent
3b	Install FCU ESP
4	Eliminate coker blowdown pond
10	Sour water system improvements

Least Preferred

3a	Replace FCU cyclones
7b	Upgrade drainage system
7c	Upgrade process water treatment plant

For the Instructor: Teaching Note on "Total Quality Management: A Methodology for Pollution Prevention"

Purpose

This exercise is designed for inclusion in an introductory Total Quality Management course. The material requires between 50 and 80 minutes of class time for discussion of the articles and case study. The reading material should be assigned to students prior to class. There are in-class discussion points as well as homework questions.

While designed for industrial engineering students, the material is appropriate for other engineering students and business school students (both undergraduate and graduate levels). Students should have a familiarity with the concepts of customer focus, continuous improvement, teamwork, and strong management commitment prior to the class.

Answers

1. Students should mention some of the following:
   - Customer focus calls for reduction of waste.
   - Root-cause analysis prevents waste rather than controls it.
   - "Zero waste" is analogous to "zero defects."
   - Deming's principles call for elimination of waste.
   - Continuous improvement of process waste also identifies quality issues.
   - Team approach encourages different perspectives on the problem.
2. Potential answers include:
   - Plant workers
   - People downstream from plant who use the river for drinking water
   - Fish downstream from plant
   - Birds dependent on fish for food
   - Fishermen
   - Farmers who use river water for irrigation
   - Children playing near dump (land or water)
   - Asthmatics downwind from plan
   - Homeowners near the plant who want to sell their houses
   - Nearby residents who are allergic to pollutants (air or water)
3. It doesn't get to the root of the problem. It controls existing waste rather than finding ways to prevent it. It is reactive to regulation rather than proactive. Also, environmental engineers are not familiar enough with the processes to suggest improvements.
4. The team approach allows more factors of the environmental issue to be considered, because more staff are contributing specialized knowledge of the various processes that affect those issues.

5 Some answers are:

- Results of customer focus groups' requesting "environmentally friendly" products
- Publicity of competitors' economic success with TQEM
- Legislation requiring pollution prevention
- Inclusion of environmental quality criteria, such as those required by the Malcolm Baldridge Award, ISO-9000, and Ford Q-1.

The matrix at the end of this compendium's Resource List indicates 20 books and articles on TQM and industrial engineering.

Further information on quality awards can be obtained from the following organizations:

Malcolm Baldridge National Quality Award
A537 Administration Building
National Institute of Standards and Technology
Gaithersburg, MD 20899-0001
301/975-2036

ISO 9000
CEEM Information Services
10521 Braddock Road
Fairfax, VA 22032
800/745-5565

Ford Q-1
Ford Motor Quality Publications
c/o EDCOR Data Services
P.O. Box 9079
Farmington Hills, MI 48333-9079
810/626-3077

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The mission of the NPPC is to promote sustainable development by educating students, faculty, and professionals about pollution prevention; create educational materials; provide tools and strategies for addressing relevant environmental problems; and establish a national network of pollution prevention educators. In addition to developing educational materials and conducting research, the NPPC also offers an internship program, professional education and training, and conferences.

Your Input Is Welcome!

We are very interested in your feedback on these materials. Please take a moment to offer your comments and communicate them to us. Also contact us if you wish to receive a documents list, order any of our materials, collaborate on or review NPPC resources, or be listed in our *Directory of Pollution Prevention in Higher Education*.

We're Going Online!

The NPPC provides information on its programs and educational materials through the Internet's Worldwide Web; our URL is: **http://www.snre.umich.edu** (click on "National Pollution Prevention Center").

We may also update the NPPC information available through gopher (gopher.snre.umich.edu) and anonymous FTP (ftp.snre.umich.edu). Please contact us if you have comments about our online resources or suggestions for publicizing our educational materials through the Internet. Thank you!

Total Quality Management: A Methodology for Pollution Prevention

Prepared by Leith Harmon, NPPC Research Assistant, under the supervision of Katta Murty, Professor of Industrial and Operations Engineering, University of Michigan.

Introduction

As a result of global competition, consumers demand better product and service quality. At the same time, some consumers' environmental concerns continue to grow. Total Quality Management (TQM), a system that can help companies achieve high product and service quality, has inherent strengths that effectively address some environmental issues.

Professionals who apply TQM concepts to environmental issues have coined the term Total Quality Environmental Management (TQEM). This is a logical method for producing the results of another concept gaining speed in industry: pollution prevention. This paper explains how the concepts of TQEM can be employed to successfully prevent pollution.

Background

In *Total Quality Control*, Armand Feigenbaum defines product and service quality as:

> [T]he total composite product and service characteristics of marketing, engineering, manufacture, and maintenance through which the product and service in use will meet the expectations of the customer.[1]

To achieve product and service quality many organizations employ TQM. Its management elements include:

- Customer focus
- Continuous improvement
- Teamwork
- Strong management commitment

Yet, who is the customer, and how can TQM principles be applied to environmental concerns?

CUSTOMER FOCUS

In the context of quality, the customer is defined as the person who "employs the product and service characteristics."[2] Customers fall into two categories. The *internal* customer is the next person in the production chain; the *external* customer is the end-user of the product. For instance, in the auto industry, the person who installs the bumper is an internal customer to the department producing the bumpers; the external customer is the purchase of the finished car.

If the definition of the customer is expanded to include the people and environments effected by production process *waste*, TQM requires us to understand how this waste affects those customers and take steps to reduce it. Both W. Edwards Deming and Kiyoshi Suzaki, legends in the field of TQM, have defined waste as "that which does not add value."[3] For this paper, we define waste more specifically: the physical by-products of a process. This can be excess paper in an insurance office as well as waste chemicals from a paper mill. When we more narrowly define waste, the principles of its elimination put forth by Deming and Suzaki are no less pertinent.

As an example, many industries use the solvent trichloroethylene (TCE) in their operations. This highly toxic chemical must be contained in a closed system, as releases of TCE can be fatal. Such releases often require the evacuation of the entire facility. Here the plant workers are the unwilling internal customers of TCE fumes. The external environment is also an unwilling customer. Rivers downstream can be affected by the effluent of a paper mill or oil refinery. Aquatic life in the river and people dependent on the river for drinking water are unwilling customers of this effluent.

Continuous Improvement

Those who have embraced TQM understand that quality can only be *built* into the product, not *inspected* into. This requires the producer to continuously identify and eliminate the root causes of impediments to quality. Continuous improvement is also the key to reducing the environmental impacts of the production process.

The traditional approach to industrial waste has been to view it as a necessary, though unwanted, by-product of manufacturing. While production generates the waste, the responsibility to dispose of the waste in a safe and legal manner usually falls on the environmental engineering department. Because environmental engineers receive the waste after it has been created, they are not intimately familiar with the processes that create it. Further, because waste reduction is not a component of their performance reviews, they do not have the institutional motivation to reduce the waste.

The environmental engineering department is also responsible for completing government forms documenting the facility's wastes. Government regulations are created to ensure the health of plant workers, the surrounding community, and the environment in general. However, these regulations often create requirements that are very cumbersome and expensive for industry. For instance, under the Superfund law, a Toxic Release Inventory (TRI) must be completed each year. The TRI process, which records the volumes of waste generated by a facility, requires paperwork that can take up to three months to complete; like product quality inspection, this is certainly not value-added! Replacing toxic materials used in the manufacturing process with more environmentally benign materials reduces the paperwork.

TQEM is the logical method for preventing pollution wherever possible. Employing a customer focus and classifying the waste itself and the activities required to control it as non-value-added, TQEM calls for waste generation to be brought to a minimum.[4] Operators and process engineers, not environmental engineers, are responsible for identifying and eliminating the root causes of process waste. Employing the continuous improvement approach, "zero waste" is as important a goal as "zero defects."

As a result of TQEM projects, product quality often improves while waste is reduced. One possible explanation might be that TQEM efforts empower employees to become more familiar with all aspects of the process, not those just associated with production. When employees are forced to consider process wastes, improvements to quality characteristics can result.

Teamwork

The team approach allows all factors of the environmental issue to be considered. Accountants are familiar with cost considerations, product engineers are familiar quality considerations, process and chemical engineers are familiar with feasibility considerations, and environmental engineers are familiar with environmental impacts. Because environmental engineers are trained to deal with waste *after* it has been generated, and not in methods of preventing it from being created in the first place, engineers with knowledge of the process characteristics must be involved.

For example, degreasing certain aluminum components with TCE has required extensive safety mechanisms and procedures. Building better containment systems reduces the risk of exposure, but does not get to the root cause of the problem — the use of TCE. With this in mind, Ford, an active TQEM proponent, looked for a TCE-free solution to degreasing radiator coils.[5] Ford formed a team that included a chemical engineer, an environmental engineer, a process engineer, an accountant, and a product engineer. The variety of backgrounds on the team ensured that the pertinent issues of cost, product quality, process feasibility and environmental impact were all addressed. The Ford team designed an aqueous degreasing system (i.e., soap and water) to replace the TCE. Not only does the plant avoid using this toxic chemical, but the water in the new system is recycled as well. Significantly, the aqueous degreaser exhibits better quality characteristics than the TCE degreaser.

The above project is an example of the best of all worlds: improved quality, reduced cost, and reduced environmental impact. Certainly not all projects will prove so fruitful. Some "clean" alternatives may cost more than their polluting rivals, but that cost must be balanced with the benefits of the environmental improvement.[6] To justify this viewpoint, one needs only to look to the increasing expectations of external customers for "environmentally friendly" products.

Strong Management Commitment

It should now be clear that three of the elements of TQM — customer focus, continuous improvement, team approach — readily apply to environmental issues. As in traditional TQM settings, the last — strong management commitment — is perhaps the most important. No TQEM program will succeed without the commitment of senior management. Senior management, those who have built their careers when waste was seen as a necessary by-product, must come to understand that both internal and external customer expectations include environmentally conscious products and processes. They must learn to see the value of applying TQEM to get to the root causes of waste, and call on the cross-disciplinary teams to employ continuous improvement to implement ever "cleaner" solutions.

Conclusion

In the manufacturing setting today, the focus on environmental issues mirrors the focus on quality issues in the 1980s. As environmental regulations get stricter and more costly, as consumers demand more environmentally conscious products, and as competitors begin to see economic benefits from reducing waste, industrial management will employ TQEM as it employed TQM throughout the 1980s. The technology and the innovative spirit of employees exists; it must now be focused on the root cause of process waste to reap the rewards.

ENDNOTES

[1] Armand V. Feigenbaum. *Total Quality Control.* New York: McGraw-Hill, 1991, p 7.

[2] ibid.

[3] W. Edwards Deming. *Out of the Crisis.* Cambridge, MA: MIT, 1986, p. 92.

Kiyoshi Suzaki. *The New Manufacturing Challenge.* New York: The Free Press, 1987, p. 8.

[4] It is worth noting that some process waste (such as some wastewater) is relatively benign to the environment. The principles of TQEM should be focused on those waste streams that pose the highest risk to environmental and human health.

[5] President's Commission on Environmental Quality, Quality Environmental Management Subcommittee. *Total Quality Management: A Framework for Pollution Prevention.* Washington, 1993.

[6] Current accounting systems often neglect to apply the costs of toxic waste removal and potential liability and fines (under ever-tightening regulations) directly to the process department. These costs are generally grouped together for the whole facility. When these costs factored in, the "clean" solution often appears more attractive.

Questions

1. Relate how TQM principles apply so well to environmental issues.
2. Name three environmental customers that might be affected by a facility's waste.
3. Why is the traditional approach to industrial waste handling insufficient?
4. Why is it necessary to use the team approach when attacking waste issues?
5. What are some ways to make senior management more aware of the benefits of TQEM?

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For the Instructor: Teaching Note on "The Tragedy of the Commons and the Decision-Maker"

Purpose

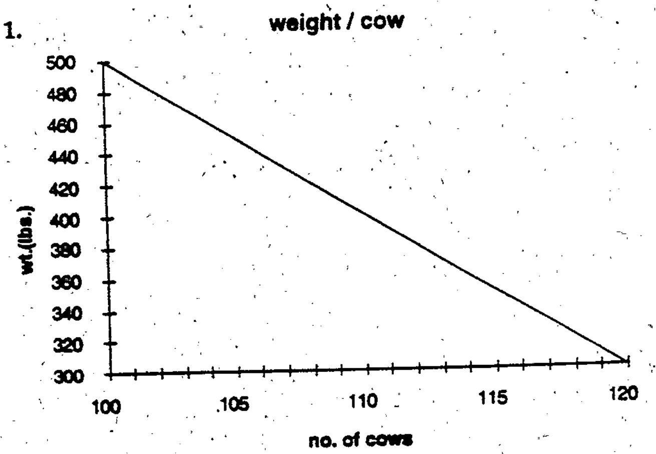
Increasingly, decision analysis techniques are being applied to decisions outside the traditional engineering and business spheres. This exercise is designed to show students that decision analysis is an effective tool for complex environmental issues.

The accompanying article, "The Tragedy of the Commons and the Decision Maker," investigates the failure of the rational decision model under certain resource allocation conditions. Students step through a decision matrix quantitatively showing "the tragedy of the commons." Further questions investigate social systems that can be employed to reduce the impact of the "tragedy."

This material was designed for inclusion in an introductory decision analysis course in industrial engineering; it is also appropriate for MBA students. Students should be familiar with the basic concepts of expected value and decision matrices.

Answers

1.



2. The Commons collapses with 120 cows.

3. Using the formula: $(20 + y)(500 - 10(y + 4x))$ where y=you and x=others, the following is obtained:

You add:	Others each add:	Your payoff:	Others' payoff:
0	0	10,000	10,000
1	0	10,290	9,200
0	1	9,200	10,290
1	1	9,450	9,450
0	0	10,000	10,000
2	0	10,560	8,400
0	2	8,400	10,560
2	2	8,800	8,800
0	0	10,000	10,000
3	0	10,810	7,600
0	3	7,600	10,810
3	3	8,050	8,050

4. As a profit maximizer, you and the other farmers will add cows until the commons collapses.

5. Using the formula ((100 + y + 4x)(500 - 10(y + 4x)))/5 where y=you and x=others, the following results:

You add:	Others each add:	Your payoff:	Others' payoff:
0	0	10,000	10,000
1	0	9,898	9,568
0	1	9,568	9,898
1	1	9,450	9,450

6. To succeed, the common herd plan must be accepted by all farmers. If one farmer breaks the agreement, s/he makes profits at the other farmers' expense (as is evident in Question 3). Further, this system hints of socialism—an idea that has its own problems. Generally, the problem must become bad enough to encourage participants to adopt the mutual system.

7. Some examples include:
   - groundwater (industrial use vs. drinking water)
   - breathable air
   - timber
   - fisheries

The matrix at the end of this compendium's Resource List indicates eight books and articles on decision analysis and industrial engineering.

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The Tragedy of the Commons and the Decision-Maker

Prepared by Leith Harmon, NPPC Research Assistant.

Background and Problem Statement

In 1968, Garret Hardin wrote an article in *Science*[1] titled "The Tragedy of the Commons." The article had a significant impact, and the issues it presented were much debated in the fields of ecology, law, philosophy, and psychology. An excerpt of the article that defines the problem follows:

> The tragedy of the commons develops this way. Picture a pasture open to all. It is to be expected that each herdsman will try to keep as many cattle as possible on the commons. Such an arrangement may work reasonably satisfactorily for centuries because tribal wars, poaching, and disease keep the numbers of both man and beast well below the carrying capacity of the land. Finally, however, comes the day of reckoning, that is, the day when the long-desired goal of social stability becomes a reality. At this point, the inherent logic of the commons remorselessly generates tragedy.
>
> As a rational being, each herdsman seeks to maximize his gain. Explicitly or implicitly, more or less consciously, he asks, "What is the utility to me of adding one more animal to my herd?" This utility has one negative and one positive component.
>
> 1. The positive component is a function of the increment of one animal. Since the herdsman receives all the proceeds from the sale of the additional animal, the positive utility is nearly +1.
> 2. The negative component is a function of the additional overgrazing created by one more animal. Since, however, the effects of overgrazing are shared by all the herdsmen, the negative utility for any particular decision-making herdsman is only a fraction of -1.
>
> Adding together the component partial utilities, the rational herdsman concludes that the only sensible course for him to pursue is to add another animal to his herd. And another, and another . . . But his conclusion is reached by each and every rational herdsman sharing the commons. Therein is the tragedy. Each man is locked into a system that compels him to increase his herd without limit — in a world that is limited. Ruin is the destination toward which all men rush, each pursuing his own best interest in a society that believes in the freedom of the commons. Freedom in a commons brings ruin to all.

The article continues with the moral, legal, and philosophical implications of the dilemma. While these discussions are beyond the scope of this exercise, you are encouraged to read the entire article.

Questions

You and four other farmers lease land from the government to graze your cattle. The land can support 100 healthy cows, where a healthy cow weighs 500 lbs. (For the sake of simplicity, assume that a cow cannot exceed 500 lbs., and that the entire 500 lbs. is meat available for market). For every cow (above 100) added to the field, each suffers a 10-lb. reduction in weight. Further, assume a cow cannot survive (or is not marketable) below 300 lbs. The government believes in a self-policing policy — you and your fellow farmers must manage your herds on your own. Then answer the questions on the next page.

[1] Hardin, Garrett. "The Tragedy of the Commons." *Science* (December 13, 1968): 1243–1248.

1. Graph the weight of each cow as a function of the number of cows in the field.

2. How many cows will cause the commons to collapse (i.e., at what point does the field fail to support any cattle)?

3. Each farmer (you and the four others) has 20 head of cattle. Develop a spreadsheet that shows the "payoff" that results from your decision to add or not add one cow vs. every one of the other farmers' decision to add or not add one cow each (the payoff should be in total pounds for each farmer's herd). As an example, the payoff for no one adding more cattle would appear as follows:

You add:	Others add:	Your payoff:	Others' payoff:
0	0	10,000	10,000

Repeat for two and three cows.

4. As a profit-maximizing farmer, do you add cattle? What do the other profit-maximizing farmers do?

5. Now, assume that the other farmers come to you with a plan to share the profits of a common herd (assuming all five farmers). Show, on a spreadsheet, the results of your decision to add or not add one cow vs. every one of the other farmers' decisions to add or not add one cow.

6. What stands in the way of implementing the plan in Question 5?

7. What other agricultural and industrial systems might be prone to the "Tragedy of the Commons" problem?

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Pollution Prevention: A Logical Role for the Industrial Engineer

Prepared by Leith Harmon, NPPC Research Assistant, under the supervision of Katta Murty, Professor of Industrial and Operations Engineering, University of Michigan.

