PROFILE OF INDUSTRIAL WASTES

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Understanding the complexity of the U.S. industrial system is crucial in developing effective technology strategies for reducing waste production and energy use in industry. There are over 360,000 industrial facilities in the United States, using thousands of processes, with thousands of different pieces of equipment, to make hundreds of thousands of products for consumers and industry. These facilities consume a multitude of raw materials and energy resources every year. While this diversity and complexity is a contributing factor to the competitive strength of U.S. industry, it is one reason why broad pollution prevention solutions have had limited impact. 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. A waste management strategy that is good for one firm may not suit another.

There is a strong link between energy use and waste production in industry. As wastes are created, energy is expended in several ways. Energy is embedded in the extraction and transformation of materials that end up as waste; heat energy may be contained in certain chemical wastes; and energy is used to treat, transport, and dispose of wastes. Because of this, industrial waste reduction efforts can have profound impacts on energy use in waste-intensive industries.

An effective national strategy for industrial pollution prevention should focus on the major waste and energy problems in industry. This ensures that the largest and most important waste problems are given priority in federally-supported R&D programs. For example, the U.S. Department of Energy's Office of Industrial Technologies has reoriented its technology R&D program to focus on seven major energy- and waste-intensive industries. By examining industrial patterns of waste generation and energy use, federal programs can target industries and processes that face the greatest economic, energy, and environmental challenges and help establish pollution prevention R&D priorities.

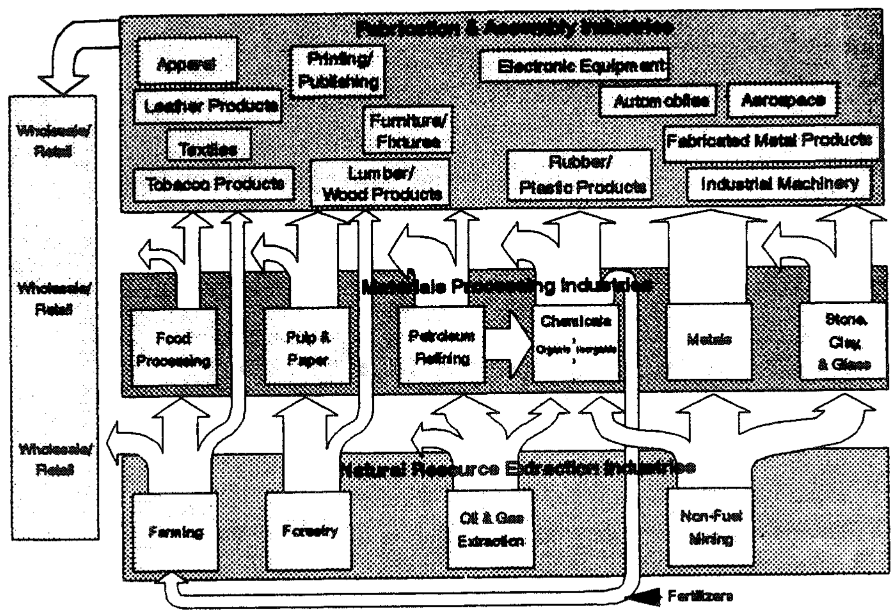
INDUSTRIAL MATERIAL FLOWS

Industry can be thought of as a complex network of material and product flows. Raw materials, fuels, refined chemicals, parts, manufactured components, etc. are acquired by companies to make products for consumers and other industrial firms. As companies transform materials to produce useful products, numerous byproducts are created. When these byproducts are perceived to have economic value they are sold as secondary products or further transformed to create other useful materials. Unfortunately, an enormous amount of industrial byproducts are deemed to have little or no economic value and are discarded as waste.

The U.S. industrial sector consists of four basic types of industries: natural resource extraction, materials and process, fabrication and assembly, and service. Major materials flow among the first three types of industries as roughly outlined in Figure 1. Industrial wastes can best be understood by considering these flows through industrial systems. Each industry, company, or facility acquires input materials, transforms these materials, produces finished outputs, and discards useless byproducts. Using engineering principles of mass flows and material balances, wastes can be calculated as the difference between the mass of all inputs and the mass of the useful outputs. With this perspective, waste reduction becomes synonymous with materials use optimization.

Large quantities of raw materials are needed to create most of the products we use and consume. Production inputs consist of primary raw materials, known as "active" inputs, and secondary materials, known as "inactive" inputs. Active inputs include the major ingredients needed for the final product -- iron ore for steel, wood pulp for paper, bauxite for aluminum, etc. Inactive inputs include ubiquitous materials, such as water and atmospheric oxygen, that are required for production but are a minor component of the finished product.

Figure 1. Generalized Industrial Materials Flows



As products and materials move from the extractive industries to the materials and process industries to the fabrication and assembly industries, more of the active inputs are used in the final product. In mining industries, for example, very large quantities of unwanted mineral impurities are discarded to obtain the desired element. At least 80 percent of the mass of the ores contain undesirable constituents; 99 percent in the case of copper. In latter production stages, such as in the transformation of iron to steel and in the subsequent forming of sheet metal for consumer products, smaller amounts of active inputs are discarded. When viewed over the full production cycle -- from mineral extraction to consumer product -- only about 6 percent of active materials are embodied in finished durable goods; 94 percent of active materials end up as waste (Ayers 1989).

