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Planning and Standards
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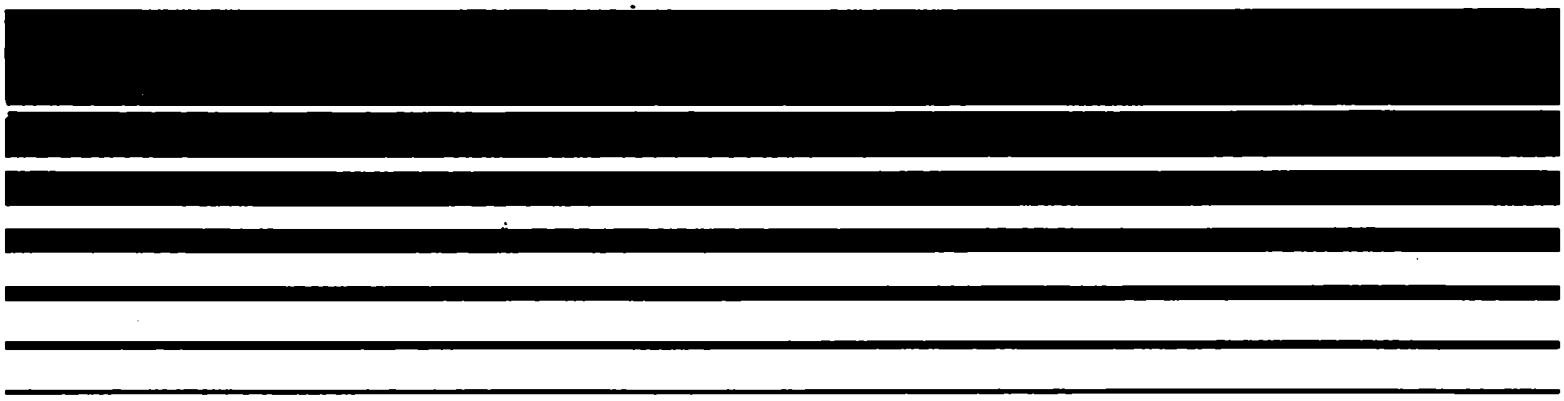
# Organic Chemical Manufacturing Volume 1: Program Report



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# Organic Chemical Manufacturing
# Volume 1: Program Report

Emissison Standards and Engineering Division

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Air, Noise, and Radiation
Office of Air Quality Planning and Standards
Research Triangle Park, North Carolina 27711

December 1980

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PROGRAM REPORT

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# PREFACE

Concern over widespread violation of the national ambient air quality standard for ozone (formerly photochemical oxidants) and over the presence of a number of toxic and potentially toxic chemicals in the atmosphere led the Environmental Protection Agency to initiate standards development programs for the control of volatile organic compound (VOC) emissions. The Synthetic Organic Chemicals Manufacturing Industry (SOCMI) standards development program was initiated in 1976. Its purpose was to gather technical and cost data on the control of air pollution in organic chemical manufacture and then to prepare (1) New Source Performance Standards (NSPS) for total volatile organic compound (VOC) emissions, (2) Control Technique Guidelines (CTG) for VOC emissions, and (3) National Emission Standards for Hazardous Air Pollutants (NESHAP) for specific volatile organic chemical emissions. This program is part of the ongoing technical activities of the Emissions Standards and Engineering Division, Office of Air Quality Planning and Standards, EPA.

IT Enviroscience (ITE) contracted with the EPA to perform the task of gathering, assembling, and analyzing data and to evaluate the VOC emission control options available to SOCMI, assess their practicality, and develop preliminary design and cost-effectiveness conclusions for the most appropriate control options. Four years of work were needed to accomplish the program objectives. The efforts of many ITE and ESED engineers were required. The program organization chart is shown in Appendix A.

The project was initiated by David R. Patrick, who continued to lead the program as the EPA project officer for the first two and one-half years of the ITE contract. Jack R. Farmer served as project officer from September 1979 to January 1980, when the present EPA project officer, Robert E. Rosensteel, was given responsibility for the program. Ralph E. White served as full-time project manager for ITE.

During the first year of the ITE contract, ITE and ESED engineers worked together as teams for process site visits and data gathering. During this period Paul Clifford and Alan Goldfarb of Mitre Corporation contributed constructively as third-party advisors. Victor Kalcevic (ITE) and Leslie Evans (ESED) served as lead engineers throughout the program. Leslie Evans and David Beck (ESED) have made major contributions to data evaluation and report organization. The ITE task leaders are shown on the organization chart in Appendix A and are listed as report authors for the 54 reports comprising this 10-volume report, which is the final product of the complex four-year program.

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# I. INTRODUCTION

The Synthetic Organic Chemicals Manufacturing Industry (SOCMI) program was initiated to gather the data necessary to develop New Source Performance Standards (NSPS) and Control Techniques Guidelines (CTG) for volatile organic compound emissions from organic chemical manufacturing. The data would also support development of National Emission Standards for Hazardous Air Pollutants (NESHAP) for benzene and other organic hazardous pollutants to be listed in the future.

The total SOCMI program is complex because the industry is large and complex. First, there are at least 400 or 500 major, commercially significant, organic chemicals being manufactured by 600 to 700 processes. Second, the industry is technologically advanced, growing, and highly competitive; thus new chemicals and processes are being constantly introduced. Finally, a significant portion of the emissions from this industry are from fugitive leaks, storage and handling losses, and secondary sources rather than from process vents.

For these same reasons it was also decided to pursue a new approach to regulation. Consequently, the program was designed to result in generic standards for manufacture of organic chemicals. In other words, instead of writing standards for each of 600 to 700 different processes, the EPA intends to write a relatively limited number of standards for the unit operations (physical processes) and unit processes (chemical processes) in use in the SOCMI. Thus standards would regulate the emissions without regard to the chemical. Aside from providing the best hope of quickly and efficiently regulating a highly complex and constantly changing industry, this approach also provides the added benefit of controlling toxic chemicals now and potentially toxic organic chemicals before they are specifically found to be toxic.

## A. BACKGROUND

The SOCMI program was initiated in March 1976 with the formation of an EPA Hydrocarbon Task Force. Their charge was to conceive of and initiate a program that would lead to regulation of air emissions from the organic chemicals industry. It was generally understood that a process and equipment standard approach would be needed, although plans for implementation had not been formulated. Obviously, the first goal was to develop a well-structured, logical program within reasonable resource and time requirements.

Several activities preceded initiation of the program. Energy and Environmental Analysis, Inc., and GCA/Technology Division were asked to outline work plans for generating the information required to implement an air-pollution control program for manufacture of organic chemicals. Concurrently, Monsanto Research Corporation was asked to identify critical organic chemical processes and operations with respect to their pollution potential. Their reports are on file at EPAs Emission Standards and Engineering Division. The results of these studies and internal CMS planning then led to a request of the Mitre Corporation to develop a Request for Proposals (RFP) for a program, to be competitively bid (Mitre is not eligible to bid competitively against profit-making concerns), for gathering the information necessary to develop regulations for organic chemical manufacture. After extensive collaboration, Mitre provided a draft RFP. This draft was further refined by EPA and then submitted to EPA Contracts for bid and award.

During the period preceding award of the ITE contract several other projects were undertaken. First, Mitre was asked to identify and rank potential organic air toxicants. This resulted in the 5-volume report Preliminary Scoring of Selected Organic Air Pollutants, EPA 450/3-77-008. In that report 643 organics were identified that are produced in quantities of about 1 MM (million) lb/yr or more. Pertinent physical, chemical, toxicological, and production data were summarized and the chemicals rank-ordered on the basis of emission potential toxicity.

ORD/IERL, Cincinnati, also completed at that time a study by Radian entitled Organic Chemical Producers Data Base, which was useful in establishing the flow of basic organic chemicals and in initially pinpointing important chemicals, manufacturers, and locations. Other ORD and ESED work available or in progress at that time was also useful.

As a supplement to locating the preliminary chemical industry data, Mitre was asked to identify and survey all pertinent organic chemical information sources, to evaluate those sources, and to provide an annotated bibliography on organic emissions from the SOCMI. This resulted in Mitre report MTR-7377.

A decision document and a public participation plan were prepared. Final program approval by the EPA Administrator was received on September 29, 1976 (copy in CMS files). Following a Federal Register notice on October 22, 1976, announcing the program, additional notification was given to approximately 100 major chemical companies, state and local agencies, public interest groups, and interested federal agencies.

The program planning phase officially ended with the contract award to IT Enviroscience in March 1977.

B. INDUSTRY DESCRIPTION

Organic chemicals are manufactured in an industrial chain that begins with about ten feedstock materials produced principally in petroleum refineries. These feedstocks then proceed through one or more processing tiers that result in literally thousands of final products. Generally speaking, each tier contains more chemicals than the preceding tier, the plants manufacturing the products are smaller than the plants supplying the feedstock, and the volatilities of the product are lower than those of the feedstocks. For these reasons in its early stages the SOCMI program was narrowed to the basic and intermediate organic chemical manufacturing industry, which encompasses about 350 to 400 of the higher volume, higher volatility products. These chemicals are also predominately manufactured in large-scale, continuous processes.

For various reasons about 65% of the SOCMI volume is produced in Texas and Louisiana, although other plants are located in most industrialized areas of the country. Each plant site may manufacture from one to several organic chemicals, using one or more processes. Most processes result in one basic product, although some produce a family of chemicals. Conversely, many chemicals are produced by more than one process. Yearly production quantities at each plant can range from a few million to several billion pounds.

Each SOCMI chemical is generally manufactured by a small number of companies (this averages less than 10, with a range of 1 to more than 20). The SOCMI chemicals are also generally manufactured at a small number of separate plant

sites (this, too, averages less than 10, but ranges from 1 to more than 50). Many companies operate more than one plant to manufacture the same chemical.

When these variations are combined with differences in plant age, location, and operation, it is not surprising that few chemical plants are alike. This is true even within a single company manufacturing the same chemical at different sites. An added complication is that many chemical companies license processes from other chemical companies or third parties, often foreign.

Finally, the SOCMI is a highly competitive industry whose economic lifeblood is technology and that is characterized by rapid growth and technological change. Thus the introduction of new and more economical processes is common, as is the termination of older processes that are no longer economical. Under these conditions it is understandable that the industry is highly protective of its technology.

The above description of the SOCMI clearly shows why regulation of VOC emissions from this industry in the normal way, i.e., by individual chemical process, would have been very difficult. That approach would have necessitated literally hundreds of individual standards. Furthermore, each standard would affect only a limited number of plants and would have to be changed frequently as the industry changed. This would be neither cost effective nor practically achievable. Obviously, a more generalized approach to regulating VOC emissions from the SOCMI was necessary.

C. VOC EMISSIONS FROM THE SOCMI

Preliminary analysis showed that, although the SOCMI is complex and diverse, VOC emissions occur from four main types of sources: vents on storage and transportation vessels (storage and handling emissions), leaks and spills of VOC (fugitive emissions), evaporation of VOC from solid, liquid, and aqueous wastes (secondary emissions), and process vents. Each source is briefly described below.

Emissions from storage vents occur predominately as working and breathing losses from fixed- and floating-roof tanks, and those from transportation vessels result from filling and breathing. Fugitive emissions are principally

leaks from defective or inadequate seals in such equipment as pumps, valves, and compressors. They also include losses from open-ended valves, sampling purge material, and cooling towers. Secondary emissions, so-called because they frequently occur away from the process site at a wastewater treatment plant or landfill, result from waste disposal and include evaporation of VOC from solid, liquid, and aqueous wastes generated within the process. Emissions of VOC from process vents occur predominately as the result of venting of inert gases or from the release of volatiles that cannot be economically captured. Upset releases also fall in this category.

Total SOCMI VOC emissions are projected to be about 1.4 billion lb/yr by 1982. This estimate is adjusted on the basis of a 5.9% industry growth rate per year. Of this amount 9% are attributed to storage losses, 32% to fugitive emissions, 4% to secondary emissions, and 55% to process vent emissions. These estimates are based on Texas and Louisiana emission inventory data supplemented with detailed information obtained through a large number of plant visits and industry inquiries. Uncontrolled plant emissions range from a few thousand to many millions of pounds per year. The total VOC emission estimate is less than half of that presented in the earlier report, Control Techniques for Volatile Organic Emissions from Stationary Sources, EPA-450/2-78-022 (May 1978) and likely reflects recent pollution control efforts by the industry and inaccuracies in the earlier estimates.

## D. TECHNICAL PROGRAM

Development of a broad approach to regulate VOC emissions from the SOCMI was initiated in 1976 based on the suggestions of B. J. Steigerwald, EPA. The initial goal was to develop an expeditious method for preparation of NSPS, for the organic chemical industry, that would broadly control both oxidant precursors and potentially toxic organics. A number of possible approaches were identified and assessed. Some of the important problems that were recognized were (1) how to factor toxicity and reactivity into regulations, (2) the lack of authority at that time for EPA promulgating equipment standards, and (3) the uncertainty of methodology for economic analysis.

After three short studies were initiated with contractors to assess some of the problems. GCA/Technology Division and EEA, Inc., recommended longer range EPA

activities aimed at efficient regulation of the SOCMI. Monsanto Research Company evaluated the possible use of unit operations and unit processes in SOCMI regulation. After these studies were completed and reviewed, an RFP was issued in July 1976, and a contract was awarded to Hydroscience, Inc. (a wholly owned subsidiary of the Dow Chemical Company) in March 1977. In April 1980 the Knoxville, Tennessee, operations of Hydroscience, Inc., underwent a name and ownership change. The Hydroscience Tennessee operation became IT Enviroscience (ITE), a wholly owned subsidiary of IT Corporation, a California-based environmental management company whose major interests are in hazardous waste treatment, recycle, and disposal. The contract performance continued uninterruptedly under the new entity.

Although structured to generate data and report on unit processes and unit operations, the SOCMI contract laid out only the broad concept of the regulations. ITE was required only to develop relevant technical and cost data, in a form to be agreed upon with the EPA; then the EPA would prepare standards. Actual standards preparation was not planned as part of this contract because the successful bidder was required to have detailed chemical industry experience. Standards development by such a contractor would likely involve conflicts of interest.

After award of the contract EPA and ITE developed a detailed work plan that was believed to be capable of providing the necessary documentation for the desired generic standards. That work plan identified storage and handling, fugitive leaks, and waste disposal as separate emission sources and as sources that could more quickly lead to a generic regulatory package than could the unit processes/unit operations. The work plan also called for the preparation of detailed technical reports on the manufacture of the 350 or 400 SOCMI chemicals. These reports would be prepared by a small number of very detailed early studies being conducted first and then the level of details progressively reduced and extrapolated to a larger number of later studies. Each chemical report would thus require less effort than the one preceding it.

The first work plan was predicated on several assumptions: (1) It was believed that the SOCMI was easily separable into 350 or 400 chemicals and that there

were significant emissions from most of these. (2) It was assumed that data existed in public and/or open industry files on a majority of the emission sources. (3) It was assumed that there were sufficient similarities between the many chemical manufacturing processes to allow extrapolation across chemical and process lines. (4) It was assumed that some well-controlled examples existed for a majority of emission sources as the result of state or local regulation. These assumptions had to be changed as discussed in the next section.

At the beginning of this program the problem of developing the proper data base for standards and guidelines to cover the manufacture of literally thousands of organic chemicals in hundreds of different processes seemed almost insurmountable. However, after careful analysis of the industry and its sources and an extensive review of basic chemical engineering literature, a solution began to emerge. First, it was found that the bulk of emissions come from the manufacture of a limited number of chemicals. Next, it was found that, although the manufacture of organic chemicals is complex and diverse, VOC emissions occur in only four ways: (1) emissions from storage tanks and transportation vessels, (2) fugitive leaks and spills, (3) losses of VOC from liquid, aqueous, and solid wastes, and (4) emissions from process vents. The solution to the standards problem, then, was to develop a data-base program suitable for standards and guidelines specific to the four sources. These were designated generic because they represented a limited number of standards capable of encompassing a large number of different emission sources independent of the specific chemical and process.

## E. SUMMARY

This 10-volume report is the final product of the ITE contract for assessment of SOCMI VOC emissions and evaluation of emission control options. This program report constitutes Volume I. Following is a brief description of the contents of the remaining volumes of this final report:

1. Volume II: Analysis of Emissions from Carrier Gas Producing Reactions, Air Oxidation Process Emissions, Vacuum System Emissions, and Upset Releases

This volume contains a detailed discussion of the carrier-gas generic standard

approach and explains its use for projecting VOC emissions. Through four separate reports the generic approach is used to demonstrate the projection of VOC emissions from chemical reactions in general, air-oxidation processes specifically, vacuum operations, and potential emissions from upset releases. The VOC emissions discussed in these four reports cover essentially all VOC process emissions from SOCMI. Each report also discusses the control options applicable for the VOC emissions projected.

2. Volume III: Analysis of Fugitive Emission Sources, Storage and Handling, and Secondary Emission Sources

   This volume contains three reports covering the VOC emission estimates from nonprocess sources. The available control options are discussed, and a cost analysis is presented for each appropriate control device. The EPA plans to develop generic NSPS for the control of VOC emissions covered by Volumes II and III.

3. Volume IV: Control Device Evaluations of Thermal Oxidation, Catalytic Oxidation, and Flares

   Volume V: Control Device Evaluations of Carbon Adsorption, Absorption, and Condensation

   The combustion control devices covered by Volume IV plus the three control device reports of Volume V cover all of the significant add-on VOC emission control devices used by SOCMI. The reports include descriptions of the control devices, their capabilities and limitations in controlling VOC emissions, control efficiencies, cost of control, and environmental impact considerations. This work is intended to be the most comprehensive and up-to-date assessment of VOC emission controls developed by the Office of Air Quality Planning and Standards (OAQPS). These volumes should be valuable not only for selecting and evaluating control options for emission sources within SOCMI but also for other VOC emission sources.

4. Volumes VI—X: Chemical Process Reports

   The last five volumes of the report are a consolidation of 39 ITE product reports. Each product report is an in-depth technical analysis presenting information on the plants producing a particular chemical product or products,

typical production routes, associated VOC emissions, feasible emission controls, control costs (from a new-plant perspective), and other impacts from application of the controls. These studies substantially constitute the data base for the generic source analyses of Volumes II and III.

All of the data presented in the 39 product reports of Volumes VI-X and the non-process emission reports of Volume III are given in the metric system. This is in keeping with the EPA overall plan to convert to the metric system. By the time these reports were completed, it became apparent that the effort required for this conversion was much more time consuming and costly than had been anticipated. Industry had also expressed strong opposition to the conversion. Furthermore, the concepts covered by the control device evaluations and generic process emission studies are quite complex and comprehension of these concepts would be considerably more difficult if presented in the metric system. Therefore, all of the data in the remaining reports were retained in conventional English units.

5. Product Report Grouping

The chemicals covered in each product report volume are listed in each table of contents. Basically the chemicals are grouped according to the type of feedstock used in their production. The chemicals in Volume VI and VII are produced from cyclic chemical feedstock (mainly benzene and cyclohexane). The chemicals in Volume IX are produced from $C_1$ and $C_2$ feedstocks, and those in Volume X are produced from $C_3$ and $C_4$ feedstocks. Volume VIII was formed from the decision to include all the major halogenated chemical products in one volume.

# II. HISTORY OF THE PROGRAM

## A. PROGRAM EVOLUTION

As the study progressed through its first two years the original perception of the SOCMI study underwent drastic changes as the result of data that were gathered from over 75 plant visits, several hundred detailed inquiries of SOCMI companies, and detailed surveys of the Texas and Louisiana air pollution files. Some of the conclusions that were reached, particularly as they relate to the assumptions existing at the time that the program was initiated, are as follows:

First, perhaps as many as two-thirds of the 350 or 400 chemical processes appear to result in negligible nationwide emissions, with the exception of storage and fugitive emissions, with the bulk of industry emissions appearing to be concentrated in the highest volume processes. Figure II-1 shows the cumulative percent of SOCMI estimated emissions for the top 140 ranked products. (The top 140 ranked products are shown in Appendix B.) The 140 ranked products result in almost 90% of the total estimated SOCMI emissions. It can be concluded from this that detailed work on 140 chemicals would be much more cost effective than work on 350 or 400 chemicals.

Second, it became apparent that information on emissions was scarce, particularly for smaller sources. Even the manufacturers themselves do not have data in many emission areas. Furthermore, the emission inventory information in state files was often estimated, as well as frequently confidential and therefore not easily accessible. Also, technical literature was general and was rarely directed toward air emissions. These facts further argued against preparation of 350 or 400 documents and argued for the broader generic approach.

Next, although unit operations and unit processes appeared to be sufficiently similar across chemical processes to allow generic process emission standards to be developed at completion of the program, each complete chemical process was so different that extrapolation across processes for efficiency in report preparation appeared to be virtually impossible. This raised further questions concerning the feasibility of preparing 350 to 400 specific chemical reports.

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Number of Products Versus Percent of Total 1982 Emissions Addressed

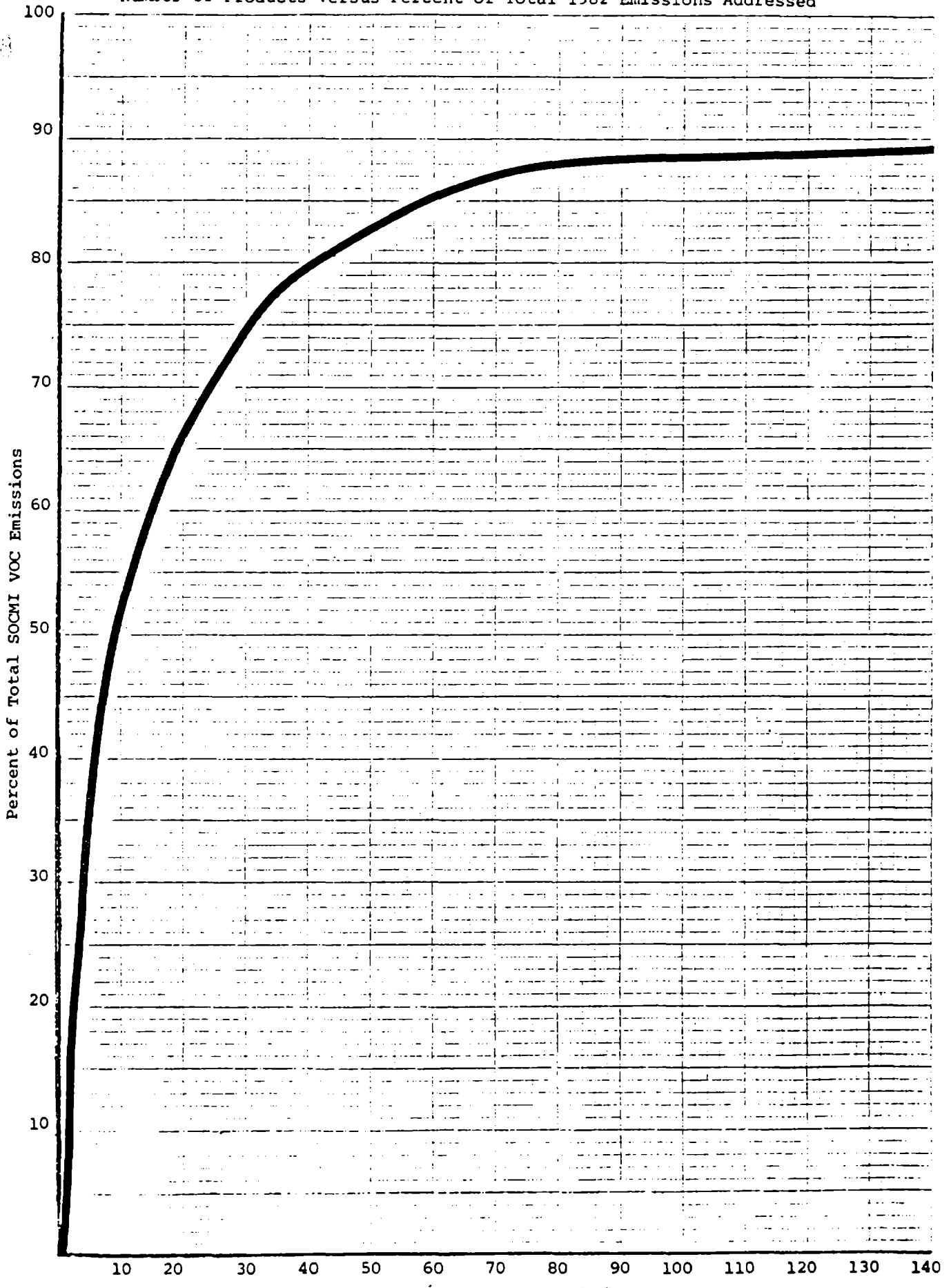


Fig. II-1 Number of Products Ranked

Finally, although there are many well-controlled plants, many are still significant emitters. State regulations have been responsible for some control, but only a few states have vigorously pursued regulation of the SOCMI. A factor very important to emission reduction has been the controls applied for other than air pollution reasons, for example, odor, flammability, and high chemical costs.

