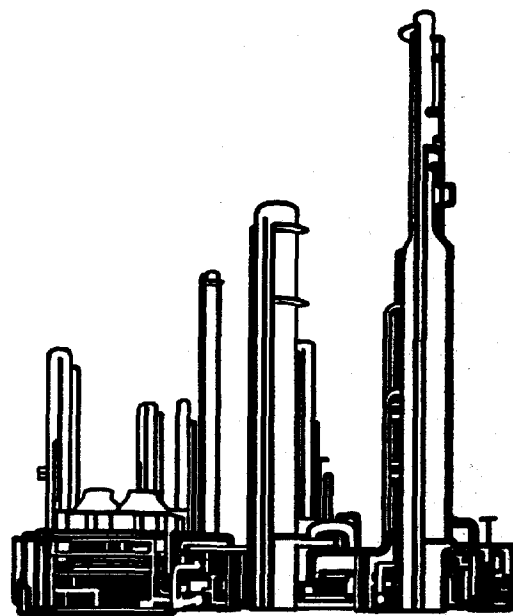


THE GENERATION AND MANAGEMENT OF WASTES AND SECONDARY MATERIALS IN THE PETROLEUM REFINING INDUSTRY : 1987 - 1988



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HEALTH AND ENVIRONMENTAL AFFAIRS DEPARTMENT

February 1991

API Publication 300

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ACKNOWLEDGEMENTS

This project was performed within the API through the combined efforts of staff members, consultants and company representatives. Barbara Bush, a Senior Regulatory Analyst in API's Health and Environmental Affairs Department (HEAD), served as the Project Director, providing the technical leadership, management guidance--and enthusiasm--to keep the project on track. Nikki Koch, also a Senior Regulatory Analyst in HEAD, assisted in the administrative aspects of the survey. Paul Wakim from the Statistics Department contributed to the development of the questionnaire and report. Ralph Mittl directed the data analysis effort, including the data verification, the development of modeling procedures and the generation of estimates and data tables. Mike Robey and Wendy Sams of Information Systems provided computer support and were instrumental in automating the database. Administrative support over the two years of preparation was ably provided by Cheryl Hawkins.

Wendall Clark (W.C. Consultants) manned the central clearinghouse throughout the project, answering respondent questions, reviewing all returned questionnaires and clarifying ambiguous responses.

Gail Levine (SUMMATIONS) served as Project Manager, providing expertise in survey design and administration, as well as coordinating the data handling and analysis, and assumed responsibility for reporting the research.

Oversight for the project was provided by company representative members of the Waste Minimization Survey Workgroup. Mark Hopkins from Chevron served as Chairman of the group; his commitment to the effort and technical guidance in defining the objectives and scope of the survey assured the successful completion of the project. Curt Beyer from Exxon and John Lemen from Texaco provided additional oversight and refining expertise which facilitated completion of the job.



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EXECUTIVE SUMMARY

In 1989, the American Petroleum Institute (API) initiated a census survey of domestic refineries. The goal of this effort was to document the management of waste and secondary materials in 1987 and 1988. To do so, the survey described "waste" **more broadly** than RCRA's definition of "solid waste", including hazardous and non-hazardous wastes and secondary materials that might otherwise be considered byproducts or recyclable materials.

To generate data that could be used in a variety of contexts, including waste minimization, the survey incorporated the components of the integrated waste management hierarchy. Thus, waste management activities were categorized as either source reduction, recycle, treatment or disposal.

Additional goals of the survey were to: 1) evaluate possible factors, such as refinery size, complexity or location, that might influence the amount of waste generated; 2) evaluate historical trends in the management of waste by comparing 1987 and 1988 data to the data gathered for 1981; and 3) establish baseline information on current waste management practices from which future industry progress can be evaluated.

SURVEY PROCEDURES

A census approach was used wherein all U.S. refineries were sent survey materials. These data collection forms requested quantitative information on the generation and subsequent recycle, treatment and disposal of 28 possible refining waste streams. Refineries were also asked to supply information on their facilities, including age, size, complexity and segregation of wastewater system.