Introduction

Industrial engineers do not generally concern themselves with pollution, but with the production process. Historically, that has meant minimizing cost and maximizing throughput and quality. The waste generated in these processes has been taken as a given, to be dealt with by environmental engineers.

However, as Stephan Schmidheiny of the Business Council for Sustainable Development describes the environmental crisis, it is everyone's concern:

> Several global trends demand any thinking person's attention .... First, the human population is growing extremely rapidly .... Second, the last few decades have witnessed an accelerated consumption of natural resources .... Third, both population growth and the wasteful consumption of resources play a role in the degradation of many parts of the environment .... Fourth, as ecosystems are degraded, the biological diversity and genetic resources they contain are lost .... Fifth, this overuse and misuse of resources is accompanied by the pollution of atmosphere, water and soil — often with substances that persist for long periods.[1]

Currently as well as historically, industry has dealt with pollution by using increasingly more sophisticated and expensive methods of control and treatment. In light of the issues Schmidheiny raises, the use of these technologies adds an ever-increasing, non-value-added component to product cost. A more proactive approach is demanded: pollution must be prevented, not just controlled after the fact.

The more pollution is prevented from ever being produced, the less money has to be spent controlling it. The prevention/control issue arises in other settings outside of process waste. For instance, antibiotics *control* illnesses; vaccines *prevent* them. Similarly, inspection *controls* defects; design for quality *prevents* defects.

Therefore, the question arises: What role can and should the industrial engineer play in pollution prevention? Because industrial engineers (along with chemical and mechanical engineers) are responsible for the production process, they should have a role in managing its undesired outputs (waste) as well as its desired outputs (product). Environmental engineers should be called on in instances when wastes cannot be prevented at their source by process engineers.

Why Pollution Prevention?

In the past, governmental regulations have emphasized pollution control. The Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA, or "Superfund") and the Superfund Amendments and Reauthorization Act (SARA) oversee the resolution of past toxic waste disposal activities that have adversely impacted the environment. The Resource Conservation and Recovery Act (RCRA) regulates current disposal activities. The U. S. Environmental Protection Agency (EPA) is authorized to fine parties that do not follow the stipulations of these acts. Not only are companies legally bound to dispose of their waste pursuant with these laws, but they are also required to produce extensive documentation of the wastes they generate, which is both time-consuming and expensive.

1/5

C~: way pollution prevention saves companies money is through decreased regulatory compliance and waste treatment costs. It can also position them more competitively for future regulation. In 1990, Congress passed the Pollution Prevention Act, which established a national policy that "pollution should be prevented or reduced at the source whenever feasible."[2] Unlike the acts discussed above, the Pollution Prevention Act is not enforceable. However, as of 1993, 15 states had issued mandatory, enforceable regulations on pollution prevention[3]; others will likely follow. Other countries already have enforceable policies in place. In Germany, for example, companies are required to collect and recycle all packaging of their product; they are thus forced to develop innovative methods of reducing unnecessary packaging.[4] Whether or not a similar law is passed in the United States, farsighted companies will see pollution prevention as a proactive and cost-effective method of dealing with waste in the future.

Pollution prevention also allows a company to minimize the future waste-disposal liability. Under Superfund, businesses can be held liable for the future cleanup costs of contaminated sites, *even if the company followed the waste disposal procedures put forth by regulations at the time of disposal.* Thus, preventing pollution reduces costs a firm can expect to pay in the future.

Government isn't the only group calling for pollution prevention: consumers as well are demanding that manufacturers produce products sensitive to the environment. All things being equal, Ford Motor Company's market research shows that consumers are more likely to buy a product manufactured by the company that is perceived as "green." Roper Starch Worldwide annual surveys show that

> as the public's environmental knowledge grows, so will the cost of being perceived as a polluter . . . . McDonald's is a [good] case in point. In the 1980s, the company had a negative environmental image associated with its use of polystyrene packaging. Now it has become one of the leading proponents of recycling and consumer education, and it is the top-rated company in the U.S. in terms of its environmental reputation among consumers.[5]

Principles of Pollution Prevention for the Industrial Engineer

While pollution prevention focuses on the reward of a cleaner environment, the benefits to a company's bottom line should not be overlooked. L. P. Sullivan states that quality-focused actions and expenditures are:

> strongly centered in the problem-solving arena, with less attention to the other end of the spectrum: product development . . . . To move to the same position as the Japanese . . . the quality issue must be pushed farther and farther upstream.[6]

This paradigm can also be used to illustrate pollution's impacts on and costs to the production process. The Taguchi loss function and the Taguchi methods have shown that engineers who initially perform to specification and subsequently design products and processes for quality can reduce the costs of production. The same concepts apply equally well to preventing pollution. Focus on waste treatment should be replaced by efforts to continuously improve current manufacturing processes to minimize waste. As these projects reach a mature state, focus should in turn be placed on designing products and processes that prevent waste in the first place. (See **Figure 1**)

In current practice, products and processes are generally designed without regard to waste. The responsibility for dealing with waste falls to the environmental engineer, who must handle these process by-products after they are produced. This is similar to designing a product merely for function, concerned more with short-term cost and throughput than with quality and long-term cost (per Taguchi's Loss Function), and relying on inspection to root out defective products.

For example, for the majority of companies painting auto bodies, the process utilizes solvents containing toluene and xylene. These toxic chemicals comprise the majority of airborne pollutants released to the environment by auto companies. Sophisticated smoke stack scrubbers send solvents skyward. Per Sullivan's paradigm, using scrubbers qualifies as treatment.

In following Sullivan's model, businesses should first begin to address pollution at the manufacturing process level. While treatment focuses on handling waste after the fact, waste reduction is a proactive approach: taking an existing process and minimizing the waste it produces by making small mechanical and chemical process changes.

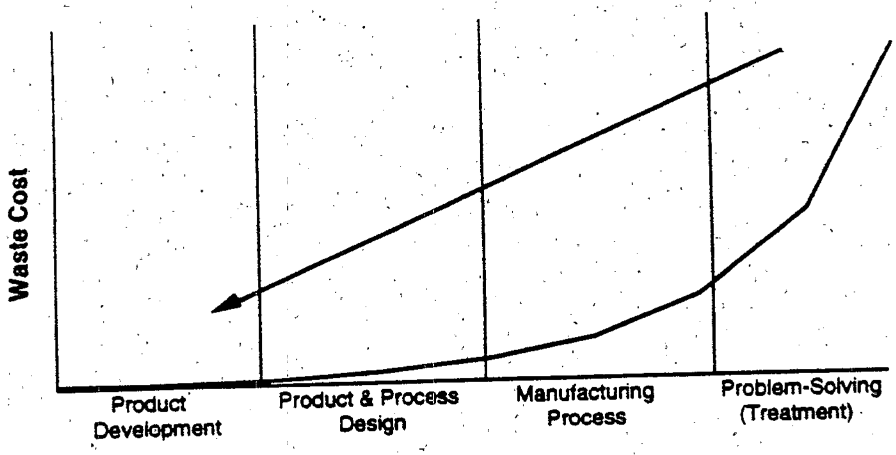

FIGURE 1: POTENTIAL FOR POLLUTION PREVENTION

Some forward-thinking companies (such as 3M, Dow, Ford, S. C. Johnson & Sons, Polaroid, and IBM) have begun to study their current manufacturing processes in an effort to reduce the waste they generate. While Toyota has made continuous process improvement famous in an effort to reduce defects, 3M and Dow have used the idea of continuous improvement in an effort to reduce process waste. Through a formalized program, "Pollution Prevention Pays," 3M has been able to halve its pollution between 1975 and 1989. Dow's program, "Waste Reduction Always Pays" (WRAP), has resulted in a 21% reduction in overall releases reported under SARA between 1987 and 1989.

In the paint shop example, it is common for American auto companies to change paint color with each car that goes through the process. As a result, any paint remaining in the previous lines must be purged before painting each car; in addition, the purging and refilling setup activity adds time to the process. When auto manufacturers change from this process to "block painting" (sending like-colored cars through the paint line in batches), they reduce purged paint sludge and the fugitive solvent emissions of toluene and xylene. Further, block painting decreases the setup time involved in the process.

Whether addressing quality or waste, continuous improvement can only go so far in improving a process that has already been designed. Once all marginal gains are realized in the current process, attention needs to be directed to designing processes that prevent waste from ever being created.

Continuing the paint shop example, technology now exists to paint cars without the toxic toluene and xylene solvents. Similar to the way a photocopier affixes ink to paper, electrostatic painting can adhere paint to treated metal. While the scrubber represents treatment and block painting represents waste reduction, shifting to the electrostatic painting process represents pollution prevention by design. According to data from Toyota, the electrostatic technology exists, and actually exhibits better quality characteristics than solvent-based painting. Unfortunately, paint booths represent a large capital investment (upwards of $10 million) that is usually amortized over a decade. Because the Big Three automakers have all invested in new solvent-based paint booths within the past five years, electrostatic painting will not become commonplace in the U.S. for another five to ten years.

The IE/OR Pollution Prevention Educational Resource Compendium

It should now be obvious that industrial engineers, along with their chemical and mechanical engineering colleagues, must play a role in developing industrial processes that prevent pollution. To adequately train future engineers, curricula must be developed, catalogued, and disseminated to industrial engineering faculty. The accompanying "Pollution Prevention and IE/OR Resource List" addresses this need by taking inventory of the pollution prevention educational resources available in the field. To assist readers in focusing on their field of specialty, these materials are organized by industrial engineering subtopics: Decision Analysis, Facilities Planning, Operations Research, Production Contol, Total Quality Management, Capital Budgeting, and Organizational Design/Management of Change. Existing educational material includes books, journal articles, case studies, and syllabi. Other materials in this compendium include articles, case studies with teaching notes, and problem sets.

Conclusion

The goal of pollution prevention in the design process is an ideal toward which all companies should strive. Given the present state of American industry, however, significant gains can still be achieved in altering current manufacturing processes. And, as long as this is the case, industrial engineers will to play a crucial role in the successful implementation of pollution prevention.

ENDNOTES

[1] Stephan Schmidheiny. *Changing Course*. Cambridge, MA: MIT Press, 1992.

[2] Pollution Prevention Act of 1990, 42 Pub. L. No. 101-508, §§6601–6610, 104 Stat. 1388.

[3] A list of current state pollution prevention laws is available in the NPPC's Business Law Compendium, in "Business Law and Pollution Prevention Resource List."

[4] Joanna D. Underwood and Bette Fishbein. "Making Wasteful Packaging Extinct." *The New York Times* (April 4, 1993): sec. 3, p. F13.

[5] Peter Stisser. "A DEEPER Shade of Green." *American Demographics* (March 1994): 26, 28.

[6] L.P. Sullivan. "The Seven Stages of Company-wide Quality Control." *Quality Progress*, (May 1986): 39–50.

Discussion Points

Why should a company look to pollution prevention?

Historically, industry has dealt with pollution using increasingly more sophisticated and expensive methods of control. The use of these technologies adds an ever increasing non value-added component to a product's cost. A more proactive approach is demanded when addressing this issue. Pollution must be prevented, not just controlled after the fact. With pollution prevention, there will be less pollution to control, resulting in lowered costs.

Companies are legally bound to dispose of their waste properly. Further, they are also required to produce time consuming documentation of the wastes they generate. Far sighted companies will see pollution prevention as a proactive and cost-effective method of dealing with waste in the future.

What are other examples of the prevention/control issue?

The prevention/control issue arises in other settings outside of pollution prevention. For instance, vaccines *prevent* illnesses, while antibiotics *control* illnesses. Preventative car maintenance *prevents* wear, while replacing worn parts deals with the problem after the fact. Design for quality *prevents* defects, while inspection *controls* defects.

What is the industrial engineer's role in P2?

Because the industrial engineer (along with chemical and mechanical engineers) is responsible for the production process, he/she should be responsible for managing the undesired outputs (waste) of the production process as well as the desired output (product). The environmental engineer should be called on to treat only those wastes that cannot be prevented by process engineers.

What are examples of pollution treatment and control?

- smoke stack scrubbers
- waste water treatment
- landfill disposal

What are some examples of existing manufacturing process change to reduce pollution?

- block painting
- recycling rinse water
- recycling washer chemicals
- recycling office paper
- reusable containers

What are some examples of process design to prevent pollution?

- electrostatic painting
- packaging redesign
- "paperless" office automation

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Pollution Prevention and IE/OR Resource List

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Educational Tools

Articles

Harmon, Leith S. "A Logical Role for the Industrial Engineer: Pollution Prevention." NPPC, 1995. [G] ▲

———. "Pollution Prevention and Facilities Planning." NPPC, 1995. [FP] ▲

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Focuses on incorporating environmental factors into traditional decision models. His courses include "Introduction to Environmental Studies" and "Environmental Policy Analysis," which apply decision techniques to environmental issues.

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His popular graduate course, "Pollution Prevention," examines how a manufacturer can go about manufacturing a product more efficiently based on a thorough process analysis and material balance. He is past president of the American Institute of Pollution Prevention.

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Organizations

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An independent, non-profit organization that promotes environmentally conscious business practices through its ten-point code of environmental conduct. Businesses sign an agreement to follow the code of conduct and report on their performance. This information is then available to the public.

Jane McGuire
The Global Environmental Management Initiative
2000 L Street NW, Suite 710
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202/296-7449

A business coalition of 27 leading American companies, dedicated to fostering environmental excellence in businesses worldwide. Through workshops, an annual conference, and many documents, GEMI shares its mission with corporations, government, non-profit organizations, and academia. Specific educational tools include primers on Total Quality Environmental Management (TQEM) and Benchmarking. Under development are primers on Environmental Reporting and Cost Effective Pollution Prevention.

Lawrence Molinaro, Jr.
Management Institute for Environment and Business
1220 16th Street NW
Washington, DC 20036
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Fax: 202/833-6228

An independent, non-profit organization that promotes environmentally conscious and competent general management by integrating environmental issues into management research, education and practice. Its educational initiatives include *Production and Operations Management and the Environment*, the first of seven modules on environmental considerations in business.

	G	CB	DA	FP	OR	OD/MC	PC	TQM
Alm, 1992								x
Amoco, 1995			x					
Ausubel and Sladovich, 1989						x	x	
Bender et al., 1981			x		x			
Berglund and Lawson, 1991	x							
Bodily, 1982					x			
Brown, 1981						x	x	
Burall, 1991				x		x		
Cairncross, 1991						x	x	x
Caplan, 1992/93						x		x
Chechile and Carlisle, 1991			x					
Cramer and Roes, 1993						x		x
Dauncey, 1991	x							x
Deland, 1991	x							x
Early, 1990				x				
Feichtinger and Luptacik, 1987					x			
Freeman et al., 1992	x						x	x
Friedlander, 1989	x							
Frosch and Gallopoulos, 1989	x						x	x
Goldner, 1991	x					x		
Green, 1993								x
Gregory et al., 1992					x			
Hahn, 1984					x			
Hämälainen, 1992			x					
Harmon (Logical Role), 1995	x							
Harmon (P2 and Fac. Plan.), 1995				x				
Harmon (TQM), 1995								x
Harmon (Tragedy), 1995			x					
Harmon and Murty, 1995								x
Haynsworth and Lyons, 1987							x	
Hirschhorn and Oldenburg, 1991						x	x	x
Imbler, 1989	x	x						
Keeney, 1988			x					
Kharbanda and Stallworthy, 1990	x			x		x	x	
Kirsh and Looby, 1991	x							
Koelsch, 1991	x							
Koenigsberger, 1992	x							

	G	CB	DA	FP	OR	OD/MC	PC	TQM
Konz, 1985				x				
Kraft, 1992				x				
Maruchek and Robbins, 1988							x	
Molinaro, 1991						x	x	x
O'Sullivan, 1991	x					x	x	
Olsen, 1983						x		
Oskamp, 1983						x		
Painter et al., 1983						x		
Piasecki and Asmus, 1990						x		x
Pojasek, 1991	x							
Pojasek and Coli, 1991	x							
PCEQ, 1993								x
Price, 1990	x						x	
Remmers et al., 1990					x			
Robinson and Schroeder, 1992							x	x
Schmidheiny, 1992	x			x		x	x	
Tusa, 1987								x
Upton and Margolis, 1990							x	
U.S. EPA, 1991						x		
Van Steen, 1987			x					
Van Weenen and Eckels, 1991				x				x
Von Winterfeldt, 1982			x					
Winett and Ester, 1983						x		
Wisner and Fawcett, 1991							x	x

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The mission of the NPPC is to promote sustainable development by educating students, faculty, and professionals about pollution prevention; create educational materials; provide tools and strategies for addressing relevant environmental problems; and establish a national network of pollution prevention educators. In addition to developing educational materials and conducting research, the NPPC also offers an internship program, professional education and training, and conferences.

Your Input Is Welcome!

We are very interested in your feedback on these materials. Please take a moment to offer your comments and communicate them to us. Also contact us if you wish to receive a documents list, order any of our materials, collaborate on or review NPPC resources, or be listed in our *Directory of Pollution Prevention in Higher Education*.

We're Going Online!

The NPPC provides information on its programs and educational materials through the Internet's Worldwide Web; our URL is: **http://www.snre.umich.edu/** (click on "National Pollution Prevention Center").

We may also update the NPPC information available through gopher (gopher.snre.umich.edu) and anonymous FTP (ftp.snre.umich.edu). Please contact us if you have comments about our online resources or suggestions for publicizing our educational materials through the Internet. Thank you!

Annotated Bibliography of IE/OR-Related Pollution Prevention Sources

For information on obtaining many of the sources listed here, see the Resource List, which is arranged by publication type. Bracketed abbreviations indicate the IE/OR subdiscipline(s) to which each document is relevant: General [G], Decision Analysis [DA], Facilities Planning [FP], Operations Research [OR], Production Control [PC], Total Quality Management [TQM], Capital Budgeting [CB], and Organizational Design/Management of Change [OD/MC]. This information is also shown in the matrix at the end of this document.

Alm, Alvin L. "Pollution Prevention and TQM." *Environmental Science and Technology*, 26 (1992): 452.

The author discusses the conceptual similarities of TQM and pollution prevention. He calls on environmental professionals to embrace TQM, and calls on companies with existing TQM programs to embrace pollution prevention. [TQM]

Amoco Corporation. *Second Victory at Yorktown.* 1993.

This 30-minute video documents the cooperative project between Amoco and the EPA to explore pollution reduction at a petroleum refinery. The results of the project have important implications for both engineering and business.

