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Summary of the Energy Efficient, Waste-Reducing Technology Assessment Conducted for DOE and EPAct 2108

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ABSTRACT

The industrial sector is the most complex and diverse segment of the U.S. economy. There are more than 360,000 industrial facilities in the U.S., using tens of thousands of processes with millions of different pieces of equipment and employing nearly 30 million people to make hundreds of thousands of products. These facilities consume large quantities of raw materials and energy resources every year. Their waste streams, as well as the technology options for preventing them, are very specific not only to individual industries, but even to plants within the same industry that produce similar products.

On October 24, 1992, President Bush signed the Energy Policy Act of 1992 (EPAct) into law as Public Law 102-486. Section 2108 of the Act requires the Department of Energy (DOE) to identify opportunities to demonstrate energy efficient pollution prevention technologies and processes. As a first step in DOE's response to congress, Sandia National Laboratories lead a fast tracked project to compile information from the open literature, and pilot a process for identifying and prioritizing opportunity areas from industrial and federal experts. Approximately 300 documents were collected and reviewed, and knowledgeable individuals in government, universities, and trade associations were interviewed. Additionally, a panel of experts associated with the petroleum industry was assembled for the future opportunity assessments pilot. These activities were conducted between May and August, 1993. The project background and results are summarized herein.

INTRODUCTION

On October 24, 1992, President Bush signed the Energy Policy Act of 1992 (EPAct, Public Law 102-486). Section 2108, subsections (b) and (c), of 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. This work was conducted in close consultation with the Environmental Protection Agency and was based on literature searches

Pollution Prevention/ Waste Reduction/ Waste Minimization
In this project, these terms referred to the reduction of wastes at the source, including recycling of material within the process.

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DISCLAIMER

and contacts with experts in industry, academia, and the research community. Information was collected and summarized between May and August 1993.

A comprehensive report containing detailed results was prepared and is available to the public. (SNL 1994)

Objectives

This project addressed the requirements under Section 2108 subsections (b) and (c):

> Energy efficient pollution prevention technologies are those technologies that reduce both waste production and energy use.

- *(b)* - identify opportunities to demonstrate energy efficient pollution prevention technologies and processes
- *(c)(1)* - assess technologies from Subsection (b) to increase productivity and simultaneously reduce the consumption of energy and material resources, and the production of waste
- *(c)(2)* - assess the current use of such technologies by industry in the U.S.
- Determine the status of technologies currently being developed, including:
  - *(c)(3)* - projected commercial availability
  - *(c)(4)* - energy savings resulting from their use
  - *(c)(5)* - environmental benefits
  - *(c)(6)* - costs
- *(c)(7)* - evaluate any existing federal or state regulatory disincentives for the employment of such technologies
- *(c)(8)* - evaluate other barriers to the use of such technologies

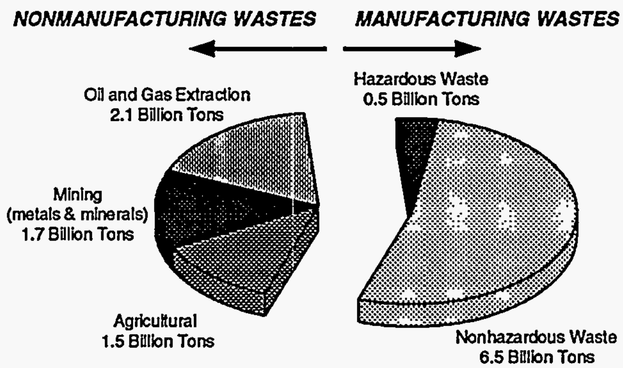
BACKGROUND

Identifying opportunities for the demonstration of energy efficient pollution prevention technologies and processes for the industrial sector is neither simple nor trivial. The industrial sector is the most complex and diverse segment of the U.S. economy. There are more than 360,000 industrial facilities in the U.S., using tens of thousands of processes with millions of different pieces of equipment and employing nearly 20 million people to make hundreds of thousands of products. These facilities consume large quantities of raw materials and energy resources every year. Their waste streams, as well as the technology options for preventing them, are very specific not only to individual industries, but even to plants within the same industry that produce similar products. The following looks at: (1) the volume of waste produced by industry; (2) the amount of energy used by industry; and (3) the economics of pollution control expenses. This information made a strong case for focusing the efforts of Section 2108 on a subset of industries that have the largest composite impact in these three areas.