As a result of these findings the program plan was revised to focus on fewer individual chemicals and processes. The revised approach required focus by ITE on the top 140 chemicals and preparation of detailed technical reports for only the more significant ones. Storage, fugitive, and secondary emissions remained as major subject categories, and unit process/unit operation data continued to be gathered for generic process emission standards. Analysis continued to indicate that the ability to develop the necessary industry-wide regulations would not be adversely affected. In other words, the data necessary to support the desired generic standards still appeared to be available, even though fewer individual processes were to be studied.

The only major program casualty was the loss of a large number of individual chemical process CTGs. It had been originally planned that up to 350 or 400 chemical process CTGs would be written as described above. This number had to be dramatically reduced. However, this loss does not appear to be serious, for the following reasons. CTGs are most effective when they apply to a large number of separate sources in several states, when the sources are in nonattainment areas, and when little control is currently present. Since the majority of the emission sources are located in Texas and Louisiana, a large number of CTGs could prove burdensome to those state agencies. Furthermore, many sources are in attainment areas, which would reduce the effectiveness of the CTGs. Finally, many sources are already controlled, and so the CTG benefit would be further reduced. All these facts indicate that the incremental benefits of a large number of CTGs would be marginal at best.

The more reasonable approach appeared to be to prepare individual chemical process CTGs on only the larger, more widely dispersed, and less well-controlled processes and to supplement them with the planned CTGs for storage, fugitive, waste disposal, and unit processes/unit operations, along with technical

reports on other chemicals for information. Not only would this approach be most likely to best interface with the NSPS program, but it would also probably help state and local agencies to best utilize their resources in meeting their needs to attain the oxidant standard as expeditiously as possible and to control problem chemical processes.

B. SURVEY AND RANKING

At the program inception it was apparent that an important factor in the success of the overall program was going to be the ranking of processes in order of importance. It was considered necessary for the generic concept that unit operations and unit processes be evaluated in proportion to their importance. If the generic concept turned out not to work, it would be important to have studied the most important emission sources for regulation. It was also considered important that the processes with the more toxic emissions take some measure of precedence over those with less toxic emissions. Therefore an extensive survey and ranking operation was established. The goal of this operation was to compile all pertinent data related to VOC emissions, growth, process design, and toxicity. Preliminary survey and ranking studies had previously been performed by Radian and Mitre, but those studies had incorporated simplifying assumptions that were not adequate for the depth and degree of effort expended by this program. By using the Radian and Mitre studies as starting points and incorporating Monsanto Research Corporation studies, Houdry studies, and data from the Texas and Louisiana Air Control Agencies (covering 65% of SOCMI), the resulting survey and ranking tables of Appendix B were believed to be the most up-to-date, complete, and accurate VOC emission projections from SOCMI available. However, several changes have occurred during the programs that necessitated major adjustments.

Prior to this program previous studies had indicated that, in general, storage and handling emissions constituted approximately 8% of SOCMI VOC emissions, fugitive emissions ~20%, and secondary emissions up to 5%. As the result of more recent studies the estimate for storage and handling emissions is now 9%, fugitive emissions 32%, and secondary emissions up to 4%. These estimates are discussed in detail in their respective reports in Volume III. The initial estimates were with reference to a total 1982 SOCMI VOC emission projection of approximately 1779 MM lb. The current estimate is based on a revised total

1982 VOC emission projection of 1434 MM lb. As a result of the detailed studies covered by the 39 product reports presented in Volumes VI—X, there is every indication that the VOC emissions from the SOCMI have been dramatically reduced.

Table II-1 is a comparison of the initial emission estimates and current estimates for nearly all the individual processes studied and reported in Volumes VI—X. Since the initial estimates were made, the fugitive-emission factors have essentially doubled, the storage-emission factors have decreased, and the secondary emission estimate has remained unchanged. The updated factors have been applied to all components of the current estimate. As with any such table, inconsistencies persist. With both estimates care was taken to include all emissions but avoid double counting. During preparation of the initial program estimates it was often necessary to prorate combined emission data from several different processes. In some cases this proration was very inaccurate and may distort the comparison of emissions for specific products, but does not diminish the accuracy for larger groups of products.

The results clearly indicate that the VOC emissions from the processes studied are only half the emissions estimated at program initiation. Since both emission estimates were created from data reported by industry, it appears that the SOCMI has accomplished a dramatic reduction of VOC emissions. Indications are that, if studies are continued for all products listed in Appendix B, a similar reduction of VOC process emissions would be observed.

## C. DATA GATHERING

At the program inception it was reasoned that the air quality control agencies for many states would be visited, requiring a large number of trips to be made to several states. It was soon determined that approximately 65% of SOCMI was concentrated in Louisiana and Texas, especially the first- and second-tier chemicals of major interest for this program. Therefore early efforts were concentrated on obtaining industry emission data from the Louisiana and Texas Air Control Agencies. Both agencies extended excellent cooperation, and after careful attention to prevent the release of confidential information approximately 7000 pages of emissions data were copied that contributed greatly to the survey and ranking information included in this report.

Table II-1. VOC Emission Estimates for 1982

| Product | Production (MM lb) | Growth (%) | VOC Emissions (MM lb) | |
|---|---|---|---|---|
| | | | Current Estimate | Initial Estimate |
| Acrylonitrile | 2,440 | 8 | 145.50 | 254.00 |
| DMT/TPA | 8,243 | 8 | 99.38 | 141.41 |
| Ethylene dichloride | 14,005 | 5 | 90.92 | 116.48 |
| Ethylene | 33,138 | 4.5 | 73.31 | 81.97 |
| Propylene oxide | 2,420 | 5 | 29.54[a] | 49.98 |
| Formaldehyde | 7,539 | 4.5 | 27.42 | 40.91 |
| Cyclohexanol/cyclohexanone | 2,448 | 1.5 | 26.52 | 43.35 |
| Acetic acid | 3,315 | 5 | 23.4[a] | 26.80 |
| Acrylic acid | 788 | 8 | 22.48 | 25.38 |
| Ethylene oxide | 6,105 | 5 | 21.39 | 137.87 |
| Maleic anhydride | 451 | 8 | 16.46 | 36.18 |
| Butadiene | 3,956 | 3 | 15.83[a] | 12.50 |
| Ethylbenzene/styrene | 6,831 | 6 | 15.75 | 57.84 |
| Ethylene glycols | 5,447 | 4 | 15.59 | 15.24 |
| Fluorocarbons | 1,009 | 5.5 | 11.44[a] | 5.00 |
| Phenol/acetone | 3,287 | 4.5 | 9.68 | 32.23 |
| Methanol | 9,423 | 7 | 8.31 | 38.49 |
| Cyclohexane | 2,779 | 5 | 4.40 | 1.80 |
| Chloromethane/MeOH | 1,929 | 8 | 4.17 | 2.85 |
| Perchloroethylene | 834 | 0 | 3.9[a] | 4.40 |
| Acetic anhydride | 1,555 | 1 | 3.18[a] | 18.45 |
| Alkylbenzene | 607 | 2 | 3.17 | 0.08 |
| Caprolactam | 1,071 | 5.5 | 2.86[a] | 4.88 |
| Toluene diisocyanate | 684 | 3.5 | 2.81[a] | 6.52 |
| Chlorobenzene | 405 | 0 | 2.70 | 2.25 |
| Chloromethane/methane | 440 | 0 | 2.37 | 11.19 |
| Nitrobenzene | 752 | 7 | 1.67 | 3.70 |
| Vinyl acetate | 2,055 | 6 | 1.37[a] | 19.73 |
| Carbon tetrachloride | 519 | (-10.0) | 1.21 | 9.54 |
| Cumene | 3,282 | 4.4 | 0.98 | 3.99 |
| Epichlorohydrin | 378 | 5.5 | 0.68[a] | 1.88 |

Table II-1. (Continued)

| Product | Production (MM lbs) | Growth (%) | VOC Emissions (MM lb) Current Estimate | VOC Emissions (MM lb) Initial Estimate |
|---|---|---|---|---|
| Glycerin | 125 | 0 | 0.59[a] | 21.48 |
| 1,1,1-Trichloroethane | 710 | 6 | 0.48 | 14.89 |
| Chloroprene | 396 | 3 | 0.41[a] | 13.69 |
| Acrolein | 50 | 2 | 0.24[a] | 6.13 |
| Adipic acid | 2,020 | 4.5 | 0.18 | 0.41 |
| Aniline | 833 | 8 | 0.16[a] | 2.66 |
| Glycol ethers | 833 | 5 | 0.14[a] | 0.47 |
| Methyl ethyl ketone | 653 | 5 | 0.11[a] | 0.43 |
| Ethyl acetate | 183 | 3 | 0.04[a] | 1.21 |
| Acetaldehyde | 988 | 3.5 | 0.01[a] | 7.27 |
| | 136,013 | | 726 | 1373.78 |
| Waste sulfuric acid recovery[b] | | | 7.26 | |
| | | | 733 | |

[a]Estimates were doubled because the study estimate for these products did not include storage, fugitive, or secondary emissions.

[b]Was not a part of the initial emissions estimate.

Technical data collection from industry was initiated through the Chemical Manufacturers Association (CMA) and the Texas Chemical Council. Three meetings were held during the first year, including a detailed presentation of the data ITE had assembled on the first ten processes. CMA technical work groups were set up to assist with data collection and to review the ITE draft reports. Draft report reviews by industry and the CMA task groups have been very helpful in improving the quality and accuracy of reports throughout the program.

To obtain the industry data required, it was necessary to have direct contact with the production managers for the products involved. This necessitated more than 60 process discussions involving more than 30 separate companies. On some occasions brief plant tours were included, and on other occasions central meetings were held with a group of production managers during which several processes were covered. In all cases the ITE engineers studied previous EPA reports concerning the process and available technical literature. The ITE engineers always prepared moderately detailed process flow sheets before making the site visit so that discussions of process emissions and factors related to VOC emissions would be as efficient and rewarding as possible. The process information prepared before site visits also established the data as being in the public domain and therefore nonconfidential.

D. CONFIDENTIALITY

After the program was initiated, an additional problem surfaced that necessitated some program redirection. Although it had been anticipated that some resistance would be encountered when data were being gathered that might be considered as proprietary, the determined resistance from some industries was found to be greater than the EPA had expected. It became apparent that the SOCMI, perhaps more than any other industry studied by the ESED, considers their process technology, know-how, and other information to be absolutely vital to their competitive positions. Therefore both ESED and ITE had to spend an inordinate amount of time (weeks) on problems dealing with trade secrets, confidentiality agreements (in excess of 50 agreements between ITE and over 30 separate companies), and in general working out mechanisms by which industry would release information needed for the program and still retain their proprietary protection.

The standard procedure employed by ITE to protect industry's confidential data was to allow the company to thoroughly review all notes. In many instances all plant visit notes were left with the companies. Any data considered confidential was so indicated or removed. Trip reports were always submitted to the company before release to ensure that they contained no confidential data. No company data were ever reproduced in a product report that did not already appear in the released nonconfidential trip report. At the conclusion of this program confidential data will not be retained by ITE but will be forwarded to ESED, returned to the company, or destroyed.

Although some of the confidential data obtained during the program were useful for verifying design concepts and emission factors, the quality of the reports has not suffered by their exclusion. The most common problem was the desire of industry to keep specific plant capacities and production rates confidential; however, industry always agreed to reveal the emission factors (lb of VOC emission/lb of product), which were the most important data required for this program. To project total emissions from a chemical process, ITE used the model-plant approach as explained in the product reports (Volumes VI—X), combined with production and capacity data from published literature.

When industry was given the opportunity to review draft product reports, they realized that none of their confidential information was revealed and the fear of releasing proprietary information to the public was abated. Once the problem of confidentiality was cleared, industry was quick to realize that it was in their best interest to aid in the development of reports that were as practical and accurate as possible, with an absence of large data gaps that would have required further effort. The cooperation by industry in general has been excellent.

# III. GENERIC REGULATIONS OF SOCMI EMISSIONS

As was discussed earlier, are only four major sources of emissions: storage vents, fugitive leaks, waste disposal, and process vents. Although the methods of control differ for these four sources, in each case the emissions result from the volatility of the organic chemicals involved, the conditions (e.g., temperature, pressure, and inert-gas flow) that affect volatility, and the potential for emission (e.g., vent release, high inert-gas flow, etc.). Thus it was assumed from the beginning of the program that all these sources could be regulated and that regulations could be independent of specific chemical or process; that is, that they could be generic in nature. A second assumption was that generic regulation of SOCMI could result in the same degree and extent of control that would be obtained by the more normal process specific regulations but with far fewer total regulations. Finally, analysis indicated that storage, fugitive, and secondary controls should be relatively straightforward but that process vent control would be much more complicated.

## A. STORAGE VENTS

Storage emissions are easily characterized and identified. In fact, equations were generally available at program inception both for predicting emissions and pinpointing factors affecting them. The major difficulty in the SOCMI program was characterization of storage in the chemical industry, since this effort spans hundred of chemicals, thousands of tanks and vessels, and a wide range of volatility. Computer assistance was applied to adequately deal with these variables. The regulatory approach, nevertheless, was straightforward. Control equipment (pressure tanks, floating-roof tanks, and add-on control devices)will be required, depending on the volatility of the stored material, the size of the tank or vessel, and analysis of the impacts of the control.

## B. FUGITIVE LEAKS

Fugitive emissions were also expected to be easily characterized and identified. Potential leak sources were well known, with predominant emissions coming from defective valve, pump, and compressor seals. The regulatory approach was again seen as straightforward, centering on better housekeeping through a directed leak detection and maintenance program. Certain equipment requirements were also envisioned, all of which were to be based on the potential for leakage,

which includes consideration of the physical state of the leaking material and the frequency of seal failure. The major difficulties would be in defining the leak potential in the SOCMI and in establishing the best approach for leak detection. Because of the occupational exposure that results from most fugitive leaks, coordination with the Occupational Safety and Health Administration (OSHA) was also expected to be necessary.

C. WASTE DISPOSAL

Secondary emissions were expected to be significant but difficult to define since little relevant literature appeared to be available. The SOCMI program was thus designed specifically to gather information relating to solid, liquid, and aqueous waste streams and the VOC content of those streams. Control of emissions at the waste disposal or treatment sites was beyond the scope of this program; however, focus on control of VOC entry into the waste streams was believed to hold great promise as a general and environmentally sound method of emission reduction. Thus standards were planned to improve plant operation and maintenance. The major difficulty expected to be encountered was lack of data, and thus quantification, on the part of industry. Coordination with pending regulations under the Resource Recovery and Conversation Act (RRCA) was expected to be necessary.

D. PROCESS VENTS

Process vents in the SOCMI create several unique problems that make regulation of air emissions difficult. Normally a regulation is developed to cover a source that is common to a sizable industry segment. In this case, however, there are literally thousands of different process vents associated with the many processes involved in the manufacture of SOCMI chemicals. Waste gases also span a wide range of chemical and physical properties. For these and other reasons, process vents required a more general approach to regulation than had been used in the past.

Chemical engineering principles suggested a way to handle this problem. First, all chemical manufacturing is made up of unit processes and unit operations. Chemical reactions, such as oxidation and chlorination, take place in unit processes. Physical changes, such as separation and drying, take place in unit operations. Although a large number of different unit processes and unit opera-

tions are known, only a small number are both widely used in the SOCMI and capable of emitting significant quantities of VOC.

Next, although there is a wide range of emissions from process vents, only a few different reasons exist for their release. These reasons include pressure relief, removal of inert gases or other undesired volatiles, and evacuation of equipment for vacuum processing. Analysis further indicated that the major causes of SOCMI emissions are release of inert gases or reaction gases and venting of VOCs when their capture is not economical.

The approach to regulation of process vents, then, was to focus on only the significant unit processes and unit operations and to develop regulations around common gas-stream properties.

Several problems were anticipated: (1) Many separate chemical processes would have to be examined in order for sufficient data to be obtained to support standards. (2) It would have to be determined whether the unit processes and unit operations were similar enough across different manufacturing processes to permit common regulations, which, in fact, might not be determined until late in the data-gathering effort. (3) A method of performing the impact analyses for process vent standards, as with the other generic standards, would have to be developed. Nevertheless, it was believed that these hurdles could be overcome. Add-on controls would likely form the basis for process vent control, although improved operation and maintenance should also find use. Size and volatility cutoffs would probably be necessary, depending on the results of the impact analyses.

# IV. PROGRAM REPORTS

This final report contains all the specific study reports developed throughout the program. It is intended to serve as the formal compilation of technical and cost data to support the standards to be developed covering process-vent emissions, storage emissions, fugitive emissions, secondary sources, and any other standards developed as a result of this program.

## A. GENERIC PROCESS-VENT STANDARDS

The generic process-vent-emission reports comprise Volume II. The approach to development of generic process-vent standards is conceptually straightforward. First, a theoretical prediction of maximum VOC concentration in the emission was developed and the major influencing variables were identified. These variables were checked against the data gathered for the 39 product reports contained in Volumes VI—X. A similar procedure was developed to project flow rate ranges, primarily based on an inert-gas flow relationship. These concepts are explained in detail in Volume II.

A range or regime of potential waste-gas concentrations and flows was established. With reference to the control device evaluations of Volumes IV—V, the control device options applicable to each flow regime are discussed. The next step planned in the subsequent program to develop standards for these process-vent emissions will be to determine cost effectiveness based on the costs presented in the control device evaluation reports and to determine the cost impacts on industry. These economic analysis steps are not part of the SOCMI program covered by this report. However, specific cost-effectiveness determinations are presented for the products reported on in Volumes VI—X.

Preliminary estimates indicated the relative emission contributions of the various unit processes and unit operations shown in Tables IV-1 and IV-2. Through analyses of this type of data, including the distribution of reaction modules, process modules, and control modules (Survey and Ranking, Appendix B), it was determined that the process-vent emissions could be essentially covered by the process-emission reports presented in Volume II. The principal emission mechanism and the most important variable is inert-carrier-gas flow. Attempts to characterize this variable have been reasonably successful, with stoichiome-

Table IV-1. Emissions Associated with Unit Processes

| Unit Process | No. of Products Produced Using Unit Process | No. of Ranked Products Containing Unit Process | Estimated Contribution to Total Unit Process Emissions (%) | Cumulative Contribution (%) |
|---|---|---|---|---|
| Oxidation | 63 | 43 | 48.3 | 48.3 |
| Halogenation | 67 | 43 | 14.5 | 62.3 |
| Hydrogenation | 26 | 13 | 10.8 | 73.1 |
| Esterification | 24 | 8 | 6.9 | 80.0 |
| Alkylation | 15 | 5 | 4.0 | 84.0 |
| Sulfonation | 11 | 6 | 3.4 | 87.4 |
| Dehydrogenation | 15 | 4 | 2.7 | 90.1 |
| Hydrolysis | 27 | 8 | 2.4 | 92.5 |
| Reforming | 1 | 1 | 2.2 | 94.7 |
| Carbonylation | 10 | 8 | 1.2 | 95.9 |
| Oxyacetylation | 1 | 2 | 1.0 | 96.9 |
| Nitration | 12 | 1 | 0.8 | 97.7 |
| Dehydration | 18 | 4 | 0.7 | 98.4 |
| Ammonolysis | 11 | 6 | 0.6 | 99.0 |
| Condensation | 51 | 4 | 0.5 | 99.5 |
| Dealkylation | 4 | 1 | 0 | 99.5* |

*Less than 100 because of rounding errors.

Table IV-2. Emissions Associated with Unit Operations

| Unit Operation | No. of Times Unit Operation Used in the SOCMI | Estimated Contribution to Total Unit Process Emissions (%) | Cumulative Contribution (%) |
|---|---|---|---|
| Absorption | 475 | 58.1 | 58.1 |
| Scrubbing/washing | 543 | 27.9 | 86.0 |
| Distillation | 3651 | 10.4 | 96.4 |
| Drying | 251 | 3.3 | 99.7 |
| Filtration | 120 | 0.1 | 99.8 |
| Extraction | 110 | 0 | 99.8 |
| Settling | 24 | 0 | 99.8 |
| Crystallization | 144 | 0 | 99.8* |
| Separation | 384 | | |
| Quenching | 146 | | |
| Evaporation | 127 | | |
| Ion exchange | 120 | | |
| Dilution | 71 | | |
| Mixing/blending | 56 | | |

*Less than 100 because of rounding errors.

try, vapor pressure, and explosive limits being the major factors influencing waste-gas VOC concentrations. The methodology of projecting waste-gas flow and VOC concentrations is described in detail in Volume II.

The conclusion from the above estimates was that a limited number of process-vent standards may very well successfully result in a high degree of coverage of the SOCMI process vents. To be significant and not economically prohibitive, VOC emissions must have either low concentration/high volume or high concentration/low volume. Furthermore, highly efficient, widely applicable control mechanisms for these two types of exit gas streams are limited in number. Therefore present analysis indicates that only very few generic standards will be necessary to deal adequately with SOCMI process vents. The principal difficulty will be in developing appropriate techniques for economic analysis.

B. NONPROCESS EMISSIONS

Volume III presents the nonprocess-emission studies for storage, fugitive, and secondary sources. Based on test results reported by the EPA the estimate of emissions from storage-tank vents has been reduced. This is because the AP-42 emission equations used to estimate storage losses have been found to overstate the breathing losses by a factor of 4.

Fugitive emissions consist primarily of leaks from equipment handling the flow of VOC, i.e., pumps, flanges, and valves. The fugitive emissions estimates reported by this study are based on equipment count estimates for the processes studied and fugitive emission factors provided by other EPA contract studies. These fugitive emission factors are much greater than the emissions factors used at the start of the program and the estimates for fugitive emissions have been increased accordingly.

Even though a serious attempt was made during site visits to obtain data for estimating emissions resulting from VOC waste disposal, very little useful information was obtained. Industry apparently had done very little to assess this situation. Based on the information obtained and with heavy reliance on theoretical calculations, the secondary VOC emissions are estimated to be approximately 90 MM lb/yr. The EPA plans to conduct a sampling program to improve this estimate and to establish a better basis for regulation.

C. CONTROL DEVICE EVALUATIONS

Volumes IV and V discuss in detail the VOC emission control devices used throughout the SOCMI. For comparison purposes Table IV-3 lists the resulting relative cost-effectiveness estimates for the ranges of VOC concentrations and flow rates for each applicable control device. Table IV-3 does not include the very-high-temperature thermal oxidation required for VOC containing halogens or sulfur, nor does it include flares since they are primarily dedicated to intermittent flows at very high flow rates.

D. PRODUCT/PROCESS REPORTS

Table IV-4 lists all the individual products and processes studied during the program. These studies are covered by the 39 reports that constitute Volumes VI—X of this final report. The primary consideration for selecting the product to be studied was the amount of VOC emissions estimated for 1982. Toxicity was also an important selection factor, as is discussed in Appendix B. For study and site visit efficiency, products and processes were studied in groups. Therefore some products were covered that appear far down the survey and ranking list of Appendix B. Even though the studies were initiated on a priority basis, the final completion dates are out of sequence. The product studies shown in Table IV-4 are listed in the essentially random order of completion.

