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RESEARCH AGENDA FOR WASTE MINIMIZATION *

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ABSTRACT

Because of the large quantities of materials and energy used by the chemical industry, significant opportunities are available for waste reduction. Waste reduction techniques include improvements in process selectivity and/or conversion, the ability to operate at lower temperatures and/or pressures, processes requiring fewer steps, feedstocks with fewer inherent by-products, more efficient equipment design, products and/or catalysts with longer lives, more efficient unit operations, innovative process integration, avoidance of heat degradation of reaction products, new uses for otherwise valueless by-products, and elimination of leaks and fugitive emissions. The implementation of waste minimization alternatives in the chemical industry was categorized in terms of near- (0-5 years implementation), mid- (5-10 years), and long-term impacts (10+ years).

KEY WORDS

Chemical industry, waste minimization, waste reduction, research agenda

INTRODUCTION

Each year, U.S. industry generates about 12 billion tons of industrial waste and uses about 30 quads of energy to produce goods. Industry seeks to improve the efficiency of its operations. Process modifications, raw material changes, and other actions needed to significantly reduce wastes are often technologically risky and require significant investment. The U.S. Department of Energy's (DOE's) primary strategy is to reduce the wastes generated or, when that is not possible or economical, to utilize wastes by conversion to energy or useful products. DOE estimates that opportunities for waste reduction represent a potential energy conversion source of at

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least 3 quads of energy annually, and that opportunities for waste utilization and conversion represent an additional 3 quads of energy supply.

To assist the U.S. Department of Energy, Argonne National Laboratory (ANL), with help from Chem Systems Incorporated [Argonne National Laboratory and Chem Systems Inc., 1990], has identified and evaluated opportunities for waste reduction in the industrial sector in collaboration with industry. ANL consulted with a number of chemical firms about the kind of research and development programs that industry would find helpful in its efforts to reduce wastes. Industries participating in this project are listed in Table 1.

The converse of waste is efficiency. Accordingly, this study examined how increased efficiency may be achieved in those segments of the chemical industry that would have a significant impact on all of industry. This involves a reduction in energy and/or feedstock requirements. In those instances where by-product formation is unavoidable, the study sought to define the opportunity for recycling and reuse so that such by-products could be utilized, enabling the overall feedstock requirements for industry to be reduced.

Waste reduction may be achieved by consideration of the following techniques, used singly or in combination with one another:

- Improvements in process selectivity and/or conversion
- The ability to operate at lower temperatures and/or pressures
- Processes requiring fewer steps
- Products and/or catalysts with longer lives
- The use of feedstocks having fewer inherent by-products
- More efficient equipment design
- Innovative unit operations
- Innovative process integration
- New uses for otherwise valueless by-products
- The avoidance of heat degradation of reaction products
- The elimination of leaks and fugitive emissions

Wastes include streams or materials that are vented to the air, discharged to the water, or sent to another location, such as a landfill, an incinerator, flare, or biological treatment facility. The two most common waste reduction techniques are to make less waste initially and to recycle waste products back to the process [Nelson, 1990]. Source reduction involves both product and process changes designed to minimize the production of waste material by-products (including energy). Sometimes, it may be possible to reduce emissions by operating waste treatment plants more efficiently. The overall goal of waste elimination/waste reduction, however, is to avoid making the wastes in the first place. Almost every part of a process can present opportunities for waste reduction. This study examined changes that affected everything from raw materials to process control.

OBJECTIVES

The objective of this study was to provide an indication of the opportunity for waste reduction and energy savings in the chemical industry. The purpose of our waste minimization program is to identify opportunities for waste minimization in the industrial sector in collaboration with industry. The ultimate objective of this effort is to identify technology development needs that, through research and development, could yield significant reductions in the generation of waste materials (and energy) in industry.