Industrial Waste Generation

The total U.S. industrial waste stream is estimated to be more than 12 billion tons per year (Figure 1). Nonhazardous manufacturing wastes, estimated at 6.5 billion tons per year, account for roughly 50% of all industrial wastes, while hazardous wastes account for about 4%. The remainder of industrial wastes comes from nonmanufacturing industries.

Figure 1
Estimates of Industrial Waste Generation



Total for Industry: 12.3 Billion tons/yr

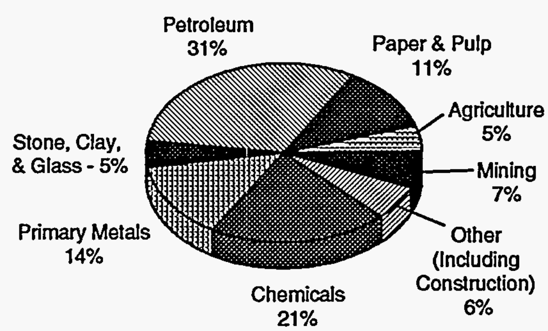
Sources:
EPA 1993a, EPA 1992a, EPA 1991, EPA 1988, EPA 1987, OTA 1992

While the focus to date has been on controlling the pollution and wastes that are produced, there is increasing interest in reducing the wastes and pollution that are produced in the first place. Pollution prevention concepts are not new. For many years, certain industries have practiced pollution prevention and recycling when it made economic sense. DOE, EPA, and other federal agencies are endeavoring to extend pollution prevention concepts and practices, and place this long-term solution at the forefront of environmental management.

Energy Use

Industry accounts for nearly 31 quads[1], or 37%, of all U.S. energy consumption (Figure 2), and most of this energy is used in the manufacturing sectors. The cost to industry for this energy is about $130 billion per year.

Figure 2
Industrial Energy Consumption



Total Industry Consumption in 1992
30.63 Quadrillion BTU

Sources: EIA 1993, EIA 1992, EIA 1991

Waste generation is often equated with energy use. When waste is produced, energy is almost always consumed at the same time. Each waste that is produced by an industrial process is associated with the use of energy, both for creation of the waste, and also for the ensuing handling, treatment, and disposal. When the waste that is generated is reduced, the energy that is used is decreased. This returns double in

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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.

that a reduced need for energy means the waste products from energy conversion at the power plant are also diminished. Industrial waste reduction and decreased energy use are often interconnected.

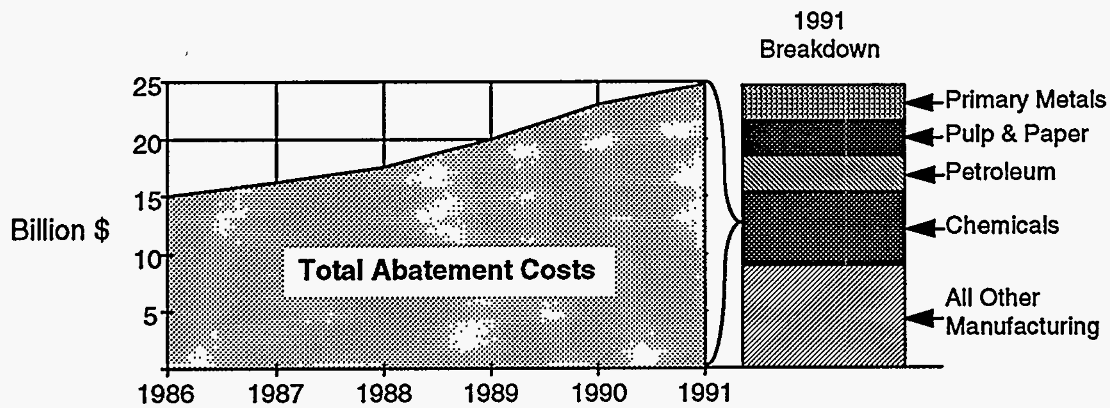
Economic Impacts of Waste Production

The economic burden of waste production in industry is not well understood. Further, current accounting methods have not been able to capture its full costs. Production costs are affected by a wide range of factors such as materials use, energy use, labor productivity, capital productivity, environmental controls, and liability. The extent to which production and management of wastes, separate from products, influences the need for increased resources is not easily identified. Further, there are costs not associated with the production process itself that may ultimately present a large hidden cost; for example, liability costs.