As shown by Table IV-4, the 39 product reports have addressed 64 products manufactured by 97 processes. These reports account for approximately 80% of the SOCMI VOC emissions initially projected for 1982. Since approximately 30% of the SOCMI VOC initial emission estimate is covered by the reports for fugitive, storage and handling, and secondary emissions, this total program has addressed approximately 85% of the total SOCMI VOC emissions. Not counted are the VOC emissions addressed by the generic process-emission reports.

Table IV-3. Cost-Effectiveness Summary of Control Devices[a]

| VOC Concentration ($ppm_v$) | Flow Rate (scfm) | Cost Effectiveness (per lb of VOC Removed) | | | | |
|---|---|---|---|---|---|---|
| | | Thermal Oxidation[b] | Catalytic Oxidation[b] | Carbon Adsorption[c] | Gas Absorption[c] | Condensation[c] |
| 1,000 | 100 | | | | | |
| | 1,000 | $2.30 | $1.80 | $0.63 | $1.28 | |
| | 5,000 | 0.90 | 0.73 | 0.27 | 0.83 | |
| | 50,000 | 0.60 | 0.41 | 0.12 | 0.55 | |
| | 100,000 | 0.56 | 0.39 | 0.11 | | |
| 5,000 | 100 | | | | | 0.62 |
| | 1,000 | 0.43 | 0.32 | 0.15 | 0.33 | 0.14 |
| | 5,000 | 0.17 | 0.12 | 0.08 | 0.14 | |
| | 50,000 | 0.10 | 0.05 | 0.05 | 0.11 | |
| | 100,000 | 0.10 | 0.05 | 0.05 | | |
| 10,000 | 100 | | | | | 0.32 |
| | 1,000 | 0.19 | 0.17 | | 0.17 | 0.08 |
| | 5,000 | 0.06 | 0.05 | | 0.07 | |
| | 50,000 | 0.03 | 0.02 | | 0.05 | |
| | 100,000 | 0.03 | 0.02 | | | |
| 25,000 | 110 | | | | | 0.14 |
| | 1,000 | 0.08 | | | 0.07 | 0.03 |
| | 5,000 | 0.03 | | | 0.04 | |
| | 50,000 | 0.02 | | | 0.02 | |
| | 100,000 | 0.02 | | | 0.02 | |

[a]Values in some cases interpolated from cost effectiveness given in individual control device reports.

[b]Based on recuperative heat recovery.

[c]... no credit for VOC

Table IV-4. SOCMI VOC Emissions Addressed

| Product | Process | 1982 Emissions (%)[a] |
|---|---|---|
| Maleic anhydride | Benzene oxidation | 2.2 |
| | Butane oxidation | |
| Cyclohexane | Benzene | 0.1 |
| | Petroleum extraction | |
| Ethylbenzene | Benzene alkylation | 2.9 |
| Styrene | Benzene alkylation | 0.4 |
| Methylene chloride | Methanol | 0.1 |
| Chloroform | Methanol | 0.0 |
| Methyl chloride | Methanol | 0.1 |
| Nitrobenzene | Benzene nitration | 0.2 |
| Ethylene | E/P cracking | 4.6 |
| | N/G cracking | |
| Propylene | E/P cracking | 1.9 |
| | N/G cracking | |
| Acrylic acid | Propylene oxidation | 1.4 |
| | HP modified Reppe | |
| Methyl acrylate | Direct esterification | |
| Ethyl acrylate | LP modified Reppe | 0.2 |
| Butyl acrylate | Direct esterification | 0.0 |
| 2-Ethylhexyl acrylate | Trans-esterification | |
| Chlorobenzene | Benzene chlorination | 0.1 |
| o-Dichlorobenzene | Benzene chlorination | |
| p-Dichlorobenzene | Benzene chlorination | |
| Acrylonitrile | Propylene ammoxidation | 14.3 |
| Hydrogen cyanide | Propylene ammoxidation | 2.5 |
| Cyclohexanol/ cyclohexanone | Cyclohexanone oxidation | 2.4 |
| | Phenol hydrogenation | |
| Linear alkylbenzene | Paraffin chlorination | 0.0 |
| | Paraffin dehydrogenation | |
| Adipic acid | Nitric acid oxidation | 0.0 |

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Table IV-4. (Continued)

| Product | Process | 1982 Emissions (%)[a] |
|---|---|---|
| Formaldehyde | Dehydrogenation/oxidation - silver catalyst | 2.3 |
| | Oxidation - metal oxide catalyst | |
| Ethylene dichloride | Direct chlorination | 6.5 |
| | Oxychlorination | |
| Ethylene oxide | Air-oxidation | 7.7 |
| | Oxygen-oxidation | |
| Butadiene | n-Butane dehydrogenation | 0.7 |
| | n-Butene oxidative dehydrogenation | |
| | Ethylene by-product | |
| Vinyl acetate | Ethylene vapor phase | 1.1 |
| Methyl chloride | Methane chlorination | 0.0 |
| Methylene chloride | Methane chlorination | 0.3 |
| Chloroform | Methane chlorination | 0.3 |
| Carbon tetrachloride | Methane chlorination | 0.0 |
| Acetaldehyde | Ethylene air-oxidation | 0.4 |
| | Ethylene oxygen-oxidation | |
| Acetic anhydride | Acetic acid pyrolysis | 1.0 |
| Glycol ethers | Ethylene oxide | 0.0 |
| Fluorocarbons | Fluorination | 0.2 |
| Methyl methacrylate | Acetone cyanohydrin | 2.9 |
| Acetic acid | Methanol carbonylation | 0.3 |
| Acetic acid | Butane oxidation | 0.6 |
| Acetic acid | Acetaldehyde oxidation | 0.6 |
| Formic acid | Butane oxidation | 0.0 |
| Methyl ethyl ketone | Butanol dehydrogenation | 0.0 |
| Ethyl acetate | Esterification | 0.1 |
| Carbon tetrachloride | Hydrocarbon chlorinolysis | 0.3 |
| Perchloroethylene | Hydrocarbon chlorinolysis | |
| Epichlorohydrin | Allyl chloride | 0.1 |
| Allyl chloride | Propylene chlorination | 0.7 |
| Acrolein | Propylene oxidation | 0.3 |

Table IV-4. (Continued)

| Product | Process | 1982 Emissions (%)[a] |
|---|---|---|
| Allyl alcohol | Allyl chloride hydrolysis | 0.0 |
| | Propylene oxide | |
| Glycerin | Epichlorohydrin | 0.5 |
| Glycerin | Acrolein | 0.0 |
| | Allyl alcohol | |
| Methanol | Methane | 2.2 |
| Caprolactam | Conventional | 0.2 |
| Caprolactam | BASF | 0.1 |
| Caprolactam | DSM/HOP (Stamicarbon) | 0.0 |
| Toluene diisocyanate | Diaminotoluene | 0.4 |
| Ethanolamines | Ethylene oxide | 0.1 |
| Dimethyl terephthalate | Via TPA | 1.0 |
| Dimethyl terephthalate | Hercofina | 5.6 |
| Terephthalic acid | Oxidation and purification | 1.8 |
| 1,1,1-Trichloroethane | Vinyl chloride | 0.8 |
| | Ethane chlorination | |
| Perchloroethylene | EDC chlorination | 0.2 |
| | EDC oxychlorination | |
| Trichloroethylene | EDC chlorination | |
| | EDC oxychlorination | |
| Vinylidene chloride | Trichloroethane | 0.1 |
| Cumene | Phosphoric catalyst | 0.2 |
| | Alumium chloride catalyst | |
| Ethylene glycol | Ethylene oxide | 0.9 |
| Sulfuric acid | Direct evaporation | 0.2[b] |
| | Indirect evaporation | |
| | Regeneration | |
| Propylene oxide | Chlorohydrination | 2.6 |
| Propylene oxide | Isobutane hydroperoxidation | 0.1 |
| | Ethylbenzene hydroperoxidation | 0.1 |
| Chloroprene | Butadiene | 0.8 |
| Aniline | Nitrobenzene hydrogenation | 0.1 |
| Phenol | Cumene | 1.1 |
| Acetone | Cumene | 0.5 |
| | | 79.4 |

[a] Percent of initial 1982 SOCMI emission projections addressed.

[b] Emissions from waste sulfuric acid recovery not initially considered.

# V. TOTAL-VOC-EMISSION SUMMARY

## A. ESTIMATED EMISSIONS

The generic reports of Volume III present independent estimates of the total SOCMI VOC emissions. These estimates are based primarily on study data of 1978 and have not been projected to 1982.

| | VOC Emissions (MM lb) |
|---|---|
| Storage and handling | 80 |
| Secondary | 90 |
| Fugitive | 460-700 |

The estimate of total SOCMI emissions presented in the Storage and Handling report in Volume III is 35% lower than the estimate for 1982 projected from the product study reports. This is because the average vapor pressures estimated in the Storage and Handling report are lower than those observed during the product studies and the fact that the Storage and Handling report is based on 1978 data.

For the estimate of total SOCMI emissions presented in the Secondary Emissions report in Volume III it is assumed that the VOC in wastewater has the average vapor pressure of the products. The actual average vapor pressure may be somewhat lower and therefore result in fewer secondary emissions. The secondary emissions projected from product studies are based on a very limited amount of actual data. Both estimates are only order-of-magnitude estimates and the difference between the two estimates presented for secondary emissions is considered to be within the accuracy expected.

The above emissions estimate for fugitive emissions is based on data collected in 1978. The fact that new plants come on stream every year indicates that fugitive emissions would be expected to increase. However, this is largely offset by the fact that many older obsolete plants are shut down and replaced with modern high volume facilities with reduced fugitive emissions because fewer valves and pumps are used for handling a greater volume of VOC liquids.

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The above range of 460 to 700 MM lb of VOC fugitive emissions per year represents the difference between an estimate that the SOCMI has the same degree of fugitive emissions control as observed by a petroleum industry study (defined by this program as uncontrolled emissions) and an estimate that the SOCMI averages 50% of the maintenance and monitoring prescribed to control fugitive emissions. Based on the observations made during the performance of this program and the SOCMI incentives concerning economics, odor, toxicity, and regulatory pressures, it is estimated that the SOCMI fugitive VOC emissions in 1982 will be approximately 460 MM lb.

Based on the SOCMI product studies in Volume VI-X, the emission estimates in Tables II-1 and C-1, and the futitive emissions estimate explained above, the total VOC emissions projected for 1982 are estimated to be 1434 MM lb. The initial projection for 1982 was 1779 MM lb. The methods for determining these projections are explained in Appendix C. The breakdown of this 1982 emission projection by source is as follows:

| | VOC Emissions (MM lb) | Amount (%) |
|---|---|---|
| Process | 792 | 55 |
| Fugitive | 460 | 32 |
| Storage and handling | 124 | 9 |
| Secondary | 58 | 4 |
| | 1434 | 100 |

As shown in Table IV-1 and discussed in the Air Oxidation Emission Projection report in Volume II, oxidation process reactions contribute close to 50% of all process-source emissions. From the standpoint of unit operations the greatest volume of VOC emissions is contributed by vacuum systems. As is discussed in the Vacuum System Emission Projections report of Volume II, the number of vacuum systems incorporated by the SOCMI is difficult to estimate, but these systems are believed to contribute at least 158 MM lb of VOC per year.

While the studies described in Volumes VI—X were being conducted, particular attention was given to the potential for benzene emissions. Following is a summary of the SOCMI benzene emissions projected for 1982. Over 90% of the benzene emissions result from the manufacture of four products.

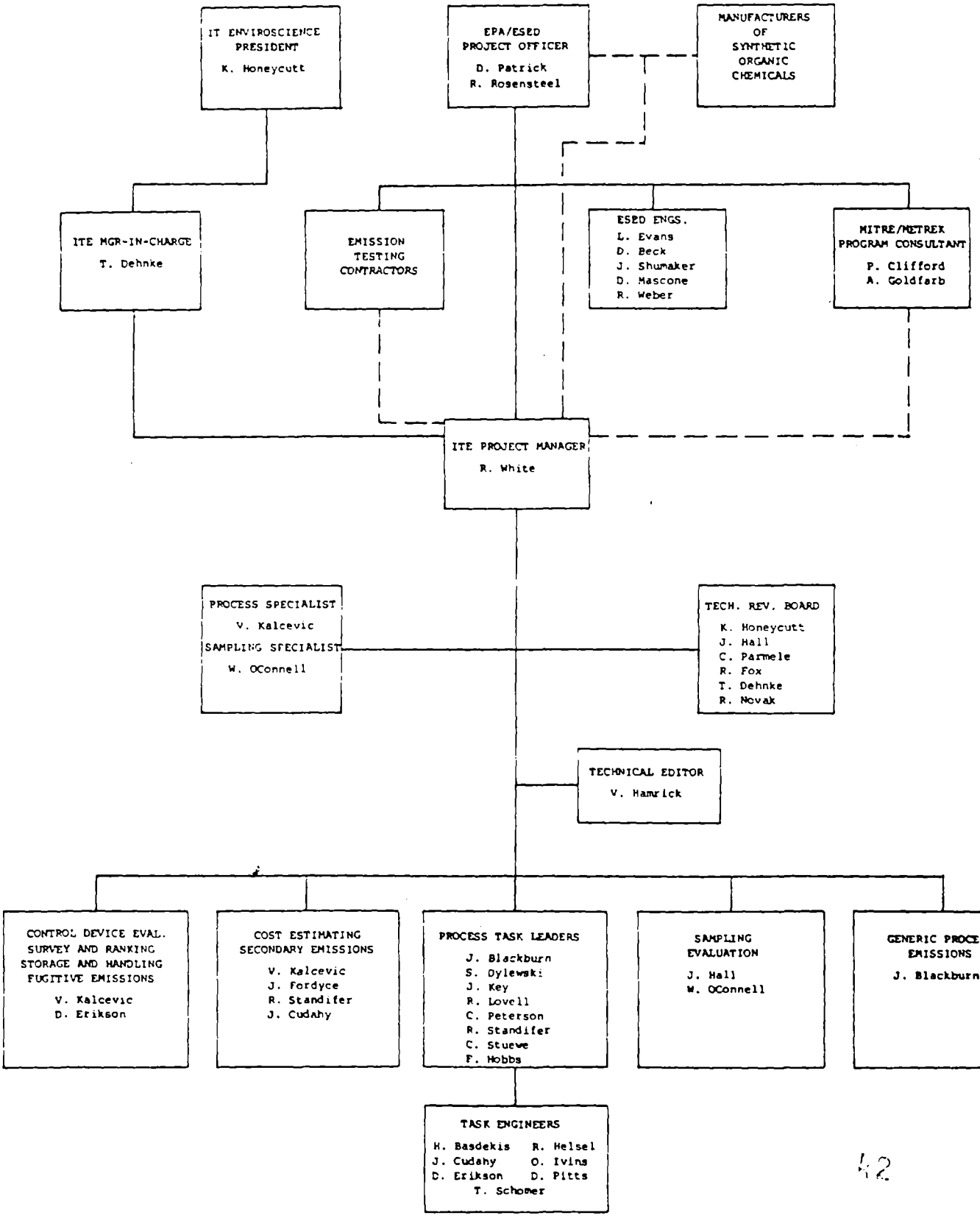
| Product | Estimated Benzene Emissions (MM lb/yr) |
|---|---|
| Maleic anhydride | 12.78 |
| Ethylbenzene/styrene | 6.83 |
| Ethylene | 2.81 |
| Alkylbenzene | 2.62 |
| Nitrobenzene | 1.17 |
| Chlorobenzene | 0.92 |
| Caprolactam | 0.04 |
| Acetic anhydride | 0.02 |
| Aniline | 0.01 |
| Total | 27.20 |

B. CONCLUSIONS

As shown in Table II-1 and discussed in Appendix C, the estimated emissions from the manufacture of the products studied are only about half the initial estimate made early in the program. The initial estimate was based largely on Louisiana and Texas Air Control Agency data supplied to them by industry surveys for 1975 and 1976. The current estimate is based on site visits to many of these same industry sources. The evidence clearly shows that a dramatic improvement in emissions from the SOCMI has occurred during the last few years. The greatest improvement has been in the control of emissions from process vents. The motivation for these improvements obviously includes the economic advantage of VOC loss prevention, industry's genuine concern for the environment, plus current and anticipated regulatory pressures.

# APPENDIX A

## PROGRAM ORGANIZATION




PROGRAM ORGANIZATION

# APPENDIX B

## SURVEY AND RANKING

# APPENDIX B

## SURVEY AND RANKING

The primary objective of the survey and ranking task was to provide the necessary data to rank order the processes to assure that the most significant processes were studied in the most detail early in the project.

This report describes the methods used and gives the results for ranking 140 products.

Four areas were identified and considered to rank order the processes:

1. Gross Emissions - The total quantity of non-methane hydrocarbons emitted from the manufacture of a specific compound by each one or more processes annually.

2. Growth Factor - The projected rate of annual growth expected through 1982. Very low or negative growth compounds were given lower priority than potentially high growth compounds.

3. Modular Contribution - A breakdown of the various manufacturing processes into the specific types of reaction processes and emission control modules associated with each process. Primary emphasis was given to processes which would yield information that could be utilized to help study similar aspects of other processes.

4. Toxicity Score - A means of differentiating the potential health hazards between processes that emit varying amounts of less toxic and more toxic chemicals.

### Gross Emissions Determination

Total annual production multiplied by an emission factor (lbs. material lost per lb. of product) yields the annual gross non-methane hydrocarbons (NMHC) emissions. 1976 was used as the base year since it was the most recent year for which complete actual production data could be obtained. Production data was supplied by the annual chemicals manufacturing report in Chemical and Engineering News and Chemicals Economics Handbook published by Stanford Research Institute.

Information used to determine emission factors was gathered from the Texas and Louisiana State Air Control Boards. Non-confidential emissions inventories, some selected construction permit files in Louisiana, and most of the pertinent non-confidential construction permit files in Texas were also used when available.

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Considerable judgment was used in calculating emission factors from the data in the inventory questionnaires and permits. Many files did not contain adequate production breakdowns for individual plant sites. In these cases, plant production was estimated by taking the capacities listed in The Chemical Marketing Reporter Chemical Profiles or the 1976 Directory of Chemical Producers and multiplying by the average industry percentage of production in relation to capacity. Several questionnaires did not contain sufficient information to enable the designation of which emission point originated with which process. When apparently good analytical data was available and the vented emissions were broken down into components, the processes could be separated with some degree of certainty.

In some cases, where multiple processes used common vents, the emissions had to be allocated, usually on a weight percentage basis of production. Judgments were also required even when all information was available and emission factors could be readily calculated. The factors for two similar facilities were often quite dissimilar. If a factor for one facility agreed well with published data, then that factor was selected as being more accurate. In some cases, where no comparable data was available, an average was taken. In a number of cases, the calculated emission factors were rejected as being unreasonably below expected levels.

In those cases where an emission factor could not be obtained because of the reasons stated above or because there were no producing sites in Texas and/or Louisiana, the Radian, Monsanto, or Houdry data were used when available.

When a compound was produced by two or more distinctly different processes, emission factors were determined for each significant method of manufacture. Radian's production percentage breakdown for each process was used where revised data were not available. The VOC emissions estimated for the top 140 chemicals are shown by Table I.

## Growth Factor Determination

Rank ordering is based on 1982 projected gross NMHC emissions. Since most pre-1975 growth projections are invalid due to the economic recession of 1975, revised figures were needed. The source of these revised projections were the Chemical Economics Handbook and Chemical Marketing Reporter. Using the new growth rates, the 1982 gross emission data was obtained by compounding the 1976 data over six years. The average annual growth was approximately 6%.

## Modular Contribution

The various units which comprise the anatomy of a synthetic organic chemical production plant had to be broken down and identified. Although

each plant has an individual character of its own, there are still common operations or sections which can be related to other processes. These sections or modules were assigned to three categories: reaction, process, and emission control. Reaction modules describe the initial portion of the process where the compound is made, i.e., alkylation, oxidation, chlorination, etc. Process modules comprise the various unit operations that the compound or product must go through during its manufacture and which can result in the release of emissions, i.e., distillation, absorbtion, extraction, etc. Emission control modules define the device or devices used to prevent or control emissions, i.e., flare, condensor, thermal oxidizer, etc.

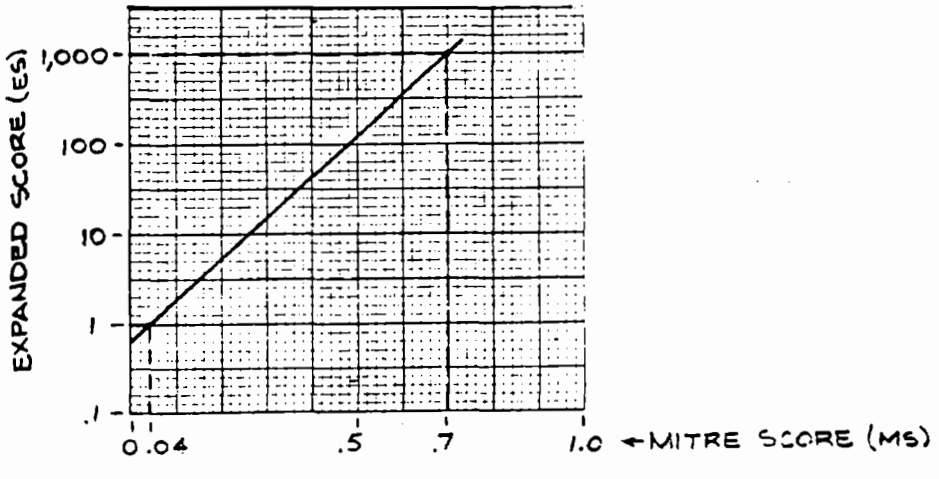
Modular contribution was a judgment assessment of the value of studying a particular process with regard to the transfer of emission related technology to other process studies where similar process modules can be identified. Three (3) grids depicting the various reaction, process, and emission control modules are shown in Tables II, III, and IV.

Toxicity Score Determination

Toxicity score was obtained by multiplying the annual gross emissions (broken down by MM lbs. of each major component) by a toxicity factor assigned to each component. These quantities are then totaled, resulting in a toxicity score for the compound under consideration. (See Figure 1 as an example).

Two methods were used to determine the toxicity factor and resulting toxicity score.

Exponential toxicity scores were computed from the EPA's formula which uses the MITRE toxicity ratios. The MITRE scoring (EPA-450/3-77-008a) has been "expanded" to show more accurately the "real" difference in toxicity between less toxic and more toxic chemicals. In the MITRE system a very toxic chemical, vinyl chloride, has a score of 0.7 while a typical chemical, with few toxic properties, methylal, has a score of 0.04. The ratio between these two MITRE scores is only 17.5. A judgment was made that the ratio of 1000 better shows the real difference in toxicity of these two chemicals, then the MITRE scoring was used as an exponent to calculate an "expanded score". The formula for the expansion is $ES = .657\ e^{10.5\ (MS)}$



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The expanded score was used in the same way as the MITRE score would be used. The toxicity score is obtained by multiplying the expanded score by the MM lbs. of VOC emissions. The exponential toxicity scores are shown in Table I.

Linear toxicity scores were computed by multiplying the component gross emissions (MM lbs.) times two different toxicity numbers. The first number, ranging from 1 to a maximum of 6, represents the MITRE score plus 1 for acute toxicity. This is consistent with other toxicity scoring such as the one sited in "Clinical Toxicity of Commercial Products". The second number represents the carcinogenic, mutagenic, and teratogenic potential. If a compound was given a 4 or 5 per the MITRE score in any or all of the three categories, it was assigned a 5; if under test, a 3, and if it had not been tested or had scored a negative result, it was given a 1. (See Figure 1 for example). The maximum toxicity factor for this method was 6 x 5 = 30. The minimum was 1 x 1 = 1. The linear toxicity scores are also shown in Table I.