BACKGROUND

Thirty-one chemicals were selected [Jody, et al., 1990] from among 50 top chemicals produced in the United States in 1988, as identified by Chemical and Engineering News [1989]. These 31 chemicals were selected for analysis on the basis of (1) the availability of data on energy usage and (2) information identifying the predominant process used in the manufacture of the chemical. These 31 chemicals were used to select those chemicals of particular significance to the chemical industry. Once the process for production of the chemical was selected, a calculation of the minimum theoretical energy required to effect the production of the chemical was performed. The calculation was based on the net chemical reaction for production of the chemical and was not based on a detailed analysis of the various unit operations that comprise the complete process for the production of the chemical. The difference between the actual energy consumption as derived from the literature and the calculated minimum theoretical energy required for the reaction to produce the chemical was taken as an indication of the relative potential for energy conservation in the chemical industry. Note that the difference between these two values should not be interpreted as an absolute potential.

The estimation of the optimum energy (i.e., reversible work) that the thermodynamically ideal process consumes or produces was based on the overall process reaction subject to the following assumptions:

- Reactants and products are at ambient temperature and pressure.
- Reactants and products are separated into individual components.
- Processes are internally and externally reversible, including all heat transfer steps.
- Changes in kinetic and potential energy are negligible.
- Chemical energy is the minimum amount of shaft work needed to synthesize a substance or environmental state by means of processes involving heat transfer and mass transfer only with the environment.

The results of this analysis are summarized in Table 2. The first column lists the annual production in 1988 [Chemical and Engineering News, 1989]. The second column lists the minimum theoretical energy required to produce the chemical, and the third column lists actual energy consumption (indicated by a negative sign) or energy recovered (indicated by a positive sign) in the production of the chemical. The final column lists the maximum energy (i.e., the energy difference) that could be saved or recovered as a result of energy conservation in units of 10^6 Btu/ton of product.

In any commercial process, ideal conditions are unlikely to be achieved, and energy beyond that represented by the overall reaction will be required for ancillary process operations, such as pumps, compressors, fans, as well as for unit operations preceding and/or following that represented by the overall net reaction. Furthermore, chemical reactions always involve irreversibilities, as do heat-transfer operations. Therefore, true reversible processes are not attainable. Further, practical and economic considerations dictate that significant deviations from the reversible case be implemented.

RESULTS AND DISCUSSION

The chemical industry consumes more energy for heat and power than any other industry. In addition, the chemical industry uses natural gas and petroleum as feed stocks, transforming them into familiar products. Any reduction in wasted materials reduces the consumption of our scarce hydrocarbon reserves and benefits the environment. Figure 1 presents a schematic diagram of the flow and transformation of material in the chemical industry.

Discussions with the industries listed in Table 1 yielded the candidate topics for waste reduction in the chemical industry, which were identified as having near-, mid-, and long-term impact. These topics are summarized in Table 3. Several of these topics are described in more detail as examples for their potential to impact the chemical industry.

Lower-Temperature Processing: Lower-pressure (and therefore lower temperature) operation of distillations and other conventional separations can reduce losses from polymerization and degradation of monomers, biological products, and other heat-sensitive materials, with less inhibitors. Lower-temperature coolants on process overheads can help reduce losses of volatiles to vent systems discharging to flares. Replacing cooling water with chilled water can reduce by-products related to reactions on surfaces in jacket- or coil-cooled reactors. Cool storage can provide the capacity to condense and recycle upset releases of volatiles that might otherwise be sent to flares. Such releases often overwhelm vent refrigeration systems without cool storage that are typically sized for normal vent flows.

In-Plant Conversion of Waste Streams to Clean Fuels or Feeds: Many organic chemical processes produce tars that are separated and sent to hazardous waste disposal or to in-plant incinerators. Some of these streams contain significant inorganic contents. Pressurized gasification can achieve complete conversion at a higher temperature than incineration with oxygen, and the syngas is cleaned in a pressurized process to obtain a clean fuel or chemical feedstock gas. No permits are required for their convertors per se, but only for their ultimate combustor, if the gas is used for fuel. Extensive pilot testing of waste gasification and leachability testing of the inorganic slag residues would be required before gasification of any particular type of residue could be commercialized.