Amoco Corporation and the University of Michigan. "Amoco and the Environmental Decision Analysis." NPPC, 1995.

Investigates Amoco's use of the Analytical Hierarchy Process in a pollution prevention project at its Yorktown refinery. Includes discussion questions.

Ausubel, Jesse H., and Hedy E. Sladovich. *Technology and the Environment*, pp. 143–252. Washington: National Academy Press, 1989.

Under the subject titles of "Industrial Metabolism," "Dematerialization," and "Regularities in Technological Development," this book presents the concept of how technology interacts with the environment. While the material is somewhat technical in nature, the systems approach to environmental problems makes it relevant to industrial engineering. Production processes are reviewed to identify associated environmental problems. The authors discuss the use of technology to solve environmental problems, specific opportunities to use technology, and the importance of educating current and future engineers and managing technological change in employing this technology. The tone of the book tends toward the "technology can solve all our problems" side of the debate. [OD/MC][PC]

Bender, Paul S., William D. Northup, and Jeremy F. Shapiro. "Practical Modeling for Resource Management." *Harvard Business Review* 60 (March/April 1981): 163–173.

International Paper is the world's largest manufacturer of paper products. Managing these resources is clearly a formidable task. The authors discuss the successful design, implementation and use of a practical modeling system to manage these resources. Implicit in this model is the requirement to minimize waste. [DA][OR]

Berglund, R.L., and C.T. Lawson. "Preventing Pollution in the CPI." *Chemical Engineering* 98 (September 1991): 120–127.

This article provides a thorough review of the components of pollution prevention in the chemical process industries (CPI). Successful pollution prevention programs demand the attention to eight aspects of a manufacturing operation: product design, process design, plant configuration, information and control systems, human resources, research and development, suppliers' role and relationship, and organization. [G]

Bodily, Sam. "Armco Inc.—The Bubble Policy" (Report #UVA-QA-227). Charlottesville, VA: Darden Graduate School of Business (University of Virginia), 1982.

This case employs a simplified linear programming model to evaluate operating and capital investment options under the "bubble policy" method for measuring air pollution emissions. [OR]

Brown, Lester. *Building a Sustainable Society*, pp. 284–348. New York: Norton, 1981.

The author first discusses the effects of industrialization on the environment. He then identifies social and economic strategies for sustainable development. Of these strategies, changing social values and altering the role of business are particularly relevant to organizational design; the strategies relevant to production control include alternative energy sources and altering the role of business. [OD/MC][PC]

Burall, Paul. *Green Design*. London: The Design Council, 1991.

This book is a reference for the use of environmentally considerate materials and technologies. The specific industrial examples about material substitution, recycling, packaging and energy use, and efficiency are relevant to facilities planning; the author looks at motivation and management of technological change as it relates to implementing these technologies. [FP][OD/MC]

Cairncross, Frances. *Costing the Earth*, 143–252. London: The Economist Books, 1991.

This book looks at the unique environmental challenges facing business and government today. The shortcomings of contemporary accounting methods and process control techniques in dealing with environmental issues are explored in detail. The author shows that internalizing environmental costs can lead to prosperity. To this end, a "green" checklist is provided for industry. Similar to quality checklists in many ways, this checklist includes management-of-change elements managers should employ as well as factors for consideration in production control. The author also provides data for societal costs of pollution and the value of natural resources that go unused. [OD/MC][PC][TQM]

Caplan, Darlene W. "Sylvania's GTE Products Problem Stoppers: #1 Employee Involvement Team." *Total Quality Environmental Management* 2 (Winter 1992/93): 159–164.

The article discusses the winner of the 1992 Association for Quality and Participation's National Team Excellence Competition. A nine-person work team called the Problem Solvers from Sylvania Lighting in York, Pennsylvania, won for eliminating glass waste at York by recycling it in the plant. [TQM][OD/MC]

Chechile, Richard A., and Susan Carlisle. *Environmental Decision Making*. New York: Van Nostrand Reinhold, 1991.

This book discusses the following topics: psychological factors; ecosystem perspectives; probability, utility and decision trees; factoring risk; the economic model; resource allocation; ethical aspects; public policy decision making; regulatory decisions; and international decision making. Of particular interest to industrial engineers are the introductory chapter (which expands the currently used elements of the decision making process to include costs external to the decision-maker), and the use of utility theory in environmental decision making. [DA]

Cramer, J.M., and B. Roes. "Total Employee Involvement: Measures for Success." *Total Quality Environmental Management* 3 (Autumn 1993): 39–52.

Whether environmental management is successful depends partly on whether managers can actively involve employees in policy formulation and implementation. This not only generates shop-floor support for environmental policy, it also makes use of employees' environmental knowledge and expertise. [OD/MC][TQM]

Dauncey, Guy. "How Green Is Your Company?—A Corporate 'Green Rating.'" In *Green Business: Hope or Hoax?* edited by Christopher Plant and Judith Plant, 66–70. Philadelphia: New Society, 1991.

Describes how a company can set up a framework for judging its "greenness": (1) establish cross-departmental "environmental action teams"; (2) appoint an "environmental vice-president" with responsibility to improve the company's environmental profile; (3) commission an environmental audit; (4) develop staff and customer questionnaires to solicit company actions and products; (5) hold cross-company environmental hearings to engage staff; and (6) instruct each department to develop an environmental plan. Includes examples. Such material is easily adapted to quality audit programs. [TQM]

Deland, Michael R. "An Ounce of Prevention . . . After 20 Years of Cure." *Environmental Science and Technology*, 25 (1991): 4.

As chair of the President's Council on Environmental Quality under George Bush, Deland writes on why business should embrace P2. He argues that companies should implement pollution prevention because of cost and regulatory advantages in addition to protecting future generations of workers; he also suggests applying TQM methods to implement pollution prevention programs. Although from a previous administration, the article still provides a good look at the government's perspective. [G][TQM]

Early, William F., and Mark A. Eldson. "Design for Zero Releases." *Hydrocarbon Processing* 69 (August 1990): 47–49.

Provides methods for incorporating environmental issues into chemical facility design. (This article is written specifically about chemical manufacturing processes and design considerations — flanges and welded connections, valves, relief valves, pumps, transfer lines/hoses, installation, and operation — and thus is not recommended for general reading.) [FP]

Evanhoff, Stephan P. "Hazardous Waste Reduction in the Aerospace Industry." *Chemical Engineering Progress* 86 (April 1990): 51–61.

This article outlines the aerospace industry's manufacturing process wastes, explaining the processes used (degreasing, surface finishing painting, surface cleaning, maintenance, transportation, and laboratory R&D) and the wastes generated. It then outlines current recycling and recovery technologies used in the industry. The information describes processes and their chemical and mechanical attributes. While it is too specific for general industrial engineering curricula, it provides a good overview for industrial engineers interested in the aerospace industry.

Feichtinger, G., and M. Luptacik. "Optimal Production and Abatement Policies of a Firm." *European Journal of Operations Research* 29 (1987): 274–285.

This article examines the relationship between the loss of jobs caused by increased environmental regulation and the loss of environmental quality caused by pollution. The authors develop a model that determines an optimal path where pollution control increases as the number of employees rise. [OR]

Freeman, Henry, Teresa Harten, Johnny Springer, Paul Randall, Mary Ann Curran, and Kenneth Stone. "Industrial Pollution Prevention: A Critical Review." *Air and Waste* (Journal of the Air and Waste Management Association) 42, no. 5 (May 1992): 618–656.

A comprehensive review of pollution prevention activities around the country, this article discusses pollution prevention; governmental legislation and programs; industrial programs; pollution prevention assessments and measurement issues; and incentives and barriers to pollution prevention, life cycle analysis, and product design. Identifies and critiques topical material for each topic. A very good reference for gathering comprehensive pollution prevention information. [G][TQM][PC]

Friedlander, Sheldon K. "Pollution Prevention: Implications for Engineering Design, Research and Education." *Environment* 31 (May 1989): 10–15, 36–38.

As pollution prevention and other proactive strategies gain momentum as environmental strategies, engineers are faced with the challenge of developing technological solutions. The author looks at source reduction and product design as they effect research and education. [G]

Frosch, Robert A., and Nicholas E. Gallopoulos. "Strategies for Manufacturing." *Scientific American* 261 (September 1989): 144–152.

The authors present the idea of the "industrial ecosystem" in this article. As natural resources become more scarce, this idea should gain interest in industry. Three "industrial ecosystems" are presented: the production of plastics from petroleum, the conversion of iron ore to steel, and the use of platinum as a catalyst.[G][PC][TQM]

Goldner, Howard J. "Waste Minimization Starts at the Top." *Research and Development Magazine* 33 (September 1991): 48–52.

This article presents the importance of a company's research and development department in bringing about successful pollution prevention projects. Not only should R&D focus on the product, but it should focus on the manufacturing process, as well. To motivate this shift in R&D's orientation, top management must understand the need and benefits of pollution prevention initiatives. [G][OD/MC]

Green, Philip E.J. "Environmental TQM." *Quality Progress* 26 (May 1993): 77–80.

The author stresses that "quality professionals have a tremendous contribution to make. As iconoclasts, they have learned to challenge sacred assumptions and develop new and better ways to work. They have learned to establish credibility for new work and management practices." Deming's 14 points to environmental issues are discussed, as well as benefits to protecting the environment, and altering managers' attitudes. [TQM]

Gregory, Paul, Richard Larson, and Alan Minkoff. "Dirty Work." *OR/MS Today* 19 (June 1992): 34–39.

The authors discuss the increased use of marine transport to dispose of New York City's waste due to closed landfills. To optimize allocation of the garbage barge armada, the authors developed the Barge Operation Systems Simulation. As a result of this model, refuse barges move through New York Harbor more effectively. An issue unanswered by the article is the necessity to reduce the waste generated by New Yorkers. [OR]

Hahn, Robert W. "On Reconciling Conflicting Goals: Applications of Multi-objective Programming." *Operations Research* 32, no. 1 (1984): 221–288.

In most mathematical programming problems, the goal is to minimize cost subject to feasibility constraints and a set of targets. In contrast, multi-objective programming treats the objectives as the choice variables, and cost as a parameter. This article uses the two approaches to analyze a pollution emission problem. The comparison reveals that the traditional cost-minimizing approach can generate solutions that are inefficient, in the sense that greater emissions reductions could have been attained at the same cost. Because the solution sets to the two problems may differ, the author derives conditions under which the two approaches yield a similar set of results. [OR]

Hämälainen, Raimo P. "Decision Analysis Makes Its Way Into Environmental Policy in Finland." *OR/MS Today* (June 1992): 40–43.

The author discusses using decision analysis techniques in developing decisions outside the traditional engineering and business spheres. He then describes his HIPRE decision-support software, which was used to assist the Finnish government in making acid rain policy. [DA]

Harmon, Leith S. "A Logical Role for the Industrial Engineer: Pollution Prevention." NPPC, 1995.

Discusses the inherent and critical role industrial engineers must play in developing successful pollution prevention programs. Explains regulatory and market factors for P2 and outlines a framework for P2 within a firm. Provides accompanying questions and answers. [G]

———. "Pollution Prevention and Facilities Planning." NPPC, 1995.

Discusses the need for facility planners to consciously include environmental considerations when locating and designing facilities. Provides accompanying questions and possible answers. [FP]

———. "Total Quality Management: A Methodology for Pollution Prevention." NPPC, 1995.

Discusses how the four elements of Total Quality Management — customer focus, continuous improvement, teamwork, and strong management commitment — can all be applied to prevent pollution. Provides accompanying questions and possible answers. [TQM]

———. "The Tragedy of the Commons and the Decision Maker." NPPC, 1995.

Investigates the failure of the rational decision model under certain resource allocation conditions. Provides accompanying questions and answers. [DA]

Harmon, Leith S., and Katta Murty. "Pollution Prevention as Continuous Improvement at Ford Motor Company." NPPC, 1995.

Describes Ford's successful use of continuous improvement techniques to reduce waste at its Livonia, MI, Transmission Plant. Discusses a cross-disciplinary team and the waste-prevention opportunities it developed as well as a P2 guidebook that could be used for waste prevention at other Ford plants. Provides accompanying questions, answers, and discussion points. [TQM]

Haynsworth, H.C., and R. Tim Lyons. "Remanufacturing By Design." *Production and Inventory Management* (2nd Quarter 1987): 24–29.

"Design for remanufacturability" is an idea that is gaining ground both here and in Europe. The automotive industry is the primary industry utilizing this strategy. The benefits of using remanufactured parts include increased savings for customers, better performance than reconditioned parts, reduction of capital spending, and reduced need for raw material. The author points out how this strategy can be incorporated into the product life cycle. Problems include difficulties in developing a collection and distribution network for the used parts, and the perceived quality problem of using "previously used" parts. [PC]

Hethcoat, Henry G. "Minimize Refinery Waste." *Hydrocarbon Processing* 69 (August 1990): 51–54.

This article outlines the petroleum industry's manufacturing processes and their attendant wastes. The author explains the current recycling and recovery technologies (integrated units, in-line bleeding, crude tank mixers, air cooler maximization, demineralized river water, amine degradation prevention) used in the industry. The information describes processes and their chemical and mechanical attributes. While it is too specific for general industrial engineering curricula, it provides a good overview for industrial engineers interested in the petroleum industry.

Hirschhorn, Joel S., and Kirsten U. Oldenburg. *Prosperity Without Pollution.* New York: Van Nostrand Reinhold, 1991.

This comprehensive book looks at the issue of pollution prevention from social, organizational, and industrial management perspectives (in contrast to many pollution prevention guides, which primarily provide a technical perspective). The first half of the book is particularly relevant to production control. Chapter 3, "Achieving Success By Overcoming Obstacles," is pertinant to organizational design and the management of change along with quality management programs. Chapter 4, "Data Tells the Story: Too Much Waste," presents the surprisingly complex issues that surround tracking waste. Chapter 7, "Changing Consumption: Reducing Garbage," discusses how consumers are a factor in the reduction of waste. Chapter 9, "No Time to Waste," discusses public policy responsibilities in pollution prevention. [PC][TQM][OD/MC]

Hocking, Martin B. "Paper vs. Polystyrene: A Complex Choice." *Science* 251 (February 1, 1991): 504–505.

Using life cycle analysis, the author analyzes the environmental effects of paper vs. polystyrene packaging. This article is one of the ground-breaking discussions of life-cycle analysis. While the author concludes that polystyrene is less damaging to the environment for single use situations, recent changes in paper production technology cast doubts on that conclusion today. From an educational standpoint, the significance of this article lies not in the authors conclusions but in his methodology. As such, the article can be used to introduce the *process* of life cycle analysis.

Imbler, C. Clarke. "Who Pays the Price for Environmental Pollution?" *Pollution Engineering* 21 (Sept. 1989): 92–94.

This editorial piece outlines the weaknesses inherent in the many regulatory "solutions" to the country's waste problems. The author discusses how RCRA and Superfund create litigious behavior and do not fully address the true costs of pollution cleanup. This article might be used to make a strong case for pollution prevention: if the waste is not generated, liability under the various regulations will not occur. Total cost accounting (including the expected costs of waste handling, waste disposal, and liability in the capital budgeting process) can make pollution prevention projects appear more economically attractive. [G][CB]

Keeney, Ralph L. "Structuring Objectives for Problems of Public Interest." *Operations Research* 36, no. 3 (May/June 1988): 396–405.

Sustainable development requires that industry view all costs (not just those internal to the firm) of doing business when making decisions. When the environmental issues are included in the business decision process, the set of stakeholders must be expanded beyond the traditional group of stockholders, customers, and employees. The author presents a model of decision analysis that includes a hierarchy of multiple objectives representing all stakeholders affected by the decision. [DA]

Kharbanda, O.P., and E.A. Stallworthy. *Waste Management.* New York: Auburn House, 1990.

This book presents a good introductory discussion on why industrial engineers should be concerned with pollution prevention. The increasing costs and hazards associated with waste handling require more comprehensive waste management. The authors describe the pollution hierarchy and call for wasteless processes wherever possible. Waste should be minimized only when wasteless processes do not exist. Where waste minimization is infeasible, recycling should be employed; waste treatment should be viewed as an alternative of last resort.

The book describes our society's waste problems, emphasizing management's role in implementing solutions. Specific production control and management techniques are discussed along with clear examples of pertinent technologies that can be employed in facilities planning; these examples would be very appropriate for classroom discussion of pollution prevention techniques. [G][FP][OD/MC][PC]

Kirsh, F.W., and G.P. Looby, "Case Study: Pollution Prevention in Practice." *Pollution Prevention Review* 1, no. 2 (Spring 1991): 25–28.

This article presents four case studies that show how small- and medium-sized companies can not only reduce waste, but also save enough money to pay for any capital changes. [G]

Koelsch, James R. "Knee Deep in Liability?" *Manufacturing Engineering* 107 (August 1991): 28–33.

The article outlines the negative results of not handling spent coolants properly. It discusses how one production manager faces fines and imprisonment for not handling spent coolants as outlined in the Resource Conservation and Recovery Act (RCRA). It also covers management techniques (planning, documentation, and proper maintenance) that not only reduce liability, but reduce spent coolant as well. While pollution prevention is not explicitly discussed, it is the underlying message in the article. [G]

Koenigsberger, M.D. "Preventing Pollution at the Source." *Chemical Engineering Progress* 82 (May 1986): 7–9.

The article briefly outlines 3M's efforts in pollution prevention. It suggests methods for implementing a P2 program and discusses the following potential barriers:

- Senior management support may be difficult to get.
- Even though operating and maintenance costs almost always make pollution more expensive to control than prevent, the initial investment for pollution prevention equipment might still be higher.
- P2 technology may not be viable.
- P2 may be viewed as an untried substitute.
- Marketing often hinders reformulation. [G]

Konz, Steven A. *Facility Design*, pp. 347–353. New York: John Wiley and Sons, 1985.

This is a is a textbook for the field of facilities planning. The section cited briefly discusses the importance of including waste reduction criteria in the facility design process. Includes industry examples. [FP]

Kraft, Robert L. "Incorporate Environmental Reviews Into Facility Design." *Chemical Engineering Progress* 88 (August 1992): 46–52.

This article provides a comprehensive plan for incorporating environmental concerns into facility design. Although the issues addressed tend to be chemical process-oriented, the techniques outlined can be generalized to all manufacturing. The 10 components of the review process are:

1. Conduct initial and pre-design assessments.
2. Assign project environmental responsibility.
3. Define the project's environmental objectives.
4. Identify the need for any permits.
5. Determine environmental compliance requirements.
6. Perform an overall waste minimization analysis.
7. Apply "best environmental practices" for emission-free and discharge-free facilities.
8. Determine waste treatment & disposal requirements.
9. Perform engineering evaluations of waste management options.
10. Complete project environmental review. [FP]

Maruchek, Ann, and Lansdon Robbins. "Business Ethics: The Materials/Manufacturing Perspective." *Production and Inventory Management Journal* 29 (4th Quarter 1988): 16–19.

