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Full Report: Assessment and Opportunity Identification of Energy Efficient Pollution Prevention Technologies and Processes

Prepared in Response to Section 2108 subsections (b) and (c) of the Energy Policy Act of 1992

Prepared by
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Data gathering and report preparation occurred from May to August 1993. This report responds to Section 2108, subsections (b) and (c), of the Energy Policy Act of 1992. This is the full report and includes the data collected from that effort (SAND94-2568). In addition, a report summarizing all of the findings of this full report is available (SAND93-2122). Since this work was completed, a report that responds to Section 2108 subsection (a) has been drafted. Information about this later report is available from Mr. Bruce Cranford, DOE/OIT/EE-22.

This volume contains background information in support of a report to Congress responding to the National Energy Policy Act (EPAct) Section 2108.

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EXECUTIVE SUMMARY

U.S. industry produces about 12 billion tons of waste a year, or two-thirds of the waste generated in the U.S. The costs of handling and disposing of these wastes are significant, estimated to be between $25 and $43 billion in 1991, and represent an increase of 66% since 1986. U.S. industry also uses about one-third of all energy consumed in the nation, which adds to the environmental burden. Industrial wastes affect the environmental well-being of the nation and, because of their growing costs, the competitive abilities of U.S. industry. As part of a national effort to reduce industrial wastes, the U.S. Congress passed the Energy Policy Act (EPAct, P.L. 102-486). Section 2108, subsections (b) and (c), of EPAct requires the Department of Energy (DOE) to identify opportunities to demonstrate energy efficient pollution prevention technologies and processes; to assess their availability and the energy, environmental, and cost effects of such technologies; and to report the results. Work for this report clearly pointed to two things, that there is insufficient data on wastes and that there is great breadth and diversity in the U.S. industrial sector. This report identifies:

- information currently available on industrial sector waste streams,
- opportunities for demonstration of energy efficient pollution prevention technologies in two industries that produce significant amounts of waste—chemicals and petroleum,
- characteristics of waste reducing and energy saving technologies identifiable in the public literature,
- and potential barriers to adoption of waste reducing technologies by industry.

Industrial Waste Generation and Energy Use

Data obtained indicated that seven industries account for the vast majority of industrial waste generation, energy usage, and economic burden of pollution abatement. These seven industries—agriculture; mining; pulp and paper; chemicals; petroleum; stone, clay, and glass; and primary metals—are the focus of this report and collectively account for:

94% of nonhazardous wastes
94% of energy consumption
73% of toxic releases
95% of hazardous wastes
92% of air pollutants
67% of pollution abatement costs

Opportunities for the Demonstration of Energy Efficient Pollution Prevention Technologies and Processes

Opportunities for demonstration of energy efficient pollution prevention technologies and processes will continue to be identified by DOE. To date, such opportunities have been identified for the chemical and petroleum industries—two waste-producing and energy-using industries. Generation of wastewater was the overriding theme of the opportunity sets identified in both industries. Emissions to the air were another common concern cutting across both industries.

Petroleum Industry Waste Reduction Demonstration Opportunities *(Ranked by Importance of Federal Role)*	Chemical Industry Waste Reduction R&D Opportunities
1. Toxic Air Emissions 2. Locating Orphan Wells 3. Wastewater Management 4. Advanced Geophysical Diagnostics 5. Oil/Water Emulsion Breaking 6. Spent Catalyst Reuse 7. Dry Hydrogen Sulfide Adsorption	• Separation of dilute organics from water • Alternative in-process separation techniques for organic/inorganic/aqueous solutions • Emission control of dilute volatile organic compounds • Total water reuse • Low-cost sorbent regeneration process • Post consumer recycling, upgrading, and separation

Assessment of Technologies

A search of the open literature for waste reduction technologies in the seven industry sectors targeted revealed 590 specific technologies with positive waste reduction impacts. The chemical industry accounted for most of them (156), followed by the petroleum industry (130), primary metals (101), paper and pulp (85), agriculture (58), mining (34), and stone, clay and glass (26). Most of the technologies (87%) involved process redesign, in-process recycling, and increasing operational efficiencies. Only 3% of the technologies involved changes in the product itself. About two-thirds of the technologies did not have associated quantitative data on energy use, associated costs, or amount of waste reduction.

Of the 590 technologies, 489 appear to be in broad use within industry. The technologies that are already in use as well as the remaining 101 under development all tend to be very specific to a given industry. Very few (27) of the technologies included information on energy use, suggesting that the importance of the energy savings resulting from waste reduction is not broadly understood. Eighty-four percent (497) of the technologies included information on specific qualitative environmental benefits to be achieved through the technology, most commonly reduction of wastes or of the hazard of the wastes. About 24% of the technologies had information on the costs of implementing waste reduction technologies, ranging from $17,000 to $400 million, and 92 technologies estimated savings totaling $190 million and averaging $2.3 million per year.

Barriers To Adoption

Finally, a brief review of the barriers to adoption of waste reduction technologies revealed the extremely complex and variant nature of a host of possible disincentives a company may face. These disincentives can be regulatory, economic, technological, organizational, or cultural, and could vary not only by industry but by individual company.

1. INTRODUCTION

1.1. PURPOSE

On October 24, 1992, the President signed the Energy Policy Act of 1992 (EPAct, Law 102-486). Section 2108, subsections (b) and (c), of the EPAct requires the Department of Energy to identify opportunities to demonstrate energy efficient pollution prevention technologies and processes; to assess the availability and the energy, environmental, and cost effects of such technologies; and to report the results within one year. This report is in response to that requirement.[1] There is a summary of this full report available. (SAND.Doc.No.)

> **Pollution Prevention/Waste Reduction/Waste Minimization**
> While distinctions can be made between these terms, for the purposes of this report they will all mean the reduction of wastes at the source, including recycling of material within the process

Section 2108, subsection (a), authorizes the DOE *to continue to carry out a 5-year program to improve the energy efficiency and cost effectiveness of pollution prevention technologies and processes, including source reduction and waste minimization technologies and processes*. National waste reduction efforts in both the private and public sectors encompass a variety of activities to decrease the amount of wastes that ultimately enter our air, water, and land. DOE's Office of Industrial Technologies (DOE/OIT) recognized the importance of these efforts and confirmed the federal government's commitment to waste reduction by establishing the Industrial Waste Program (IWP) in 1990. The program is driven by industry and national needs, and is working on new technologies and information dissemination that industry identifies as vital.

The national benefits of new technologies do not accrue to the economy until transferred to industry and incorporated into commercially available processes or products. The IWP has been designed with technology transfer in mind. Industry actively participates in both projects and program planning, thereby increasing the likelihood of commercialization and future participation. Academic participation in the IWP is also important, not only for the technical expertise of the nation's universities and colleges, but also in helping build the foundations for an intrinsic waste minimization outlook for future generations. In the relatively short time since inception, the IWP has already commercialized four significant energy efficient pollution prevention technologies that are now improving U.S. industry's productivity and competitiveness.

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[1] The Office of Technology Assessment is producing a report entitled *Industry Technology and the Environment: Competitive Challenges and Business Opportunities*, which will examine, in part, pollution prevention technology and its relationship to industrial competitiveness. This report will be released in January 1994.

EPAct Section 2108 stipulates that in preparing this response, DOE will consult with the:

- EPA
- other federal, state, or local officials the Secretary of Energy considers necessary
- representatives of appropriate industries
- members of organizations formed to further the goals of environmental protection or energy efficiency
- other appropriate interested members of the public.

Subsections (b) and (c) of Section 2108, the focus of this report, are shown in the next section. A complete copy of the EPAct Section 2108 language is provided in Appendix A.

1.2. OBJECTIVES

EPAct Section 2108, subsections (b) and (c), define the objectives of this project as:

- ***Section (b)*** - identify opportunities to demonstrate energy-efficient pollution-prevention technologies and processes
- ***Section (c1)*** - assess technologies from Section (b) to increase productivity and simultaneously reduce the consumption of energy and material resources, and the production of waste
- ***Section (c2)*** - assess the current use of such technologies by industry in the U.S.
- Determine the status of technologies currently being developed, including:
    - ***Section (c3)*** – projected commercial availability
    - ***Section (c4)*** – energy savings resulting from their use
    - ***Section (c5)*** – environmental benefits
    - ***Section (c6)*** – costs
- ***Section (c7)*** - evaluate any existing federal or state regulatory disincentives for the employment of such technologies
- ***Section (c8)*** - evaluate other barriers to the use of such technologies

This report contains five major sections, as follows.

1. The first section describes the purpose, objectives, and approach used in producing this report.
2. The second section provides:
    - a discussion of the complexities of industry as it applies to waste reduction and energy efficiency

- what is currently known about the wastes and energy usage of industry
- the rationale for selection of the seven industries studied in this project
- a brief description of the industries investigated including their products and waste streams

3. The third section contains the results of the information collection effort in the following three areas:
   a. results of the identification of opportunities for demonstration of technologies
   b. results of the literature review on waste-reduction technologies in use or under development by industry
   c. results of a review of barriers to adoption of waste-reduction opportunities by industry
4. The fourth section includes the summary findings from the work accomplished to date.
5. The last section provides various appendices with more detailed information and results relevant to specific areas in this report. The last appendix contains the references and contacts for this report divided by the major sections of the report.

1.3. APPROACH

There were three separate but integrated information collection efforts for this report. Collection of information and preparation of the report occurred between May and August of 1993.

1.3.1. Identification of Opportunities - Vital Issues Process

The process for identification and evaluation of opportunities for the demonstration of waste-reducing technologies involved the use of the Vital Issues Process developed by Sandia National Laboratories. In this process, consensus-building dialogue among key stakeholders is employed as a means to obtain information and opinions directly from industry. Careful selection of a small number of expert panelists capable of addressing topics from a crosscutting, multidimensional perspective as part of a consensus-building exercise ensures the results reflect accurately the environment in which U.S. industry must implement technological advances.

Two panels were convened. The first established a working definition of an energy-efficient pollution-prevention technology demonstration opportunity and developed a weighted set of criteria for screening possible technology demonstrations in any major industrial sector. A second panel identified and ranked candidate energy-efficient pollution-prevention technology demonstrations in the petroleum industry in accordance with the screening criteria generated by the first panel. The latter panel serves as a model for obtaining similar direct input from other selected sectors. Petroleum extraction, which is categorized in the Department of Commerce's Standard Industrial Classification (SIC) codes as mining, was included in this panel. Complete reports for both panels that include a description of the methodology are in Appendices C and D.

In addition, a workshop held before the passage of EPAct included identification of opportunities for waste reduction in the chemicals manufacturing industry. These opportunities are summarized in the technologies results section.

1.3.2. Literature Review of Technologies

EPAct directs in subsection (c) that a detailed assessment be made for the technologies identified in subsection (b). To optimize the time and resources available, the assessment to date is built on contacts with trade association members and a systematic review of the literature for pollution-prevention technologies. The information, in turn, has been evaluated relative to the criteria requested in subsection (c). This background provides insight into the current state of pollution-prevention technologies in industry and will support future efforts to identify demonstration opportunities.

The assessment of technologies with waste-reduction benefits focused on the seven industry sectors producing the most wastes. The selection of these seven is described in more detail in the overview section. Material was collected primarily by conducting a literature search and contacting trade association representatives in the targeted industrial sectors. Also, consultants, as well as individuals involved in waste-reduction programs, at universities, and in state and federal agencies knowledgeable about waste-reduction technologies were contacted. In some instances, the original contacts did not have specific waste-reduction information, but provided referrals.

The literature search included searches of INFOTRAC, ProQuest ABI-INFORM, CERAMIC ABSTRACTS CD-ROM, and AGRICOLA data bases. In addition, the U.S. Environmental Protection Agency's Pollution Prevention Information Exchange System (PIES) case study database provided information on some waste-reduction technologies and the Pollution Prevention Program Summary was used for additional contact information.

The initial approach focused on contacting individuals in government, universities, and other organizations that have been active or knowledgeable about waste reduction. The search was expanded to include trade association representatives in the targeted industrial sectors and to states known to have active pollution prevention/waste reduction technical assistance programs. See Appendix E for a list of representatives and experts contacted.

The information requested from trade associations and state programs included reports, publications, and lists of publications describing waste-reduction technologies. Because the data used in this review were obtained from a variety of sources and written and collected for various purposes, they provided varying levels of detail. The technology information has been organized under the categories below for each of the technologies identified (the categories are defined in Appendix B):

- industrial sector;
- primary waste reduction strategy;
- environmental benefits;
- estimated energy savings;
- estimated waste reduction;
- capital investment;
- annual cost savings; and
- payback.

Approximately 300 documents (reports, books, and journal articles) were reviewed. At this stage, there was no attempt to balance the technology summaries by industrial sector, geographic location, or other factors that may influence adoption of new technologies. Appendix B shows the complete technology summaries for each industrial sector.

1.3.3. Evaluation of Barriers to Adoption of Waste-Reduction Technologies

The overview of the section on barriers to adoption of waste-reduction technologies was summarized from information available in the public literature. The documents most used included the following sources: a recent DOE report (DOE 1991) examining the incentives and disincentives to industrial waste reduction in existing and proposed legislation; an EPA Office of Solid Waste (EPA 1993) report that is still being finalized that summarizes the barriers and incentives in 50 documents from government, academia, and industry; and a group of 60 documents—primarily journal articles—referring to barriers to waste reduction that were located through a literature search. In addition, telephone interviews were conducted with three experts to obtain information to complement that found in the literature. All of these sources are listed in Appendix E.

2. BACKGROUND

The complexity of the U.S. industrial system will have a significant effect on any assessment of the use of, or opportunities for, waste-reducing energy-efficient technologies. There are more than 360,000 industrial facilities in the United States using tens of thousands of processes and millions of different pieces of equipment to make hundreds of thousands of products. These facilities consume a multitude of raw materials and energy resources every year. The waste streams that are generated, as well as the technology options for preventing them, are highly diverse, even among plants within the same industry producing similar products. This section reviews industrial waste and energy use as it is relevant to this report. Each of the seven industries producing the most wastes and using the most energy are described briefly at the end of this section.

2.1. OVERVIEW OF INDUSTRIAL WASTE GENERATION AND ENERGY USAGE

2.1.1. Industrial Waste Generation

The data available on waste generation in industry are neither comprehensive nor complete. The focus of industrial waste data collection has been largely on what comes out of the end of the pipe or goes up the stack. Little effort has been made to understand how much waste is generated and the ultimate fate of all materials and byproducts of production. Furthermore, the federal government's historical emphasis has been on the impacts of waste in specific media—air, land, or water—revealing little about how wastes are generated within industrial subsectors and their physical characteristics or about cross-media transfers.

A search of the literature and contacts with various trade associations determined that:

- there is no accurate, up-to-date, single source of data on wastes, hazardous or otherwise;
- many of the data surveys ask only for estimates of quantities of wastes and, because each respondent's capability of estimating differs, the accuracy and comparability of the data is questionable;
- information on nonhazardous wastes is not collected on a consistent basis; and
- data may be incomplete because of industry's reluctance to provide information that could result in greater regulation.

The data available on waste generation in industry must be pieced together from a variety of sources that may have very different definitions of wastes and that provide information reported in different years. For example, there is a large disparity among data sources over the amount and type of industrial waste that is generated. Some wastes are reported on a dry weight basis, while others are reported as wet wastes. Some aggregate estimates of waste may originate from actual reported data, while others are projected based on statistical surveys. In addition, the specific waste streams regulated under a given statute can change, further complicating the analysis of waste trends over time.

Despite these deficiencies, the available data can provide some insight into the origins and most significant generators of industrial waste. First, however, a working definition of "industry" and "waste" is needed. The Standard Industrial Classification (SIC) codes, defined by the Department of Commerce, help classify the wide range of enterprises that comprise industry. For the purposes of this report, industry is defined as agriculture (SIC 1-9), mining (SIC 10, 12, 13 and 14), and manufacturing (SIC 20-39). Industries not included in our definition are construction, transportation and public utilities, wholesale and retail trade, and a variety of service industries. As will be shown, these are not significant contributors to the overall industrial waste generation in the U.S. Coal mining is not included in the following overview of industry waste streams and energy use, but was included in the subsequent literature review for waste-reducing technologies. For purposes of this discussion, industrial wastes will include and exclude those wastes listed in Exhibit 2.1.

Exhibit 2.1: Scope of Industrial Wastes

Wastes included in this section

- hazardous and nonhazardous wastes as defined by the Resource and Conservation Recovery Act (RCRA)
- toxic wastes as defined by the Toxic Release Inventory (TRI)
- metal and minerals mining wastes
- oil and gas exploration and production wastes
- selected gaseous wastes

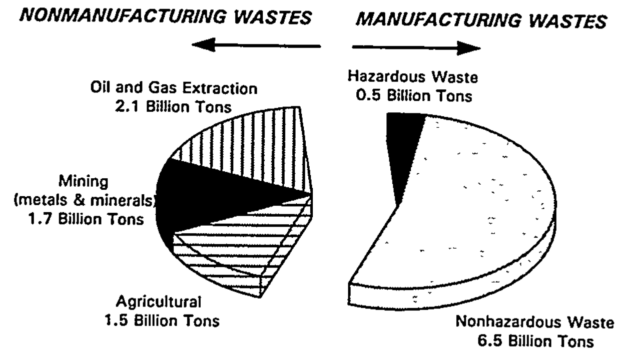
Wastes excluded from this section

- radioactive waste
- municipal solid waste
- infectious hospital waste
- construction and demolition waste
- utility waste
- very-small-quantity hazardous waste

The total U.S. industrial waste stream is estimated to be more than 12 billion tons per year (see Figure 2.1). Nonhazardous manufacturing wastes, estimated at 6.5 billion tons per year, account for about 53% of all industrial generation, while hazardous manufacturing wastes account for only about 4%. The remainder of industrial wastes come from the nonmanufacturing industries: metals and minerals mining, oil and gas extraction and production, and agricultural activities.

Figure 2.1

Estimates of Industrial Waste Generation



Total for Industry: 12.3 Billion tons/yr

Sources: EPA 1993a, EPA 1992a, EPA 1991, EPA 1988, EPA 1987, OTA 1992

Within manufacturing sectors, five industries account for 90% of nonhazardous waste (See Figure 2.2): pulp and paper (SIC 26); chemicals (SIC 28); petroleum refining (SIC 29); stone, clay, and glass (SIC 32); and primary metals (SIC 33). About 97% of this waste is disposed of in surface impoundments at the plant site where it is generated. Very little is known about these wastes, and the

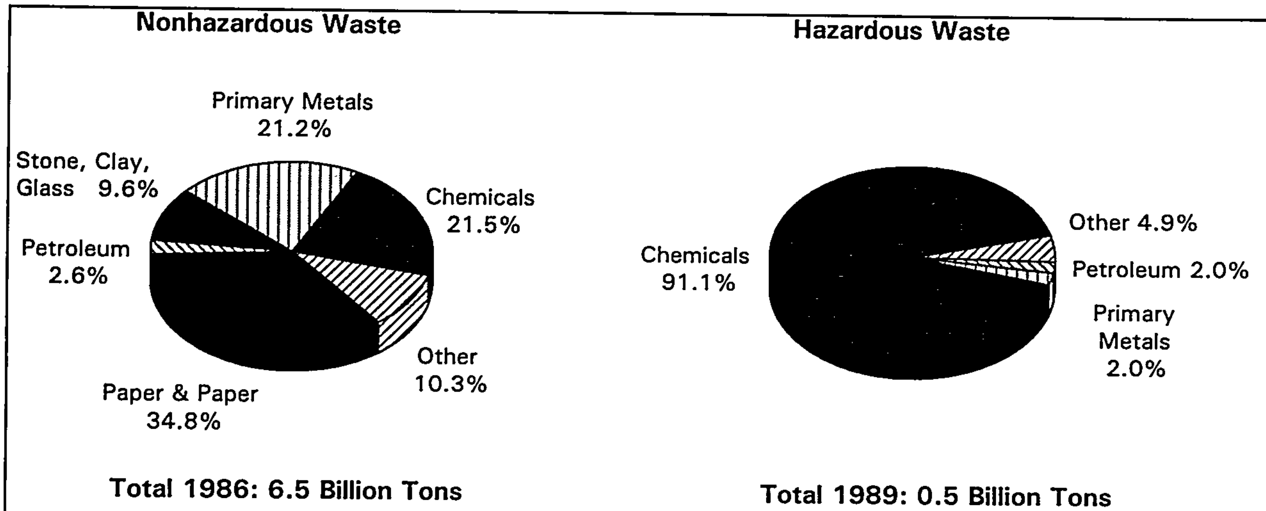


Figure 2.2
Manufacturing Hazardous and Nonhazardous Wastes

Source: EPA 1988, EPA 1993

data collected by the Environmental Protection Agency (EPA) as part of a Resource Conservation and Recovery Act (RCRA) reporting requirement in 1988, and containing information from 1986, has not been updated. (EPA 1988)

While hazardous wastes make up a smaller portion of the total industrial waste stream, they represent a greater risk to the environment and human health and are more closely regulated. Hazardous waste is characterized under RCRA as being toxic, corrosive, reactive, ignitable, or as mixtures containing "listed" hazardous wastes. In 1989, EPA estimated that about 200 million tons of hazardous solid waste were managed in treatment, storage, and disposal facilities regulated under RCRA (TSDRs) and another 300 million tons were believed to be managed outside the scope of the RCRA permitting system. (EPA 1993) The chemicals industry alone accounts for more than 90% of hazardous waste generation.

Nonmanufacturing industries, including mining and agriculture, also generate significant quantities of waste (see Exhibit 2.2). These wastes are regulated under a variety of statutes, and defining what constitutes "waste" is quite difficult. Mining wastes considered for this report consist of wastes from oil and gas extraction and production, metal mining, and nonmetallic minerals (except fuels); coal mining wastes are not included. Agricultural wastes consist mainly of feedlot wastes and crop wastes. EPA estimates the upper limit of agricultural wastes at one billion gallons per day, which translates to 1.5 billion tons per year. (EPA 1988) Overall, nonmanufacturing wastes represent about 40% of the total industrial waste stream.

Exhibit 2.2: Nonmanufacturing Wastes

Agriculture (SIC 1, 2)
- includes feedlot, crop production, irrigation, and collected field runoff wastes
- excludes wastes used as fertilizers
- excludes wastes not disposed of in surface impoundments

Mining (SIC 10, 14)
- covers metals and minerals
- includes extraction and benefaction wastes: waste rock (mine waste) and tailings
- excludes coal for this section only
- excludes mine water and mineral processing wastes

Oil and Gas Extraction (SIC 13)
- includes exploration and production wastes: produced water (including that reinjected underground for EOR) and drilling waste
- excludes associated wastes (0.1% of oil and gas wastes)

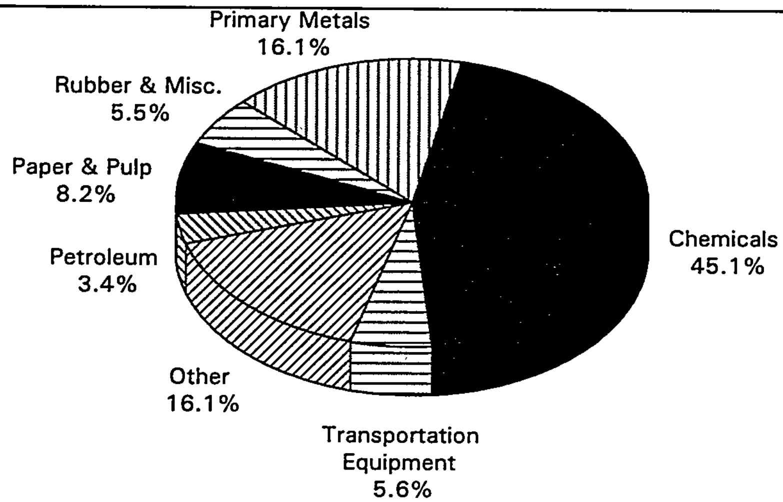
These estimates of industrial waste streams can be deceptive, however. In addition to the differences in the reporting basis and the year of the data, the amount of water contained in the waste stream greatly affects its weight. For example, water accounts for up to 95% of the weight of hazardous wastes and roughly 70% for nonhazardous wastes. (EPA 1993, OTA 1992) Furthermore, nearly all of the weight of oil and gas extraction wastes is water (about 98%). Therefore, the estimates of industrial waste streams summarized in Figure 2.1 are only a rough gauge for identifying waste priorities within industry.

2.1.2. Environmental Considerations

Another important aspect of industrial waste is its potential impact on the environment. Many industrial operations contribute to worker exposure to toxic products and wastes, and to the environmental and health problems associated with waste disposal sites. In addition, industry may generate wastes that have been associated with habitat destruction (e.g., sulfuric acid, hydrochloric acid), and pursue activities that are associated with the depletion or destruction of natural resources (e.g., land and water pollution from mining, oil and gas extraction, etc.).

While being a small percentage of the total, toxic wastes and air emissions are considered to be among the most important waste problems of industry. Concern over the effects of these wastes on the environment has led to tight regulation and high pollution compliance costs for industry.

In 1990, industry was responsible for nearly 2 million tons of toxic chemical wastes (Figure 2.3). (EPA 1992) The chemical industry was responsible for producing the bulk of these wastes, followed by the primary metals and the paper products industries. Together these three industries account for two-thirds of the total toxic waste stream. Topping the list of toxics was ammonium sulfate, often used as an agricultural fertilizer or as a coproduct of some chemical processes and a byproduct of steel coke ovens. Other major toxics included widely used commodity acids (e.g., sulfuric, hydrochloric), and commonly used solvents and chemical building blocks (e.g., methanol, toluene, acetone, xylene, trichloroethane, etc.). (EPA 1992)



Total 1990: 1.8 Million Tons

Figure 2.3

Toxic Releases in Manufacturing

Source: ***EPA 1992***

Industrial processes result in numerous gaseous byproducts, many of which are characterized as airborne pollutants. Several air pollutants—particulates, sulfur oxides (SO_X), nitrogen oxides (NO_X), volatile organic compounds (VOCs), and carbon monoxide (CO)—contribute to poor urban air quality and regional air problems like acid rain. A portion of these pollutants results from industrial fuel combustion, while others are generated by industrial processes. EPA has estimated that industrial sources account for more than 40% of all reactive VOC emissions, for about 15% of sulfur oxide emissions, and for about 3% of nitrogen oxide emissions in the U.S. (EPA 1991a).

Elevated levels of these pollutants can cause a variety of adverse health effects. They have also been blamed for reduced crop yields and stunted forest growth. Ozone, for example, is a major component of smog and is produced through chemical reactions that involve both NO_X and VOCs. Inhaling ozone can induce coughing, breathing difficulties, and temporary reduction of normal lung function, and is suspected of contributing to the development of chronic lung diseases. Acidic deposition, or "acid rain," occurs when pollutants (primarily SO_X, NO_X, and VOCs) form acidic compounds in the atmosphere, which are later deposited on the earth in rain, snow, or fog. The detrimental effects of these acidic compounds on aquatic systems, forests, and human health are of major concern to the public. In 1990, air emissions from the manufacturing industries reached over 10 million tons, as shown in Figure 2.4. The industries that produce the most airborne pollutants are the chemicals; petroleum refining; primary metals; pulp and paper; and stone, clay, and glass industries.

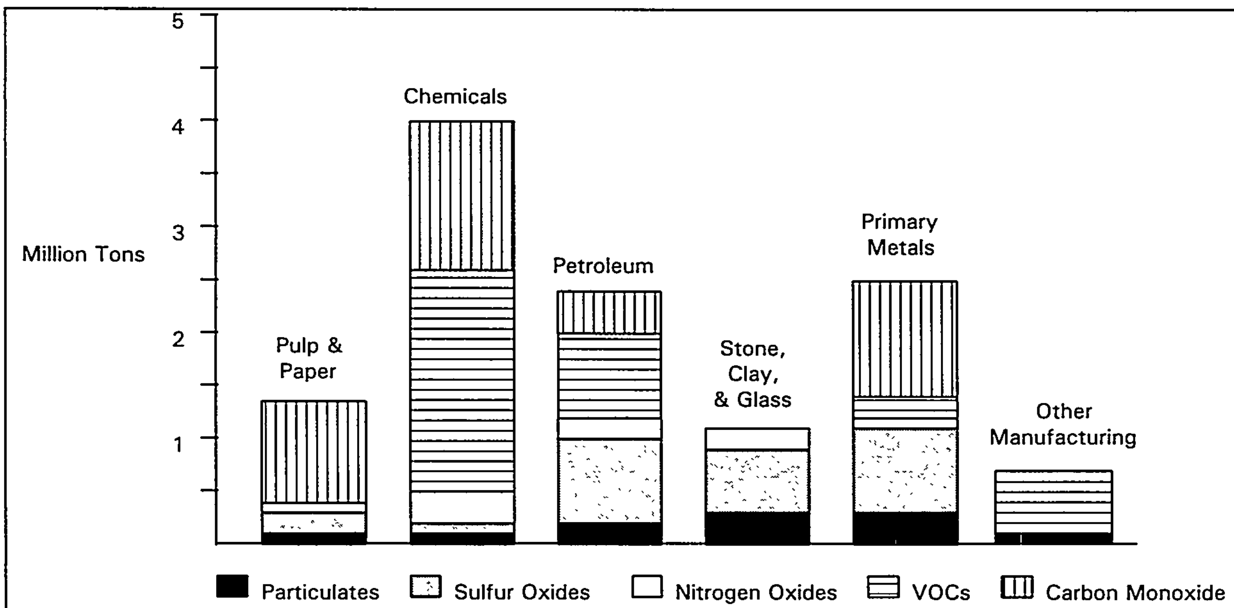


Figure 2.4
Manufacturing Air Emissions

Source: EPA 1991a

Industry also emits gases associated with global warming (e.g., carbon dioxide, methane, nitrous oxide, and CFCs). While significant uncertainty still remains about the magnitude of future climate change from greenhouse gases, the potential effects of sustained temperature rises (e.g., rising sea levels, availability of water, etc.) continue to be a cause for concern and study. In addition, industry manufactures all of the chlorofluorcarbons (CFCs) in use and emits some waste CFCs. CFCs are associated with depletion of the stratospheric ozone layer, which normally filters the ultraviolet radiation that can be harmful to human health and the environment. While they remain in wide use, international agreements have been adopted to control and eventually phase out the use of CFCs entirely over the next 10 years.

2.1.3. Energy Use and Industrial Waste

When industry generates waste, valuable energy is often depleted. This wasted energy is accounted for in the embodied energy of unused or poorly used raw materials, in the energy content of the waste streams, and in the energy required to manage and dispose of wastes. Unnecessary energy consumption, as well as the generation of waste that could be avoided, are both symptomatic of a common problem—inefficient production processes. When a process is energy inefficient, scarce energy resources are not being used effectively. When waste is created, materials, as well as energy, are not being used efficiently.

Industry accounts for about 37% of all energy consumption in the United States. In 1992, U.S. industry directly consumed nearly 24 quads[1] of energy resources (Figure 2.5). Electrical energy losses, or energy consumption associated with the transmission and generation of electricity, added about another 7 quads of energy used indirectly by the industrial sector. (EIA 1993)

Within the manufacturing industries, energy resources are used to generate heat and power, and as feedstocks for materials production. About 47% of industrial energy consumption is used to generate heat and power in boilers, furnaces, and cogeneration systems to provide process heat, shaft drive, and other functional uses. Feedstock energy, which accounts for about 23% of industrial energy consumption, is used primarily for its chemical content rather than heating value, e.g., petroleum used to produce petrochemicals, natural gas used to produce ammonia, etc. As shown in Figure 2.5, the same industries that produce the most industrial waste also account for over 80% of total manufacturing energy consumption.

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[1]A "quad" is an energy unit equivalent to 1×10^{15} Btu, or a quadrillion Btu. This is the energy used by about 9.5 million U.S. homes annually.

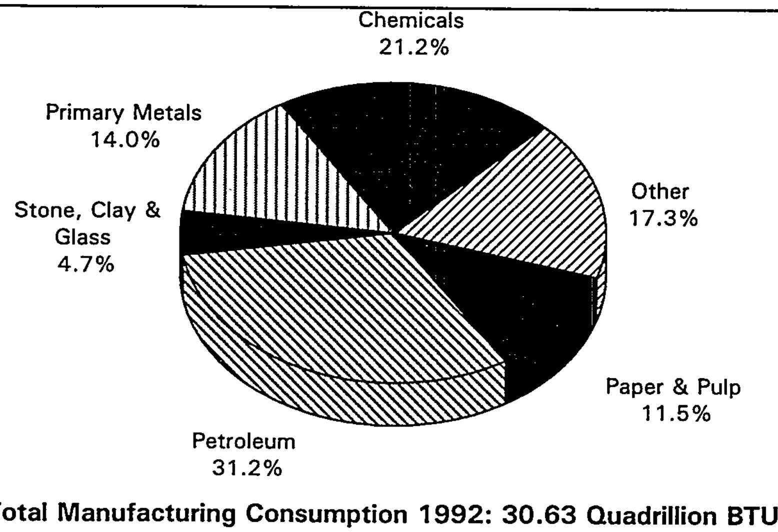

Figure 2.5
Industrial Manufacturing Energy Consumption

Sources: EIA 1991, EIA 1992, EIA 1993

In the nonmanufacturing sector, the mining and agricultural industries are the major consumers of energy resources. The U.S. Department of Agriculture estimated that in 1987 the agricultural sector directly consumed about 0.8 quads of energy for heat and power, and about 0.7 quads embodied in fertilizers and pesticides. (IEA 1990) Energy is consumed at every step in the modern agricultural production process, and over 90% of direct energy use is petroleum-based. Energy consumption associated with mining activities (SIC 10-14) was estimated to be 2 quads (including electrical energy losses) in 1987. (DOC 1990) In the metal mining industries, the bulk of energy is used for communication, benefaction, and smelting and refining of ores. For coal mining, as well as oil and gas extraction activities, very little information is available about the distribution of energy use. (DOE 1990)

2.1.4. Economic Impacts of Waste Production

The economic burden of waste production in industry is not well understood. Production costs are affected by a wide range of factors such as materials use, energy use, labor productivity, capital productivity, environmental controls, and liability. Waste production and management activities affect each of these costs in a variety of ways that differ among firms. In addition, waste reduction projects that are undertaken by companies more often result in reduced material or labor costs than in reduced pollution control costs. Further, potential liability costs are extremely hard to quantify, and therefore extremely hard to factor into the financial equation. Finally, since manufacturing relies on the production and consumption of numerous intermediate products, the impact of pollution prevention across all of industry, while it could have substantial economic implications, cannot be fully accounted for using current accounting methods.

The chief direct cost associated with waste management is the cost of pollution abatement. Even here, estimates of industry expenditures vary greatly. According to the Pollution Abatement and Control Expenditures (PACE) survey, manufacturers spent approximately $25 billion on pollution abatement in 1991. (DOC 1993) However, EPA estimates that "private" pollution abatement spending was $42.9 billion in 1986 (EPA 1990a); and the Survey of Current Business, which uses a broader definition of costs, estimates total national environmental spending at almost $90 billion, and total business spending at $54.7 billion (61% of the national total). (Rutledge 1992) As shown in Figure 2.6, four industries (chemicals, petroleum refining, primary metals, and pulp and paper) account for 66% of industrial spending on pollution control.

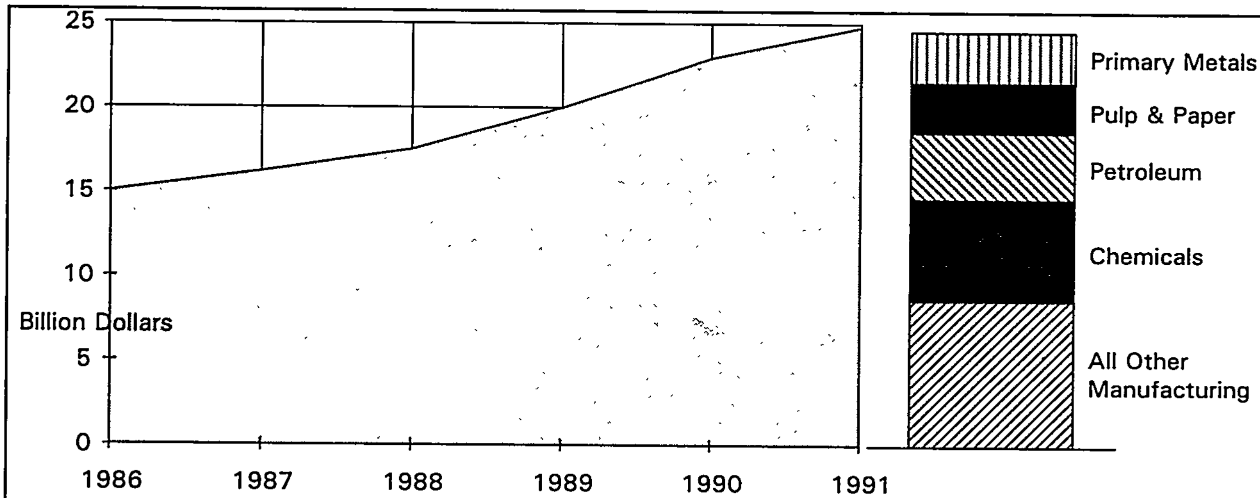

Figure 2.6
Industrial Pollution Abatement Costs and Expenditures

Source: DOC 1993

A 1992 study attempted to measure the impact of future pollution prevention activities in industry on the national economy. (Teclaw 1993) The study estimated that with modest industrial pollution prevention efforts, the Gross Domestic Product would increase $1.9 trillion over the period 1996 to 2010, yielding a net present value of $335 billion (1992 dollars). In addition, the study estimated that this growth would be accompanied by an increase in employment of 16 million person-years. This impact, which was based on input-output analysis of interindustry interactions, can be viewed as one very rough gauge of the economic burden associated with avoidable waste generation and management in industry.

2.2. Industrial Targets for Waste-Reduction Technology Assessments

As shown in the information presented above, 5 of the 20 manufacturing industries—chemicals, pulp and paper, primary metals, petroleum, and stone, clay and glass—emerge as the major manufacturing sectors of waste generation and energy use (see Table 2.1).

Table 2.1
Manufacturing Industry Selection for Study

		Key Waste Criteria (Overall Ranking among 20 Sectors)					
SIC	**Industry**	Nonhazardous Waste	Hazardous Waste	Air Pollutants	Toxic Waste	Energy Use	Pollution Abatement Expenditures
26	Pulp & Paper	1	13	4	3	4	3
28	Chemicals	2	1	2	1	2	1
29	Petroleum	7	2	3	7	1	2
32	Stone, Clay, Glass	4	10	5	16	6	10
33	Primary Metals	3	3	1	2	3	4
Percent of Total Represented by these five industries		**90%**	**95%**	**92%**	**73%**	**83%**	**67%**

Because of the complexity and diversity of industry and the technologies they employ, and for efficient use of the resources available to this project, this response to EPAct Section 2108 is focused on these five manufacturing sectors, and on agriculture and mining in the nonmanufacturing sectors. The agriculture (SIC1-9) and mining (SIC10, 13, 14) sectors account for an additional 4% of nonhazardous wastes and 11% of energy use.

- 94% of nonhazardous wastes,
- 95% of hazardous wastes,
- 92% of air pollutants,
- 73% of toxic releases,
- 94% of energy consumption, and
- 67% of pollution abatement expenditures.

These seven sectors of U.S. industry offer the most significant opportunities for the reduction of waste while improving energy efficiency. Following are general descriptions of the seven industries.

2.2.1. Agriculture (SIC 01/02)

Background

The agriculture industry includes the growth and harvesting of farm crops and livestock. Modern agricultural practices are energy intensive, from fuel for machinery, equipment, and heat to the energy embodied in fertilizers and pesticides. The labor needed to farm an acre has declined 75% while output per acre has doubled since 1940. Fertilizer and pesticide costs exceed other costs, such as seeds and fuel, for many major commodities. (DOE 1990 pp. 1-4)

Due to the availability of reliable figures, agricultural wastes in this report consist mainly of feedlot wastes and crop wastes. It should be noted, however, that even though the data is not available to support its inclusion, one of the great material wastes in this industry may be the loss of topsoil from nonconservative agricultural practices. Further, large amounts of pesticides and fertilizers are used in the agriculture industry, and while these inputs are not pollutants, they do produce pollution. (WERC pp. 2-3)

Waste Generation

Agricultural wastes make up 1.5 of the 12 billion tons (12%) of industrial wastes produced annually.

Energy Usage

Agriculture consumes about 1.5 quads of energy (5% of the total 31 quads used by industry), 0.8 quads for heat and power and about 0.7 quads embodied in fertilizers and pesticides.