Avoidance of Extraneous Water Streams Introduced to Chemical Processes: In many chemical and refinery processes, steam jet evacuators or ejectors are used to create process vacuum conditions. Direct steam stripping also is used to make separations of organics in many processes. These operations result in contaminated waste streams that are typically treated in bioponds or concentrated and then incinerated. It may be better to reduce losses by eliminating this water, which is used solely to perform a physical function (such as to create a vacuum, improve separation coefficients in distillation, etc.). A mechanical vacuum system offers an alternative to steam jets, which do not create volumes of contaminated water as a by-product. Heat pumps can be used to recycle the contaminated condensates from the overheads of steam strippers.

Selective Separation by Membranes: Membranes offer an attractive alternative to distillation as a means of separating products at much lower energy costs and superior means of product recovery. Current polymeric membranes suffer from attack by solvents and are limited by temperature to a narrow operating range. The membranes are subject to clogging and cannot be readily cleaned. Ceramic and metallic membranes offer an attractive alternative because they avoid these problems. There are virtually no developed applications for the severe temperature and corrosive conditions encountered in the petrochemical industry.

Novel Selective Energy Sources: Most processes proceed by application of substantial amounts of heat, a nonselective energy source. The use of ultrasound techniques enables the reactions to proceed at lower temperatures. Laser systems enable reactions to proceed at lower temperatures because selection of the proper frequency enables activation of the specific chemical bond of interest. Magnetic fields and the use of microwaves have found applicability in biochemical systems. Selective reactions with less energy consumption are possible by using alternative energy sources that enhance both the selectivity and conversion at ambient temperatures.

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Table 1. Industries Participating In Project

- Air Products & Chemicals, Inc.
- Amoco Chemical Co.
- Arco Chemical Co
- Catalytica
- Chevron Chemical Co.
- Eastman Chemical Co.
- Electric Power Research Institute
- Exxon Chemical Co.
- Monsanto Co.
- Shell Development Co.
- Union Carbide Corp.