The authors contend that true impacts of "green" consumerism can be made in the supplier/customer relationship rather than in the consumer sphere. Increasingly, the supplier's product affects the customer's reputation and even liability. The authors show how environmental sensitivity is everyone's concern, and that activities such as purchasing can effect the environment. [PC]

Molinaro, Lawrence, Jr. *Production and Operations Management and the Environment*. Washington: Management Institute for Environment and Business, 1991.

This reader, the first of seven MEB modules on environmental considerations in business, includes articles and case studies relevant to several subdisciplines in IE/OR. Chapter 1, "Introduction to Pollution Prevention and Waste Reduction," applies to all. Chapters 6, "Managing Technology for Environmental Strategy," and 7, "The Regulatory Environment and Operations," apply to organizational design and management of change. Chapters 2, "Waste Minimization in the Production Process," 3, "Materials Management," and 4, "Quantitative Models: Environmental Management

Applications," apply to production control. Chapters 2 and 5, "The Environmental Audit," apply to Total Quality Management. [OD/MC][PC][TQM]

O'Sullivan, Dermot. "Bayer Targets Process Modification as Approach to Pollution Prevention." *Chemical & Engineering News* 69 (October 21, 1991): 21–25.

This article discusses how the large chemical company has targeted one sixth of its capital spending in pollution prevention. The article discusses incorporating the "prevention, reduction, recycling" idea into the corporate culture. Specific projects are also discussed. [OD/MC][G][PC]

Olsen, Marvin E. "Public Acceptance of Consumer Energy Conservation Strategies." *Journal of Economic Psychology* 4, no. 2 (October 1983): 183–196.

The policy of reducing consumer energy consumption can be implemented through several broad courses of action. This study investigates six alternative strategies for promoting energy conservation: financial incentives, community programs, efficiency standards, land-use changes, consumption limits. and price increases. Public acceptance of the strategies varies widely, from 83% for financial incentives to 9% for price increases. The single best predictor of acceptance is preference for a soft rather than hard energy policy path; the second-best predictor is perceived seriousness of the energy problem. In general, Americans can be described as supporting a diverse set of strategies for encouraging consumer energy conservation. [OD/MC]

Oskamp, Stuart. "Psychology's Role in the Conserving Society." *Population and Environment* 6, no. 4 (Winter 1983: Behavioral Science Issue): 255–293.

The author defines the hard energy path as: heavy reliance on high technology, highly centralized power plants, and recklessly high levels of energy use. This is perpetuated by extremely powerful institutional and societal forces. Industry has huge investments in present equipment and procedures. Many policy implications can be drawn from psychological research: Emphasize individual benefits of conservation rather than sacrifices. Don't make financial savings the sole justification for conservation. Don't expect information alone to motivate people to conserve. Stress benefits of conservation to society in order to give people an altruistic rational for conserving. Finally, whenever possible, spread conservation information through interpersonal interaction and "hands on" demonstrations rather than through the impersonal mass media. [OD/MC]

Painter, John, Rachel Semenik, and Russell Belk. "Is There a Generalized Energy Conservation Ethic? A Comparison of the Determinants of Gasoline and Home Heating Energy Conservation." *Journal of Economic Psychology* 3, no. 3-4 (September 1983): 317–331.

Compared to other socially responsible behaviors such as pollution reduction, the conservation of energy is more likely to be motivated by more purely economic incentives. The study suggests that studies of conservation behavior that combine conservers of different fuels or that attempt to generalize from conservation of one fuel to conservation of others may be quite misleading. [OD/MC]

Piasecki, Bruce, and Peter Asmus. *In Search of Environmental Excellence*. New York: Simon and Schuster, 1990.

Chapter 5, "Industry and the Environment: Creating Affordable Beliefs," discusses the need and provides examples of how companies have made the organizational and cultural changes required for successful pollution prevention. Many of these changes mirror those required for the successful implementation of quality programs. [OD/MC][TQM]

Pojasek, Robert B. "For Pollution Prevention: Be Descriptive Not Prescriptive." *Chemical Engineering* 98 (September 1991): 136–139.

The author describes a "descriptive" approach to pollution prevention. This type of strategy is required for studying unique processes. Under this plan, those people closest to the process are called upon to develop creative and innovative solutions to the pollution problems at hand. [G]

Pojasek, Robert B., and Lawrence J. Coli. "Measuring Pollution Prevention Progress." *Pollution Prevention Review* 1, no. 2 (Spring 1991): 119–130.

Successful pollution prevention programs require quantifiable measures, which are used in identifying waste streams and providing goals for future improvement. Issues in developing these measures are discussed. [G]

President's Commission on Environmental Quality, Quality Environmental Management Subcommittee. *Total Quality Management: A Framework for Pollution Prevention*. Washington: President's Commission on Environmental Quality, 1993.

Under the auspices of the President's Commission on Environmental Quality (PCEQ), 11 corporations volunteered to demonstrate the viability of TQM as a methodology for achieving pollution prevention. Included are summaries of the results of projects at AT&T, Chevron, Dow, DuPont, Ford, GE, International Paper, Merck, Procter & Gamble, 3M, and the U.S. Generating Company. [TQM]

Price, Roger L. "Stopping Waste at the Source." *Civil Engineering* 60 (April 1990): 67–69.

Inventory control, material-handling, and scheduling all provide opportunities for waste reduction. These traditional industrial engineering fields require an environmental "spin" before waste reduction opportunities can be identified. The author also discusses process redesign, raw material substitution, and industrial ecology. [PC][G]

Remmers, J., Th. Morgenstern, G. Schoens, H.-D. Haasis, and O. Rentz. "Integration of Air Pollution Control Technologies in Linear Energy-Environmental Models." *European Journal of Operational Research* 47 (1990): 306–316.

This article discusses alterations to the Energy Flow Optimization Model (EFOM) to address pollution reduction. The model was generated as a result of concern over Europe's increasing levels of air pollution. [OR]

Robinson, Alan G., and Dean M. Schroeder. "Detecting and Eliminating Invisible Waste." *Production and Inventory Management Journal* 33, no. 4 (Fourth Quarter 1992): 37–42.

This article discusses the idea of invisible waste in the production process. It explores why the waste is invisible, identifies sources of those wastes, and proposes the following principles to detect and eliminate them:

1. When evaluating or applying a new management technique, identify the sources of waste that it exposes or eliminates, those that it cannot expose or eliminate, those it will create, and the complementary techniques required to address these limitations.
2. Do not limit training to specific job methods — employees must also know how to make improvements to their jobs.
3. Increase the number of perspectives from which the process is seen.
4. Whenever significant change is made to any component of the productive system, examine the entire process for new sources of waste.

While the authors expand the definition of waste to include labor inefficiencies, the principles presented are relevant to pollution prevention. [PC][TQM]

Schmidheiny, Stephan, with the Business Council for Sustainable Development. *Changing Course: A Global Business Perspective on Development and the Environment*. Cambridge, MA: MIT Press, 1992.

Developed under the auspices of an international group of business leaders, this comprehensive book looks at all aspects of integrating environmental concerns into industrial management. The chapters are (1) "The Business of Sustainable Development"; (2) "Pricing the Environment: Markets, Costs, and Instruments"; (3) "Energy and the Marketplace"; (4) "Capital Markets: Financing Sustainable Development"; (5) "Trade and Sustainable Development"; (6) "Managing Corporate Change"; (7) "The Innovation Process"; (8) "Technology Cooperation; (9) "Sustainable Management of Renewable Resources"; and (10) "Leadership for Sustainable Development." The case studies about managing change in business, business partnerships, stakeholder partnerships, financial partnerships, cleaner production, cleaner products, and sustainable resource use are apropos to industrial engineering. Chapters 1, 6, 7, 8, 9, and 10 are especially relevant to organizational design and management of change, as are the case studies about managing business, business partnerships, stakeholder partnerships, financial partnerships, and sustainable resource use. Chapters 1, 3, 7, and 8 are especially relevant to production control, as are the case studies about managing cleaner production, cleaner products, and sustainable resource use; those cases are also relevant to facilities planning. [G][FP][OD/MC][PC]

Tusa, Wayne. "Developing an Environmental Audit Program." *Risk Management* 32 (August 1987): 24–29.

The article discusses reasons for and ways to set up an environmental audit program. Though not stated in the article, such a program ties in nicely with quality audit systems. [TQM]

U.S. Environmental Protection Agency, Office of Pollution Prevention. *Pollution Prevention 1991: Progress on Reducing Industrial Pollutants.* EPA/21P-3003. Washington: U.S. EPA, 1991.

This EPA publication presents trends and describes industrial and governmental programs. Chapter 3 provides examples of specific organizational efforts to better facilitate pollution prevention. It is good reference for governmental contacts. [OD/MC]

Upton, Dave, and Joshua Margolis. "Australian Paper Manufacturers," Cases A and B (Report #N9-691-041). Boston: Harvard Business School, 1990.

In the light of a competitor's problems with toxic chemicals, these cases explore Australian Paper Manufacturers' options in expanding uncoated, fine paper capacity, along with dealing with toxic chemicals, forestry and recycling. [PC]

Van Steen, Jacques F.J. "A Methodology for Aiding Hazardous Materials Transportation." *European Journal of Operational Research* 32 (1987): 231–244.

Risk assessment plays a large role in environmental decision-making. This article develops a model for risk analysis associated with the transportation of hazardous waste. Value judgments and the perception of risk are included in the model. [DA]

Van Weenen, J.C, and J. Eckels. "Design and Waste Prevention." *The Environmental Professional* 11 (1991): 231–235.

The article discusses methods for designing products and processes with waste prevention as a specific goal. A matrix method — the Design Environment Cube (similar to life-cycle matrices and "house of quality" models) — is presented. The authors then point out that further research is needed in the areas in decision-making systems, influencing systems, and design for durability and reuse. [FP][TQM]

Von Winterfeldt, Detlof. "Setting Standards for Offshore Oil Discharges: A Regulatory Decision Analysis." *Operations Research* 30 (September/October 1982): 867–886.

Offshore oil production platforms continually discharge oily water into the surrounding marine environment. To reduce the environmental risk from these discharges, emission standards are set on the oil concentration in the effluent. This paper describes a decision-analysis model for aiding regulators and platform operators in the standard-setting process. The model combines three submodules: a regulator model, an operator model, and an impact model. [DA]

Winett, Rachel A., and Peter Ester. "Behavior Science and Energy Conservation: Conceptualizations, Strategies, Outcomes, Energy Policy Applications." *Journal of Economic Psychology* 3, no. 3-4 (September 1983): 203–229.

The importance of human behaviors in energy conservation is well-known in behavior science, but this position has hardly made its way into policy. The authors suggest these preliminary steps as a minimum:

1. Delineate the most significant energy-consuming practices.
2. Assess technical contexts — make sure policy is pertinent to consumer behavior.
3. Assess attitudes, beliefs, information, values, and current behaviors concerning the practices in different population segments.
4. Conduct analyses by population segments — mismatches lead to failure.
5. Pre-test material to assure quality.
6. Analyze higher -level influences limiting change.
7. Use substitution strategies — decrease an inappropriate behavior and increase the appropriate one.
8. Use reciprocal reinforcement — reward multiple and concerned parties for their efforts. [OD/MC]

Wisner, Joel D., and Stanley E. Fawcett. "Linking Firm Strategy to Operating Decisions Through Performance Measurement." *Production and Inventory Management Journal* 32, no. 3 (Third Quarter 1991): 5–11.

Companies must reevaluate their approach to competition in the global economy. One area that needs reevaluation is performance measurement. In order to guide a firm's operating decisions toward strategic objectives, performance criteria must be flexible, easy to implement, timely, clearly defined at all management levels, and derived from the firm's strategic objectives. The article discusses the characteristics of world-class manufacturers and how they use performance measures competitively. It then discusses the development of a successful performance measurement system with criteria in quality, cost, flexibility, dependability, and innovation. Noticeably missing is the area of environmental performance. But, given (a) the authors' premise that these performance measures should be derived from a firm's strategic plan, and (b) the increasing strategic emphasis on environmental quality, environmental performance measures are a logical extension. The development of such criteria might serve as a good classroom exercise in a production control, operations management, or quality class. [PC][TQM]

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	G	CB	DA	FP	OR	OD/MC	PC	TQM
Alm, 1992								✗
Amoco, 1995			✗					
Ausubel and Sladovich, 1989						✗	✗	
Bender et al., 1981			✗		✗			
Berglund and Lawson, 1991	✗							
Bodily, 1982					✗			
Brown, 1981						✗	✗	
Burall, 1991				✗		✗		
Cairncross, 1991						✗	✗	✗
Caplan, 1992/93						✗		✗
Chechile and Carlisle, 1991			✗					
Cramer and Roes, 1993						✗		✗
Dauncey, 1991	✗							✗
Deland, 1991	✗							✗
Early, 1990				✗				
Feichtinger and Luptacik, 1987					✗			
Freeman et al., 1992	✗						✗	✗
Friedlander, 1989	✗							
Frosch and Gallopoulos, 1989	✗						✗	✗
Goldner, 1991	✗					✗		
Green, 1993								✗
Gregory et al., 1992					✗			
Hahn, 1984					✗			
Hämälainen, 1992			✗					
Harmon (Logical Role), 1995	✗							
Harmon (P2 and Fac. Plan.), 1995				✗				
Harmon (TQM), 1995								✗
Harmon (Tragedy), 1995			✗					
Harmon and Murty, 1995								✗
Haynsworth and Lyons, 1987							✗	
Hirschhorn and Oldenburg, 1991						✗	✗	✗
Imbler, 1989	✗	✗						
Keeney, 1988			✗					
Kharbanda and Stallworthy, 1990	✗			✗		✗	✗	
Kirsh and Looby, 1991	✗							
Koelsch, 1991	✗							
Koenigsberger, 1992	✗							
Konz, 1985				✗				

	G	CB	DA	FP	OR	OD/MC	PC	TQM
Kraft, 1992				x				
Maruchek and Robbins, 1988							x	
Molinaro, 1991						x	x	x
O'Sullivan, 1991	x					x	x	
Olsen, 1983						x		
Oskamp, 1983						x		
Painter et al., 1983						x		
Piasecki and Asmus, 1990						x		x
Pojasek, 1991	x							
Pojasek and Coli, 1991	x							
PCEQ, 1993								x
Price, 1990	x						x	
Remmers et al., 1990					x			
Robinson and Schroeder, 1992							x	x
Schmidheiny, 1992	x			x		x	x	
Tusa, 1987								x
Upton and Margolis, 1990							x	
U.S. EPA, 1991						x		
Van Steen, 1987			x					
Van Weenen and Eckels, 1991				x				x
Von Winterfeldt, 1982			x					
Winett and Ester, 1983						x		
Wisner and Fawcett, 1991							x	x

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Annotated Bibliography of IE/OR-Related Pollution Prevention Sources

For information on obtaining many of the sources listed here, see the Resource List, which is arranged by publication type. Bracketed abbreviations indicate the IE/OR subdiscipline(s) to which each document is relevant: General [G], Decision Analysis [DA], Facilities Planning [FP], Operations Research [OR], Production Control [PC], Total Quality Management [TQM], Capital Budgeting [CB], and Organizational Design/Management of Change [OD/MC]. This information is also shown in the matrix at the end of this document.

Alm, Alvin L. "Pollution Prevention and TQM." *Environmental Science and Technology*, 26 (1992): 452.

The author discusses the conceptual similarities of TQM and pollution prevention. He calls on environmental professionals to embrace TQM, and calls on companies with existing TQM programs to embrace pollution prevention. [TQM]

Amoco Corporation. *Second Victory at Yorktown.* 1993.

This 30-minute video documents the cooperative project between Amoco and the EPA to explore pollution reduction at a petroleum refinery. The results of the project have important implications for both engineering and business.

Amoco Corporation and the University of Michigan. "Amoco and the Environmental Decision Analysis." NPPC, 1995.

Investigates Amoco's use of the Analytical Hierarchy Process in a pollution prevention project at its Yorktown refinery. Includes discussion questions.

Ausubel, Jesse H., and Hedy E. Sladovich. *Technology and the Environment*, pp. 143–252. Washington: National Academy Press, 1989.

Under the subject titles of "Industrial Metabolism," "Dematerialization," and "Regularities in Technological Development," this book presents the concept of how technology interacts with the environment. While the material . somewhat technical in nature, the systems approach to environmental problems makes it relevant to industrial engineering. Production processes are reviewed to identify associated environmental problems. The authors discuss the use of technology to solve environmental problems, specific opportunities to use technology, and the importance of educating current and future engineers and managing technological change in employing this technology. The tone of the book tends toward the "technology can solve all our problems" side of the debate. [OD/MC][PC]

Bender, Paul S., William D. Northup, and Jeremy F. Shapiro. "Practical Modeling for Resource Management." *Harvard Business Review* 60 (March/April 1981): 163–173.

International Paper is the world's largest manufacturer of paper products. Managing these resources is clearly a formidable task. The authors discuss the successful design, implementation and use of a practical modeling system to manage these resources. Implicit in this model is the requirement to minimize waste. [DA][OR]

Berglund, R.L., and C.T. Lawson. "Preventing Pollution in the CPI." *Chemical Engineering* 98 (September 1991): 120–127.

This article provides a thorough review of the components of pollution prevention in the chemical process industries (CPI). Successful pollution prevention programs demand the attention to eight aspects of a manufacturing operation: product design, process design, plant configuration, information and control systems, human resources, research and development, suppliers' role and relationship, and organization. [G]

Bodily, Sam. "Armco Inc.—The Bubble Policy" (Report #UVA-QA-227). Charlottesville, VA: Darden Graduate School of Business (University of Virginia), 1982.

This case employs a simplified linear programming model to evaluate operating and capital investment options under the "bubble policy" method for measuring air pollution emissions. [OR]

Brown, Lester. *Building a Sustainable Society*, pp. 284–348. New York: Norton, 1981.

The author first discusses the effects of industrialization on the environment. He then identifies social and economic strategies for sustainable development. Of these strategies, changing social values and altering the role of business are particularly relevant to organizational design; the strategies relevant to production control include alternative energy sources and altering the role of business. [OD/MC][PC]

Burall, Paul. *Green Design*. London: The Design Council, 1991.