Rank Ordering

The processes, as rank ordered for this study, are listed in Table I. All four of the areas previously described were considered in rank ordering the compounds for selection. The 1982 total projected NMHC emissions were given the most weight in a selection decision; however, modular contribution and toxicity scores were used to choose between compounds having relatively equal amounts of gross emissions.

The study ranking table is ranked according to the most significant process for each compound. The secondary processes are grouped under each compound, and the decision regarding their study priority is made on an individual process comparison basis. Process studies were grouped for practical study convenience.

Other factors also entered into the selection process. Vinyl chloride, for instance, was omitted for study, even though it ranked first because a considerable amount of effort and resulting reports have already been compiled on this compound. Processes which use benzene as a raw material such as nitrobenzene, chlorobenzene, and linear alkyl benzene were assigned early in the project as a result of increased governmental interest and investigation into benzene's toxological effects. Some compounds have arbitrarily been put on hold due to their negative growth forecast.

In some cases, compounds were grouped with other compounds for practical study efficiency and were selected for study earlier than they would have been if they were studied "on their own merits".

This method of survey and ranking is considered to be a significant improvement over previous methods because of the following incorporations:

1. Actual plant data, regarding the quantity and composition of emissions, was used to calculate emission factors in the majority of cases.

2. Toxicity scores are based on the relative toxicity and amount of each individual component in the emission, not just the compound or product being manufactured.

3. The chemical manufactures in the states of Texas and Louisiana, which were used as the data source, accounting for approximately 65% of the total U.S. synthetic organic chemical production.

FORMALDEHYDE

FIGURE 1

| Production M Pounds | x | Emission Factor lb/lb of Product | Component | = | Annual Gross Emissions M Pounds | x | EPA Exponential Toxicity Factor | = | Toxicity Score |
|---|---|---|---|---|---|---|---|---|---|
| 5621.0 | x | .00077 | Formaldehyde | = | 4.330 | x | 152.10 | = | 659.0 |
| | | .00036 | Methanol | = | 2.020 | | 4.59 | = | 9.3 |
| | | .00400 | Ethanol | = | 22.480 | | 2.75 | = | 61.8 |
| | | .00513 | | | 28.830 | | | | 730.1 |

Linear Toxicity Score

| Component | Gross Emissions | x | Acute Toxicity Factor | x | Teratogen Carcinogen Mutagen | = | Toxicity Score |
|---|---|---|---|---|---|---|---|
| Formaldehyde | 4.330 | x | 4 | x | 5 | = | 86.6 |
| Methanol | 2.020 | x | 4 | x | 1 | = | 8.1 |
| Ethanol | 22.480 | x | 3 | x | 1 | = | 67.4 |
| | 28.830 | | | | | | 162.1 |

Growth Rate = 6%/Year (Over next 6 years, i.e. 1982)

| | | | |
|---|---|---|---|
| Gross Emissions | 28.83 x 1.419 = 40.92 | 1982 Projected | - See (→) on Tables II, III, and IV |
| Exponential Toxicity | 730.1 x 1.419 = 1036 | | |
| Linear Toxicity | 162.1 x 1.419 = 230 | | |

TABLE I

SURVEY AND RANKING PROCESS STUDIES

| SEL. RANK NO. | CHEMICAL NAME | ASSIGNED TASK LEADER | 1982 % OF TOTAL PROD. | PROCESS USED | 1976 GROSS NMHC EMISSIONS M LBS | PERCENT GROWTH | 1982 GROSS NMHC EMISSIONS M LBS | RANK | 1982 TOXICITY SCORE RANK EXPON. | LINEAR | EMISSION FACTOR LB/LB | EMISSION FACTOR SOURCE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | VINYL CHLORIDE | | 1% | ACETYLENE | .395 | 6.99% | .593 | 105 | 27 | 110 | .00689 | B |
| | | | 99% | ETHYLENE DICHLORIDE | 40.034 | 6.99% | 60.080 | 5 | 1 | 6 | .00704 | B |
| 2 | ACRYLONITRILE | KEY | 100% | PROPYLENE OXIDATION | 151.496 | 8.99% | 254.0* | 1 | 5 | 3 | .09979 | A/B |
| 3 | ETHYLENE DICHLORIDE | KEY | 0% | ACETYLENE | | | | | | | | |
| | | KEY | 50% | DIRECT CHLORINATION | 29.494 | 7.36% | 45.165 | 10 | 4 | 1 | .00759 | A |
| | | KEY | 50% | OXYCHLORINATION | 46.569 | 7.36% | 71.314 | 4 | 3 | 2 | .01199 | B |
| 4 | MALEIC ANHYDRIDE | LAWSON | 85% | BENZENE OXIDATION | 23.165 | 9.15% | 39.180 | 13 | 2 | 4 | .09334 | A/B |
| | | LAWSON | 15% | BUTANE OXIDATION | | | | | | | | |
| 5 | ETHYLENE OXIDE | LOVELL | 66% | AIR OXIDATION/ ETHYLENE | 91.955 | 5.99% | 130.4* | 2 | 9 | 7 | .03329 | C |
| | | LOVELL | 34% | O2 OXIDATION/ ETHYLENE | 5.263 | 5.99% | 7.466 | 40 | 96 | 84 | .00369 | C |
| 6 | DIMETHYL TEREPHTHALATE ( DMT) | DYLEWSKI | 23% | AMOCO VIA TPA | 5.551 | 7.99% | 8.809 | 34 | 80 | 55 | .00861 | C |
| | | DYLEWSKI | 35% | DUPONT | 2.204 | 7.99% | 3.499 | 64 | 66 | 33 | .00224 | C |
| | | DYLEWSKI | 17% | EASTMAN VIA TPA | 3.084 | 7.99% | 4.894 | 54 | 90 | 68 | .00647 | C |
| | | DYLEWSKI | 25% | HERCULES | 63.209 | 7.99% | 100.3* | 3 | 28 | 5 | .09029 | C |
| 7 | ETHYLENE | STANDIFER | 46% | NAPTHA GAS OIL PYROLYSIS | 22.355 | 14.47% | 50.302 | 8 | 11 | 19 | .00342 | D |
| | | STANDIFER | 52% | NATURAL GAS LIQUIDS PYROLYAS | 29.619 | 1.11% | 31.664 | 15 | 16 | 23 | .00190 | D |
| | | STANDIFER | 2% | REFINERY BY PRODUCT | | | | | | | | |
| 8 | ETHYLBENZENE | KEY | 98% | BENZENE ALKYLATION | 32.250 | 7.93% | 51.000 | 6 | 6 | 8 | .00600 | A |
| | | KEY | 2% | MIXED XYLENE EXTRACT | .072 | -13.1* | .031 | 158 | 170 | 169 | .00017 | |
| 9 | HYDROGEN CYANIDE (HCN) | BLACKBURN | 50% | ACRYLONITRILE COPRODUCT | 29.999 | 6.49% | 43.773 | 11 | 17 | 17 | .09979 | A/B |
| | | BLACKBURN | 50% | ANDRUSSON PROCESS | 2.464 | 6.49% | 3.596 | 63 | 33 | 31 | .00819 | A |
| 10 | STYRENE | KEY | 100% | ETHYL BENZENE | 4.535 | 6.99% | 6.807 | 43 | 7 | 22 | .00071 | C |
| 11 | 1,1,1, TRICHLOROETHANE | STANDIFER | 10% | ETHANE CHLORINATION | | | | | | | | |
| | | STANDIFER | 74% | VINYL CHLORIDE | 8.976 | 8.99% | 14.886 | 23 | 8 | 9 | .01899 | B |
| | | STANDIFER | 16% | VINYLIDENE CHLORIDE | | | | | | | | |
| 12 | CARBON TETRACHLORIDE | STUEWE | 38% | CARBON DISULFIDE | 5.209 | -4.00% | 4.077 | 59 | 10 | 29 | .01599 | B |

TABLE I

SURVEY AND RANKING PROCESS STUDIES

| SEL. RANK NO. | CHEMICAL NAME | ASSIGNED TASK LEADER | 1982 % OF TOTAL PROD. | PROCESS USED | 1976 GROSS NMHC EMISSIONS M LBS | PERCENT GROWTH | 1982 GROSS NMHC EMISSIONS M LBS | RANK | 1982 TOXICITY SCORE RANK EXPON. | LINEAR | EMISSION FACTOR LB/LB | EMISSION FACTOR SOURCE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 12 | CARBON TETRACHLORIDE | STUEWE | 42% | CHLOROPARAFFIN CHLOROLYSIS | 6.117 | -4.00% | 4.788 | 56 | 43 | 51 | .01699 | B |
| | | STUEWE | 20% | METHANE | .956 | -4.00% | .670 | 101 | 39 | 80 | .00499 | A |
| 13 | FORMALDEHYDE | LOVELL | 23% | METAL OXIDE/ METHANOL | 6.632 | 5.99% | 9.407 | 32 | 48 | 32 | .00512 | A |
| | | LOVELL | 77% | SILVER CATALYST/ METHANOL | 22.203 | 5.99% | 31.496 | 16 | 26 | 10 | .00512 | A |
| 14 | METHYL METHACRYLATE ( MMA) | BLACKBURN | 100% | ACETONE CYANOHYDRIN | 32.972 | 7.49% | 50.886 | 7 | 58 | 14 | .06049 | A/B |
| 15 | PROPYLENE OXIDE | STUEWE | 60% | CHLOROHYDRIN | 35.067 | 5.80% | 49.199 | 9 | 46 | 12 | .02959 | B |
| | | STUEWE | 40% | PEROXIDATION | .433 | 10.45% | .786 | 100 | 125 | 104 | .00070 | A |
| 16 | PROPYLENE | | 54% | NAPTHA/GAS OIL PYROLYSIS | 12.730 | 14.49% | 28.673 | 17 | 19 | 26 | .00342 | D |
| | | | 16% | NATURAL GAS LIQUIDS PYROL | 3.049 | 7.49% | 4.706 | 58 | 49 | 76 | .00189 | D |
| | | | 30% | REFINERY BY PRODUCT | | | | | | | | |
| 17 | NITROBENZENE | STUEWE | 100% | BENZENE NITRATION | 2.268 | 8.49% | 3.701 | 61 | 12 | 27 | .00299 | D |
| 18 | ETHYLENE GLYCOL | LOVELL | 100% | ETHYLENE OXIDE | 10.742 | 5.99% | 15.238 | 22 | 13 | 21 | .00319 | A |
| 19 | CYCLOHEXANOL/ CYCLOHEX-ANONE | BLACKBURN | 75% | CYCLOHEXANE | 35.020 | 3.49% | 43.048 | 12 | 63 | 15 | .04446 | A |
| | | BLACKBURN | 25% | PHENOL | .241 | 3.49% | .296 | 123 | 127 | 128 | .00091 | A |
| 20 | CUMENE | STUEWE | 100% | BENZENE | 2.661 | 6.99% | 3.994 | 60 | 14 | 37 | .00097 | A |
| 21 | METHANOL (METHYL ALCOHOL) | KEY | 100% | METHANE | 25.650 | 6.99% | 38.494 | 14 | 62 | 19 | .00410 | A |
| 22 | PHENOL | STUEWE | 3% | BENZENE CHLORINATION | | | | | | | | |
| | | STUEWE | 2% | BENZENE SULFONATION | | | | | | | | |
| | | STUEWE | 93% | CUMENE | 12.627 | 6.99% | 18.950 | 19 | 21 | 13 | .00621 | A |
| | | STUEWE | 2% | TOLUENE OXIDATION | | | | | | | | |
| 23 | ANILINE | STUEWE | 100% | NITROBENZENE HYDROGENATION | 1.631 | 8.49% | 2.661 | 67 | 15 | 35 | .00299 | D |
| 24 | FLUOROCARBONS | STANDIFER | 100% | CCl4/C2Cl6 FLUORINATION | 5.001 | .00% | 5.001 | 52 | 18 | 43 | .00499 | B |
| 25 | PERCHLOROETHYLENE | STANDIFER/* | 0% | ACETYLENE | | | | | | | | |
| | | STANDIFER/* | 66% | ETHYLENE DICHLORIDE | 1.253 | 15.59% | 2.991 | 66 | 34 | 44 | .00544 | B |
| | | STANDIFER/* | 34% | METHANE | 1.314 | 1.22% | 1.413 | 89 | 23 | 64 | .00499 | A |
| 26 | TEREPHTHALIC ACID (TPA) | DYLEWSKI | 39% | AMOCO | 4.334 | 7.99% | 6.878 | 42 | 83 | 63 | .00854 | C |
| | | DYLEWSKI | 47% | EASTMAN | 6.201 | 7.99% | 9.841 | 30 | 64 | 28 | .01014 | C |
| | | DYLEWSKI | 14% | MOBIL | 10.033 | 7.99% | 15.922 | 21 | 81 | 34 | .05512 | C |

TABLE I

SURVEY AND RANKING PROCESS STUDIES

| SEL. RANK NO. | CHEMICAL NAME | ASSIGNED TASK LEADER | 1982 % OF TOTAL PROD. | PROCESS USED | 1976 GROSS NMHC EMISSIONS M LBS | PERCENT GROWTH | 1982 GROSS NMHC EMISSIONS M LBS | RANK | 1982 TOXICITY SCORE RANK EXPON. | LINEAR | EMISSION FACTOR LB/LB | EMISSION FACTOR SOURCE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 27 | CHLOROBENZENE | DYLEWSKI | 100% | BENZENE CHLORONATION | 1.996 | 1.99% | 2.248 | 74 | 20 | 53 | .00434 | B |
| 28 | ACRYLIC ACID | BLACKBURN | 23% | MODIFIED REPP | .218 | -4.12% | .169 | 132 | 149 | 134 | .00195 | A |
| | | BLACKBURN | 77% | PROPYLENE OXIDATION | 10.933 | 14.93% | 25.205 | 18 | 32 | 20 | .08703 | B |
| 29 | ACETIC ACID | KEY | 33% | ACETALDEHYDE | 10.012 | 1.82% | 11.158 | 27 | 56 | 16 | .00980 | B |
| | | KEY | 44% | BUTANE OXIDATION | .342 | 77.43% | 10.692 | 28 | 71 | 39 | .00704 | B |
| | | KEY | 19% | METHANOL | 2.915 | 9.07% | 4.911 | 53 | 77 | 69 | .00749 | B |
| | | KEY | 4% | OTHERS | | | | | | | | |
| 30 | CHLOROPRENE | DYLEWSKI | 100% | VIA BUTADIENE | 11.875 | 2.39% | 13.691 | 24 | 29 | 11 | .03149 | A |
| 31 | ALKYL LEADS | | 5% | ELETROLYSIS | | | | | | | | |
| | | | 95% | ETHYL CHLORIDE | 4.827 | -11.0* | 2.399 | 71 | 22 | 71 | .00812 | A |
| 32 | ACETONE | STUEWE | 69% | CUMENE | 5.658 | 7.05% | 8.517 | 35 | 30 | 24 | .00521 | A |
| | | STUEWE | 31% | ISOPROPANOL | 5.102 | -1.13% | 4.765 | 57 | 87 | 52 | .00649 | B |
| 33 | ETHYL CHLORIDE | | 4% | ETHANOL/ETHANE | | | | | | | | |
| | | | 96% | ETHYLENE CHLORINATION | 8.672 | -7.00% | 5.611 | 49 | 25 | 30 | .01349 | B |
| 34 | ETHANOLAMINES | LOVELL | 100% | ETHYLENE OXIDE | 1.431 | 2.99% | 1.709 | 84 | 24 | 45 | .00499 | B |
| 35 | VINYL ACETATE ( VA) | DYLEWSKI | 13% | ACETYLENE VAPOR PHASE | 1.630 | 6.99% | 2.447 | 70 | 92 | 73 | .00846 | C |
| | | DYLEWSKI | 72% | ETHYLENE VAPOR PHASE | 6.515 | 6.99% | 9.777 | 31 | 65 | 25 | .00610 | C |
| | | DYLEWSKI | 15% | ETHYLENE LIQUID PHASE | 5.002 | 6.99% | 7.507 | 39 | 61 | 38 | .02251 | C |
| 36 | METHYLENE CHLORIDE | STUEWE | 35% | METHANE CHLORINATION | 3.561 | 9.01% | 5.978 | 47 | 38 | 42 | .01699 | B |
| | | STUEWE | 65% | METHANOL/METHYL CHLORIDE | .538 | 12.18% | 1.273 | 90 | 51 | 58 | .00194 | A |
| 37 | 1.3 BUTADIENE | STANDIFER | 80% | ETHYLENE COPRODUCT | 4.011 | 14.04% | 8.827 | 33 | 36 | 61 | .00267 | D |
| | | STANDIFER | 13% | N-BUTANE | 7.157 | -12.2* | 3.270 | 65 | 108 | 83 | .00610 | B |
| | | STANDIFER | 7% | N-BUTENE | .978 | -11.1* | .481 | 108 | 150 | 140 | .00166 | B |
| 38 | VINYLIDENE CHLORIDE | STANDIFER | 50% | 1,1,1 TRICHLORDETH* | 1.772 | 6.99% | 2.660 | 68 | 31 | 48 | .01899 | B |
| | | STANDIFER | 50% | 1,1,2 TRICHLORDETH* | | | | | | | | |
| 39 | TOLUENE DIISOCYANATE ( TDI) | STANDIFER | 100% | DIAMINOTOLUENE | 3.984 | 0.99% | 6.515 | 45 | 35 | 40 | .00699 | A/B |
| 40 | CHLOROFORM | STUEWE | 61% | METHANE CHLORONATION | 3.017 | 8.99% | 5.060 | 51 | 41 | 49 | .01699 | B |
| | | STUEWE | 39% | METHANOL CHLORONATION | .221 | 8.99% | .371 | 119 | 73 | 86 | .00194 | A |
| 41 | PHTHALATE ANHYDRIDE | | 30% | NAPTHALENE | | | | | | | | |
| | | | 70% | O-XYLENE | 1.338 | 6.49% | 1.953 | 76 | 37 | 47 | .00211 | A |

TABLE I

SURVEY AND RANKING PROCESS STUDIES

| SEL. (VK NO. | CHEMICAL NAME | ASSIGNED TASK LEADER | 1982 % OF TOTAL PROD. | PROCESS USED | 1976 GROSS NMHC EMISSIONS M LBS | PERCENT GROWTH | 1982 GROSS NMHC EMISSIONS M LBS | RANK | 1982 TOXICITY SCORE RANK EXPON. | LINEAR | EMISSION FACTOR LB/LB | EMISSION FACTOR SOURCE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 42 | ISOPROPANOL ( ISOPROPYL ALCOHOL) | | 100% | PROPYLENE/H2SO4 | 4.566 | 1.99% | 5.142 | 50 | 40 | 60 | .00235 | A |
| 43 | ACETIC ANHYDRIDE | KEY | 100% | ACETIC ACID | 15.452 | 2.99% | 18.451 | 20 | 74 | 62 | .01009 | B |
| 44 | GLYCEROL ( SYNTHETIC ONLY) | PETERSON | 14% | ACOLEIN | .421 | 1.99% | .474 | 109 | 122 | 130 | .01909 | C |
| | | PETERSON | 15% | ALLYL ALCOHOL | .756 | 1.99% | .852 | 98 | 86 | 102 | .03199 | C |
| | | PETERSON | 71% | EPICHLOROHYDRIN | 7.233 | 1.99% | 8.145 | 36 | 47 | 65 | .06459 | C |
| 45 | NITROPHENOL | | 100% | PHENOL NITRATION | 1.837 | 3.49% | 2.258 | 73 | 42 | 46 | .05249 | B |
| 46 | CYCLOHEXANE | BLACKBURN | 84% | BENZENE HYDROGENATION | 1.228 | 6.53% | 1.796 | 78 | 44 | 70 | .00072 | D |
| | | BLACKBURN | 16% | PETROLEUM DISTILLATION | | | | | | | | |
| 47 | BISPHENOL A | | 100% | PHENOL/ACETONE | .841 | 10.99% | 1.574 | 87 | 45 | 54 | .00199 | A |
| 48 | CELLULOSE ACETATE | | 100% | CELLULOSE ESTERIFICATI* | 7.897 | .49% | 8.137 | 37 | 59 | 56 | .01099 | B |
| 49 | CA PROLACTAM | BLACKBURN | 100% | CYCLOHEXANONE | 3.541 | 5.49% | 4.882 | 55 | 53 | 66 | .00453 | A |
| 50 | PENTAERYTHRITOL | | 100% | FORMALDEHYDE/ ACETALDEHYDE | 1.809 | 2.99% | 2.160 | 75 | 57 | 36 | .01719 | A |
| 51 | NONYL PHENOL | | 100% | PHENOL ALKYLATION | .511 | 3.49% | .628 | 104 | 50 | 75 | .00655 | A |
| 52 | ACRYLAMIDE | | 100% | ACRYLONITRILE | .122 | 8.49% | .199 | 126 | 52 | 92 | .00239 | A |
| 53 | DIETHYLENE, TRIETHYLENE GLYCOLS | LAWSON | 100% | COPRODUCTS W/ ETHYLENE GLYCOL | 1.157 | 5.99% | 1.641 | 85 | 55 | 81 | .00319 | A |
| 54 | FUMARIC ACID | | 100% | MALEIC ACID/ SOMERIZATION | .388 | 1.99% | .437 | 113 | 54 | 95 | .01149 | B |
| 55 | PROPYLENE GLYCOLS (MONO, DI, TRI) | | 100% | PROPYLENE OXIDE HYDRATION | 6.507 | 7.49% | 10.043 | 29 | 75 | 50 | .01258 | A |
| 56 | EPICHLOROHYDRIN | PETERSON | 100% | ALLYL CHLORIDE/ HCI | 1.621 | 2.49% | 1.880 | 77 | 60 | 88 | .00286 | A |
| 57 | ALLYL CHLORIDE | PETERSON | 100% | PROPYLENE CHLORINATION | 8.963 | 4.99% | 12.012 | 25 | 95 | 74 | .02699 | A |
| 58 | ADIPONITRILE/HMDA | DYLEWSKI | 11% | ACRYLONITRILE | | | | | | | | |
| | | DYLEWSKI | 24% | ADIPIC ACID | | | | | | | | |
| | | DYLEWSKI | 65% | BUTADIENE | 8.336 | 4.99% | 11.171 | 26 | 101 | 78 | .01499 | B |
| 59 | TRICHLOROETHYLENE | STANDIFER | 9% | ACETYLENE | | | | | | | | |
| | | STANDIFER | 91% | ETHYLENE | 1.486 | -8.00% | .901 | 96 | 67 | 82 | .00538 | A |
| 60 | METHYL ISOBUTYL KEYTONE (MIBK) | | 100% | MESITYL ALCOHOL | 8.354 | -6.00% | 5.763 | 48 | 82 | 41 | .04229 | A |
| 61 | PYRIDINE | | 100% | FORMALDEHYDE/ ACETALDEHYDE | .727 | 2.99% | .868 | 97 | 69 | 67 | .01499 | B |
| 62 | BENZENE | | 80% | NOT IN PROJECT SCOPE | | | | | | | | |
| | | | 20% | TOLUENE HYDRODEALKYL* | .326 | .21% | .331 | 122 | 68 | 105 | .00010 | A |