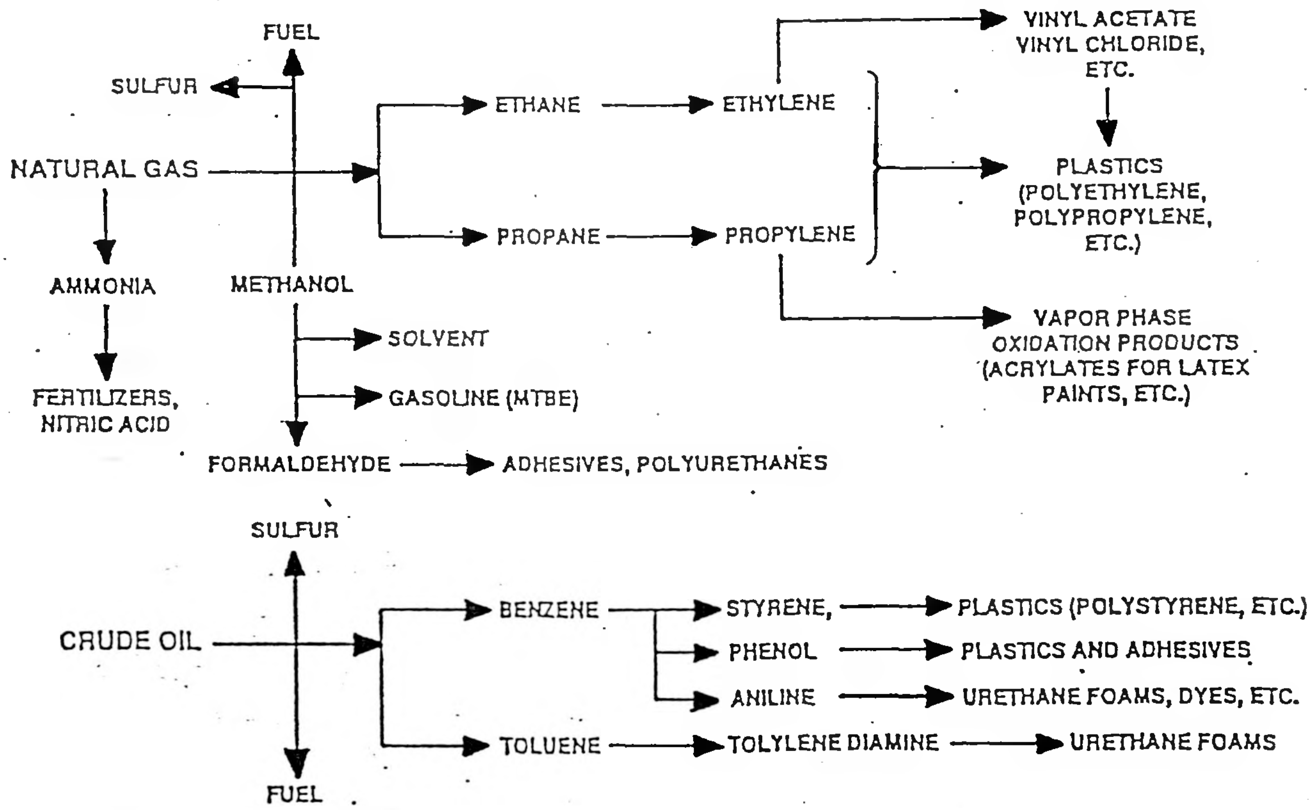

Figure 1. Principal Flows and Transformations of Material in the Petrochemical Industry

Table 2. Maximum Theoretical Energy Difference Potential in the Manufacture of Leading Chemicals.

Chemical	Annual Production (10^6 tons)	Reversible Energy	Actual Energy Consumption (10^6 btu/ton)	Max.Energy Difference
Sulfuric Acid	42.78	3.97	1.97	2.00
Nitrogen & Oxygen	44.60	-0.65	-3.89	3.24
Ammonia	16.95	-1.52	-10.61	9.09
Lime	16.17	-1.12	-7.00	5.88
Chlorine & Sodium Hydroxide	23.32	-2.95	-21.10	18.15
Sodium Carbonate	9.55	-0.85	-1.51	0.66
Nitric Acid	7.89	9.70	0.04	9.66
Ethylene	18.28	-2.88	-18.21	15.34
Propylene	9.99	-2.09	-5.24	3.15
Vinyl Chloride	4.53	-1.74	-8.28	6.55
Ethylene Glycol	2.45	-0.23	-6.12	5.90
Ethylene Oxide	2.69	1.59	1.08	0.51
Styrene	4.30	-0.69	-10.25	9.56
Methanol	3.67	-3.26	-4.89	1.63
Ethylbenzene	4.97	0.50	-0.72	1.23
Benzene/ Toluene/Xylene	14.92	-7.86	-10.59	2.73
Butadiene	1.60	-2.65	-10.65	8.00
Formaldehyde	3.37	4.72	-0.63	5.35
Calcium Chloride*	0.66	0.00	0.00	0.00
Hydrochloric Acid*	2.94	0.00	0.00	0.00
Carbon Dioxide*	4.69	0.00	0.00	0.00
Acetic Acid	1.58	3.74	-0.97	4.71
Cyclohexane	1.16	1.00	-1.58	2.58
Phenol & Acetone	2.91	4.83	0.00	4.83
Cumene	2.40	0.45	-0.28	0.73
Ethylene Dichloride	6.83	2.01	1.47	0.53
Phosphoric Acid*	11.72	-6.64	-11.29	4.65
Urea	7.88	-3.29	-4.56	1.27
Ammonium Nitrate*	7.19	0.93	0.00	0.93
Isopropyl Alcohol	0.71	-1.40	-27.90	26.50

*Material produced mainly as a by-product; its energy consumption is not estimated.

Table 3. Implementation of Various Waste Minimization Alternatives in the Chemical Industry

NEAR-TERM IMPACT (0-5 years)

Low-temperature processing
Control system surroundings
Recovery of process material from waste streams
In-plant conversion of waste streams to clean fuels/feed
Avoidance of extraneous water streams being introduced to chemical processes
Selective separation by membranes
Nylon-6 manufacture
Polyethylene terephthalate
Sulfur utilization

MID-TERM IMPACT (5-10 years)

Steam pyrolysis of hydrocarbons
Vapor phase oxidation
Novel energy sources
Dehydrogenation
Formaldehyde
Carbon Dioxide

LONG-TERM IMPACT (10+ years)

Amination
Ammonia
Methanol
Recyclable polymer systems