Survey materials requesting data for 1987 and 1988 were sent out in September 1989. All survey responses were initially reviewed and questionable answers were followed up with telephone calls to respondents to verify the data.

To generate estimates of the waste management quantities for the entire U.S. refining industry, two regression models were developed: one for facilities with capacities greater than 200,000 barrels per stream day and another for smaller refineries. **All waste quantities contained in this report represent estimates for the entire refining industry generated by these models.**

RESULTS

There was an excellent response to the survey: 115 refineries out of the total U.S. population of 176 refineries participated. These respondents represent 80 percent of the domestic crude refining capacity. This outstanding response aided in making confident estimates of the amount of waste managed by the entire U.S. refining industry.

Waste Generation

The amount of waste managed by the refining industry in a given year includes the amount generated, any pre-treatment additives used and the net amount removed from/placed into storage.

$$\begin{array}{ccccccc} \text{Total Quantity} & = & \text{Quantity} & + & \text{Treatment} & + & \text{Net From} \\ \text{Waste Managed} & & \text{Generated} & & \text{Additives} & & \text{Storage} \end{array}$$

The total amount of waste generated by the 176 U.S. refineries is estimated to be:

- o 16.1 million wet tons in 1987 and
- o 16.0 million wet tons in 1988.

When the data is arrayed according to the six refining waste stream categories used in the survey (Figure 1), the Aqueous Waste category represents approximately 76 percent of all wastes generated in both years. This is due to the fact that four refineries generated extremely large amounts of the individual waste stream, "**Other Aqueous Wastes NOS (Not Otherwise Specified)**." (The large quantities of these waste streams are directly related to the facilities' use of deep well injection disposal techniques--a practice that does not necessitate pre-treatment to reduce the quantity of waste.)

Among the other waste categories, Oily Sludges/Other Organic Wastes was the largest, followed by Chemicals/Inorganic Wastes and Contaminated Soils/Solids.

As noted in Figure 1, the relative proportion of the six waste categories remained comparable over the survey period. Similarly, the quantities of the 28 individual waste streams that comprise each category (e.g., API Separator Sludge is a waste stream in the Oily Sludge/Other Organic Waste category) that are generated in the two survey years also remained relatively constant.