Examples of simple material balances for selected U.S. manufacturing industries are shown in Figure 2 (Ayers 1993). These balances, which were based on available production data, indicate that manufacturing industries use as much as 95 percent, and as little as 11 percent, of active inputs in their finished product. While these calculations oversimplify the complex interchange of materials and byproducts throughout our industrial system, they provide a valuable context for examining waste production that is not complicated by the inclusion of water or conflicting judgements of what constitutes waste.

As a more practical matter, most industrial wastes are regulated, measured, and reported based on the total waste output, which includes inactive materials such as water. The best available estimates indicate that U.S. industry generates approximately 14 billion tons of waste products each year (Figure 3). These wastes include gaseous emissions, solid wastes, sludges, and large amounts of wastewater. Most of the wastes are generated in the manufacturing sector, which is responsible for roughly 8.5 billion tons per year. The remaining industrial wastes, about 5.5 billion tons per year, come from three nonmanufacturing sectors: metals and mineral mining, oil and gas extraction and production, and agriculture. This estimate, however, is only a rough approximation of the true extent of waste generation; the information available to construct this or any such estimate is generally poor and must be pieced together from a variety of sources that have different definitions of wastes, different reporting years, and different methods of accounting for water content.

CHARACTERISTICS OF INDUSTRIAL WASTE

The nature, source, and amount of industrial wastes is not well understood. The biggest difficulty in characterizing waste streams is the lack of a consistent and agreed upon definition of waste. For example, agricultural byproducts that are returned to the soil may be viewed as a waste or a useful product. Furthermore, since most wastes contain a large portion of water, some may argue that an entire stream is a waste while others may not consider the water component to be a waste. Conflicting definitions, combined with the scarcity of

Figure 2. Material Balances in Selected Industries

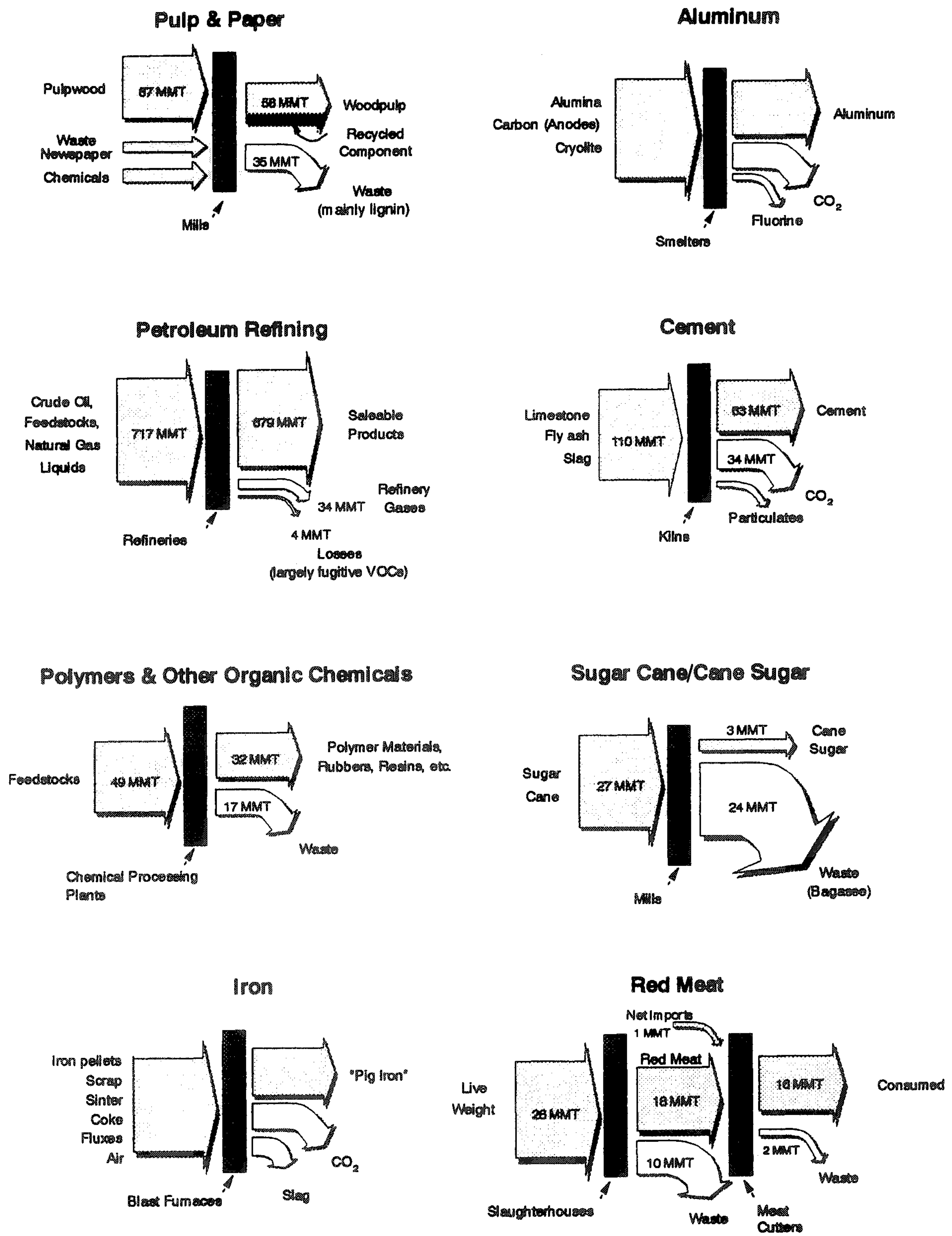
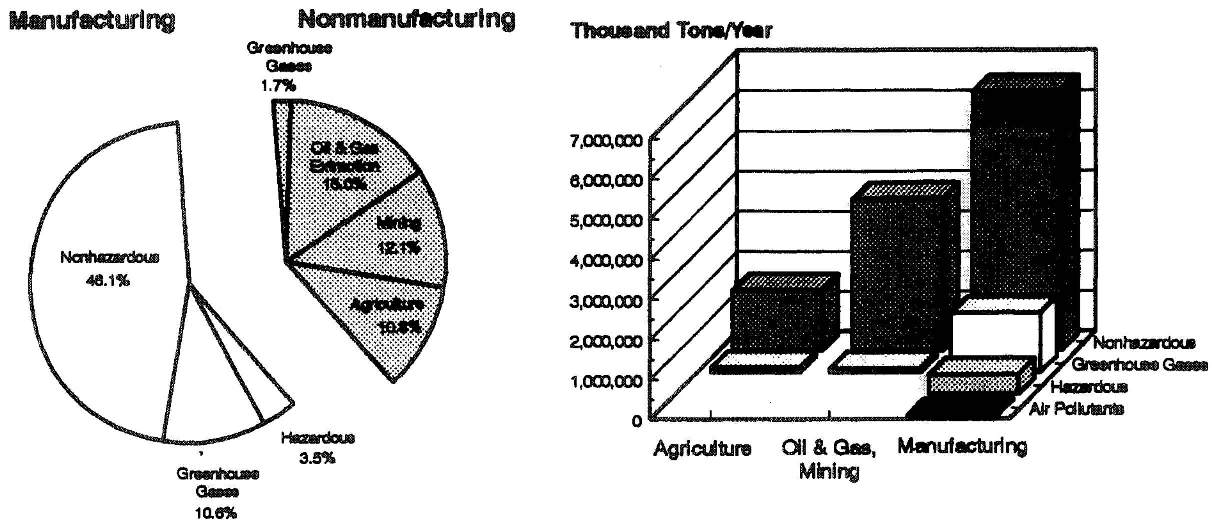