This book is a reference for the use of environmentally considerate materials and technologies. The specific industrial examples about material substitution, recycling, packaging and energy use, and efficiency are relevant to facilities planning; the author looks at motivation and management of technological change as it relates to implementing these technologies. [FP][OD/MC]

Cairncross, Frances. *Costing the Earth*, 143–252. London: The Economist Books, 1991.

This book looks at the unique environmental challenges facing business and government today. The shortcomings of contemporary accounting methods and process control techniques in dealing with environmental issues are explored in detail. The author shows that internalizing environmental costs can lead to prosperity. To this end, a "green" checklist is provided for industry. Similar to quality checklists in many ways, this checklist includes management-of-change elements managers should employ as well as factors for consideration in production control. The author also provides data for societal costs of pollution and the value of natural resources that go unused. [OD/MC][PC][TQM]

Caplan, Darlene W. "Sylvania's GTE Products Problem Stoppers: #1 Employee Involvement Team." *Total Quality Environmental Management* 2 (Winter 1992/93): 159–164.

The article discusses the winner of the 1992 Association for Quality and Participation's National Team Excellence Competition. A nine-person work team called the Problem Solvers from Sylvania Lighting in York, Pennsylvania, won for eliminating glass waste at York by recycling it in the plant. [TQM][OD/MC]

Chechile, Richard A., and Susan Carlisle. *Environmental Decision Making*. New York: Van Nostrand Reinhold, 1991.

This book discusses the following topics: psychological factors; ecosystem perspectives; probability, utility and decision trees; factoring risk; the economic model; resource allocation; ethical aspects; public policy decision making; regulatory decisions; and international decision making. Of particular interest to industrial engineers are the introductory chapter (which expands the currently used elements of the decision making process to include costs external to the decision-maker), and the use of utility theory in environmental decision making. [DA]

Cramer, J.M., and B. Roes. "Total Employee Involvement: Measures for Success." *Total Quality Environmental Management* 3 (Autumn 1993): 39–52.

Whether environmental management is successful depends partly on whether managers can actively involve employees in policy formulation and implementation. This not only generates shop-floor support for environmental policy, it also makes use of employees' environmental knowledge and expertise. [OD/MC][TQM]

Dauncey, Guy. "How Green Is Your Company?—A Corporate 'Green Rating.'" In *Green Business: Hope or Hoax?* edited by Christopher Plant and Judith Plant, 66–70. Philadelphia: New Society, 1991.

Describes how a company can set up a framework for judging its "greenness": (1) establish cross-departmental "environmental action teams"; (2) appoint an "environmental vice-president" with responsibility to improve the company's environmental profile; (3) commission an environmental audit; (4) develop staff and customer questionnaires to solicit company actions and products; (5) hold cross-company environmental hearings to engage staff; and (6) instruct each department to develop an environmental plan. Includes examples. Such material is easily adapted to quality audit programs. [TQM]

Deland, Michael R. "An Ounce of Prevention . . . After 20 Years of Cure." *Environmental Science and Technology*, 25 (1991): 4.

As chair of the President's Council on Environmental Quality under George Bush, Deland writes on why business should embrace P2. He argues that companies should implement pollution prevention because of cost and regulatory advantages in addition to protecting future generations of workers; he also suggests applying TQM methods to implement pollution prevention programs. Although from a previous administration, the article still provides a good look at the government's perspective. [G][TQM]

Early, William F., and Mark A. Eldson. "Design for Zero Releases." *Hydrocarbon Processing* 69 (August 1990): 47–49.

Provides methods for incorporating environmental issues into chemical facility design. (This article is written specifically about chemical manufacturing processes and design considerations — flanges and welded connections, valves, relief valves, pumps, transfer lines/hoses, installation, and operation — and thus is not recommended for general reading.) [FP]

Evanhoff, Stephan P. "Hazardous Waste Reduction in the Aerospace Industry." *Chemical Engineering Progress* 86 (April 1990): 51–61.

This article outlines the aerospace industry's manufacturing process wastes, explaining the processes used (degreasing, surface finishing painting, surface cleaning, maintenance, transportation, and laboratory R&D) and the wastes generated. It then outlines current recycling and recovery technologies used in the industry. The information describes processes and their chemical and mechanical attributes. While it is too specific for general industrial engineering curricula, it provides a good overview for industrial engineers interested in the aerospace industry.

Feichtinger, G., and M. Luptacik. "Optimal Production and Abatement Policies of a Firm." *European Journal of Operations Research* 29 (1987): 274–285.

This article examines the relationship between the loss of jobs caused by increased environmental regulation and the loss of environmental quality caused by pollution. The authors develop a model that determines an optimal path where pollution control increases as the number of employees rise. [OR]

Freeman, Henry, Teresa Harten, Johnny Springer, Paul Randall, Mary Ann Curran, and Kenneth Stone. "Industrial Pollution Prevention: A Critical Review." *Air and Waste* (Journal of the Air and Waste Management Association) 42, no. 5 (May 1992): 618–656.

A comprehensive review of pollution prevention activities around the country, this article discusses pollution prevention; governmental legislation and programs; industrial programs; pollution prevention assessments and measurement issues; and incentives and barriers to pollution prevention, life cycle analysis, and product design. Identifies and critiques topical material for each topic. A very good reference for gathering comprehensive pollution prevention information. [G][TQM][PC]

Friedlander, Sheldon K. "Pollution Prevention: Implications for Engineering Design, Research and Education." *Environment* 31 (May 1989): 10–15, 36–38.

As pollution prevention and other proactive strategies gain momentum as environmental strategies, engineers are faced with the challenge of developing technological solutions. The author looks at source reduction and product design as they effect research and education. [G]

Frosch, Robert A., and Nicholas E. Gallopoulos. "Strategies for Manufacturing." *Scientific American* 261 (September 1989): 144–152.

The authors present the idea of the "industrial ecosystem" in this article. As natural resources become more scarce, this idea should gain interest in industry. Three "industrial ecosystems" are presented: the production of plastics from petroleum, the conversion of iron ore to steel, and the use of platinum as a catalyst.[G][PC][TQM]

Goldner, Howard J. "Waste Minimization Starts at the Top." *Research and Development Magazine* 33 (September 1991): 48–52.

This article presents the importance of a company's research and development department in bringing about successful pollution prevention projects. Not only should R&D focus on the product, but it should focus on the manufacturing process, as well. To motivate this shift in R&D's orientation, top management must understand the need and benefits of pollution prevention initiatives. [G][OD/MC]

Green, Philip E.J. "Environmental TQM." *Quality Progress* 26 (May 1993): 77–80.

The author stresses that "quality professionals have a tremendous contribution to make. As iconoclasts, they have learned to challenge sacred assumptions and develop new and better ways to work. They have learned to establish credibility for new work and management practices." Deming's 14 points to environmental issues are discussed, as well as benefits to protecting the environment, and altering managers' attitudes. [TQM]

Gregory, Paul, Richard Larson, and Alan Minkoff. "Dirty Work." *OR/MS Today* 19 (June 1992): 34–39.

The authors discuss the increased use of marine transport to dispose of New York City's waste due to closed landfills. To optimize allocation of the garbage barge armada, the authors developed the Barge Operation Systems Simulation. As a result of this model, refuse barges move through New York Harbor more effectively. An issue unanswered by the article is the necessity to reduce the waste generated by New Yorkers. [OR]

Hahn, Robert W. "On Reconciling Conflicting Goals: Applications of Multi-objective Programming." *Operations Research* 32, no. 1 (1984): 221–288.

In most mathematical programming problems, the goal is to minimize cost subject to feasibility constraints and a set of targets. In contrast, multi-objective programming treats the objectives as the choice variables, and cost as a parameter. This article uses the two approaches to analyze a pollution emission problem. The comparison reveals that the traditional cost-minimizing approach can generate solutions that are inefficient, in the sense that greater emissions reductions could have been attained at the same cost. Because the solution sets to the two problems may differ, the author derives conditions under which the two approaches yield a similar set of results. [OR]

Hämälainen, Raimo P. "Decision Analysis Makes Its Way Into Environmental Policy in Finland." *OR/MS Today* (June 1992): 40–43.

The author discusses using decision analysis techniques in developing decisions outside the traditional engineering and business spheres. He then describes his HIPRE decision-support software, which was used to assist the Finnish government in making acid rain policy. [DA]

Harmon, Leith S. "A Logical Role for the Industrial Engineer: Pollution Prevention." NPPC, 1995.

Discusses the inherent and critical role industrial engineers must play in developing successful pollution prevention programs. Explains regulatory and market factors for P2 and outlines a framework for P2 within a firm. Provides accompanying questions and answers. [G]

———. "Pollution Prevention and Facilities Planning." NPPC, 1995.

Discusses the need for facility planners to consciously include environmental considerations when locating and designing facilities. Provides accompanying questions and possible answers. [FP]

———. "Total Quality Management: A Methodology for Pollution Prevention." NPPC, 1995.

Discusses how the four elements of Total Quality Management — customer focus, continuous improvement, teamwork, and strong management commitment — can all be applied to prevent pollution. Provides accompanying questions and possible answers. [TQM]

———. "The Tragedy of the Commons and the Decision Maker." NPPC, 1995.

Investigates the failure of the rational decision model under certain resource allocation conditions. Provides accompanying questions and answers. [DA]

Harmon, Leith S., and Katta Murty. "Pollution Prevention as Continuous Improvement at Ford Motor Company." NPPC, 1995.

Describes Ford's successful use of continuous improvement techniques to reduce waste at its Livonia, MI, Transmission Plant. Discusses a cross-disciplinary team and the waste-prevention opportunities it developed as well as a P2 guidebook that could be used for waste prevention at other Ford plants. Provides accompanying questions, answers, and discussion points. [TQM]

Haynsworth, H.C., and R. Tim Lyons. "Remanufacturing By Design." *Production and Inventory Management* (2nd Quarter 1987): 24–29.

"Design for remanufacturability" is an idea that is gaining ground both here and in Europe. The automotive industry is the primary industry utilizing this strategy. The benefits of using remanufactured parts include increased savings for customers, better performance than reconditioned parts, reduction of capital spending, and reduced need for raw material. The author points out how this strategy can be incorporated into the product life cycle. Problems include difficulties in developing a collection and distribution network for the used parts, and the perceived quality problem of using "previously used" parts. [PC]

Hethcoat, Henry G. "Minimize Refinery Waste." *Hydrocarbon Processing* 69 (August 1990): 51–54.

This article outlines the petroleum industry's manufacturing processes and their attendant wastes. The author explains the current recycling and recovery technologies (integrated units, in-line bleeding, crude tank mixers, air cooler maximization, demineralized river water, amine degradation prevention) used in the industry. The information describes processes and their chemical and mechanical attributes. While it is too specific for general industrial engineering curricula, it provides a good overview for industrial engineers interested in the petroleum industry.

Hirschhorn, Joel S., and Kirsten U. Oldenburg. *Prosperity Without Pollution.* New York: Van Nostrand Reinhold, 1991.

This comprehensive book looks at the issue of pollution prevention from social, organizational, and industrial management perspectives (in contrast to many pollution prevention guides, which primarily provide a technical perspective). The first half of the book is particularly relevant to production control. Chapter 3, "Achieving Success By Overcoming Obstacles," is pertinant to organizational design and the management of change along with quality management programs. Chapter 4, "Data Tells the Story: Too Much Waste," presents the surprisingly complex issues that surround tracking waste. Chapter 7, "Changing Consumption: Reducing Garbage," discusses how consumers are a factor in the reduction of waste. Chapter 9, "No Time to Waste," discusses public policy responsibilities in pollution prevention. [PC][TQM][OD/MC]

Hocking, Martin B. "Paper vs. Polystyrene: A Complex Choice." *Science* 251 (February 1, 1991): 504–505.

Using life cycle analysis, the author analyzes the environmental effects of paper vs. polystyrene packaging. This article is one of the ground-breaking discussions of life-cycle analysis. While the author concludes that polystyrene is less damaging to the environment for single use situations, recent changes in paper production technology cast doubts on that conclusion today. From an educational standpoint, the significance of this article lies not in the authors conclusions but in his methodology. As such, the article can be used to introduce the *process* of life cycle analysis.

Imbler, C. Clarke. "Who Pays the Price for Environmental Pollution?" *Pollution Engineering* 21 (Sept. 1989): 92–94.

This editorial piece outlines the weaknesses inherent in the many regulatory "solutions" to the country's waste problems. The author discusses how RCRA and Superfund create litigious behavior and do not fully address the true costs of pollution cleanup. This article might be used to make a strong case for pollution prevention: if the waste is not generated, liability under the various regulations will not occur. Total cost accounting (including the expected costs of waste handling, waste disposal, and liability in the capital budgeting process) can make pollution prevention projects appear more economically attractive. [G][CB]

Keeney, Ralph L. "Structuring Objectives for Problems of Public Interest." *Operations Research* 36, no. 3 (May/June 1988): 396–405.

Sustainable development requires that industry view all costs (not just those internal to the firm) of doing business when making decisions. When the environmental issues are included in the business decision process, the set of stakeholders must be expanded beyond the traditional group of stockholders, customers, and employees. The author presents a model of decision analysis that includes a hierarchy of multiple objectives representing all stakeholders affected by the decision. [DA]

Kharbanda, O.P., and E.A. Stallworthy. *Waste Management.* New York: Auburn House, 1990.

This book presents a good introductory discussion on why industrial engineers should be concerned with pollution prevention. The increasing costs and hazards associated with waste handling require more comprehensive waste management. The authors describe the pollution hierarchy and call for wasteless processes wherever possible. Waste should be minimized only when wasteless processes do not exist. Where waste minimization is infeasible, recycling should be employed; waste treatment should be viewed as an alternative of last resort.

The book describes our society's waste problems, emphasizing management's role in implementing

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solutions. Specific production control and management techniques are discussed along with clear examples of pertinent technologies that can be employed in facilities planning; these examples would be very appropriate for classroom discussion of pollution prevention techniques. [G][FP][OD/MC][PC]

Kirsh, F.W., and G.P. Looby, "Case Study: Pollution Prevention in Practice." *Pollution Prevention Review* 1, no. 2 (Spring 1991): 25–28.

This article presents four case studies that show how small- and medium-sized companies can not only reduce waste, but also save enough money to pay for any capital changes. [G]

Koelsch, James R. "Knee Deep in Liability?" *Manufacturing Engineering* 107 (August 1991): 28–33.

The article outlines the negative results of not handling spent coolants properly. It discusses how one production manager faces fines and imprisonment for not handling spent coolants as outlined in the Resource Conservation and Recovery Act (RCRA). It also covers management techniques (planning, documentation, and proper maintenance) that not only reduce liability, but reduce spent coolant as well. While pollution prevention is not explicitly discussed, it is the underlying message in the article. [G]

Koenigsberger, M.D. "Preventing Pollution at the Source." *Chemical Engineering Progress* 82 (May 1986): 7–9.

The article briefly outlines 3M's efforts in pollution prevention. It suggests methods for implementing a P2 program and discusses the following potential barriers:

- Senior management support may be difficult to get.
- Even though operating and maintenance costs almost always make pollution more expensive to control than prevent, the initial investment for pollution prevention equipment might still be higher.
- P2 technology may not be viable.
- P2 may be viewed as an untried substitute.
- Marketing often hinders reformulation. [G]

Konz, Steven A. *Facility Design*, pp. 347–353. New York: John Wiley and Sons, 1985.

This is a is a textbook for the field of facilities planning. The section cited briefly discusses the importance of including waste reduction criteria in the facility design process. Includes industry examples. [FP]

Kraft, Robert L. "Incorporate Environmental Reviews Into Facility Design." *Chemical Engineering Progress* 88 (August 1992): 46–52.

This article provides a comprehensive plan for incorporating environmental concerns into facility design. Although the issues addressed tend to be chemical process-oriented, the techniques outlined can be generalized to all manufacturing. The 10 components of the review process are:

1. Conduct initial and pre-design assessments.
2. Assign project environmental responsibility.
3. Define the project's environmental objectives.
4. Identify the need for any permits.
5. Determine environmental compliance requirements.
6. Perform an overall waste minimization analysis.
7. Apply "best environmental practices" for emission-free and discharge-free facilities.
8. Determine waste treatment & disposal requirements.
9. Perform engineering evaluations of waste management options.
10. Complete project environmental review. [FP]

Maruchek, Ann, and Lansdon Robbins. "Business Ethics: The Materials/Manufacturing Perspective." *Production and Inventory Management Journal* 29 (4th Quarter 1988): 16–19.

The authors contend that true impacts of "green" consumerism can be made in the supplier/customer relationship rather than in the consumer sphere. Increasingly, the supplier's product affects the customer's reputation and even liability. The authors show how environmental sensitivity is everyone's concern, and that activities such as purchasing can effect the environment. [PC]

Molinaro, Lawrence, Jr. *Production and Operations Management and the Environment.* Washington: Management Institute for Environment and Business, 1991.

This reader, the first of seven MEB modules on environmental considerations in business, includes articles and case studies relevant to several subdisciplines in IE/OR. Chapter 1, "Introduction to Pollution Prevention and Waste Reduction," applies to all. Chapters 6, "Managing Technology for Environmental Strategy," and 7, "The Regulatory Environment and Operations," apply to organizational design and management of change. Chapters 2, "Waste Minimization in the Production Process," 3, "Materials Management," and 4, "Quantitative Models: Environmental Management

Applications," apply to production control. Chapters 2 and 5, "The Environmental Audit," apply to Total Quality Management. [OD/MC][PC][TQM]

O'Sullivan, Dermot. "Bayer Targets Process Modification as Approach to Pollution Prevention." *Chemical & Engineering News* 69 (October 21, 1991): 21–25.

This article discusses how the large chemical company has targeted one sixth of its capital spending in pollution prevention. The article discusses incorporating the "prevention, reduction, recycling" idea into the corporate culture. Specific projects are also discussed. [OD/MC][G][PC]

Olsen, Marvin E. "Public Acceptance of Consumer Energy Conservation Strategies." *Journal of Economic Psychology* 4, no. 2 (October 1983): 183–196.

The policy of reducing consumer energy consumption can be implemented through several broad courses of action. This study investigates six alternative strategies for promoting energy conservation: financial incentives, community programs, efficiency standards, land-use changes, consumption limits. and price increases. Public acceptance of the strategies varies widely, from 83% for financial incentives to 9% for price increases. The single best predictor of acceptance is preference for a soft rather than hard energy policy path; the second-best predictor is perceived seriousness of the energy problem. In general, Americans can be described as supporting a diverse set of strategies for encouraging consumer energy conservation. [OD/MC]

Oskamp, Stuart. "Psychology's Role in the Conserving Society." *Population and Environment* 6, no. 4 (Winter 1983: Behavioral Science Issue): 255–293.