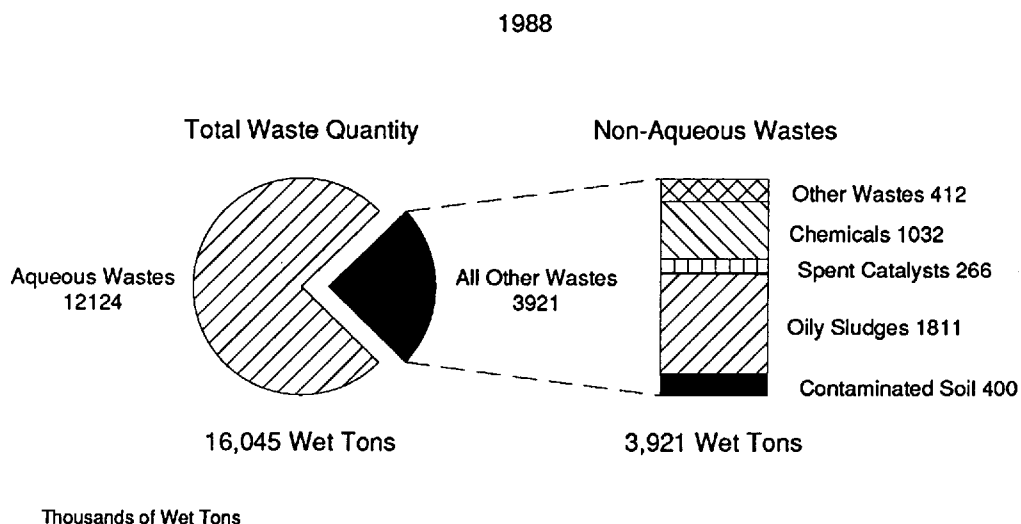
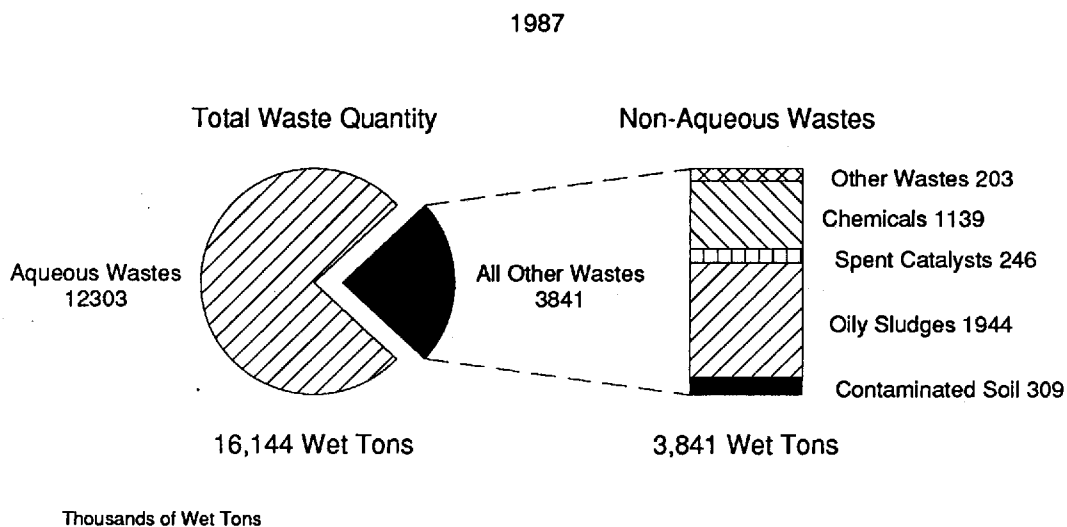
The use of treatment additives and the amount of wastes removed from or placed into storage did not significantly change the amount of waste managed in either survey year.

Comparison of the total amount of waste generated to the total crude throughput provides an appropriate context for viewing the quantities of waste generated in the petroleum refining industry:

	<u>1987</u>	<u>1988</u>
Waste Generated (Million wet tons)	16.1	16.0
Crude Throughput (Million tons)	631	650
Waste/Crude Throughput (%)	2.56	2.47

As indicated, the amount of waste is less than 3 percent of throughput. When the

FIGURE 1 - COMPARISON OF WASTE GENERATION : 1987 - 1988



generation rates are adjusted to control for the four outlier facilities that generated unusually large quantities of waste relative to the balance of the refining industry, the ratio of waste to throughput is reduced to less than 1 percent!

Waste Management

The total quantity of waste managed is equal to the amount of waste recycled, treated, land treated and disposed.

$$\begin{array}{l} \text{Total Quantity} \\ \text{Waste Managed} \end{array} = \begin{array}{l} \text{Quantity} \\ \text{Recycled} \end{array} + \begin{array}{l} \text{Quantity} \\ \text{Treated} \end{array} + \begin{array}{l} \text{Quantity} \\ \text{Land Treated} \end{array} + \begin{array}{l} \text{Quantity} \\ \text{Disposed} \end{array}$$

Figure 2 summarizes the management of refining waste. In order to display the typical relationships among the various waste management practices within the industry, the outlier values--the 11 million wet tons of dilute aqueous wastes generated by the four facilities that inject these wastes--were not included in this summary.