TABLE I

SURVEY AND RANKING PROCESS STUDIES

| SEL. RANK NO. | CHEMICAL NAME | ASSIGNED TASK LEADER | 1982 % OF TOTAL PROD. | PROCESS USED | 1976 GROSS NMHC EMISSIONS M LBS | PERCENT GROWTH | 1982 GROSS NMHC EMISSIONS M LBS | RANK | 1982 TOXICITY SCORE EXPON. | RANK LINEAR | EMISSION FACTOR LB/LB | EMISSION FACTOR SOURCE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 63 | ETHANOL (ETHYL ALCOHOL) | | 100% | ETHYLENE | 5.759 | 2.49% | 6.679 | 44 | 91 | 57 | .00384 | A |
| 64 | UREA | STANDIFER | 100% | NH3/CO2 | 5.386 | 5.69% | 7.512 | 38 | 99 | 59 | .00065 | A |
| 65 | ACETALDEHYDE | LOVELL | 0% | ETHANOL OXIDATION | 1.649 | | | | | | .00999 | B |
| | | LOVELL | 100% | ETHYLENE | 5.488 | 4.80% | 7.271 | 41 | 93 | 77 | .00586 | A |
| 66 | ISOPRENE | | 67% | C4 HYDROCARBONS | | | | | | | | |
| | | | 33% | SIOAMYLENE EXTRACTION | .246 | 11.99% | .486 | 107 | 70 | 85 | .00218 | A |
| 67 | FURFURAL | | 100% | POLY SACCHARIDES HYDROLYSIS | 2.341 | 1.99% | 2.636 | 69 | 76 | 79 | .01499 | B |
| 68 | GLYCOL ETHERS | LOVELL | 97% | ETHYLENE OXIDE | .321 | 5.99% | .455 | 112 | 72 | 99 | .00058 | A |
| | | LOVELL | 3% | PROPYLENE OXIDE | .009 | 5.99% | .014 | 163 | 166 | 165 | .00058 | A |
| 69 | DINITROTOLUENE | | 100% | TOLUENE DINITRATION | .920 | 10.99% | 1.721 | 83 | 79 | 87 | .00175 | A |
| 70 | SEC-BUTANOL | | 100% | BUTYLENES | 2.426 | 6.79% | 3.601 | 62 | 84 | 72 | .00699 | B |
| 71 | LINEAR ALKYL BENZENE | PETERSON | 100% | BENZENE ALKYLATION | .068 | 1.99% | .077 | 143 | 78 | 126 | .00009 | A |
| 72 | ACROLEIN | PETERSON | 100% | PROPYLENE OXIDATION | 4.942 | 5.99% | 6.127 | 46 | 107 | 90 | .07449 | B |
| 73 | DIPHENYLAMINE | | 100% | ANILINE AMINATION | .039 | 4.99% | .053 | 151 | 85 | 127 | .00099 | B |
| 74 | METHYL STYRENE | | 15% | CUMENE DEHYDROGENAT* | | | | | | | | |
| | | | 85% | CUMENE PROCESS BY-PRODUCTS | .272 | 5.99% | .386 | 117 | 89 | 103 | .00521 | A |
| 75 | ETHYLENE DIAMINE/ TRIETHYLENE TETRAMINE | | 100% | EDC AMMONOLYSIS | .131 | 4.99% | .176 | 130 | 88 | 112 | .00099 | B |
| 76 | ETHYL ACRYLATE | BLACKBURN | 61% | ACETYLENE ( REPPE) | 1.098 | 7.99% | 1.742 | 81 | 136 | 114 | .00609 | B |
| | | BLACKBURN | 39% | DIRECT ESTERIFICATI* | 1.093 | 7.99% | 1.734 | 82 | 104 | 91 | .00949 | B |
| 77 | METHYL CHLORIDE | STUEWE | 2% | METHANE CHLORINATION | .189 | -3.26% | .155 | 135 | 102 | 131 | .01699 | B |
| | | STUEWE | 98% | METHANOL HYDROCHLORIN* | .975 | 3.67% | 1.210 | 93 | 106 | 100 | .00269 | A |
| 78 | METHYLENE DIPHENOL DIISOCYANATE (* | | 100% | DPMDA/PHOSGENE | .089 | 10.99% | .168 | 134 | 94 | 118 | .00023 | A |
| 79 | N-BUTYRALDEHYDE | | 100% | OXO PROCESS | 1.927 | 4.24% | 2.346 | 72 | 109 | 89 | .00243 | A |
| 80 | NITROANILINE | | 100% | NITRO CHLOR BENZENE | .071 | .00% | .071 | 144 | 97 | 122 | .00599 | B |
| 81 | ACETOPHONE | | 60% | CUMENE PEROXIDATION | .134 | 5.99% | .191 | 128 | 98 | 116 | .00521 | A |
| | | | 40% | ETHYL BENZENE OXIDATION | | | | | | | | |

TABLE I

SURVEY AND RANKING PROCESS STUDIES

| SEL. RANK NO. | CHEMICAL NAME | ASSIGNED TASK LEADER | 1982 % OF TOTAL PROD. | PROCESS USED | 1976 GROSS NMHC EMISSIONS M LBS | PERCENT GROWTH | 1982 GROSS NMHC EMISSIONS M LBS | RANK | 1982 TOXICITY SCORE RANK EXPON. | LINEAR | EMISSION FACTOR LB/LB | EMISSION FACTOR SOURCE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 82 | ISOPHTHALATE ACID | | 100% | M-XYLENE OXIDATION | .235 | 11.99% | .465 | 110 | 100 | 98 | .00199 | B |
| 83 | BENZOIC ACID | | 100% | TOLUENE AIR OXIDATION | .279 | 4.99% | .375 | 118 | 105 | 96 | .00199 | B |
| 84 | DIISOOCTYL PHTHALATE (DI2-ETHYLHEXYL) | | 100% | PHTHALATE ANHYDRIDE/ ALCOHOL | .593 | 6.19% | .851 | 99 | 103 | 109 | .00199 | B |
| 85 | 2-ETHYL 1-HEXANOL | | 100% | ALDO COND./OXO | 1.130 | 7.99% | 1.794 | 79 | 117 | 94 | .00252 | A |
| 86 | N-BUTANOL (BUTYL ALCOHOL) | | 20% | ACETALDEHYDE | | | | | | | | |
| | | | 80% | OXO PROCESS | 1.265 | 3.99% | 1.601 | 86 | 120 | 97 | .00252 | A |
| 87 | PROPIONIC ACID | | 7% | OTHERS | | | | | | | | |
| | | | 93% | OXO PROCESS | .424 | 6.99% | .637 | 103 | 115 | 93 | .00599 | B |
| 88 | ETHYL ACETATE | KEY | 100% | ACETIC ACID | 1.077 | 1.99% | 1.213 | 92 | 121 | 101 | .00499 | B |
| 89 | ETHYLENE DIBROMIDE | | 100% | ETHYLENE BROMINATION | 1.508 | -3.00% | 1.256 | 91 | 119 | 107 | .00749 | B |
| 90 | ACETONE CYANOHYDRIN | BLACKBURN | 100% | ACETONE CYANATION | .283 | 8.49% | .462 | 111 | 110 | 117 | .00051 | A |
| 91 | BENZYL CHLORIDE | | 100% | TOLUENE CHLORINATION | .134 | 3.99% | .170 | 131 | 116 | 108 | .00149 | B |
| 92 | DICHLOROPHENOL | | 45% | PHENOL CHLORINATION | .009 | 2.99% | .011 | 165 | 118 | 152 | .00099 | B |
| | | | 55% | TRICHLOROBENZE* | .219 | 2.99% | .261 | 124 | 134 | 135 | .01896 | A |
| 93 | ISOBUTYRALDEHYDE | | 100% | OXO PROCESS | .941 | 2.99% | 1.123 | 94 | 128 | 106 | .00252 | A |
| 94 | CRESYLIC ACIDS ( SYN) | | 4% | CYMENE OXIDATION | | | | | | | | |
| | | | 80% | NATURAL COAL TAR | | | | | | | | |
| | | | 8% | PHENOL/METHANOL | .013 | 4.99% | .018 | 161 | 123 | 149 | .00099 | B |
| | | | 8% | TOLUENE SULFONATION | .013 | 4.99% | .018 | 162 | 130 | 148 | .00099 | B |
| 95 | N-N DIMETHYL ANILINE | | 100% | ANALINE AMINOLYSIS | .039 | 4.99% | .053 | 150 | 111 | 132 | .00199 | B |
| 96 | ACETYLENE | | 30% | CALCIUM CARBIDE | | | | | | | | |
| | | | 8% | ETHYLENE BY-PRODUCT | | | | | | | | |
| | | | 62% | HYDROCARBON OXIDATION | 1.779 | .00% | 1.779 | 80 | 133 | 113 | .00580 | A |
| 97 | PHOSGENE | | 100% | CO/CI2 | .146 | 9.99% | .259 | 125 | 114 | 129 | .00017 | A |
| 98 | T-BUTANOL | | 21% | ISOBUTYLENE | .167 | .07% | .168 | 133 | 160 | 156 | .00049 | B |
| | | | 79% | PROPYLENE OXIDE CO-PRODUCT | .556 | 8.36% | .901 | 95 | 126 | 119 | .00070 | A |
| 99 | SALICYLIC ACID | | 100% | SODIUM PHENATE | .023 | 1.99% | .027 | 160 | 112 | 137 | .00049 | B |
| 100 | DIMETHYL HYDRAZINE | | 100% | NITROSODIMETHYL AMINE | .001 | 4.99% | .00268 | 173 | 113 | 164 | .00049 | B |
| 101 | DODECENE | | 100% | MONENE COPRODUCT | 1.444 | .99% | 1.533 | 88 | 135 | 120 | .00499 | B |

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SURVEY AND RANKING PROCESS STUDIES

| SEL. RANK NO. | CHEMICAL NAME | ASSIGNED TASK LEADER | 1982 % OF TOTAL PROD. | PROCESS USED | 1976 GROSS NMHC EMISSIONS M LBS | PERCENT GROWTH | 1982 GROSS NMHC EMISSIONS M LBS | RANK | 1982 TOXICITY SCORE RANK EXPON. | LINEAR | EMISSION FACTOR LB/LB | EMISSION FACTOR SOURCE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 102 | DIISOLDCYL PHTHALATE | | 100% | PHTHALATE ANHYDRIDE/ ISODECANOL | .286 | 3.49% | .351 | 121 | 124 | 133 | .00199 | B |
| 103 | BUTYL ACRYLATE | BLACKBURN | 100% | ACRYLIC ACID ESTERIFICAION | .410 | 7.99% | .651 | 102 | 132 | 111 | .00199 | B |
| 104 | CHLOROSULFONIC ACID | | 100% | SO3 HYDROCHLORIN* | .344 | 1.99% | .388 | 116 | 129 | 125 | .00249 | B |
| 105 | METHYL ETHYL KEYTONE (MEK) | KEY | 25% | BUTANE OXIDATION | | | | | | | | |
| | | KEY | 75% | SEC-BUTANOL | .321 | 4.99% | .430 | 114 | 139 | 115 | .00099 | B |
| 106 | ISOBUTANOL ( ISOBUTYL ALCOHOL) | | 100% | OXO PROCESS | .442 | 2.99% | .528 | 106 | 138 | 121 | .00252 | A |
| 107 | HYDROQUINONE | | 100% | ACETONE COPRODUCT | .037 | .00% | .037 | 155 | 131 | 139 | .00149 | B |
| 108 | MONO, DI, TRI, METHYL AMINES | | 100% | METHANOL AMMONOLYSIS | .238 | 6.99% | .358 | 120 | 143 | 124 | .00099 | B |
| 109 | ADIPIC ACID | BLACKBURN | 100% | CYCLOHEXANE | .325 | 4.06% | .412 | 115 | 147 | 123 | .00026 | A |
| | | BLACKBURN | 0% | PHENOL | | | | | | | | |
| 110 | CHLORONITROBENZE* | | 100% | CHLOROBENZENE NITRATION | .173 | 1.99% | .195 | 127 | 141 | 136 | .00164 | B |
| 111 | CARBON DISULFIDE | | 100% | METHANE SULFUR VAPOR | .081 | 2.99% | .097 | 140 | 140 | 143 | .00015 | A/C |
| 112 | BIPHENYL | | 100% | TOLUENE HYDRODEALKYL* | .006 | .00% | .00625 | 170 | 137 | 166 | .00010 | A |
| 113 | ACETYL CHLORIDE | | 100% | SODIUM SCETATE | .039 | 4.99% | .053 | 149 | 144 | 138 | .00099 | B |
| 114 | MONO, DI, TRI, ETHYL AMINE | | 100% | ETHANOL AMMONOLYSIS | .074 | 5.99% | .106 | 139 | 145 | 144 | .00099 | B |
| 115 | CHLOROACETIC ACID | | 100% | ACETIC ACID CHLORONATION | .072 | 1.99% | .081 | 141 | 146 | 147 | .00099 | B |
| 116 | BENZOPHENONE | | 100% | BENZENE/CARBON TET | .001 | 4.99% | .00241 | 172 | 142 | 171 | .00149 | B |
| 117 | METHYL BROMIDE | | 100% | METHANOL/HBR | .017 | 6.99% | .027 | 159 | 148 | 159 | .00049 | B |
| 118 | PROPYL ALCOHOL | | 87% | OXO PROCESS | .072 | 7.99% | .114 | 138 | 155 | 142 | .00103 | A |
| | | | 13% | PROPANE OXIDATION | .025 | 7.99% | .041 | 154 | 169 | 163 | .00249 | B |
| 119 | BUTYL AMINC | | 100% | BUTYRALDEHYDE HYDROGEN'T'N | .125 | 2.99% | .150 | 136 | 153 | 141 | .00599 | B |
| 120 | ETHYL (DIETHYL) ETHER | | 100% | ETHANOL | .179 | .00% | .179 | 129 | 152 | 145 | .00299 | B |
| 121 | PROPYL AMINES (M-D-T) | | 50% | N-PROPYL ALCOHOL | .056 | .99% | .060 | 146 | 163 | 154 | .00599 | B |
| | | | 50% | N-PROPYL CHLORIDE | .056 | .99% | .060 | 147 | 164 | 155 | .00599 | B |
| 122 | CROTONALDEHYDE | | 100% | ALDO PROCESS | .009 | 3.99% | .012 | 164 | 154 | 150 | .00049 | B |
| 123 | ISOOCTYL ALCOHOL | | 100% | OXO PROCESS/ HYDROGENATION | .143 | -3.50% | .116 | 137 | 157 | 146 | .00099 | B |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 124 | FORMIC ACID | KEY | 98.* | N-BUTANE OXIDATION | .027 | 3.99% | .035 | 156 | 151 | 162 | .00049 | B |
| | | KEY | 1.5% | OTHERS | | | | | | | | |
| 125 | ETHYLENE GLYCOL ME ETHER ACETATE | | 100% | ETHOXY ETHANOL ESTER | .046 | 4.99% | .062 | 145 | 156 | 153 | .00049 | B |
| 126 | LINEAR ALKYL SULFONATE | | 100% | LAB SULFONATION | .050 | 1.99% | .056 | 148 | 158 | 158 | .00007 | A |
| 127 | ISODECANOL | | 25% | N-PARAFFIN OXIDATION | | | | | | | | |
| | | | 75% | OXO PROCESS | .058 | 4.99% | .078 | 142 | 165 | 151 | .00099 | B |
| 128 | ALLYL ALCOHOL | PETERSON | 47% | ALLYL CHLORIDE HYDROLYSIS | | | | | | | | |
| | | PETERSON | 6% | PROP GLYCOL DEHYDRATION | | | | | | | | |
| | | PETERSON | 47% | PROP OXIDE ISOMERIZATION | .009 | 1.99% | .010 | 166 | 159 | 160 | .00025 | A |
| 129 | ISOPROPYL ACETATE | | 100% | ISOPROPANOL ESTERIFICATI* | .039 | 4.99% | .053 | 152 | 162 | 157 | .00099 | B |
| 130 | METHYL ACETATE | | 100% | ACETIC ACID/ METHANOL | .029 | 1.99% | .033 | 157 | 167 | 161 | .00199 | B |
| 131 | CYCLOOCTADIENE | | 100% | BUTADIENE DIMERIZATION | .030 | 6.99% | .045 | 153 | 161 | 167 | .00149 | B |
| 132 | HEXACHLOROBENZENE | | 100% | HEXACHLOROCYCL* | .001 | 1.99% | .00180 | 176 | 168 | 173 | .00049 | B |
| 133 | N-BUTYL ACETATE | | 100% | ESTERIFICATION | .008 | 1.49% | .00984 | 167 | 171 | 168 | .00007 | A |
| 134 | BUTYRIC ACID | | 33% | BUTYRALDEHYDE OXIDATION | | | | | | | | |
| | | | 67% | N-BUTANE OXIDATION | .005 | 4.99% | .00732 | 169 | 174 | 172 | .00135 | A |
| 135 | DINITROPHENOL | | 100% | DNC BENZENE HYDROLYSIS | .001 | 4.99% | .00201 | 174 | 173 | 175 | .00149 | B |
| 136 | AMINO ETHYLETHANSLAM* | | 100% | ETHYLENEDIAMIN* | .007 | 2.99% | .00888 | 168 | 175 | 170 | .00123 | A |
| 137 | CYCLOHEXYLAMINE | | 50% | ANILINE | | | | | | | | |
| | | | 50% | CYCLOHEXANONE | .003 | 4.99% | .00469 | 171 | 172 | 174 | .00049 | B |
| 138 | TOLUENE SULFONIC ACIDS | | 100% | TOLUENE SULFONATION | .002 | .00% | .00233 | 175 | 176 | 176 | .00012 | B |
| 139 | BENZYL BENZOATE | | 50% | BENZALDEHYDE | .000 | 4.99% | .00093 | | | | .00099 | B |
| | | | 50% | BENZYL ALCOHOL/ ACID | .000 | 4.99% | .00093 | | | | .00099 | B |
| 140 | BENZOYL CHLORIDE | | 100% | BENZOIC ACID | .000 | 4.99% | .00010 | | | | .00004 | B |

Source Codes: A - State EIQ's; B - Monsanto Research Corp./Radian; C - Houdry; D - HI Site Visits; E - Product Report

TABLE II

SURVEY AND RANKING PROCESS STUDIES

| Selection Ranking No. | Chemical | | 1982 % of Total Production | Process | REACTION MODULES ** |
|---|---|---|---|---|---|
| 1 | Acrylonitrile | * | 100% | Ammoxidation | A |
| 2 | Ethylene Dichloride | * | 50% | Direct chlorination | A |
| | | * | 50% | Oxychlorination | A |
| | | | - | Acetylene | |
| 3 | Ethylene Oxide | * | 66% | Air Oxidation ethylene | A |
| | | * | 34% | $O_2$ Oxidation ethylene | A |
| 4 | Ethylbenzene | * | 98% | Benzene alkylation | A |
| | | | 2% | Mixed xylene extraction (not in scope) | |
| 5 | Ethylene | * | 100% | Cracking | A |
| 6 | Vinyl Chloride | | 99% | Ethylene dichloride | A |
| | | | 1% | Acetylene | |
| 7 | Dimethyl Terephthalate | * | 25% | Hercules | A B C |
| | | | 35% | DuPont | A B C |
| | | * | 23% | Amoco via TPA | A B |
| | | * | 17% | Eastman via TPA | A B C |
| 8 | Maleic Anhydride | * | 85% | Benzene oxidation | A |
| | | * | 15% | Butane oxidation | A |
| 9 | Propylene Oxide | * | 60% | Chlorohydrin | A |
| | | * | 40% | Peroxidation | A |
| 10 | Methyl Methacrylate | * | 100% | Acetone cyanohydrin | D A B C E |
| 11 | Formaldehyde | * | 77% | Silver catalyst high methanol | A B |

Oxidation, Chlorination, Hydrogenation, Pyrolysis, Esterification, Hydration, Dehydrochlorination, Ammonolysis, Sulfonation, Alkylation, Hydroformulation, Neutralization, Dehydration, Dehydrogenation, Condensation, Hydrolysis, Ammoxidation, Oxychlorination, Hydrochlorination, Peroxidation, Carbonolation, Reduction, Cleaving, Acidification, Oxyacetylation, Phosgenation, Alcoholysis, Saponification, Hydrocyanation, Nitration, Fusion, Reforming, Hydrodimerization, Addition Ester, Fluoronation, Bromination, Hydrodealkylation, Hydrobromination

*Processes assigned for study

** Letter indicates the order of occurance.

TABLE II
(Continued)

SURVEY AND RANKING PROCESS STUDIES

| Selection Ranking No. | Chemical | | 1982 % of Total Production | Process |
|---|---|---|---|---|
| | | | 23% | Low methanol |
| 12 | Nitrobenzene | * | 100% | Benzene nitration |
| 13 | Cyclohexane | * | 84% | Benzene |
| | | | 16% | Petroleum distillation (not in scope) |
| 14 | Acrylic Acid | * | 77% | Propylene oxidation |
| | | | 23% | Modified Repp |
| 15 | Phenol | * | 93% | Cumene |
| | | | 3% | Benzene chlorination |
| | | | 2% | Toluene oxidation |
| | | | 2% | Benzene sulfonation |
| 16 | Methanol | * | 100% | Methane |
| 17 | 1,1,1 Trichloroethane | * | 74% | Vinyl chloride |
| | | | 16% | Vinylidene chloride |
| | | | 10% | Ethane |
| 18 | Acetic Acid | * | 33% | Acetaldehyde |
| | | * | 44% | Butane oxidation |
| | | * | 19% | Methanol-CO |
| | | | 4% | Others |
| 19 | Ethylene Glycol | * | 100% | Ethylene oxide |
| 20 | Terephthalic Acid | | 14% | Mobil |
| | | * | 47% | Eastman |
| | | * | 39% | Amoco |

*Processes assigned for study

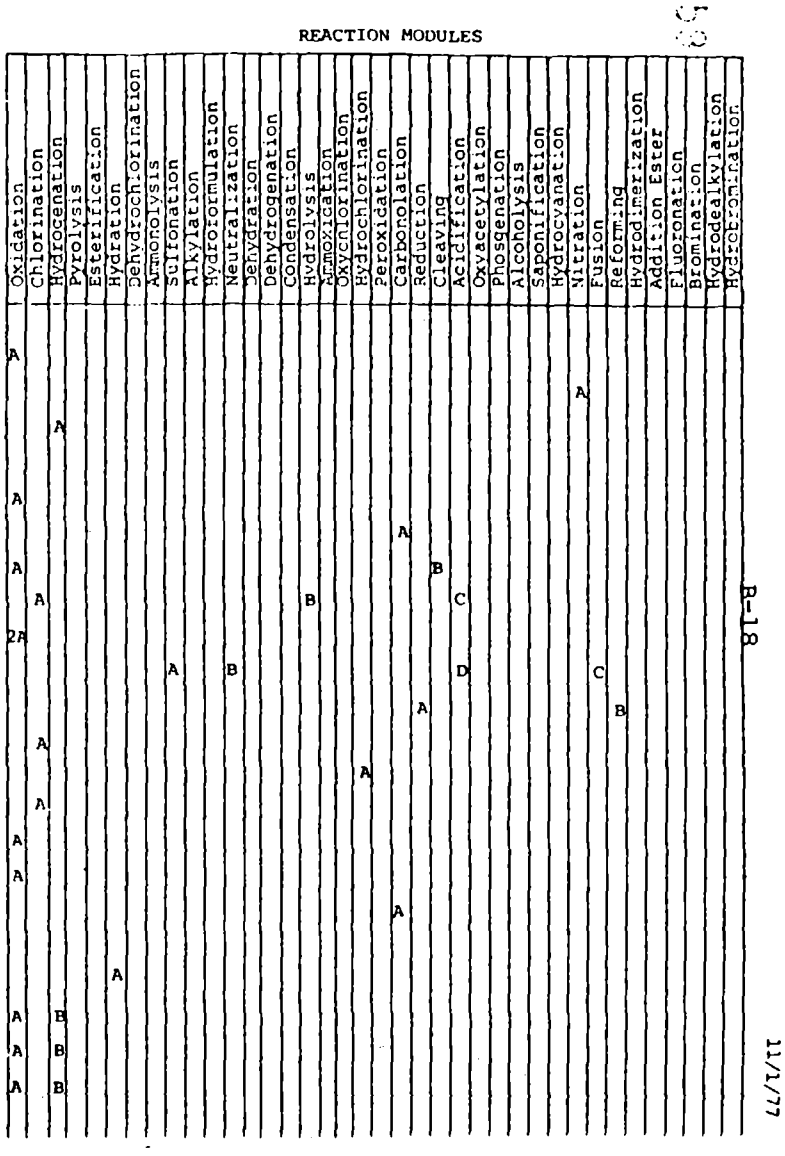




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TABLE II
(Continued)