2.2.2. Mining Industry (SIC 10/12/13/14)

Background

The mining industry is composed of three distinct subindustries: mineral and metal mining; coal mining; and oil and gas extraction. (DOE 1990 p.1) There are two types of waste associated with mining per se: overburden, the earth displaced in the process of searching for and removing ore; and gangue, the unwanted components removed on-site by physical methods, such as screening, washing, settling, flotation, and centrifuging. (WERC p. 6)

About 95% of the mineral and metal mining in this country is of iron, copper, lead and zinc, gold, silver, and bauxite and other aluminum ores. The quality and grade of metal and mineral resources in the U.S. is continually decreasing as richer deposits are exhausted, leaving only lower grade deposits. For example, the National Research Council estimates that, by the year 2000, the average grade of copper, which accounts for the highest value of annual shipments of minerals, will be about 20% as opposed to the current average grade of 65%. This will mean that about three times as much ore will need to be extracted and processed to obtain the same amount of copper. (DOE 1990 pp. 1-2)

Coal is the world's most abundant fossil energy resource. (DOE 1990 p. 11) A recent study suggests a waste overburden of 1.6 to 2 tons for each ton of coal produced. In addition to overburden, most utility coal is washed, resulting in sulfurous waste refuse, a major source of acid mine drainage. (WERC p. 8)

Oil and natural gas extraction includes the exploration, drilling, extraction, and production of the crude products that go into petroleum refining. (DOE 1990 p. 19) Waste streams for this sector include such things as the barite "drilling mud" and oily wastewater.

For the purposes of this section only, mining wastes consist of wastes from oil and gas extraction and production, metal mining, and nonmetallic minerals (except fuels). Coal mining wastes, mine water, and mineral processing wastes are not included.

Waste Generation

Mining wastes make up 3.8 of the 12 billion tons (31%) of industrial wastes produced annually.

Energy Usage

Energy use was estimated to be 2.1 quads in 1987 (7% of the total 31 quads used by industry).

2.2.3. Pulp and Paper Industry (SIC 26)

Background

Paper production produces large waste streams because of the loss of a significant part of the raw weight of the wood and most of the chemicals used in pulping. Pulping is the process of disintegrating wood fibers to produce the material used to make paper. A significant portion of the mass of the pulpwood necessary for pulp and paper production is not cellulose, but the lignin that holds the cellulose fibers together. A recent study done for DOE estimated that the pulping process results in a 40% loss in mass from the original feedstock. In addition, the pulping process involves a significant quantity of chemicals including clay, lime, sulfur, soda ash, sodium hydroxide, sodium sulfate, sulfuric acid, chorine, and salt. Except for clay, which is embodied in the paper products as filling and coating material, the chemicals are usually discharged after they are used. (WERC pp. 5-6).

Waste Generation

The pulp and paper industry produces 34.8% of nonhazardous manufacturing wastes, or 2.3 billion tons annually.

Energy Usage

In 1992, pulp and paper consumed 11.5%, or 3.4 quads, of energy consumed by manufacturing industries.

2.2.4. Chemical Industry (SIC 28)

Background

The chemical industry is extremely broad, encompassing several areas, including organic chemicals, inorganic chemicals, agricultural chemicals, paints and coatings, and adhesives and sealants. A recent EPA report points out that the industry has been a leader in pollution prevention, implementing innovative pollution-prevention measures. These changes, despite the breadth of the industry, tend to be specific to a single process, a single piece of equipment, or a single product. For example, while solvent recovery is a clear opportunity of broad magnitude across the industry, it is applicable only in terms of the needs and components of a specific process. (EPA 1991c p. 17) Because of the magnitude of waste production and energy use, this industry may provide the greatest and most immediate opportunities for waste reduction and energy conservation.

Most of the products of the industry are used dissipatively and become wastes relatively soon after their use. Most production requires a sequence of several processes, each with its own wastes; the cumulative waste produced can be significant. For example, a sequence requiring three processes, each with an efficiency of 85 to 90%, could result in total waste produced of 35%. (WERC p. 17)

The inorganic chemical industry may have more difficulty than the organic chemical industry in taking on new technology as its products are commodity chemicals for which the technology has been established and the plants and process equipment have been amortized over long time periods. Therefore, while modernization of technologies may be cost-effective and result in waste minimization, payback to the company may not be adequate to be attractive. (EPA 1991c p. 18)

Waste Generation

The chemical industry produces

- 91.1%, or 0.46 billion tons, of total hazardous waste generation in the U.S.
- 21.5%, or 1.4 billion tons, of total nonhazardous manufacturing wastes.

The industry is the largest emitter of toxic chemicals, accounting for almost half of the total.

Energy Usage

The chemical industry is a large energy consumer, accounting for 21%, or 6.4 quads, of industrial energy consumption.

2.2.5. Petroleum Refining Industry (SIC 29)

Background

The petroleum refining industry processes crude oil into useful products through a series of separation and transformation processes. (DOE 1990 p. 1) This industry is unique in that the raw materials, primary wastes, and products of petroleum refining are essentially the same. Most refining products are the result of a series of process operations and the "waste" from one process can be used for source reduction at a later stage. Therefore source reduction and recovery/recycle can be indistinguishable. Two types of waste problems affecting the petroleum refining industry include oily wastewaters and sludges at the bottom of tanks. (EPA 1991c p. 24)

The petroleum refining industry is currently experiencing some degree of flux as individual refiners assess their ability to comply with the requirements of the Clean Air Act Amendments (CAAA) of 1990, which requires that gasoline meet strict new requirements regarding composition and reduction in tailpipe emissions. Given that motor gasoline accounts for more than 45% of the products of petroleum refining, CAAA requirements for gasoline reformulation will have a significant effect on the petroleum refining industry. For the most part, smaller refineries will experience the greatest burden as the equipment investment to produce products that comply with environmental regulations will be greater on a per-barrel basis for smaller refineries. (DOC 1993 pp. 4-3, 4-4)

Waste Generation

The petroleum refining industry generates

- 3.4%, or 1.8 million tons, of toxic releases in manufacturing.
- 2.6%, or 0.17 billion tons, of nonhazardous wastes.
- 2.0%, or 0.01 billion tons, of hazardous wastes.

Energy Usage

The industry consumes 31.2 %, or 9.5 quads, of industrial energy consumption.

2.2.6. Stone, Clay, and Glass Industries (SIC 32)

Background

The major outputs of the stone, clay, and glass industry are refractories (heat-resistant substances), glass, and portland cement. All are basically durable materials used in structures or long-lived products. (WERC p. 13)

Glass manufacture is a large, widely diversified, energy-intensive industry. There are four types of glass: flat glass, container glass, pressed and blown glass, and glass fiber insulation. The basic glass industries produced approximately 19 million tons of glass in 1985. (DOE 1990 p. 1) The flat glass and container glass industries have undergone consolidation in the last five years, reducing the number of companies and increasing their debt as a result of both plant modernization and leveraged buyouts. Overall, the glass industry faces a number of problems, including plant overcapacity, industry consolidation, capital-intensiveness, and cyclical and moderate growth prospects. (DOE 1990 p. 3)

Cement is the primary binding ingredient in concrete mixtures and is primarily used in building materials. The industry produced 78.3 million tons in 1988, of which 96% was portland cement. (DOE 1990 p.1) Cement manufacturing is an energy intensive industry with energy costs comprising about 40% or more of direct manufacturing costs. (DOE 1990 p. 3) Cement is made by quarrying, crushing, grinding, and blending the raw materials; processing them in kilns at high temperatures (2700-2900F); and fine grinding the resulting marble-sized pellets (clinker) with some gypsum into extremely fine powder. (DOE 1990 p.6)

Waste Generation

The stone, clay, and glass industries generate 9.6%, or 0.62 billion tons, of nonhazardous manufacturing wastes.

Energy Usage

The industries consume 5%, or 1.5 quads, of industrial energy consumption.

2.2.7. Primary Metals Industry (SIC 33)

Background

This industry includes the production and casting (shaping) of metals, principally iron and steel, aluminum, copper, lead, titanium, and zinc. (DOC 1993) Primary metals are produced from metal-bearing ores. The metal is separated from the unwanted rock in the ore—the gangue—often by crushing or grinding and flotation. Smelting, a chemical reduction accomplished by heat and a reducing agent such as another metal or by electrolysis, is often required to produce a pure metal. The gangue that remains with the ore is separated during smelting and referred to as slag, a molten mix of gangue minerals. Metals may also be separated from ores at various stages by leaching, the washing away of unwanted compounds with an appropriate solvent. Once the metals are pure, they are formed into appropriate shapes—sheets, ingots, or even into specific parts. (Bailer pp. 725-6) This industry is extremely energy intensive, (DOE 1990 p. 5, DOC 1993 p. 13-5) and the emissions from energy use are an important resulting waste. Wastes include such things as the unwanted byproducts of manufacture; the inherent and sometimes hazardous materials included in the ore and that remain in the gangue; and process inputs that are not consumed, for example, the spent cyanide baths used for case hardening of steel.

The largest producers are iron and steel and aluminum. (DOC 1993 pp. 13-2, 13-5, 13-7, 13-8, 13-10, 13-12) The iron and steel industry experienced intense pressure in the 1980s from foreign competition, bankruptcies, forced mergers, and massive layoffs. (DOE 1990 p.1) The response of the industry has been to restructure itself and to invest in modern technology and equipment. Current indicators show signs that the industry is emerging from recession. (DOC 1993 p. 13-1) In tandem with the changes in the industry have been depressed prices, high costs for labor and new facilities, and heightened competition. (DOC 1993 p. 13-1) Electricity is the single most costly input for aluminum production.

Increasing costs of electricity, particularly due to Clean Air Act Amendments requiring reduced emissions, could decrease the international competitiveness of U.S. aluminum producers. (DOC 1993 p. 13-5)

Waste Generation

The primary metals industry generates

- 16.1% (of 1.8 million tons) of industrial toxic releases in manufacturing.
- 21.2%, or 1.38 billion tons, of nonhazardous manufacturing wastes and 2.0%, or 0.01 billion tons, of hazardous wastes.

The industry is the second highest industrial producer of air emissions, at almost 3 million tons.

Energy Usage

The industry consumes 14.0%, or 4.3 quads, of total manufacturing energy consumption.

3. RESULTS

3.1. IDENTIFICATION OF OPPORTUNITIES

In EPAct Section 2108(b), Congress requires DOE to identify opportunities for the demonstration of energy-efficient pollution-prevention technologies and processes. These opportunities are considered to be broad areas of need for waste reduction that will be addressed through specific waste-reducing technologies and/or processes that, in turn, need to be demonstrated to be effective. It is of critical importance that opportunities for the demonstration of waste-reducing technologies be identified by industrial representatives to ensure that the opportunities reflect industrial needs that are both significant and timely. To date two panels have occurred within the context of responding to EPAct Section 2108, one to establish criteria for evaluating the relative importance of opportunities that are identified, and one to identify opportunities within the petroleum industry. In addition, a workshop held in 1991, prior to the passage of EPAct, under the auspices of the Industrial Waste Program (IWP) and the American Institute of Chemical Engineers (AIChE), identified several opportunities for waste reduction in the chemical industry. This section describes the results of the two panels and the workshop. The full panel reports are contained in Appendices C and D.

3.1.1. Principal Results of the Criteria Panel

Recognizing the need for consistency across the results of seven different panels—one for each of the seven industries targeted for this response to EPAct Section 2108—a first panel was convened to develop explicit and consistent criteria by which opportunities could be ranked in their order of relative importance. This panel, with members from industry, academia, federal government, and an environmental public interest group, first arrived at a consensus definition of energy-efficient pollution-prevention technology demonstration opportunities.

> *Opportunities for the demonstration of energy-efficient, pollution-prevention, economically competitive technologies and processes consist of the use of hardware, software, and/or an operational procedure in a monitored industrial setting to determine and display improved performance, thereby encouraging timely adoption by similar firms so as to assure environmental quality.*

Given that future panels may be tasked with identifying demonstration opportunities with the greatest potential for improvement in energy efficiency, pollution prevention, and economic competitiveness, the panel, through iterative discussion, identified and ranked in descending order of their relative importance the following five criteria for screening technology demonstration opportunities. The criteria were ranked and weighted to allow technology demonstration opportunities to be assigned a composite score by the members of future panels.

- Magnitude of systemic energy, environmental, and economic impacts
- Probability of success
- Implementation costs/cost-effectiveness
- Time frame for results
- Measurability/accountability/performance tracking

In addition to the criteria identified above, the panel recognized that while there may be an important government role in leveraging public monies with private capital or in steering developmental programs for some opportunities, not all opportunities are equally appropriate for government involvement. Further, the panel recognized that the role for government involvement is fundamentally a different type of criterion than the five identified above and that demonstration opportunities could be examined from two perspectives, with regard to their specific features and to the appropriateness of government participation.

3.1.2. Principal Results of the Petroleum Panel

The second panel had members representing the petroleum industry, academia, the National Academy of Sciences, and environmental and regulatory consultants, and had two main tasks—identifying and then ranking energy-efficient pollution-prevention demonstration opportunities in the petroleum industry. The overriding theme of energy-efficient pollution-prevention demonstration opportunities identified in the petroleum industry involved wastes and water, including produced water, process water, groundwater, and surface water. This result is not surprising given that the volume of water managed in upstream operations can be ten times the volume of petroleum, while it is about equal to the volume of petroleum in downstream operations. To a lesser extent, technologies addressing emissions to the air and land, especially involving toxic substances, were identified and discussed.

The panel began by identifying a large number of potential opportunities for technology demonstrations and consolidating them into the following nine broad categories:

- Combustion emissions and toxic releases
- Decommissioning of nonproductive or abandoned wells
- Heat management

- Leak and fugitive emissions detection and prevention
- Oil/water emulsion breaking and solids separation
- Reservoir management and diagnostics
- Spent materials handling
- Sulfur and heavy metals extraction
- Wastewater management, handling, and reduction

Some of these categories are only applicable to exploration and production (upstream) technologies (e.g., decommissioning of nonproductive or abandoned wells and reservoir management and diagnostics); others are essentially applicable only to refining and processing (downstream) activities (e.g., heat management and sulfur and heavy metals extraction). The remaining five categories could include technologies addressing either upstream or downstream operations.

Twenty technology demonstration opportunities were placed within these nine categories. While each technology area was considered to contain worthwhile demonstration opportunities, the panel, following discussion and consolidation of the 20 technologies, focused on a subset of seven for which the most thorough definition, discussion, and analysis were immediately possible.

The seven identified areas for technology demonstration opportunities include two addressing environmental concerns associated with upstream and downstream operations, respectively, and three having potential broad application across the entire petroleum industry. The seven technology areas are:

- Advanced geophysical diagnostics
- Locating orphan wells
- Spent catalyst reuse
- Dry hydrogen sulfide adsorption
- Toxic gaseous emissions
- Oil/water emulsion breaking by chemical additives
- Wastewater management

The panel developed the following working definitions of the seven identified technology areas to describe the most important features and benefits of the prospective technologies.

Advanced geophysical diagnostics was narrowed to the use of current capabilities in new ways, for example, three-dimensional seismic surveys, which are commonly used during offshore exploration, in onshore producing fields to better characterize the reservoir conditions as a means to minimize the drilling of unproductive wells while conducting an in-fill drilling program. This new application of an existing technique could significantly reduce the volume of produced water, the single largest waste stream in the petroleum industry, and avoid pollution from the drilling of unnecessary wells.

Locating orphan wells refers to new technology applied to locating old wells, abandoned mostly prior to 1940, that do not have recorded locations and ownership. These wells were generally plugged inadequately if at all and often are a recognized source of groundwater pollution or pose a serious threat to groundwater resources. Candidate technologies in the area would be expected to include remote subsurface sensing techniques developed for defense purposes.

Spent catalyst reuse consists of technologies for extracting metals of lower value than precious metals from catalysts used in fluid catalytic cracking (FCC) and hyrdodesulfurization (HDS) units in refineries. The extracted metals, such as nickel, vanadium, cobalt, and tungsten, could be sold in commercial markets and the remaining material could be reused in catalyst production. Technologies capable of capitalizing on the silica content of spent FCC catalysts, such as cement production, were included in this category. Elimination of substantial volumes of spent catalysts presently disposed of in landfills could result from deployment of proven technologies in this area.

Recent developments permitting the design of improved burners and injectors for flue gas and volatile organic compound (VOC) combustion in refineries promise a means of reducing *toxic gaseous emissions*. Catalytic combustion technologies could be included as well. Greater opportunities for new technology demonstrations were judged to be present for managing air toxics than for addressing emissions of standard combustion products including carbon monoxide, sulfur oxides, and nitrous oxides. Technologies in this area would reduce toxic air pollution associated with noncommercial fuel combustion processes in refineries.

Dry hydrogen sulfide adsorption is the most specific of the technology areas. This area represents methods to replace amine-based aqueous solutions for treating gas streams to remove hydrogen sulfide in refineries and possibly in natural gas processing plants. The captured sulfur would be recoverable as elemental sulfur or sulfuric acid through widely used processes. These technologies would reduce the pollution associated with the disposal or accidental release of amine solutions.

Oil/water emulsion breaking technologies focuses on gaining a better understanding and characterization of the activity and reactivity of chemical species when added in mixtures for the purpose of breaking organic/water emulsions and on designing optimized separation units. The objectives are to obtain improved formulations for treating emulsions and to better predict the impact of these additives on subsequent processing steps. Technologies in this area would greatly reduce wastewater volumes by facilitating water recycling and minimizing the need for water treatment before disposal.

Wastewater management technology focuses on techniques capable of making contributions toward achieving an on-site, closed-cycle water management system in a refinery. Included are integrated heat management techniques for the express purpose of water management in a refinery as well as techniques to efficiently reuse impure waters in the refining process. An ultimate objective would be to allow operation of a zero-water-release refinery. Reducing or preventing groundwater and surface water pollution would be the principal benefit gained from these technologies.

3.1.3. Ranking of Technology Demonstrations

Using the criteria developed by the first panel, this panel ranked the demonstration opportunities described above first in their general order of relative importance for a composite set of criteria, then in the order of relative importance for a government role in their demonstration. Because of the panel members' experience in and knowledge of the petroleum industry, the ranking of opportunities reflects not only waste-reduction needs but is also sensitive to the ability of the industry to take on new technologies. The panel noted that an effective technology demonstration program would necessarily involve selection of specifically defined technologies within one or more of these areas.

Petroleum Industry - Order from Overall Composite Ranking
1. Wastewater management
2. Advanced geophysical diagnostics
3. Toxic air emissions
4. Spent catalyst reuse
5. Dry hydrogen sulfide adsorption
6. Locating orphan wells
7. Oil/water emulsion breaking by chemical additives

Petroleum Industry - Order Relative to Importance of a Federal Role
1. Toxic air emissions
2. Locating orphan wells
3. Wastewater management
4. Advanced geophysical diagnostics
5. Oil/water emulsion breaking by chemical additives
6. Spent catalyst reuse
7. Dry hydrogen sulfide adsorption

3.1.4. Waste-Reduction Opportunities in the Chemical Industry—Workshop Results

Before passage of EPAct, the IWP sponsored, with the AIChE, a workshop to examine waste-reduction opportunities in the chemical industry. The results, while they are not specifically focused on pollution prevention and they have not been evaluated in light of the definition and criteria developed as part of this work, do offer some insight into the types of opportunities for waste reduction in the chemical industry. The proceedings of the workshop are summarized in the joint DOE/AIChE Report, "*The CWRT*[1] *on: Waste Reduction Opportunities in Industry.*" (DOE 1991a) The workshop identified the following high priority technological areas with opportunities to exploit waste reduction in the production and use of chemicals.

Chemical Industry - Highest Priority R&D Technologies from Waste-Reduction Opportunities Workshop
• Separation of dilute organics from water • Alternative in-process separation techniques for organic/inorganic/aqueous solutions • Emission control of dilute volatile organic compounds* • Total water reuse • Low-cost sorbent regeneration processes • Post-consumer recycling, upgrading, and separation*
* While this report is concerned with pollution prevention, the industrial panel results did include these two pollution treatment strategies.

The generation of wastewater was the overriding theme of the opportunity sets identified by the chemical and petroleum industries. Air emissions involving toxic substances are another common concern cutting across both industries.

[1]Center for Waste Reduction Technology

3. RESULTS-continued

3.2. WASTE-REDUCTION TECHNOLOGIES

EPAct directs in subsection (c) that an assessment be made for the technologies identified in subsection (b). That assessment has not yet occurred in the level of detail called for by the Act for the chemical, petroleum, and other, previously identified, sectors. To optimize the time and resources available to address EPAct Section 2108, the focus has been on providing a foundation for addressing opportunity identification and subsequent assessment activities. This foundation is built on a systematic review of the literature for pollution-prevention technologies which have, in turn, been evaluated relative to the information requested in subsection (c). This background will both provide an insight into the current state of pollution-prevention technologies in industry and support future efforts to identify demonstration opportunities. The results derived from the open literature are summarized below.

3.2.1. Approach - Technology Assessments

The review of existing and developing technologies that involve waste-reduction objectives encompassed the open literature and appropriate databases. In addition, knowledgeable individuals in government, universities, and other organizations were contacted, as well as trade association representatives in the targeted industry sectors and representatives of states with active pollution-prevention/waste-reduction technical assistance programs. Approximately 300 documents (reports, books, and journal articles) were collected and reviewed.

Waste-Reduction Strategies

- ❑ ***process redesign*** - refinements or alterations in the production process itself
- ❑ ***in-process recycling*** - waste is reclaimed and processed to recover a usable product, or reused within an industrial process
- ❑ ***input substitution*** - substituting a material for one that is less toxic or that causes less of a waste treatment or disposal problem; also includes input purification
- ❑ ***product change*** - redesigning the end product to optimize material use and minimize waste
- ❑ ***operational efficiencies*** - various measures taken to reduce waste—includes things like plant maintenance and production practices, inventory control, employee training, waste stream segregation, spill/leak prevention, scheduling improvement, and the use of computers for monitoring and analysis.

There are thousands of technologies currently under development, many of which may have positive impacts on waste reduction and energy efficiency. Without a specific reference in the literature to waste reduction, however, they would need to be examined in detail on a case-by-case basis to determine waste and energy effects. Therefore, the scope of this groundwork was limited to specific technologies whose principal function was waste reduction with a relatively short period for commercialization (typically 1 to 5 years). Fundamental process advantages (e.g., direct steel making), though offering potential reductions in waste and savings in energy, were not considered in this study.

3.2.2. Summary Findings

The literature review resulted in 590 specific technologies with positive reduction impacts for the seven industrial sectors covered. Please note that all 590 technologies are listed in Appendix B. Figure 3.1 shows a breakdown of the number of technologies logged for each sector.

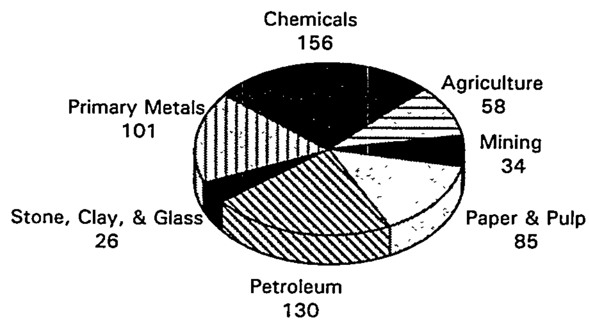

Figure 3.1

Total Number of Technologies by Industrial Sector (590 Total)

Figure 3.2 shows the number of entries by the waste-reduction strategy employed. (See box on previous page for definitions of strategies.) Of the technologies logged, process redesign, in-process recycling, and operational efficiency strategies make up 87% of the total. Product change technologies found in the open literature were minimal at just 3%.

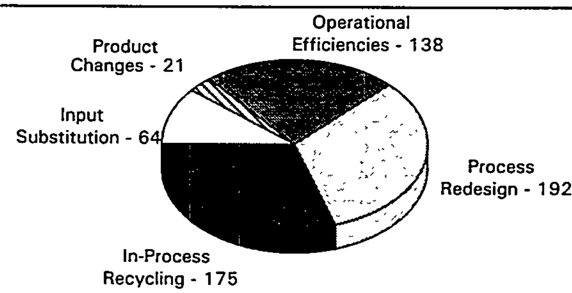

Figure 3.2

Total Number of Technologies by Waste-Reduction Strategy (590 Total)

Figure 3.3 shows which of the 590 technologies included some type of quantitative information on energy impact, waste reduction, and/or costs or cost savings.

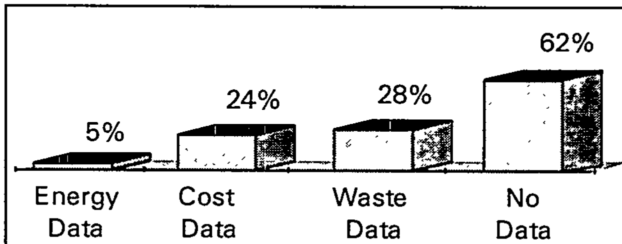

Figure 3.3

Technologies With Quantitative Energy, Waste, and/or Cost Data

The 590 technologies were classified by industrial sector into pollution issues, and are summarized in Table 3.1. This classification suggests the pollution issues applicable to waste-reduction efforts for each industry sector.

Table 3.1
Literature Review - Technology/Pollution Issue Categories - by Industry Sector

Agriculture	– biotechnology ** – reduced dust control ◆ – improved pesticide application	– precision agriculture** – sustainable agriculture
Mining	– drilling and workover fluids ◆ – mining through hard rock ◆ – oily sludge separation**	– ore processing ◆ – use of solvents and chemicals
Pulp & Paper	– kraft pulping** • washing • dry debarking ◆ • delignification • cooking ◆ • bleaching	– nonkraft pulping** • sulfite pulping • solvent pulping ■ • mechanical pulping ◆
Chemical[1]	– solvent recovery – product substitution/reformulation – process redesign issues	– recycle of product containers – process controls **
Petroleum	– processing tank bottoms crude ** – treating tail gas ■ – cooling tower blowdown ◆ – spent clay processing/treatment ◆ – spent caustic processing/treatment ◆	– solvents and chemicals usage – spent catalyst processing/ treatment** – oily sludges recovery/reprocessing – sandblast media discharge
Stone, Clay, Glass	– dust control measures	– water capture and reuse
Primary Metals	– case hardening baths – casting sands waste reduction ◆ – desulfurization – dust control measures ◆	– metal parts cleaning ◆ – pickling – quenching ◆ – slag management

◆ Indicates that only existing technologies were recorded for this area.
■ Indicates that only developing technologies were recorded for this area.
** Indicates a technology listed on one or more lists of critical technologies. (Kaarsberg)

[1] The chemical industry covered a large range of processes and products. Therefore, further categorization was not pursued for this industry.

3.2.3. Existing Technologies

(c1) - assessment of the technologies available to increase productivity and simultaneously reduce the consumption of energy and material resources, and the production of wastes identified in (b)

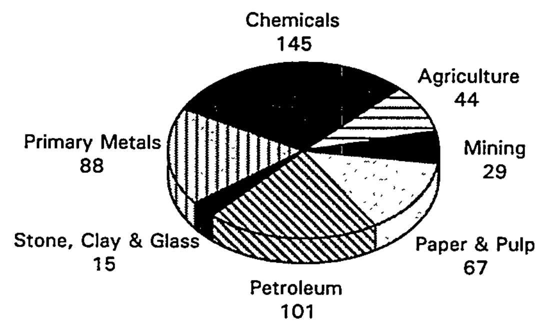

Figure 3.4

Existing Technologies Recorded (489 Total)

Of the 590 total technologies recorded, 489 are existing, that is, in relatively broad use within industry (Figure 3.4). The existing technologies ran about 5:1 to those classified as developing technologies. Virtually all references used were 1987 or later, with the majority 1991 or later. Twenty-nine percent of the existing technologies were from the chemical industry, while only 3% were from stone, clay, and glass. This difference may be partially explained by the fact that the chemical industry involves a larger array of processes and products than does the stone, clay, and glass sector. Unfortunately, the technologies in the literature did not provide sufficient information to assess productivity. To the extent that information was available on energy, natural resources, and wastes, it is discussed in the following sections.

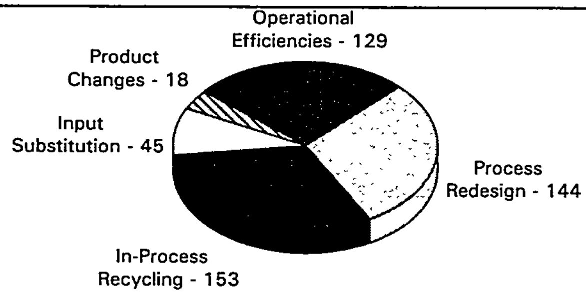

Figure 3.5

Existing Technologies by Strategy (489 Total)

When reviewed by waste-reducing strategy application (Figure 3.5), in-process recycling, process redesign, and operational efficiencies were recorded in roughly equal numbers (~29% of each). There were significantly fewer product-change and input-substitution technologies by comparison.

The 489 existing technologies identified in the literature consisted of a broad range of technologies that were often very specific to a given industry. For example, a successful existing technology for waste reduction involves the making of a polymer byproduct from the manufacture of propylene into caulking for mobile homes. The estimated waste reduction of this technology was 50%, capital investment was $750k, and the annual savings was $8.7 million. (Tsuji)

3.2.4. Current Use by Industry

(c2) - assessment of the current use of such technologies by industry in the United States

In reviewing the 489 individual technologies identified herein, most are in actual use. While many technologies are detailed for a specific company or process, they may be in wider use than indicated by the source document.

In general, the adoption and ultimate use of a technology that reduces waste and saves energy are related to the following factors:

- The technology is seen as cost-effective,
- The technology is known (industry/companies aware of its existence),
- A company or industry is able to adequately assess its need for a technology, or
- There is no other barrier, regulatory, cultural, or otherwise, preventing its use.

3.2.5. Developing Technologies and Projected Availability

(c3) - the status of any such technologies currently being developed, together with projected commercial availability

"Developing" technologies in the literature review were defined as those still in isolated use (i.e., demonstration phase), or clearly still under development. This review found 101 such technologies (Figure 3.6). Because of the smaller set of data found, this group may not be as characteristic of industry activity as is the group of existing technologies. For example, the chemical industry at 11 technologies recorded could be interpreted to be on the same par as stone, clay, and glass, also with 11. This is counterintuitive, however, to the significant level of technology development work incorporating waste and energy reduction in the chemical industry.

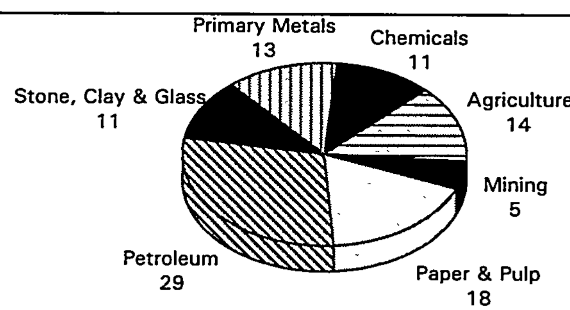

Figure 3.6

Developing Technologies Recorded (101 Total)

Grouped by waste-reduction strategy, nearly half of those recorded involve process-redesign efforts (Figure 3.7). This suggests a strong development effort involving this strategy versus the others.

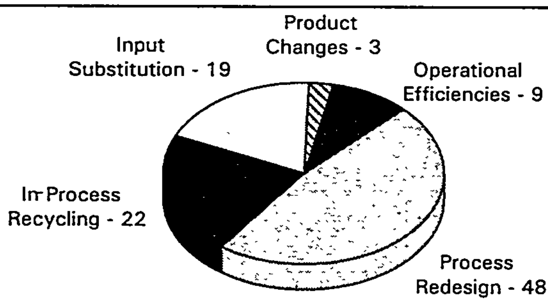

Figure 3.7

Developing Technologies by Strategy (101 Total)

Information on commercial availability of the developing technologies identified was generally not included in the literature. In documenting the technologies, however, it was perceived that most are relatively near-term, with availability estimated to be within a 1- to 4-year period.

As with the existing technologies, the developing technologies tended to be very specific to a given industry. For example, a promising developing technology involves the use of a closed furnace to replace the open hearth furnace in production of silicon and ferrosilicon. Use of this technology is predicted to reduce wastes by over 0.4 million ton/yr by the year 2010, and to save 86 trillion Btu/yr of energy. This technology is expected to be commercialized within 1 to 2 years. (Cranford)

3.2.6. Energy Savings

(c4) - the energy saving resulting from the use of such technologies

As shown previously in Figure 3.3, information on energy efficiency and use was not generally included in the sources. Only 27 provided energy impact information. Of the 16 existing technologies, 14 were from the paper and pulp industry. Of the 11 developing technology sources with energy impact information, 7 are DOE/OIT Industrial Waste Program (IWP) projects, which specifically require energy reduction analysis as part of the project description.

There were eight sources providing a percentage reduction from whatever the "before" condition was. The average reduction of these eight was 31%, with a range from 3% to 80%. In addition, 20 sources provided annual energy savings estimates. The average of these 20 was about 3 trillion Btu/yr, even though a few registered a net energy increase. The range of energy impact for the 20 listings was from a net increase of 56 million Btu/yr, to a net savings of 86 trillion Btu/yr.

One conceivable perspective on the lack of energy impact information in the literature is

"The cost of energy usage is small (typically a few percent for most manufacturing industries) and declining, while the cost of waste disposal and associated liability costs is climbing rapidly; therefore, industry is much more interested in new technologies for waste reduction then for energy savings, even though the same technology often does both." (Kaarsberg, p. 5)

Anecdotal information on the energy savings potential from waste minimization technology development is seen in the existing projects and recent proposals of DOE's IWP:

- Even if only 20% of the current IWP 16 project portfolio proves successful, the estimated impact on U.S. industry energy consumption will be a reduction of 340 trillion Btu/yr by the year 2010. This savings is roughly 1.0% of the current total U.S. industrial energy usage. (Cranford)

- Of industry proposals received in response to competitive solicitations issued during 1992 and 1993, 19 emerged as viable developmental opportunities. The average annual energy savings estimated per project (year 2010) was 120 trillion Btu/yr.

Not every waste-reduction technology would be expected to achieve these levels of energy savings, but reasonable possibilities are shown from these examples.

3.2.7. Environmental Benefits

(c5) - the environmental benefits of such technologies

Of the 590 total entries, 497 recorded specific qualitative environmental benefits. Some of the more common benefits observed were:

- reduction in the quantity of a given waste already being produced
- substitution of a nonhazardous material for a hazardous material
- reduced toxicity of a given waste
- recovery and reuse of a previously discarded waste
- reduced use of water
- reduced air emissions

Of the 590 technologies, 117 provided an actual percentage reduction, or an estimated potential reduction in waste generation. The average reduction was 69%, with a range from 3% to 100%. In addition, 66 listed actual quantity predictions or measurements of waste reduced.

Also, returning to the IWP project and proposal sets identified in the last section:

- It is estimated that the current project portfolio will reduce waste by over 42 million tons/yr by the year 2010 (again, assuming a 20% success rate). This waste reduction is roughly 0.3% of the current total U.S. industrial wastes.

- The 19 IWP proposals have an average waste-reduction forecast of 24 million tons/yr per project.

3.2.8. Costs (and Cost Savings)

(c6) - the costs of such technologies

About 24% of the technologies recorded provided some insight into the expense of implementing the technology and/or an indication of the cost savings. Capital costs for 80 technologies ranged from $17,000 to $400 million. Annual cost savings for 92 technologies were estimated, with three indicating a net loss of annual revenue. The technologies ranged from a net annual loss of $7.1 million to an annual savings of $75 million. The total annual savings to industry of these 92 entries was over $190 million, with an average of $2.3 million saved per year. The average payback period of 63 listings was just over three years. What can be summarized from the technologies recorded that did include cost data is that, in general, the annual savings can be significant. It must be mentioned, however, that the data set is biased in that negative cost impacts are much less likely to be documented in the open literature. Further, the fact that only one out of four technologies included information on costs suggests that it is difficult to account for all of the costs or benefits of pollution prevention, particularly indirect costs such as training or permitting or costs that cannot be predicted such as future liability costs. More information on this subject can be obtained in a recent EPA report on total cost assessment. (EPA 1992)

An example of successful cost-effective waste-reduction implementation is provided in a recent literature search conducted in support of an IWP economic study on U.S. waste-reduction potential. (WERC 1993) The study summarized the economic benefits of 75 industrial-waste-minimization projects. Most involved capital or operating investments with the principal objective of reducing waste. Again, the data are biased in that unsuccessful projects are not likely to be presented as case studies in the literature. Bias acknowledged, the study found that

- the total annual savings of the 75-project portfolio was $34 million,
- the average annual savings was approximately $500,000 per company,

- the average project payback was less than two years (31% of the projects had a payback of fewer than 6 months, and 86% had paybacks of 36 months or less), and
- 55% of the investments were under $100,000.

Furthermore, the existing IWP project portfolio is projected to improve industrial competitiveness through lowering costs by at least $2 billion/yr (by the year 2010—20% success rate). Moreover, the IWP has found that, based on current projects and proposals, industry has a typical minimum return on investment requirement of about 15%. While this certainly varies with economic conditions, degree of perceived risk, and the individual company's financial situation, it is an indicator that for investment purposes, successful waste-reduction projects can provide at least this level of return for an up-front investment.

3. RESULTS-continued

3.3. BARRIERS TO ADOPTION OF WASTE-REDUCTION TECHNOLOGIES

While there is a clear need to reduce industrial wastes, waste-reduction efforts are not widespread. This section provides an overview of some of the issues affecting the development and commercialization of waste-reducing technologies by industry. Review of the material suggests that the regulatory, social, economic, and cultural framework within which industry operates may be as big a factor as technological considerations in the greater use of waste-reduction technologies. Even a brief review of the environment within which the process of waste reduction must occur reveals an extremely complicated mixture of issues—several of which can be either positive or negative depending on the specific nature of any given situation. This review of barriers to adoption of waste reduction technologies focuses on three areas. The first area describes federal regulatory barriers to waste reduction. The second is a very broad-based overview of barriers to adoption of technology in general and related to the following areas: structural shifts in industry, resources, competition, and market conditions. The final area summarizes the barriers and incentives to adoption by industry of waste-reduction technologies specifically identified in the literature and categorized by the following topics: regulatory, economic and financial, technological, corporate management/organization, and cultural.

3.3.1. Regulatory Barriers

Federal regulatory barriers deserve special note because of the role that Congress and the federal government play in making and implementing legislation and the resulting regulation. Most of the legislation and regulations affecting possible waste-reduction efforts were designed to control wastes and pollution that have already been generated—end-of-pipe pollutants—rather than to prevent or to reduce wastes from the start.

Federal regulations have acted as an incentive to waste reduction through the costs they impose on treating and disposing of wastes that are generated. However, they also embody specific disincentives to waste reduction as they not only drain resources that could otherwise be used to develop more efficient processes but they also impose some restrictions on possible waste-reduction efforts. The actual costs of compliance with environmental regulations varies by industry, but can be significant. For example, the Department of Commerce estimates that 20% of the chemical industry's 1992 capital expenditures of $25 billion was for environmental abatement or compliance. In addition to the costs of compliance, federal regulations tend to take a "command and control" approach in which strict requirements must be met. While this approach has been effective in protecting human and environmental health from discharged pollutants, it provides little room for flexibility in achieving compliance. Not only does this approach tend to entrench existing technologies, it actively discourages long-term innovation. Following are three examples of how regulations can preclude using innovative or alternative approaches.

- RCRA was enacted in 1976 to regulate waste generators, waste transporters, and waste management facilities. It contains very specific requirements that must be met regarding the handling and treatment of end-of-pipe pollutants. These requirements present significant obstacles to attempts to recycle, reuse, or reclaim the waste products of an industrial process involving hazardous chemicals.
- Regulations that require treatment and disposal of byproducts of industrial processes within a specific time frame may preclude alternative uses because the time necessary for such an alternative use may be longer than the regulated time frame.
- The permitting process required for industrial processes using products classified as hazardous under RCRA can be difficult, lengthy, and costly, thereby discouraging manufacturers from instituting any change that would require repermitting.

One particular concern in using a "command and control" approach that was mentioned in several journal articles is that the lack of flexibility in this approach provides no incentive for voluntary efforts at waste reduction. It is generally accepted that the first 25% to 50% of waste reduction can be relatively easy and inexpensive, involving "housekeeping" changes. Once these types of changes have been made, waste reduction becomes more expensive and time-consuming. A company that has reduced the wastes it produces by voluntarily using these housekeeping methods is then at a cost disadvantage when later required by regulation to reduce wastes further, compared to a company that has not taken early voluntary waste reduction efforts.

Several sources also noted that the lack of coordination among federal, state, and local regulations is, perhaps, a major way in which regulations can act as disincentives. Federal, state, and local regulations that have been enacted over the past two decades have focused on protecting and enhancing the quality of a specific medium—air, water, or land—by regulating a specific end-of-pipe pollutant. While these regulations have contributed to improving environmental conditions, they have also created a set of uncoordinated requirements—each with different standards, methods of regulation, and administrative requirements. Further, since these standards, methods, and requirements may differ by state or location within a state, the complexity is increased for companies with plants in multiple locations. The inherent complexity of the current regulatory framework increases the burden on industry by requiring compliance with uncoordinated, possibly inconsistent, and potentially changing requirements, and fosters the view of pollution prevention or control as something to be handled only as required rather than as something to be incorporated into process planning and day-to-day business.