Figure 3. Industrial Waste Generation -- The Big Picture
Total Waste Production = 14.0 Billion Tons/Year



reliable data, create confusion over the magnitude of industrial wastes and the opportunities to reduce them.

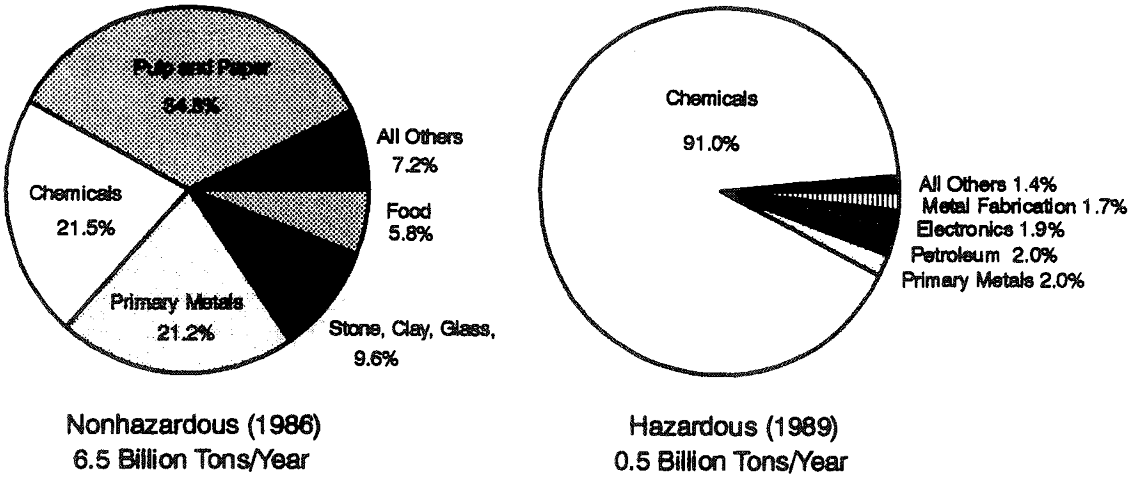
Our environmental laws distinguish among industrial wastes according to their potential environmental impacts, usually by media (air, land, water). These laws have focused on limiting the release of pollutants to the environment and have not typically been concerned with waste generation rates or non-polluting waste streams. Because most national waste data is collected to comply with these laws, limited information is available on waste generation by industry or by process. The following analysis covers industrial wastes as reported in the major data sources, which are linked to regulatory requirements. These wastes include the major hazardous and nonhazardous waste streams of manufacturing, unclassified (exempt) wastes from nonmanufacturing activities, and other key industrial wastes.