SURVEY AND RANKING PROCESS STUDIES

| Selection Ranking No. | Chemical | | 1982 % of Total Production | Process | REACTION MODULES |
|---|---|---|---|---|---|
| 21 | Styrene | * | 100% | Ethylbenzene | Hydrogenation A |
| 22 | Chloroprene | | 100% | Butadiene | Chlorination A |
| 23 | Acetic Anhydride | * | 100% | Acetic acid | Oxidation A |
| 24 | Cyclohexanol/Cyclohexanone | * | 75% | Cyclohexane | Oxidation A |
| | | | 25% | Phenol | Pyrolysis A |
| 25 | Allyl Chloride | | 100% | Propylene Chlorination | Chlorination A |
| 26 | Adiponitrile/HMDA | | 65% | Butadiene | Chlorination A; Hydrogenation B |
| | | | 24% | Adipic acid | Ammonolysis A; Dehydrogenation B |
| | | | 11% | Acrylonitrile | Hydrocyanation A |
| 27 | Carbon Tetrachloride | * | 38% | $CS_2$ | Chlorination A |
| | | * | 42% | HC Chlorination | Chlorination A; Pyrolysis B |
| | | * | 20% | Methane | Chlorination A; Neutralization B; Reduction 1 |
| 28 | Vinyl Acetate | * | 72% | Ethylene vapor phase | Oxyacetylation A |
| | | | 15% | Ethylene liquid phase | Oxyacetylation A |
| | | | 13% | Acetylene vapor phase | Addition Ester A |
| 29 | Methylene Chloride | * | 61% | Methanol | Chlorination A |
| | | * | 39% | Methane | Chlorination A |
| 30 | Acetone | * | 60% | Cumene | Oxidation A; Cleaving B |
| | | | 40% | Isopropanol (two separate processes) | Oxidation A; Dehydrogenation A |
| 31 | Methyl Chloride | * | 97% | Methanol | Chlorination A |
| | | * | 3% | Methane | Chlorination A |

*Processes assigned for study

TABLE II
(Continued)

SURVEY AND RANKING PROCESS STUDIES

| Selection Ranking No. | Chemical | | 1982 % of Total Production | Process |
|---|---|---|---|---|
| 32 | Glycerol | | 71% | Epichlorohydrin |
| | | | 15% | Allyl alcohol |
| | | * | 14% | Acrolein |
| 33 | Urea | | 100% | $NH_3/CO_2$ |
| 34 | Acetaldehyde | * | 100% | Ethylene |
| | | | | Ethanol oxidation |
| 35 | Toluene Diisocyanate | | 100% | Diaminotoluene |
| 36 | Ethyl Chloride | | 96% | Ethylene |
| | | | 4% | Ethanol/ethane |
| 37 | Cumene | * | 100% | Benzene |
| 38 | Chlorobenzene | * | 100% | Benzene |
| 39 | Hydrogen Cyanide | | 50% | Andrussow process |
| | | | 50% | Acrylonitrile by-product |
| 40 | Fluorocarbons | | 100% | $CCl_4/C_2Cl_6$ Fluorination |
| 41 | Perchloroethylene | * | 66% | Ethylene dichloride |
| | | * | 34% | HC Chlorination |
| | | | | Acetylene |
| 42 | Butadiene | * | 80% | Ethylene co-product |
| | | * | 13% | n-butane |
| | | * | 7% | n-butenes |
| 43 | Acrolein | * | 100% | Propylene |

*Processes assigned for study

REACTION MODULES

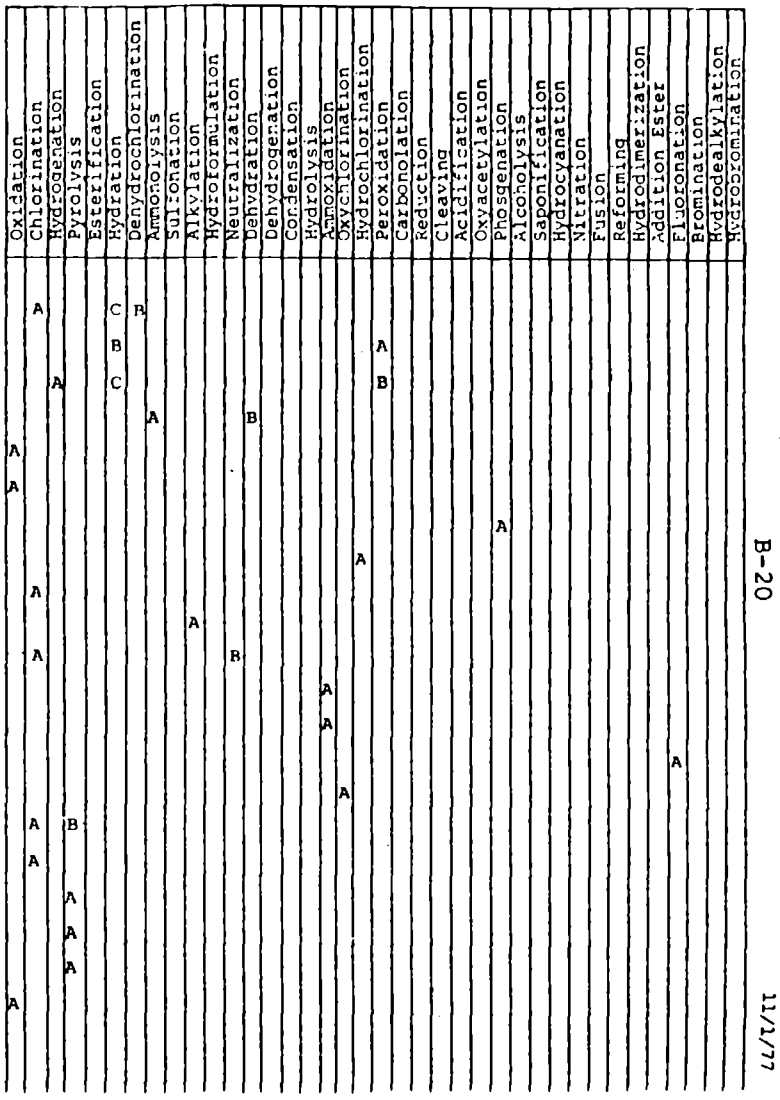

TABLE II
(Continued)

SURVEY AND RANKING PROCESS STUDIES

| Selection Ranking No. | Chemical | | 1982 % of Total Production | Process |
|---|---|---|---|---|
| 44 | Ethanol | | 100% | Ethylene |
| 45 | Chloroform | * | 61% | Methane |
| | | * | 39% | Methanol |
| 46 | Ethanolamines | | 100% | Ethylene oxide |
| 47 | 2-Ethyl Hexanol | | 100% | Oxo |
| 48 | Vinylidene Chloride | * | 50% | 1,1,1 Trichloroethane |
| | | * | 50% | 1,1,2 Trichloroethane |
| 49 | Alkyl Leads | | 95% | Ethyl chloride |
| | | | 5% | Electrolysis |
| 50 | Isopropanol | | 100% | $H_2SO_4$ hydration of propylene |
| 51 | Phthalic Anhydride | | 70% | o-xylene |
| | | | 30% | Napthalene |
| 52 | Methyl Isobutyl ketone | | 100% | Mesityl alcohol |
| 53 | Pentaerythritol | | 100% | HCHO/Acetaldehyde |
| 54 | Sec butanol | | 100% | Butylenes |
| 55 | Bisphenol A | | 100% | Phenol acetone |
| 56 | Trichloroethyene | * | 91% | Ethylene |
| | | | 9% | Acetylene |
| 57 | n-butyraldehyde | | 100% | OXO process |
| 58 | di/tri ethylene glycol | | 100% | Ethylene glycol co-products |

*Processes assigned for study

REACTION MODULES

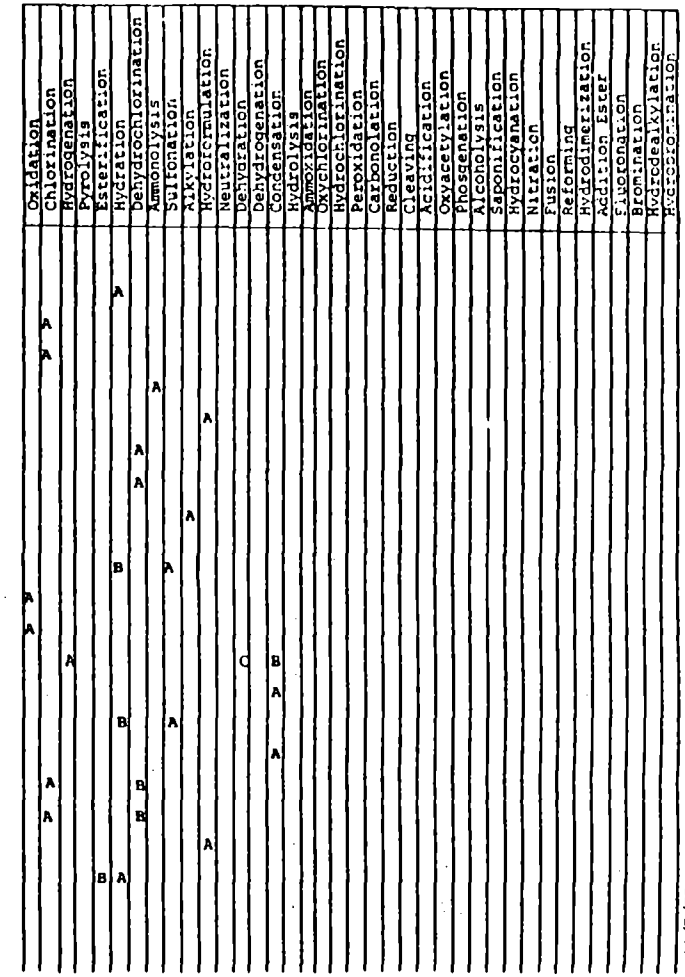


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TABLE II
(Continued)

SURVEY AND RANKING PROCESS STUDIES

| Selection Ranking No. | Chemical | 1982 % of Total Production | Process |
|---|---|---|---|
| 59 | Epichlorohydrin | * 100% | Allyl chloride chlorohydrination |
| 60 | Nonyl Phenol | 100% | Phenol alkylation |
| 61 | Ethyl acrylate | 39% | Direct esterification |
| | | 61% | Acetylene |
| 62 | Ethylene dibromide | 100% | Bromination of ethylene |
| 63 | Acetylene | 62% | Natural gas |
| | | 30% | Calcium carbide (not in scope) |
| | | 8% | Ethylene co-product |
| 64 | n-butanol | 80% | OXO process |
| | | 20% | Acetaldehyde |
| 65 | t-butyl alcohol | 70% | Propylene oxide by-product |
| | | 30% | Isobutylenes |
| 66 | Isoprene | 33% | Isoamylene extraction |
| | | 67% | $C_4$'s (not in scope) |
| 67 | Glycol ethers | * 97% | Ethylene oxide |
| | | 3% | Propylene oxide |
| 68 | Isophthalic acid | 100% | m-xylene oxidation |
| 69 | Ethyl acetate | 100% | Acetic acid |
| 70 | Methyl ethyl ketone | 75% | Sec butanol |
| | | 25% | Butane oxidation |

*Processes assigned for study

REACTION MODULES

| | Oxidation | Chlorination | Hydrogenation | Pyrolysis | Esterification | Hydration | Dehydrochlorination | Ammonolysis | Sulfonation | Alkylation | Hydroformulation | Neutralization | Dehydration | Dehydrogenation | Condensation | Hydrolysis | Ammoxidation | Oxychlorination | Hydrochlorination | Peroxidation | Carbonylation | Reduction | Cleaving | Acidification | Oxyacetylation | Phosgenation | Alcoholysis | Saponification | Hydrovanation | Nitration | Fusion | Reforming | Hydrodimerization | Addition Ester | Fluorination | Bromination | Hydrodealkylation | Hydrochlorination |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 59 | | | | | | | A | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 60 | | | | | | | | | | A | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 61 | | | | | A | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 62 | | | | | | | | | | | | | | | | | | | | | A | | | | | | | | | | | | | | A | | |
| 63 | | | | A | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 64 | | | | A | | | | | | | A | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 65 | A | | B | | | | | | A | | | | | | A | | B | | | | | | | | | | | | | | | | | | | | |
| 66 | | | | | | | | | | | | | | A | | | | | | | | | | | | | | | | | | | | | | | |
| 67 | | | | | | | | | | | | | | | | | | | | | | | | | | | A | | | | | | | | | | |
| 68 | A | | | | | | | | | | | | | | | | | | | | | | | | | A | | | | | | | | | | | |
| 69 | | | | | A | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 70 | A | | | | | | | | | | | | | A | | | | | | | | | | | | | | | | | | | | | | | |

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**TABLE II**
**(Continued)**

**SURVEY AND RANKING PROCESS STUDIES**

| Selection Ranking No. | Chemical | 1982 % of Total Production | Process | REACTION MODULES |
|---|---|---|---|---|
| 71 | Benzoic acid | 100% | Toluene oxidation | A |
| 72 | Adipic acid | 100% | Cyclohexane | 2A |
| 73 | Benzene | 28% | Hydrodealkylation of toluene | A |
| | | 72% | Not in project scope | |
| 74 | Ethylene diamine | 100% | EDC ammonolysis | A |
| 75 | Methyl amines | 100% | Methanol ammonolysis | A |
| 76 | Isobutyl alcohol | 100% | OXO process | A |
| 77 | Phosgene | 100% | Carbon monoxide chlorination | A |
| 78 | Diisodecyl phthalate | 100% | Phthalic anhydride, isodecanol | A B |
| 79 | Isobutyraldehyde | 100% | OXO process | A |
| 80 | Methylene diphenyl | 100% | Diphenyl methane diamine/phosgene | A |
| 81 | Benzyl Chloride | 100% | Toluene chlorination | A |
| 82 | Diethyl ether | 100% | Ethanol based | A |
| 83 | Linear alkyl benzene | * 100% | Benzene | A |
| 84 | Ethyl amines | 100% | Ethanol ammonolysis | A |
| 85 | Chloroacetic acid | 100% | Acetic acid chlorination | A |
| 86 | Linear alkyl sulfonates | 100% | LAB sulfonation | A B C |
| 87 | Formic acid | 98.5% | Butane oxidation | A |
| | | 1.5% | Others | A |
| 88 | Methyl bromide | 100% | Hydrobromination of methanol | A |

Oxidation
Chlorination
Hydrogenation
Pyrolysis
Esterification
Hydration
Dehydrochlorination
Ammonolysis
Sulfonation
Alkylation
Hydroformulation
Neutralization
Dehydration
Dehydrogenation
Condensation
Hydrolysis
Ammoxidation
Oxychlorination
Hydrochlorination
Peroxidation
Carbonolation
Reduction
Cleaving
Acidification
Oxyacetylation
Phosgenation
Alcoholysis
Saponification
Hydrocyanation
Nitration
Fusion
Reforming
Hydrodimerization
Addition Ester
Fluoronation
Bromination
Hydrodealkylation
Hydrobromination

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TABLE II
(Continued)

REACTION MODULES

| Rank No. | Chemical | Process | Oxidation | Chlorination | Hydrogenation | Pyrolysis | Esterification | Hydration | Dehydrochlorination | Ammonolysis | Sulfonation | Alkylation | Hydroformulation | Neutralization | Dehydration | Dehydrogenation | Condensation | Hydrolysis | Ammonization | Oxychlorination | Hydrochlorination | Peroxidation | Carbonolation | Reduction | Cleaving | Acidification | Oxyacetylation | Phosgenation | Alcoholysis | Saponification | Hydrocyanation | Nitration | Fusion | Reforming | Hydroximerization | Addition Ester | Fluorination | Bromination | Hydrogenalkylation | Hydrocyanation | Isomerization |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 89 | Propylene glycols | Propylene oxide hydration | | | | | | A | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 90 | Caprolactam | Cyclohexanone | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | A |
| 91 | Dinitrotoluene | Toluene dinitration | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 2 A | | | | | | | | | |
| 92 | Fumaric acid | Maleic acid isomerization | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | A |
| 93 | Diisoctyl phthalate | Phthalic anhydride | | | | | A | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 94 | Propionic acid | Oxo process | | | | | | | | | | | A | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | LPG oxidation | A | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 95 | Acetone cyanohydrin | Acetone/HCN | | | | | | | | | | | | | | | | | | | | | | | | | | | | | A | | | | | | | | | | |
| 96 | Acrylamide | Acrylonitrile | | | | | | | | | | | | | | | | A | | | | | | | | | | | | | | | | | | | | | | | |
| 97 | Methyl styrene | Cumene byproduct | | | | | | | | | | | | | | A | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | Others | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 98 | Chloronitrobenzenes | Chlorobenzene | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | A | | | | | | | | | |
| 99 | Carbon disulfide | Thacker process | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 100 | Diphenyl | Toluene/Benzene | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | A | | |
| 101 | n-butyl acetate | Butanol/acetic acid | | | | | A | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 102 | Benzophenone | Benzone/carbon tetrachloride | | | | | | | | | | A | | | | | | B | | | | | | | | | | | | | | | | | | | | | | | |
| 103 | Benzyl benzoate | Benzaldehyde | A | | | | B | | | | | | | | | | | | | | | | | A | | | | | | | | | | | | | | | | | |
| | | Benzyl alcohol | | | | | A | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

TABLE II
(Continued)

| Rank No. | Chemical | Process | REACTION MODULES |
|---|---|---|---|
| 104 | Aminoethylethanolamine | Ethylene oxide | A |
| 105 | Chlorosulfuric acid | (Chlorobenzene) | A |
| 106 | Dimethylhydrazine | Dimethylamine | A |
| 107 | n-dimethyl aniline | Aniline/methanol | A |
| 108 | Hexachlorobenzene | Hexachlorocyclohexane | A |
| 109 | Methyl acetate | Acetic acid | A |
| 110 | n-propyl alcohol | Propion aldehyde | C A B |
| 111 | Salicylic acid | Sodium phenate | A B |
| 112 | Diphenylamine | Aniline | A |
| 113 | Acetophenone | Cumene | A B |
| | | Ethylbenzene | A B |
| 114 | Acetyl chloride | Sodium acetate | A |
| 115 | Propylene | Naptha/gas oil | A |
| | | Natural gas/liquids | A |
| | | Refinery byproduct | |
| 116 | Aniline | Nitrobenzene hydrogenation | A |
| 117 | Furfural | Polysaccharides hydrolysis | A |
| 118 | Butyl amines | Butyraldehyde hydrogenation | A A |

TABLE II
(Continued)

| Rank No. | Chemical | Process | REACTION MODULES |
|---|---|---|---|
| 119 | Allyl alcohol | Allyl chloride hydrolysis | |
| | | Propylene glycol dehydration | |
| | | Propylene oxide isomerization | |
| 120 | Pyridine/picoline | Formaldehyde/acetaldehyde | |
| 121 | Cyclohexyl amine | Aniline | |
| | | Cyclohexanone | |
| 122 | Cresylic acids | Phenol methanol | |
| | | Toluene sulfonation | |
| | | Cymene oxidation | |
| | | Natural coal tar | |
| 123 | Crotonaldehyde | Aldo process | |
| 124 | Hydroquinone | Acetone coproduct | |
| 125 | Isodecanol | Oxo process | |
| | | n-paraffin oxidation | |
| 126 | Isooctyl alcohol | Oxo process | |
| 127 | **Cellulose acetate** | Cellulose esterification | |
| 128 | **Isopropyl acetate** | Isopropanol | |
| 129 | Cyclooctadiene | Butadiene | |

TABLE II
(Continued)

| Rank No. | Chemical | Process | REACTION MODULES |
|---|---|---|---|
| 130 | Dinitrophenol | DNC benzene | |
| 131 | Dichlorophenol | Phenol chlorination | |
| 132 | Butyl acrylate | Acrylic acid | |
| 133 | Propyl amines | n-propanol | |
| | | n-propyl chloride | |
| 134 | Dodecene | Nonene coproduct | |
| 135 | Nitro aniline | Nitrochlorobenzene | |
| 136 | Nitrophenol | Phenol nitration | |
| 137 | Ethylene glycol MEE Acetate | Ethoxy ethanol | |
| 138 | Butyric acid | Butyraldehyde | |
| | | Butane oxidation | |
| 139 | Toluene sulfonic acid | Toluene | |
| 140 | Benzoyl chloride | Benzoic acid | |

TABLE III

| No. | Product | Process | Process Modules * | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Distillation | Absorption | Scrubbing/Washing | Extraction | Evaporation | Crystallization | Drying | Screening/Settling | Mixing/Blending | Separating | Filtration | Quenching | Ion Exchange | Dilution |
| 1. | Acrylonitrile | SOHIO Amoxidation | 5 | 1 | | | | | | | | | | 1 | | |
| 2. | Ethylene dichloride | Ethylene oxychlorination | 3 | 1 | 1 | | | | | | | | | 1 | | |
| 3. | Dimethylterephthalate | p-xylene oxidation | 1 | | 2 | | | 4 | 2 | | | | | | | |
| 4. | Vinyl chloride | Ethylene dichloride dehydrochlorination | 6 | 1 | | | | | | | | | | | | |
| 5. | Ethylene oxide | Ethylene oxidation | 3 | 2 | | | | | | | | | | | | 1 |
| 6. | Ethyl benzene | Benzene alkylation | 5 | | | | | | | | | | | | | |
| 7. | Styrene | Ethyl benzene dehydrogenation | 6 | | | | | | | | | 1 | | | | |
| 8. | Maleic anhydride | Benzene oxidation | 1 | 2 | | | 2 | 1 | | | | 1 | 1 | | | |
| 9. | Propylene oxide | Proplyene chlorohydrin | 3 | | 1 | | | | | | | 1 | | | | |
| 10. | Vinyl acetate | Ethylene vapor phase | 9 | 1 | 2 | | | | | | | | | | | |
| 11. | Methyl methacrylate | Acetone hydrocyanation | 4 | | | | | | 1 | | | | | | | |
| 12. | Formaldehyde | Silver catalyst high methanol | 1 | 2 | 1 | | | | | | | | | | 2 | 1 |
| 13. | Ethylene | Hydrocarbon pyrolysis | 8 | 1 | | | | | 1 | | | | | 1 | | |
| 14. | 1,3 butadiene | Hydrocarbon pyrolysis | 10 | 1 | | 2 | 1 | | | | | | | 2 | | |
| 15. | Acrylic acid/esters | Propylene oxidation | 4 | 1 | | 1 | | | | | | | | 1 | | |
| 16. | Cyclohexane | Benzene hydrogenation | 1 | | | | | | | | | 1 | | | | |
| 17. | Acetic acid | Butane oxidation | 7 | 1 | 1 | | | | | | | | | | | |
| 18. | Methanol | High pressure methane synthesis | 2 | | | | | | | | | 1 | | | | |
| 19. | 1.1,1 trichloroethane | Vinylidene chloride chlorination | 5 | 1 | | | | | | | | | | | | |
| 20. | Trichloroethylene | EDC dehydrochlorination | 3 | | | | | | 1 | | | | | | | |
| 21. | Methylene chloride | Methyl chloride chlorination | 2 | | 2 | | | | | | | | | | | |
| 22. | Carbon tetrachloride | Methane chlorination | 4 | | | | | | 1 | | | 3 | | | | |
| 23. | Phenol | Cumene | 9 | | 1 | | | | | | | | | | | |
| 24. | Acetone | Cumene | 9 | | 1 | | | | | | | | | | | |

*Number indicates the number of units associated with the process.