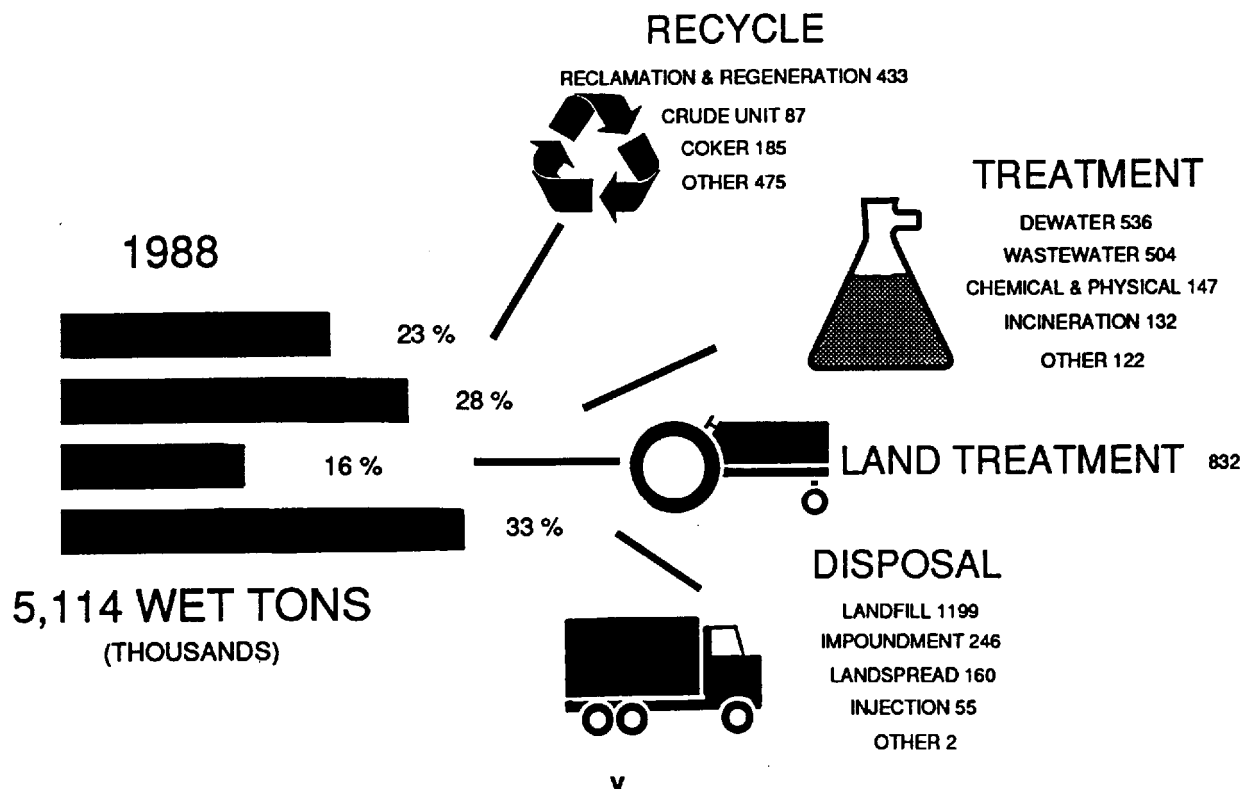
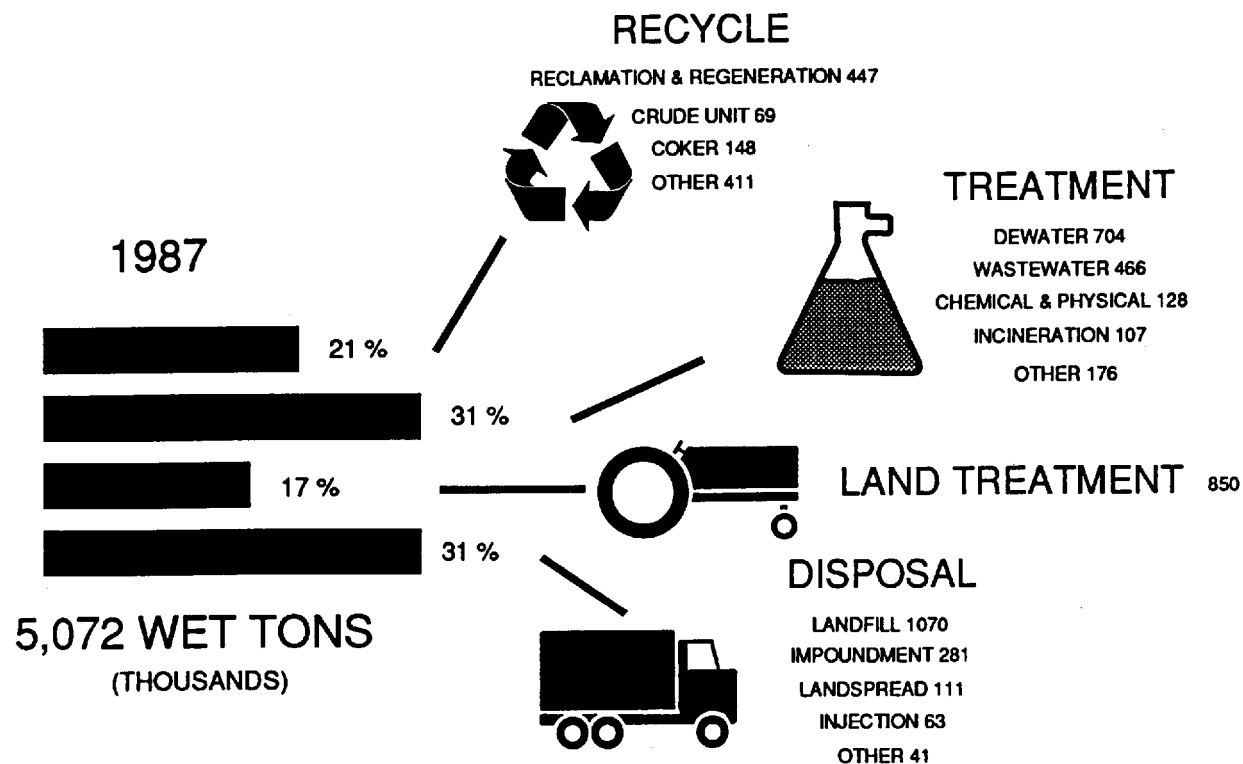
As illustrated, 21 percent and 23 percent of waste was eliminated from the management system by recycling for 1987 and 1988, respectively. This recycle rate does not include the extensive recycling of hydrocarbon materials in the refining industry that is an in-process, source reduction step, prior to classifying those materials as waste for survey purposes. The recycling practices illustrated here highlight that over 400 thousand wet tons of Spent Catalysts and Chemical/Inorganics (Spent Acids, Caustics) are reclaimed or regenerated. In addition, over 200 thousand wet tons of hydrocarbon containing wastes were recycled to crude units or cokers.