3.3.2. General Barriers to the Adoption of Technology

Potential waste-reduction efforts must occur within a broad framework of forces and conditions of which regulation is only a part. In order to develop a picture of the breadth and complexity of this framework, this section focuses on four very broad and general areas and is based on telephone interviews with the experts listed in Appendix E. The discussion is by no means considered to be comprehensive but rather as suggestive of the general environment affecting industry's ability to adopt new technology.

3.3.2.1. Structural Shifts

Structural shifts involve changes that have an effect across industries. Such a shift changes where opportunities for new products or technologies lie as well as changing which companies can take advantage of them. It can be either positive by making new opportunities for better products or for reducing costs, or negative because of the dislocations it produces in the existing economic situation. For example, by switching from steel to plastic, the car manufacturing industry would profoundly affect the steel industry in a negative way just as it would positively affect the plastics industry. The effects of such a shift would range from the obvious immediate economic effects to potential political ramifications if a decision is made to ameliorate the effects of the transition. The affected industries' ability to incorporate change, in conjunction with the speed of such a shift, will determine the potential effects of the change. Industries with long-established technologies, processes, and equipment may be less fluid and so less able to respond to such a shift without severe consequences than would industries that are more fluid because they are already involved in adapting or evolving equipment and/or technologies. The speed with which such a shift takes place can be affected by many things. In the example in which car manufacturers shift from steel to plastic, such a shift may be slowed for many reasons:

- A political decision may be made to slow the shift in order to allow for an easier transition out of concern for steel workers and for maintaining the nation's steel-making capability.
- The public may prefer steel because it is perceived to be safe and reliable or because plastic is not perceived to be as effective as steel. This could, of course, be a marketing consideration as well as a technical issue.
- It may be easier technically for a plant to tool up (change the processes and equipment) for steel parts than for plastic parts.
- Changing the processes and equipment to switch from steel to plastic could involve billions of dollars across the car manufacturing industry, making a possible failure a significant risk.
- A change as fundamental as this would involve meeting many new regulatory requirements. Meeting these requirements would, in turn, increase the costs of the change and decrease potential savings or payback to the company for introducing the change.

3.3.2.2. Resources

Resources can be seen as being of three types: the material inputs embodied in the final product; the capital available to a company or industry for all of its activities; and the people with the training, experience, and skill necessary to combine all of the elements into a final product. There may be barriers to the adoption of a new technology related to any one of these types of resources. The concern regarding material input is not just that a new technology may require more expensive inputs, but that it may require an input that has an uncertain or unstable supply. Using our earlier example of car manufacturers shifting from steel to plastic, management may determine, given the high costs of retooling and uncertainty about the future availability of petroleum, and therefore of plastics, that such a shift is too risky. Because the benefits of a waste-reducing technology are not easily quantifiable and are not all private returns, a waste-reducing technology may not appear to yield as much obvious near-term profit as other possible technological changes that could reduce the time or costs of producing the product. Therefore, waste-reducing technologies may be at a disadvantage in competing for available, and usually limited, capital resources, especially in the potentially high-cost areas of research, development, and demonstration. Finally, people are extremely important resources, and as companies have streamlined their operations over the past few years, the people to conceptualize, develop, and champion new technologies simply may not be available.

3.3.2.3. Competition

To the extent that a waste-reducing technology results in a product that the consumer can differentiate from other similar products—usually either in costs or appearance—such a technology can be a barrier or an incentive. For example, producing gypsum board from waste products or recycled materials may produce a product that is visually not as appealing as a product produced from virgin materials, and, despite a lower cost and the advantage of reducing waste that has to be treated and disposed of, consumers may prefer the latter.

The competitive position of the industry or individual companies may also affect the adoption of waste-reducing technologies. A highly competitive industry may have more incentive to adopt new technologies in general if those technologies will give its product a positive distinction over its competitor's product, or more disincentive, as with the gypsum board example, if the product is negatively affected. It should be noted that to some extent, negative distinctions introduced by a technology that are appearance- or cost-related may be largely solved through effective marketing and information dissemination. Alternatively, a highly concentrated industry in which there is little competition among companies may have less incentive to change or adopt new technologies.

Clearly related to all of these issues is that some companies may be more capable of taking on research and development and change than other companies. A company that has been producing a successful product and has a large investment in existing processes and equipment may find change to be very risky. On the other hand, an industry that is already fluid and changing and rapidly responding to the marketplace, as is the electronics industry, for example, may be able to incorporate change with much less risk and therefore less resistance.

3.3.2.4. Market Conditions

While closely related to the aspects mentioned above, it is clear that market conditions in general will affect an industry's and a company's willingness and ability to invest in waste-reduction efforts versus other competing investment possibilities. The things that will affect this decision include whether the market is depressed or growing; whether an industry is competitive or concentrated; firm size and funds available for research and development at the company level; the industry's ability to accept changes; whether the costs of process and equipment change, of product inputs, or of potential market share loss to the industry is unusually high; the demand for the industry's product; and whether the market is global or national.

3.3.3. Specific Barriers and Incentives to the Adoption of Waste-Reducing Technologies

Waste-reduction efforts must occur within a very broad and complicated context, some aspects of which are discussed above. It is possible, however, to identify areas that may represent specific barriers to the adoption of waste-reduction technologies. Table 1[1] summarizes barriers and incentives to adoption by industry of waste-reducing technology in the areas listed below.

- Regulatory: Environmental regulations, while effective at pollution control, tend to be uncoordinated, costly in resources and time, inflexible, and inconsistently enforced, all of which discourage innovative or voluntary action.
- Economic and Financial: Because it is difficult to quantify the benefits of waste reduction and because innovation can be both costly and risky, waste-reduction technologies may have difficulty competing for available capital resources.
- Technological: The development of a new technology, and marketing of the resulting product, can be a long and expensive process, and there is no guarantee that taking on this task will result in an economic payoff. The costs may be especially burdensome, if not prohibitive, for smaller companies.

[1]Table 1 is based primarily on information in: EPA. *Compendium of Pollution Prevention Barriers and Incentives.* (Final Draft). Office of Solid Waste and Emergency Response, U.S. Environmental Protection Agency. Washington, D.C. March 1993. We also reviewed 60 documents, listed in the appendix, and included the barriers and incentives identified in those documents that were not already listed in the EPA report. These additions were extremely few and tended to be further clarification or expansions of items described in the EPA report.

- Corporate Management/Organization: Corporate management is responsible for producing a profitable and effective product. This ultimate responsibility will affect any decisions about adopting new technologies.
- Cultural: An atmosphere in which waste reduction is held to be important and valuable by the interested parties—industry, government, and the public—as well as in which information about waste reduction and waste reduction technologies is readily available, will affect the ultimate value to and interest by industry in adopting waste-reduction technologies.

A final note on barriers to adoption of waste-reduction technologies: As part of the effort to identify waste-reduction technologies for this report, we looked for barriers identified in the literature that were associated with the specific technologies and found that the waste-reduction technologies identified in the public domain do not tend to identify barriers to their adoption. However, in developing the overview sections for each industry for which information was collected, the unique nature of each industry was highlighted. Where one industry is founded on well-established processes and large expensive equipment, another is currently actively involved in reviewing new technologies and in sharing information on those technologies. Where one industry is in a precarious financial position, another has a strong and stable financial outlook. The characteristics of a specific industry will be important in determining its ability to take on new technology in general and waste-reducing technologies specifically, as will the regulatory, social, economic, and cultural framework within which the industry operates.

Table 1. Summary of Barriers and Incentives to Industrial Waste Reduction

	BARRIERS	INCENTIVES
Regulatory	Regulations may discourage innovation because of the additional regulatory requirements associated with the innovations. For example, almost any modification to a facility will require a time-consuming and costly process to obtain a permit, as well as additional reporting and tracking requirements.	Stringent regulations may provide incentives for waste minimization in order to avoid or lessen compliance burdens.
	The permitting process can be lengthy, costly, and difficult.	Mandated pollution-prevention and waste-minimization programs encourage companies to develop formal waste minimization programs that demonstrate a commitment to waste reduction.
	Ambiguous definitions, confusing regulations, and inconsistent application of regulations across federal, state, and local agencies discourage innovation by creating an atmosphere of uncertainty.	Flexibility in regulatory compliance requirements (for example, waivers or extensions) may encourage companies to innovate and implement waste-minimization technologies.
	Innovative systems may be subject to more stringent, and therefore more expensive, regulatory requirements than existing processes.	Changes to the current permitting system, which industry perceives to be costly and overly burdensome, may encourage innovation.
	EPA's "command and control" regulatory system, through inflexibility, may discourage innovative waste minimization systems. For example, compliance deadlines or specified treatment standards may give insufficient lead-time for adopting new technologies.	New regulations that emphasize pollution prevention and waste minimization may allow for more flexible enforcement and increased enforcement ability.
	Lack of coordination among federal, state, and local regulations creates confusion and additional burden upon the regulated community.	
	Enforcement of regulations is inconsistent, encouraging companies to meet the bare minimum requirements.	

	BARRIERS	INCENTIVES
Economic and Financial	As available capital is usually limited, only projects with the highest rates of return are funded. This may mean that pollution-prevention/waste-minimization projects are not funded as they are difficult to value properly. To the extent that the market in general is weak, this effect is compounded.	Reducing or eliminating waste generation can reduce regulatory compliance costs and reduce a company's potential liability for as-yet unidentified risks.
	The costs associated with innovative technologies can be extremely high, making proven waste-management techniques less costly than unproven waste-minimization efforts. This can be especially true for companies with a large investment in existing equipment or processes or for small companies.	Waste generation is becoming increasingly expensive due to fees and taxes designed to capture the true costs of disposal.
	Current cost accounting practices often do not incorporate the full benefits of pollution prevention, therefore masking their financial benefits.	Governmental assistance, especially for smaller companies lacking necessary capital, may make development and implementation of pollution-prevention and waste-minimization technologies more affordable.
Technological	To the extent that pollution-prevention technologies are unproven, companies are hesitant to implement systems with uncertain reliability or potential quality reduction in product.	Where adaptable and affordable technologies and equipment already exist, firms can avoid R&D costs.
	Adopting an alternative process may involve technical problems and difficulties as well as halting operations, all of which have a cost to the company.	
	Many companies do not have the expertise in-house to design or implement pollution-prevention technologies.	
	Because of the great diversity within many industries, available technologies must be customized for each plant.	
	New technology may require inputs that are expensive or that have an uncertain supply.	

	BARRIERS	INCENTIVES
Corporate Management/ Organization	Most companies prefer to maintain the status quo as long as profitability does not decrease—"unnecessary" changes are viewed as "unnecessary risk." A company with a large investment in the status quo—existing processes and equipment—may be most likely to view change as unnecessary and risky. Senior management provides little support for middle- and lower-level managers to take the initiative on pollution prevention. Two types of organizational difficulties may impede pollution prevention progress. Companies may have separate production staff, compliance staff, and/or environmental staff. In addition, responsibility for implementation may rest with mid-level managers who do not have decision-making authority. Waste minimization and pollution prevention often lack funding, staffing, and support because they are seen as long-term goals, not immediate needs.	Long-term commitment and support from top managers and decision-makers encourage new ideas and attitudes toward implementation of waste-minimization/pollution-prevention activities.
Cultural	Lack of meaningful discussion on pollution prevention/waste minimization among industry, government, and public actors. Companies will not want to alienate consumers by switching from a perceived "safe" technology to a new, unproven one, or from the resulting accepted and successful product to a product that is perceived as different and therefore unproven. Waste minimization and pollution-prevention practices can improve a company's image within the community as well as with potential customers. Public pressure can be an incentive when waste production, reduction, and treatment information is made public.	Information on available technologies and potential benefits is not being transferred adequately to industry to stimulate pollution prevention. There are few ways to quantify the success of various pollution-prevention programs. Industry is often suspicious of the reliability of available information. Federal and state sponsored information networks help disseminate reliable information to interested parties.

4. SUMMARY OF KEY FINDINGS

1. Industry is very diverse and complex. Because of this complexity and resource limitations, a complete assessment of energy-efficient pollution-prevention technology demonstration opportunities will not be concluded by October 1993. This is an ongoing activity within the DOE Industrial Waste Program.

2. Opportunities for demonstration/development of energy-efficient pollution-prevention technologies and processes have been identified for the chemical and petroleum industries.

3. Seven industries provide the overwhelming preponderance of waste generation, energy use, and pollution abatement expenditures. These industries—agriculture; mining; paper and pulp; chemicals; petroleum refining; stone, clay and glass; and primary metals—provide the focus for this EPAct Section 2108 response.

4. A review of the open literature supplied 590 specific existing and developing technologies with waste reduction as a principal objective. Those recorded are not an inclusive list of all technologies, but serve as a reasonable framework of current activity within the targeted industry sectors.

5. Though quantitative data on waste reduction and cost impacts were not prevalent in the open literature, those providing this type of information showed significant environmental benefits and favorable economics resulting from adoption of waste-reducing technologies. Though acknowledged as a biased set of information, the potential positive effects of waste reduction are clearly demonstrated.

6. Very little information on energy efficiency impacts from waste-reduction technology implementation was seen in the open literature. It is likely that energy efficiency itself is not a substantial driver for industry's implementing pollution-prevention technologies, but instead is seen as an auxiliary benefit.

7. A majority of activities identified from the open literature involve redesign of the production process as a key strategy for waste reduction, particularly for technologies under development. In-process recycling and operational efficiency measures are also common strategies.

8. The forces and conditions encouraging and discouraging adoption of waste-reducing technology are highly complex and interrelated. Further, while there are barriers that are identifiable across industries, there are also barriers that are industry- and even company-specific. Non-technological barriers are fundamentally a large issue in the advancement of waste minimization business practices and technology implementation. Company-specific, public, and federal attitudes play a critical role in the ultimate success and time frame.

APPENDIX A

ENERGY POLICY ACT, SECTION 2108—LEGISLATION

SEC. 2108. ENERGY EFFICIENT ENVIRONMENTAL PROGRAM.

(a) Program Direction.—The Secretary, in consultation with the Administrator of the Environmental Protection Agency, is authorized to continue to carry out a 5-year program to improve the energy efficiency and cost effectiveness of pollution prevention technologies and processes, including source reduction and waste minimization technologies and processes. The purposes of this section shall be to—

(1) apply a systems approach to minimizing adverse environmental effects of industrial production in the most cost effective and energy efficient manner; and

(2) incorporate consideration of the entire materials and energy cycle with the goal of minimizing adverse environmental impacts.

(b) Identification of Opportunities.—Within 9 months after the date of enactment of this Act, the Secretary, in consultation with the Administrator of the Environmental Protection Agency, shall identify opportunities for the demonstration of energy efficient pollution prevention technologies and processes.

(c) Report.—Within 1 year after the date of enactment of this Act, the Secretary shall submit a report to Congress evaluating the opportunities identified under subsection (b). Such report shall include—

(1) an assessment of the technologies available to increase productivity and simultaneously reduce the consumption of energy and material resources and the production of wastes;

(2) an assessment of the current use of such technologies by industry in the United States;

(3) the status of any such technologies currently being developed, together with projected schedules of their commercial availability;

(4) the energy savings resulting from the use of such technologies;

(5) the environmental benefits of such technologies;

(6) the costs of such technologies;

(7) an evaluation of any existing Federal or State regulatory disincentives for the employment of such technologies; and

(8) an evaluation of any other barriers to the use of such technologies.

In preparing the report required by this subsection, the Secretary shall consult with the Administrator of the Environmental Protection Agency, any other Federal, State, or local official the Secretary considers necessary, representatives of appropriate industries, members of organizations formed to further the goals of environmental protection or energy efficiency, and other appropriate interested members of the public, as determined by the Secretary.

(d) Proposals.—Within 1 year after the date of enactment of this Act, the Secretary, in consultation with the Administrator of the Environmental Protection Agency, shall solicit proposals for activities under this section. Proposals selected under this subsection shall demonstrate—

(1) technical viability and cost effectiveness; and

(2) procedures for technology transfer and information outreach during and after completion of the project.

APPENDIX B

TECHNOLOGIES DOCUMENTED FOR SELECTED INDUSTRIES

This appendix contains the summary records of technologies identified in the open literature search. Tables and figures which summarize information in the specific tables is provided first. Acronyms and abbreviations used are at the end of this Appendix.

The detailed technology listings are organized and listed by

i. industry
ii. existing/developing technology
iii. waste reduction strategy (see descriptors below).

At the end of each industry section, the references specific to that section are provided. Descriptions of the column headings are also provided.

Appendix B Contents

Waste Reduction Strategy Descriptions

Process redesign--refinements or alterations in the production process itself

In-process recycling--waste is reclaimed and processed to recover a usable product, or reused within the industrial process

Input substitution--substituting a material for one that is less toxic or that causes less of a waste treatment or disposal problem; also includes input purification

Product changes--redesigning the end product to optimize material use and minimize waste

Operational efficiencies--various measures taken to reduce waste--includes things like plant maintenance and production practices, inventory control, employee training, waste steam segregation, spill/leak prevention, scheduling improvement, and the use of computers for monitoring and analysis

Table B-1
Overall Numbers of Technologies Recorded by Industrial Sector

Industrial Sector	# Existing Technologies Listed	# Developing Technologies Listed	Total
Agriculture	44	14	**58**
Mining	29	5	**34**
Paper & Pulp	67	18	**85**
Chemical	145	11	**156**
Petroleum	101	29	**130**
Stone, Clay, & Glass	15	11	**26**
Primary Metals	88	13	**101**
Totals	**489**	**101**	**590**

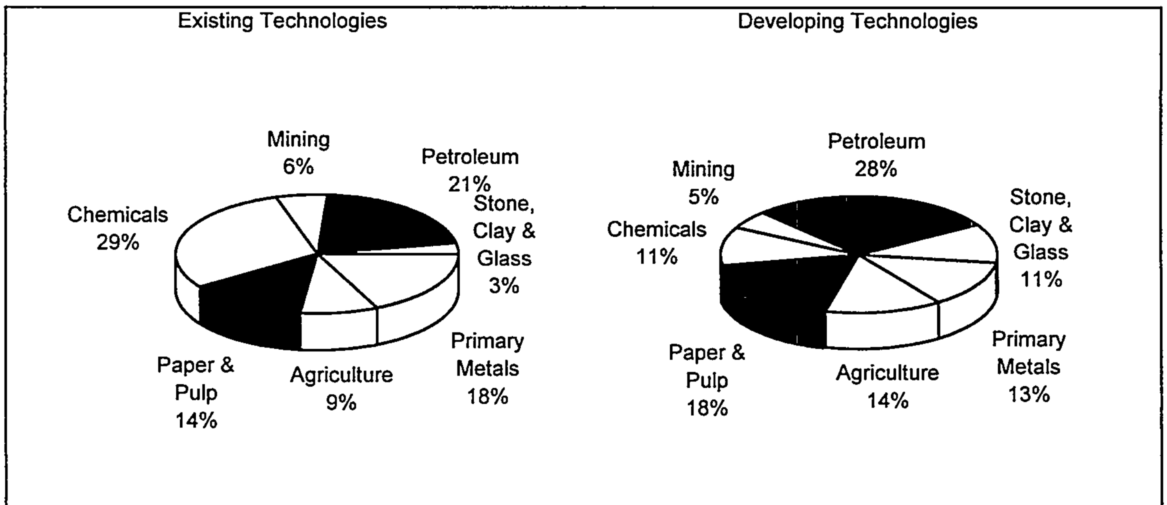

Figure B-1
Percentage Breakdown of Technologies Recorded by Industrial Sector

Table B-2
Number of Technologies Recorded by Industry and Waste Reduction Strategy

	Process Redesign		In Process Recycling		Input Substitution		Product Changes		Operational Efficiencies	
INDUSTRIAL SECTOR	Existing Tech Listed	Devping Tech Listed	Existing Tech Listed	Devping Tech Listed	Existing Tech Listed	Devping Tech Listed	Existing Tech Listed	Devping Tech Listed	Existing Tech Listed	Devping Tech Listed
Agriculture	8	2	1	0	3	5	1	3	31	4
Mining	7	1	10	4	6	0	0	0	6	0
Paper & Pulp	41	13	17	1	8	4	0	0	1	0
Chemical	24	9	61	1	12	1	13	0	35	0
Petroleum	37	11	35	9	5	4	2	0	22	5
Stn, Clay, Gls	8	3	2	4	3	4	2	0	0	0
Primary Mtls	19	9	27	3	8	1	0	0	34	0
Totals	**144**	**48**	**153**	**22**	**45**	**19**	**18**	**3**	**129**	**9**

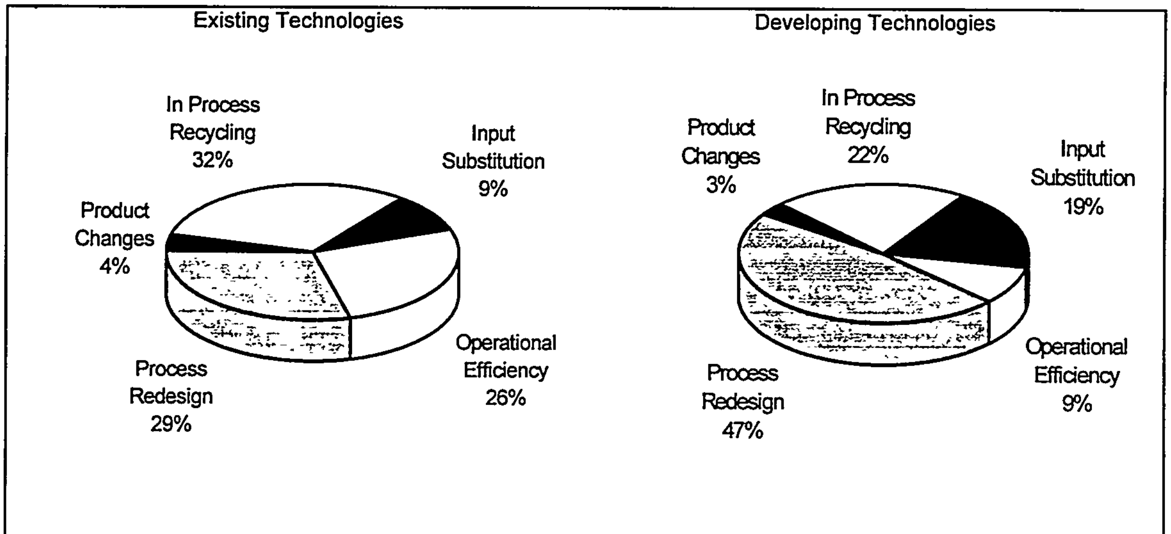

Figure B-2
Percentages of Technologies Recorded by Waste Reduction Strategy

Table B-3
Summary Table of Technologies Recorded with Energy, Waste or Cost Data

Summary	Total # Technologies	# With Energy Data	# With Waste Data	# With Cost Data
Existing	489	16	137	122
Developing	101	11	27	19
Totals	**590**	**27**	**164**	**141**

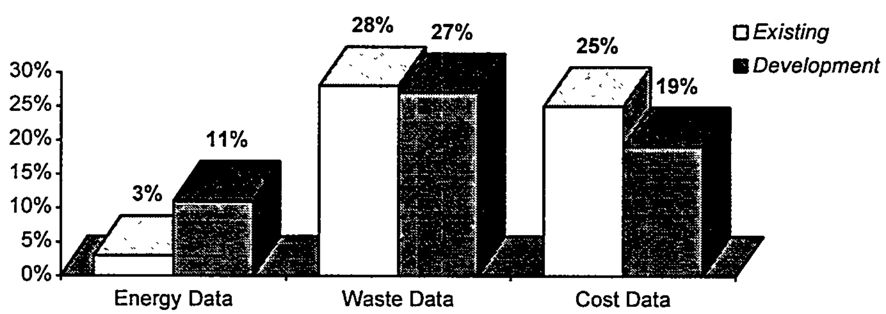

Figure B-3
Percentage of Technologies Recorded That Included Energy, Waste, or Cost Data

Table B-4
Overall Number of Technologies Recorded by Waste-Reduction Strategy and Industrial Sector

		Existing Technologies				Developing Technologies			
Waste - Reduction Strategy	Industrial Sector	Total # Tech.	# With Energy Data	# With Waste Data	# With Cost Data	Total # Tech.	# With Energy Data	# With Waste Data	# With Cost Data
Process Redesign	Agriculture	8	0	1	0	2	0	0	0
	Mining	7	0	1	1	1	1	0	0
	Paper & Pulp	41	11	26	25	13	1	3	3
	Chemical	24	0	10	9	9	6	5	1
	Petroleum	37	0	14	5	11	1	9	4
	Stone, Clay, & Glass	8	0	2	2	3	1	0	0
	Primary Metals	19	2	2	4	9	1	0	2
	Totals	*144*	*13*	*56*	*46*	*48*	*11*	*17*	*10*
In-Process Recycling	Agriculture	1	0	0	0	0	0	0	0
	Mining	10	0	1	0	4	0	1	1
	Paper & Pulp	17	0	6	8	1	0	1	1
	Chemical	61	0	22	30	1	0	0	0
	Petroleum	35	0	9	4	9	0	2	0
	Stone, Clay, & Glass	2	0	1	0	4	0	1	2
	Primary Metals	27	0	3	6	3	0	0	1
	Totals	*153*	*0*	*42*	*48*	*22*	*0*	*5*	*5*
Input Substitution	Agriculture	3	0	0	0	5	0	0	0
	Mining	6	0	1	0	0	0	0	0
	Paper & Pulp	8	3	5	4	4	0	3	3
	Chemical	12	0	3	1	1	0	0	0
	Petroleum	5	0	2	2	4	0	1	0
	Stone, Clay, & Glass	3	0	0	0	4	0	0	0
	Primary Metals	8	0	0	1	1	0	0	0
	Totals	*45*	*3*	*11*	*8*	*19*	*0*	*4*	*3*
Product Changes	Agriculture	1	0	0	0	3	0	0	0
	Mining	0	0	0	0	0	0	0	0
	Paper & Pulp	0	0	0	0	0	0	0	0
	Chemical	13	0	3	1	0	0	0	0
	Petroleum	2	0	1	0	0	0	0	0
	Stone, Clay, & Glass	2	0	0	0	0	0	0	0
	Primary Metals	0	0	0	0	0	0	0	0
	Totals	*18*	*0*	*4*	*1*	*3*	*0*	*0*	*0*
Operational Efficiencies	Agriculture	31	0	1	1	4	0	0	0
	Mining	6	0	0	0	0	0	0	0
	Paper & Pulp	1	0	0	0	0	0	0	0
	Chemical	35	0	15	15	0	0	0	0
	Petroleum	22	0	6	2	5	0	1	1
	Stone, Clay, & Glass	0	0	0	0	0	0	0	0
	Primary Metals	34	0	2	1	0	0	0	0
	Totals	*129*	*0*	*24*	*19*	*9*	*0*	*1*	*1*

<u>Descriptions of Columns Found in Technology Tables</u>

Product: Overall product description.

Waste reduction technology description: A brief description of the technology is given.

Environmental benefits: Any environmental benefits that have been accrued (for existing technologies) or may potentially result (for new technologies) from the technology's use.

Estimated energy savings: The net energy savings that has resulted from (for existing technologies) or is expected to result from (for new technologies) the specific technology's use. (Reported by either percentage or quantity, or by both if available).

Estimated waste reduction: The amount of liquid or solid waste reduction that has resulted from (for existing technologies) or is expected to result from (for new technologies) the specific technology's use. (Reported by either percentage or quantity, or by both if available.)

Effects: Any information, including legislative, regulatory, economic, technical, etc., on the effects of the specific technology's continued use (existing technologies) or introduction (new technologies) are cited, if the information is available.

Capital investment: Capital investment costs include total up-front costs associated with the program or project, including new equipment, process changes, equipment modifications, and associated installation/changeover (labor and materials) costs.

Annual cost savings: Any cost savings projected on an annual basis is included. This includes savings obtained from reductions in disposal, raw material, liability, and other operating costs.

Payback period: The time period within which the investment is recovered. To calculate the payback period, the installed capital investment cost is divided by the net annual cost savings.

Reference year: The date of the reference document.

Reference: An abbreviated, coded reference is noted. See the attached reference list (just behind the industry sector tables) for complete reference information.

AGRICULTURE - EXISTING TECHNOLOGIES

Existing Waste-Reducing Technologies Found in the Open Literature - Listed by Waste-Reduction Strategy

Process Redesign

Product	Waste-Reduction Technology Description	Environmental Benefits	Estimated Energy Savings	Estimated Waste Reduction	Effects	Capital Investment	Annual Cost Savings	Payback Period (yrs)	Ref. Year	Ref.
Crops	Crop rotation	Eliminates fungicide applications; reduces application of granular insecticide; cuts frequency of insecticide spraying			Lower production costs; U.S. farm policy discourages this technique—commodities programs pay farmers based on yield				1988	NC8
Crops	Mechanical weeding	Reduced pesticide usage		50%	Used in combination w/ridge tilling or other special planting techniques, cuts pesticide use & erosion by >50%; need more labor & mgmt; U.S. farm policy discourages adoption					
Crops	Chemigation practices to prevent ground water contamination	Prevents over-application of pesticides			More uniform pesticide distribution; reduced mechanical crop damage; reduced operator hazards				1988	NC1
Crops	Gravity flow in-field sprayer rinse system to reduce pesticide waste	Protects water supply & environment from unnecessary pesticide contamination			Easy to use, inexpensive (less than $100)				1988	NC2
Crops	Pressure flow in-field sprayer rinse system to reduce pesticide waste	Protects water supply & environment from unnecessary pesticide contamination			Easy to use, inexpensive ($100)				1988	NC2
Crops	Application of machine vision to shape analysis in leaf & plant identification	Minimizes pesticide usage			Problem w/variability that exists in biological environment; rule-based pattern recognition system causes the identifying features to become discrete				1993	TASAE3
Crops	Reverse jet compressed air cleaned filter dust collectors	Reduced dust pollution; reduced occupational disease & explosion risk			Can remove dust from fabric while in operation, allowing control air quantities to remain constant; can operate for long uninterrupted pds & handle high dust loads; reduce machinery failure & liability				1992	AE2

AGRICULTURE - EXISTING TECHNOLOGIES

Existing Waste-Reducing Technologies Found in the Open Literature - Listed by Waste-Reduction Strategy

Product	Waste-Reduction Technology Description	Environmental Benefits	Estimated Energy Savings	Estimated Waste Reduction	Effects	Capital Investment	Annual Cost Savings	Payback Period (yrs)	Ref. Year	Ref.
Crops	Use of resistant cultivars to reduce pest crop damage	Reduced need for pesticides			Production cost savings due to reduced pesticide usage (potential savings range from $5-20/acre--herbicides, $5-25/acre--fungicides, & $20-30/acre--insecticides)				1988	NC8

In-Process Recycling

Product	Waste-Reduction Technology Description	Environmental Benefits	Estimated Energy Savings	Estimated Waste Reduction	Effects	Capital Investment	Annual Cost Savings	Payback Period (yrs)	Ref. Year	Ref.
Livestock	Highly efficient sequencing reactor converts livestock waste to methane gas	Reduced animal manure into municipal waste steams & surface & ground water			Converts waste into methane for cogeneration at farms, feedlots, & animal processing plants				1993	FC

Input Substitution

Product	Waste-Reduction Technology Description	Environmental Benefits	Estimated Energy Savings	Estimated Waste Reduction	Effects	Capital Investment	Annual Cost Savings	Payback Period (yrs)	Ref. Year	Ref.
Crops	Substitution of less toxic, less persistent or less leachable pesticides	Reduced surface & groundwater pollution							1988	NC7
Crops	Use of natural predators for pest control	Reduced pesticide usage			Lower production costs				1989	BW1
Livestock/ crops	Conversion of animal fat & plant oils into vitamins, antioxidants, pharmaceuticals, & non-phosphate soaps, shampoos, & cleaners	Reduced processed animal & plant waste into waste stream			Waste recovery				1993	FC

Product Changes

Product	Waste-Reduction Technology Description	Environmental Benefits	Estimated Energy Savings	Estimated Waste Reduction	Effects	Capital Investment	Annual Cost Savings	Payback Period (yrs)	Ref. Year	Ref.
Crops	Bacillus thuringiensis (Bt) "bio-rational" pesticide that produces protein toxic to some insects	Pesticide breaks down quickly into harmless components			Short field life; affects only insects that eat from the protected plant				1992	WRI1/ WRI2

Existing Waste-Reducing Technologies Found in the Open Literature - Listed by Waste-Reduction Strategy

Operational Efficiencies

Product	Waste-Reduction Technology Description	Environmental Benefits	Estimated Energy Savings	Estimated Waste Reduction	Effects	Capital Investment	Annual Cost Savings	Payback Period (yrs)	Ref. Year	Ref.
Crops	Ridge tilling	Reduced pesticide usage		50%	Used in combination with mech. weeding cuts pesticide use & erosion by >50%; need more labor & mgmt; U. S. farm policy discourages adoption				1989	BW2
Crops	Banding herbicides for weed control	Reduced pesticide usage			Production cost savings on pesticides				1988	NC8
Crops	Accurate pest & weed identification	Reduced pesticide usage			Aids in pesticide selection, rate, timing, & application method; more cost-effective use of chemicals				1988	NC8
Crops	Soil sampling for lime & fertilizer requirements	Reduced pesticide usage			Lower production costs due to reduced pesticide needs				1988	NC8
Crops	Recording & analyzing field histories for pests, fertility levels, previous cropping & pesticide treatments	Reduced pesticide usage			Lower production costs				1988	NC8
Crops	Using expert & decision support systems to resolve conflicting irrigation & insecticide scheduling recommendations	Minimizes pesticide usage							1992	TASAE1
Crops	Using visual images to gather information about the spectrum & distribution of weed seedling populations in fields	Minimizes pesticide usage			Relatively high error rate				1991	TASAE2
Crops	Irrigation scheduling via computer	Reduces need for pesticides			Lower pesticide expenses; implementation costs $0.40/acre				1988	NCS
Crops	Using oil as dust suppressants in grain-handling facilities	Reduced dust pollution; reduced occupational disease			Minimizes worker liability				1992	TASAE4
Crops	Soil sampling for nematodes	Reduced need for nematicide applications			Because soil-applied nematicides are expensive, sampling indicates whether needed or not	$80-120/acre			1988	NC8

AGRICULTURE - EXISTING TECHNOLOGIES

Existing Waste-Reducing Technologies Found in the Open Literature - Listed by Waste-Reduction Strategy

Product	Waste-Reduction Technology Description	Environmental Benefits	Estimated Energy Savings	Estimated Waste Reduction	Effects	Capital Investment	Annual Cost Savings	Payback Period (yrs)	Ref. Year	Ref.
Crops	Local proximity hoods at dust generation points (in farm bldgs, mills & other facilities)	Reduced dust pollution; reduced occupational disease & explosion risk			Reduced product waste; reduced machinery failure; minimized liability				1992	AE2
Crops	Enclosures for fixed locations for dust containment	Reduced dust pollution; reduced occupational disease & explosion risk			Reduced product waste; reduced machinery failure; minimized liability				1992	AE2
Crops	Cyclones for dust collection & separation	Reduced dust pollution; reduced occupational disease & explosion risk			Not good when fine dust involved, dust carryover in cleaned air, discharged from cyclone--air vented out of bldg. takes heat with it; reduced machinery failure; minimizes liability				1992	AE2
Crops	Mechanical shake fabric filters for intermittent or continuous dust collection	Reduced dust pollution; reduced occupational disease & explosion risk			Work well if can be stopped at regular intervals to allow shaker system to operate; must be sized for worst operating conditions; can be used for many manual operations				1992	AE2
Crops	Various techniques to prevent particle formation incl. disease prevention in the field, decay prevention & insect infestation prevention, pesticide min., & feed preparation techniques to minimize fine particle formation	Reduced dust pollution; reduced occupational disease & explosion risk			Reduced product waste; reduced machinery failure; minimized liability				1992	AE1
Crops	Leakproof ducting & conveyor systems for grain & concentrate feeds to capture dust at primary sources	Prevents particle release & dust cloud formation; reduced occupational disease & explosion risk			Minimizes worker liability				1992	AE1
Crops	Crop maturation acceleration to make crops less susceptible to insect damage	Reduced insecticide usage			Increases yield & quality, better market price				1988	NC8
Crops	Vacuum dust from floors, ledges, etc., to control dust at secondary source points	Prevents particle release & dust cloud formation; reduced occupational disease			Minimizes worker liability				1992	AE1

Existing Waste-Reducing Technologies Found in the Open Literature - Listed by Waste-Reduction Strategy

Product	Waste-Reduction Technology Description	Environmental Benefits	Estimated Energy Savings	Estimated Waste Reduction	Effects	Capital Investment	Annual Cost Savings	Payback Period (yrs)	Ref. Year	Ref.
Crops	Microprocessor-controlled milling systems to reduce dust	Prevents particle release & dust cloud formation; reduced occupational disease			Minimizes worker liability				1992	AE1
Crops	Air swept grain storage systems to reduce worker exposure to dust	Prevents particle release & dust cloud formation; reduced occupational disease			Minimizes worker liability				1992	AE1
Crops	Filtered air in tractor & combine harvester cabs	Reduced occupational disease			Minimizes worker liability				1992	AE1
Crops	Discrete control/observation rooms in mills, dryers, & other facilities	Reduced occupational disease			Minimizes worker liability				1992	AE1
Crops	Regular & systematic scouting to evaluate pest populations	Reduced pesticide usage			Gives producer time to evaluate treatment options that may save money & pesticide				1988	NC8
Crops	Using economic threshold (ET) to determine pesticide treatment needs	Reduced pesticide usage			Lower production costs				1988	NC8
Crops/ Livestock	Ventilation systems to remove suspended particles from enclosed workspaces	Removes suspended particles from enclosed work spaces; reduced occupational disease			Minimizes worker liability				1992	AE1
Crops/ Livestock	Air cleaning by filtration to remove suspended particles from enclosed workspaces	Removes suspended particles from enclosed work spaces; reduced occupational disease			Minimizes worker liability				1992	AE1
Crops/ Livestock	Air ionization to precipitate particles for dust control in enclosed workspaces	Removes suspended particles from enclosed work spaces; reduced occupational disease			Minimizes worker liability				1992	AE1
Crops/ Livestock	Management-worker education & "persuasion"				Minimizes worker liability				1992	AE1
Livestock	Altering temperature & relative humidity for dust control within enclosed livestock units	Prevents particle release & dust cloud formation; reduced occupational disease			Minimizes worker liability				1992	AE1
Livestock	Adjusting stock rate within enclosed livestock units to control dust at primary source	Prevents particle release & dust cloud formation; reduced occupational disease			Minimizes worker liability				1992	AE1
Livestock	Volumetric space/animal (space plan./planning) within enclosed livestock units to control dust at primary source	Prevents particle release & dust cloud formation; reduced occupational disease			Minimizes worker liability				1992	AE1

AGRICULTURE - DEVELOPING TECHNOLOGIES

Developing Waste-Reducing Technologies Found in the Open Literature - Listed by Waste-Reduction Strategy

Process Redesign

Product	Waste-Reduction Technology Description	Environmental Benefits	Estimated Energy Savings	Estimated Waste Reduction	Effects	Capital Investment	Annual Cost Savings	Payback Period (yrs)	Ref. Year	Ref.
Crops	Direct injection of pesticides into a spray system as a rinse water minimization technology	Reduces human exposure to pesticides; reduces hazards associated w/measuring, mixing, & the transfer of mixed spray materials			Eliminates/significantly reduces the generation of unused mixtures; quick, easy method of sprayer cleaning; improved sprayer efficiency; reduced chemical & waste disposal costs; less flexible, product specific; more complex skill & training required, expensive				1987	EPA5
Crops	Ground application of wind-assisted dispersal technique as a control tactic in range caterpillar IPM program	Optimizes pesticide use			More efficient application of pesticides				1987	Huddleston et al.