Nonhazardous wastes make up the largest category of industrial wastes. Manufacturers generate an estimated 6.5 billion tons of nonhazardous waste per year (EPA 1988). These wastes are defined as "solid wastes" by legislation, but have been estimated to contain roughly 70 percent water by weight. The data reported on nonhazardous wastes is derived from numerous sources, many of which are over ten years old. As a result, data for this waste type has the greatest degree of uncertainty and inconsistency.

Within manufacturing, over 90 percent of the nonhazardous waste is produced by five industries: chemicals; primary metals; pulp and paper; stone, clay and glass; and food products (Figure 4). About 97 percent of this waste is disposed of in surface impoundments at the plant site where it was generated. Very little is known about the characteristics of these wastes except what has been studied within specific industries (such as the chemical and petroleum industries) that collect waste data through their respective industry trade organizations.

Hazardous wastes make up a smaller portion of the total industrial waste stream, but they represent a greater risk to the environment and human health and are therefore more closely regulated. Hazardous waste is characterized as having toxic, corrosive, reactive, or ignitable properties. In addition, mixtures containing specific ("listed") substances are considered hazardous. According to EPA, in 1993 about 235 million tons of hazardous waste were managed in treatment, storage, and disposal facilities regulated under the Resource Conservation and Recovery Act (RCRA). EPA estimates that over 90 percent of the weight of these wastes are hazardous wastewaters. While data collection covered 22,615 sites throughout the United States, many hazardous wastes are managed outside the scope of the RCRA permitting system (EPA 1995a). Analysis of the

Figure 4. Nonhazardous and Hazardous Wastes in Manufacturing



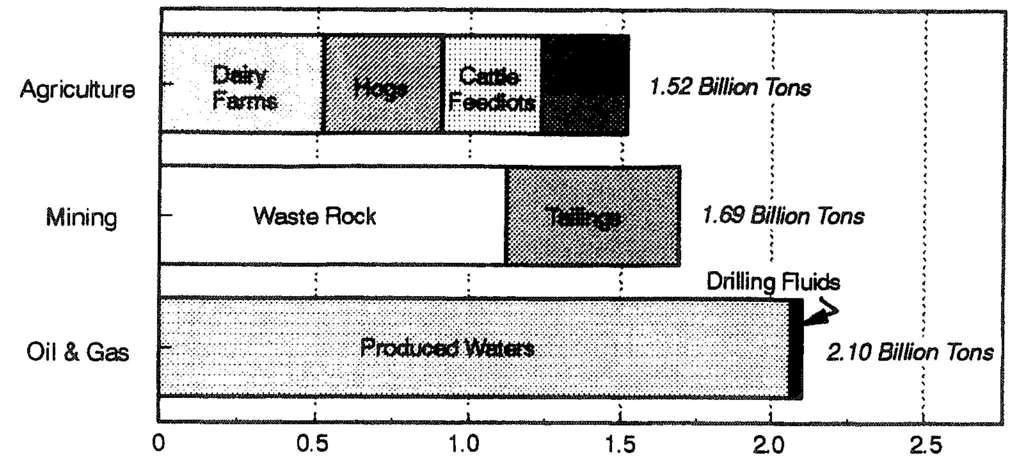
hazardous waste data for 1986 indicates that the reported wastes represent only about 40 percent of the total estimated hazardous waste stream in industry (EPA 1991). This suggests that all of industry generated over 500 million tons of hazardous waste in 1993.

Much of the hazardous waste generated in the United States is concentrated in a small number of large manufacturing complexes. Of the 22,615 sites covered in the 1993 RCRA reporting, 50 sites (less than 0.5 percent) accounted for 81 percent of all wastes. Of these sites, 48 are petroleum refining or chemical facilities. Other industries that contain large hazardous waste generators are electronic and electric equipment, fabricated metal products, and primary metals. EPA discontinued reporting emissions by industry in the 1989 survey, although individual facilities continue to be coded by four-digit industrial code in the main database. Hazardous waste generation by industry is shown in Figure 4 using the 1989 survey data.

Nonmanufacturing industries, particularly mining and agriculture, also generate significant quantities of waste. These wastes are classified as "exempt" wastes under RCRA, and the task of defining what constitutes "waste" is quite difficult. For example, some have argued that the removal and replacement of overburden in mining or the plowing under of dried corn stalks in farming should not be considered part of the industrial waste stream. Mining wastes considered for this report include wastes from oil and gas extraction and production, metal mining, and nonmetallic minerals (except fuels); coal mining wastes are not included (EPA 1987, EPA 1985). 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) (Figure 5). Overall, nonmanufacturing wastes represent about 40 percent of the total industrial solid waste stream.