Figure 2 suggests that the petroleum refining industry relies equally on treatment, an intermediate waste management preference, and disposal to manage its wastes. Approximately 75 percent of the treatment category involves "dewatering" of oily sludges and the "wastewater" treatment of dilute aqueous wastes. (The quantities of waste treated in the wastewater system represent less than 8 percent of the total water flow through this system.)

Other treatments performed on petroleum wastes included chemical/physical techniques and incineration, but neither accounted for much more than 100 thousand wet tons in either survey period or 2 percent of the total amount of waste managed.

Regarding disposal techniques, when the outliers have been excluded, approximately 85 percent of refining wastes that were ultimately disposed were placed in landfills, with most of this going to offsite landfills. When the outliers are included this typical profile is distorted such that deep well injection becomes the leading disposal technique.

Figure 2. Summary of Waste Management Practices (Outliers Removed)



Land treatment was the management practice least used by the refining industry, accounting for 17 percent of the total quantity managed in 1987 and 16 percent in 1988.

Comparison to 1981 Survey

The results from the 1987 - 1988 survey were compared to those obtained for 1981. Because of differences in survey procedures, the only comparable data were for "disposal" techniques for the five RCRA listed hazardous wastes. (The 1987 and 1988 land treatment and incineration quantity estimates were added to the disposal quantities to facilitate comparison with the 1981 data which was collected in that format. It also appears that recycle to coker may have been included in the 1981 definition of disposal, but quantitative information on how much material was handled in this manner was not collected.)