Input Substitution

Product	Waste-Reduction Technology Description	Environmental Benefits	Estimated Energy Savings	Estimated Waste Reduction	Effects	Capital Investment	Annual Cost Savings	Payback Period (yrs)	Ref. Year	Ref.
Crops	Introduction of exotic insects to control exotic weeds, leafy spurge & knapweed	Reduced herbicide usage							1993	Thompson
Crops	Biological control of native snakeweeds & locoweeds using existing native herbivores	Reduces, eliminates, or extends life of herbicide treatments							1993	Thompson
Crops	Using molecular biological techniques to help characterize nematode-induced feeding site development	Reduces nematicide use			Minimizes pesticide expenditures				1993	Thompson et al.
Crops	Incorporation of novel genes for collagenase production into crop plants to control nematodes	Reduces nematicide use			Minimizes pesticide expenditures				1993	Thomas & Kemp
Crops	Collagenase expression in transgenic plants: an alternative to nematicides	Reduces chemical pesticide use; reduces groundwater contamination			Minimizes pesticide expenditures; increases crop productivity				1991	Havstad

AGRICULTURE - DEVELOPING TECHNOLOGIES

Developing Waste-Reducing Technologies Found in the Open Literature - Listed by Waste-Reduction Strategy

Product	Waste-Reduction Technology Description	Environmental Benefits	Estimated Energy Savings	Estimated Waste Reduction	Effects	Capital Investment	Annual Cost Savings	Payback Period (yrs)	Ref. Year	Ref.
Product Changes										
Crops	Microbial inocula to diminish need for chemical fertilization and pest control	Reduced fertilizer and pesticide usage			Reduced expenses for fertilizer & pesticides				1992	WRI1
Crops	Modification of genetic characteristics to diminish need for chemical fertilization & pest control	Reduced fertilizer and pesticide usage			Reduced expenses for fertilizer & pesticides				1992	WRI1/ SC
Crops	Genetic engineering of nitrogen fixation	Makes synthetic fertilizers unnecessary; manufacture of these fertilizers currently consumes 2% of all ind. energy; reduced nitrous oxide emission			Fear that use of synthetic herbicides may lead to increased use of herbicides; fear that releasing genetically-modified organisms might result in unintended disaster				1992	WRI1/ SA
Operational Efficiencies										
Crops	Spurred anoda interference to determine if weed infestation warrants treatment	Reduced pesticide usage			Minimizes pesticide costs				1992	Schroeder
Crops	Interaction between weeds & pathogenic root-knot nematodes	Reduced pesticide usage			Minimizes pesticide costs				1993	Schroeder
Crops	Characterizing the influence of traditional rangeland insecticide treatments on native herbivores of native weeds	Reduced pesticide usage							1993	Thompson
Crops	Computer monitoring of fertilizer, pesticide, & water inputs using electr., chemical, &/or biological sensors	Minimizes pesticide usage			Appropriation depends on a synthesis of developments in the information sciences & other fields outside ag; Ag policies have favored conventional chemical-intensive farming techniques				1992	WRI1

TABLE REF	AGRICULTURAL PRODUCTION TECHNOLOGIES REFERENCES
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AE2	Whitehead, John, "Dust control for the agricultural industry," *Agricultural Engineer*, Spring 1992, pp. 17-19.
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FG	________, "Understanding Technology Transfer--The importance of research applying agricultural biotechnology to world markets," Fahrenheit Group, 1993.
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Huddleston et al.	Huddleston, E. W., Sanderson, R., Ross, J. B., and Henderson, J. A., "Comparison of a Wind-assisted Dispersal Technique and Aerial Application for Range Caterpillar (Lepidoptera: Saturniidae) Management," *Journal of Economic Entomology*, Vol. 80, No. 1, February 1987, pp. 226-229.
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NC8	Haning, Blanche C. and Smolen, Michael D., eds., "Reducing Pesticides and Saving Money Using Integrated Pest Management (IPM)," *Pesticides and Water Quality Fact Sheet #8*, North Carolina Agricultural Extension Service series, North Carolina Pollution Prevention Program, Raleigh, North Carolina, 1988.
SA1	Ross, Marc H. and Steinmeyer, Daniel, "Energy for Industry," *Scientific American*, Vol. 263, No. 3, September 1990, p. 98.
SC	Moffat, Anne S., "Corn Transformed," *Science*, Vol. 249, 1990, p. 630.

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TASAE1	Batchelor, W. D. and McClendon, R. W., "A Blackboard Approach for Resolving Conflicting Irrigation and Insecticide Scheduling Recommendations," *Transactions of the American Society of Agricultural Engineers*, Vol. 35, No. 2, March-April 1992, pp. 741-747.
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Thompson	Thompson, David, "Characterizing the influence of traditional rangeland insecticide treatments on native herbivores of native weeds," (project description of ongoing research—New Mexico State University), July 1993.
Thompson	Thompson, David, "Introduction of exotic insects to control exotic weeds, leafy spurge, & knapweed," (project description of ongoing research—New Mexico State University), July 1993.
Thompson	Thompson, David, "Biological control of native snakeweeds & locoweeds using existing native herbivores," (project description on on-going research—New Mexico State University), July 1993.

MINING - EXISTING TECHNOLOGIES

Existing Waste-Reducing Technologies Found in the Open Literature - Listed by Waste-Reduction Strategy

Product	Waste-Reduction Technology Description	Environmental Benefits	Estimated Energy Savings	Estimated Waste Reduction	Effects	Capital Investment	Annual Cost Savings	Payback Period (yrs)	Ref. Year	Ref.
Process Redesign										
Hardrock	Reuse/recycle of tailings pond water	Reduces discharges of tailing leach water to near zero							1993	SAIC
Hardrock	Recovery of lead from auto batteries using the Ginatta process	More effective lead recovery from automotive batteries			More effective lead recovery from automotive batteries				1992	Ayres
Ore	Thin-layer leaching for ore processing	Reduced water use; reduced tailings volume; less fugitive dust generated		25%		$30,000	5 to 15%		1978	PIES
Petroleum	Recovery of oil & washwater in a closed-loop oily water recycling system	Recovered oil is burned in a generator that supplies heat & electrical power							1993	PNWPPC
Petroleum	Low solids nondispersed drilling fluid systems	Uses much lower water volumes			Reduces water use & waste volumes to be disposed of				1991	API 1
Petroleum	Chelated iron processing for removal of H_2S from gas streams	Captures H_2S from gas stream & yields a nontoxic solution that can be disposed of as a nonhazardous waste							1991	API 1
Petroleum	Vanadium recovery from purge streams for sulfur removal	Recovers vanadium from waste stream. Reduces volume of waste generated			In CA, vanadium content makes the waste listed a hazardous waste; removal allows use of conventional disposal/treatment methods				1991	API 1
In-Process Recycling										
Hardrock	Recovery of molybdenum by ion exchange mine process & runoff waters	Decreases discharge of metals to receiving waters							1986	PPPP
Hardrock	Use of swift electroclear process for removal of iron manganese, zinc, & copper from process water	Reduces contaminants in waste stream discharges		90, 96%	90% removal of Fe, Mn, Zn, Cu; 96% removal of Cn					
Petroleum	Removal of solids from drilling fluids by desilters	Allows drilling fluid life to be extended, thus reduces the amount of waste generated			Reduces volumes of waste generated & reduces drilling fluid chemical costs				1991	API 1
Petroleum	Removal of solids from drilling fluids by mud cleaners	Allows drilling fluid life to be extended, thus reduces the amount of waste generated			Reduces volumes of waste generated & reduces drilling fluid chemical costs				1991	API 1

Existing Waste-Reducing Technologies Found in the Open Literature - Listed by Waste-Reduction Strategy

Product	Waste-Reduction Technology Description	Environmental Benefits	Estimated Energy Savings	Estimated Waste Reduction	Effects	Capital Investment	Annual Cost Savings	Payback Period (yrs)	Ref. Year	Ref.
Petroleum	Removal of solids from drilling fluids by centrifugation	Allows drilling fluid life to be extended, thus reduces the amount of waste generated			Reduces volumes of waste generated & reduces drilling fluid chemical costs				1991	API 1
Petroleum	Centrifugation for separation of oily sludges				Product recovery, waste generation reduction				1991	API 1
Petroleum	CO_2 absorption for recovery of triethylene glycol (TEG)	Recovery of TEG decreases waste disposal requirements			Total operating costs are a fraction of glycol purchase costs				1991	API 1
Petroleum	Oil separation and removal from drilling fluids	Reduces toxicity of drilling fluids and allows reuse of separated oil							1991	API 1
Petroleum	Removal of solids from drilling fluids using shale shakers	Allows drilling fluid life to be extended, thus reduces the amount of waste generated			Reduces volumes of waste generated & reduces drilling fluid chemical costs				1991	API 1
Petroleum	Removal of solids from drilling fluids by desanders	Allows drilling fluid life to be extended, thus reduces the amount of waste generated			Reduces volumes of waste generated & reduces drilling fluid chemical costs				1991	API 1

Input Substitution

Product	Waste-Reduction Technology Description	Environmental Benefits	Estimated Energy Savings	Estimated Waste Reduction	Effects	Capital Investment	Annual Cost Savings	Payback Period (yrs)	Ref. Year	Ref.
Petroleum	Substitution of chrome-free liquid sulfonates & polysaccharide polymers for reducing drilling fluid viscosity	Do not need to dispose of as a hazardous waste			Material substitution reduces toxicity & disposal costs				1991	API 1
Petroleum	Substitution of highbase number oil & oil filter system for conventional system in on-site engines	Reduced oil disposal		80%	Reduced annual oil consumption				1993	PNWPPC
Petroleum	Substitution of mineral oil for diesel oil as an effective replacement for stuck spotting fluids	Do not need to dispose of as a hazardous waste			Material substitution reduces toxicity & disposal costs				1991	API 1
Petroleum	Substitution of lubra beads & gilsonite-based additives to replace diesel oil	Do not need to dispose of as a hazardous waste			Material substitution reduces toxicity & disposal costs				1991	API 1
Petroleum	Substitution of isothiazoline & amines to replace pentachlorophenols & paraformaldehyde as biocides	Do not need to dispose of as a hazardous waste			Material substitution reduces toxicity & disposal costs				1991	API 1

MINING - EXISTING TECHNOLOGIES

Existing Waste-Reducing Technologies Found in the Open Literature - Listed by Waste-Reduction Strategy

Product	Waste-Reduction Technology Description	Environmental Benefits	Estimated Energy Savings	Estimated Waste Reduction	Effects	Capital Investment	Annual Cost Savings	Payback Period (yrs)	Ref. Year	Ref.
Petroleum	Substitution of sulfite and organic corrosion inhibitors to replace chromate corrosion inhibitors	Do not need to dispose of as a hazardous waste			Material substitution reduces toxicity & disposal costs				1991	API 1

Operational Efficiencies

Product	Waste-Reduction Technology Description	Environmental Benefits	Estimated Energy Savings	Estimated Waste Reduction	Effects	Capital Investment	Annual Cost Savings	Payback Period (yrs)	Ref. Year	Ref.
Hardrock	Use of vegetative cover to control leaching of heavy metals from mine tailings	Established vegetation reduces leaching metals to receiving streams & ground water							1993	Schwab & Banks
Hardrock	Control of a run-on & runoff from mining facilities	Controlling run-on & runoff water reduces contaminants in discharge system							1993	SAIC
Hardrock	Stockpile capping to reduce leachate generator from tailings piles	Stabilizes tailings piles & prevents generation of leachate							1993	SAIC
Hardrock	Reduction of stream contamination by stream channel diversion	Diversion of stream prevents contact w/spoil material, prevents formation of acid drainage							1993	SAIC
Hardrock	Constructed wetlands to sequester metals in leachate & control erosion from tailings								1993	SAIC
Petroleum	Recycling gravels & drill cuttings for road & pad maintenance				Reduces disposal costs				1993	PNWPPC

Developing Waste-Reducing Technologies Found in the Open Literature - Listed by Waste-Reduction Strategy

Product	Waste-Reduction Technology Description	Environmental Benefits	Estimated Energy Savings	Estimated Waste Reduction	Effects	Capital Investment	Annual Cost Savings	Payback Period (yrs)	Ref. Year	Ref.
Process Redesign										
Nat gas	Optimization of natural gas purification process using direct read infrared methods	Lower energy requirements & combustion by-products	3.5 x 10E14 Btu/yr/ut						1992	IWRP
In-Process Recycling										
Petroleum	Filter press for oily sludge segregation			70% 31,400 bbls	High capital cost; possible high energy requirement	$3M	$272k	3.5	1991	API 1
Petroleum	Recovery of amine used for treating gas for acidic gas removal	Reduced waste disposal, present deep well injection method may not be allowed in future			If injection not allowed, other disposal methods expensive; allows for reuse/recovery, reduces waste generated				1991	API 1
Petroleum	Recovery of DEA from high brine DEA solutions using ion exchange	When DEA is contaminated, total solution is usually disposed of. Recovery of DEA allows reuse of solution & reduction in waste generated							1991	API 1
Petroleum	H_2S gas cleaning by direct sulfur recovery	Product recovery			Gas stream must be cleaned anyway; allows some value added product recovery of elemental sulfur				1991	API 1

TABLE REF	MINING TECHNOLOGIES REFERENCES
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Existing Waste-Reducing Technologies Found in the Open Literature - Listed by Waste-Reduction Strategy

Product	Waste-Reduction Technology Description	Environmental Benefits	Estimated Energy Savings	Estimated Waste Reduction	Effects	Capital Investment	Annual Cost Savings	Payback Period (yrs)	Ref. Year	Ref.
Process Redesign										
Pulp & Paper	Kamyr equipment used to reduce volume of effluent	Bleaching effluent reduced to 15 m^3/ton of pulp			Improved waste management				1987	PIES/ CPEC
Pulp & Paper	Modification of bleaching stage in pulp manufacturing	Rate of coloration of wastes is reduced by half			Additional energy & manpower expenses- ff13.3/ton; savings of ff9.1/ton of pulp in raw chemical costs and water consumption	ff24M	ff9.1/ton		und	PIES/UN
Pulp & Paper	Oxygen bleaching of softwood, kraft pulp by Modo-cil-oxygen/alkali bleaching process to reduce chlorine consumption	BOD levels reduced 50%; consumption reduced 50%; color discharges reduced 50%; reduced toxics in chlorine discharge		50%, 50% 50% 50%	Bleaching costs reduced by 10-15%; met gov't regs; bleaching capacity increased; improved quality	$225M			1987 1982 1982	PIES/ CPEC PPP PPP
Pulp & Paper	Pre-chlorination Eo (caustic extraction w/5kg/ton pulp of elemental oxygen)	Reduction in adsorbable organic halogens			Reduction in chlorine consumption; low capital costs vs. oxygen delignification processes; higher O & M costs; less reduction of adsorbable o. halogens vs. oxygen delignification system				1992	WRB/ OME
Pulp & Paper	Peroxide & peroxide-enhanced extraction	Reduction in adsorbable organic halogens (25%) in untreated effluent		25%	By recycling effluents, color reduced to 90% & BOD to 40%, w/chlorinated organic substances eliminated				1992	WRB/ OME
Pulp & Paper	Magnetically coupled, corrosion-resistant, reversible gear pump for ClO_2 bleaching				Eliminates hazards & equipment maintenance in removing spent acids from ClO_2 generating system				1991	LANL
Pulp & Paper	Switch from batch to multiple-point chlorine additions in bleaching process	Reduced dioxin formation		90%	Reduced dioxin formation				1991	LANL

PAPER & PULP - EXISTING TECHNOLOGIES

Existing Waste-Reducing Technologies Found in the Open Literature - Listed by Waste-Reduction Strategy

Product	Waste-Reduction Technology Description	Environmental Benefits	Estimated Energy Savings	Estimated Waste Reduction	Effects	Capital Investment	Annual Cost Savings	Payback Period (yrs)	Ref. Year	Ref.
Pulp & Paper	Oxygen delignification of kraft pulp entering the bleaching process	Allows most bleached kraft mills to reduce BOD discharges to approx. 50% & color by 60%; organochlorines discharges reduced to 35-50%; reduced toxicity to fish by 50-70%; TCDD & TCDF not detectable	1.5MW	50%, 50% 50% 50%, 50% 13,200 kg/day	Reduced kappa number of pulp (50%); pulp strength adversely affected; recovery boiler required; washing must be controlled before & after oxy. delig. stage for opt. performance; less wood substance dissolved in bleaching process—incr. organic material dischg.	\$20M \$27.5M \$34.7M	\$8/ton \$3.3M \$2M	8.33 17.35	1992 1992 1992 1992	WRB/ OME EPA3 EPA3 McC
Pulp & Paper	Chlorine dioxide delignification	Reduced adsorbable organic halogens & color; some reduction in COD, acute toxicity, & sublethal toxicity; reduced highly chlorinated phenolic compounds; reduced dioxins & chlorinated organics		94%	100% substitution of ClO_2 for Cl_2 resulted in a 94% decrease in chlorinated phenolic compounds; viscosity, strength, & brightness reversion increased; NaOH consumption decreased; increased costs: Can\$9-\$15/metric ton pulp; O & M costs: 30-50% substitution decreased costs, a 60-100% substitution increased costs	Can\$2-20M			1992	EPA3
Pulp & Paper	Modified continuous cooking of kraft pulp Low kappa continuous pulping (MCC-Kamyr) Extended cooking (mod. cont. cooking) Extended cooking (if batch dig. exist) Extended cooking (if old, cont. digest) Extended cooking (if suit. cont. digest)	Reduced BOD & COD discharges; reduced adsorbable organic halogens; reduced chlorophenols & chloroform; modified cont. cooking pulps allow 10% reduction in bleaching chemicals	3.4 MW 3.4 MW 3.4 MW	10% 7,500 kg/day 7,500 kg/day 7,500 kg/day	Increases time for liquor penetration; produces stronger pulp; effluent quality improved w/extended cooking; reduces demand for bleaching chemicals, lowers cost; TCDD & TCDF still detectable	\$65M \$46M \$45.6M \$32.6M \$4.6M	\$3.5M \$3.4M \$2.8M \$3.7M	13.14 13.41 11.64 1.24	1992 1992 1992 1992 1992 1992	WRB/ OME EPA3 EPA3 McC McC McC
Pulp & Paper	SuperBatch™ cooking of bleached kraft pulp	Reduced COD in effluent (80%) vs. conventional cooking methods		80%	More homogeneous & selective delignification possible; strength properties improved; lower kappa number				1992	EPA3
Pulp & Paper	Extended cooking w/Eop	TCDD & TCDF not detectable	5.1MW	7,500kg/day	Incremental power decreased 5.1MW	\$47M	\$3.3M	14.2	1992	McC

Existing Waste-Reducing Technologies Found in the Open Literature - Listed by Waste-Reduction Strategy

Product	Waste-Reduction Technology Description	Environmental Benefits	Estimated Energy Savings	Estimated Waste Reduction	Effects	Capital Investment	Annual Cost Savings	Payback Period (yrs)	Ref. Year	Ref.
Pulp & Paper	Extended cooking w/oxygen delignification	TCDD & TCDF not detectable; reduced BOD	3.9MW	16,400 kg/day	Incremental power decreased 3.9MW	$71.6M	$6M	11.93	1992	McC
Pulp & Paper	Extended cooking w/100% substit. of chlorine with chlorine dioxide	TCDD & TCDF not detectable; reduced BOD	0.1MW	7,500kg/day	Incremental power decreased 0.1MW	$54.5M	$70,000	None	1992	McC
Pulp & Paper	Extended cooking w/oxygen delignification &100% substitution	TCDD & TCDF not detectable; reduced BOD	2.6MW	16,400 kg/day	Incremental power decreased 2.6MW	$75.2M	$4.6M	16.34	1992	McC
Pulp & Paper	Extended cooking w/oxygen delignification & Eop	TCDD & TCDF not detectable; reduced BOD	6.3MW	16,400 kg/day	Incremental power decreased 6.3MW	$73M	$4.4M	16.5	1992	McC
Pulp & Paper	High-efficiency pulp washing of kraft pulp; brown stock washing	Reduced COD and BOD discharges to effluent			Inefficient washing leads to chemicals & dissolved wood later entering wastewater stream; poor washing & use of chlorine-based bleaching chemicals lead to chlorinated organics; Reduced lignin; savings as chemicals recovered; separates spent calcium base sulfite liquor from pulp fibers	$8M $24M	$1.4M	5.7	1992 1992 1982	WRB/ OME EPA3 PPP
Pulp & Paper	Reduced emissions by low-odor recovery boiler installation	88% reduction in particulates emissions; 99% in sulfur gases		88%, 99%					1987	PIES/ CPEC
Pulp & Paper	Closed-cycle technology for bleached kraft pulp mills	Reduced wastewater & wastewater contamination; BOD discharge as low as 7.5kg/ton pulp; about 70% of chlorine in first bleaching stage is replaced by ClO_2		80%, 80%	Reduced wastewater & wastewater contamination in bleached kraft process (1975 $); high quality, strong, bright, & stable pulp produced; increased yield; eliminates need for secondary biological treatment plant; reduced chemical purchases	$4.5M 5% incr. conv./ 1 0% decr.pol. ab. eq.			und 1982	PIES/UN PPP
Pulp & Paper	Chip screening by thickness vs length (kraft pulp); replaced rotary screens w/3-stage chip screening	Reduced knotter rejects; reduced load to waste disposal system; reduced pulp screening rejects	3.75%	50% /1%	Allows more uniform liquor penetration, ensures higher quality, stronger pulp; greater use of raw material & reduced solid waste; increased yield; reduced white liquor use, alkali use	$22M	$5.3M	4.15	1992 1991	WRB/ OME LANL

Existing Waste-Reducing Technologies Found in the Open Literature - Listed by Waste-Reduction Strategy

Product	Waste-Reduction Technology Description	Environmental Benefits	Estimated Energy Savings	Estimated Waste Reduction	Effects	Capital Investment	Annual Cost Savings	Payback Period (yrs)	Ref. Year	Ref.
Pulp & Paper	Oxygen reinforces caustic extraction stages	Reduced discharge of organochlorines		15%	Reduced requirements for ClO_2 in later stages; reduces organochlorines	$IM			1992	EPA3
Pulp & Paper	Hydrogen peroxide reinforces caustic extraction stages	Reduced discharge of organochlorines		15%	Operating costs higher than oxygen reinforcement; reduces organochlorines; implementation costs normally trivial				1992	EPA3
Pulp & Paper	Sulfite pulping is replaced by bleached chemi-thermo-mechanical pulping (BCTMP)	Reduced sulfite wastes and BOD loadings; chlorine-free process; decreased effluent volume	13.50%	55%	Increases production by 6.25%; improves quality; BCTMP is less expensive than low-yield sulfite pulping; sells for 15% less; contains lignin—causes brightness reversion when exposed to light	$400M			1987 1992	PIES/ CPEC EPA3
Pulp & Paper	Sulfonated chemi-mechanical pulp (SCMP) plant used to reduce sulfite effluent	Reduction in particulate emissions; sulfur dioxide emissions reduced; 79% reduction in BOD discharges; 84% reduction in pollution vs. conventional pulping	25%	96.40% 72% 79%, 84% 74-374 μ/m^3 127 tons/day	37 to 75% reduction in particulate emissions; scrubber removes 96.4% hydrogen sulfide, 100% sulfur dioxide; produces superior pulp; use up to 40% hardwoods, conserve softwoods which are more costly; increased pulp yield (1978 data)	$30M $23M		3	1987 1987 1982	PIES/ CPEC PIES/ CPEC PPP
Pulp & Paper	Replacing ground wood operation w/ thermo-mechanical-pulping (TMP)	Lower BOD produced compared to ground wood pulping; does not require sulphite pulp; solids recovery; less water used			Requires twice as much power as ground wood process; higher yield & lower BOD vs. ground wood process; stronger pulp than kraft; uses less water & effluent easier to treat	$100-$150M $800k	$300,000	2.67	1992 1982 1982	WRB/ OME PPP PPP
Pulp & Paper	Sulfite process--low yield sulfite pulping	Chlorine-free process			Sulfite pulps not as strong as kraft pulps; bleach better than kraft pulps w/hydrogen peroxide bleaching; totally chlorine-free pulps produced				1992	EPA3
Pulp & Paper	Using soda pulping process & fluidized bed furnace recovery system				Black liquor is burned & soda recovered for pulping process; corrugating medium can be made from 100% secondary fibers in closed cycle mills, eliminating process effluent	$10.4M			1992	WRB/ OME

Existing Waste-Reducing Technologies Found in the Open Literature - Listed by Waste-Reduction Strategy

Product	Waste-Reduction Technology Description	Environmental Benefits	Estimated Energy Savings	Estimated Waste Reduction	Effects	Capital Investment	Annual Cost Savings	Payback Period (yrs)	Ref. Year	Ref.
Pulp & Paper	Recovery boiler adjusted for non-kraft pulping systems	Control of increased organic & inorganic material			Non-kraft processes can cause up to 15% increase in solids to recovery boiler & a 16% increase in heat input; increased capacity can cause ash buildup on the heat transfer surfaces; boiler must be shut off periodically to wash off ash				1992	EPA3
Pulp & Paper	Jet scrubbers & activated coal catalytic oxidative adsorption process control odor	Removal of hydrogen sulfide (HS) & mercaptains		98%	Removal of hydrogen sulfide (HS) & mercaptains				1982	PPP
Pulp & Paper	Munters particulate removal unit reduces particulate emissions from the smelt dissolving stack	Particulate emissions reduced to 0.2 kg/ton			Improved waste management	$40k			1987	PIES/ CPEC
Pulp & Paper	Application of black liquor disilication technology	Alkaline pulp pollution eliminated; produces 15-125 kg SiO_2 solids/ton vs. 250-300 kg solids $CaCO_3$/ton of dissolved black liquor solids			Increased efficiency; silica problems do not permit chemical recovery, company must purchase pulping chemicals				und	PIES/UN
Pulp & Paper	Paper manufacturing process modification	Smaller volume of wastewater is generated; 180 kg/ton paper no longer discharged		$10m^3$	$10m^3$ wastewater reduction; 11.5kg suspended matter reduction; 1.5kg BOD reduction; 1 kg COD reduction; no disposal problems as sludge is incinerated	ff10.1M			und	PIES/UN
Pulp & Paper	Wood chips or sawmill waste converted to pulp for newspaper print (Jylha Tandem Thermo-mechanical pulp production process)		80%		80% recovery of electric energy (steam), which can be used for drying paper or pulp, evaporating process liquors, or power generation	$12.9M		0.5	und	PIES/UN
Pulp & Paper	Papricycle process reduces organochlorine discharges	Reduced organochlorine discharges & PCDD/PCDF			Reduced fresh caustic requirements; 36% savings of caustic by recovery	<$3M			1992	WRB/ OME
Pulp & Paper	Improved lime-mud washing			61%	Lime losses reduced 61% from 36 lb/ton to 14 lb/ton over a 10-yr period				1991	LANL

Existing Waste-Reducing Technologies Found in the Open Literature - Listed by Waste-Reduction Strategy

Product	Waste-Reduction Technology Description	Environmental Benefits	Estimated Energy Savings	Estimated Waste Reduction	Effects	Capital Investment	Annual Cost Savings	Payback Period (yrs)	Ref. Year	Ref.
Pulp & Paper	Computerized control of start-up temperature in paper coating & drying process	Prevented 237 tons of solid waste & 53 tons of air pollutants			Avoided $533,200/yr in start-up waste		$533,200		1991	LANL
Pulp & Paper	Black liquor recovery	Reduced BOD, COD, & suspended solids by 90%, 62%, & 90% resp.		90%, 62%	Increased production				1982	PPP
Pulp & Paper	Recovery boiler	Reduce odor & particulate emissions			Capable of burning 4.8m lbs of black liquor solids/day				1982	PPP
Pulp & Paper	Dynamic bleaching	Bleaching effluent volumes reduced		$15m^3$/ton	Double capacity; bleaching effluent volumes reduced	$150M			1982	PPP
Pulp & Paper	Counter-current horizontal belt washers	Decreased BOD		15-20 tons/day	Allows concentration & recovery of spent sulfite liquor solids to improve by-product alcohol & vanilla production				1982	PPP
Pulp & Paper	Protein by-product process-alternative to biological ww treatment	Reduced BOD		40%	Produces 1900 lb/hr animal feed protein	$12M			1982	PPP

In-Process Recycling

Product	Waste-Reduction Technology Description	Environmental Benefits	Estimated Energy Savings	Estimated Waste Reduction	Effects	Capital Investment	Annual Cost Savings	Payback Period (yrs)	Ref. Year	Ref.
Pulp & Paper	Solvent recovery			80-95%	Substantial savings in raw materials; operational costs approx. $9000/yr (cost data applies to all 5 tech.)		$27,400	8.2	1986	PIES/ EMPE
Pulp & Paper	Coal burning replaced by thermal recovery of waste sulfite liquor	Reduced sulfite discharge from coal furnaces			Thermal recovery of waste sulfite liquor reduced treatment and disposal costs; saves money in coal requirements	$32M	$10M	3.2	1987	PIES/ CPEC
Pulp & Paper	Ultrafiltration treats ink & starch ww & leaves recyclable product	96% reduction in wastewater effluent		96%	No longer classified as a hazardous waste generator; operating temps must be maintained between 5 & 80°C; membrane surface must be cleaned weekly	$63k		1.08 to 1.35	und	PIES/PDH
Pulp & Paper	Wet air oxidation of ww treatment sludge recovers the filler clay (Zimpro process)	Sludge disposal via incineration or lagooning is eliminated			Recovered filler clay can be reused in paper production	ff5.75m	ff830,000	6.93	und	PIES/UN

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Existing Waste-Reducing Technologies Found in the Open Literature - Listed by Waste-Reduction Strategy

Product	Waste-Reduction Technology Description	Environmental Benefits	Estimated Energy Savings	Estimated Waste Reduction	Effects	Capital Investment	Annual Cost Savings	Payback Period (yrs)	Ref. Year	Ref.
Pulp & Paper	Paper-board making with closed water systems	Wastewater production eliminated—less than 0.5 kg BOD/ton pulp; reduced water consumption; reduced solids generation		5% 30% $15m^3$ 15m3/ton	Savings in waste treatment; experienced problems w/product quality while closed up water system; microbial growth enhanced by starch in filter; excessive heat a problem	$457k	10£/ton	0.625	und 1992	PIES/UN WRB/ OME
Pulp & Paper	Sludge dewatered on sloped concrete pads & water is reused	Reduced volume of waste to be land treated		75%	Reduced volume of waste to be land treated				und	PIES/NC
Pulp & Paper	White water management minimizes effluent at source	Reduced raw materials waste; reduced water consumption			Treating effluent streams is expensive; biological growth occurs when nutrient concentrations increase				1992	WRB/ OME
Pulp & Paper	Primary sludge pellets replace natural gas as fuel	Reduced solid waste disposal to landfills; non-polluting process			Reduced fuel cost—natural gas requires three times as much energy than do pellets—save $37.60/ton sludge; reduced waste disposal costs; improved incineration on the grate & bark burning efficiciency; requires sufficient amt of sludge				1984	TAPPI
Pulp & Paper	Added floatation deinking process to existing washing process for wastepaper feedstock				Increased flexibility in types of wastepaper that can be accepted				1991	LANL
Pulp & Paper	Gravity strainers remove fibers & solids from press-section water for recirculation				Eliminated water-treatment & sewer-use costs; reduced steam consumption; eliminated labor costs in maintaining tubular pressure filters				1991	LANL
Pulp & Paper	Collected sludge "bioash" for fertilizer	Reduced solid waste disposal to landfills	.		Avoided cost of sludge disposal				1991	LANL
Pulp & Paper	Utilized mechanical agitation to dissolve accumulated sludge from storage tank	Reused chemicals; reduced solid waste disposal to landfills			Recovered over $200,000 worth of chemicals; avoided $1.5 million cost of disposing sludge in landfill & restoring tank to full capacity			2	1991	LANL

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Existing Waste-Reducing Technologies Found in the Open Literature - Listed by Waste-Reduction Strategy

Product	Waste-Reduction Technology Description	Environmental Benefits	Estimated Energy Savings	Estimated Waste Reduction	Effects	Capital Investment	Annual Cost Savings	Payback Period (yrs)	Ref. Year	Ref.
Pulp & Paper	Digester blow-tank system installed to recover spent sulfite liquor	Reduced BOD load		90-95%	90-95% spent sulfite liquor recovered—reduces BOD load	$10M			1991	LANL
Pulp & Paper	Closed-process water system	Reused sludge			Nutrient content of circuit water is lower than most closed systems; sludge is reused in paper stock; costs $11.3/ton of paper				1982	PPP
Pulp & Paper	Sludge used as fiberboard	Sludge by-product utilization			Sludge by-product utilization				1982	PPP
Pulp & Paper	Closed water recycling system	Reduced freshwater consumption		89% $63m^3$/ton	No economical desalting technology has stopped complete water recycling; reused effluent; no substitution corrosion				1982	PPP
Pulp & Paper	Wet oxidation sludge to recover filler materials	Sludge eliminated; BOD & COD reduced			Recovers filler clay & energy from sludge	$17,780		6	1982	PPP

Input Substitution

Product	Waste-Reduction Technology Description	Environmental Benefits	Estimated Energy Savings	Estimated Waste Reduction	Effects	Capital Investment	Annual Cost Savings	Payback Period (yrs)	Ref. Year	Ref.
Pulp & Paper	Substituted oxygen-extraction for chlorine	Reduced formation of dioxins			Removal of residual lignin from cellulose; reduced dioxin formation				1991	LANL
Pulp & Paper	100% substitution w/o Eop	TCDD & TCDF are no longer detectable	(5.3)MW	0	Incremental power increased 5.3MW	$15.9M	($7.1M)	None	1992	McC
Pulp & Paper	50% substitution w/o Eop	Low TCDD & TCDF	2.7MW	0	Incremental power decreased 2.7MW	$5M	$1.9M	2.63	1992	McC
Pulp & Paper	100 substitution w/Eop	TCDD & TCDF not detectable	(1.7)MW	0	Incremental power increased 1.7MW	$13.6M	($3.2M)	None	1992	McC
Pulp & Paper	Wet barking in drums is substituted with dry wood barking	Wastewater generation virtually eliminated; reduced load on the effluent system; reduced water requirements; avoid resin acids, nonpersistent toxic & colored substances produced w/wet debarking		$25m^3$/ton	Savings in treatment of wet bark & higher energy content of dry bark; 20% steam requirements provided by bark-fired boilers; avoids wasted cooking & bleaching chemicals; reduced load on chem. recovery cycle; $25m^3$/ton pulp reduction in mill effl.	$10-$20M	not subst.		und 1992 1992	PIES/UN WRB/ OME EPA3

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Existing Waste-Reducing Technologies Found in the Open Literature - Listed by Waste-Reduction Strategy

Product	Waste-Reduction Technology Description	Environmental Benefits	Estimated Energy Savings	Estimated Waste Reduction	Effects	Capital Investment	Annual Cost Savings	Payback Period (yrs)	Ref. Year	Ref.
Pulp & Paper	Switch from calcium bisulfate to magnesium bisulfate process to recover cooking liquors	Reduced BOD (85%)		85% 255kg/ton	Energy savings; reduced BOD; required pulpwashing unit, liquor evaporation unit; recovery boiler; & recuperation unit				1982	PPP
Pulp & Paper	Substituted aqueous-based for solvent-based solutions in coating machines	Reduced emissions; improved air quality			Millions of dollars saved—from $8000 to $500/ton solvent removed; met overall emissions goal & avg. air quality target				1991	LANL
Pulp & Paper	Substituted CO_2 for mineral acids to buffer wastewater from drinking facility	Eliminated hazards from acid spills & fumes			Reduced chemical costs; maintained consistent pH level in sewer pipes w/o corrosion or scalding				1991	LANL

Operational Efficiencies

Product	Waste-Reduction Technology Description	Environmental Benefits	Estimated Energy Savings	Estimated Waste Reduction	Effects	Capital Investment	Annual Cost Savings	Payback Period (yrs)	Ref. Year	Ref.
Pulp & Paper	Mgmt practices—Best Management Practice Plan				Preventative measures to keep toxic & hazardous materials from reaching the environment				1992	WRB/ OME

Developing Waste-Reducing Technologies Found in the Open Literature - Listed by Waste-Reduction Strategy

Product	Waste-Reduction Technology Description	Environmental Benefits	Estimated Energy Savings	Estimated Waste Reduction	Effects	Capital Investment	Annual Cost Savings	Payback Period (yrs)	Ref. Year	Ref.
Process Redesign										
Pulp & Paper	Eliminate chlorine compounds from kraft pulp bleaching-hydrogen peroxide (H_2O_2) process (Lignox™ process); H_2O_2 bleaching	Adsorbable organic halogens discharges reduced; no organochlorine discharge			Lower use of chlorine compounds than conventional bleach plant using oxygen delignification; operating costs higher than comparable pulp quality of O_2 delignification processes				1992 1992 1992	WRB/ OME EPA3 EPA3
Pulp & Paper	Eliminate chlorine compounds from kraft pulp bleaching-oxygen/ozone process (ozone delignification)	75% reduction of ClO_2 use in molecular chlorine substitution processes; 90% reduction in COD in effluent; reduced water consumption; reduced BOD5, color, & chlorine-containing materials		75% /90%	Requires substantial invest. cost, but will lower O & M costs significantly; more expensive & less efficient than oxygen delignification & extended cooking processes; O_2 used for ozone is recyclable; reduced bleaching costs				1992 1992 1992	WRB/ OME EPA3 EPA3
Pulp & Paper	Hot alkali extraction to reduce the kappa number of pulp				Net gain in energy for mills w/ adequate recovery boilers; greater removal of the lignin in the pulp to obtain lower kappa				1992	WRB/ OME
Pulp & Paper	Organocell--sulfur-free process for pulping; alkaline solvent process	Sulfur-free process; chlorine-free process			Uses mixture of methanol, water & sodium hydroxide, explosion-proof measures must be taken; extra steam required to run methanol recovery; pulp strength is somewhat less than kraft pulp; higher O & M costs				1992 1992	WRB/ OME EPA3

Developing Waste-Reducing Technologies Found in the Open Literature - Listed by Waste-Reduction Strategy

Product	Waste-Reduction Technology Description	Environmental Benefits	Estimated Energy Savings	Estimated Waste Reduction	Effects	Capital Investment	Annual Cost Savings	Payback Period (yrs)	Ref. Year	Ref.
Pulp & Paper	Alcell (reg) pulping of hardwood chips; Alcell-cellulose, closed-cycle process used to separate lignin from wood pulp	Sulfur-free, odorless		33%	Does not require a recovery boiler so capital costs are lower; pulp strength similar to kraft pulp & capacity is often better; eliminates liquor dregs & lime grits; minimizes knots & rejects—greater use of raw material; produces recoverable ethanol; requires 70-80% capital/ton, as does kraft process				1992 1991	EPA3 LANL
Pulp & Paper	Alkaline sulfite anthraquinone methanol (ASAM)--alkaline solvent process				Implementation costs 10-20% more than conventional kraft pulp mills; exceeds kraft pulp strength; good for bleaching & cooking at low kappa numbers; higher costs compensated for by higher bleaching yield (45.5% vs. 43.5%); O & M costs exceed those of kraft mills				1992	EPA3
Pulp & Paper	Sulfite process--closed-cycle pulping	Eliminates effluent discharge			Reduced wastewater				1992	EPA3
Pulp & Paper	Neutral sulfite-anthraquinone (NSAQ) process	Eliminates production of dioxins, furans, & other chlorinated organics; low levels of BOD & COD			Higher pulp yield vs. kraft process (62-65% for NSAQ, 55% for kraft); high brightness of unbleached pulp; recyclable bleach effluent; unbleached pulp is easily bleachable				1990	EPA4
Pulp & Paper	Alcohol pulping offers alternative to standard kraft processes				Closed cycle for pulping chemicals is alternative to standard kraft process				1982	PPP
Pulp & Paper	Solvent vapor curtains to reduce VOC losses			20-95%	Substantial savings in raw materials; operational costs approx. $9000/yr (cost data applies to all 5 tech.)		$27,400	8.2	1986	PIES/ EMPE
Pulp & Paper	Low temperature solvent pumps				Substantial savings in raw materials; operational costs approx. $9000/yr (cost data applies to all 5 tech.)		$27,400	8.2	1986	PIES/ EMPE

Developing Waste-Reducing Technologies Found in the Open Literature - Listed by Waste-Reduction Strategy

Product	Waste-Reduction Technology Description	Environmental Benefits	Estimated Energy Savings	Estimated Waste Reduction	Effects	Capital Investment	Annual Cost Savings	Payback Period (yrs)	Ref. Year	Ref.
Pulp & Paper	Pressurized grinding of processed woods for mechanical pulp production				Improved paper properties & reduced energy consumption				und	PIES/UN
Pulp & Paper	Thin film evaporator for black liquor	Reduced fossil fuel consumption-87%	8.70%		Saves energy; concentrate black liquor to 90% solids vs. 65% solids by conventional evaporators	$6.2-$8.8M			1982	PPP

In-Process Recycling

Product	Waste-Reduction Technology Description	Environmental Benefits	Estimated Energy Savings	Estimated Waste Reduction	Effects	Capital Investment	Annual Cost Savings	Payback Period (yrs)	Ref. Year	Ref.
Pulp & Paper	In-house solvent recycling			80-95%	Substantial savings in raw materials; operational costs approx. $9000/yr (cost data applies to all 5 tech.)		$27,400	8.2	1986	PIES/ EMPE

Input Substitution

Product	Waste-Reduction Technology Description	Environmental Benefits	Estimated Energy Savings	Estimated Waste Reduction	Effects	Capital Investment	Annual Cost Savings	Payback Period (yrs)	Ref. Year	Ref.
Pulp & Paper	Substitution of chlorine w/chlorine dioxide in bleaching of kraft pulp	Elimination of detectable quantities of PCDD/PCDF & 2,3,7,8 TCDD; reduced organochlorine discharges; BOD, color, & toxicity possibly reduced; 60 kg Cl/ton pulp used vs. 40 kg ClO_2/ton pulp; reduces dioxins		60% 87% 164 lb/ton	Improved efficiency & pulp quality; least expensive approach to reducing adsorbable organic halogens; reduces up to 80% organochlorines; does not prepare mill for O_2 delig. nor zero effl.; high O & M costs; *if 100% substitution	$45M $25M			1992 1992 1991	WRB/ OME EPA3 LANL
Pulp & Paper	Replacement of chlorine compounds with enzymes & H_2O_2 or sodium hydrosulfite; bleaching w/ enzyme xylanase	Decreased adsorbable organic halogens emissions; reduced chlorine usage		25%	pH must be maintained between 4 & 9 for enzyme activity; chemical savings & pollutant reduction; maintained pulp quality; 15-25% savings in chlorine	$10k-100k			1992 1992 1992	WRB/ OME EPA3 EPA3
Pulp & Paper	Sulfite pulping is replaced by recycling				Problem of replacing sulfite pulping solved with new recycling approach				1987	PIES/ CPEC
Pulp & Paper	Replacement of solvent-based ink w/ water-based ink			20-95%	Substantial savings in raw materials; operational costs approx. $9000/yr (cost data applies to all 5 tech.)		$27,400	8.2	1986	PIES/ EMPE