The author defines the hard energy path as: heavy reliance on high technology, highly centralized power plants, and recklessly high levels of energy use. This is perpetuated by extremely powerful institutional and societal forces. Industry has huge investments in present equipment and procedures. Many policy implications can be drawn from psychological research: Emphasize individual benefits of conservation rather than sacrifices. Don't make financial savings the sole justification for conservation. Don't expect information alone to motivate people to conserve. Stress benefits of conservation to society in order to give people an altruistic rational for conserving. Finally, whenever possible, spread conservation information through interpersonal interaction and "hands on" demonstrations rather than through the impersonal mass media. [OD/MC]

Painter, John, Rachel Semenik, and Russell Belk. "Is There a Generalized Energy Conservation Ethic? A Comparison of the Determinants of Gasoline and Home Heating Energy Conservation." *Journal of Economic Psychology* 3, no. 3-4 (September 1983): 317–331.

Compared to other socially responsible behaviors such as pollution reduction, the conservation of energy is more likely to be motivated by more purely economic incentives. The study suggests that studies of conservation behavior that combine conservers of different fuels or that attempt to generalize from conservation of one fuel to conservation of others may be quite misleading. [OD/MC]

Piasecki, Bruce, and Peter Asmus. *In Search of Environmental Excellence*. New York: Simon and Schuster, 1990.

Chapter 5, "Industry and the Environment: Creating Affordable Beliefs," discusses the need and provides examples of how companies have made the organizational and cultural changes required for successful pollution prevention. Many of these changes mirror those required for the successful implementation of quality programs. [OD/MC][TQM]

Pojasek, Robert B. "For Pollution Prevention: Be Descriptive Not Prescriptive." *Chemical Engineering* 98 (September 1991): 136–139.

The author describes a "descriptive" approach to pollution prevention. This type of strategy is required for studying unique processes. Under this plan, those people closest to the process are called upon to develop creative and innovative solutions to the pollution problems at hand. [G]

Pojasek, Robert B., and Lawrence J. Coli. "Measuring Pollution Prevention Progress." *Pollution Prevention Review* 1, no. 2 (Spring 1991): 119–130.

Successful pollution prevention programs require quantifiable measures, which are used in identifying waste streams and providing goals for future improvement. Issues in developing these measures are discussed. [G]

President's Commission on Environmental Quality, Quality Environmental Management Subcommittee. *Total Quality Management: A Framework for Pollution Prevention.* Washington: President's Commission on Environmental Quality, 1993.

Under the auspices of the President's Commission on Environmental Quality (PCEQ), 11 corporations volunteered to demonstrate the viability of TQM as a methodology for achieving pollution prevention. Included are summaries of the results of projects at AT&T, Chevron, Dow, DuPont, Ford, GE, International Paper, Merck, Procter & Gamble, 3M, and the U.S. Generating Company. [TQM]

Price, Roger L. "Stopping Waste at the Source." *Civil Engineering* 60 (April 1990): 67–69.

Inventory control, material-handling, and scheduling all provide opportunities for waste reduction. These traditional industrial engineering fields require an environmental "spin" before waste reduction opportunities can be identified. The author also discusses process redesign, raw material substitution, and industrial ecology. [PC][G]

Remmers, J., Th. Morgenstern, G. Schoens, H.-D. Haasis, and O. Rentz. "Integration of Air Pollution Control Technologies in Linear Energy-Environmental Models." *European Journal of Operational Research* 47 (1990): 306–316.

This article discusses alterations to the Energy Flow Optimization Model (EFOM) to address pollution reduction. The model was generated as a result of concern over Europe's increasing levels of air pollution. [OR]

Robinson, Alan G., and Dean M. Schroeder. "Detecting and Eliminating Invisible Waste." *Production and Inventory Management Journal* 33, no. 4 (Fourth Quarter 1992): 37–42.

This article discusses the idea of invisible waste in the production process. It explores why the waste is invisible, identifies sources of those wastes, and proposes the following principles to detect and eliminate them:

1. When evaluating or applying a new management technique, identify the sources of waste that it exposes or eliminates, those that it cannot expose or eliminate, those it will create, and the complementary techniques required to address these limitations.
2. Do not limit training to specific job methods — employees must also know how to make improvements to their jobs.
3. Increase the number of perspectives from which the process is seen.
4. Whenever significant change is made to any component of the productive system, examine the entire process for new sources of waste.

While the authors expand the definition of waste to include labor inefficiencies, the principles presented are relevant to pollution prevention. [PC][TQM]

Schmidheiny, Stephan, with the Business Council for Sustainable Development. *Changing Course: A Global Business Perspective on Development and the Environment.* Cambridge, MA: MIT Press, 1992.

Developed under the auspices of an international group of business leaders, this comprehensive book looks at all aspects of integrating environmental concerns into industrial management. The chapters are (1) "The Business of Sustainable Development"; (2) "Pricing the Environment: Markets, Costs, and Instruments"; (3) "Energy and the Marketplace"; (4) "Capital Markets: Financing Sustainable Development"; (5) "Trade and Sustainable Development"; (6) "Managing Corporate Change"; (7) "The Innovation Process"; (8) "Technology Cooperation; (9) "Sustainable Management of Renewable Resources"; and (10) "Leadership for Sustainable Development." The case studies about managing change in business, business partnerships, stakeholder partnerships, financial partnerships, cleaner production, cleaner products, and sustainable resource use are apropos to industrial engineering. Chapters 1, 6, 7, 8, 9, and 10 are especially relevant to organizational design and management of change, as are the case studies about managing business, business partnerships, stakeholder partnerships, financial partnerships, and sustainable resource use. Chapters 1, 3, 7, and 8 are especially relevant to production control, as are the case studies about managing cleaner production, cleaner products, and sustainable resource use; those cases are also relevant to facilities planning. [G][FP][OD/MC][PC]

Tusa, Wayne. "Developing an Environmental Audit Program." *Risk Management* 32 (August 1987): 24–29.

The article discusses reasons for and ways to set up an environmental audit program. Though not stated in the article, such a program ties in nicely with quality audit systems. [TQM]

U.S. Environmental Protection Agency, Office of Pollution Prevention. *Pollution Prevention 1991: Progress on Reducing Industrial Pollutants*. EPA/21P-3003. Washington: U.S. EPA, 1991.

This EPA publication presents trends and describes industrial and governmental programs. Chapter 3 provides examples of specific organizational efforts to better facilitate pollution prevention. It is good reference for governmental contacts. [OD/MC]

Upton, Dave, and Joshua Margolis. "Australian Paper Manufacturers," Cases A and B (Report #N9-691-041). Boston: Harvard Business School, 1990.

In the light of a competitor's problems with toxic chemicals, these cases explore Australian Paper Manufacturers' options in expanding uncoated, fine paper capacity, along with dealing with toxic chemicals, forestry and recycling. [PC]

Van Steen, Jacques F.J. "A Methodology for Aiding Hazardous Materials Transportation." *European Journal of Operational Research* 32 (1987): 231–244.

Risk assessment plays a large role in environmental decision-making. This article develops a model for risk analysis associated with the transportation of hazardous waste. Value judgments and the perception of risk are included in the model. [DA]

Van Weenen, J.C, and J. Eckels. "Design and Waste Prevention." *The Environmental Professional* 11 (1991): 231–235.

The article discusses methods for designing products and processes with waste prevention as a specific goal. A matrix method — the Design Environment Cube (similar to life-cycle matrices and "house of quality" models) — is presented. The authors then point out that further research is needed in the areas in decision-making systems, influencing systems, and design for durability and reuse. [FP][TQM]

Von Winterfeldt, Detlof. "Setting Standards for Offshore Oil Discharges: A Regulatory Decision Analysis." *Operations Research* 30 (September/October 1982): 867–886.

Offshore oil production platforms continually discharge oily water into the surrounding marine environment. To reduce the environmental risk from these discharges, emission standards are set on the oil concentration in the effluent. This paper describes a decision-analysis model for aiding regulators and platform operators in the standard-setting process. The model combines three submodules: a regulator model, an operator model, and an impact model. [DA]

Winett, Rachel A., and Peter Ester. "Behavior Science and Energy Conservation: Conceptualizations, Strategies, Outcomes, Energy Policy Applications." *Journal of Economic Psychology* 3, no. 3-4 (September 1983): 203–229.

The importance of human behaviors in energy conservation is well-known in behavior science, but this position has hardly made its way into policy. The authors suggest these preliminary steps as a minimum:

1. Delineate the most significant energy-consuming practices.
2. Assess technical contexts — make sure policy is pertinent to consumer behavior.
3. Assess attitudes, beliefs, information, values, and current behaviors concerning the practices in different population segments.
4. Conduct analyses by population segments — mismatches lead to failure.
5. Pre-test material to assure quality.
6. Analyze higher -level influences limiting change.
7. Use substitution strategies — decrease an inappropriate behavior and increase the appropriate one.
8. Use reciprocal reinforcement — reward multiple and concerned parties for their efforts. [OD/MC]

Wisner, Joel D., and Stanley E. Fawcett. "Linking Firm Strategy to Operating Decisions Through Performance Measurement." *Production and Inventory Management Journal* 32, no. 3 (Third Quarter 1991): 5–11.

Companies must reevaluate their approach to competition in the global economy. One area that needs reevaluation is performance measurement. In order to guide a firm's operating decisions toward strategic objectives, performance criteria must be flexible, easy to implement, timely, clearly defined at all management levels, and derived from the firm's strategic objectives. The article discusses the characteristics of world-class manufacturers and how they use performance measures competitively. It then discusses the development of a successful performance measurement system with criteria in quality, cost, flexibility, dependability, and innovation. Noticeably missing is the area of environmental performance. But, given (a) the authors' premise that these performance measures should be derived from a firm's strategic plan, and (b) the increasing strategic emphasis on environmental quality, environmental performance measures are a logical extension. The development of such criteria might serve as a good classroom exercise in a production control, operations management, or quality class. [PC][TQM]

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CE-176 POLLUTION PREVENTION MANAGEMENT

Catalog Description

Rather than designing water, air and waste treatment facilities, engineers are often asked to help prevent the generation of these wastes. Tools for understanding, communicating and managing industrial manufacturing processes are presented using actual cases. Practical problem-solving methodologies are incorporated using a rigorous engineering framework of problem assessment, data management, feasibility and implementation. Senior standing and engineering or physical science background. Pojasek. Spring.

Rationale

Using a pollution prevention project in a designated manufacturing facility, allows students to exploit the knowledge they have learned about pollution prevention methods. Creative problem-solving and total quality management procedures are introduced in the context of pollution prevention. The course includes examples of changing operating practices, materials substitution, process/product changes and recycling. The proper use of the engineering method for planning and implementing pollution prevention is stressed.

This is an elective course in both the Hazardous Materials Management program and the Environmental Engineering M.S. programs in the Department of Civil and Environmental Engineering. As of December 1993, this course has been offered five times as CE-194J Pollution Prevention.

<u>Office Hours</u>. Dr. Pojasek will be available one hour before every class, i.e., 5:30 to 6:30 p.m. He is also available by appointment and by telephone during the normal business day at the following location:

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	G	CB	DA	FP	OR	OD/MC	PC	TQM
Alm, 1992								x
Amoco, 1995			x					
Ausubel and Sladovich, 1989						x	x	
Bender et al., 1981			x		x			
Berglund and Lawson, 1991	x							
Bodily, 1982					x			
Brown, 1981						x	x	
Burall, 1991				x		x		
Cairncross, 1991						x	x	x
Caplan, 1992/93						x		x
Chechile and Carlisle, 1991			x					
Cramer and Roes, 1993						x		x
Dauncey, 1991	x							x
Deland, 1991	x							x
Early, 1990				x				
Feichtinger and Luptacik, 1987					x			
Freeman et al., 1992	x						x	x
Friedlander, 1989	x							
Frosch and Gallopoulos, 1989	x						x	x
Goldner, 1991	x					x		
Green, 1993								x
Gregory et al., 1992					x			
Hahn, 1984					x			
Hämälainen, 1992			x					
Harmon (Logical Role), 1995	x							
Harmon (P2 and Fac. Plan.), 1995				x				
Harmon (TQM), 1995								x
Harmon (Tragedy), 1995			x					
Harmon and Murty, 1995								x
Haynsworth and Lyons, 1987							x	
Hirschhorn and Oldenburg, 1991						x	x	x
Imbler, 1989	x	x						
Keeney, 1988			x					
Kharbanda and Stallworthy, 1990	x			x		x	x	
Kirsh and Looby, 1991	x							
Koelsch, 1991	x							
Koenigsberger, 1992	x							
Konz, 1985				x				

	G	CB	DA	FP	OR	OD/MC	PC	TQM
Kraft, 1992				x				
Maruchek and Robbins, 1988							x	
Molinaro, 1991						x	x	x
O'Sullivan, 1991	x					x	x	
Olsen, 1983						x		
Oskamp, 1983						x		
Painter et al., 1983						x		
Piasecki and Asmus, 1990						x		x
Pojasek, 1991	x							
Pojasek and Coli, 1991	x							
PCEQ, 1993								x
Price, 1990	x						x	
Remmers et al., 1990					x			
Robinson and Schroeder, 1992							x	x
Schmidheiny, 1992	x			x		x	x	
Tusa, 1987								x
Upton and Margolis, 1990							x	
U.S. EPA, 1991						x		
Van Steen, 1987			x					
Van Weenen and Eckels, 1991				x				x
Von Winterfeldt, 1982			x					
Winett and Ester, 1983						x		
Wisner and Fawcett, 1991							x	x

Published by:
The National Pollution Prevention Center for Higher Education
University of Michigan, Dana Building
430 East University Ave.
Ann Arbor, MI 48109-1115
• Phone: 313-764-1412
• Fax: 313-936-2195
• E-mail: nppc@umich.edu

The mission of the NPPC is to promote sustainable development by educating students, faculty, and professionals about pollution prevention; create educational materials; provide tools and strategies for addressing relevant environmental problems; and establish a national network of pollution prevention educators. In addition to developing educational materials and conducting research, the NPPC also offers an internship program, professional education and training, and conferences.

Your Input is Welcome!

We are very interested in your feedback on these materials. Please take a moment to offer your comments and communicate them to us. Also contact us if you wish to receive a documents list, order any of our materials, collaborate on or review NPPC resources, or be listed in our *Directory of Pollution Prevention in Higher Education*.

We're Going Online!

The NPPC provides information on its programs and educational materials through the Internet's Worldwide Web; our URL is: **http://www.snre.umich.edu/** (click on the "National Pollution Prevention Center"

We may also update the NPPC information available through gopher (gopher.snre.umich.edu) and anonymous FTP (ftp.snre.umich.edu). Please contact us if you have comments about our online resources or suggestions for publicizing our educational materials through the Internet. Thank you!

Course Syllabi

- *Environmental Science and Public Policy: Reducing Industrial Waste*
  William Clark and Robert Frosch, Harvard University
- *Clean Fuels and Clean Technology: The Technical, Environmental, and Policy Issues.*
  Rex T. Ellington, University of Oklahoma
- *Pollution Prevention*
  Robert B. Pojasek, Tufts University
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Industrial Engineering and Operations Research

NATIONAL POLLUTION PREVENTION CENTER FOR HIGHER EDUCATION

Clean Fuels and Clean Technology: The Technical, Environmental, and Policy Issues

Rex T. Ellington
HON 3993, May 1994
University of Oklahoma

National Pollution Prevention Center for Higher Education • University of Michigan
Dana Building, 430 East University, Ann Arbor MI 48109-1115
Phone: 313.764.1412 • Fax: 313.936.2195 • E-mail: nppc@umich.edu

HON 3993 002

Clean Fuels and Clean Technology: The Technical, Environmental, and Policy Issues

Dr. Mark Meo and Dr. Rex Ellington

Course Description:

Clean fuels and clean technologies are widely perceived to be essential to world economic development. This colloquium is designed to provide undergraduate students in any major with an appreciation of how technology and policy have evolved in response to rising national and international demands for environmental quality, and the roles that technical and policy criteria play in guiding planning, management, and decision making. The discussion will focus on: (1) The challenges placed on industry to develop fuels and technologies with which economic development can proceed in a more environmentally-benign and sustainable manner, and (2) The evolution in public policy that has sought to place a value on natural resources that is commensurate with their services to society. A probing type of study will be employed to teach students how to analyze complex issues and expand their horizons. Discussion topics will include examination of energy systems and applications, technological innovations for minimizing material and energy use, the evolution of business and public policy issues, institutional frameworks and management strategies, assessment criteria, and the research and development agenda. The course is an interdisciplinary one that is led by a professor with a background in ecology, environmental science, and public policy analysis and a professor emeritus of chemical engineering who has substantial experience in corporate leadership and management.

Requirements:

Students will be asked to prepare two brief papers, midterm and final, based on assigned readings, handouts, and class discussion. Access to reference and special library materials will be facilitated by the instructors.

Reading List:

"Energy for Planet Earth," Scientific American, Vol. 263, No. 3, September 1990.

U.S. Congress, Office of Technology Assessment, Green Products by Design: Choices for a Cleaner Environment, OTA-E-541 (Washington, DC: U.S. Government Printing Office, October 1992).

Additionally, selected readings from books and journals will be assigned.

Industrial Engineering and Operations Research

NATIONAL POLLUTION PREVENTION CENTER FOR HIGHER EDUCATION

Clean Fuels and Clean Technology: The Technical, Environmental, and Policy Issues

Rex T. Ellington

HON 3993, May 1994

University of Oklahoma

HON 3993 002

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Pollution Prevention

Robert B. Pojasek
CE-194J, Spring 1994
Tufts University

Department of Civil/Environmental Engineering
TUFTS UNIVERSITY

Spring 1994

CE-194J Pollution Prevention
Instructor: Dr. Robert B. Pojasek

COURSE DESCRIPTION

Rather than designing water, air, and waste treatment facilities, engineers are often asked to help prevent the generation of these wastes. Tools for understanding, communicating, and managing industrial manufacturing processes are presented using actual cases. Practical problem-solving methodologies are incorporated using a rigorous engineering framework of problem assessment data management, feasibility study, and implementation.