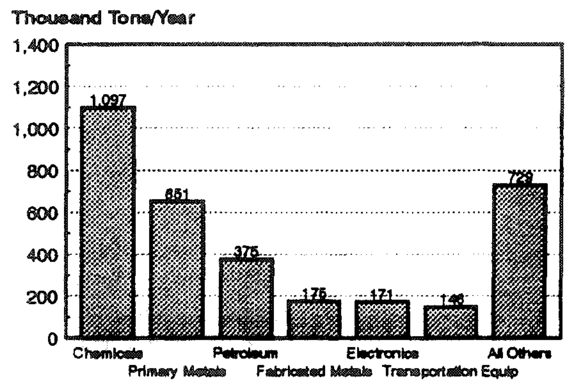
Toxic waste emissions from manufacturing are of special interest due to their potentially severe impact on the health of workers, local communities, and the ecology. In 1993, U.S. companies released and transferred 3.3 million tons of toxic wastes (EPA 1995b) (Figure 6). The chemical industry was responsible for the largest portion of these wastes, followed by primary metals and the petroleum refining industries. Together these three industries account for nearly two-thirds of the total toxic waste stream. Topping the list of toxics are widely used commodity acids (e.g., sulfuric, hydrochloric), copper, ammonia, zinc compounds, lead compounds, and commonly used solvents and chemical building blocks (e.g., methanol, toluene, acetone, xylene, trichloroethane, etc.) (EPA 1995b).

Figure 5. Sources of Nonmanufacturing Wastes - 1986



Airborne pollutants are gaseous by-products of fossil fuel combustion and other industrial activities. Several of these 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. EPA has estimated that industrial sources directly account for nearly half of all reactive VOC emissions, about 20 percent of sulfur oxide emissions, and about 2 percent of nitrogen oxide emissions in the United States (EPA 1994). In addition, industrial use of electricity indirectly accounts for an additional 25 percent of sulfur oxide emissions and 11 percent of nitrogen oxide emissions.

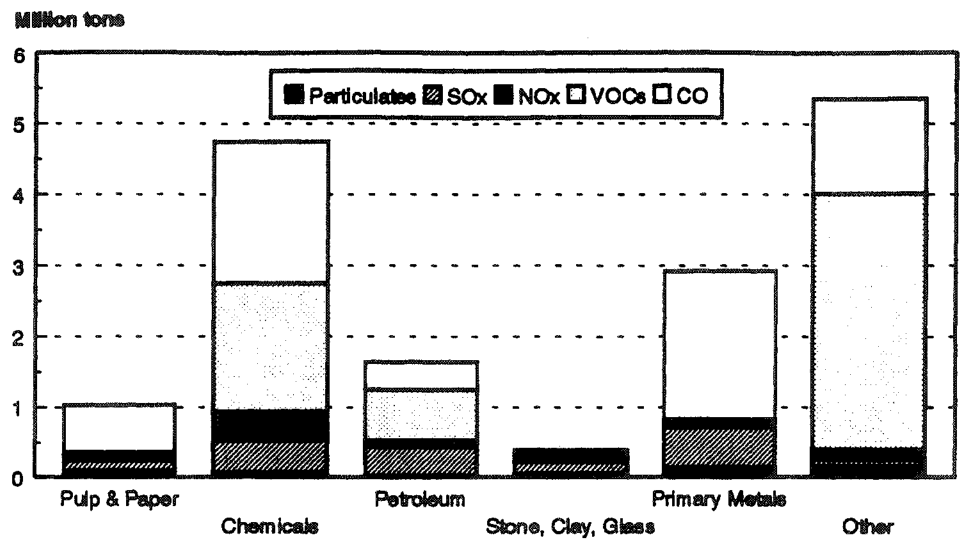
Figure 6. Toxic Wastes in Industry - 1993



Elevated levels of these pollutants can lead to a variety of adverse health effects, and have also been blamed for reduced crop yields and stunted forest growth. Ozone, for example, produced through chemical reactions that involve both NO_x and VOCs, is a major component of smog. Acidic deposition, or "acid rain," occurs when pollutants (primarily SO_x, NO_x, and VOCs) form acidic compounds in the atmosphere and are later deposited on the earth by 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 1993, air emissions from the manufacturing industries reached over 16 million tons (Figure 7). The highest producers of airborne pollutants are the chemical; primary metals; pulp and paper; petroleum refining, and stone, clay and glass industries.

Greenhouse gases comprise a group of gaseous wastes that are associated with global climate change. Major contributors include carbon dioxide, methane, nitrous oxide, and chlorofluorocarbons (CFCs). Carbon dioxide, the largest source of greenhouse gases, is produced by fossil fuel combustion and certain industrial processes (including cement manufacture, lime manufacture, limestone in steelmaking, carbon dioxide manufacture, soda ash manufacture and use, and aluminum production). In 1993, an estimated 1.6 billion tons of CO_2 was emitted

Figure 7. Industrial Air Emissions - 1993



by industry (EIA 1994). Industrial methane emissions, which result from agricultural activities and energy production and use, were estimated at 15 million tons in 1992 (EIA 1994). 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.