Pollution control expenditures are one aspect of waste production that can be examined. Estimates for the amount that industry spends on pollution abatement vary significantly. EPA estimated industry's share of control, treatment, and disposal cost to be more than $70 billion in 1990 (EPA 1990). The Pollution Abatement and Control Expenditures survey estimates that manufacturers spent approximately $25 billion on pollution abatement in 1991 (Figure 3). Most of these costs are related to toxic wastes, which are less than 1% of the ~12 billion tons. At this time, there is no accurate estimate for the total cost to industry of the impacts of waste materials production.

Figure 3

Industrial Pollution Abatement Costs and Expenditures



Source: DOC 1993

Industries Targeted for Section 2108

Given the complexity and diversity of U.S. industry, the focus of this report was limited to those industries with the most significant overall impacts and representing the greatest opportunities for industrial waste and energy reduction. The seven industry sectors targeted were:

Assessment of Technologies (2108(c)(1) - (c)(6))

Subsection 2108(c)(1) required that an assessment be made for the technologies identified in subsection (b). To optimize the time and resources available to address the assessment requirements of Section 2108, the focus was on providing a foundation for addressing opportunity identification and subsequent assessment activities. This foundation was built on a systematic review of the literature for pollution prevention technologies which were, in turn, evaluated relative to the information requested in subsection 2108(c). This background provided insight into the current state of pollution preventing technologies in industry and will support future efforts to identify demonstration opportunities. The results derived from the open literature are summarized below.

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.

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.

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.

Summary Findings

The literature review resulted in 590 specific technologies with positive reduction impacts for the seven industrial sectors covered Figure 4 shows a breakdown of the number of technologies logged for each industry sector.

Figure 5 shows the number of entries by the waste reduction strategy employed. 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 6 shows which of the 590 technologies included some type of quantitative information on energy impact, waste reduction, and/or costs or cost savings.

The 590 technologies were classified by industrial sector into pollution issues, and are summarized in Table 4. This classification suggests the pollution issues applicable to waste reduction efforts for each industry sector.

Existing Technologies

(c)(1) - 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)

Of the 590 total technologies recorded, 489 are existing, that is, in relatively broad use within industry (Figure 7). 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.

Figure 4

Total Number of Technologies by Industrial Sector (590 Total)

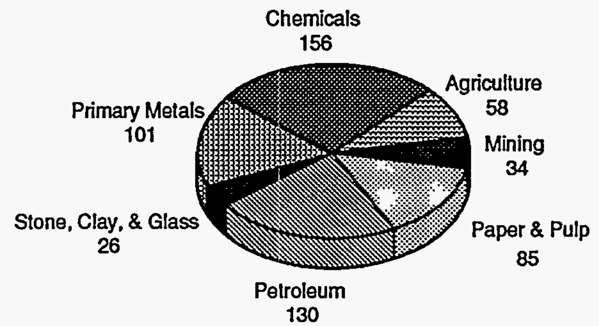


Figure 5

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

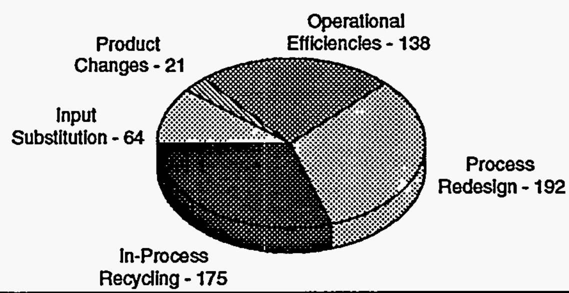


Figure 6

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

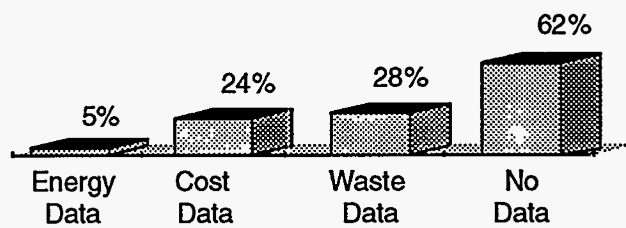


Table 4
Literature Review - Technology/Pollution Issue Categories - by Industry Sector

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[5]	– 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.