This is a "hands-on" course where the student will learn by actually working on a pollution prevention project. In lieu of a final examination, the student will work in a small group to evaluate a designated manufacturing facility. Together they will prepare process flow diagrams, materials accounting summaries, a description of all of the opportunities for pollution prevention, and a rank ordering of these opportunities. Each student in the group will then research one of the primary opportunities, conduct a feasibility study, and make recommendations for implementation. Using a pollution prevention project in an actual facility allows students to exploit the knowledge they have learned about pollution prevention methods. Creative problem-solving and quality improvement procedures are introduced in the context of pollution prevention. The course includes examples of changing operating practices, materials substitution, process/product changes and recycling/reuse. Proper use of the engineering method for planning and implementing pollution prevention is stressed.

COURSE SCHEDULE

1. January 24, 1993 — INTRODUCTION TO POLLUTION PREVENTION

Without dwelling extensively on the terminology and definitional problems that currently exist in this emerging field, some generic pollution prevention theories and concepts will be presented. These concepts will include chemical use cycles, the waste management hierarchy, shifting media, materials use and loss control, efficiency concepts, and broader concepts of sustainable development. Incentives and impediments to the use of pollution prevention practices in industry will be examined along with pressures that have been brought to bear to induce facilities to utilize these practices. No attempt will be made to examine specific pollution prevention legislation or regulations.

2. January 31, 1994 UNDERSTANDING MANUFACTURING AND MANAGEMENT

Emphasis in this course is placed on pollution prevention in manufacturing. All manufacturing categories have commonalities which, when recognized, allow the pollution prevention practitioner to apply the concepts described in the previous class without regard to the type of industry. Consideration must be given to the product life cycles and the supplier/customer connections. The manner in which manufacturing is managed is a key to the successful implementation of pollution prevention. Understanding the culture of the organization is very important. Analogous management programs (such as quality improvement, just-in-time and computer integrated manufacturing) will be discussed along with a model for manufacturing for competitive advantage in a global marketplace.

3. February 7, 1994 PREPARING FOR AN ASSESSMENT

Process mapping is utilized to help develop a picture of the process or operation being examined for pollution prevention. Resolving the differences between the way different people see the process and what is actually happening is a valuable activity. A variety of mapping and other visualization techniques will be evaluated along with analogies to road maps and electrical schematic diagrams. Using process flow diagrams to help understand process functionality is at the heart of the descriptive approach to pollution prevention assessments. Conducting materials accounting and activity-based costing activities and looking at ancillary/intermittent operations using the process flow diagram as a template are skills that are required for a proper assessment.

4. February 14, 1994 CONDUCTING THE FACILITY ASSESSMENT

To conduct a successful pollution prevention assessment, one must learn to become a good EXPLORER. Utilizing prescriptive tools (i.e., checklists, worksheets and questionnaires) for conducting assessments have many problems associated with them. Process flow diagrams and materials accounting are the keystone of a descriptive approach to pollution prevention. It is important that the facility assessment identify all the losses from the process or operation. Documentation of the assessment will be discussed.

5. February 23, 1994 DEVELOPING POLLUTION PREVENTION OPPORTUNITIES (Wednesday)

An ARTIST takes information gathered from the assessment and uses graphical techniques to present the data and find trends. Every loss identified in the assessment is an opportunity not to have that loss. A variety of quality improvement tools can be used to describe the opportunity and to qualify which opportunities are most important. Criteria for screening and various techniques for prioritizing the opportunities will be explored.

6. February 28, 1994 PREPARING FOR THE FEASIBILITY STUDY

Avoiding the search for "right answers" is the key to proper preparation for a feasibility study. Use of brainstorming, storyboarding, mindmapping, and computer simulation are important to derive as many alternatives for each pollution prevention opportunity selected to study. Categories of alternatives that will be discussed include the following: operating practices, materials substitution, process/product change and recycle/reuse. The importance of creative thought in this activity will be emphasized.

7. March 7, 1994 CHARACTERIZING THE ALTERNATIVES

Operating practices are often referred to as the "low hanging fruit" of pollution prevention. These are the easiest alternatives to implement and may often lead to the largest increments of reduction. Materials substitution is most frequently utilized by industry to move from listed regulated materials to unlisted materials. There are many cases where the substitute causes unanticipated problems or simply shifts the media of the lost material. Process change can range from equipment modification and process automation to quantum leaps in the manner in which an item is manufactured. Industrial ecology is a term used to examine the concept of recycling. There is often an overlap between recycling and treatment. Information resources will be explored.

8. March 14, 1994 MID-TERM EXAMINATION

9. March 21, 1994 NO CLASS----SPRING BREAK-----

10. March 28, 1994 CONDUCTING THE FEASIBILITY STUDY

Conducting the feasibility study is like being a JUDGE. Considering the specifics in each case is important. Criteria for screening alternatives will include effectiveness, implementability, and cost. Pollution prevention evaluations must avoid the use of "killer phrases." A more detailed analysis of the primary alternatives will consider engineering economics and institutional considerations. The need for bench and pilot testing must be determined at this time. All this activity will help establish a successful implementation program.

11. April 4, 1994 PLANNING FOR IMPLEMENTATION

Using continuous improvement and strategic planning concepts are important to get everybody moving in the same direction. A good plan will have measurements built into the implementation process. Benchmarking is often utilized in this planning effort. It is very important that the plan fit the culture of the firm. Regulations may have different planning requirements. Perhaps there is a way to have one plan and meet varied externally applied requirements.

12. April 11, 1994 IMPLEMENTATION

Implementing the alternatives selected in the feasibility study is often like being a WARRIOR. Instead of having to fight to get something implemented, teamwork, program integration, and proper preparation should help facilitate project and program implementation. Means for sustaining pollution prevention programs and leveraging them with other

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management initiatives is quite important to maximizing the benefits associated with pollution prevention.

13. April 18, 1994 — NO CLASS

14. April 25, 1994 — DESIGN FOR X

It is always preferable to design pollution prevention into new processes and products. The "X" can stand for the following terms: environment, recyclability, disassembly, remanufacturability, reliability, durability, etc. These terms have been in use for a long time and are all related to one another. Problems with retrofitting and justifying the costs of capital improvements will be explored. Life cycle impacts of these changes will be discussed. **Note: The term papers will be due on this date.**

15. May 2, 1994 — PLANTS OF THE FUTURE

Each of the important lessons learned in this course will be utilized to conjecture on the design of future facilities. The concept of breakthrough technologies will be explored. Roles of government, academia, industry and the investment community in moving in this direction will presented. Programs which currently exist to look at this issue will be evaluated. **Note: Course evaluation forms will be completed during this class.**

COURSE INFORMATION

Textbooks. There are four texts: "A Kick in the Seat of the Pants" by Roger von Oeck (ISBN 0-06-096024-8 pbk.); "21st Century Manufacturing" by Thomas G. Gunn (ISBN 0-88730-546-6); "Facility Pollution Prevention Guide," EPA/600/R-92/088, 1992; and "Guides to Pollution Prevention-The Paint Manufacturing Industry," EPA/625/7-90/005, 1990.

Additional reading materials will be handed out each week in class or be placed in reserve reading in the departmental library.

Class Schedule. Each class will begin promptly at 6:30 p.m. on the dates indicated above and will end at 9 p.m.

Grading. Each student will receive a letter grade based on the following components:

1. Mid-term examination = 40%
2. Term project = 50%
   - Group Report = 33%
   - Individual Report = 67%
3. Classroom Participation = 10%

Office Hours. Dr. Pojasek will be available one hour before every class, i.e., 5:30 to 6:30 p.m. He is also available by appointment and by telephone during the normal business day at the following location:

GEI Consultants, Inc.
1021 Main Street
Winchester, MA 01890
(617) 721-4097 (Voice Mail)
(617) 721-4073 (Fax)

CE-176 POLLUTION PREVENTION MANAGEMENT

Catalog Description

Rather than designing water, air and waste treatment facilities, engineers are often asked to help prevent the generation of these wastes. Tools for understanding, communicating and managing industrial manufacturing processes are presented using actual cases. Practical problem-solving methodologies are incorporated using a rigorous engineering framework of problem assessment, data management, feasibility and implementation. Senior standing and engineering or physical science background. Pojasek. Spring.

Rationale

Using a pollution prevention project in a designated manufacturing facility, allows students to exploit the knowledge they have learned about pollution prevention methods. Creative problem-solving and total quality management procedures are introduced in the context of pollution prevention. The course includes examples of changing operating practices, materials substitution, process/product changes and recycling. The proper use of the engineering method for planning and implementing pollution prevention is stressed.

This is an elective course in both the Hazardous Materials Management program and the Environmental Engineering M.S. programs in the Department of Civil and Environmental Engineering. As of December 1993, this course has been offered five times as CE-194J Pollution Prevention.

Industrial Engineering and Operations Research
NATIONAL POLLUTION PREVENTION CENTER FOR HIGHER EDUCATION

Hazardous Material/Waste Management

Wayne C. Turner
INDEN 5943, Spring 1994
Oklahoma State University

INDEN 5943

HAZARDOUS MATERIAL/WASTE MANAGEMENT

SPRING 1994

CATALOG DESCRIPTION

Management of hazardous materials and waste by the generator to reduce operating costs and protect employees. Emphasis on hazardous communication program, reducing volume and toxicity, and management activities.

PREREQUISITES

INDEN 3503, CHEM 1515 or equivalent

TEXT

Several sources of reference will be used but the primary text is:

Handbook on Hazardous Materials Management, Edited by Tom Carson and Doye Cox, Institute of Hazardous Materials Management, Fourth Edition, 1992, Rockville, MD.

REFERENCES

- Code of Federal Regulations, Volumes 29, 40, 49 and others as needed, U.S. Government Printing Office.

- Turner, W. C., Text material developed for extension courses over the last 10 years at OSU.

- Serious Reduction of Hazardous Waste For Pollution Prevention and Industrial Efficiency, Congress of the United States, U.S. Government Printing Office.

- Huisingh, Donald, Vicki Bailey, Making Pollution Prevention Pay, Pergamon, New York, NY 1982.

- Overcash, Michael R., Techniques for Industrial Pollution Prevention, Lewis Publishers Inc, Chelsae, Michigan, 1986.

- Blakeslee, H. William, et.al., A Practical Guide to Plant Environmental Audits, Van Nostrand Reinhold, New York, NY 1985.

- Noll, Kenneth E., et.al. Recovery, Recycle and Reuse of Industrial Waste, Lewis Publishers Inc., Chelsae, Michigan, 1985.

- Tavlarides, Lawrence L., Process Modifications for Industrial Pollution Source Reduction, Lewis Publishers Inc., Chelsae, Michigan, 1985.

COURSE OBJECTIVES

Upon completion of the course, the student should be able to

- design, implement, and manage a hazard communication program including employee and community "right to know"
- design, implement, and manage a hazardous material/waste Volume and toxicity reduction program.
- prepare contingency plans, training programs, record keeping systems, and management structure for a comprehensive hazardous material/waste management program.
- deal effectively (from a generator viewpoint) with all state, federal, and local regulation agencies.

COURSE OUTLINE	PERCENT TIME
o Hazardous Material/Waste Perspective significance of the problem, impact on industry and commerce, cost reduction potential	5%
o Hazard Communication Program Employee and Community Right to Know, training, record keeping, management review, labeling	20%

- **Hazardous Waste Management** — 35%
  Definition of hazardous waste, volume in industry, Federal and State regulations, coordination, record keeping, transportation, route selection, choosing transporters and disposal facilities, trends

- **Reducing Volume and Toxicity** — 15%
  Objectives, product redesign, process redesign, management systems, decision model, "True Cost" model, industrial process resource recovery

- **Management Systems Review** — 10%
  Review of program, coordination, dealing with regulations agencies, avoiding duplication

- **Plant Tours, Outside Speakers, Test** — 10%
  Industrial Engineering consultants talk about opportunities in industry, tours of successful operations

INDEN 5943

HAZARDOUS MATERIAL/WASTE GENERATION MANAGEMENT

INSTRUCTOR::
W. C. Turner, PhD, PE
318 Engineering North
Industrial Engineering
Oklahoma State University
(405) 744-6055

GRADUATE ASSISTANT:

OFFICE HOURS: ____________ ________________

CLASS HOURS: Stillwater (TO BE DETERMINED)

Tulsa Monday 4:30-7:15 P.M.
(with 1-15 minute break)

SYLLABUS: See attached

			TOTAL
GRADING:	Two Tests @	25%	50%
	1 Term Paper	20%	20%
	Homework-Presentation	10%	10%
	Exam	20%	20%

Tests will be one hour in length and in class; but I retain the right to give a take home test if I feel it's best.

Term Paper: Topic must be agreed upon in advance. Paper should be of graduate level and written accordingly, (spelling, grammar, etc. will be graded). e.g. "Waste Management Plan for ACDZ Co."

Presentation-Homework: In addition, you will research into one topic (normally same topic as term paper) of general interest to the class and make a 10 minute presentation. You will be graded on the use of visuals, etc. (I want a copy of your visuals.)

Text: Handbook on Hazardous Materials Management: Edited by Tom Carson and Doye Cox, Institute of Hazardous Materials Management, Fourth Edition, 1992, Rockville, MD.

In addition, I will have 1 or 2 sets of my transparencies and actual regulations at UCT (OSU office) and in Industrial Engineering 322 Engineering North (Stillwater). You may xerox these or simply use as necessary by dropping by the office. **You may not take them home.**

For Spring 1994, I will have an abbreviated set available to you for $10.00 each. Please make checks out to "Industrial Engineering". I will bring them each week. First week is "on the house".

WEEK OF	SUBJECT	ASSIGNMENTS Dr. Turner's Transparencies and Reading From Text Shown Below
January 10	Introduction & Basics	P59-82,179-186,187-194,195-204 213-228,229-249,249-265,265-272,285-296, (1st & 3rd week)
January 17	Introduction & Basics UCT will have a short meeting September 8 to make up Labor Day	
January 24	Practices & Procedures	P83-122
*January 31	Chemistry - Radiation **BRING SCIENTIFIC CALCULATOR TO CLASS**	P1-55
**February 7	Practices and Procedures	P83-122, P273-284
February 14	(TEST 1) Employee Right to Know	P175-178
February 21	Community Right to Know	P205-212
February 28	Transportation	P145-174
March 7	**Spring Break**	
March 14	Transportation Choosing	P145-174
March 21	Choosing Transporters, Disposal Options, Disposal Sites	P113-122, P389-406
March 28	Spill Prevention & Control	P305-370 (Misc. Reading)

April 4	(TEST 2) Environmental Audits (Operations)	P371-378
April 11	Environmental Audits (Operations) (Real Estate)	P407-454
***April 18	Hazardous Material/Waste Tank Management	
April 25	Reducing Volume & Toxicity	P297-304, P379
May 2	EXAM - Tulsa	

* Talks Begin
** Topics Chosen
*** Papers Due (FIRM) - 5 points off each day late

GRADING OF TERM PAPERS

1) Choice of Subject — Maximum <u>10 points</u>

2) Grammar, Spelling — Maximum <u>25 points</u>

3) Report Structure — Maximum <u>25 points</u>

   Abstract, Table of Contents,
   List of Tables & Figures, Bibliography - format, overall appearance of report, conclusions

4) Report Content — Maximum <u>40 points</u>
   Development of Subject, flow, closure, amount of research, content of Bibliography

///

TERM PAPER SUPPLEMENT

* Please note the grading on format (#3 25 pts)

I believe it's important to have a properly structured paper. Thus,

Abstract	5 pts.
Table of Contents	5 pts.
Format of Bibliography	5 pts.
Conclusions - Summary	5 pts.
Overall Appearance	5 pts.

* On grammar and spelling I will deduct 4 points each mistake up to the maximum of 25 points.

* On choice of subject, you must tell me why it's appropriate for you in this course. You must do this in a separate memo to me that is turned in with the report.

Remember we are studying how to be better managers of hazardous materials/waste in operating entities (hospitals, manufacturing plants, schools, etc.) You then must address this in your argument.

Industrial Engineering and Operations Research

NATIONAL POLLUTION PREVENTION CENTER FOR HIGHER EDUCATION

Hazardous Material/Waste Management

Wayne C. Turner

INDEN 5943, Spring 1994

Oklahoma State University

National Pollution Prevention Center for Higher Education • University of Michigan
Dana Building, 430 East University, Ann Arbor MI 48109-1115
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  Industrial Engineering consultants talk about opportunities in industry, tours of successful operations

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January 24	Practices & Procedures	P83-122
*January 31	Chemistry - Radiation BRING SCIENTIFIC CALCULATOR TO CLASS	P1-55
**February 7	Practices and Procedures	P83-122, P273-284
February 14	(TEST 1) Employee Right to Know	P175-178
February 21	Community Right to Know	P205-212
February 28	Transportation	P145-174
March 7	Spring Break	
March 14	Transportation Choosing	P145-174
March 21	Choosing Transporters, Disposal Options, Disposal Sites	P113-122, P389-406
March 28	Spill Prevention & Control	P305-370 (Misc. Reading)

April 4	(TEST 2) Environmental Audits (Operations)	 P371-378
April 11	Environmental Audits (Operations) (Real Estate)	P407-454
***April 18	Hazardous Material/Waste Tank Management	
April 25	Reducing Volume & Toxicity	P297-304, P379
May 2	**EXAM - Tulsa**	

* Talks Begin
** Topics Chosen
*** Papers Due (FIRM) - 5 points off each day late

GRADING OF TERM PAPERS

1) Choice of Subject — Maximum 10 points

2) Grammar, Spelling — Maximum 25 points

3) Report Structure — Maximum 25 points

   Abstract, Table of Contents,
   List of Tables & Figures, Bibliography - format, overall appearance of report, conclusions

4) Report Content — Maximum 40 points
   Development of Subject, flow, closure, amount of research, content of Bibliography

TERM PAPER SUPPLEMENT

* Please note the grading on format (#3 25 pts)

I believe it's important to have a properly structured paper. Thus,

Abstract	5 pts.
Table of Contents	5 pts.
Format of Bibliography	5 pts.
Conclusions - Summary	5 pts.
Overall Appearance	5 pts.

* On grammar and spelling I will deduct 4 points each mistake up to the maximum of 25 points.

* On choice of subject, you must tell me <u>why it's appropriate for you in this course</u>. You must do this in a separate memo to me that is turned in with the report.

Remember we are studying how to be better managers of hazardous materials/waste in operating entities (hospitals, manufacturing plants, schools, etc.) You then must address this in your argument.