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Existing Waste-Reducing Technologies Found in the Open Literature - Listed by Waste-Reduction Strategy

Process Redesign

Product	Waste-Reduction Technology Description	Environmental Benefits	Estimated Energy Savings	Estimated Waste Reduction	Effects	Capital Investment	Annual Cost Savings	Payback Period (yrs)	Ref. Year	Ref.
Ag chem	Installed closed-loop process water recycling system to replace single-pass system	Water resources conservation; reduced threat to groundwater, river water, & air contamination		280,000 gal/day	Compliance w/Clean Air Act; cost savings		$2M	1	1986	Huisingh
Chemical	Neutralized & heat stabilized dye mixtures prior to dye-cake separation	Avoided formation of diazo and coupler impurities in the effluent			Avoided formation of diazo and coupler impurities in the effluent				1989	LANL
Chemical	Switched to foam balls for flushing pipes	Reduced wastewater		70%	Disposal cost savings		$240k		1991	LANL
Chemical	Redesigned drums with concave top to enhance draining	Reduced wastage of product			Only 0.1 pint remains in drum compared to 0.25-0.5 gal. remaining in conventional drums				1991	LANL
Chemical	Implemented & upgraded computer control of chloralkali plant	Prevented waste		59k ton/yr	Savings		$753k		1991	LANL
Chemical	Eliminated an intermediate processing step at a polystyrene plant	Reduced waste		90k lb/yr	Savings		$150k		1991	LANL
Chemical	Computerized control of cellulose resin process	Reduced air emissions		28% (1989)	Reduced air emissions				1991	LANL
Chemical	Utilized chlorine process in production of titanium dioxide				Eliminated need for acid recycling equip.; sold waste ferric chloride to water treatment plants as filtering materials				1991	LANL
Chemical	Discovered new process to manufacture Roundup-brand herbicide	Reduced waste volume		80%	Savings in raw material costs; total cost reduction by 22%		$75 million		1991	LANL
Chemical	Added 2~200 ppm non-ionic oil-soluble surfacants to limestone slurry; increased dissolution rate in wet flue-gas desulfurization scrubbers				Improved removal efficiency of SO_2 (sulfur dioxide up to 30%)				1991	LANL
Chemical	Streamlined photographic chemical plants	Reduced waste generated		31%	Reduced disposal costs		$250K		1991	
Chemical	Eliminated CFCs in the manufacture of Cell-Aire polyethylene foam	Eliminated need for CFCs			Eliminated need for CFCs				1991	LANL

CHEMICAL - EXISTING TECHNOLOGIES

Existing Waste-Reducing Technologies Found in the Open Literature - Listed by Waste-Reduction Strategy

Product	Waste-Reduction Technology Description	Environmental Benefits	Estimated Energy Savings	Estimated Waste Reduction	Effects	Capital Investment	Annual Cost Savings	Payback Period (yrs)	Ref. Year	Ref.
Chemical	Combined blowing agent with polymer mix in foam-blowing systems	Eliminated need for CFCs			Eliminated need for CFCs				1991	LANL
Chemical	Increased catalyst selectivity towards acrylonitrile formation	Decreased impurities			Increased acrylonitrile yield				1986	EPA 6
Chemical	Alternated allyl chloride reactor design to provide more mixing	Decrease in tar formation			Better mixing; increased allyl chloride yield				1986	EPA 6
Chemical	Reevaluation of kinetics & design for chlorohydroxylation reactor	Avoids generation of by-products							1986	EPA 6
Chemical	Modification of filtration process	Reduced solid waste generated			Eliminates the need for filter aids				1986	EPA 6
Chemical	Use of alternate coagulation procedures	Reduced aqueous waste produced			Reduced quantity of water required				1986	EPA 6
Chemical	Use of additives to the ethylene dichloride feed to pyrolysis	Supresses mentyl chloride formation			Improved ethylene dichloride conversion				1986	EPA 6
Drugs	Modified mole ratios of reagent to produce intermediates used in antibiotic manufacture	Reduced volume of toluene-concentrated wastewater generated			Increased product stability		$280k		und	CHMR
Dyes	Modified a yellow dye mfg process to substitute a solvent for nitrobenzene	Reduced nitrobenzene waste (hazardous)		200,000 lbs/yr	Cost svgs from reduced disposal costs; energy svgs	$100k	$200k	0.5	1992	INFORM
Dyes	Eliminated excess metals in dye mfg. by shifting purification to early part of process	Reduced hazardous heavy metals		100% 45,000 lbs/yr	Increased yield by 11%	none	$86.5k	0.167	1992	INFORM
Misc	Producing polyethylene using COMPOL process	Lower hydrocarbon emissions; reduced CO_2 emissions; reduced water usage by 30% in 1980s			Reduced energy consumption; 70% of wastewater is recycled				1993	Clements & Thompson
Plastics	Use of new catalyst system in manufacture of nylon	Reduced aqueous waste by 50%; reduced organic waste		50%	Higher yield; adiponitrile produced from butadiene w/o producing brine as a by-product				1988	Hollod & McCartney

CHEMICAL - EXISTING TECHNOLOGIES

Existing Waste-Reducing Technologies Found in the Open Literature - Listed by Waste-Reduction Strategy

In-Process Recycling

Product	Waste-Reduction Technology Description	Environmental Benefits	Estimated Energy Savings	Estimated Waste Reduction	Effects	Capital Investment	Annual Cost Savings	Payback Period (yrs)	Ref. Year	Ref.
Ag chem	Collect & reuse spent rinse solvent for subsequent rinsing or pesticide formulation	Reuse of solvent			Reduced solvent requirements				1987	CA
Ag chem	Return waste container to pesticide supplier for refill	Reduced container wastes			Reduced disposal costs				1987	CA
Ag chem	Solvent recovery by distillation	Reduced solvent wastes generated; improved health & safety conditions		70%	Reduced waste disposal costs; resources conserved		$37k	immediate	1986	Huisingh
Chemical	Utilized unreacted by-products from one process to another process as feedstock instead of burning them to generate steam				Reduced maintenance costs of removing hydrochloric acid			Less than 1 year	1991	LANL
Chemical	Recycled scrap from production of styrofoam board insulation	Nearly eliminated need to send waste to landfill			Nearly eliminated need to send waste to landfill				1991	LANL
Chemical	Collected & purified spent acid for reuse	Reduced waste disposed			Savings in neutralizing, disposal, & new purchase of acid		$20M		1991	LANL
Chemical	Recycled solvents used in manufacturing of verdict-brand herbicide	Reduced amount of solvent disposed as toxic waste		50%	Cost savings		$3M		1991	LANL
Chemical	Recycled viscous tar/catalyst mixture in agricultural chemicals plant	Reduced tar formations		43%	Cost savings	$100k	$3M		1991	LANL
Chemical	Collected by-product hydrochloric acid for sale to other plants				Minimized need of neutralize spent acid		$20M		1991	LANL
Chemical	Collect specialty chemical by-product for feedstock for Dowper dry-cleaning fluid	Eliminated need to burn 150 lb/yr of by-products			Savings in disposal costs & raw material costs		$15M		1991	LANL
Chemical	Reprocesses anhydrous HCI from freon production				Resulting hydrogen & chlorine gases can be used in production process				1991	LANL
Chemical	Recovered methyl-glutaonitrile, by-product of adiponitrile production				Reformulated & sold as a high-yield hydrogenation catalyst for polymer production				1991	LANL

CHEMICAL - EXISTING TECHNOLOGIES

Existing Waste-Reducing Technologies Found in the Open Literature - Listed by Waste-Reduction Strategy

Product	Waste-Reduction Technology Description	Environmental Benefits	Estimated Energy Savings	Estimated Waste Reduction	Effects	Capital Investment	Annual Cost Savings	Payback Period (yrs)	Ref. Year	Ref.
Chemical	Recovered isobutyl esters of di-basic acids generated in production of adipic acid				Sales as a solvent-substitute for methylene chloride & acetone grew by 15%/yr to 20%/yr				1991	LANL
Chemical	Recovered solvents & titanium by-products from waste stream for insecticide production	Reduced toxic emissions		20% 25M lb/yr	Sent treated titanium to another plant to manufacture pigments				1991	LANL
Chemical	Installed new equipment to recover chemicals used to produce fungicide	Reduced waste discharges		95%	Savings in reclaimed chemicals		$50k		1991	LANL
Chemical	Installed new recovery unit for solvents used to produce paint	Reduced waste discharges			Savings in waste disposal costs		$200k		1991	LANL
Chemical	Recovered dibasic acid, by-product from production of nylon				Avoided expense of incineration of by-products Sold as solvent				1991	LANL
Chemical	Calcium sulfate from production of hydrofluoric acid sold as soil stabilizer and construction material	Reduced accumulated solid waste		4 mil tons	Reduced accumulated solid waste				1991	LANL
Chemical	Recycling, incineration, & source reduction implemented at film manufacturing plant	Reduced hazardous waste for off-site disposal (99.9%)		99.90%	Reduced hazardous waste for off-site disposal (99.9%)				1991	LANL
Chemical	Extruded polyester fibers from recycled polyethylene terephtalate bottles for home insulation				Recycled PET bottles are a source of high-purity of high-intrinsic-viscosity polyester				1991	LANL
Chemical	Polymer by-product from propylene manufacturing made into caulking for mobile homes	Waste volume cut in half		50%	Savings in incineration costs	$750k	$8.7 million		1991	LANL
Chemical	Repackaged laundry detergent in plastic bottles containing 35% recycled resin				Saved same on disposal cost of plastic containers				1991	LANL
Chemical	Purchased scrap industrial polyethylene from various producers for processing into trash bags	Recycled over 100 million lb/yr of polyethylene			Cheaper than virgin resin and is readily available from municipal solid waste				1991	LANL

Existing Waste-Reducing Technologies Found in the Open Literature - Listed by Waste-Reduction Strategy

Product	Waste-Reduction Technology Description	Environmental Benefits	Estimated Energy Savings	Estimated Waste Reduction	Effects	Capital Investment	Annual Cost Savings	Payback Period (yrs)	Ref. Year	Ref.
Chemical	Recovered dibasic acid, by-product from production of nylon				Avoided expense of incineration of by-products; sold to utilities for use in flue-gas desulfurization				1991	LANL
Chemical	Capture & reuse of chemical vapors rather than incinerating them	Reduced incineration of wastes			Savings in labor, energy & maintenance costs		$1.5 million		1991	LANL
Chemical	Captured volatile toxic solvents in mineral-oil both for reuse in nylon-fiber production	Reduced toxic air emissions		90%	Saved few million dollars annually in raw material costs				1991	LANL
Chemical	Cooled waste vapors to capture & recrystallize paradichlorobenzene (PDCB) for reuse in moth balls manufacturing	Reduced air and water emissions of PDCB		90% 1 mil lb.	Reduced air and water emissions of PDCB				1991	LANL
Chemical	Repackaged laundry detergent in bottles with 25% recycled plastic				Saved portion of cost to dispose of plastic containers				1991	LANL
Chemical	Repackaged cleaners in bottles containing 100% recycled plastic resin				Saved portion of cost to dispose of plastic containers				1991	LANL
Chemical	Recycled cooling water through plant	Cut waste-water in half		50%	Saved money by building smaller treatment plant		$320k		1991	LANL
Chemical	Converted boiler to burn solvent laden exhaust from coater				Energy savings; eliminated add-on pollution control equip.		$270k		1991	LANL
Chemical	Installed decanter system to remove & reuse 1,1,1-trichloroethane from wastewater in film developing				Saved over $20k first 4 years		$5k	1 year	1991	LANL
Chemical	Installed evaporation equip. to recover ammonium sulfate from magnetic oxide production wastewater	Prevented water pollution		677 ton/yr	Eliminated need for $1M in water pollution control equip.			< 3 yrs.	1991	LANL
Chemical	Installed fully automated high-pressure system with solvent recovery to clean tanks				Savings in solvent & labor costs	$69k	$61.5k	1 yr.	1991	LANL
Chemical	Installed pipes to catch solvent vapors at industrial tape plant & burned vapors as fuel				Savings in energy costs	$270k	$155k in 1st yr.		1991	LANL

CHEMICAL - EXISTING TECHNOLOGIES

Existing Waste-Reducing Technologies Found in the Open Literature - Listed by Waste-Reduction Strategy

Product	Waste-Reduction Technology Description	Environmental Benefits	Estimated Energy Savings	Estimated Waste Reduction	Effects	Capital Investment	Annual Cost Savings	Payback Period (yrs)	Ref. Year	Ref.
Chemical	Recovered and reused solvents in videotape production				Expected to save between $5 & $7M in solvent purchases				1991	LANL
Chemical	Collected used packaging from videotape rolls for reuse				Saved customers the cost of disposal				1991	LANL
Chemical	Collected plastic trimmings from plastic diapers				Sold for reprocessing into coat hangers				1991	LANL
Chemical	Separated cooling water recycling instead of disposal with wastewater				Scaled down ww treatment unit 52% from 2100 gal/min to 1000 gal/min; Savings on construction of ww treatment plant		$800k		1991	LANL
Chemical	Established recycling programs for its plastic containers and tote bags	Ground-up plastics reprocessed into usable products			Customers receive up to 10% of original cost				1991	LANL
Chemical	Storage & reuse of rinsewater & other cleaning wastes	Reduces ww generation greatly			Allows product recovery				1986	EPA 6
Chemical	Combustion of waste with attendant HCI & heat recovery	Reduced waste load			Energy recovery results in lower steam requirement; recovered HCI can be reused				1986	EPA 6
Chemical	Recovery of chlorine by oxidation	Reduced waste volume							1986	EPA 6
Chemical	Recovery & recycle from aqueous wastes	Reduced phenol in waste			Reuse of materials				1986	EPA 6
Chemical	Recycle waste fiber				Easy to reprocess, but quality is decreased				1986	EPA 6
Chemical	Thermal oxidation with recovery of HCl and heat	Reduced waste load			Recovered HCl can be sold or reused				1986	EPA 6
Chemical	Recovery of spent heat transfer fluid by batch distillation	Eliminates the need to dispose of spent & contaminated fluid					$164k		und	D. Allen
Chemical	Recovery of spent freon by batch distillation				Eliminates the disposal costs of spent solvent		$1,800		1989	WRRC
Chemical	Crystallization of waste sulfuric acid with lime for neutralization	Eliminates need to dispose of waste sulfuric acid			Water can be reused in the process & solid gypsum can be sold as a by-product				1987	Dunson
Chemical	Hyper filtration for recovery of caustic use for pretreating fabric prior to dying	Reduces amount of spent caustic for disposal		90%			$1.9 million	12-18 mo	1989	Johnson

CHEMICAL - EXISTING TECHNOLOGIES

Existing Waste-Reducing Technologies Found in the Open Literature - Listed by Waste-Reduction Strategy

Product	Waste-Reduction Technology Description	Environmental Benefits	Estimated Energy Savings	Estimated Waste Reduction	Effects	Capital Investment	Annual Cost Savings	Payback Period (yrs)	Ref. Year	Ref.
Chemical	Recovery of dimethylteraphthalate (DMT) & ethylene glycol (EG) from waste polyethylene terephthalate (PET)			90%	Recovers 50 million lbs of DMT & 15 million lbs of EG annually				1987	Mussgnug
Chemical	Silver recovery from waste photo chemicals	Eliminates discharges to environment			Value of recovered material is $100 million/year				1987	Mussgnug
Ind. inorganic	Recycling of desalination water in hydrazine production process	Reduced wastewater generated		90%	O & M costs 40% lower than standard technique	ff52M	ff7M		und	PIES
Ind. inorganic	Recycling of fluoride by-product	Reduced threat to surface & groundwater quality; reduce waste; resource conservation		1000 yd^3/yr	8000 tons of calcium fluoride & 1000 tons of lime recovered/yr; 4 yrs to implement; improved health & safety conditions	$4.5M	$1M	4.5	1986	Huisingh
Ind. inorganic	Closed-loop reclamation of heat transfer fluid, paracymene, by distillation	Reduced hazardous waste		90%	No waste is generated in the process loop; reduced waste shipping costs	$86k	$21k	2.5	1989	NC
Ind. inorganic	Recycling of toluene solvents by batch distillation	Reduced off-site shipment of spent toluene		467,000 lbs	Savings in new toluene purchases & disposal costs	$106k	$350k	0.3	1990	NC
Misc	Recycled spent solvent from semi-solid organic peroxide production	Reduced waste		90%	Reduced raw material costs; increased production capacity		$50k	0.5	1990	NYSDEC
Org fibers	Modified distillation unit helps recycle isopropyl alcohol solvent	Reduced solvent wastes generated; reduced threat to air & groundwater quality		10,000 gal/yr	In-house recycling recovers 90% of solvent vs. 85% off-site recycle; improved quality control; 3 mos. to implement; energy cost $5520/yr	$7.5k	$90k	0.08	1986	Huisingh
Paints	Batch distillation unit recycles tank wash-out solvents	Reduced off-site shipments		270,000 lbs	Reduces volumes of virgin & recycled solvents employed in the cleaning process	$60k		1	1989	NC
Paints	Thin-film evaporator distills & reclaims spent solvents on-site	Reduced off-site shipments of non-halogenated solvents		689,000 lbs	Reduced transportation costs & risks	$175k		0.667	1990	NC
Toilet prep	Heat recovery from ignitable hydro-alcoholic wastes	Elimination of hydro-alcoholic wastes; elimination of threat to groundwater quality			Hazardous waste disposal costs eliminated; elimination of fire hazard during transport; fuel oil svgs=>1000 gal/yr	$7.5k	$2.8k	2.7	1986	Huisingh

Existing Waste-Reducing Technologies Found in the Open Literature - Listed by Waste-Reduction Strategy

Input Substitution

Product	Waste-Reduction Technology Description	Environmental Benefits	Estimated Energy Savings	Estimated Waste Reduction	Effects	Capital Investment	Annual Cost Savings	Payback Period (yrs)	Ref. Year	Ref.
Ag chem	Substitution of industrial by-products for virgin raw materials	Prevention of groundwater contamination risks due to landfilling			Cost savings; resource conservation				1986	Huisingh
Chemical	Blended blowing agent with water in foam-blowing system	Reduced amount of chlorofluorocarbons (CFCs) used			Reduced amount of chlorofluorocarbons (CFCs) used				1991	LANL
Chemical	Blend of compounds substituted for CFC-12 in existing refrigeration and air-conditioning equipment	Compounds in mixture degrade before reaching stratospheric ozone layer			Compounds in mixture degrade before reaching stratospheric ozone layer				1991	LANL
Chemical	Reformulated rigid urethane foam froth systems with non-regulated hydrofluoralkane blowing agent	Eliminated needs for CFCs			Eliminated needs for CFCs				1991	LANL
Chemical	Substituted recycled CO_2 for 65% propellant solvent in spray-paint equipment	Reduced volatile organic emissions		72%	Reduced volatile organic emissions				1991	LANL
Chemical	Switched from slaked lime to caustic soda for neutralizing waste from silicone products plant	Reduced organic wastes by 50% & sludge volume by 75%		50% 75%	Savings in disposal costs		$500k		1991	LANL
Chemical	Reformulated solvents	Reduced toxic waste		50%	Reduced toxic waste				1991	LANL
Chemical	Use of purified feedstock	Avoided generation of corrosive wastes			Avoided generation of corrosive wastes				1986	EPA 6
Chemical	Use of high-purity ores	Reduced generation of ferric chloride			Minimized the amount of impurities entering the process 99% recovery of chlorine				1986	EPA 6
Dyes	Substituting a chrome (III) compound for sodium dichromate	Avoided use of carcinogenic hexavalent chromium			Reduced dye time from 2 days to under 1 hr; increased overall yields of dyes from 12% to 25%; enhanced shelf life of dyes				1991	NYSDEC
Dyes	Non-heavy metal oxidizing agent replaces sodium dichromate & waste stream is recycled	Avoided use of carcinogenic chromium (VI); no color is released to the environment; waste stream is eliminated			Product is superior to that of conventional method; closed-loop process; eliminated liability risks for waste disposal				1991	NYSDEC

Existing Waste-Reducing Technologies Found in the Open Literature - Listed by Waste-Reduction Strategy

Product	Waste-Reduction Technology Description	Environmental Benefits	Estimated Energy Savings	Estimated Waste Reduction	Effects	Capital Investment	Annual Cost Savings	Payback Period (yrs)	Ref. Year	Ref.
Paints	Use of paint pigments in slurry or paste form rather than powder form	Reduces or eliminates the generation of pigment dust waste			Reduced need for air pollution equipment to control pigment dusts				1988	Lewis

Product Changes

Product	Waste-Reduction Technology Description	Environmental Benefits	Estimated Energy Savings	Estimated Waste Reduction	Effects	Capital Investment	Annual Cost Savings	Payback Period (yrs)	Ref. Year	Ref.
Chemical	Developed dairylide-free & heavy-metal-free dyes	Avoided use of cadmium, lead & other heavy metals in plastics			Avoided use of cadmium, lead & other heavy metals in plastics				1991	LANL
Chemical	Developed water-based thermally stable, adhesive primer	Contains less volatile organic compound (VOC) emissions than solvent-based adhesive primers		3.5-4.4%	Eliminated need for chromate corrosion inhibitors				1991	LANL
Chemical	Packaged insecticides in water-soluble containers	Eliminated hazardous waste			Eliminated metal container, which is hazardous from remaining pesticide				1991	LANL
Chemical	Introduced low-dose Accent-brand sulfonylurea herbicide that inhibits enzyme activity of special weeds	Less toxic by-products generated (5%) than conventional herbicides		5%	Required only a fraction of raw materials				1991	LANL
Chemical	Utilized heat-stable, heavy-metal-free colorants for resterilizable surgical handles	Avoided use of cadmium, lead, and other heavy metals in plastics			Avoided use of cadmium, lead, and other heavy metals in plastics				1991	LANL
Chemical	Introduced low-toxicity Dimension- rand dipthiopyn weed killer that inhibits germination of weed seeds in lawns	Designed to biodegrade in 30-90 days. Minimized effect on groundwater due to low solubility			Designed to biodegrade in 30-90 days. Minimized effect on groundwater due to low solubility				1991	LANL
Chemical	Eliminated mercury from batteries	Batteries are recyclable			Batteries are recyclable				1991	LANL
Chemical	Reformulated detergents				Reduced plastic packaging by 15%				1991	LANL
Chemical	Developed extensive line of heavy-metal-free organic pigments & dyes	Avoided use of Cd, Pb, & other heavy metals in plastics			Avoided use of Cd, Pb, & other heavy metals in plastics				1991	LANL
Chemical	Substituted water-based coatings on medicine tablets	Prevented air pollutants; reduced environmental hazards		24 ton/yr	Eliminated need for $180k in emission-control equipment; savings in solvent costs	$60k	$15k	< 1 yr	1991	LANL

Existing Waste-Reducing Technologies Found in the Open Literature - Listed by Waste-Reduction Strategy

Product	Waste-Reduction Technology Description	Environmental Benefits	Estimated Energy Savings	Estimated Waste Reduction	Effects	Capital Investment	Annual Cost Savings	Payback Period (yrs)	Ref. Year	Ref.
Chemical	Reformulated fabric dyes with a minimum of sulfur reducer & a proprietary reducing agent	Reduced odor levels emitted			Reduced amount of sulfides and water needed				1991	LANL
Chemical	Developed adhesive that requires no solvents				Eliminated need for $2 million in pollution-control equipment				1991	LANL
Packaging	The pesticide Dursban is packaged in water-soluble packages instead of metal cans	Reduced packaging waste			Reduced packaging waste				1991	PIES

Operational Efficiencies

Product	Waste-Reduction Technology Description	Environmental Benefits	Estimated Energy Savings	Estimated Waste Reduction	Effects	Capital Investment	Annual Cost Savings	Payback Period (yrs)	Ref. Year	Ref.
Adhesives	Ultrafiltration cleans waste latex solutions from adhesive manufacturing	Reduced waste volume		90-98%	Annual O & M cost $57k; irreversible membrane fouling occurs; treatment costs: $11.28/1000 gal. waste				1979	PIES
Ag chem	Use of compactor reduces hazardous waste stream volumes	Reduced solid waste generated			Reduced raw material requirements; solid wastes are not eliminated	$60k		0.333	1983	PIES
Ag chem	Use of pipes & pumps to transfer liquids rather than bulk containers	Reduced volume of wastes			Reduced material loss				1987	CA
Ag chem	Separation of organic chemicals permits reuse of dust	Eliminates waste dust; reduced threat to soil & groundwater		45,000 lbs/yr	Reduced liability risks; material conservation	$9.6k	$11.6k	0.83	1986	Huisingh
Ag chem	Waste from dust collectors is packaged into bags & palletized	Reduced waste volume		50%	Metal drums previously used & landfilled are now recycled; 50% more contained waste is transportable; 50% reduction in disposal costs				1988	Lewis
Alkalines	Changes in floor trenching & collection systems reduces waste	Reduced alkaline waste generated		80%	Product quality not affected; reduced liability due to reduced hazardous waste	$200k			1987	PIES
Chemical	Installed distillation process to recover benzene from liquid wastes from propylene oxide plant	Prevented benzene from reaching water treatment unit & from evaporating into air			Prevented benzene from reaching water treatment unit & from evaporating into air				1991	LANL
Chemical	Liquid phase oxidation process treats waste from dinitrotoluene unit	Eliminates hazardous waste		1300 tons per year	Eliminates hazardous waste				1991	LANL

CHEMICAL - EXISTING TECHNOLOGIES

Existing Waste-Reducing Technologies Found in the Open Literature - Listed by Waste-Reduction Strategy

Product	Waste-Reduction Technology Description	Environmental Benefits	Estimated Energy Savings	Estimated Waste Reduction	Effects	Capital Investment	Annual Cost Savings	Payback Period (yrs)	Ref. Year	Ref.
Chemical	Substituted returnable, plastic shipping containers for cardboard containers	Reduced disposal of containers			Reduced product damage in shipping & saved customers the cost of disposal				1991	LANL
Chemical	Minimized spillage in loading & unloading of phenol & urea resins	Reduced phenol waste & eliminated most solid hazardous wastes generated by the manuf. process		93% since 1991	Conservation of raw materials; reduced likelihood of environmental pollution				1991 1986	LANL Huisingh
Chemical	Reused some chemicals and utilized less water for rinsing resin tanks	Reduced sludge volume disposed			Reduced sludge disposal costs		$49,000		1991	LANL
Chemical	Implemented several modifications to operating procedures at herbicide plant	Reduced incinerated wastes		43%	Raw materials savings		$3.4M		1991	LANL
Chemical	Installed corrosion-resistant piping to prevent cross contamination between conduits at a chlorine plant	Prevented waste		> 4.5M lb/yr	Eliminated need to neutralize contaminated caustic; saved 4.1M lb/yr of hydrochloric acid (HCl)		$890k		1991	LANL
Chemical	Installed floating roofs over solvent tanks to prevent emissions				Savings on solvents			1 yr.	1991	LANL
Chemical	Applied dust-control technologies to adhesive manufacturing	Prevented release of talc, clag and calcium carbonate		200 lb/3 days	Prevented release of talc, clag and calcium carbonate				1991	LANL
Chemical	Adopted sonic cleaning to vibrate residue off reactor vessels instead of flushing with water				Savings on water treatment: $575k in first year	$36k	$575k	1 yr	1991	LANL
Chemical	Redesign resin spray booth & installed additional equipment	Eliminated need for special incineration of 500,000 lb/yr of overspray			Eliminated need for special incineration of 500,000 lb/yr of overspray		$125k		1991	LANL
Chemical	Segregation & destruction of acrylonitrile & acetonitrile column bottoms	Reduced content of hazardous compounds in wastewater			Reduced content of hazardous compounds in wastewater				1986	EPA 6
Chemical	Use of high pressure spray nozzles	Cut water consumption 80-90%		80-90%	Cut water consumption 80-90%				1986	EPA 6
Chemical	Dry clean-up methods for spills	Greatly decreases the waste volume			Floor sweeping can be recovered and reused				1986	EPA 6
Chemical	Use of non-stick heat exchange	Reduces wastes from equipment cleaning			Reduces deposit clingage				1986	EPA 6
Chemical	Reduce the use of toxic raw materials	Lower toxicity of hazardous wastes							1986	EPA 6

CHEMICAL - EXISTING TECHNOLOGIES

Existing Waste-Reducing Technologies Found in the Open Literature - Listed by Waste-Reduction Strategy

Product	Waste-Reduction Technology Description	Environmental Benefits	Estimated Energy Savings	Estimated Waste Reduction	Effects	Capital Investment	Annual Cost Savings	Payback Period (yrs)	Ref. Year	Ref.
Chemical	Use of plastic of foam "pig" (slug) to clean pipes				Increases the yield; reduces the amount of pipe cleaning required				1986	EPA 6
Ind. inorganic	Installation of floating roofs & conservation vents to retain solvents	Reduced organic air emissions from tanks by 30% to 75%		45%	Prevented the loss of $1.5M worth of solvents; conserved solvent resources; floating roofs cost from $500-1000/tank		$150k	<1	1986	Huisingh
Ind. organic	Resin adsorption system	Reduced emissions; cumene conservation		80%	Savings in cumene: 715,000 lbs/yr		$175k	0.08	1986	Huisingh
Ind. organic	Installation of surplus condenser	Reduced threat to air quality; cumene conservation			Savings in cumene: 400,000 lbs/yr		$100k	0.05	1986	Huisingh
Ind. organic	Installation of floating roofs on acetone storage tanks	Reduced threat to air quality			Decreased health risks caused by exposure to phenol & acetone vapors				1986	Huisingh
Misc	Collection & recovery system installed to isolate solids from waste slurry	Reduced material waste			Recovered solids are used in the manufacture of a paste product; reduced treatment costs		$50k	0.75	1990	NYSDEC
Misc	Reduction of reagent usage	Dilute aqueous dimethyl formamide disposals reduced		94%	Disposal cost svgs of 82%; raw material cost svgs of 88%; reduced need for excess thionyl chloride by 86%		$2,468		1987	Hollinsed
Misc	Chemical location inventory in laboratories	Prevents material waste			Prevents overpurchasing of chemicals				1991	Matteson & Hadley
Misc	Chemical reuse facility in laboratories	Prevents material waste			Prevents overpurchasing of chemicals				1991	Matteson & Hadley
Packaging	Install new distillation columns containing high-efficiency packing materials	Reduced glycols in waste-water stream		50%	Raw material savings; reduced wastewater incinerator oil consumption by 100,000 gal/yr	$250k	$325k		1991	NYSDEC
Paints	Reduce frequency of cleaning to reduce equipment cleaning wastes	Reduced amount of chemical cleaning wastes			Reduced usage of solvent, caustic solution, or water				1988	Horton
Paints	Manual scraping & Teflon coating of tanks increases yield	Reduced quantity of waste paint			Reduced cleaning solvent req'd; reduced amount of paint clinging to tank walls				1988	Lewis
Paints	High-pressure water systems limit water used in cleaning equipment	Reduces cleaning water use by 80-90%		80-90%	Removes partially dried paint, thus reducing need for caustic cleaning				1988	Lewis

Developing Waste-Reducing Technologies Found in the Open Literature - Listed by Waste-Reduction Strategy

Process Redesign

Product	Waste-Reduction Technology Description	Environmental Benefits	Estimated Energy Savings	Estimated Waste Reduction	Effects	Capital Investment	Annual Cost Savings	Payback Period (yrs)	Ref. Year	Ref.
Chemical	On-demand production of hazardous chemicals	Eliminates over-production & storage chemicals. Prevents their accidental entry to the environment							1992	Mitchell
Chemical	On-demand electrochemical arsine generator to substitute on-site arsine storage	Eliminates on-site storage of arsine & the mus for off-site production and transport							1992	Mitchell
Drugs	Ultrasonic tank cleaning	Hazardous waste reduced	3.51 billion Btus/yr	45%	Reduced solvents, chemical waste, & energy required to reprocess solvents	$627k	$293k	2.3	1992	OIT/IWRP
Misc	Separation of glycols from ww by applying reverse osmosis technology	Reduced need for incinerating wastewater			Reduced fuel demand by 250,000 gal/yr				1991	NYSDEC
Misc	Dual cure photocatalyst coatings system	Reduced VOC & CO_2 emissions	27 x 10E12 btu/yr	2.47 x 10E6 lbs/yr	Great flexibility in tailoring the final product				1992	OIT/IWRP
Misc	VOC control strategies	Reduced VOC emissions	30 trillion Btus/yr	63,000 tons/yr	Energy savings				1992	OIT/IWRP
Misc	Use of hydrous metal oxide catalysts for production of oxygenated products	Eliminates aqueous waste	50% 2.56x10E12 Btus/yr	7.5M tons/yr	Lower energy requirements; reduced amount of by-products				1992	OIT/IWRP
Misc	Chemical hydrogenation & recycle or organic wastes	Avoids formation of toxins produced in incomplete combustion	14,130 Btu/lb		Hydrogenation is superior to incineration due to its ability to recover & recycle hydrogen chloride; energy savings				1988	Kalnes & James
Silicon	Closed furnace replaces open-hearth furnace in silicon & ferrosilicon production	Reduces waste & hazardous off-gas	86 x 10E12 btu/yr	5.84 x 10E6 lbs/yr	Capital costs will be 40% less than open furnaces; reduced production costs from $0.58 lb to $0.41/lb; projected energy svgs year 2010				1992	OIT/IWRP

CHEMICAL - DEVELOPING TECHNOLOGIES

Developing Waste-Reducing Technologies Found in the Open Literature - Listed by Waste-Reduction Strategy

Product	Waste-Reduction Technology Description	Environmental Benefits	Estimated Energy Savings	Estimated Waste Reduction	Effects	Capital Investment	Annual Cost Savings	Payback Period (yrs)	Ref. Year	Ref.
In-Process Recycling										
Chemical	Catalytic hydroprocessing of chlorinated organics	Reduces discharge of chlorinated organics to environment			Recovery of by-products				und	D. Allen
Input Substitution										
Chemical	Chemical substitutes or replacements for high-priority toxic chemicals	Replaces solvents or other chemicals like methylene chloride, chloroform, mercury with more environmentally benign formulators							1992	Mitchell

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Existing Waste-Reducing Technologies Found in the Open Literature - Listed by Waste-Reduction Strategy

Process Redesign

Product	Waste-Reduction Technology Description	Environmental Benefits	Estimated Energy Savings	Estimated Waste Reduction	Effects	Capital Investment	Annual Cost Savings	Payback Period (yrs)	Ref. Year	Ref.
Petroleum	Changed method of tank cleaning	Reduced hazardous waste production			Recovery of valuable oil from oily solids; shorter off-stream times; hazardous waste reduction				1986	OTA1
Petroleum	Chevron polysulfide process reduces ammonia & hydrogen sulfide	Reduces ammonia; reduces wastewater volume			Reduces stripping steam & effluent volume; longer equipment life & reduced compressor failings				1986	OTA1
Petroleum	Substituting high-pressure filters for lower-pressure filters to increase oil recovery from clay filter cake	Oil recovery			Oil recovery from muds & clay filter cake increased				1986	OTA1
Petroleum	Vacuum distillation to recover oil for in-process recycling	Oil recovery			Increased percentage of oil recovery from muds & clay filter cake				1986	OTA1
Petroleum	Cold lime softening to remove total dissolved solids from cooling water makeup stream	Minimizes production of a primary sludge			Treatment cycles increase from 3 to 10; blowdown rate for a 50,000 gpm recirculating cooling tower decrease from 850 gpm to 150 gpm; minimizes wastewater treatment & waste production; conserves cooling water makeup				1991	API1
Petroleum	Reverse osmosis to remove TDS from cooling water makeup stream	Maximizes production of dissolved sludge			Treatment cycles increase from 3 to 10; blowdown rate for a 50,000 gpm recirculating cooling tower decrease from 850 gpm to 150 gpm; minimizes wastewater treatment & waste production; conserves cooling water makeup				1991	API1

Existing Waste-Reducing Technologies Found in the Open Literature - Listed by Waste-Reduction Strategy

Product	Waste-Reduction Technology Description	Environmental Benefits	Estimated Energy Savings	Estimated Waste Reduction	Effects	Capital Investment	Annual Cost Savings	Payback Period (yrs)	Ref. Year	Ref.
Petroleum	Electrodialysis for the removal of TDS from cooling water makeup stream	Maximizes production of primary sludge			Treatment cycles increase from 3 to 10; blowdown rate for a 50,000 gpm recirculating cooling tower decrease from 850 gpm to 150 gpm; minimizes wastewater treatment & waste production; conserves cooling water makeup				1991	API1
Petroleum	Chromate precipitation process minimizes toxics produced from corrosion inhibitors	Chromate concentration reduced		15-45 ppm	Chromate concentration reduced from 20 to 50 ppm to less than 5 ppm				1991	API1
Petroleum	Ion exchange for chromate recovery from cooling tower effluent	Chromate concentration reduced			Chromate recovery from cooling tower effluent				1991	API1
Petroleum	Chlorine vaporization into cooling systems controls biological growth				Controls deposition of biological growth				1991	API1
Petroleum	pH adjustment controls carbonate scaling	pH control has little impact on toxicity			Controls deposits on cooling tower; little impact on toxicity				1991	API1
Petroleum	Mechanical seals on pumps reduce air emissions & releases to oily drains	Reduces air emissions; reduces releases to oily drain; reduces oil content of solid waste			Same as environmental benefits				1986	OTA1
Petroleum	Chevron recovered oil process reduces hazardous organic waste production	Reduces production of hazardous organic wastes			Processes recovered oil efficiently; better desalter operation; less oil transferred to oily drain; reduces hazardous organic wastes				1986	OTA1
Petroleum	Belt filter press used for oil recovery from oily sludges	Reduction in volume of residues; recovered oil & water		95%	95% reduction in disposal waste; 99% oil recovery				1987	API2
Petroleum	Plate filter used for oil recovery from oily sludges	Reduction in volume of residues; oil recovery		91%	90.5% reduction in disposal waste; 97% oil recovery; if feed is properly conditioned, plate filers are effective at breaking emulsions; conditioning req. addition of lime & sometimes iron salts				1987	API2

Existing Waste-Reducing Technologies Found in the Open Literature - Listed by Waste-Reduction Strategy

Product	Waste-Reduction Technology Description	Environmental Benefits	Estimated Energy Savings	Estimated Waste Reduction	Effects	Capital Investment	Annual Cost Savings	Payback Period (yrs)	Ref. Year	Ref.
Petroleum	Rotary drum vacuum filter used to recover oil from oily sludges	Reduction in volume of residues; oil recovery		99%	More than 99% reduction of leachate concentration				1987	API2
Petroleum	Delayed coking unit modified to inject oily sludge and biosludge	Land disposal of waste eliminated			$90,000/yr utility requirements; oper. costs-$2/bbl sludge, off-site haz. waste disposal-$40/bbl; hydrocarbons in products; ash content increased (1975); waste recycled to produce fuel & coke	$200k to $300k			1991	API1
Petroleum	Mobile centrifuge system separates waste emulsion into solids, water, oil	Toxic emulsions avoided; water reusable		5%	5% volume reduction-solid slop into solid coke; 100,000 bbl/yr high-quality oil recovered for refining				1991	LANL
Petroleum	Oil-water separators used to recover oil from wet crude oil operations	Reduced oily waste production			Recovered oil can be used to reduce feed-stock; less oily waste requiring disposal	$500k ($500k for three separators)	$2M	0.25	1987	PIES/ CPEC
Petroleum	Oily sand cleaning system reduces oily sand waste and recovers oil	Reduced disposal of oily fluids		392 m^3/yr	Reduced disposal of oily fluids	$200k	$325k	0.62	1987	PIES/ CPEC
Petroleum	Filtration reduces sludge volume			40-55%	Sludge does not have to be preconditioned as does oily sludge; may be 30 to 35% solids, filtration reduces the then a sludge of 40 to 45% solids; alternative to permanent filter installation mass to be disposed 40 to 55% which is then a sludge of 40 to 45% solids; alternative to permanent filter installation				1991	API1
Petroleum	Chemical coagulation removes add'l oil & suspended solids after gravitation settling				Neutralizes charges on particles so they can coagulate & settle by gravity; reactions with sodium bicarbonate & chemical anticoagulants produce $Al(OH)_3$ & $FE(OH)_3$ flocs				1991	API1

Existing Waste-Reducing Technologies Found in the Open Literature - Listed by Waste-Reduction Strategy