The number of respondents reporting disposal of each hazardous waste stream were quite similar. For example, whereas 95 refineries reported API Separator Sludge in 1981, 90 and 93 reported for 1987 and 1988, respectively.

The "disposal" data for the five streams is provided below. As indicated, the reduction between 1981 and 1987 was over 20 percent and an even greater reduction was noted in 1988. This change between 1987 and 1988 was due to over 150 thousand wet tons of API Separator Sludge that was removed from storage for handling in 1987, compared to the 60 thousand wet tons removed from storage in 1988.

	Estimated "Disposal" Quantities (Thousands of Wet Tons)		
	1981	1987	1988
API Separator Sludge	393	365	191
DAF Float	308	254	310
Slop Oil Emulsion Solids	144	66	86
Leaded Tank Bottoms	4	6	4
Heat Exchanger Bundle	1	1	3
Cleaning Sludge			
TOTAL	850	693	593
Crude Throughput (Thousand tons)	574,900	631,212	650,128
Disposed Hazardous Waste : Throughput	1:676	1:910	1:1096
Disposed Hazardous Waste/Throughput (%)	0.15	0.11	0.09

One difference noted between the two surveys involved the use of land treatment units. In 1981, 58 refineries reported use of onsite landfarms while only 43 reported use of landfarms in 1987 and 42 in 1988.

WASTE MINIMIZATION/FUTURE SURVEYS

Given the variability noted in the responses between refineries (e.g., no two refineries reported the management of the same series of wastes or even the same management steps/removal efficiencies for the same waste streams), and the potential impact of changing regulations on the amount of waste generated, several years of reporting will be needed to establish a baseline for future comparisons.

Use of the waste management hierarchy in the data collection materials will facilitate assessment of industry progress over time, particularly after the source reduction questions have been refined to reduce misunderstanding and to improve the quality of the corresponding data. While this longitudinal database is being established, the industry plans to use the survey instruments and data to accomplish the following:

- o promote accounting of waste generation and management practices across the industry;
- o assist individual refineries in monitoring their progress on waste minimization by providing detailed, automated data for site specific planning purposes; and
- o plan research projects that can promote new technology/practices to reduce sources of waste or to further diminish the disposal needs for the industry.

1.0 INTRODUCTION

The American Petroleum Institute (API) has periodically conducted surveys to establish the quantity and disposition of wastes in the petroleum refining industry. The first such survey was conducted in 1976, prior to classification of any listed hazardous wastes under the Resource Conservation and Recovery Act (RCRA). A second waste survey collected information on waste generated in 1981.

The goal of the present 1987 - 1988 survey was to update the existing information on **waste generation** and to begin to chronicle trends in **waste management** in the refining segment of the petroleum industry.¹ In light of that emphasis on waste management activities, the approach of collecting constituent level information on waste streams used in previous surveys was not employed. Rather, API incorporated the components of the integrated waste management hierarchy in the data collection instruments for the present effort. Thus, waste management activities are categorized as either source reduction, recycling, waste treatment, or disposal.

Employment of the waste management hierarchy should facilitate the use of this database by various parties, particularly those interested in waste minimization. Use of the survey as a tool for monitoring the industry's progress on waste minimization was, in fact, one of the original goals for this effort. The difficulties encountered by other industry groups in documenting waste reductions, coupled with the knowledge of the differences among refineries and their practices, has tempered API's hope for any immediate feedback on waste minimization. Indeed, API's current plan is to attempt to establish a baseline by collecting at least three to four years of consecutive data. Then, data from subsequent survey efforts can be compared with that baseline and trends in waste management practices can be established.