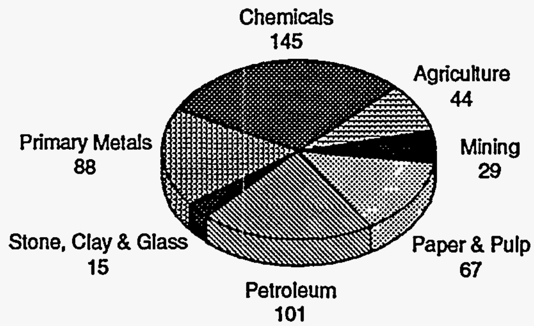
■ Indicates that only developing technologies were recorded for this area.

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

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 7

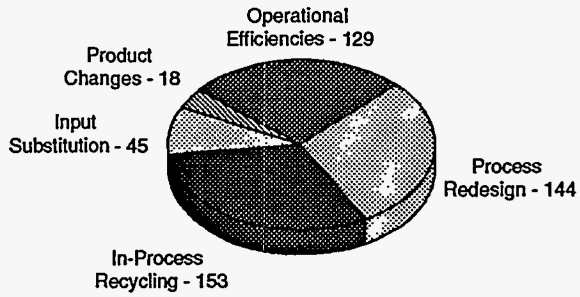
Existing Technologies Recorded (489 Total)



When reviewed by waste-reducing strategy application (Figure 8), 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.

Figure 8

Existing Technologies by Strategy (489 Total)



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 by-product 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).

Current Use by Industry

(c)(2) - 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 about (industry/companies aware of its existence)

- a company or industry is able to adequately assess its need for a technology
- there is no other barrier, regulatory, cultural, or otherwise, preventing its use

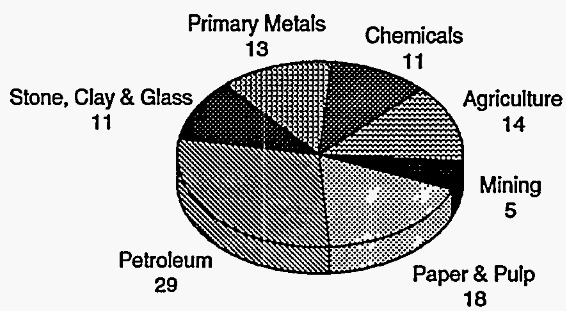
Developing Technologies and Projected Availability

(c)(3) - 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 9). 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 9

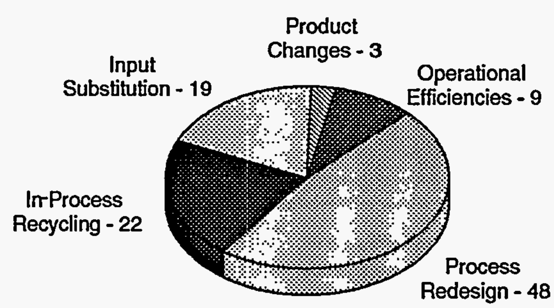
Developing Technologies Recorded (101 Total)



Grouped by waste reduction strategy, nearly half of those recorded involve process redesign efforts (Figure 10). This suggests a strong development effort involving this strategy versus the others.

Figure 10

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 one- to four-year period.

Energy Savings

(c)(4) - the energy saving resulting from the use of such technologies

As shown previously in Figure 6, 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.

Environmental Benefits

(c)(5) - 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.

Costs (and Cost Savings)

(c)(6) - 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, permitting, or costs that cannot be predicted, such as future liability costs.

More information on this subject can be obtained in an EPA report on total cost assessment (EPA 1992b).