Product	Waste-Reduction Technology Description	Environmental Benefits	Estimated Energy Savings	Estimated Waste Reduction	Effects	Capital Investment	Annual Cost Savings	Payback Period (yrs)	Ref. Year	Ref.
Petroleum	Polyelectrolytes (water-soluble organic polymers) act as coagulant aids				Help bridge across small floc particles & produce larger, stronger particles that settle rapidly w/o breaking up				1991	API1
Petroleum	All-organic systems replace dissolved air flotation (DAF) units using alum or iron salts				Reduced float volume (to 0.1 to 0.2% of feed volume)				1991	API1
Petroleum	Floating roof on storage tanks to reduce loss of hydrogen sulfide & hydrocarbon to the atmosphere				Hydrogen sulfide sometimes converts to sulfur or sulfuric acid; decreases product loss; controls VOCs				1986	OTA1
Petroleum	Conservation vents added to storage tanks to reduce VOCs release to the atmosphere	Reduced VOCs released			Reduced product loss, VOCs released				1986	OTA1
Petroleum	Chevron long-life treating process	Reduces production of organic and inorganic sludges							1986	OTA1
Petroleum	New gasoline, emission control (EC-1), reduces air pollutants	Reduces carbon monoxide (CO), nitrogen oxide (NOx), ozone, & particulate matter		42% 250 tons/day	Reduces air pollution to meet federal & state ambient air quality standards; EC-1 costs $0.02/gal. more to produce than regular leaded gasoline	$2M			1991	EPA1
Petroleum	Fixation treats wastes to form solid or semisolid product	Reduces leachability of hazardous material sludge wastes		98%	Does not recover oil, remove haz. materials, or reduce waste volume; volume & weight of material req. disposal increases from 10 to 100%; reduces leachability of haz. wastes				1987	API2
Petroleum	Process modification to reduce load to treatment plant			20%	Reduced load to treatment plant				1986	EPA2
Petroleum	Aluminum hydroxide removal from sludge for reclamation			60%	Reclaimed aluminum hydroxide				1986	EPA2
Petroleum	Alkylation units using octane enhancers (methyl-tertiary-butyl-ether) reduces lead in gasoline	Elimination of wastes due to tetra-ethyl lead production, leaded gasoline storage tank sludge, & emission of lead into the environment			More acid wastes are expected to be produced				1988	Leeman
Petroleum	Hydrocarbon raw material replaces oil as the phenol-absorbing medium in a mfg unit	Reduced waste disposed of off-site		100% 240 tons/yr	Reduce waste disposed of off-site; increase raw material savings					

Existing Waste-Reducing Technologies Found in the Open Literature - Listed by Waste-Reduction Strategy

Product	Waste-Reduction Technology Description	Environmental Benefits	Estimated Energy Savings	Estimated Waste Reduction	Effects	Capital Investment	Annual Cost Savings	Payback Period (yrs)	Ref. Year	Ref.
Petroleum	Dry-phase neutralization of alkylates generated from styrene production	Eliminated waste otherwise discharged to the environment		100%	Improved output 1-2%; 100% reduction in water usage (requires none); 100% reduction in waste discharged; equal amount of raw material used (1978)	ff5.25M			und	PIES/UN
Petroleum	Hydrogen washing by potassium carbonate in ammonia production	Ammonia discharge eliminated		100%	Substantial energy savings through steam saving; ammonia discharge eliminated				und	PIES/UN
Petroleum	Neutralization of spent caustics for treatment								1986	EPA2
Petroleum	High-temperature, high-pressure wet oxidation system treats spent scrubber water from coke manufacturing	Reused coke			Waste reused in plant or marketed as fertilizer; helped to meet brine quality & vent gas composition requirements				1987	PIES/ CPEC

In-Process Recycling

Product	Waste-Reduction Technology Description	Environmental Benefits	Estimated Energy Savings	Estimated Waste Reduction	Effects	Capital Investment	Annual Cost Savings	Payback Period (yrs)	Ref. Year	Ref.
Petroleum	Reuse of catalyst fines from a fluid catalytic conversion unit (FCCU)	When FCCU fines are recycled they are no longer a hazardous waste					$242k		1991	API1
Petroleum	Press filters used to recover usable product	Waste made non-hazardous			Filter cake is non-hazardous after process				1988	Leeman
Petroleum	Recycle solvents off-site by vendor				Some vendors supply fresh solvents in exchange for old ones				1991	API1
Petroleum	Recycle solvents by on-site distillation system				These systems must be good for plants using solvents exceeding 1000 gal/yr				1991	API1
Petroleum	Off-site recycling of phenols from caustic				Caustic containing phenolics can be sold to chemical recovery companies; phenolic content between 13-14% is usually req. to make it economical; sulfide sulfur should not exceed .5% by weight				1991	API1

PETROLEUM REFINING - EXISTING TECHNOLOGIES

Existing Waste-Reducing Technologies Found in the Open Literature - Listed by Waste-Reduction Strategy

Product	Waste-Reduction Technology Description	Environmental Benefits	Estimated Energy Savings	Estimated Waste Reduction	Effects	Capital Investment	Annual Cost Savings	Payback Period (yrs)	Ref. Year	Ref.
Petroleum	On-site recycling of phenols from caustic				Organic overloading & extreme odor possible; equipment req. is expensive; pH must be reduced to around 3				1991	API1
Petroleum	Spent caustic chemicals used for treatment of wood products	Eliminates need to dispose of hazardous waste		100%	Eliminates need to neutralize & dispose of hazardous waste; disposal cost svgs.				1991	LANL
Petroleum	Sulphidic & phenolic caustics used as feedstocks for the production of new chemical products	Avoided disposal of hazardous waste			Avoided disposal of hazardous waste				1988	Leeman
Petroleum	Recycling to metals reclamation	Reuse of metals			Reuse of hydrotreating catalysts & catalytic reforming catalysts; marketability of catalysts				1991	API1
Petroleum	Cat poly catalyst used as pozzolan material in concrete manufacturing	Reuse of waste			Concrete produced exceeds standards for strength				1988	Leeman
Petroleum	FCC equilibrium catalyst is alumina source & admixture in cement mfg.	Reuse of waste			Reduced waste disposed of				1988	Leeman
Petroleum	Recovery of oil from clay filters by backwashing	Hazardous waste clay becomes non-hazardous waste clay			Oil recovery, reduced hazardous waste				1991	API1
Petroleum	Recovery of oil from clay filters by steam	Hazardous waste reduced			Oil recovery, reduced hazardous waste				1991	API1
Petroleum	Spent jet fuel treater clay deoiling	Hazardous waste made nonhazardous			Hazardous waste made nonhazardous; decrease disposal costs; implementation costs insignificant if use existing materials: about 2000 jet fuel bbls/yr recovered and recycled				1991	API1
Petroleum	Cooling tower blowdown recycled as process water				Recycling applications vary depending on climate & refinery size				1986	OTA1
Petroleum	Filtration-belt filter press recycles oil	Reduces waste volume, recycles oil			Easy to implement, reduced waste volume				1991	API1
Petroleum	Recessed chamber pressure filter	Oil recovery			Oil recovery				1991	API1

Existing Waste-Reducing Technologies Found in the Open Literature - Listed by Waste-Reduction Strategy

Product	Waste-Reduction Technology Description	Environmental Benefits	Estimated Energy Savings	Estimated Waste Reduction	Effects	Capital Investment	Annual Cost Savings	Payback Period (yrs)	Ref. Year	Ref.
Petroleum	Rotary vacuum filter	Oil recovery			Oil recovery; installation requires upstream & downstream facilities; less oil recovery compared to belt filter press				1991	API1
Petroleum	Scroll centrifuges—vertical	Oil recovery; reduced waste volume			Oil recovery, waste volume reduction; cost 35-50% more to manufacture than horizontal; used at high temps & pressures; O & M cost savings				1991	API1
Petroleum	Scroll centrifuges—horizontal	Oil recovery; reduced waste volume			Oil recovery, waste volume reduction; cost 35-50% less to manufacture than vertical; capital cost usually less than filter system; O & M cost savings				1991	API1
Petroleum	Disc centrifuge				Can produce a force less than or equal to 7000 to 9000 times that of gravity; capital costs usually less than filter system; operating cost savings				1991	API1
Petroleum	Delayed coker recycle-quench water injection				Hydrocarbon recovery (1970s)				1991	API1
Petroleum	Desalter effluent deoiling	Oil-free water is discharged		122.4 tons	Approximately 862 tons/yr removed; disposal cost savings $200/ton	$60k	$24.5k	2.45	1991	API1
Petroleum	Oil recovery from slurry oil & FCC fine mixtures	Reduced volume to be disposed of			Reduced oil content in waste by 90%				1987	Adams & Caulfield
Petroleum	Production of fluorspar from calcium fluoride slurry				Calcium fluoride slurry from lime neutralization of sludge can be converted to fluorspar & sold to steel & glass industries as a fluxing agent				1991	API1
Petroleum	Recycle and reuse of used oil	Recycled oil		50%	Oil reuse				1991	LANL
Petroleum	Metal recovered from used lead-acid batteries	Reduced waste volume		75%	Disposal cost savings & waste reduction		$70k		1991	LANL
Petroleum	15% recycled plastic resin used in packaging motor oil	Recycled plastics used; less plastics produced			Disposal cost savings—plastic containers				1991	LANL

Existing Waste-Reducing Technologies Found in the Open Literature - Listed by Waste-Reduction Strategy

Product	Waste-Reduction Technology Description	Environmental Benefits	Estimated Energy Savings	Estimated Waste Reduction	Effects	Capital Investment	Annual Cost Savings	Payback Period (yrs)	Ref. Year	Ref.
Petroleum	Conversion of waste HCl into chlorine			300,000 tons/yr	Reduced waste HCl and reuse of chlorine				1986	EPA2
Petroleum	Return of distillation residue to process as raw material			4MM lb/yr	Reused distillation residues				1986	EPA2
Petroleum	Contaminated process water recycled instead of being deep-well injected	Recycled water		78%	Avoids high cost & risk involved in deep-well injection				1987	PIES/ CPEC
Petroleum	Alumina is sold as raw material in manufacture of several alumina products	Reduced hazardous waste disposal		20-50% 8000 tons	Consistency is important for marketing wastes through CA Waste Exchange				1987	CTMA
Petroleum	Refinery hazardous wastes used as feedstock to coker in the same facility	Recycled listed & non-listed hazardous wastes			Oily waste feedstock includes DAF float, slop oil emulsion solids, API separator sludge, tank bottom sludge, & bio-sludge				1988	Leeman
Petroleum	Caustic neutralization using CO_2 from the fluid catalytic cracker flue gas	Use of CO_2 decreases volumes of waste generated							1990	Freeman
Petroleum	Water recycled from asbestos/cement panels and pipes manufacturing	Reduces volume of disposed residue; reduces wastewater discharge		57% 100%	57% reduction of discharged residue; almost 100% reduction of wastewater discharge	ff5.5M			und	PIES/UN

Input Substitution

Product	Waste-Reduction Technology Description	Environmental Benefits	Estimated Energy Savings	Estimated Waste Reduction	Effects	Capital Investment	Annual Cost Savings	Payback Period (yrs)	Ref. Year	Ref.
Petroleum	Alternative sand blast media for preparing tanks, process units, & piping for painting			90% 2,790 tpy	310 tons/yr is nonhazardous waste	$1.5M			1991	API1
Petroleum	Phosphate-based corrosion inhibitors substituted for chromate-based ones in cooling water systems	Eliminates source of hazardous characteristics of refinery wastewater treatment sludges			Reduces hazardous waste				1988	Leeman
Petroleum	Storm water replaces fresh water in cooling towers	Reduced fresh water use			Storm water usually does not require softening; softening waste reduced				1991	API1
Petroleum	Wood substitutes oil for steam production	Reduced sulfur emissions			Wood-fired boiler reaches maximum capacity in 1/6 the time of oil-fired boiler	$587.5k	$118.8k	4.95	1987	PIES/ CPEC
Petroleum	Replacement of cooling water with air cooling	Less water required		97%	Reduced water requirements				1986	OTA1

PETROLEUM REFINING - EXISTING TECHNOLOGIES

Existing Waste-Reducing Technologies Found in the Open Literature - Listed by Waste-Reduction Strategy

Product	Waste-Reduction Technology Description	Environmental Benefits	Estimated Energy Savings	Estimated Waste Reduction	Effects	Capital Investment	Annual Cost Savings	Payback Period (yrs)	Ref. Year	Ref.
Product Changes										
Petroleum	Reformulate gasoline to substitute lead gasoline	Reduced benzene and sulfur emissions		7%	Offset 120 tons of benzene & sulfur/day; 840,000 gal/day sold in Los Angeles				1991	LANL
Petroleum	Reformation of end product to reduce hydrocarbon waste	Reduced hydrocarbon waste		100%	Reduced hydrocarbon waste				1986	EPA2
Operational Efficiencies										
Petroleum	Reusable drums	Reduces waste drums			Reduces waste by reusing drums				1991	API1
Petroleum	Education & training				Slop oils increase maintenance costs				1991	API1
Petroleum	Planting ground cover	Reduced solids entering wastewater treatment plants			Reduced solids entering sewer system				1991	API1
Petroleum	Paving/dust control	Reduced solids entering sewer system			Reduced solids entering sewer system				1991	API1
Petroleum	Cleaning ditches to keep solids out of sewer system				Reduced solids entering sewer system				1991	API1
Petroleum	Overflow weirs control; exchanger bundle cleaning solids				Avoids complications of exchange solids attracting oil; reduces generation of fine solids-stabilized emulsions				1991	API1
Petroleum	Maintenance staff controls fluid catalytic cracking units (FCCU) & coke fines	Reduced coke fine waste			Coke fine recovery				1991	API1
Petroleum	Avoid introducing surfactants to oily water upstream of centrifugal pump	Reduced emulsion & sludge formation			Reduced emulsion & sludge formation				1991	API1
Petroleum	Wash water enters waste stream downstream the air floatation unit				Minimizes emulsion and sludge separation				1991	API1
Petroleum	Emulsion-breaking agents used to treat sludges	Reduced quantities of organic sludges produced			Increased oil yield; reduced quantities of organic sludges produced				1986	OTA1
Petroleum	Prevent mixing of clean rainwater runoff with oily wastes	Reduced amount of hazardous waste			Reduced load to ww treatment plant				1988	Leeman

Existing Waste-Reducing Technologies Found in the Open Literature - Listed by Waste-Reduction Strategy

Product	Waste-Reduction Technology Description	Environmental Benefits	Estimated Energy Savings	Estimated Waste Reduction	Effects	Capital Investment	Annual Cost Savings	Payback Period (yrs)	Ref. Year	Ref.
Petroleum	Reduction in pump cooling water supplied	Reduced water usage			Reduced water requirements; enhanced performance due to less condensation				1986	OTA1
Petroleum	Computerized chemical inventory	Reduced unnecessary chemicals							1991	EPA1
Petroleum	Screening of solids from exchanger cleaning	Reduced solids entering the wastewater treatment plant		100%	Screens collect the solids, but allow the water & oil to enter the ww treatment system; collected solids are dry enough for disposal—do not require further dewatering				1991	API1
Petroleum	Storage of radioactive waste reduces hazardous waste by about one-half	Reduced hazardous waste		50% 312,000 gal/yr	Reduced hazardous waste				1986	EPA2
Petroleum	Adjusting processes to ensure consistent waste composition	Reduced hazardous waste disposal		20-50% 8000 tons	Consistency is important for marketing wastes through CA Waste Exchange				1987	CTMA
Petroleum	Segregating wastes for ease in recycling or exchange	Reduced hazardous waste disposal		20-50% 8000 tons	Consistency is important for marketing wastes through CA Waste Exchange				1987	CTMA
Petroleum	Geodesic domes replace floating roofs on storage tanks	Reduction of wastewater			Geodesic domes prevent about 100% rainfall from entering the tank; internal rate of return: 25-30%				1988	Leeman
Petroleum	Modified truck loading racks	Reduced waste produced		50%					1988	Leeman
Petroleum	Minimize the intrusion of air into the reactor system to reduce phenol generation				Reduced generation of phenol, therefore less phenol content in petroleum products				1990	Willenbrink
Petroleum	Location of leaks & repairs reduce oil loss to sewer system	Reduced oil wastage			Reduced 198,000 bbls/day of oil lost to sewer system			1	1990	Willenbrink
Petroleum	Biosystem solids segregated from the oil-separator solids	Reduced hazardous waste		70% 14,000 tons/yr	Second pressure filtration system was costly	$750k			1990	Willenbrink

Developing Waste-Reducing Technologies Found in the Open Literature - Listed by Waste-Reduction Strategy

Process Redesign

Product	Waste-Reduction Technology Description	Environmental Benefits	Estimated Energy Savings	Estimated Waste Reduction	Effects	Capital Investment	Annual Cost Savings	Payback Period (yrs)	Ref. Year	Ref.
Petroleum	Stretford chemical recovery process (SCRP)	Reduced solution disposal		89% 200,000 gal/yr	Dumping freq. reduced from every 2.5 mo. to 1/yr; full-size SCRP unit would eliminate solution dumping entirely	$750k	$180k	4.17	1991	API1
Petroleum	Recovery of spent solvent/oil mix by a "solvent saver"	Reduced hazardous waste produced		99% 299-399 gal/yr	Solvent recovery; reduced worker exposure		$2k		1991	EPA1
Petroleum	Solvent extraction of wastes at petroleum refineries	Recovery of "product oil" & "product water"; recycled solvent		99% 72%	More than 99% indicator organics red.; 72% reduction in TCLP leachates; can extract both oil & water from oil-water-solids; total metal concent. increased from waste feed to product solids				1987	API2
Petroleum	Partial sewer segregation				Greater ease in treating wastewater				1991	API1
Petroleum	Organic polymers aid in oil, water, & solid separation				Can achieve optimal oil-water water-solids mixture separation				1991	API1
Petroleum	Thermal treatment removes water & VOCs from refinery waste	VOCs removed from petroleum refinery waste		97%	Highly effective; product solids suited for land disposal				1987	API2
Petroleum	Rotary pyrolysis process recovers bitumen from mineral oil sands	Reduction of organics		99%	No problems anticipated for system integration; almost all organics in waste reduced to below detect. levels				1987	API2
Coal	Open gradient magnetic separation for physical coal cleaning	Lowers sulfur content of coal; reduces SO_x in emission & increases efficiency		75%	75% less use than conventional tech.				1990	ICPP
Petroleum	Multi-objective program as a method for determining the optimal structure of petrochemical processing w/least toxicity	Long-range method of evaluating complex processes to minimize waste generation							1985	Fathi & Afshar
Petroleum	Hydrogen sulfide utilization	Reduced sulfur dioxide, spent catalyst, & carbon dioxide	66 x10E12 Btus/yr	11.05 million tons/yr	Lower operating costs; hydrogen source is hydrogen sulfide waste gas		$4M	.67 to 5.50	1992	OIT/IWRP

Developing Waste-Reducing Technologies Found in the Open Literature - Listed by Waste-Reduction Strategy

Product	Waste-Reduction Technology Description	Environmental Benefits	Estimated Energy Savings	Estimated Waste Reduction	Effects	Capital Investment	Annual Cost Savings	Payback Period (yrs)	Ref. Year	Ref.
Petroleum	Degassing of water vapors from ammonium nitrate production	Produces less pollution		93%	Energy usage about the same; material ff300k yield consumption is reduced; better material			7.00	und	PIES/UN

In-Process Recycling

Product	Waste-Reduction Technology Description	Environmental Benefits	Estimated Energy Savings	Estimated Waste Reduction	Effects	Capital Investment	Annual Cost Savings	Payback Period (yrs)	Ref. Year	Ref.
Petroleum	Methyldiothanolamine (MDEA) conversion	Reduced H_2S in tail gas			Enriched H_2S stream is recycled for sulfur; reduced H_20 in tail gas				1991	API1
Petroleum	Anthraquinine disulfuric acid (ADA) recovered by charcoal adsorption	ADA recovered		95%	95% ADA recovered				1991	API1
Petroleum	Vanadium recovery by ion exchange	Vanadium recovered		85%	80-95% vanadium recovered; vanadium sensitive to thiosulfate purge concentration				1991	API1
Petroleum	Mixer keeps sludges in suspension to minimize tank bottom sludge	Recover oil, minimize waste			Very difficult to remove tank bottom muck				1991	API1
Petroleum	Recycling spent catalysts to cement manufacturers	Recycling spent catalysts			Spent catalysts from FCCUs contain silica & alumina; reuse of catalysts				1991	API1
Petroleum	Cat poly catalyst used as source of phosphorus fertilizer for agronomic crops	Reuse of waste			Possible market for wastes				1988	Leeman
Petroleum	Thermal treatment	Maximizes oil recovery; reduces toxicity & volume			Maximizes oil recovery; reduces toxicity & volume in a short time				1991	API1
Petroleum	Delayed coker recycle-coking cycle injection				Hyrdrocarbon recovery				1991	API1
Petroleum	Delayed coker recycle-blowdown injection				Hyrdrocarbon recovery				1991	API1

PETROLEUM REFINING - DEVELOPING TECHNOLOGIES

Developing Waste-Reducing Technologies Found in the Open Literature - Listed by Waste-Reduction Strategy

Input Substitution

Product	Waste-Reduction Technology Description	Environmental Benefits	Estimated Energy Savings	Estimated Waste Reduction	Effects	Capital Investment	Annual Cost Savings	Payback Period (yrs)	Ref. Year	Ref.
Petroleum	Abrasive blast media (ABM)	Less toxic than sand			Less toxic than sand, little safety control needed, lower disposal costs than for sand				1991	API1
Petroleum	Copper slag abrasive with recycling			94%	Heavier than most coatings & therefore easy to separate & recycle; about 94% can be recovered & reused				1991	API1
Petroleum	Alumina oxide abrasive with recycling				Uses same equipment as sand blasting; recyclable; vender will install recycling equipment at their expense if media is purchased at specified price				1991	API1
Petroleum	Replace phenol extraction to minimize waste from ww system	Fewer hazardous materials used			Less expensive and less toxic compared to phenol				1991	API1

Operational Efficiencies

Product	Waste-Reduction Technology Description	Environmental Benefits	Estimated Energy Savings	Estimated Waste Reduction	Effects	Capital Investment	Annual Cost Savings	Payback Period (yrs)	Ref. Year	Ref.
Petroleum	Antifoulants control exchange; cleaning solids	Reduces exchanger cleaning sludge; minimizes formation of a listed waste			Stops scale from foaming				1991	API1
Petroleum	Chemical heat exchanger cleaning	Reduces sludge volume			Reduces sludge volume by recovering oil				1991	API1
Petroleum	Vacuum system control; FCCUs & coke fines	Better material usage			Collected coke fines may be recycled for cement or fuel				1991	API1
Petroleum	Dust control, chemicals control FCCUs & coke fines				Reduces dust & coke fine migration				1991	API1
Petroleum	Street sweeper to reduce oily sludges			50% 8800 tons		$85k			1991	API1

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Existing Waste-Reducing Technologies Found in the Open Literature - Listed by Waste-Reduction Strategy

Process Redesign

Product	Waste-Reduction Technology Description	Environmental Benefits	Estimated Energy Savings	Estimated Waste Reduction	Effects	Capital Investment	Annual Cost Savings	Payback Period (yrs)	Ref. Year	Ref.
Cement	Cement kiln NOx & SOx reduced by omputer optimized process control	NOx & SOx reduced		40% 200 ppm	Economic savings in energy costs; longer kiln lining life; higher quality klinkers	£203k	£500k	0.41		PIES/
Concrete	Above-ground concrete containment cells for coarse solids disposal & water reuse	Decreased atmospheric emissions & water use rates			Decrease in wastewater discharge				1991	NSA
Concrete stripping	Developed dry-abrasive system for stripping concrete floors	Eliminated toxic waste & health hazards			Compatible w/water-based urethane coatings w/o solvents				1991	LANL
Glass cutting	Removal of contaminants from glass cutting wastes by centrifugation	Allows reuse of glass cutting wastes & oil recovery			Allows reuse of glass cutting wastes & oil recovery	ff1.495M				PIES/
Rock	Plate clarifiers for removal of rock fines & reuse of process water	Decrease in emissions to atmosphere & water use rates			Decrease in wastewater discharge				1991	NSA
Rock	Rock crushing plant wet suppression dust control system	Dust emission reduction		97%					1991	NSA
Rock	Bag house filters for dry dust control	Dust emission reduction							1991	NSA
Rock	Closed-circuit settling ponds for disposal of rock fines & reuse of process water	Reduced material releases to the environment			Zero water discharge				1991	NSA

In-Process Recycling

Product	Waste-Reduction Technology Description	Environmental Benefits	Estimated Energy Savings	Estimated Waste Reduction	Effects	Capital Investment	Annual Cost Savings	Payback Period (yrs)	Ref. Year	Ref.
Cement	Recycling of collected cement dust	Eliminates the need to dispose of collected fines			Reduces waste disposal costs; product reuse				1993	Shoenberger & Kirlin
Ceramics	Recycling of enamels for frit resmelting	Reduces disposal costs		58%					1990	Rodie

Existing Waste-Reducing Technologies Found in the Open Literature - Listed by Waste-Reduction Strategy

Product	Waste-Reduction Technology Description	Environmental Benefits	Estimated Energy Savings	Estimated Waste Reduction	Effects	Capital Investment	Annual Cost Savings	Payback Period (yrs)	Ref. Year	Ref.
Input Substitution										
Cement	Using lubricating oil as cement kiln fuel	Eliminates disposal of lubricating oil; recycle used oil			Disposal cost savings					PIES/
Cooling towers	Non-chromate corrosion inhibitors protect against heated steel tube corrosion	Chromate eliminated from process wastewaters			1972 data				1993	PIES/
Rock	Use of surfactants as a wetting agent for fine dust control	Reduced material releases to the environment			More effective dust control using less water than simple wet suppression systems				1991	NSA
Product Changes										
Glass	Developed extensive line of lead- and cadmium-free glazes	Avoided cadmium, lead, & others heavy metals use							1991	LANL
Glass	Developed extensive line of lead-free glazes for glass	Avoided use of lead in glass			Avoided use of lead in glass				1991	LANL

Developing Waste-Reducing Technologies Found in the Open Literature - Listed by Waste-Reduction Strategy

Product	Waste-Reduction Technology Description	Environmental Benefits	Estimated Energy Savings	Estimated Waste Reduction	Effects	Capital Investment	Annual Cost Savings	Payback Period (yrs)	Ref. Year	Ref.
Process Redesign										
Cement	Production of aluminum oxide together w/cement	No waste products & "red mud" generation eliminated by process			Production increased by 25% & no waste products generated					PIES/
Glass	Glass-melting furnace uses glass fiber waste		44% 12.9MJ/kg						1990	Tomik
Glass	Recycling cullet for use in glass container furnaces	Reduces waste disposal			Reduces waste disposal costs; product reuse				1988	Denapoli & Kilpatrick
In-Process Recycling										
Asbestos/ cement	Recycling of water from manufacturing of asbestos/cement panels & pipes	Residues & wastewater generation reduced (57% & 100% respectively)		57%, 100%		ff5.5M				PIES/UN
Glass	Utilizing waste cullet w/opacified phosphate glass for the production of glass-kremnezit				Saves about 50,000 rubles/yr		50k		1989	Tatarintsev
Glass	Use of waste products in glass melting	Eliminates need for waste disposal			Incorporates waste materials into glass product				1991	Pankova & Belyaeva
Graphite	Recovery of synthetic flake graphite & iron oxide from kish	Eliminates kish as a waste material			Recovers valuable by-product				1993	Landreth et al.

Developing Waste-Reducing Technologies Found in the Open Literature - Listed by Waste-Reduction Strategy

Input Substitution

Product	Waste-Reduction Technology Description	Environmental Benefits	Estimated Energy Savings	Estimated Waste Reduction	Effects	Capital Investment	Annual Cost Savings	Payback Period (yrs)	Ref. Year	Ref.
Brick tiles fiberglass	Vetrification of MSW fly ash for the production of brick tiles or fiberglass	Eliminates the disposal of fly ash in landfills & uses it beneficially for production of bricks or tiles							1991	NYSDEC
Cement	Liquid & solid hazardous waste as a substitute fuel in cement kilns	Hazardous waste derived fuel can be destructed while providing a fuel source			Direct offset of fossil fuel consumption				1993	Abbruzzese
Glass	Metallurgical wastes for use in the production of smalt (glass cooking)	Reduction or recycle of waste materials			Reduces waste disposal costs; product reuse				1989	Gomozova et al.
Glass	Use of electric arc furnace dust for the production of glass frit	Eliminates electric arc furnace dust as a waste material			Reduces waste disposal costs				1993	Futornick

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Existing Waste-Reducing Technologies Found in the Open Literature - Listed by Waste-Reduction Strategy

Process Redesign

Product	Waste-Reduction Technology Description	Environmental Benefits	Estimated Energy Savings	Estimated Waste Reduction	Effects	Capital Investment	Annual Cost Savings	Payback Period (yrs)	Ref. Year	Ref.
Metal	Chemelec system recovers zinc from pickling & plating rinse waters	Total zinc drag-out reduced	(6.4 kW)	86% 840 g/hr	No payback due to annual costs	$180,000	-21600	None	1987	PIES
Metal	Dry Scrubbing--Pneumatic scrubbing reclaims sand	Reduces amount of sand being disposed			Reuse of sand by removing some of the binder chemicals				1992	EPA5
Metal	Closed-loop wastewater system replaced by single-pass system	Reduced threat of ground- & surface-water pollution			Capital costs reduced 50% to 75%; decreased health risks		$20,995	3.5 yrs.	1986	Huisingh
Metal	Mechanical Scrubbing--Vibro-energy systems use synchronous & diametric vibration	Reduced load of sand disposed			Frictional & compressive forces separate binder from sand				1992	EPA5
Metal	Multiple-Hearth Vertical Shaft furnace reclaims sand	Reduced load of sand disposed			Provides excellent contact between sand grains by a rotating vertical shaft				1992	EPA5
Metal	Changing the core sand knockout procedure to keep sand from being mixed with sand before disposal	Reduces the amount of listed hazardous wastes			Reduces overall amount of sand being discarded				1992	EPA5
Metal	Ion nitriding process offers alternative to cyanide-containing baths	Minimizes or eliminates hazardous waste			Lower energy consumption; increased control & properties				1992	EPA5
Metal	Induction hardening--alternative to neutral hardening in electric or gas furnaces	Minimizes or eliminates hazardous waste			Large working areas or furnace enclosures not needed				1987	PIES
Metal	Pretreatment of rinse water from steel wire manufacturing (chemical precipitation)	Limits waste			Water & sewer rates drop		$64,800			PIES
Metal	Install induction furnaces	Emits about 75% less dust & fumes than an EAF			Emission-control equipment may be minimized				1992	EPA5
Metal	Heating tundish by electric induction instead of fossil fuel	Elimination of hydrogen gasses in molten bath; elimination of corrosive, polluting waste gas	206 Btu/yr	80% 147,000,000 lbs.	Improved production yields; 98% energy efficient	$600,000	$5.8 million		1992	OIT-IWRP
Metal	Electric induction melting furnaces used to melt gray iron	Eliminates generation of air pollution control residuals			Air pollution control equipment is not necessary				1988	Oman

PRIMARY METALS - EXISTING TECHNOLOGIES

Existing Waste-Reducing Technologies Found in the Open Literature - Listed by Waste-Reduction Strategy

Product	Waste-Reduction Technology Description	Environmental Benefits	Estimated Energy Savings	Estimated Waste Reduction	Effects	Capital Investment	Annual Cost Savings	Payback Period (yrs)	Ref. Year	Ref.
Metal	Improve process control--completely react CaC_2 with sulfur	Eliminates generation of hazardous waste			Amount of sulfur in scrap varies, so exact dosage of CaC_2 is difficult to determine				1988	Oman
Metal	Improve process control--fine granules, coated granules, & solid rods of CaC_2 used to control chemical reaction	Eliminates generation of hazardous waste			Reduce amount of excess CaC_2 (20-30% excess) used				1992	EPA5
Metal	Ruthner Neolyte Process for pickling of special steel strips	Decreased pollution			High-quality steel surfaces; high investment costs					ANWT
Metal	Low-cyanide salt bath for nitro-carburizing treatments	Avoids the generation of hazardous sludge			Avoids high cost of detoxifying cyanide effluents				1992	EPA5
Metal	Using organic polymers for bath regeneration low-cyanide alternative for cyanide baths				When using water quenching, the low level of cyanide permits easier detoxification				1992	EPA5
Metal	Dewater quenchant oils by passing the bath through a centrifuge				Water in quenchant oils results can increase fire hazards				1992	EPA5
Metal	Ultrafilter water-polymer quenchants				Ultrafiltration can remove salt continuously				1992	EPA5

In-Process Recycling

Product	Waste-Reduction Technology Description	Environmental Benefits	Estimated Energy Savings	Estimated Waste Reduction	Effects	Capital Investment	Annual Cost Savings	Payback Period (yrs)	Ref. Year	Ref.
Metal	Copper electroplating sludges are fed to a smelting reactor for recovery	Safe copper recovery operation that provides alternative to sludge disposal			Sludges containing PCBs, beryllium, & other carcinogens are not safely recycled				1987	PIES
Metal	Collection of telephone wire & cable, switch boxes & hooks, circuit boards, & casings for recycle	Reuse of waste			Gained over $2M/year from recycling copper scrap; waste materials sold for recycling; 97% of oven door seal against leaks which exceeds 90% EPA requirement				1991	LANL
Metal	Recovery of heavy metals from carbon steel Electric Arc Furnace dust	Reduces solid hazardous waste disposal to landfills			Recycled heavy metals are marketable				1983	PIES
Metal	Processed coal-tar sludge collected from coke plant tar decanter can replace fuel oil	Reduced waste sent to landfill			Energy & disposal savings; avoided need to dump nearly 10M gal of tar-decanter sludge since 1985; improved coke-oven performance				1991	LANL

Existing Waste-Reducing Technologies Found in the Open Literature - Listed by Waste-Reduction Strategy

Product	Waste-Reduction Technology Description	Environmental Benefits	Estimated Energy Savings	Estimated Waste Reduction	Effects	Capital Investment	Annual Cost Savings	Payback Period (yrs)	Ref. Year	Ref.
Metal	Rotary (Waelz) Kiln technology to recover metals from EAF dust	Reduced solid hazardous waste disposal			Reduces ferrous iron oxide to solid iron; must be large to be economical				1992	EPA5
Metal	Pyrometallurgical methods for metals recovery from EAF dust	Reduced solid hazardous waste disposal			Process is based on reduction of Zn, Pb, Cd, & others				1992	EPA5
Metal	Electrothermic Shaft Furnace to extract zinc from EAF dust	Reduced solid hazardous waste disposal			Dust must contain 40% of Zn; Zn recovered in metallic form				1992	EPA5
Metal	Zinc oxide enrichment method for recovery of metals from EAF dust	Reduced solid hazardous waste disposal			Zinc oxide recovery cost is estimated at $159/ton of dust				1992	EPA5
Metal	Fugitive dust recovered & reused in an iron foundry	Reduced sludge generation by 1,300 m^3/year			99% recovery of molding material; improved working environment	£19,000	£84,000		1989	PIES
Metal	Foundry sand waste used in bituminous concrete (asphalt)	Reduced load of sand disposed			Foundry sand can be used as partial aggregate for asphalt				1992	EPA5
Metal	Use of spent foundry sands in cement manufacturing	Reduced load of sand disposed			Use of spent sand increased cement compressive strengths				1992	EPA5
Metal	Recovery of hydrochloric acid from the pickling process	Reduced HCl consumption to 2-2.5 kg/ton steel from 18 kg/ton			Investment & operating costs compensated by HCl savings					ANWT
Metal	Recycling of dust from EAF	Reduced disposal of solid hazardous waste to landfills			Power consumption increased approx. 4%; zinc content must be greater than 20% of dust	$230,000			1986	Krishnan
Metal	Recovery of hydrochloric acid & water from spent pickle liquor	Reclaimed 3,500 gal/d HCl & 13,000 gal/d water, ferrous chloride diversion			Minimizes corporate liability; high construction costs				1991	PIES
Metal	Use of mineral wool & cellulose filters to remove contaminants from quenchant oil	Quenchant oil is recycled			Exhausted filters disposed of as hazardous waste				1992	EPA5
Metal	Magnetic filters, traps, &/or strainers used to recover contaminants from quenchant oil	Quenchant oil is recycled			Useful in removing scale & other foreign materials				1992	EPA5
Metal	Clay filters used to remove contaminants from quenchant oil for recycling	Quenchant oil & clay filters are recyclable			Clay filtering media is more expensive than mineral wool				1992	EPA5
Metal	Sand reclamation by screens, ferric magnets, & a rotary kiln	Off-site shipment of hazardous waste sand reduced in 1990		1,590,000 lb	Reclaimed brass is resmelted; reclaimed sand is reused	$500,000		1.5-2 yrs.	1990	NC

Existing Waste-Reducing Technologies Found in the Open Literature - Listed by Waste-Reduction Strategy

Product	Waste-Reduction Technology Description	Environmental Benefits	Estimated Energy Savings	Estimated Waste Reduction	Effects	Capital Investment	Annual Cost Savings	Payback Period (yrs)	Ref. Year	Ref.
Metal	Improvements made to brass reclamation process by screens, magnets, & rotary kiln	Off-site shipments of lead-contaminated sands dropped an additional 234,000 lb.		234,000 lb	Nearly all casting sands were recyclable after improvements				1991	NC
Metal	Reclaimed brass & sand by use of screens, magnets, & a rotary kiln	Off-site shipments of lead-contaminated sands dropped		1,433,000 lb	Waste shipments will approach zero with upgrades		$750,000	6 mo.	1991	NC
Metal	Screening used sand to recover metal pieces	Increased usage of raw material			Recovered metal often has sand adhered to it that generates slag when remelted				1992	EPA5
Metal	Slag from stainless steel melting operations is recycled as feed for cupola furnaces	Hazardous slag becomes non-hazardous			Cupola furnace slag takes trace metals form the induction furnace slag				1992	EPA5
Metal	Sale of waste EAF dust for zinc recovery	Elimination of pollution risks; conservation of material resources			Reduce disposal costs & risks		$129,000	Instant	1986	Huisingh
Metal	Silicon waste recovered & marketed as concrete additive	Eliminated need for landfill disposal			$1 million/year in revenue				1985	PIES
Metal	Reclamation of waste foundry sands	Eliminated disposal of all spent sand (1,200 tons/yr)			Reduced purchase of virgin sand by about 800 tons/yr	$700,000		<2	1992	CDTSC
Metal	Silica-based baghouse dust is used in cement manufacturing	Eliminates landfill disposal			Baghouse dusts may constitute 5-10% of raw materials in cement				1992	EPA5
Metal	Recycling of blast furnace slag				Marketable: 2/3 slag used as road building material; 1/3 slag used in cement				1987	Philip

Input Substitution

Product	Waste-Reduction Technology Description	Environmental Benefits	Estimated Energy Savings	Estimated Waste Reduction	Effects	Capital Investment	Annual Cost Savings	Payback Period (yrs)	Ref. Year	Ref.
Metal	Substituted non-toxic, starch-based binder system for oven-baked sand cores	Virtually no odor or smoke			Improved scratch hardness & shakeout properties of sand cores				1991	LANL
Metal	Use of liquid spray compositions	Reduced waste of excess abrasives used			Wear of wheel & the requirement for cleaning are reduced or eliminated				1986	EPA6
Metal	Alter raw materials to minimize the generation of hazardous waste	Reduced Lead (Pb) from 13 mg/L to 1 mg/L & Cadmium (Cd) from 1.2 mg/L to 0.42 mg/L			Economics of purchasing raw materials with lower Pb & Cd does not favor competition				1988	Oman

PRIMARY METALS - EXISTING TECHNOLOGIES

Existing Waste-Reducing Technologies Found in the Open Literature - Listed by Waste-Reduction Strategy

Product	Waste-Reduction Technology Description	Environmental Benefits	Estimated Energy Savings	Estimated Waste Reduction	Effects	Capital Investment	Annual Cost Savings	Payback Period (yrs)	Ref. Year	Ref.
Metal	Alter charge metal by purchasing low-sulfur scrap	Reduce need for desulfurization & thus reduce hazardous desulfurization slag			Economics may not be favorable due to cost of high-quality scrap				1988	Oman
Metal	Substituted silicate binder for resin binder in sand molding & coremaking	Eliminated odors & smoke			Improved worker environment; improved quality & finish of sand molds & cores; improved collapsibility of silicate-bonded sand w/reuse rate <=85%				1991	LANL
Metal	Substituted H_2O_2 for chemical removal of surface oxides from brass wire	Eliminated chromic acid from pickling process			Cut waste treatment costs		$43.2k		1991	LANL
Metal	Use of greaseless or water-based binders for polishing or buffing	Conservation of wheel & parts, reducing the need for disposal			Wheel life is extended; reduced hazard of binders burning				1986	EPA6
Metal	Use of deionized water for rinsing				Extend plating bath life by reducing impurities from tap water; rinses can be reused				1986	EPA6