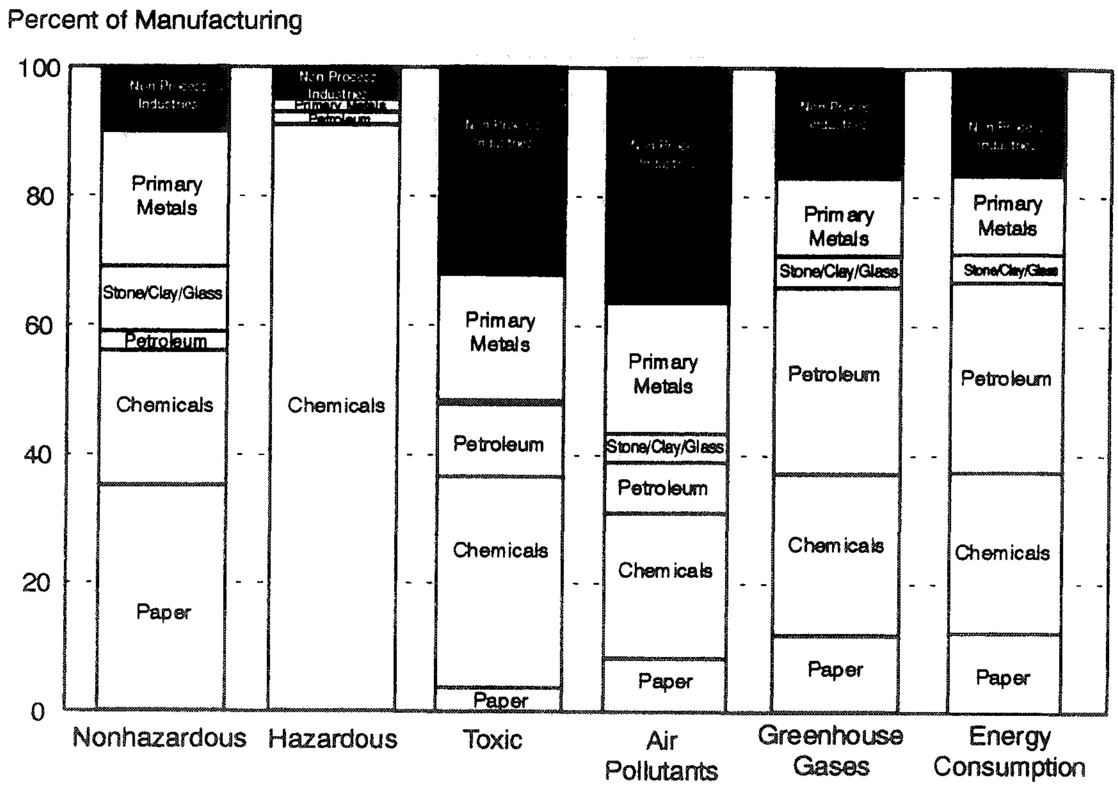
In addition, industry manufactures all of the CFCs in use and emits some waste CFCs. CFCs are associated with the depletion of the stratospheric ozone layer, which normally filters the ultraviolet radiation that can be harmful to human health and the environment. While CFCs remain in wide use, international agreements have already been adopted to control and eventually phase out the use of harmful CFCs entirely over the next ten years.

WASTE GENERATION AND ENERGY USE BY INDUSTRIAL SECTOR

Waste generation and energy use in manufacturing is concentrated in a few sectors. Five major industries -- chemicals; pulp and paper; primary metals; petroleum; and stone, clay and glass -- account for over 80 percent of most waste products within the manufacturing sector (Figure 8). These materials and processing industries, which produce and use chemicals in large quantities, are typically characterized by continuous processes, large energy use, large by-product streams, and diverse and unique waste profiles. These industries are large waste producers because they are all "weight-reducing" industries that use large quantities of raw materials to produce much smaller quantities of final products. These industries also use processes that tend to require very large amounts of water, which often gets contaminated and must then be treated as a hazardous waste. This greatly increases the weight and volume of their waste streams.

The Department of Energy's Office of Industrial Technologies has focused its technology R&D program on the energy efficiency and pollution prevention needs of seven key process industries that comprise these five major industries. These include chemicals, petroleum refining, forest products (pulp and paper plus lumber and wood products), steel (primary metals), aluminum (primary metals), metal casting (primary metals), and glass. Detailed data on waste generation by these process industries is incomplete. While good data exists on waste emissions of toxic chemicals, this only accounts for less than one-tenth of one percent of industrial waste streams. Hazardous waste data exists by specific industries by waste stream but EPA does not consider information at this level to be reliable. Nonhazardous wastes have been estimated for components of the chemical industry but not for any of the others. With support from DOE, Energetics, Incorporated has begun to construct a database of waste stream estimates by four-digit SIC level within the manufacturing industries.

Figure 8. Process Industries Dominate Waste Generation in Manufacturing



There is a strong relationship between energy use and waste production in manufacturing. The major process industries engage in intensive transformation of raw materials into intermediate industrial products. This transformation involves the separation and synthesis of materials which is both energy intensive and waste intensive. Figure 9 shows the distribution of waste generation and energy use within manufacturing. With the exception of the petroleum refining industry, the process industries show a strong relationship between energy use and waste generation. Petroleum refining shows much higher energy consumption relative to waste because many of their waste products are consumed as energy. The pulp and paper industry, which shows high waste levels relative to energy consumption, contains very high amounts of wastewaters that may overstate the weight of their waste streams relative to other industries.