Such a long term effort should clearly document the annual fluctuation in waste generation within the industry and how various imminent regulatory events affect waste management practices (e.g., promulgation of the new Toxicity Characteristic, the land disposal bans, listing of new refinery wastes as hazardous under RCRA). By accounting for the impact of those intervening events, the industry will be better able to assess its progress on waste minimization. Moreover, a longer term effort will allow for subsequent revisions of the survey instruments, enabling collection of more precise information over time. In the interim, however, API will be able to (1) disseminate information on the practices that contribute to reductions in waste and (2) promote recordkeeping of industry waste management practices through continued use of the survey materials.

¹ As will be described in greater detail later in this report, the 1987-1988 survey collected information on secondary materials--those that might become wastes if not beneficially used, reused or recycled--as well as waste materials. Throughout this report, the term "waste" is used to refer to both those materials traditionally considered as wastes and to secondary materials.

2.0 METHODOLOGY

2.1 SURVEY DESIGN

A census approach was adopted for this study. Respondents were asked to supply information for the years 1987 and 1988.

To develop a comprehensive list of all active domestic refineries, the listings developed by the National Petroleum Refiners Association (NPRA), the U.S. Oil and Gas Journal, Pennwell's Worldwide Refining and Gas Processing Directory: 1987 & 1988 and the Department of Energy's Petroleum Supply Annual, Volume 1 for 1987 and 1988 were compared. After removing those facilities that only produce asphalt or are natural gas processors and do not refine crude oil, a total of 176 refineries remained. Those refineries were owned by 86 companies, 29 of which were API members and 43 that belonged to NPRA (but did not also belong to API). The remaining 14 companies did not belong to either trade association.

2.2 DATA COLLECTION

The survey questionnaire consisted of 13 short answer questions and 56 "data sheets." (See Appendix A.) Two series of 28 data sheets — one for 1987 and another for 1988 — were included in each survey package.

The short answer questions elicited information on the age, size, and complexity of the refinery, as well as descriptive information on practices or events that could influence the reliability of the data collected.

To facilitate the collection of comparable data across refineries, a list of 28 typical refinery waste streams was developed. Two criteria that guided the development of that listing were:

- 1) the need to parallel the actual grouping/co-mingling of wastes and secondary materials that occurs in refineries; and,
- 2) the desire to keep the number of discrete streams manageable from a survey completion perspective.

As listed in Table I and described in more detail in the Appendix, five of the waste streams are the RCRA listed hazardous wastes for the refining industry; the remaining 23 categories are generally broader groupings of wastes and secondary materials, such as **Pond Sediments**, **Waste Oils/Spent Solvents**, or **Other Contaminated Soils**.

Table I. Refining Waste Streams

Oily Sludges/Other Organic Wastes

API Separator Sludge*
 DAF Float*
 Slop Oil Emulsion Solids*
 Leaded Tank Bottoms*
 Other Separator Sludges
 Pond Sediments
 Nonleaded Tank Bottoms
 Waste Oils/Spent Solvents
 Other Oily Sludges/Organic Wastes NOS**

Contaminated Soils/Solids

Heat Exchanger Bundle Cleaning Sludge*
 Contaminated Soil/Solids
 Waste Coke/Carbon/Charcoal
 Waste Sulfur
 Other Contaminated Soils NOS

Other Wastes

Other Wastes NOS

Spent Catalysts

Fluid Cracking Catalyst or Equivalent
 Hydroprocessing Catalyst
 Other Spent Catalyst NOS

Aqueous Waste

Biomass
 Oil Contaminated Waters
 (Not Wastewater)
 High pH/Low pH Waters
 Spent Sulfite Solution
 Spent Stretford Solution
 Other Aqueous Wastes NOS

Chemicals/Inorganic Wastes

Spent Caustics
 Spent Acids
 Waste Amines
 Other Inorganic Wastes NOS

* RCRA listed hazardous wastes for the petroleum refining industry.

** NOS - Not Otherwise Specified

The "data sheets" captured quantitative data on the amount of each waste/secondary material generated and its subsequent management. Respondents were asked to enter the amount of material managed by various onsite and offsite recycle, treatment, and disposal practices.