Operational Efficiencies

Product	Waste-Reduction Technology Description	Environmental Benefits	Estimated Energy Savings	Estimated Waste Reduction	Effects	Capital Investment	Annual Cost Savings	Payback Period (yrs)	Ref. Year	Ref.
Metal	Locate cold cleaning tanks away from heat; Control amount of heat to vapor degreaser; avoid spraying parts above vapor zone	Waste reduced							1986	EPA6
Metal	Waste segregation of hazardous chrome & non-hazardous aluminum hydroxide	Reduces hazardous waste generation			Savings on avoided hazardous waste treatment & disposal costs				1984	PIES
Metal	Installation of lids on solvent tanks	Reduces frequency of solvent disposal		24%-50%	Reduced loss of vapor-degreaser solvent				1986	EPA6
Metal	Installation of fog nozzles on heated aqueous cleaner tanks	Reduced water consumption			Reduced drag-out from cleaner and plating baths				1986	EPA6
Metal	Avoid solvent vapor drag-out	Reduced waste of solvents			Workpiece should be inserted into solvent slowly				1986	EPA6
Metal	Use of mineral oil helps minimize degradation of oil quenchant at high temperatures	Reduced quenchant wasted			Increases quenching effectiveness; lengthens useful life				1992	EPA5

Existing Waste-Reducing Technologies Found in the Open Literature - Listed by Waste-Reduction Strategy

Product	Waste-Reduction Technology Description	Environmental Benefits	Estimated Energy Savings	Estimated Waste Reduction	Effects	Capital Investment	Annual Cost Savings	Payback Period (yrs)	Ref. Year	Ref.
Metal	Redesigned plugs on coke-oven doors for easier cleaning	Reduced leaks from coke oven doors							1991	LANL
Metal	Consolidate cold cleaning operations into a centralized vapor degreasing operation	Reduced frequency of solvent disposal			Vapor degreaser can operate up to a level of 25-30% contamination				1986	EPA6
Metal	Increase freeboard space	Reduced emissions			Reduced need for solvent replacement				1986	EPA6
Metal	Lift barrel out of rinse, drain, & re-immerse to improve rinsing efficiency	Reduces wasted rinse media			Improved rinsing efficiency				1989	Tsai & Nixon
Metal	Replumbing the dust collector ducting to collect metal chips for recycling	Reduces the amount of listed hazardous wastes			Reduces overall amount of sand being discarded				1992	EPA5
Metal	Installing new baghouse on sand system to separate sand dusts from furnace dusts	Reduces the amount of listed hazardous wastes			Reduces overall amount of sand being discarded				1992	EPA5
Metal	Installing new screening system on main molding system to clean metal from sand	Reduces the amount of listed hazardous wastes			Reduces overall amount of sand being discarded				1992	EPA5
Metal	Installing a magnetic separation system on the shotblast system to allow recycling of metal dust	Reduces the amount of listed hazardous wastes			Reduces overall amount of sand being discarded				1992	EPA5
Metal	Detoxifying unusable sand	Reduces the amount of listed hazardous wastes			Reduces overall amount of sand being discarded				1992	EPA5
Metal	Control temperature of oil quenchant system	Reduces quenchant wastes			Avoids oil degradation & carbonaceous deposits				1992	EPA5
Metal	Minimize drag-out by substituting racks for trays for carrying workpieces	Minimizes waste of bath media			Reduces amount of bath media being carried out of the bath				1992	EPA5
Metal	Dragout tanks protect running rinse water from contamination	Minimizes hazardous waste generation			Recovery of valuable raw materials; provides income for environmental protection				1989	Tsai & Nixon
Metal	Mixing CaC_2 desulfurization slag & furnace dust reduces toxicity	Hazardous waste is made non-hazardous			pH of mixture must be monitored to avoid lead leaching out; disposal costs reduced from $100/ton to $35/ton	$1.751M	$577k	3	1988 1989	Oman Drabkin & Rissmann

Existing Waste-Reducing Technologies Found in the Open Literature - Listed by Waste-Reduction Strategy

Product	Waste-Reduction Technology Description	Environmental Benefits	Estimated Energy Savings	Estimated Waste Reduction	Effects	Capital Investment	Annual Cost Savings	Payback Period (yrs)	Ref. Year	Ref.
Metal	Control of water level in mass finishing equipment	Conservation of water			Too little water used increases the replacement rate of abrasive				1986	EPA6
Metal	Proper design & operation of rack system	Conservation of water			Solution drag-out is reduced; capital & operating costs for waste treatment are minimized				1986	EPA6
Metal	Proper design & operation of barrel system	Conservation of water			Barrel should be immersed partially for efficiency				1986	EPA6
Metal	Installation of water sprays on rinse tanks	Conservation of water			Increased rinsing efficiency				1986	EPA6
Metal	Efficient parts rinsing before entering soak tank extends solvent life	Conservation of solvent			Cleaning load reduced & thus solution life is extended				1986	EPA6
Metal	Remove sludge frequently	Conservation of chemicals			Replacement chemical costs reduced 20%				1986	EPA6
Metal	Installation of freeboard chillers in addition to cooling jackets	Conservation in solvent		60%	Reduction in solvent consumption				1986	EPA6
Metal	Applying forced air to the workpiece removes surface oil	Avoids generation of hazardous waste; reduces quenchant waste			Minimizes drag-out of quenchant				1992	EPA5
Metal	Minimize drag-out of molten salts by removing salt sludge mechanically or by filtration	Avoids generation of hazardous waste			Extended life of quenching media				1992	EPA5
Metal	Removal of sludge from tank bottoms to maintain cleaning efficiency	Avoids acid formation			Maintains cleaning efficiency by removing contaminants				1986	EPA6
Metal	Graphite cover helps maintain bath composition & prolong its life				Uncovered baths are exposed to carbonate, which corrodes the pot & reduces the bath life				1992	EPA5
Metal	Periodic cleaning increases the longevity of molten baths by removing impurities				Carbonates are removed with a perforated ladle extending bath life				1992	EPA5
Metal	Water separator should be cleaned & hecked for drainage to avoid water contamination				Avoid acid formation by avoiding water contamination				1986	EPA6
Metal	Analysis of solvent lengthens usage of solvent				Expense of analysis is usually offset by the savings in solvent				1986	EPA6

PRIMARY METALS - EXISTING TECHNOLOGIES

Existing Waste-Reducing Technologies Found in the Open Literature - Listed by Waste-Reduction Strategy

Product	Waste-Reduction Technology Description	Environmental Benefits	Estimated Energy Savings	Estimated Waste Reduction	Effects	Capital Investment	Annual Cost Savings	Payback Period (yrs)	Ref. Year	Ref.
Metal	Standardizing the solvent used in cold cleaning tanks makes recycling more attractive				Improves potential for recycling				1986	EPA6

Developing Waste-Reducing Technologies Found in the Open Literature - Listed by Waste-Reduction Strategy

Product	Waste-Reduction Technology Description	Environmental Benefits	Estimated Energy Savings	Estimated Waste Reduction	Effects	Capital Investment	Annual Cost Savings	Payback Period (yrs)	Ref. Year	Ref.
Process Redesign										
Metal	Decrease desulfurization to generate less hazardous waste	Wastes generated no longer considered hazardous			Eliminates need to add excess calcium carbide to molten metal				1988	Oman
Metal	Airless spray method for painting	Reduced generation of hazardous waste			Reduced loss of paint from 8.0 m^3 to 6.5m^3	$4,800	$38,500	1.5 mo.	1993	UNEP
Metal	Pressure atomized electrostatic spray for painting metal surfaces	Reduced generation of hazardous waste			Reduced loss of paint from 8.0m^3 to 5.6m^3	$13,000	$39,400	4 mo.	1993	UNEP
Metal	Direct steelmaking process	Reduced environmental damage caused by coke ovens	25%		Decline in capital costs; simplifies process				1990	Ross & Steinmeyer
Metal	Circulating bed combustor process of spent potliners	Reduced cyanide & leachable fluoride levels			Ash from combustion of spent potliners would probably not be considered hazardous				1988	Ogden
Metal	Ion carburizing process--alternative to cyanide-containing baths	Minimizes or eliminates hazardous waste			Lower energy consumption; faster cycle times				1992	EPA5
Metal	Direct steelmaking process	Eliminates need for polluting coke ovens			Could increase competitiveness of small industries				1990	POPE
Metal	Dry-type dusting waste gas scrubbing system	Eliminates disposal of coarse dust & fine oxygen-converter sludge			Reuse of materials; avoids disposal costs				1987	Philipp
Metal	Metallurgical post-treatment to improve slag volume consistency	Avoids dumping of oxygen-converter slags							1987	Philipp
In-Process Recycling										
Metal	Calcium fluoride recovery from spent pickle liquor treated with slaked lime	Reduced generation of sludge			95% recovered fluoride used as fluorspar flux	$300,000	$168,000	2.5		Drabkin
Metal	Decomposite steelmaking shop slags sold for fertilizers	Avoids dumping of oxygen-converter slags			Possible market for wastes				1987	Philipp
Metal	Recycling desulfurization slag to reclaim metal				Product quality is good; sulfur does not concentrate in metal				1988	Oman

Developing Waste-Reducing Technologies Found in the Open Literature - Listed by Waste-Reduction Strategy

Product	Waste-Reduction Technology Description	Environmental Benefits	Estimated Energy Savings	Estimated Waste Reduction	Effects	Capital Investment	Annual Cost Savings	Payback Period (yrs)	Ref. Year	Ref.
Input Substitution										
Metal	Substitute CaC_2 with calcium oxide, calcium fluoride, & other materials	Eliminates generation of hazardous waste			Economics are better compared to CaC_2 desulfurization				1988	Oman

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APPENDIX C

Vital Issues Report Identifying Evaluation Criteria

This appendix contains the report from the Vital Issues Panel meeting held June 8, 1993. The panel developed a working defintion of a technology demonstration opportunity and a list of six criteria for use by future industry-specific panels in screening technology demonstration opportunities.

Energy Policy Act of 1992
§2108
Energy Efficient Environment Program

Opportunities for Energy-Efficient, Pollution-Prevention Technology Demonstrations

Report of the
Sandia National Laboratories
Vital Issues Panel
Washington, D.C.
June 8, 1993

Sponsored by the
Industrial Waste Reduction Program
U.S. Department of Energy

Introduction

Pursuant to §2108 of the Energy Policy Act of 1992 (EPAct), the Secretary of the U.S. Department of Energy, in consultation with the Administrator of the U.S. Environmental Protection Agency, was authorized to conduct programs designed to improve the energy efficiency and cost effectiveness of pollution-prevention technologies and processes, including source reduction and waste minimization technologies and processes. Presumably, these technologies and processes would be capable of increasing industrial productivity, while simultaneously reducing the consumption of energy and material resources and the production of wastes. Specifically in §2108(b), the Secretary, in consultation with the Administrator, was directed to identify opportunities for the demonstration of energy-efficient, pollution-prevention technologies and processes. A report containing this information was required to be submitted to the U.S. Congress within nine months after the enactment of the Act.

Approach

A panel of stakeholders and constituency groups was convened on June 8, 1993 (see Attachment A), by Sandia National Laboratories to assist the Department of Energy in the development of its response to §2108(b) of EPAct (see Attachment B). Panel members included representatives from industry, federal agencies, universities, and an environmental organization (see Attachment C). The panel was charged (see Attachment D) to:

(1) develop a working definition of an energy-efficient, pollution-prevention technology demonstration;

(2) identify criteria for screening candidate technology demonstrations; and

(3) rank and weight selected criteria for application by subsequent panels.

In contrast to this panel, each of these follow-up panels will be focused on opportunities for technology demonstrations in a single industrial sector chosen among agriculture, chemicals, mining, petroleum, primary metals, pulp and paper, and stone, clay, and glass. The methodology developed by Sandia National Laboratories, called the Vital Issues Process (see Attachment E), was employed to assist the panel in meeting its charge.

Definition of Technology Demonstrations

To stimulate thought and to provide a basis for the panel discussions, a strawman definition of an energy-efficient, pollution-prevention technology demonstration was provided to the panelists in advance of the meeting, viz.:

> *An energy-efficient, pollution-prevention technology demonstration is the installation of hardware, software, and/or an operational procedure in a monitored industrial setting to determine and display technical and economic performance, thereby encouraging timely adoption by similar firms.*

This definition triggered a lengthy discussion of the relative merits of being focused on simply technologies available for demonstration or alternatively emphasizing the concept of opportunities for pollution prevention and energy efficiency. The latter position being judged by some panelists to be more responsive to the language of EPAct. Narrow and broad interpretations of technology were deliberated by the panel with general agreement being reached that technology should be viewed from a systems perspective to include hardware, software, and operational or managerial practices. While straightforward housekeeping programs to save energy, reduce pollution, and lower costs are important activities to be adopted by industry, these actions seemed generally inappropriate for a technology demonstration in the EPAct context.

Demonstration opportunities imply a follow-up process to diffuse attractive technology throughout industry. Discussions of the conditions necessary for successful technology diffusion; the importance of macro- and micro-economic concepts of productivity, competitiveness, and cost effectiveness; the value of deploying existing technologies in contrast to developing new technologies; and the need for efficient methods of information dissemination occupied the attention of the panelists. Simultaneously the panel was struggling to capture within a working definition the most important factors involved in identifying technology demonstrations. Energy-efficient, pollution-prevention technologies pose a special challenge because reducing pollution while lowering energy consumption are often competing interests in industrial processes. Alternatively, reductions in material flows commonly result in smaller waste streams and energy requirements by simply partially eliminating the source of pollution and the energy embodied in the unneeded materials.

In order to achieve closure on the definitional charge, the panel arrived at a consensus objective within the EPAct framework as follows:

Identify demonstration opportunities with the greatest potential for improvement in energy efficiency, pollution prevention, and economic competitiveness.

Each of the three major principles identified in this objective statement contain a number of operational elements. Energy efficiency may be quantified, for example, by considerations of energy consumption per unit of product output, energy use per unit of pollutants generated, and product life-cycle energy consumption including disposal. Qualitative considerations include type of fuel consumed, fuel diversity, and energy implications of regulatory compliance.

Reduction of ecological, environmental, and human health effects of production in all economic sectors as well as in individual and commercial consumption of products and services was agreed upon by a majority of the panelists as the principal driver behind pollution prevention. Quantitatively, measures of pollution prevention may include volume of pollutants, pollutant toxicity levels, and human health and ecological risk, all expressed in a normalized unit product or service output basis. Mechanisms to achieve pollution prevention discussed by the panel included: material selection and substitution; design of products, processes, and practices; housekeeping practices and modifications to manufacturing processes; and reducing exposure to pollutants. Many of these mechanisms are encompassed by the concept of source reduction.*

Maintaining a multi-media perspective and minimizing the simple transfer of pollutants from one media to another were also viewed as important considerations. Moreover, the panelists

*As defined by the Pollution Prevention Act of 1900, source reduction means any practice that (i) reduces the amount of any hazardous substance, pollutant, or contaminant entering any waste stream or otherwise released into the environment (including fugitive emissions) prior to recycling, treatment, or disposal and (ii) reduces the hazards to public health and the environment associated with the release of such substances, pollutants, or contaminants. The term includes equipment or technology modifications, process or procedure modifications, reformulation or redesign of products, substitution of raw materials, and improvements in housekeeping, maintenance, training, or inventory control.

expressed a preference for pollution and health risk reductions to be considered in a product life-cycle sense, while acknowledging the substantial difficulty in transforming this qualitative concept into defensible quantitative measures. Work force training and process serviceability and maintainability were identified as collateral costs of pollution-prevention initiatives.

In the context of the consensus objective, discussions of economic competitiveness focused on company-level topics such as lowering costs (e.g., direct product expenses, overhead, and capital expenditures); raising revenues through establishing and maintaining premium prices or being first to the market; strategic product positioning and differentiation; incorporating regulatory risk into product design and production; and sustaining a competitive advantage by maintaining a skilled, knowledgeable work force and exploiting barriers of entry to others. Companies adopting energy-efficient, pollution-prevention strategies must be able to achieve economic returns related to these considerations commensurate with the required resource investments in order to make sustained contributions to environmental quality.

Using the consensus objective as guidance and building on the discussions of energy efficiency, pollution prevention, and economic competitiveness, the panel formulated a working definition of a technology demonstration opportunity. This definition captured the elements of the consensus objective and provided a foundation for the derivation of screening criteria for technology demonstrations.

> ***Opportunities for the demonstration of energy-efficient, pollution-prevention, economically competitive technologies and processes consist of the use of hardware, software, and/or an operational procedure in a monitored industrial setting to determine and display improved performance, thereby encouraging timely adoption by similar firms so as to assure environmental quality.***

For opportunities to be converted into actual demonstrations of technology, mutual benefits must accrue to the respective participants. This observation, which is occasionally discounted in the conceptual design of joint public/private initiatives, was explicitly noted by the panel.

Identification of Screening Criteria

A strawman set of criteria for screening energy-efficient, pollution-prevention technology demonstrations was provided to the panelists in advance to encourage reflection on the subject prior to the meeting. These criteria included:

- *energy savings;*
- *pollution prevention/waste reduction;*
- *cost effectiveness;*
- *technological maturity; and*
- *reproducibility/transferability.*

Following a discussion of the strawman criteria, the panel agreed upon a modified set of six criteria for use in screening technology demonstration opportunities, namely:

- ***magnitude of systemic energy, environmental, and economic impacts;***
- ***government role;***
- ***probability of success;***
- ***implementation costs/cost effectiveness;***
- ***time frame for results; and***
- ***measurability /accountability/performance tracking.***

These criteria were derived with industrial sector independence in mind to allow their application to opportunities for technology demonstrations across a wide variety of industries.

Magnitude of the systemic energy, environmental, and economic impacts represents a composite measure of the energy-efficiency, pollution-prevention, and economic-competitiveness aspects of a technology. The need for a systems perspective in making either qualitative or quantitative evaluations is made explicit by the wording of this criterion. Because energy efficiency, pollution prevention, and economic competitiveness are assumed to be positive attributes of a technology, singular favorable assessments of these factors are mutually reinforcing.

Government role is a measure of the need for and appropriateness of government involvement in a technology demonstration. This criterion implicitly incorporates judgments of proper uses for public funds.

Probability of success is a measure of whether the objectives of a technology demonstration are likely to be achieved. A set of ideal objectives should mesh well with the consensus objective for technology demonstrations reached by the panel. Perspectives of all participants should be factored into qualitative and quantitative evaluations of technologies in accordance with this criterion.

Implementation costs/cost effectiveness is a measure of the monetary costs compared to the quantifiable benefits, monetary and otherwise, of widespread deployment of a technology. For consistency, quantitative measures of this criterion should associate higher values with increasing cost effectiveness and, generally, lower implementation costs.

Time frame for results is a measure of the duration period between a decision to go forward with a technology demonstration and returns being accrued by individual firms and society as a result of adopting this technology. In general, shorter time frames are preferable to longer ones because, among other reasons, the time value of money and appropriate monetary and social discount rates are important considerations.

Measurability/accountability/performance tracking is a measure of the ability to monitor energy, environmental, and economic performance of a technology demonstration. Important considerations associated with this criterion include measurement simplicity, cost, and ease of reporting results in an understandable format. While protecting essential proprietary information, the tracking measures should be accessible to the public.

In carrying out the charge of identifying screening criteria, the panelists were tasked to assess the characteristics of necessity, sufficiency, and operationality. Each criterion satisfied the necessary condition because elimination from the set would omit an important aspect of judging candidate technology demonstrations. Collectively, the six criteria satisfy the sufficient condition if all of the important aspects of screening candidate technologies for demonstration are captured. Lastly, the operational condition is met if the criteria individually and collectively can be applied with minimal ambiguity to assess the relative merits of candidate technology demonstrations.

Ranking and Weighting of Screening Criteria

The Vital Issues Process employs a paired-comparison procedure requiring individual panelists to privately assess the relative importance of each criterion against all of the other criteria. To translate these assessments into quantitative scores, the following numerical scale was used:

- much greater importance = 5;
- greater importance = 4;
- equal importance = 3;
- less importance = 2; and
- much less importance = 1.

A special scoring sheet was provided to facilitate the recording of numerical scores for subsequent analysis. In this manner, a consensus ranking of the criteria, along with a numerical weighting factor assigned to each criterion, are obtained simultaneously.

In preparation for making the paired comparisons among criteria, each criterion was discussed in detail. Important components and elements constituting a specific criterion were identified and debated. This process incorporated a review of the strengths and weaknesses, advantages and disadvantages, and functionality of each criterion by the panel. For example, the congruence of the magnitude of systemic energy, environmental, and economic impacts criterion with the adopted working definition of technology demonstration opportunities and the language of EPAct was noted. The merits of a composite criterion versus separate criteria addressing energy, pollution, and cost considerations were debated. Means to avoid the effective elimination of serendipitous events and high-risk, high-reward activities received attention of the panel.

Topics that arose during the discussions on government role included balancing societal returns with industrial returns, exercising leadership and overcoming impediments by government agencies, leveraging of public monies with private capital, and steering developmental programs while avoiding unnecessary government participation in activities likely to be undertaken by business in any case. Panelists also observed that industry/government partnerships are being employed as a national competitiveness tool widely within the industrialized world.

Attractive opportunities for and successful demonstration of new technologies must be cognizant of rigorous assessments of the technology, the responsible organization(s), and the ability to diffuse the results. In this context, topics such as critical path analysis, fall-back options in the event of failures, collateral technology needs and availability, the role of champions internal to the implementing organization, corporate cultures, reproducibility and transferability of technologies in different settings, challenges in communicating technological advantages, and difficulty of collaborating with competitors or even customers were discussed. These and other issues broadly defining technological and organizational maturity and level of risk surfaced under the deliberations of the probability of success criterion.

Cost considerations ranging from monetary to social were included in the discussions on the criterion of implementation costs/cost effectiveness. Challenges associated with life-cycle cost computations, concerns regarding freezing technological advances as the result of high implementation costs, maintaining capital and operating costs in the competitive range, costs for new socially desirable technologies possibly exceeding the benefits from corporate perspectives, tax implications of expensing or capitalizing expenditures, subjective judgments and social values becoming inappropriately intertwined with more objective monetary costs were specific topics addressed by the panelists. From an operational perspective, corporate accounting costs were agreed upon as the principal focus of this criterion, with social cost considerations being adequately, and more appropriately, represented by the government role criterion.

Technology development, demonstration, and dissemination times were highlighted by the panel as elements of the criterion of time frames for results. Other issues discussed included the possibility of longer term projects having the potential for larger returns, caution against biases toward shorter term activities being more consistent with political time horizons, and the need to achieve some early successes to sustain support for innovative programs. The panel observed that industry and technology maturity levels can be expected to influence time frames for successful technology demonstrations and that care should be taken to make public investments in industries whose natural life cycles will allow returns to accrue over long periods of time. Simply put, panelists acknowledged the often close coupling of time with money and risk.

The panel interactions on the criterion of measurability/accountability/performance tracking centered on methodological, cost, confidentiality, and information dissemination issues. Standardization in reporting, monitoring duration, and simplicity, cost, and value relationships were stressed in the discussions. Considerable debate occurred regarding whether this criterion was implicitly embodied in all of the other criteria and, therefore, should not stand alone. A clear consensus emerged that useful monitoring of technology demonstrations was of sufficiently high importance to warrant the inclusion of a separate criterion.

The quantitative analysis of the paired comparisons performed by each panelist produced the following ranking of the criteria in descending order of importance:

- ***magnitude of systemic energy, environmental, and economic impacts;***
- ***probability of success;***
- ***implementation costs/cost effectiveness;***
- ***measurability/accountability/performance tracking;***
- ***time frame for results; and***
- ***government role.***

Interestingly, the criterion receiving the highest average score (magnitude) showed a relatively high level of disagreement among the panelists. Probability of success, the second ranked criterion, had the least disagreement.

A summary of the quantitative results is shown in Figure 1. The position of the center "X" denotes the average importance assigned to the criterion (e.g., implementation costs/cost

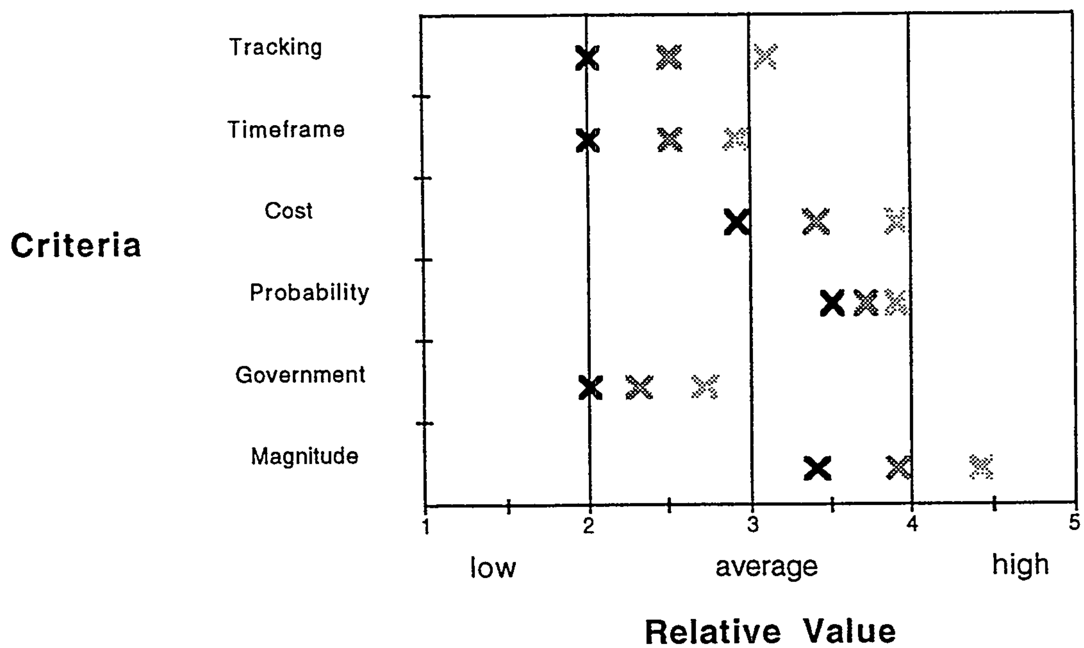

Fig. 1. Summary of the numerical ranking of technology demonstration screening criteria.

effectiveness received an average score of 3.4). Disagreement among the panelists is illustrated by the total distance between the left- and right-hand "Xs" for a specific criterion. Greater disagreement corresponds to longer distances.

Summary

The Vital Issues Panel effectively met the charge of developing a working definition of technology demonstration opportunities, identifying screening criteria for technology demonstrations, and ranking and weighting those criteria for use by subsequent panels addressing technologies within selected industrial sectors. Future panels will be conducted within the context of the constraints of the technology demonstration working definition crafted by this panel.

Opportunities for the demonstration of energy-efficient, pollution-prevention, economically competitive technologies and processes consist of the use of hardware, software, and/or an operational procedure in a monitored industrial setting to determining and display improved performance, thereby encouraging timely adoption by similar firms so as to assure environmental quality.

These panels will be charged with identifying and prioritizing candidate technology demonstrations within the agriculture, chemicals, mining, petroleum, pulp and paper, and stone, clay, and glass industries.

The screening criteria and weights, excluding the criterion of government role, developed by this panel for application by the subsequent panels are:

Criterion	Relative Weight
Magnitude of systemic energy, environmental, and economic impacts	0.25
Probability of success	0.22
Implementation costs/cost effectiveness	0.21
Time frame for results	0.16
Measurability/accountability/performance tracking	0.16

Government role was not assigned a weight in this tabulation because of a preference among the panelists to place this criterion into a fundamentally different category than the remaining five criteria.

Attachment A

AGENDA

Sandia National Laboratories
EPAct Section 2108 Vital Issues Panel
Washington, D.C.
J.W. Marriott Hotel
June 8, 1993

Time	Topic	Principal Discussant(s)
9:00	Welcome and Introduction	Dennis Engi
9:30	EPAct Section 2108 Overview and Panel Process	Engi
9:45	Discussion of Technology Demonstration Definition	All (facilitated by Engi)
10:45	Break	
11:00	Discussion of Technology Evaluation Criteria	All (facilitated by Engi)
12:00	Catered Lunch	
1:15	Discussion of Technology Evaluation Criteria	All (facilitated by Engi)
2:15	Explanation of the Criteria Ranking Process	Engi
2:30	Break	
2:45	Ranking of Technology Evaluation Criteria	All (facilitated by Engi)
4:00	Summary and Close	Engi
4:15	Adjourn	

Attachment B

Energy Policy Act of 1992

SEC. 2108. ENERGY EFFICIENT ENVIRONMENTAL PROGRAM.

(a) PROGRAM DIRECTION. -- The Secretary, in consultation with the Administrator of the Environmental Protection Agency, is authorized to continue to carry out a 5-year program to improve the energy efficiency and cost effectiveness of pollution prevention technologies and processes, including source reduction and waste minimization technologies and processes. The purposes of this section shall be to--

(1) apply a systems approach to minimizing adverse environmental effects of industrial production in the most cost effective and energy efficient manner; and

(2) incorporate consideration of the entire materials and energy cycle with the goal of minimizing adverse environmental impacts.

(b) IDENTIFICATION OF OPPORTUNITIES. -- Within 9 months after the date of enactment of this Act, the Secretary, in consultation with the Administrator of the Environmental Protection Agency, shall identify opportunities for the demonstration of energy efficient pollution prevention technologies and processes.

(c) REPORT. -- Within 1 year after the date of enactment of this Act, the Secretary shall submit a report to Congress evaluating the opportunities identified under subsection (b). Such report shall include--

(1) an assessment of the technologies available to increase productivity and simultaneously reduce the consumption of energy and material resources and the production of wastes;

(2) an assessment of the current use of such technologies by industry in the United States;

(3) the status of any such technologies currently being developed, together with projected schedules of their commercial availability;

(4) the energy savings resulting from the use of such technologies;

(5) the environmental benefits of such technologies;

(6) the costs of such technologies;

(7) an evaluation of any existing Federal or State regulatory disincentives for the employment of such technologies; and

(8) an evaluation of any other barriers to the use of such technologies.

In preparing the report required by this subsection, the Secretary shall consult with the Administrator of the Environmental Protection Agency, any other Federal, State, or local official the Secretary considers necessary, representatives of appropriate industries, members of organizations formed to further the goals of environmental protection or energy efficiency, and other appropriate interested members of the public, as determined by the Secretary.

(d) PROPOSALS. --- Within 1 year after the date of enactment of this Act, the Secretary, in consultation with the Administrator of the Environmental Protection Agency, shall solicit proposals for activities under this section. Proposals selected under this subsection shall demonstrate--

(1) technical viability and cost effectiveness; and

(2) procedures for technology transfer and information outreach during and after completion of the project.

Attachment C

Panelists

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Attachment D

Date

Name
Title
Organization
Address

Salutation:

You are invited to participate on a Vital Issues Panel on June 8, 1993. The panel will be held in Washington, D.C. at a convenient location to be determined beginning at 9:00 am. The principal purpose of this panel is to identify a set of criteria that may be used to screen potential technology demonstrations in seven major industrial sectors. This panel is being convened to support the preparation of a report by the Secretary of the U.S. Department of Energy to Congress required by Section 2108 of the Energy Policy Act of 1992 (EPAct). The focus of EPAct Section 2108 is on energy-efficient, pollution-prevention technologies suitable for demonstration and subsequent adoption by U.S. industry.

The Vital Issues Process is a strategic planning tool developed by Sandia National Laboratories which identifies a portfolio of programmatic activities aimed at satisfying an organization's high-level goals and objectives through panel discussions. The Vital Issues Panels for EPAct Section 2108 will provide the Secretary with information and stakeholder input that will be used in the report to Congress and may ultimately assist in the design of an energy-efficient, pollution-prevention technology demonstration program.

This meeting will be an intensive, one-day exercise involving six to eight other experts drawn from the following institutional affiliations to ensure that a broad perspective on technology demonstrations is achieved:

- government;
- industry;
- environmental groups; and
- academe.

Our hope is that representation of these various institutional perspectives will result in a dialogue focused on the variety of relevant dimensions associated with the salient aspects of choosing preferred technologies for demonstration. Three distinct, but interrelated products, are expected to result from the panel discussions and deliberations:

- a working definition of an energy-efficient, pollution-prevention technology demonstration;
- a list of criteria useful for evaluating the relative merits of candidate technologies available for demonstration; and
- a ranking of the relative importance of these criteria.

To stimulate your thinking, the following *strawman* definition is offered:

> An *energy-efficient, pollution-prevention technology demonstration* is the installation of hardware, software, and/or an operational procedure in a monitored industrial setting to determine and display technical and economic performance, thereby encouraging timely adoption by similar firms.

A *strawman* set of evaluation criteria for assessing candidate technologies includes:

- energy savings;
- pollution prevention/waste reduction;
- cost effectiveness;
- technological maturity; and
- reproducibility/transferability.

I want to emphasize that the above definition and criteria are just *strawmen* intended to stimulate your thinking about the subject of the panel. Once the panelists collectively develop a working definition and prepare a set of criteria, a structured process of paired comparisons to ascertain the relative importance of the criteria will be conducted.

To help service the ambitious nature of this panel meeting, we will have both a facilitator and a rapporteur. Our intent is to prepare a report summarizing the panel meeting. Prior to publication of the report, each panelist will have an opportunity to review and comment on the draft report text. The report will be provided to subsequent panels whose objectives will be to identify and rank specific energy-efficient, pollution-prevention technologies for demonstration in chosen industrial sectors. Therefore, the products of this first panel will provide a foundation for screening opportunities for industry/government partnerships involving technology demonstrations.

In preparation, please think through the *strawman* definition for an energy-efficient, pollution-prevention technology demonstration and *strawman* list of technology screening criteria. We plan for the panel discussions to generate a clear, unambiguous definition that is as complete, yet succinct, as possible. Also in developing the screening criteria, three different conditions will be considered: necessary, sufficient, and operational. A criterion satisfies the necessary condition if its elimination from the set of criteria allows an important aspect of judging candidate technology demonstrations to go unrecognized. The set of criteria satisfies the sufficient condition if all the important aspects of screening technologies for demonstration are captured. And, finally, the criteria are operational if they can be applied to assess the relative merits of candidate technology demonstrations.

If you have any questions concerning any aspect of the panel, please contact Suzie Convery at (505) 260-1800. Thank you, in advance, for your participation on this panel. I look forward to seeing you on June 8.

Sincerely,

Dennis Engi, Manager
Strategic Technologies Department

Identifying Strategic Opportunities: New Strategies for a New World

The Vital Issues Process

Process Purpose

The Vital Issues process is a strategic planning tool which identifies a portfolio of programmatic activities (an 'investment portfolio') for an organization, aimed at satisfying its high-level goals and objectives. The process requires a high level of stakeholder involvement, thus predisposing acceptance of the programmatic endeavors by those stakeholder communities.

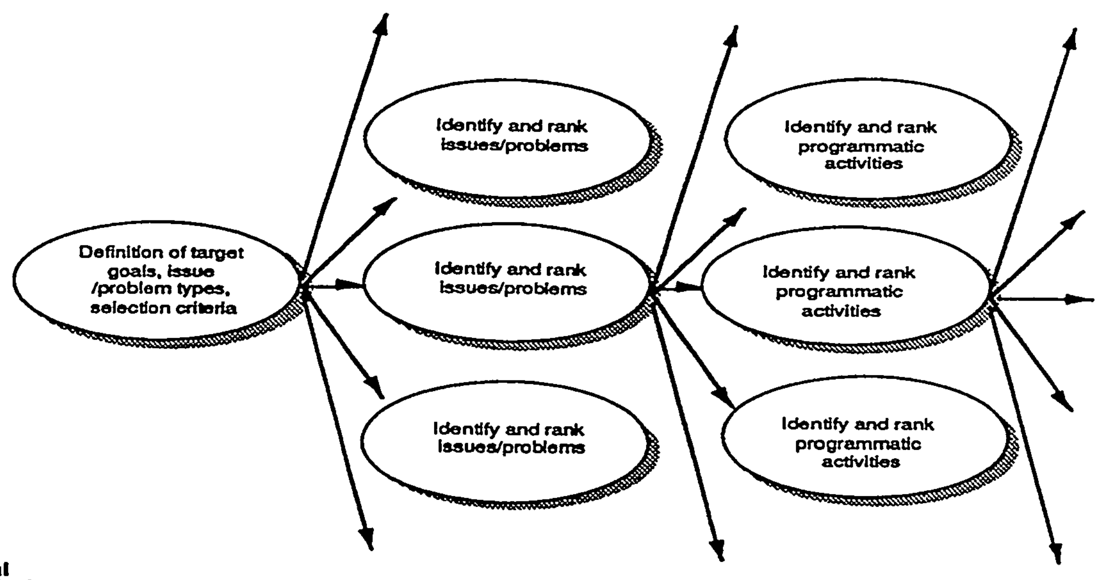
Process Description

The Vital Issues process is a multi-stage process, involving a series of day-long, intensive workshops, each of which builds on the results of the previous. The first workshop focuses on definitions, identifying target goals and objectives, describing the type of issues or problems addressed by the sponsoring organization, and identifying criteria for issue or problem selection. The next workshop (or set of workshops) uses the selection criteria and the definition of the desired issue or problem to identify and rank a set of such issues. The following workshop (or set of workshops) selects one of those identified issues (probably but not necessarily the highest ranked) and identifies and ranks associated programmatic activities. Subsequent workshops (or sets of workshops) can focus on tasks associated with specific programmatic activities. The process is illustrated in figure 1.

As group dynamics constrain the effective size of a panel to no more than twelve participants (with an optimal size of eight to ten), it is possible to run parallel panels on the same topic if the number of stakeholder or constiuency groups is greater than twelve. In such a case, representatives from the topical panels should be brought together into a 'composite' panel to generate integration of the results of the separate panels. This is illustrated in figure 2.

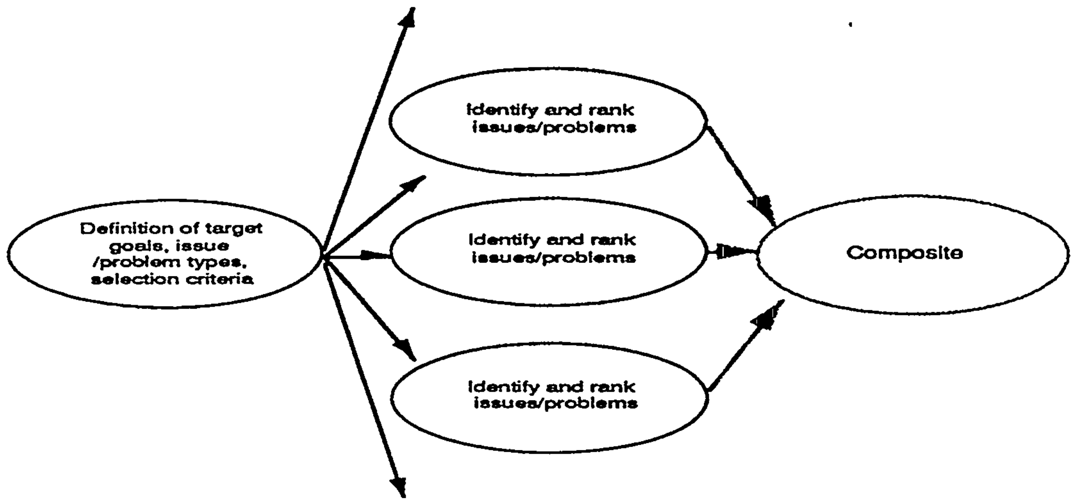
The panel of participants in each workshop will differ, as expertise will be relevant to the topic at hand. Institutional perspectives key to organizational success (such as private sector, state/federal government, and academe) should be identified a *priori* and represented on each panel. Each panel also should reflect a broad range of stakeholder communities. Individual panelists should be selected for their expertise and credibility within their professional communities.

Figure 1



Sandia National Laboratories

Figure 2

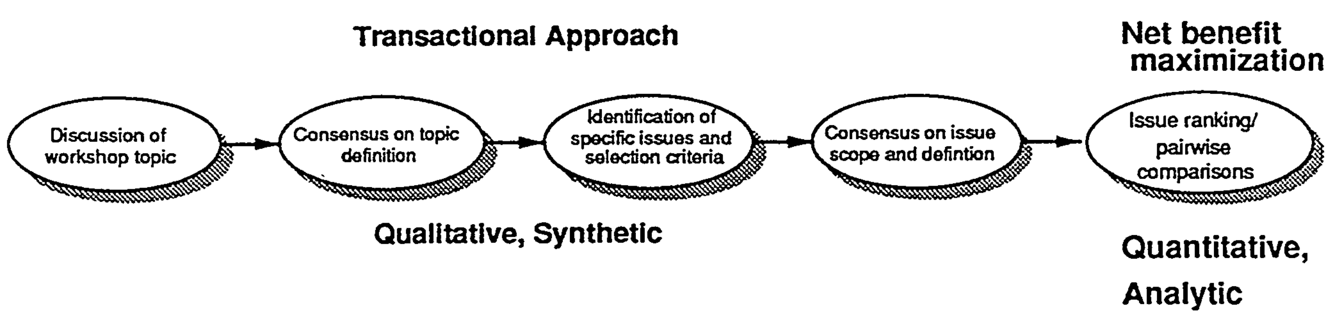


Process Methodology

The Vital Issues process incorporates two primary approaches: a qualitative, or transactional method, which takes a synthetic approach, and a quantitative, or net benefit maximization method, which performs some analytic activities. The transactional method involves dialogue among individuals or groups with some stake in the sponsoring organization's activities. Such dialogue usually focuses on problem or issue definition (which can include definition of an organization's goals and objectives) and criteria for measuring success through problem solution or goal achievement. Participation in the construction, or synthesis, of those definitions allows participants to become invested in the process. The definitions constructed by these synthetic activities form the environment within which a set of alternatives (such as issues or programs) can be identified. Net benefit maximization uses quantitative methods to perform a cost/benefit analysis on a set given alternatives, seeking to identify the alternative that provides the greatest social (or organizational) good according to some set of criteria.