TABLE III
(Continued)

| No. | Product | Process | Process Modules | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Distillation | Absorption | Scrubbing/Washing | Extraction | Evaporation | Crystallization | Drying | Screening/Settling | Mixing/Blending | Separating | Filtration | Quenching | Ion Exchange | Dilution |
| 25. | Chloroform | Methane chlorination | 2 | | 1 | | | | 1 | | | | | | | |
| 26. | Methyl chloride | Methanol chlorination | 2 | | 2 | | | | | | | | | | | |
| 27. | Nitrobenzene/aniline | Benzene nitration | 3 | | 1 | 1 | | | | | | 2 | | | | |
| 28. | Ethylene glycol | Ethylene oxide hydration | 3 | | | | 3 | | 1 | | | | | | | |
| 29. | Glycerol | Allyl chloride - edichlorohydrin | 7 | | 2 | 1 | | | | | | | | | | |
| 30. | Adiponitrile/HMDA | Butadiene chlorination | 1 | | | | | | | | | | | | | |
| 31. | Chloroprene | Butadene chlorination | 3 | 1 | | | 3 | | | | | | | | | |
| 32. | Cyclohexanol/cyclohexanone | Cyclohexane oxidation | 5 | | 2 | | | | | | | | | | | |
| 33. | Acetaldehyde | Ethylene oxidation | 2 | | 1 | | | | | | | 1 | | 1 | | |
| 34. | 2 ethyl 1 hexanol | n-butryaldehyde aldol condensation | 2 | | | | | | 1 | | | | | | | |
| 35. | Toluene diisocyanate | Amine phosgenation | 4 | | | | | | | | | | | | | |
| 36. | Chlorobenzene | Benzene chlorination | 4 | 2 | | | | 1 | | | | | | | | |
| 37. | Ethyl acrylate | Acrylic acid esterification | 4 | | | | | | 1 | | | | | | | |
| 38. | Linear alkyl benzenes/sulfonates | Alkyl benzene sulfonation | 2 | | | | | 1 | 1 | | 1 | 2 | | 1 | | |
| 39. | Acrolein | Propylene oxidation | 3 | | | | | | | | | | | | | |
| 40. | Ethyl chloride | Ethylene/HCl | 3 | | 1 | | | | | | | | | | | |
| 41. | Methyl isobutyl ketone | Acetone dehydration | 5 | 1 | | | | | | | | 3 | | | | |
| 42. | Acetylene | Methane partial oxidation | 8 | 4 | 3 | | | | | | | | | | | |
| 43. | Lead alkyls | Sodium/lead alloying with ethyl chloride | 2 | | 2 | | | | | | | | | | | |

TABLE III
(Continued)



| Rank No. | Chemical | Process | Process Modules | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Distillation | Absorption | Scrubbing/Washing | Extraction | Evaporation | Crystallization | Drying | Screening/Settling | Mixing/Blending | Separating | Filtration | Quenching | Ion Exchange | Dilution |
| 44 | Terephthalic acid | Eastman | 2 | | 1 | | | 2 | 2 | | | | 3 | | | 1 |
| | | Mobil | | | | | | | | | | | | | | |
| | | Amoco | 1 | 1 | | | | 4 | 3 | | | | | | | |
| 45 | Acetic anhydride | Acetic acid | 4 | | 1 | | | | | | | | | | | |
| 46 | Allyl chloride | Propylene | 3 | 2 | | | | | 1 | | | 1 | | | | |
| 47 | Vinyl acetate | Ethylene vapor | 8 | | 2 | | | | | | | 3 | | | 1 | |
| | | Ethylene liquid | | | | | | | | | | | | | | |
| | | Acetylene | 3 | | | | | | | | | | | | | |
| 48 | UREA | Ammonia/carbondioxide | 2 | 1 | | | | 1 | | | | | 1 | | | |
| 49 | Cumene | Benzene alkylation | 2 | | | | | | | | | | | | | |
| 50 | Caprolactam | Cyclohexanone | 2 | | | 1 | | | | | | | | | | 1 |
| 51 | Hydrogen cyanide | Andrussow process | 2 | | 3 | | | | | | | | | | | |
| | | Acrylonitrile byproduct | | | | | | | | | | | | | | |
| 52 | Fluorocarbons | $CCL_4/CH_3CL_3$ Fluorination | 3 | 1 | 1 | | | | 3 | | | 1 | | | | |
| 53 | Ethanol | Ethylene | 4 | 1 | 3 | | | | | | | 2 | | | | |
| 54 | Ethanolamines | Ethylene oxide | 4 | 1 | | | | | | | | | | | | |
| 55 | Vinylidene chloride | 1,1,1 Trichloroethane | | | | | | | | | | | | | | |
| | | 1,1,2 Trichloroethane | | | | | | | | | | | | | | |
| 56 | Isopropanol | Propylene/$H_2SO_4$ | 2 | 1 | 1 | | | | | | | | | | | 1 |
| 57 | Perchloroethylene | Ethylene dichloride | 4 | | 1 | | | | 2 | | | 3 | | | | |
| | | Methane chlorination | 3 | | | | | | | | | | | | | |

TABLE III
(Continued)

| Rank No. | Chemical | Process | Process Modules | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Distillation | Absorption | Scrubbing/Washing | Extraction | Evaporation | Crystallization | Drying | Screening/Settling | Mixing/Blending | Separating | Filtration | Quenching | Ion Exchange | Dilution |
| 58 | Sec-butanol | Butylenes | 2 | | 2 | | | | | | | | | | | 1 |
| 59 | Phthalic anhydride | o-xylene | 3 | | | | | 1 | | | | | 1 | | | |
| | | Napthalene | 2 | | 1 | | | 1 | | | | | 1 | | | |
| 60 | Pentaerythritol | HCHO/Acetaldehyde | | | | 1 | | 1 | 1 | | | | 1 | | | |
| 61 | Bisphenol A | Phenol/acetone | 1 | | 2 | | | | 1 | | | | 1 | 1 | | |
| 62 | n-butyraldehyde | Oxo process | 6 | | | | | | | | | 1 | | | | |
| 63 | Epichlorohydrin | Allyl chloride | 2 | | | | | | | | | | | | | |
| 64 | Di/triethylene glycols | ethylene glycol | 2 | | | | | | | | | | | | | |
| 65 | Dinitrotoluene | Toluene dinitration | 1 | | 1 | | 1 | | | | | | 1 | | | |
| 66 | Nonyl phenol | Phenol alkylation | 2 | | | | | | | | 1 | | | | | |
| 67 | Fumaric acid | Maleic acid isomer | | | | | | 2 | | 1 | | 1 | | | | |
| 68 | Diisooctyl phthalate | Phthalic anhydride | 2 | | 1 | | | | | | | | 1 | | | |
| 69 | Ethylene dibromide | Ethylene bromination | 2 | | 2 | | | | | | | | | | | |
| 70 | n-butanol | Oxo process | 6 | | | | | | | | | 1 | | | | |
| | | Acetaldehyde | 2 | | 2 | | | | | | | 1 | | | | 1 |
| 71 | Tert-butanol | Propylene oxide | | | | | | | | | | | | | | |
| | | Isobutylenes | 2 | | | | | | | | | | | | | 1 |
| 72 | Propylene glycols | Propylene oxide | 2 | | | | 2 | | | | | | | | | |
| 73 | Glycol ethers | Ethylene oxide | 4 | | | | | | | | | | | | | |
| 74 | Isoprene | Isoamylene extraction | 2 | 1 | | | | | | | | | | | | |
| | | $CH_4$ Hydrocarbons | | | | | | | | | | | | | | |

TABLE III
(Continued)

| Rank No. | Chemical | Process | Process Modules | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Distillation | Absorption | Scrubbing/Washing | Extraction | Evaporation | Crystallization | Drying | Screening/Settling | Mixing/Blending | Separating | Filtration | Quenching | Ion Exchange | Dilution |
| 75 | Isophthalic acid | m-xylene oxidation | 1 | | 1 | | | | | | | 1 | 1 | | | |
| 76 | Ethyl acetate | Acetic acid | 3 | | | | | | | | 2 | 1 | | | | |
| 77 | Propionic acid | Oxo process | | | | | | | | | | | | | | |
| | | LPG oxidation | | | | | | | | | | | | | | |
| 78 | Acetone cyanohydrin | Acetone/HCN | 2 | | | | 2 | | | | | | 1 | | | |
| 79 | Benzoic acid | Toluene oxidation | 5 | 1 | 3 | | | | | | 1 | 1 | 1 | | | |
| 80 | Methyl ethyl ketone | Sec-butanol | 2 | | 1 | | | | | | | 2 | | | | |
| | | Butanol oxidation | 3 | | | | | | | | | 2 | | | | |
| 81 | Adipic acid | Cyclohexane | 1 | | | | | 1 | 1 | 1 | 1 | | | | | |
| | | Phenol | 1 | | | | | 1 | 1 | 1 | 1 | | | | | |
| 82 | Benzene | Toluene hydrodealkylation | 3 | 1 | | | | | | | | 1 | | | | |
| | | Not in Scope | | | | | | | | | | | | | | |
| 83 | Acrylamide | Acrylonitrile | | | | | | 1 | | | | | 1 | | 1 | |
| 84 | Methyl styrene | Cumene byproduct | 2 | | | | | | | | | | | | | |
| | | Others | | | | | | | | | | | | | | |
| 85 | Ethylene diamine | EDC ammonolysis | 3 | | | | | | | | | | | | | |
| 86 | Diphenyl methane diisocyanate | Diamide/phosgene | 2 | | | | | | | | | 1 | | | | |
| 87 | Phosgene | $CO/Cl_2$ | | | 2 | | | | | | | | | | | |
| 88 | Methylamines | Methanol ammonolysis | 6 | | 1 | | | | | | | 1 | | | | |
| 89 | Isobutanol | Oxo process | 6 | | | | | | | | | 1 | | | | |

TABLE III
(Continued)

| Rank No. | Chemical | Process | Process Modules | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Distillation | Absorption | Scrubbing/Washing | Extraction | Evaporation | Crystallization | Drying | Screening/Settling | Mixing/Blending | Separating | Filtration | Quenching | Ion Exchange | Dilution |
| 90 | Diisodecyl phthalate | Toluene | 2 | | 1 | | | | | | | 1 | | | | |
| 91 | Isobutyraldehyde | Oxo process | 6 | | | | | | | | | 1 | | | | |
| 92 | Benzyl chloride | Toluene chlorination | 2 | | | | | | | | 1 | | | | | |
| 93 | Chloronitrobenzenes | Chlorobenzene | 1 | | | | | 2 | | | | | | | | |
| 94 | Diethyl ether | Ethanol | 2 | | 1 | | | | | | | | | | | |
| 95 | Ethylamines | Ethanolammonolysis | 4 | | | | | | | | | | | | | |
| 96 | Carbon disulfide | Methane/sulfur | 3 | | 2 | | | | | | | | | | | |
| 97 | Chloroacetic acid | Acetic acid | | | | | | 1 | 1 | | | | 1 | | | |
| 98 | Formic acid | Butane oxidation | 2 | | 1 | | | | | | | | | | | |
| | | Others | 2 | | | | | | | | | 1 | | | | |
| 99 | Biphenyl | Toluene/benzene | 3 | 1 | | | | | | | | 1 | | | | |
| 100 | n-butyl acetate | Butanol/acetic acid | 2 | | | | | | | | 1 | 1 | | | | |
| 101 | Methyl bromide | Methanol hydrobromination | 1 | | | | | | 1 | | 1 | | | | | |
| 102 | Benzo phenone | Benzene/$CCl_4$ | 2 | 1 | | | | 1 | | 1 | | | | | | |
| 103 | Beyzyl benzoate | Benzaldehyde | | | | | | | | | | | | | | |
| | | Benzyl alcohol | | | | | | | | | | | | | | |
| 104 | Amino ethyl ethanolamine | Ethylene oxide | 5 | 1 | | | 1 | | | | | | | | | |
| 105 | Chlorosulfonic acid | Chlorobenzene | | | | | | | | | | | | | | |
| 106 | Dimethyl hydrazine | Dimethyl amine | | | | | | | | | | | | | | |
| 107 | n-n dimethyl aniline | Aniline/methanol | | | | | | | | | | | | | | |

TABLE III
(Continued)

| Rank No. | Chemical | Process | Process Modules: Distillation | Absorption | Scrubbing/Washing | Extraction | Evaporation | Crystallization | Drying | Screening/Settling | Mixing/Blending | Separating | Filtration | Quenching | Ion Exchange | Dilution |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 108 | Hexachlorobenzene | Hexachlorocyclohexane | | | | | | | | | | | | | | |
| 109 | Methyl acetate | Acetic acid/methanol | 2 | | 1 | | | | 1 | | | | | | | |
| 110 | n-propyl alcohol | Propionaldehyde | 4 | | | | | | | | | 3 | | | | |
| 111 | Salicylic acid | Sodium phenate | 2 | | 1 | | | 1 | 1 | | | | 1 | | | |
| 112 | Diphenylamine | Aniline | 1 | | | | | | | | | 1 | | | | |
| 113 | Acetophenone | Cumeme | 4 | | 1 | | | 1 | | | | | | | | |
| | | Ethyl benzene | 2 | | | 1 | | | | | | | | | | |
| 114 | Acetyl chloride | Sodium acetate | | | | | | | | | | | | | | |
| 115 | Propylene | Naptha/gas oil | 8 | 1 | | | | | 1 | | | | | 1 | | |
| | | Natural gas/liquids | 8 | 1 | | | | | 1 | | | | | 1 | | |
| | | Refinery byproduct | | | | | | | | | | | | | | |
| 116 | Aniline | Nitrobenzene hydrogenation | 2 | | | 1 | | | | | | 1 | | | | |
| 117 | Furfural | Polysacchrides hydrolysis | 3 | | | | | | 1 | 1 | | | 1 | | | |
| 118 | Butylamines | Butyraldehyde | 4 | | | | | | | | | | | | | |
| 119 | Allyl alcohol | Allyl chloride hydrolysis | | | | | | | | | | | | | | |
| | | Propylene glycol dehydration | | | | | | | | | | | | | | |
| | | Propylene oxide | | | | | | | | | | | | | | |
| 120 | Pyridine/picoline | HCHO/Acetaldehyde | | | | | | | | | | | | | | |
| 121 | Cyclohexylamine | Aniline | | | | | | | | | | | | | | |
| | | Cyclohexanone | | | | | | | | | | | | | | |

TABLE III
(Continued)

| Rank No. | Chemical | Process | Process Modules | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Distillation | Absorption | Scrubbing/Washing | Extraction | Evaporation | Crystallization | Drying | Screening/Settling | Mixing/Blending | Separating | Filtration | Quenching | Ion Exchange | Dilution | |
| 122 | Cresylic acids | Phenol/methanol | 7 | | | 1 | 1 | | | | | 1 | | | | | |
| | | Toluene sulf | 2 | | | | | | | | | | | | | | |
| | | Cumene oxidation | 2 | | | | | | | | | | | | | | |
| | | Natural coal tar | 6 | | 1 | | 1 | | | | | | | | | | |
| 123 | Crotonaldehyde | Aldo process | 4 | | 1 | | | | | | | 1 | 1 | | | | |
| 124 | Hydroquinone | Acetone coproduct | 2 | | 1 | | | 1 | | | | | 2 | | | | |
| 125 | Isodecanol | Oxo process | 4 | | 2 | | | | | | | 3 | | | | | |
| | | n-paraffin oxidation | | | | | | | | | | | | | | | |
| 126 | Cellulose acetate | Esterification | 1 | | 1 | | | | 2 | | 1 | 2 | 2 | | | | |
| 127 | Isopropyl acetate | Isopropanol | 4 | | | | | | | | 1 | 2 | | | | | |
| 128 | Cyclooctadiene | Butadiene | 2 | | | | | | | | | | | | | | |
| 129 | Dinitrophenol | DNC Benzene | | | | | | | | | | | | | | | |
| 130 | Dichlorophenol | Phenol chlorination | | | | | | | | | | | | | | | |
| 131 | Butyl acrylate | Acrylic acid | 4 | | | | | | 1 | | | | | | | | |
| 132 | Propyl amines | n-propanol | 4 | | | | | | | | | | | | | | |
| | | n-propychloride | | | | | | | | | | | | | | | |
| 133 | Dodecene | Nonene coproduct | | | | | | | | | | | | | | | |
| 134 | Nitroaniline | Nitrochlorobenzene | | | | | | | | | | | | | | | |
| 135 | Nitrophenol | Phenol nitration | 1 | 1 | | 1 | | | | | | | | | 1 | | |
| 136 | Ethylene glycol MEE acetate | Ethoxy ethanol | 1 | | | | | | | | | 1 | | | | | |

TABLE III
(Continued)

| Rank No. | Chemical | Process | Distillation | Absorption | Scrubbing/Washing | Extraction | Evaporation | Crystallization | Drying | Screening/Settling | Mixing/Blending | Separating | Filtration | Quenching | Ion Exchange | Dilution |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Process Modules | | | | | | | | | | | | | |
| 137 | Butyric acid | Butyraldehyde | 1 | | | | | | | | | 1 | | | | |
| | | Butane oxidation | 2 | 1 | 1 | | | | | | | | | | | |
| 138 | Toluene sulfonic acid | Toluene | | | | | | | | | | | | | | |
| 139 | Benzoyl chloride | Benzoic acid | | | | | | | | | | | | | | |
| 140 | Isooctyl alcohol | Oxo process | 4 | | 2 | | | | | | | | | | | |

TABLE IV

EMISSION CONTROL MODULES

| Selection Ranking No. | Chemical | Process | Vent Restriction | Droplet Separation | Surface Condensation | Quench Condensation | Contact Condensation | Compression Condensation | Solvent Absorption | Solvent Absorption/Stripping | Chemical Absorption | Carbon Adsorption | Molecular Sieve | Combustion | Vapor Thermal Oxidizer | Liquid Thermal Oxidizer | Particulate Removal |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | Acrylonitrile | Propylene Ammoxidation | | X | X | | X | | | | | | | X | X | | |
| 2. | Ethylene Dichloride | Oxychlorination | | X | X | | | | | | | X | | X | X | | |
| | | Direct Chlorination | | X | X | | | | | | | X | | X | X | | |
| 3. | Ethylene Oxide | Air Oxidation/Ethylene | | | | | X | | | | | | X | X | X | | |
| | | $O_2$ Oxidation/Ethylene | | | | | X | | | | | | X | X | X | | |
| 4. | Vinyl Chloride | Ethylene Dichloride Acetylene | | | X | | | | | | | X | | X | X | | |
| 5. | Ethylene | H C Cracking | | X | X | | | | | | | | | X | X | | X |
| 6. | Ethyl Benzene | Benzene Alkylation Mixed Xylenes | | | X | | X | | | | | | | X | X | | |
| 7. | Dimethyl Terephthalate | Hercules | | | X | | | | X | | | | | X | X | | X |
| | | Dupont | | | X | | | | X | | | | | X | X | | X |
| | | Amoco via TPA | | | X | | | | X | | | | | X | X | | X |
| | | Eastman via TPA | | | X | | | | X | | | | | X | X | | X |
| 8. | Maleic Anhydride | Benzene Oxidation | | | X | | | | X | | X | X | | X | X | | |
| | | Butane Oxidation | | | | | | | | | | | | | | | |

TABLE IV
(continued)

EMISSION CONTROL MODULES

| Selection Ranking No. | Chemical | Process | Vent Restriction | Droplet Separation | Surface Condensation | Quench Condensation | Contact Condensation | Compression Condensation | Solvent Absorption | Solvent Absorption/Stripping | Chemical Absorption | Carbon Adsorption | Molecular Sieve | Combustion | Vapor Thermal Oxidizer | Liquid Thermal Oxidizer | Particulate Removal |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 9. | Propylene Oxide | Chlorohydrin | | | | | X | | | | | | | X | X | | |
| | | Peroxidation | | | | | | | | | | | | | | | |
| 10. | Methyl Methacrylate | Acetone Cyanohydrin | | | | | X | | | | X | | | X | | X | |
| 11. | Formaldehyde | Silver Catalyst | | X | X | | X | | | | X | | | | X | X | |
| | | Metal Oxide | | X | X | | X | | | | X | | | | X | X | |
| 12. | Nitrobenzene/Aniline | Benzene | | | | | X | | | | | | | | | | |
| 13. | Acrylic Acid | Propylene Oxidation | | | X | | | | | | X | | | X | X | | |
| | | Acetylene (Reppe) | | | X | | | | | | X | | | X | X | | |
| 14. | Phenol | Cumene | | | X | | | | | | | | | X | | | |
| | | Benzene Chlorination | | | | | | | | | | | | | | | |
| | | Toluene Oxidation | | | | | | | | | | | | | | | |
| | | Benzene Sulfonation | | | | | | | | | | | | | | | |
| 15. | Cyclohexanol/Cyclohexanone | Cyclohexanone | | | X | | X | | | | X | | | X | X | | |
| | | Phenol | | | | | | | | | | | | | | | |
| 16. | Methyl Alcohol (Methanol) | Methane | X | | X | | | | | | | | | X | | | |

TABLE IV
(Continued)

EMISSION CONTROL MODULES

| Selection Ranking No. | Chemical | Process | Vent Restriction | Droplet Separation | Surface Condensation | Quench Condensation | Contact Condensation | Compression Condensation | Solvent Absorption | Solvent Absorption/Stripping | Chemical Absorption | Carbon Adsorption | Molecular Sieve | Combustion | Vapor Thermal Oxidizer | Liquid Thermal Oxidizer | Particulate Removal |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 17. | 1,1,1 Trichloroethane | Vinyl Chloride | X | | X | | | | | | X | | | | | X | |
| | | Vinylidene Chloride | | | | | | | | | | | | | | | |
| 18. | Ethylene Glycol | Ethylene Oxide | | | X | | | | | | | | | | X | | X |
| 19. | Acetic Acid | Acetaldehyde | | | | | | | | | | | | | | | |
| | | Butane Oxidation | X | | X | | | | | | | | | X | X | | |
| | | Methanol/CO | | | | | | | | | | | | | | | |
| | | Others | | | | | | | | | | | | | | | |
| 20. | Terephthalic Acid | Mobil | | | | | | | | | | | | | | | |
| | | Eastman | | | | | | | | | | | | | | | |
| | | Amoco | | | | | | | | | | | | | | | |
| 21. | Styrene | Ethylbenzene | | | | | X | | | | | | | X | X | | |
| 22. | Chloroprene | Butadiene | | | X | | | | | | X | | | X | | X | |
| 23. | Acetic Anhydride | Acetic Acid | | | | | | | | | | | | | | | |
| 24. | Allyl Chloride | Propylene | | | X | | X | | | | X | | | X | | | |
| 25. | Vinyl Acetate | Ethylene Vapor | | | | | | | | | | | | X | | X | |
| | | Ethylene Liquid | | | | | | | | | | | | | | | |
| | | Acetylene | | | | | | | | | | | | | | | |
| 26. | Adiponitrile/HMDA | Butadiene | | | X | | X | | | | X | | | X | | | |
| | | Adipic Acid | | | | | | | | | | | | | | | |
| | | Acrylonitrile | | | | | | | | | | | | | | | |

TABLE IV
(Continued)

EMISSION CONTROL MODULES

| Selection Ranking No. | Chemical | Process | Vent Restriction | Droplet Separation | Surface Condensation | Quench Condensation | Contact Condensation | Compression Condensation | Solvent Absorption | Solvent Absorption/Stripping | Chemical Absorption | Carbon Adsorption | Molecular Sieve | Combustion | Vapor Thermal Oxidizer | Liquid Thermal Oxidizer | Particulate Removal |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 27. | Carbon Tetrachloride | Carbon Disulfide | | | | | | | | | | | | | | | |
| | | Chloro Paraffins | | | | | | | | | | | | | | | |
| | | Methane | | | X | | | | | | X | | | | | X | |
| 28. | Glycerol | Epichlorohydrin | | | | | | | | | | | | | | | |
| | | Allyl Alcohol | | | | | | | | | X | | | | | | |
| | | Acrolein | | | | | | | | | | | | | | | |
| 29. | Acetone | Cumene | | | X | | | | | | | | | X | | | |
| | | Isopropanol | | | | | | | | | | | | | | | |
| 30. | Urea | $NH_3/CO$ | | | | | | | | | | | | | | | X |
| 31. | Toluene Diisocyanate | Diamino Toluene | | | | | X | | | | X | | | X | X | X | |
| 32. | Propylene Glycols | Propylene Oxide | | | | | | | | | | | | | | | |
| 33. | Acetaldehyde | Ethylene | | | | | X | | | | | | | | | | |
| | | Ethanol | | | | | X | | | | | | | | | | |
| 34. | Ethyl Chloride | Ethylene | | | X | | X | | | | | | | | | X | |
| | | Ethanol/Ethane | | | | | | | | | | | | | | | |
| 35. | Methylene Chloride | Methane | | | X | | | | | | X | | | | | X | |
| | | Methanol | | | X | | | | | | X | | | | | X | |
| 36. | Butadiene | Ethylene Coproduct | | X | X | | | | | | | | | X | X | | X |
| | | n-butane | | | X | | | | | | X | | | X | X | | |
| | | n-butenes | | | X | | | | | | X | | | X | X | | |