Industrial Engineering and Operations Research

NATIONAL POLLUTION PREVENTION CENTER FOR HIGHER EDUCATION

Environmental Science and Public Policy: Reducing Industrial Wastes

William Clark and Robert Frosch
ESPP 98/ENR 204, Spring 1994
John F. Kennedy School of Government, Harvard University

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John F. Kennedy School of Government
Harvard University

MEMORANDUM

March 8, 1994

To: ESPP98 / ENR204 Students

From: Bill Clark, Bob Frosch (L-360; 5-3981)

Subject: **The Commission on Managing the Industrial Ecosystem**

As an exercise to explore the intersection of environmental science and public policy, and as a vehicle for development of your term papers, you will serve for the remainder of this term on a (simulated) Commission on Managing the Industrial Ecosystem. The purpose of this note is to set forth the terms of reference for the Commission and its schedule of tasks. [In fact, three Commissions have been established, each with an identical charge. You will conduct your work and report out your results in parallel.]

Convenor: The Commission has been convened by the New England Governors' Council, a bi-partisan coalition of Governors from each of the region's states.

Motivation: Three factors have motivated the Governors to establish the Commission:

* First, business, state and local governments and environmental groups alike have been expressing increasing dissatisfaction with the current management system. Regulations have grown increasingly complex, costs of waste disposal are rising, and yet many citizens do not feel that they are being protected from risks associated with industrial wastes.

* Second, experience with some product lines (eg. automobiles) and some policy experiments abroad (eg. Germany's takeback requirements) have led the Governors to believe that radical improvements in the management of the region's industrial ecosystem might in fact be accomplished.

* Third, the upcoming review of Federal legislation pertaining to industrial wastes provides an opportunity for the states to help shape the national policy within which the management of New England's industrial ecosystem is embedded.

Charge: The Commission has been charged by the Governors with developing a vision of how the region's industrial ecosystem should evolve into the next century.

Consistent with their commitment to an economically vibrant and environmentally responsible future for New England, the Governors seek an inspiring but realistic set of goals to guide the evolution of the industrial ecosystem, and a strategy laying out the most important actions needed to implement those goals. The Governors are unanimous in their conviction that government alone can not do the job. They therefore have instructed the Commission to consider actions needed from the private and non-governmental, as well as public sectors. They want a short, hard-hitting, but authoritative report on which they can base a region-wide campaign of education, research and development, monitoring, legislation, and corporate action. The Commission is invited to address any or all of these dimensions of industrial ecology problems and opportunities.

Composition: In keeping with the charge outlined above, the Governors have appointed Commission members (ie. you) representing the public, private, and non-governmental sectors. A distinguished and nonpartisan public servant has been asked to chair the Commission.

All members have been asked to serve in their individual rather than institutional capacities. The Governors are clearly hoping for a report that accommodates the views of, and can thus be endorsed by, the wide range of constituencies represented in the Commission's membership. A list of Commission members is appended to this note.

The work of the Commission: The Commission will produce 3 major products:

1) Final report (Summary only): The Commission will produce a 10 page Executive Summary of its findings. This will include, inter alia, a restatement of the charge, a diagnosis of the present situation and prognosis for the future, and a statement and defense of recommendations. Recommendations can entail actions on the part of all sectors of society. At the Commission's discretion, they may entail both direct interventions in the flow of industrial materials, and the building of capacity through research and monitoring programs, the design of institution, or the conduct of educational programs. Keep in mind, however, that the Summary report should highlight only the most important strategic initiatives that the Commissioners believe should receive priority attention from the Governors. Laudry lists will not be appreciated. The final report summary, as presented to the Governors, should be produced and approved jointly by the Commission members. It should not exceed 10 pages (4000 words) in length.

2) Staff papers -- the Commission's list: Like virtually all Commissions, this one will need to procure a number of technical staff papers to support its analysis and recommendations. The Commission as a whole will be required to develop a list and short (ie. less than 200 words) "abstract" of the 10 staff papers it judges most important to its work. Some of the abstracts will be produced by individual Commission members as part of their own work for the Commission (see below). Others will have to be prepared on an ad hoc basis by the Commission as a whole. Each abstract should convey why the paper has been selected for priority attention by the Commission.

3) Staff papers -- individual contributions: In addition, each Commission member will be responsible for preparing one staff (ie. term) paper in full. (Actually, Commission members may collaborate in groups of 2 or 3 in producing their staff papers,

upon approval of the Governors). These papers should provide background for and help to illuminate the work of the Commission. Final drafts should be about 12,000 words in length (and not more than 16,000).

In carrying out its work, the Commission should strongly consider addressing the following issues:

1) What should be the goals of the region's industrial ecosystem? What are we trying to accomplish?

2) What kinds of changes in technologies, institutions, behavior and knowledge are needed to meet these goals? In particular: What should government do? What should industry do? What should environmental groups do?

A possible approach to these questions would be to begin with the Commissioners representing the industrial sector proposing what industry should do, those from government proposing what government should do, etc. The Commission could then move on to examine, as a group, the "systems" consequences of each sector's proposed actions. Finally, it could move from this analysis to a specification of what additional actions are needed in order that overall goals are achieved.

Schedules and Procedures: Three formal meetings of the Commission have been scheduled, together with a number of briefings by outside experts and a site visit to an industry wrestling with industrial ecology challenges. Additional working sessions of the Commission will almost certainly be necessary, and should be arranged and scheduled as needed by the Commission members. Scheduled meetings are summarized immediately below, and discussed in more detail in the following paragraphs. Unless otherwise noted, all meetings and briefings take place in Hoffman Lab from 1-3pm:

Summary Schedule:

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[Term paper prospectus due]
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April 12: Expert witnesses: topics defined by Commission
April 19: Expert witnesses: topics defined by Commission
April 26: Final Report of Commission presented to Governors
May 3: Response of Governors to Commission
May 17 (5pm): Supporting papers due

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Formal Commission Meetings:

1) Final presentation: Presentation of final report to Governors (April 26): At that time, the Commission will deliver a 20 minute oral presentation, backed by a 10 page written Summary, abstracts (ca. 300 words each) of all 10 staff papers requested by the Commission, and copies of any presentational materials. Questions and comments from the Governors will begin then and continue a week later. Staff (ie. term) papers requested by the Commission should be drawn on in this presentation, and abstracts should be presented with the Executive Summary. Final drafts of the full papers are not due with the Governors until 5pm on May 17.

2) First meeting: The first formal meeting of the Commission is scheduled for March 8. The Governors will welcome the Commissioners and give them their formal charge. Commission members will be introduced to each other. A schedule of subsequent meetings and task assignments will be developed by the Commission;

3) Progress report (mid-term) meeting: A report on the Commission's progress is due to the Governors on April 5. This should include:

a) a written outline of the planned report (less than 3 pages);

b) a written list of the 10 most important staff papers chartered by the Commission, with a paragraph justifying each and reporting on its status (ie. being developed by a Commission member, or sought from the existing literature);

c) an oral presentation (less than 15 minutes) of the above.

Briefings: The Commission will receive a number of informal briefings from relevant experts in the course of its work:

1) In anticipation of their appointment to the Governors' Commission, most members have been attending over the past month a series of informal technical briefings on industrial ecology run by Dr. Robert Frosch of the National Academy of Engineering (February 15 and 21, and March 1).

2) Economic and regulatory dimensions of industrial waste management will be addressed by expert witnesses to the Commission on March 15.

3) Briefings on other topics, or more detailed discussions of topics already touched on, may be requested by the Commission in the course of its work.

Written submissions: Several written submissions are expected from the Commission as a whole and from its individual members:

1) By the Commission as a group:

a) April 5: Accompanying the oral presentation of its progress report, the Commission will submit i) a written outline of the planned report, stating what topics will be covered with what approach (less than 3 pages); ii) a written list of the 10 most important staff papers chartered by the Commission, with a paragraph justifying each and reporting on its status (ie. being developed by a Commission member, or sought from the existing literature).

b) April 26: Accompanying the oral presentation of the final report, the

Commission will submit i) a 10 page Summary of its findings and recommendations; ii) abstracts (ca. 300 words each) of all 10 staff papers requested by the Commission, whether these are written by Commission members or drawn from the existing literature; and iii) copies of any presentational materials. [Note that the full report of the Commission is indeed a fiction and need not be written].

2) By individual Commission members:

a) March 22 (10am): A one page prospectus for each member's "staff" (ie. term) paper must be turned in for discussion with and approval by faculty.

a) April 5: An extended (ca. 5 pages) outline of each member's "staff" (ie. term) paper must be submitted in class. This should include a 1-pg. draft Executive Summary of the paper, and the identification of major sources of information (ie. principal articles, data sets, or interviews) on which the final report will be based.

b) May 17: A final draft of each member's "staff" (ie. term) paper must be submitted by 5pm. [Target ca. 12,000 words; must be less than 16,000].

--- Finally, back in the world... ---

Grading: Grading for the course will be based on individual and group participation [40%], the extended outline of the term paper [10%], and the final draft of the term paper [50%].

In fairness to others in the class, late submissions of the written material will be penalized at a rate of 20% of the submission's value per day (eg. a final paper presented one day late will receive at most a weight of 40 out of 100 points to the final grade).

Participation grades will be informed by anonymous rankings of individual contributions to the Commission's work provided by each Commissioner's peers in his/her group. Rankings will be performed in class after the Progress Report presentation and again after the Final Report presentation.

SAMPLE TOPICS FOR STAFF PAPERS

* The current industrial structure of the region.
* A vision for the future industrial structure of the region.
* The current uses and flows of materials in the region. (Possibly for some particular material or materials.)
* Desirable/proposed changes in the uses and flows of materials in the region. (Possibly for some particular material or materials.)
* Waste disposal and pollution problems of the region.
* The current regulatory system for industrial waste in the region.
* Alternative possibilities for pollution prevention and the regulation of industrial waste in the region.
* An economic incentives system for waste minimization. (Waste prevention, waste reuse.)
* Are scrap and waste materials an asset or a liability for industrial competitiveness?

ESPP98 / ENR204 -- Spring 1994

Environmental Science and Public Policy: Reducing industrial wastes

T 1:00-3:00 -- Hoffman Lab Penthouse (Adjoins Peabody Museum)
[LIMITED ENROLLMENT: All interested attend first session]

Syllabus (January 25, 1994)

1 Introduction to the course
Outlines the objectives, approach and expectations of the course. Sketches a framework for analysis of public policy interface with technical dimensions of waste production and management. Substantive discussion focuses on a number of paradoxes of waste reduction efforts, summarized in a handout.

Part I: Science and engineering issues

2 Waste production: An overview
Provides an overview of the waste production problem, distinguishing flows associated with raw material acquisition, industrial production, and end use consumption. Introduces typology of recoverable vs dissipative material flows. Illustrates trends with time, and across countries.

3 Waste flows from a product life cycle perspective: The case of the modern automobile
Examines the material flow, waste and recovery streams inherent in production and use of the automobile. Case selected as an illustration of a relatively well-integrated product cycle in which a high fraction of wastes have either been eliminated through green design or are recovered for reuse.

4 Waste flows from a regional perspective: The case of cadmium in the Rhine Basin
Develops a systems perspectives on the multiple sources, pathways, and sinks for a single industrial chemical (cadmium) in a large river basin. Traces changes through time on the relative importance of production- and consumption-related sources of the waste stream.

Part II: Policy Perspectives

5 Economic dimensions of industial waste reduction
Examines the economic dimensions of the industrial waste problem. Includes discussion of relative costs of alternative waste reduction, disposal, and recycling technologies, pricing of externalities associated with

waste, and impact of on waste treatment of liability rulings.

6 Legal and regulatory dimensions of industrial waste reduction

Explores the impacts of alternative legal definitions of industrial wastes and hazards. Considers the unintended consequences of current regulations for industrial ecology.

7 Organizational intelligence for waste reduction

Considers the role of information and non-economic incentives in waste reduction. Special attention paid to the utility of regional electronic "clearing houses" for waste producers and users, such as proposed by the Chicago Board of Trade. Looks at role of accounting and reward structures within corporations for encouraging innovations in waste reduction.

Part III: A field study in industrial waste reduction

The class will study in depth the waste management problems and prospects of a major manufacturing company in the Boston area. The study will involve a visit to the company, as well as discussions with key staff.

8 Introduction to wastes in the XX Company

Senior official from XX provides an overview of waste problems and management efforts at the Company.

9 Site visit to XX Company

Class visits XX, observes general flow of materials, conducts small group interviews with relevant officials concerning efforts at, opportunities for, and obstacles to waste reduction.

10 Analysis of site visit experience

Student teams report on data gathered on Company XX. Class discussion of prospects for improvements, plus relative importance of economic, regulatory, information barriers to improvements in performance.

Part IV: A Massachusetts Commission on Industrial Waste Reduction

The major class exercise will be a simulation of a governor's advisory commission on public policies to enhance waste reduction in Massachusetts' industries. Class members will be broken into groups and given their charge as commission members early in the term. Subsequent meetings, in and out of class, will pave the way for presentation and discussion of the commission's findings.

11 Presentation of Commission findings in class
Teams will present their findings to the class and answer questions from a panel of critics.

12 Retrospective on Commission findings and the prospects for reducing industrial wastes.

Industrial Engineering and Operations Research

NATIONAL POLLUTION PREVENTION CENTER FOR HIGHER EDUCATION

Environmental Science and Public Policy: Reducing Industrial Wastes

William Clark and Robert Frosch
ESPP 98/ENR 204, Spring 1994
John F. Kennedy School of Government, Harvard University

[illegible]

John F. Kennedy School of Government
Harvard University

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March 8, 1994

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ESPP98 / ENR204 -- Spring 1994

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[LIMITED ENROLLMENT: All interested attend first session]

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Part II: Policy Perspectives

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Examines the economic dimensions of the industrial waste problem. Includes discussion of relative costs of alternative waste reduction, disposal, and recycling technologies, pricing of externalities associated with waste, and impact of on waste treatment of liability rulings.

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Explores the impacts of alternative legal definitions of industrial wastes and hazards. Considers the unintended consequences of current regulations for industrial ecology.

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Teams will present their findings to the class and answer questions from a panel of critics.

12 Retrospective on Commission findings and the prospects for reducing industrial wastes.

Industrial Engineering and Operations Research

NATIONAL POLLUTION PREVENTION CENTER FOR HIGHER EDUCATION

Pollution Prevention

Robert B. Pojasek
CE-194J, Spring 1994
Tufts University

National Pollution Prevention Center for Higher Education • University of Michigan
Dana Building, 430 East University, Ann Arbor MI 48109-1115
Phone: 313.764.1412 • Fax: 313.936.2195 • E-mail: nppc@umich.edu

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Department of Civil/Environmental Engineering
TUFTS UNIVERSITY

Spring 1994

CE-194J Pollution Prevention
Instructor: Dr. Robert B. Pojasek

COURSE DESCRIPTION

Rather than designing water, air, and waste treatment facilities, engineers are often asked to help prevent the generation of these wastes. Tools for understanding, communicating, and managing industrial manufacturing processes are presented using actual cases. Practical problem-solving methodologies are incorporated using a rigorous engineering framework of problem assessment data management, feasibility study, and implementation.

This is a "hands-on" course where the student will learn by actually working on a pollution prevention project. In lieu of a final examination, the student will work in a small group to evaluate a designated manufacturing facility. Together they will prepare process flow diagrams, materials accounting summaries, a description of all of the opportunities for pollution prevention, and a rank ordering of these opportunities. Each student in the group will then research one of the primary opportunities, conduct a feasibility study, and make recommendations for implementation. Using a pollution prevention project in an actual facility allows students to exploit the knowledge they have learned about pollution prevention methods. Creative problem-solving and quality improvement procedures are introduced in the context of pollution prevention. The course includes examples of changing operating practices, materials substitution, process/product changes and recycling/reuse. Proper use of the engineering method for planning and implementing pollution prevention is stressed.

COURSE SCHEDULE

1. January 24, 1993 INTRODUCTION TO POLLUTION PREVENTION

Without dwelling extensively on the terminology and definitional problems that currently exist in this emerging field, some generic pollution prevention theories and concepts will be presented. These concepts will include chemical use cycles, the waste management hierarchy, shifting media, materials use and loss control, efficiency concepts, and broader concepts of sustainable development. Incentives and impediments to the use of pollution prevention practices in industry will be examined along with pressures that have been brought to bear to induce facilities to utilize these practices. No attempt will be made to examine specific pollution prevention legislation or regulations.

2. January 31, 1994 UNDERSTANDING MANUFACTURING AND MANAGEMENT

Emphasis in this course is placed on pollution prevention in manufacturing. All manufacturing categories have commonalities which, when recognized, allow the pollution prevention practitioner to apply the concepts described in the previous class without regard to the type of industry. Consideration must be given to the product life cycles and the supplier/customer connections. The manner in which manufacturing is managed is a key to the successful implementation of pollution prevention. Understanding the culture of the organization is very important. Analogous management programs (such as quality improvement, just-in-time and computer integrated manufacturing) will be discussed along with a model for manufacturing for competitive advantage in a global marketplace.

3. February 7, 1994 PREPARING FOR AN ASSESSMENT

Process mapping is utilized to help develop a picture of the process or operation being examined for pollution prevention. Resolving the differences between the way different people see the process and what is actually happening is a valuable activity. A variety of mapping and other visualization techniques will be evaluated along with analogies to road maps and electrical schematic diagrams. Using process flow diagrams to help understand process functionality is at the heart of the descriptive approach to pollution-prevention assessments. Conducting materials accounting and activity-based costing activities and looking at ancillary/intermittent operations using the process flow diagram as a template are skills that are required for a proper assessment.

4. February 14, 1994 CONDUCTING THE FACILITY ASSESSMENT

To conduct a successful pollution prevention assessment, one must learn to become a good EXPLORER. Utilizing prescriptive tools (i.e., checklists, worksheets and questionnaires) for conducting assessments have many problems associated with them. Process flow diagrams and materials accounting are the keystone of a descriptive approach to pollution prevention. It is important that the facility assessment identify all the losses from the process or operation. Documentation of the assessment will be discussed.

5. February 23, 1994 DEVELOPING POLLUTION PREVENTION OPPORTUNITIES
(Wednesday)

An ARTIST takes information gathered from the assessment and uses graphical techniques to present the data and find trends. Every loss identified in the assessment is an opportunity not to have that loss. A variety of quality improvement tools can be used to describe the opportunity and to qualify which opportunities are most important. Criteria for screening and various techniques for prioritizing the opportunities will be explored.

6. February 28, 1994 PREPARING FOR THE FEASIBILITY STUDY

Avoiding the search for "right answers" is the key to proper preparation for a feasibility study. Use of brainstorming, storyboarding, mindmapping, and computer simulation.