Both methods are applied in each workshop of the Vital Issues process. The agenda leads off with a discussion of the topical area with which the workshop is charged, seeking to construct a definition that satisfies the group and which sets the parameters within which the specific issues, activities, or tasks are identified. A set of criteria for measuring success are also identified. Group discussion clarifies the identified issues and leads to consensus on their definition and scope. The issues are then relatively ranked (that is, the items in the set are ranked against each other, and not against any external, absolute standard) using pairwise comparisons which compares each issue to all others in the set in turn against each of the identified selection criterion by asking the scorer to assign specific values to each issue. This forces panelists to make explicit the tradeoff process and the criteria by which they are making the tradeoffs. The process is illustrated in figure 3.

Figure 3



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APPENDIX D

Vital Issues Report on the Petroleum Industry

The Vital Issues panel on the Petroleum Industry met July 23, 1993. The panel identified and ranked seven areas of opportunity for the demonstration of energy efficient pollution prevention technologies in the petroleum industry. The report from that meeting follows.

Energy Policy Act of 1992
§2108
Energy Efficient Environment Program

Energy-Efficient, Pollution-Prevention Technology Demonstrations in the Petroleum Industry

Report of the
Sandia National Laboratories
Vital Issues Panel
Houston, Texas
July 23, 1993

Sponsored by the
Industrial Waste Reduction Program
U.S. Department of Energy

Introduction

Pursuant to §2108 of the Energy Policy Act of 1992 (EPAct), the Secretary of the U.S. Department of Energy, in consultation with the Administrator of the U.S. Environmental Protection Agency, was authorized to conduct programs designed to improve the energy efficiency and cost effectiveness of pollution-prevention technologies and processes, including source reduction and waste minimization technologies and processes. Presumably, these technologies and processes would be capable of increasing industrial productivity, while simultaneously reducing the consumption of energy and material resources and the production of wastes. Specifically in §2108(b), the Secretary, in consultation with the Administrator, was directed to identify opportunities for the demonstration of energy-efficient, pollution-prevention technologies and processes. A report containing this information was required to be submitted to the U.S. Congress within nine months after the enactment of the Act. In preparing this report, the Secretary was directed to consult with the Administrator and any other federal, state, or local officials, representatives of appropriate industries, members of organizations formed to further the goals of environmental protection or energy efficiency, and interested members of the public.

Approach

A panel of stakeholders and constituency groups associated with the petroleum industry was convened on July 23, 1993 (see Appendix A), by Sandia National Laboratories to assist the Department of Energy in the development of its response to §2108(b) of EPAct (see Appendix B). Panel members included representatives from the petroleum industry, federal agencies, universities, and an environmental and regulatory consulting organization (see Appendix C). State government regulatory and federal congressional experience were also represented on the panel. The panel was charged (see Appendix D) to:

(1) identify energy-efficient, pollution-prevention technologies suitable for demonstration in the petroleum industry; and

(2) rank energy-efficient, pollution-prevention technologies in accordance with a predetermined set of screening criteria developed by a prior panel.

A methodology developed by Sandia National Laboratories, called the Vital Issues Process (see Appendix E), was employed to assist the panel in meeting its charge. This panel is the first of seven planned industrial-sector-specific panels designed to solicit input from industry representatives and other stakeholder groups. Agriculture, chemicals, mining, primary metals, pulp and paper, and stone, clay, and glass are the remaining six targeted industries.

Identification of Opportunities for Technology Demonstrations

Environmental considerations formed the basis of a wide ranging discussion of current operating challenges in the petroleum industry with potential technical solutions and technology needs. Pollution prevention and control tended to dictate the direction of the discussion when compared to energy efficiency or economic competitiveness. In fact, the panel observed that most commonly there are both energy and economic costs associated with environmental improvements, especially when approached from a treatment or so-called end-of-the-pipe perspective. The panel identified numerous technologies, technology classes, and problem areas applicable to both exploration and production (upstream) and refining and processing (downstream) operations in the petroleum industry having potential for waste reduction and/or pollution prevention.

To ensure that important technology opportunities were not being overlooked during the relatively unstructured exchanges among the panelists, the most pressing environmental problems experienced by the petroleum industry and the associated pollutants were reviewed. This exercise was based on the recognition that individual pollutants often define markets for technology solutions. Major pollutants including air emissions (e.g., sulfur oxides, nitrous oxides, and carbon monoxide); heavy metals; volatile organic compounds; toxic air emissions; a variety of solvents and chemicals; spent acids, catalysts, and other chemicals; and naturally occurring radioactive materials (NORMs) were considered in the context of identifying new technological methods of pollution mitigation. An international orientation was also used to examine possible opportunities that might be underemphasized by a strict focus on domestic issues. Oil spill remediation technology and technologies to reduce the environmental loading associated with flaring natural gas in oil fields where gas gathering systems were not present arose during this discussion.

In order to bring greater structure to the deliberations, nine broad technology categories generally corresponding to distinct problems experienced by the petroleum industry were extracted from the discussions. After reaching a consensus that these categories appropriately encompassed the previous discussions, the panelists were charged with better defining candidate technologies for demonstration within these categories, listed in alphabetical order, as follows:

- combustion emissions and toxic releases;
- decommissioning of nonproductive or abandoned wells;
- heat management;
- leak and fugitive emissions detection and prevention;
- oil/water emulsion breaking and solids separation;
- reservoir management and diagnostics;
- spent materials handling;
- sulfur and heavy metals extraction; and
- wastewater management, handling, and reduction.

Some of these categories are only applicable to upstream technologies (e.g., decommissioning of nonproductive or abandoned wells and reservoir management and diagnostics), others are essentially applicable only to downstream activities (e.g., heat management and sulfur and heavy metals extraction), while the remaining five categories could equally include technologies addressing either upstream or downstream operations.

Twenty technology demonstration opportunities were consolidated into these nine broad categories while recognizing that a variety of specific alternative technological approaches could be pursued within a given technology demonstration opportunity. In this manner, one specific technology is not highlighted to the exclusion of another and the tendency of rigidly defined preferred technology demonstrations to inhibit rather than encourage innovative technical developments is minimized. This subset of technology demonstration opportunities includes:

Combustion emissions and toxic releases -

- Point source emissions recovery - technologies for the collection of emissions, primarily volatile organic compounds (VOCs), from point sources such as combustion stacks

- Reduction of air emissions - technologies involving advanced burner and injector design to improve the combustion efficiency and completeness, thereby minimizing air emissions, especially when burning flue gases and/or volatile organic compounds (VOCs)*

Decommissioning of nonproductive or abandoned wells -

- Remote sensing of well locations - technologies to identify the locations of old, abandoned wells by airborne, surface, or subsurface methods*

- Decommissioning of orphan wells - technologies capable of eliminating the pollution potential, primarily groundwater effects, of abandoned wells with unknown locations and ownership

Heat management -

- Integrated heat management to recover water - technologies to optimize the distribution of heat in a refinery, specifically to recover wastewater for reuse*

Leak and fugitive emissions detection and prevention -

- Optical fiber sensing systems - technologies employing chemically doped optical fibers for in-situ sensing of specific chemical species

- Remote sensing of volatile organic compounds (VOCs) - technologies to remotely sense fugitive VOC emissions from values, flanges, and tanks

- Smart pigs - technologies to provide inert devices designed to be inserted and transported through pipelines, referred to in the industry as pigs, to gather information on the operating condition of the pipeline (e.g., internal rather than external leak detection)

Oil/water emulsions breaking and solids separation -

- Alternatives to halogenated and carcinogenic materials - technologies involving the use of alternative chemicals and solvents in petroleum production and processing that are environmentally benign

- Chemical species activity and reactivity - technologies capable of predicting the specific characteristics of chemical additives when mixed in known process streams as a means to formulate improved treatments (e.g., emulsion breaking) and to minimize the impact of these additives on subsequent processing steps*

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*Technologies discussed as specific examples within broad technology areas by the panel during the ranking of technology areas are denoted by an asterisk.

- Ozone and non-organic agents to control bacterial growth - technologies able to limit bacterial growth with environmentally benign materials as alternative means to control hydrogen sulfide production and resulting corrosion

Reservoir management and diagnostics -

- Geophysical diagnostics - application of surface and subsurface geophysical technologies normally used in petroleum exploration to reservoir management in producing fields to improve, for example, in-fill drilling results and to minimize water production*

- Selective resin placement - technologies capable of identifying water-producing zones for downhole plugging by resins as a means to reduce produced water volumes*

- Three-dimensional seismic surveys - application of advanced seismic technologies commonly used during offshore exploration to onshore producing fields to obtain improvements in pollution prevention, energy efficiency, and economic performance*

Spent materials handling -

- Spent catalyst reuse - technologies for allowing refinery catalysts to have an environmentally benign disposition through reuse and/or recycle rather than disposal in landfills*

Sulfur and heavy metals extraction -

- Dry hydrogen sulfide adsorption - technologies capable of removing sulfur from gaseous process streams by adsorption on solids in contrast to the standard practice of absorption by aqueous solutions containing chemical additives*

- Sludgeless selective heavy metal absorption - technologies capable of selectively absorbing heavy metals (e.g., vanadium, chromium) in process streams or wastewaters without the production of sludges presenting disposal challenges

Wastewater management, handling, and reduction -

- Elimination of process pits - technologies allowing the replacement of pits in oil fields with tanks as a means to better control wastewater discharges to soils and groundwaters

- Reuse/recycle of wastewaters - technologies to purify contaminated wastewater streams on-site and to input the resulting water streams as process water*

- Wastewater recycle from discharge to process use - technologies to recycle wastewaters into process waters and to generate manageable and predictable impacts of the use of impure water*

Upon review of this list of technology demonstration opportunities, the panel combined the items under decommissioning of nonproductive or abandoned wells into locating orphan wells because the technologies for decommissioning through plugging and abandonment are well known. The last two technology areas under wastewater management, handling, and reduction were consolidated and combined with the heat management technology. The three technology areas under leak and fugitive emissions detection and prevention were combined into one and relabeled fugitive emissions detection and prevention. Although each of these 20 technology areas was considered to be a worthwhile opportunity for demonstrations, the resources of the panel focused on seven technology areas for which the most thorough definition, discussion, and analysis were immediately possible. Following extensive discussion and reflection, these seven technology areas were better defined and retitled for convenience as follows in alphabetical order:

- advanced geophysical diagnostics;
- dry hydrogen sulfide adsorption;
- locating orphan wells;
- oil/water emulsion breaking by chemical additives;
- spent catalyst reuse;
- toxic gaseous emissions; and
- wastewater management.

During the consolidation and culling of the 20 technology demonstration opportunities into a more manageable seven technology areas, considerable discussion occurred regarding the likelihood of some technologies being adopted by industry as what are now becoming standard operating procedures or by regulatory fiat driven by legislation such as the 1990 Clean Air Act Amendments. These issues influencing the need for and/or appropriateness of technology demonstrations were left unresolved in the context of defining candidate technology demonstrations. Instead, the importance of factors such as these was agreed to be reflected in the ranking of individual technology areas. Similarly, the anticipated economic conditions facing a demonstration opportunity could easily dictate the level of industry interest and the rate of technology adoption. The relationship between actual and effective costs for new technologies arose on several occasions related to issues such as direct financial incentives, tax policies, and potential economic distortions caused by regulatory actions.

Two of the seven technology areas are most suitable for addressing environmental concerns associated with upstream and downstream operations, respectively. The three remaining technology areas encompass potential applications across the entire petroleum industry.

Technology Area Definitions

Working definitions for the seven selected technology areas were developed by the panel to further the understanding of technologies included within each group and to describe the most important features of and benefits offered by prospective technology demonstrations. For example, advanced geophysical diagnostics was narrowed to the use of current capabilities, such as three-dimensional seismic surveys commonly used during offshore exploration, in onshore producing fields to better characterize the reservoir conditions as a means to minimize the drilling of unproductive wells while conducting an in-fill drilling program. This new application of an existing technique could reduce the volume of produced water significantly, which is the single largest waste stream in the petroleum industry, and would avoid any pollution resulting from the drilling of unnecessary wells.

Dry hydrogen sulfide adsorption is, perhaps, the most specific of the technology areas. This technology area encompasses methods to replace amine-based aqueous solutions for treating gas streams to remove hydrogen sulfide, an acid gas, in refineries and possibly in natural gas processing plants. The captured sulfur would be recoverable as elemental sulfur or sulfuric acid through widely used processes. These technologies would reduce the pollution associated with the disposal or accidental release of amine solutions.

Locating orphan wells referred to new technology applied to locating old wells abandoned most commonly prior to 1940 that do not have recorded locations and known ownership. These wells were generally plugged inadequately, if at all, and often are a recognized source of groundwater pollution or pose a serious threat to groundwater resources. Candidate technologies in this area would be expected to include remote subsurface sensing techniques developed for defense purposes.

Oil/water emulsion breaking technologies was targeted toward gaining a better understanding and characterization of the activity and reactivity of chemical species when added in mixtures for the purpose of breaking organic/water emulsions and toward designing optimized separation units based on this information. The objective is to obtain improved formulations for treating emulsions, to better predict the impact of these additives on subsequent processing steps, and to design more efficient emulsion treatment vessels. Changes in the composition of additives could reduce the harmful effect of the materials on downstream processes. Technologies in this area would reduce wastewater volumes by facilitating water recycling and would minimize the need for water treatment prior to disposal.

Spent catalyst reuse consisted of technologies for extracting metals of lower value than precious metals from catalysts used in fluid catalytic cracking (FCC) and hydrodesulfurization (HDS) units in refineries. The extracted metals, such as nickel, vanadium, cobalt, and tungsten, could be sold in commercial markets and the remaining material could be reused, for example, in catalyst production. Technologies capable of capitalizing on the silica content of spent FCC catalysts, such as cement production, were also included in this category. Although some U.S. refineries already practice FCC and/or HDS catalyst reuse, elimination of substantial volumes of spent catalysts presently disposed of in landfills could result from widespread deployment of proven technologies.

Technologies addressing toxic gaseous emissions focused on recent developments permitting the design of improved burners and injectors for flue gas and volatile organic compound (VOC) combustion in refineries as a means to reduce the release of air toxics. Catalytic combustion technologies could be included in this category as well. Greater opportunities for new technology demonstrations were judged to be present for managing air toxics than for addressing emissions of the more standard combustion products such as carbon monoxide, sulfur oxides, and nitrous oxides. Technologies in this area would reduce toxic air pollution associated with noncommercial fuel combustion processes in refineries.

Wastewater management technology focused on techniques capable of making contributions toward achieving an on-site, closed-cycle water management system in a refinery. Included in this technology area were integrated heat management techniques for the expressed purpose of water management in a refinery and techniques to efficiently reuse impure waters in the refining process. An ultimate objective would be to allow operation of a zero-release refinery from a water perspective. Avoidance of groundwater and surface water pollution would be the principal benefit of deploying these technologies.

Evaluation Criteria

Six screening criteria developed by the earlier Vital Issues Panel were used for making paired comparisons across the seven selected technology areas as follows:

- *magnitude of systemic energy, environmental, and economic impacts;*
- *probability of success;*
- *implementation costs/cost effectiveness;*
- *time frame for results;*
- *measurability/accountability/performance tracking; and*
- *government role.*

The panelists reviewed each criterion to establish a consistent understanding of the most important aspects of these criteria.

Observations such as the petroleum industry historically evidencing a predictable rate of technology diffusion, the strong tendency for the industry to merely react to regulatory and environmental policies, a recognition of the need for openness in the monitoring process in order for competitive companies to be confident of the merits of any technology being demonstrated, and the importance of appropriate policies and practices regarding proprietary technology were expressed by the panelists. With respect to the first criterion, the technology identification and selection process was noted to be most heavily influenced by environmental considerations and the understanding both qualitatively and quantitatively that these technologies would aid in pollution prevention and control. In contrast, the energy impacts of these technologies were much more difficult to assess and would likely require detailed analyses to develop defensible evaluations.

Five of these six criteria were assigned fractional (normalized) weights by the prior panel to allow a composite score to be computed. Government role was not assigned a weight, thus effectively treating this criterion separately, in order to highlight potential government involvement in energy-efficient, pollution-prevention technology demonstration opportunities identified consistent with the EPAct objectives. The weighting functions are:

Criterion	Relative Weight
Magnitude of systemic energy, environmental, and economic impacts	0.25
Probability of success	0.22
Implementation costs/cost effectiveness	0.21
Time frame for results	0.16
Measurability/accountability/performance tracking	0.16

Ranking of Technology Demonstrations

The Vital Issues Process employs a paired-comparison procedure requiring individual panelists to privately assess the relative attractiveness of each technology demonstration opportunity according to a single criterion compared to all of the other candidate technologies for that same criterion. This process is repeated until paired comparisons of all technology areas are made in a similar manner for each criterion. To translate these assessments into quantitative scores, the following numerical scale is used:

- much higher than = 5;
- higher than = 4;
- same as = 3;
- lower than = 2; and
- much lower than = 1.

A set of special scoring sheets is provided to each panelist to facilitate the recording of numerical scores for subsequent analysis. In this manner, a consensus ranking of the technology demonstration opportunities, along with numerical scores assigned to each technology area, is obtained simultaneously.

The quantitative analysis of the paired comparisons performed by each panelist produced the following ranking of the seven screened technology areas, in descending order, according to a five-criterion composite score representing the weighted average of the scores for individual criteria:

- ***wastewater management;***
- ***advanced geophysical diagnostics;***
- ***toxic gaseous emissions;***
- ***spent catalyst reuse;***
- ***dry hydrogen sulfide adsorption;***
- ***locating orphan wells; and***
- ***oil/water emulsion breaking by chemical additives.***

A graphical summary of the quantitative results for the composite criterion is shown in Figure 1.

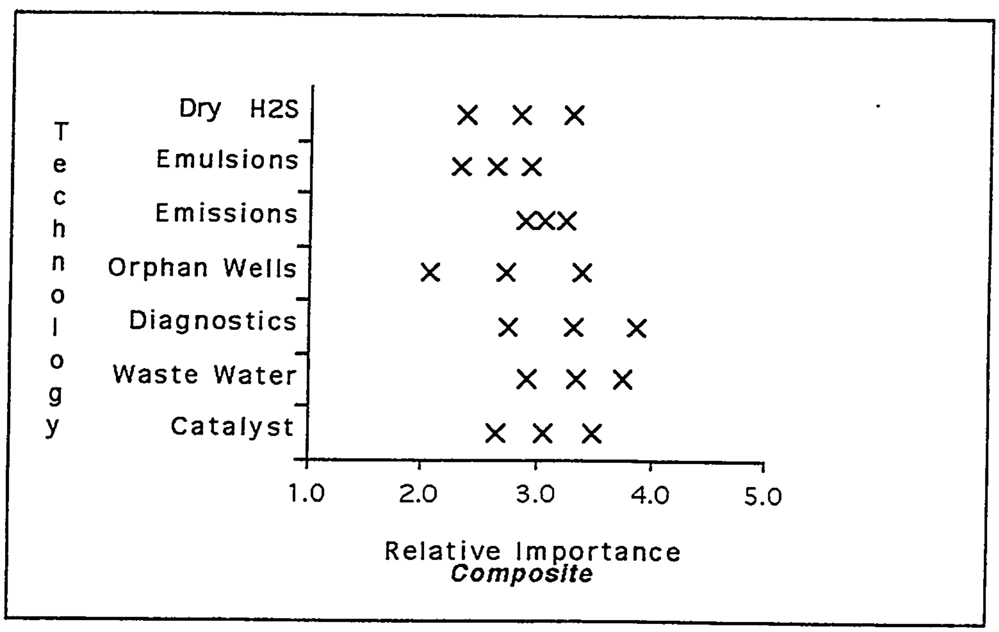

Fig. 1. Summary of the numerical ranking of selected technology demonstration opportunities according to the composite criterion. For any technology area, the distance from the center "X" to either the left- or right-hand "X" represents the standard deviation of the scores assigned by the individual panelists.

The position of the center "X" denotes the average importance of the technology demonstration opportunity (e.g., wastewater management received the highest average score among the panelists of 3.4 for the composite criterion in Figure 1). Disagreement among the panelists is illustrated by the total distance between the left- and right-hand "Xs" for a specific technology area representing an opportunity for demonstration. Greater disagreement corresponds to longer distances.

As judged by the panelists, the relative importance of a government role on technology demonstrations of the seven screened technology areas, in descending order, is:

- ***toxic gaseous emissions;***
- ***locating orphan wells;***
- ***wastewater management;***
- ***advanced geophysical diagnostics;***
- ***oil/water emulsion breaking by chemical additives;***
- ***spent catalyst reuse; and***
- ***dry hydrogen sulfide adsorption.***

The quantitative results for the government role criterion are shown in Figure 2. Interestingly, relatively little disagreement was present among the panelists when evaluating toxic gaseous emissions under either the composite (see Figure 1) or government role (see Figure 2) criterion.

Discussion and Implication of the Ranking Results

If the composite and government role criteria are combined with equal weights, three technology areas receive equally high scores, namely, toxic gaseous emissions, wastewater management, and advanced geophysical diagnostics. The higher score received by toxic gaseous emissions when considering government role independently could be used as justification for selecting this technology area as the one with the highest priority for action. This position is supported by toxic gaseous emissions having the lowest level of disagreement among the panelists on the scores for the composite, government role, and combined criteria. On the other

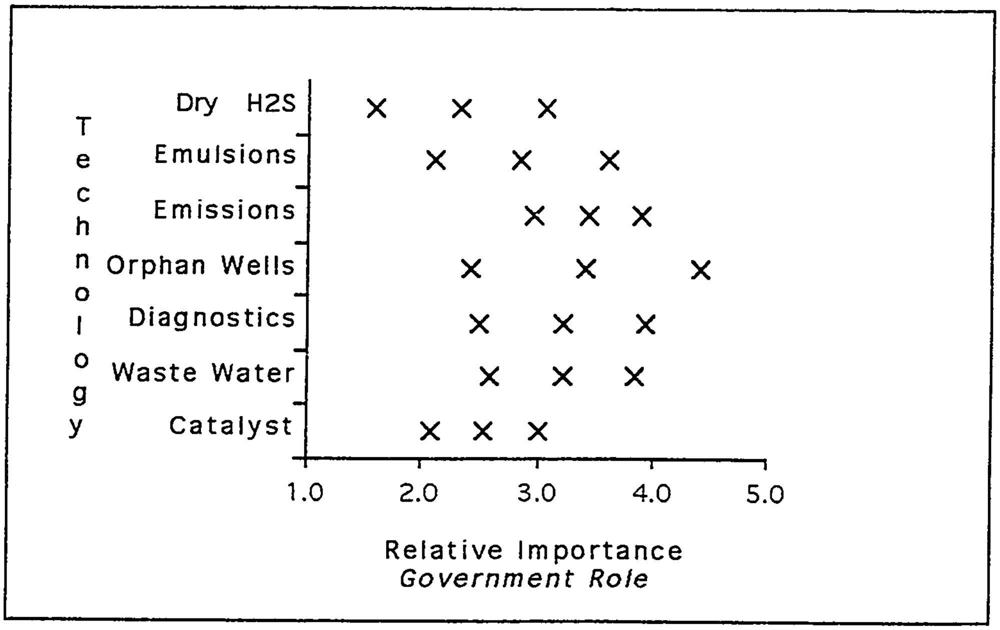

Fig. 2. Summary of the numerical ranking of the importance of a government role in specific technology demonstration opportunities. For any technology area, the distance from the center "X" to either the left- or right-hand "X" represents the standard deviation of the scores assigned by the individual panelists.

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hand, both wastewater management and advanced geophysical diagnostics showed greater disagreement among the panelists on the combined criterion than toxic gaseous emissions.

The level of disagreement can be considered as a surrogate variable for the potential range of payoffs from a technology demonstration. Consequently, the so-called longer-shot returns may be obtainable from either wastewater management or advanced geophysical diagnostics than from toxic gaseous emissions. Interestingly, if a high-risk, high-return philosophy is adopted, locating orphan wells may become an especially attractive technology demonstration candidate. This situation occurs because while the average score for locating orphan wells on the combined criterion is slightly lower than that of the three technologies with the highest scores (i.e., toxic gaseous emissions, wastewater management, and advanced geophysical diagnostics), this technology area has the highest level of disagreement among the panelists on each of the composite, government role, and combined criteria.

Concluding Remarks

Water, including produced water, process water, groundwater, and surface water, was the overriding theme of energy-efficient, pollution-prevention demonstrations in the petroleum industry expressed by the members of the panel. In fact, comments were made, somewhat in jest, that the petroleum industry is actually in the water business to a greater extent than the petroleum business. This observation has some merit because, on average, the volume of water managed in upstream operations is about ten times that of petroleum, while approximately equal volumes of water and petroleum are managed in downstream refining operations. To a lesser extent, technologies addressing emissions to the air and land, especially involving toxic substances, were identified and discussed.

Twenty candidate technology areas were identified as having strong potential demonstration opportunities. From these candidates, seven broad technology areas were ranked in accordance with a composite set of five criteria, the appropriateness of a government role in technology demonstrations, and for a combination of the composite and government role criteria. The ranking according to the combined criterion, in descending order, is:

- ***toxic gaseous emissions;***
- ***wastewater management;***
- ***advanced geophysical diagnostics;***
- ***locating orphan wells;***
- ***spent catalyst reuse;***
- ***oil/water emulsion breaking by chemical additives; and***
- ***dry hydrogen sulfide adsorption.***

As recognized by the panelists, effective implementation of a technology demonstration program in the petroleum industry will require selection among more specifically defined technologies within one or more of these areas. The need for greater definition could be satisfied by programmatic direction or by allowing interested participants to offer up thoroughly described technologies within these seven technology areas for consideration.

Attachment A

AGENDA

Sandia National Laboratories
EPAct Section 2108 Vital Issues Panel #2
Doubletree Hotel
Houston, Texas
July 23, 1993

Technology Demonstrations in the Petroleum Industry

Time	Topic	Principal Discussant(s)
8:30	Welcome and Introduction	Suzie Convery
9:00	EPAct Section 2108 Overview and Panel Process	Dennis Engi
9:30	Discussion of Candidate Technologies	All (facilitated by Convery)
10:30	Break	
10:45	Discussion of Candidate Technologies	All (facilitated by Convery)
11:30	Explanation of the Technology Ranking Process	Engi
12:00	Catered Lunch	
1:15	Ranking of Technologies	All (facilitated by Convery)
2:30	Break	
2:45	Ranking of Technologies	All (facilitated by Convery)
4:00	Summary and Close	Engi and Convery
4:15	Adjourn	

Attachment B

Energy Policy Act of 1992

SEC. 2108. ENERGY EFFICIENT ENVIRONMENTAL PROGRAM.

(a) PROGRAM DIRECTION. -- The Secretary, in consultation with the Administrator of the Environmental Protection Agency, is authorized to continue to carry out a 5-year program to improve the energy efficiency and cost effectiveness of pollution prevention technologies and processes, including source reduction and waste minimization technologies and processes. The purposes of this section shall be to--

(1) apply a systems approach to minimizing adverse environmental effects of industrial production in the most cost effective and energy efficient manner; and

(2) incorporate consideration of the entire materials and energy cycle with the goal of minimizing adverse environmental impacts.

(b) IDENTIFICATION OF OPPORTUNITIES. -- Within 9 months after the date of enactment of this Act, the Secretary, in consultation with the Administrator of the Environmental Protection Agency, shall identify opportunities for the demonstration of energy efficient pollution prevention technologies and processes.

(c) REPORT. -- Within 1 year after the date of enactment of this Act, the Secretary shall submit a report to Congress evaluating the opportunities identified under subsection (b). Such report shall include--

(1) an assessment of the technologies available to increase productivity and simultaneously reduce the consumption of energy and material resources and the production of wastes;

(2) an assessment of the current use of such technologies by industry in the United States;

(3) the status of any such technologies currently being developed, together with projected schedules of their commercial availability;

(4) the energy savings resulting from the use of such technologies;

(5) the environmental benefits of such technologies;

(6) the costs of such technologies;

(7) an evaluation of any existing Federal or State regulatory disincentives for the employment of such technologies; and

(8) an evaluation of any other barriers to the use of such technologies.

In preparing the report required by this subsection, the Secretary shall consult with the Administrator of the Environmental Protection Agency, any other Federal, State, or local official the Secretary considers necessary, representatives of appropriate industries, members of organizations formed to further the goals of environmental protection or energy efficiency, and other appropriate interested members of the public, as determined by the Secretary.

(d) PROPOSALS. --- Within 1 year after the date of enactment of this Act, the Secretary, in consultation with the Administrator of the Environmental Protection Agency, shall solicit proposals for activities under this section. Proposals selected under this subsection shall demonstrate--

(1) technical viability and cost effectiveness; and

(2) procedures for technology transfer and information outreach during and after completion of the project.

Attachment C

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Attachment D

FACT SHEET

Sandia National Laboratories
EPAct Section 2108 Vital Issues Panel #2

Technology Demonstrations in the Petroleum Industry

The principal purpose of this panel is to prioritize technologies suitable for government/industry cost-shared demonstrations in the petroleum industry. This panel is being convened to support the preparation of an initial report by the Secretary of the U.S. Department of Energy to Congress required by Section 2108 of the Energy Policy Act of 1992 (EPAct). The focus of EPAct Section 2108 is on energy-efficient, pollution-prevention technologies suitable for demonstration and subsequent adoption by U.S. industry. This panel covering the petroleum industry will serve as a model for similar panels to be conducted for six other industrial sectors later in 1993 and during 1994.

The Vital Issues Process is a strategic planning tool developed by Sandia National Laboratories which identifies a portfolio of programmatic activities aimed at satisfying an organization's high-level goals and objectives through panel discussions. The Vital Issues Panels for EPAct Section 2108 will provide the Secretary with information and stakeholder input that will be used in the report to Congress and may ultimately assist in the design of an energy-efficient, pollution-prevention technology demonstration program.

This meeting will be an intensive, one-day exercise involving six to eight other experts drawn from the following institutional affiliations to ensure that a broad perspective on potential technology demonstrations is achieved:

- industry;
- government;
- environmental groups; and
- academe.

The expectation is that representation of these various institutional perspectives will result in a dialogue focused on the variety of relevant dimensions associated with the salient aspects of choosing preferred technologies for demonstration. Two distinct, but interrelated products, are expected to result from the panel discussions and deliberations:

- a short list of energy-efficient, pollution-prevention technologies suitable for demonstration in the petroleum industry; and
- a ranking of these technologies in accordance with a predetermined set of screening criteria.

As background information, an initial panel held on June 8, 1993, established a working definition for an energy-efficient, pollution-prevention technology demonstration and ranked criteria for use in selecting candidate technologies for demonstration in seven selected industrial sectors. The definition reached by this panel is:

Opportunities for the demonstration of energy-efficient, pollution-prevention, economically competitive technologies and processes consist of the use of hardware, software, and/or an operational procedure in a monitored industrial setting to determine and display improved performance, thereby encouraging timely adoption by similar firms so as to assure environmental quality.

This panel also identified, ranked, and weighted a set of criteria in descending importance as follows:

	Weight
Magnitude of systemic energy, environmental, and economic impacts	0.25
Probability of success	0.22
Implementation costs/cost effectiveness	0.21
Time frame for results	0.16
Measurability/accountability/performance tracking	0.16

To help service the ambitious nature of this panel meeting, both a facilitator and a rapporteur will be present. A report summarizing the panel meeting will be prepared. Prior to publication of the report, each panelist will have an opportunity to review and comment on the draft report text. The report will be provided to the U.S. Department of Energy, Office of Industrial Technologies to support the Secretary in compiling the required report to Congress identifying opportunities for energy-efficient, pollution-prevention technology demonstrations.

Panelists should be prepared to identify candidate energy-efficient, pollution-prevention technologies suitable for demonstration in either the production or refining segments of the petroleum industry. These technologies should be well-defined, widely applicable in the industry, and sufficiently generic as to not be proprietary.

For additional information contact:
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Identifying Strategic Opportunities: New Strategies for a New World

The Vital Issues Process

Process Purpose

The Vital Issues process is a strategic planning tool which identifies a portfolio of programmatic activities (an 'investment portfolio') for an organization, aimed at satisfying its high-level goals and objectives. The process requires a high level of stakeholder involvement, thus predisposing acceptance of the programmatic endeavors by those stakeholder communities.

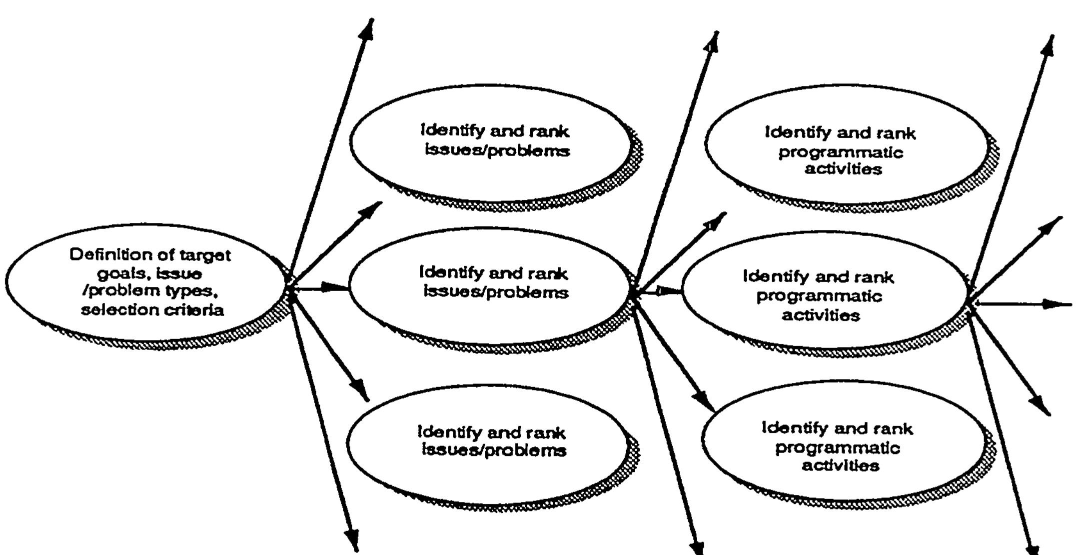
Process Description

The Vital Issues process is a multi-stage process, involving a series of day-long, intensive workshops, each of which builds on the results of the previous. The first workshop focuses on definitions, identifying target goals and objectives, describing the type of issues or problems addressed by the sponsoring organization, and identifying criteria for issue or problem selection. The next workshop (or set of workshops) uses the selection criteria and the definition of the desired issue or problem to identify and rank a set of such issues. The following workshop (or set of workshops) selects one of those identified issues (probably but not necessarily the highest ranked) and identifies and ranks associated programmatic activities. Subsequent workshops (or sets of workshops) can focus on tasks associated with specific programmatic activities. The process is illustrated in figure 1.

As group dynamics constrain the effective size of a panel to no more than twelve participants (with an optimal size of eight to ten), it is possible to run parallel panels on the same topic if the number of stakeholder or constiuency groups is greater than twelve. In such a case, representatives from the topical panels should be brought together into a 'composite' panel to generate integration of the results of the separate panels. This is illustrated in figure 2.

The panel of participants in each workshop will differ, as expertise will be relevant to the topic at hand. Institutional perspectives key to organizational success (such as private sector, state/federal government, and academe) should be identified a *priori* and represented on each panel. Each panel also should reflect a broad range of stakeholder communities. Individual panelists should be selected for their expertise and credibility within their professional communities.

Figure 1



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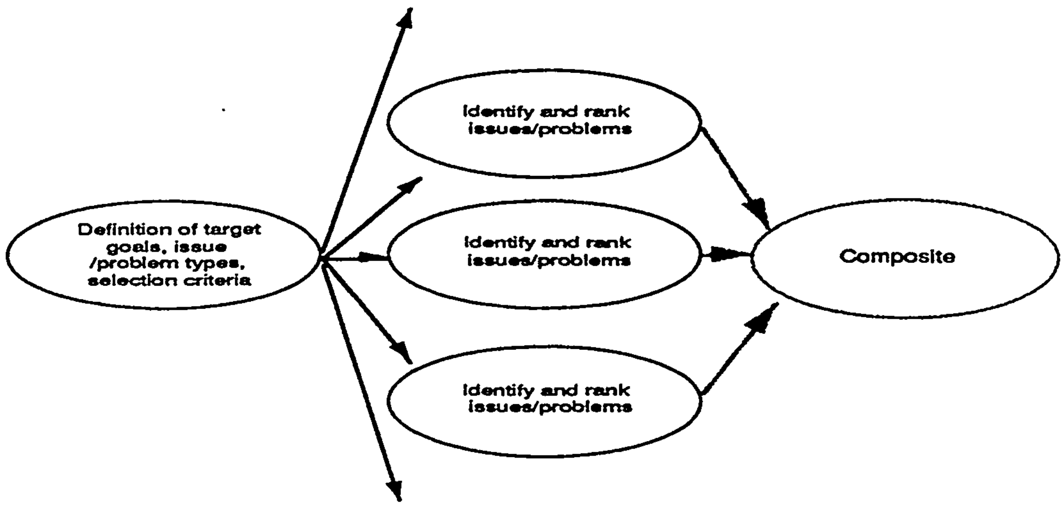


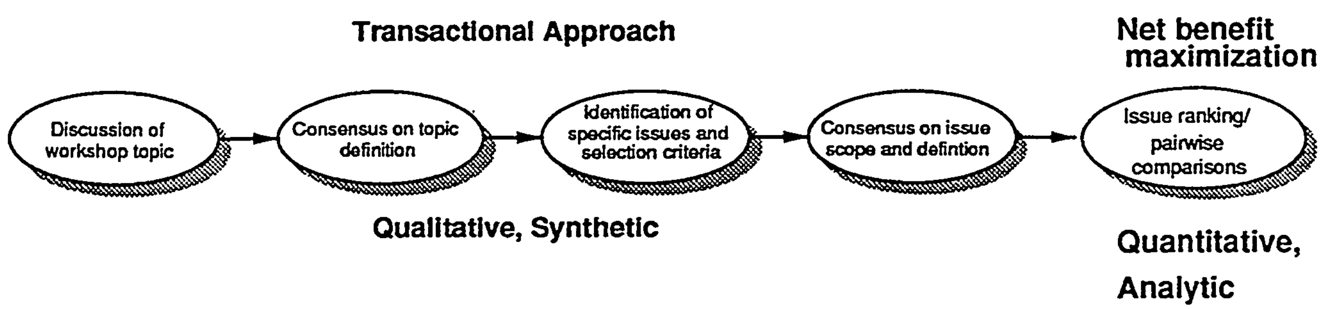
Figure 2

Process Methodology

The Vital Issues process incorporates two primary approaches: a qualitative, or transactional method, which takes a synthetic approach, and a quantitative, or net benefit maximization method, which performs some analytic activities. The transactional method involves dialogue among individuals or groups with some stake in the sponsoring organization's activities. Such dialogue usually focuses on problem or issue definition (which can include definition of an organization's goals and objectives) and criteria for measuring success through problem solution or goal achievement. Participation in the construction, or synthesis, of those definitions allows participants to become invested in the process. The definitions constructed by these synthetic activities form the environment within which a set of alternatives (such as issues or programs) can be identified. Net benefit maximization uses quantitative methods to perform a cost/benefit analysis on a set given alternatives, seeking to identify the alternative that provides the greatest social (or organizational) good according to some set of criteria.

Both methods are applied in each workshop of the Vital Issues process. The agenda leads off with a discussion of the topical area with which the workshop is charged, seeking to construct a definition that satisfies the group and which sets the parameters within which the specific issues, activities, or tasks are identified. A set of criteria for measuring success are also identified. Group discussion clarifies the identified issues and leads to consensus on their definition and scope. The issues are then relatively ranked (that is, the items in the set are ranked against each other, and not against any external, absolute standard) using pairwise comparisons which compares each issue to all others in the set in turn against each of the identified selection criterion by asking the scorer to assign specific values to each issue. This forces panelists to make explicit the tradeoff process and the criteria by which they are making the tradeoffs. The process is illustrated in figure 3.

Figure 3



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APPENDIX E

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