The energy use associated with industrial wastes is hard to estimate. DOE has estimated that embodied energy, which includes all the energy expended to extract, refine, process, and manufacture materials that end up as wastes, accounts for 4 to 7 quads. Energy needed for waste processing and disposal accounts for 2 quads and the theoretical fuel value of wastes accounts for 10 to 15 quads. However, these are very rough estimates that include a large amount of combustion energy contained in agricultural and forestry wastes. Energetics has estimated the theoretical energy content of over 50 common manufacturing waste streams, identifying both chemical (heat of combustion) and embodied energy. These estimates reflect the "captured" Btus of the waste. In practice, however, much of this energy may not be recoverable due to the explosive, reactive, and toxic nature of the waste product. A selected sample of ten high-energy wastes are shown in Figure 10.

COSTS OF ENVIRONMENTAL MANAGEMENT AND CONTROL

Industry expends significant resources to manage and control pollution. The Bureau of Economic Analysis at the Department of Commerce estimates that industry spent $53 billion in 1992 for pollution abatement and the control of waste products (Rutledge 1994). These costs include all industrial sectors, including manufacturing,

Figure 9. Relationship of Waste Generation and Energy Use

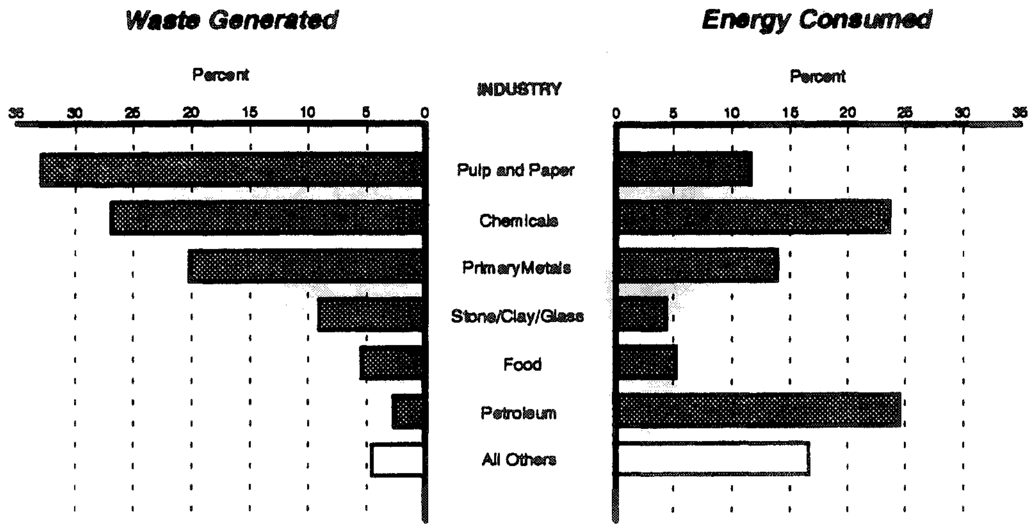
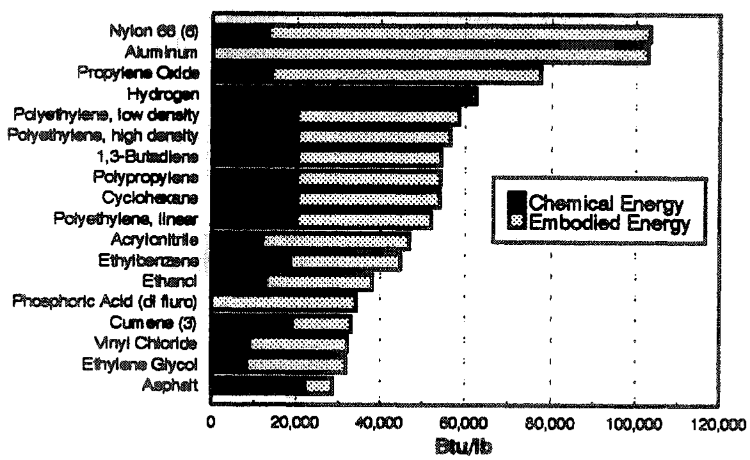