An example of successful cost-effective waste reduction implementation is provided in a recent literature search conducted in support of a DOE/Industrial Waste Program 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
  86% had paybacks of 36 months or less
- 55% of the investments were under $100,000

Evaluation of Barriers

Table 5 summarizes possible barriers to adoption of waste reduction technologies derived from information in the following sources: a DOE report (DOE 1991b) which examined the incentives and disincentives to industrial waste reduction in 16 pieces of existing legislation and their attendant regulations and in 22 pieces of proposed legislation; an EPA Office of Solid Waste (EPA 1993b) report that summarized the barriers and incentives in 50 documents from government, academia, and industry; and a group of 60 documents, primarily journal articles, located through a literature search. In addition, three experts were contacted for information to complement that obtained in the literature.

The review on barriers to adoption of waste minimization 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.

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- Convery & Associates -- Susan Convery
- Los Alamos National Laboratory -- Gerry Maestas

Table 5
Possible Barriers to Adoption of Waste Reducing, Energy Efficient Technologies

Findings	• Environmental legislation and regulations are mostly designed to control pollution already generated, rather than prevent generation. While effective at pollution control, they tend to be disconnected, costly, inflexible, counter productive and inconsistently enforced, which discourages innovative or voluntary actions, including waste reduction initiatives.
	• Characteristics of a specific industry are as important as its regulatory, social, economic, and cultural framework in determining an ability to develop and advance new technologies.
	• Federal regulations can act as an incentive through costs imposed on treatment & disposal, but limited resources are often drained that can be applied to advance efficient processes.
Regulatory Issues	• Federal regulations take a "command and control" approach in which strict prescriptive requirements must be met with little consideration for cross-media transfer. While protecting us from discharged pollutants, they provide little room for flexibility in achieving compliance. The results can be to entrench existing technologies & discourage long-term innovation.
	• RCRA has very specific requirements regarding the handling and treatment of end-of-pipe pollutants that present significant obstacles to recycle, reuse, or reclamation of the waste products including hazardous chemicals.
	• Regulations requiring treatment and disposal of by-products of industrial processes within a specific time frame can preclude alternative uses because of time incompatibility.
	• The permitting process required for processes with RCRA hazardous products can be difficult, lengthy, and costly. This often discourages manufacturers from instituting changes that would require repermitting.
	• There can be a cost disadvantage to a company that adopts voluntary waste reduction efforts when later required by regulation to reduce further, compared to a company that has not been proactive in waste reduction.
Federal, State & Local Interactions	• The complexity of uncoordinated federal, state, and local regulations, requirements, and standards increases the regulatory burden by requiring compliance with unrelated, possibly inconsistent, and potentially changing requirements. This can foster the view that pollution prevention is something to be handled only as required, rather than day-to-day.
Economic and Financial	• It can be difficult to quantify the benefits of waste reduction, which then makes it difficult to compete for limited capital resources.
Technological	• Development can be long and expensive with no guarantee of payoff. Costs may be burdensome, if not prohibitive, for smaller companies.
Management/ Organization	• Management is responsible for producing a profitable and effective product. This impacts decisions on adopting waste reducing technologies when the bottom line is affected.
Cultural	• Waste reduction may be as much a cultural issue as technological. Industry, public, and federal attitudes play a key role in technology implementation success and time frame.
Knowledge or Analysis Capacity	• The ability of particularly small and medium sized firms to assess ecological needs can have direct bearing on the adoption of waste reducing technologies. Lack of information or proper assessment capabilities can short-change technology adoption.
Structural Factors	• Changes that have a cross-cutting effect on industries can be either positive by making new opportunities for better products or for reducing costs, or negative because of the dislocations produced in the existing economic situation.
Resources	• Lack of material inputs, available capital, and people with necessary training, experience, and skills are all potential barriers to the adoption of a new technology.
Competition	• To the extent that a waste-reducing technology is differentiable from other similar products--usually either in costs or appearance--such a technology can be a barrier or an incentive.
Market Conditions	• Market conditions in general will affect willingness and ability to invest in waste reduction efforts versus other competing investment possibilities.

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