TABLE IV
(Continued)

EMISSION CONTROL MODULES

| Selection Ranking No. | Chemical | Process | Vent Restriction | Droplet Separation | Surface Condensation | Quench Condensation | Contact Condensation | Compression Condensation | Solvent Absorption | Solvent Absorption/Stripping | Chemical Absorption | Carbon Adsorption | Molecular Sieve | Combustion | Vapor Thermal Oxidizer | Liquid Thermal Oxidizer | Particulate Removal |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 37. | Cumene | Benzene Alkylation | X | | X | | | | | | X | | | X | | | |
| 38. | Chlorobenzenes | Benzene Chlorination | | X | | | X | | | | | | | | | | |
| 39. | Chloroform | Methane | | | X | | | | | | X | | | | | X | |
| | | Methanol | | | | | | | | | | | | | | | |
| 40. | Caprolactam | Cyclohexanone | | | | | | | | | | | | | | | |
| 41. | Hydrogen Cyanide | Andrussow Process | | | | | | | | | | | | X | X | | |
| | | Acrylonitrile | | | | | | | | | | | | X | X | | |
| 42. | Fluorocarbons | $CCl_4/C_2Cl_6$ Fluoro. | | | | | X | | | | X | | | X | | | |
| 43. | Acrolein | Propylene Oxidation | | | | | X | | | | | | | | | | |
| 44. | Ethyl Alcohol | Ethylene | | | X | | | | | | | | | X | | | X |
| 45. | Ethanol Amines | Ethylene Oxide | | | | | | | | | | | | X | | | |
| 46. | Vinylidene Chloride | 1,1,1 Trichloro Ethane | X | | | | | | | | | | | | | | |
| | | 1,1,1 Trichloro Ethane | | | | | | | | | | | | | | | |
| 47. | Alkyl Leads | Ethyl Chloride | | | X | | | | | | | | | X | | | |
| | | Electrolysis | | | | | | | | | | | | | | | |
| 48. | Isopropanol | Propylene/$H_2SO_4$ | | | X | | | X | | | | | | X | | | X |
| 49. | Methyl Isobutyl Ketone | Mesityl Alcohol | X | | X | | X | | | | | | | X | | | X |
| 50. | Perchloroethylene | Ethylene Dichloride | | | X | | | | | | X | | | | | X | |
| | | Methane | | | | | | | | | | | | | | | |

TABLE IV
(Continued)

EMISSION CONTROL MODULES

| Selection Ranking No. | Chemical | Process | Vent Restriction | Droplet Separation | Surface Condensation | Quench Condensation | Contact Condensation | Compression Condensation | Solvent Absorption | Solvent Absorption/Stripping | Chemical Absorption | Carbon Adsorption | Molecular Sieve | Combustion | Vapor Thermal Oxidizer | Liquid Thermal Oxidizer | Particulate Removal |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 51. | Sec-butanol | Butylenes | | | X | | | | | | X | | | X | | | |
| 52. | Phthalic Anhydride | o-xylene | | | | | | | | | | | | | | | |
| | | Napthalene | | | | | | | | | | | | | | | |
| 53. | Pentaerythritol | HCHO/Acetaldehyde | | | X | | | | | | | | | | | | X |
| 54. | Bisphenol A | Phenol/Acetone | X | | | | | | | | X | | | | | | X |
| 55. | n-Butyraldehyde | Oxo Process | | | X | | | | | | X | | | X | | | |
| 56. | Cyclohexane | Benzene | | | X | | | | | | X | | | X | X | | |
| | | Petroleum Distillation | | | | | | | | | | | | | | | |
| 57. | Epichlorohydrin | Allyl Chloride | | | | | | | X | | X | | | | | | |
| 58. | di/Triethylene Glycols | Ethylene Glycol | | | | | | | | | X | | | | | | |
| 59. | Dinitro Toluene | Toluene Dinitration | X | | | | | | X | | X | | | | X | | |
| 60. | Nonyl Phenol | Phenol Alkylation | | | | | | | | | | | | | | | |
| 61. | Fumaric Acid | Maleic Acid Isomer | | | | | | | | | | | | | | X | X |
| 62. | 2-Ethyl Hexanol | Aldo Condensation | | | X | | | | | | | | | X | | | |
| 63. | Ethyl Acrylate | Esterification | | | X | | | | | | | | | X | X | | |
| | | Acetylene | | | | | | | | | | | | | | | |
| 64. | Trichloroethylene | Ethylene | X | | X | | | | | | X | | | | | X | |
| | | Acetylene | | | | | | | | | | | | | | | |
| 65. | Methyl Chloride | Methanol | | | X | | | | | | X | | | | | X | |
| | | Methane | | | | | | | | | | | | | | | |

TABLE IV
(Continued)

EMISSION CONTROL MODULES

| Selection Ranking No. | Chemical | Process | Vent Restriction | Droplet Separation | Surface Condensation | Quench Condensation | Contact Condensation | Compression Condensation | Solvent Absorption | Solvent Absorption/Stripping | Chemical Absorption | Carbon Adsorption - | Molecular Sieve | Combustion | Vapor Thermal Oxidizer | Liquid Thermal Oxidizer | Particulate Removal |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 66. | Diisooctyl Phthalate | Phthalic Anhydride | | | | | | | | | | | | | | X | |
| 67. | Ethylene Dibromide | Ethylene Bromination | | | | | | | | | | | | | | | |
| 68. | Acetylene | H.C. Oxidation | | | X | | X | | | | X | | | X | | | |
| | | Calcium Carbide | | | | | | | | | | | | | | | |
| | | Ethylene | | | | | | | | | | | | | | | |
| 69. | n-Butanol | Oxo Process | | | X | | | | X | | | | | X | | | |
| | | Acetaldehyde | | | | | | | | | | | | | | | |
| 70. | t-Butanol | Propylene Oxide | | | | | | | | | | | | | | | |
| | | Isobutylenes | | | | | | | | | | | | | | | |
| 71. | Glycol Ethers | Ethylene Oxide | | | | | | | | | X | | | | | | |
| | | Propylene Oxide | | | | | | | | | X | | | | | | |
| 72. | Isoprene | Isoamylene Extraction | | | | X | | | | | | | | X | X | | |
| | | $C_4$ Hydrocarbons | | | | X | | | | | | | | X | X | | |
| 73. | Isopthalic Acid | m-Xylene Oxidation | | | | | | | | | | | | | | | |
| 74. | Ethyl Acetate | Acetic Acid | | | | | | | | | | | | | | X | |
| 75. | Propionic Acid | Oxo Process | | | X | | | | | | X | | | X | | | |
| | | LPG Oxidation | | | | | | | | | | | | | | | |
| 76. | Acetone Cyanohydrin | Acetone/HCN | | | | | | | | | X | | | X | | | |
| 77. | Benzoic Acid | Toluene Oxidation | | | | | | | | | | | | | | | |

TABLE IV
(Continued)

EMISSION CONTROL MODULES

| Selection Ranking No. | Chemical | Process | Vent Restriction | Droplet Separation | Surface Condensation | Quench Condensation | Contact Condensation | Compression Condensation | Solvent Absorption | Solvent Absorption/Stripping | Chemical Absorption | Carbon Adsorption | Molecular Sieve | Combustion | Vapor Thermal Oxidizer | Liquid Thermal Oxidizer | Particulate Removal |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 78. | Methyl Ethyl Ketone | Sec-butanol | | | | X | | | | | X | | | X | | X | X |
| | | Butane Oxidation | | | | | | | | | | | | | | | |
| 79. | Adipic Acid | Cyclohexane | X | X | | | | | X | | X | | | | X | | X |
| | | Phenol | | | | | | | | | | | | | | | |
| 80. | Benzene | Toluene Hydrode Alkylation | X | | X | | | | X | | | | | X | | | |
| | | Not in Project Scope | | | | | | | | | | | | | | | |
| 81. | Acrylamide | Acrylonitrile | | | | | | | | | | | | | | | |
| 82. | α-Methyl Styrene | Cumens Product | | | X | | | | | | | | | X | | X | |
| | | Others | | | | | | | | | | | | | | | |
| 83. | Ethylene Diamine | EDC Ammonolysis | X | | | | | | | | X | | | | | | |
| 84. | Methylene Diisocyanate | Diamide/Phosgene | | | | | | | X | X | X | | | | | | |
| 85. | Phosgene | $CO/Cl_2$ | | | | | | | | | X | | | X | X | | |
| 86. | Methyl Amines | Methanol Ammonolysis | X | | X | | | X | | | X | | | | | | |
| 87. | Isobutanol | Oxo Process | | | X | | | | | | X | | | X | | | |
| 88. | Diisodecyl Phthalate | P.A./Isodecanol | | | | | | | | | | | | | | X | |
| 89. | Isobutyraldehyde | Oxo Process | | | X | | | | | | X | | | X | | | |
| 90. | Benzyl Chloride | Toluene Chlorination | | | | | | | | | | | | | | | |
| 91. | Chloronitro Benzenes | Chlorobenzene | | | X | | X | | | | X | | | | | | |
| 92. | Diethyl (Ethyl) Ether | Ethanol | | | | | | | | | | | | X | | | X |

TABLE IV
(Continued)

EMISSION CONTROL MODULES

| Selection Ranking No. | Chemical | Process | Vent Restriction | Droplet Separation | Surface Condensation | Quench Condensation | Contact Condensation | Compression Condensation | Solvent Absorption | Solvent Absorption/Stripping | Chemical Absorption | Carbon Absorption | Molecular Sieve | Combustion | Vapor Thermal Oxidizer | Liquid Thermal Oxidizer | Particulate Removal |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 93. | Linear Alkyl Benzene | Benzene Alkylation | | | | | X | | | | | | | | | | |
| 94. | Ethyl Amines | Ethanol Ammonolysis | | | | | | | | | | | | | | | |
| 95. | Carbon Disulfide | Methane/Sulfur | | | | | | | X | | X | | | | | | |
| 96. | Chloro Acetic Acid | Acetic Acid | | | | | | | | | | | | | | | |
| 97. | Linear Alkyl Sulfonates | LAB Sulfonation | | | | | X | | | | | | | | | | X |
| 98. | Formic Acid | Butane Oxidation | | | X | | | | | | | | | | | | |
| | | Others | | | | | | | | | | | | | | | |
| 99. | Methyl Bromide | Methanol/HBr | | | | | | | | | | | | | | | |
| 100. | Biphenyl | Toluene/Benzene | X | | X | | | | X | | | | | X | | | |
| 101. | n-Butyl Acetate | Butanol/HOAC | | | | | | | | | X | | | X | | | |

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DGL

TABLE IV
(Continued)

| Rank No. | Chemical | Process | Control Modules: Vent Restriction | Droplet Separation | Surface Condensation | Quench Condensation | Contact Condensation | Compression Condensation | Solvent Absorption | Solvent Absorption/Stripping | Chemical Absorption | Carbon Adsorption | Molecular Sieve | Combustion | Vapor Thermal Oxidizer | Liquid Thermal Oxidizer | Particulate Removal |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 102 | Benzo phenone | Benzene/carbon tetrachloride | | | | | | | | | | | | | | | |
| 103 | Benzyl benzoate | Benzaldehyde | | | | | | | | | | | | | | | |
| | | Benzyl alcohol | | | | | | | | | | | | | | | |
| 104 | Aminoethylethanolamine | Ethylene oxide | | X | | | | | | | | | | | | X | |
| 105 | Chlorosulfuric acid | (Chlorobenzene) | | | | | | | | | | | | | | | |
| 106 | Dimethyl hydrazine | | | | | | | | | | | | | | | | |
| 107 | n-dimethyl aniline | Aniline/methanol | | | | | | | | | | | | | | | |
| 108 | Hexachlorobenzene | Hexachloro cyclohexane | | X | | | X | | | | | | | | | | |
| 109 | Methyl acetate | Acetic acid | | | | | | | | | | | | | | | |
| 110 | n-propyl alcohol | Propionaldehyde | | | | | | | | | | | | X | | | |
| 111 | Salicylic acid | Sodium phenate | | | | | | | | | | | | | | | X |
| 112 | Diphenylamine | Aniline | | | | | | | | | | | | | | | |
| 113 | Acetophenone | Cumene | | | X | | | | | | | | | X | | | |
| | | Ethylbenzene | | | | | | | | | | | | | | | |
| 114 | Acetychloride | Sodium acetate | | | | | | | | | | | | | | | |
| 115 | Propylene | Naptha/gas oil | | X | X | | | | | | | | | X | X | | X |
| | | Natural gas/liquid | | X | X | | | | | | | | | X | X | | X |
| | | Refinery byproduct | | | | | | | | | | | | | | | |

TABLE IV
(Continued)

| Rank No. | Chemical | Process | Control Modules | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Vent Restriction | Droplet Separation | Surface Condensation | Quench Condensation | Contact Condensation | Compression Condensation | Solvent Absorption | Solvent Absorption/Stripping | Chemical Absorption | Carbon Adsorption | | Molecular Sieve | Combustion | Vapor Thermal Oxidizer | Liquid Thermal Oxidizer | Particulate Removal | |
| 116 | Aniline | Nitrobenzene hydrogenation | | | | | X | | | | | | | | | | | | |
| 117 | Furfural | Polysaccahrides hydrolysis | | | | | | | | | | | | | | | | | |
| 118 | Butylamines | Butyraldehyde | X | | X | | | X | | | X | | | | | | | | |
| 119 | Allyl alcohol | Allyl chloride hydrolysis | | | X | | X | | | | X | | | | X | | | | |
| | | Propylene glycol | | | | | | | | | | | | | | | | | |
| | | Propylene oxide | | | | | | | | | | | | | X | | | | |
| 120 | Pyridine/picoline | HCHO/acetaldehyde | | | X | | | | | | | | | | X | | | | |
| 121 | Cyclohexylamine | Aniline | | | X | | | | | | X | | | | | | | | |
| | | Cyclohexanone | | | X | | | | | | X | | | | | | | | |
| 122 | Cresylic acids | Phenol/methanol | | | | | | | | | | | | | | X | X | | |
| | | Toluene sulfonation | | | | | | | | | | | | | | X | | | |
| | | Cumene oxidation | | | | | | | | | | | | | | X | | | |
| | | Natural coal tar | | | | | | | | | | | | | | X | | | |
| 123 | Crotonaldehyde | Aldo process | | | | | | | | | | | | | | | | | |
| 124 | Hydroquinone | Acetone coproduct | | | X | | | | | | | | | | X | | | | |
| 125 | Isodecanol | Oxo process | | | | | | | | | | | | | X | | | | |
| | | n-paraffin oxidation | | | | | | | | | | | | | X | | | | |
| 126 | Isooctyl alcohol | Oxo process | | | X | | | | | | | | | | | | | | |

TABLE IV
(Continued)

| Rank No. | Chemical | Process | Control Modules: Vent Restriction | Droplet Separation | Surface Condensation | Quench Condensation | Contact Condensation | Compression Condensation | Solvent Absorption | Solvent Absorption/Stripping | Chemical Absorption | Carbon Adsorption | Molecular Sieve | Combustion | Vapor Thermal Oxidizer | Liquid Thermal Oxidizer | Particulate Removal |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 127 | Cellulose acetate | Cellulose esterification | | | | | X | | | | | | | | | | |
| 128 | Isopropyl acetate | Isopropanol | | | | | | | | | | | | | | | |
| 129 | Cyclooctadiene | Butadiene | | | | | | | | | | | | | | | |
| 130 | Dinitrophenol | Dinitrochlorobenzene | | | | | | | | | | | | | | | |
| 131 | Dichlorophenol | Phenol chlorination | | | | | | | X | | | | | | | | |
| 132 | Butyl acrylate | Acrylic acid | | | | | | | | | | | | | | | |
| 133 | Propylamines | n-propanol | X | | X | | | X | | | X | | | | | | |
| | | n-propylchloride | X | | X | | | X | | | X | | | | | | |
| 134 | Dodecene | Nonene coproduct | | | | | | | | | | | | X | | | |
| 135 | Nitroaniline | Nitrochlorobenzene | | | | | | | | | | | | | | | |
| 136 | Nitrophenol | Phenol nitration | | | | | | | | | | | | | | | |
| 137 | Ethylene glycol MEE acetate | Ethoxy ethanol | | | | | | | | | | | | | | | |
| 138 | Butyric acid | Butyraldehyde | | | | | | | | | | | | | | | |
| | | Butane oxidation | | | | | | | | | | | | | | | |
| 139 | Toluene sulfonic acid | Toluene | | X | | | | | | | X | | | | | | |
| 140 | Benzoyl chloride | Benzoid acid | | | | | | | | | | | | | | | |

# APPENDIX C

## ESTIMATES OF TOTAL SOCMI VOC EMISSIONS FOR 1982

ESTIMATES OF TOTAL SOCMI VOC EMISSIONS FOR 1982



A. INITIAL EMISSIONS ESTIMATE

Basis: Survey and Ranking Studies

SOCMI production = 200,000 MM lb (1976)

6% growth = 283,700 MM lb (1982)

140 products address 205,438 MM lb of production (1982) 72.6%

1,584 MM lb of emissions (1982)

283,700—205,438 = 78,262 MM lb of production not covered by survey and ranking studies.

An estimated emission factor for the unranked chemicals was obtained by using the weighted average for the last 25 chemicals ranked on Fig. II-1 (0.0025 lb of VOC emissions/lb of production):

78,262 X 0.0025 = 195 MM lb of VOC emissions from unranked chemicals

1,584 + 195 = 1779 MM lb of VOC emissions for SOCMI in 1982, based on the initial survey and ranking studies.

B. REVISED EMISSIONS ESTIMATE

From Table II-1 the estimated emissions for the products studied are reduced from 1374 MM lb to 733 MM lb, a reduction of 47%. From all indications it appears to be a logical assumption that process emissions would be reduced by a similar amount for the remainder of the industry. However, as discussed in the Fugitive Emissions report of Volume III, fugitive emissions are more a function of equipment count than of production volume. This indicates that the initial VOC emission estimate shown above underestimated fugitive emissions for the large number of plants not studied.

By analysis of Tables II-1 and C-1 it can be seen that the first four products account for more than half of the VOC production addressed by all full-report studies. They are considered to be atypical of the great majority of production sites and were not used to determine emission factors for the remainder of the industry. The VOC emission-to-production-volume ratios for all the remaining full-study reports were used as the basis for projecting the VOC emission

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Table C-1. VOC Emission Estimates by Point Source for 1982

| Product | VOC Emissions (MM lb) | | | | |
|---|---|---|---|---|---|
| | Process | Fugitive | Storage and Handling | Secondary | Total |
| Acrylonitrile | 130.9 | 1.5 | 1.5 | 11.6 | 145.50 |
| DMT/TPA | 93.3 | 4.0 | 2.0 | Neg | 99.38 |
| Ethylene dichloride | 87.7 | 0.5 | 0.9 | 1.8 | 90.92 |
| Ethylene | 32.3 | 33.0 | 7.3 | 0.7 | 73.31 |
| Formaldehyde | 19.7 | 6.9 | 0.8 | Neg | 27.42 |
| Cyclohexanol/cyclohexonone | 24.7 | 1.3 | 0.3 | 0.3 | 26.52 |
| Acrylic acid | 4.6 | 7.3 | 2.5 | 8.1 | 22.48 |
| Ethylene oxide | 19.9 | 1.3 | 0.2 | Neg | 21.39 |
| Maleic anhydride | 9.1 | 4.4 | 2.6 | 0.3 | 16.46 |
| Ethylbenzene/styrene | 7.6 | 0.9 | 6.5 | 0.8 | 15.75 |
| Ethylene glycol | 14.0 | 0.8 | 0.1 | 0.6 | 15.59 |
| Phenol/acetone | 3.1 | 5.1 | 1.4 | 0.1 | 9.68 |
| Methanol | 0.6 | 3.2 | 4.4 | 0.1 | 8.31 |
| Cyclohexane | Neg | 0.9 | 3.4 | 0.1 | 4.40 |
| Chloromethane-methanol | 0.8 | 1.0 | 2.3 | 0.1 | 4.17 |
| Alkylbenzene | 1.3 | 0.6 | 1.0 | 0.3 | 3.17 |
| Chlorobenzene | 1.6 | 0.8 | 0.2 | 0.1 | 2.70 |
| Chloromethane-methane | 1.0 | 0.8 | 0.5 | 0.1 | 2.37 |
| Nitrobenzene | 0.4 | 0.8 | 0.2 | 0.2 | 1.67 |
| Carbon tetrachloride | 0.1 | 0.8 | 0.3 | Neg | 1.21 |
| Cumene | Neg | 0.4 | 0.5 | 0.1 | 0.98 |
| 1,1,1-Trichloroethane | Neg | 0.3 | 0.2 | Neg | 0.48 |
| Adipic acid | 0.1 | 0.1 | Neg | Neg | 0.18 |
| Full-study[a] | 453 (76.2%) | 75.7 (14.0%) | 40.1 (6.7%) | 25.4 (4.3%) | 594 |
| Starting with formaldehyde[b] | 108.6 (58.7%) | 37.7 (20.4%) | 27.4 (14.8%) | 11.3 (6.1%) | 185 |

[a] Full-study reports addressed a total annual production of 113,588 MM lb.

[b] All full-study reports (except the first four) starting with formaldehyde address a total annual production of 55,762 MM lb.

estimate for all SOCMI products not covered by a full-study report. Since the ratio of equipment components to production volume increases so dramatically in the many smaller volume plants not studied and since fugitive emissions are more a function of equipment count than of production volume, no fugitive emission factor was developed for processes not covered by study reports.

The emission projection factors derived from Table C-1 are as follows:

$$\text{Process Emissions} \quad \frac{109}{55,762} = 0.002 \text{ lb of VOC/lb of production}$$

$$\text{Storage and handling} \quad \frac{27.4}{55,762} = 0.0005 \text{ lb of VOC/lb of production}$$

$$\text{Secondary} \quad \frac{11.3}{55,762} = 0.0002 \text{ lb of VOC/lb of production}$$

The abbreviated product studies represent 22,425 MM lb of production projected to 1982. Based on the above factors to project the 1982 emission estimates for the abbreviated studies and the 147,627 MM lb of production not covered by full-study reports, the total estimated VOC emissions for 1982 are as follows:

| | Amount (MM lb) | | | | |
|---|---|---|---|---|---|
| | Process | Fugitive | Storage and Handling | Secondary | Total |
| Full report studies | 453 | 76 | 40 | 25 | 594 |
| Abbreviated-report studies | 45 | 29 | 11 | 4 | 89 |
| Not studied | 294 | 355 | 73 | 29 | 751 |
| | 792 | 460 | 124 | 58 | 1434 |
| | (55%) | (32%) | (9%) | (4%) | |

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15. SUPPLEMENTARY NOTES

16. ABSTRACT

EPA is developing new source performance standards under Section 111 of the Clean Air Act and national emission standards for hazardous air pollutants under Section 112 for volatile organic compound emissions (VOC) from organic chemical manufacturing facilities. In support of this effort, data were gathered on chemical processing routes, VOC emissions, control techniques, control costs, and environmental impacts resulting from control. These data have been analyzed and assimilated into the ten volumes comprising this report.

This volume contains a brief history of the four year project and includes emission ranking information for 140 manufactured organic chemicals.

17. KEY WORDS AND DOCUMENT ANALYSIS

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|---|---|---|
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