Figure 10. Energy Content of Selected Wastes

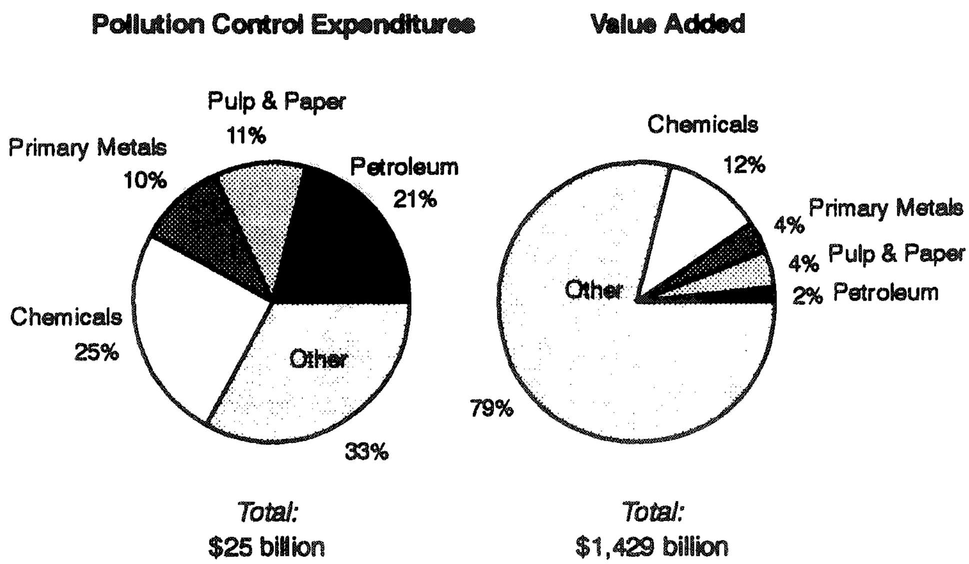


electric utilities, mining, and a variety of service and nonmanufacturing industries. Pollution control costs represent direct outlays for equipment purchases, operations, and maintenance, but do not include a wide variety of indirect costs associated with waste management.

Pollution abatement costs and expenditures by manufacturers are collected by the Census Bureau through a survey of companies. Estimates indicate that manufacturers spent roughly $25 billion on pollution control equipment and operations in 1993 (Figure 11) (DOC 1995). These costs, however, do not fall evenly among industries. Four industries account for about 70 percent of total costs, and two industries -- petroleum and chemicals -- account for about half of all pollution control costs in manufacturing. These two industries, however, only account for about 14 percent of value added, suggesting a high economic burden on these industries to control pollution.

According to the Office of Technology Assessment, manufacturers' pollution abatement expenditures may be underreported by 20 to 60 percent. Much of this underreporting is associated with interest costs, but it includes other indirect or misrepresented cost categories. Indirect costs include productivity losses, product quality degradation, indirect labor costs, legal fees, liability costs, indirect material and energy costs, interest expenses, research and development costs, and opportunity costs of alternative investments. For estimation purposes, OTA suggests a rough figure of 25 percent underestimation. Using this estimate of pollution control expenditures for manufacturing may amount to about $30 billion per year.

Figure 11. Pollution Control Expenditures (1993) and Value Added (1992)



The effect of pollution control costs on an industry's competitive advantage is difficult to gauge. Several measures can be used to assess the economic burden borne by U.S. industries and the effect these may have on competitiveness. One approach is to consider the portion of capital expenditures that is spent on pollution abatement. In 1991, 7.9 percent of all capital expenditures by manufacturers went for pollution control equipment. The petroleum industry, however, spent over 25 percent of its capital on pollution control, while the chemical industry spent over 14 percent. One industry -- metal plating and polishing -- spent over 27 percent of its capital funds for pollution control equipment.

Another approach is to consider total pollution control expenditures as a portion of sales and value added. On average, manufacturers spend 0.8 percent of sales and 1.72 percent of value added on pollution control expenditures. The petroleum refining industry spends much more than this average -- 2.25 percent of sales and 15.42 percent of value added -- on pollution control. Other industries that are far above the average include pulp mills, blast furnaces, inorganic chemicals, metals plating, chemicals, and primary metals.

Compared to other industrialized countries, the U.S. private sector spends proportionately more on pollution control. From 1974 to 1990, U.S. companies spent between 0.8 and 0.95 percent of GNP on pollution control. Other OECD countries spent considerably less, ranging from about 0.3 percent for France to 0.8 percent for Germany. These values are not very reliable, however, due to differences in how countries account for pollution control costs. For example, Germany includes interest costs while the United States does not. In recent years, the United States has out-spent Japan, Germany, the Netherlands, and other leading environmentally active countries in the portion of capital expenditures that are used for pollution control equipment.

The ultimate impact of pollution control costs on competitiveness is even more difficult to assess. Some industries, such as the chemicals industry, have high pollution abatement costs but are very competitive internationally and post significant trade surpluses ($18.8 billion trade surplus for the chemicals industry in 1991). Other industries that carry a lower pollution cost burden are struggling competitively. Several studies have indicated that any differences in environmental control costs among industrialized nations are vastly overshadowed by differences in capital and labor costs and fluctuations in exchange rates. Other studies have claimed a much higher impact. A final perspective on these costs is to compare the amount spent on pollution abatement and control compared to other corporate costs. Pollution control expenditures are about half of what industry spends on all corporate R&D and is equal to what they spend on all employee training. To the extent that pollution control diverts money from these other important activities, the competitive disadvantage may be quite real.

The full economic implications of industrial waste generation are much larger. Industry not only pays the cost of managing wastes from their operations, they pay for excess materials that are purchased and processed but end up as wastes. In addition, some studies have shown that there are tremendous social costs associated with industrial waste production. These "hidden" costs of industrial wastes, which include environmental and economic externalities, may be even more significant on a national scale.

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