Waste Generation, Treatment Additives, and Wastes removed from Storage (or placed into storage as a negative value) are considered "Inputs" to the waste management system; Recycling, Treatment, and Disposal are "Outputs" that balance the "Inputs." Information was also collected on source reduction practices and waste volumes required to be reported to Federal and state agencies.

The survey was also supplied in a computerized format on a floppy disk so respondents could report in a manner suitable for direct uploading to a mainframe computer.

2.3 SURVEY ADMINISTRATION

Survey materials were mailed out in September, 1989 with approximately two months allotted for questionnaire completion. The National Petroleum Refiners Association (NPRA) joined API in this effort and mailed out the survey materials to its member companies that were not also members of API.

Senior management of API and NPRA member companies was enlisted to support this effort. Specifically, the survey package, with sufficient copies for all refineries in a given company, was sent to the headquarters of the refining branch of each company for distribution.

Survey participants were advised to contact an API consultant experienced in refinery operations for clarification of any issues. The consultant also reviewed all returned questionnaires for completeness, proper use, and questionable input. When problems existed, calls were made to the company contact person to resolve them.

Follow up calls were placed to all non-responding refineries in January and February, 1990. From those calls it was established that many of the non-respondent refineries would not be able to participate; nonetheless, the calls did result in the receipt of completed questionnaires from several additional facilities.

2.4 DATA ANALYSIS

2.4.1 Data Verification

Programs to verify the internal consistency of responses were written using the Statistical Analysis System (SAS). Errors such as waste input and management quantities that did not balance, invalid responses, and missing but required data elements, were identified. All errors along with any responses that appeared to be aberrant values were corrected and/or verified by phone calls to the respondents. Nearly every respondent was contacted to verify some part of their response; approximately 3000 corrections were made during this extensive data cleaning effort. As is described in Appendix B, this process helped to identify several questionnaire/ data sheet items (e.g., those on source reduction and hazardous waste reporting) that need to be revised to improve the quality of the data collected.

The number of corrections are thought to reflect the complexity of the data collection forms rather than the accuracy of the data. This assumption that the corrections are due to an "instrument effect" is supported by the observation that over half of the corrections made involved the misplacement of management codes (e.g., a recycling code was placed in the source reduction blank; a treatment code was used in the disposal column).

In fact, it must be assumed that the accuracy of responses may vary because record keeping is not automated for some wastes, other waste amounts are not easily measured and in some cases, tonnages were estimated from volume information and approximated densities.

A second phase of data verification occurred during development of the estimation models. Estimation models were developed to extrapolate the quantities generated by the entire U.S. refining industry from the responses received. When the data were plotted, six cases with outlying values were identified and calls were placed to the respective refineries to verify that these were actual values. In all of these cases, the respondents confirmed the accuracy of the responses.

Because these extreme values skewed the extrapolation, they were considered to be "outliers" and treated differentially during the model development.

The six outliers included two refineries which generated no waste in 1987 nor 1988. The four other refineries generated large quantities of Other Aqueous Waste and utilized deep well injection to dispose of these dilute wastes. Unlike other refineries that discharge waste under NPDES permits or to POTWs, facilities that inject wastes remove only the solids that could block the well pores prior to disposal (i.e., they do not perform additional treatment to diminish the water content).

A brief table of the affected streams and quantities follows:

Table II. Summary of Outlier Values

WASTE STREAM	# of Facilities	87 Generation (Wet Tons)*	88 Generation (Wet Tons)*
Other Aqueous Wastes	4	11,267	11,048
All Streams	2	0	0

*Thousands

(It should be noted that the facilities with large quantities of "Other Aqueous Wastes NOS" reported quantities of the other waste streams that were in the normal range.)

2.4.2 Non-Respondent Estimation Procedures

To estimate the total amount of waste generated for all (176) of the U.S. refineries, the data obtained from the 115 survey participants had to be combined with estimates for the 61 refineries that did not participate in the study. A regression model approach (with the implicit assumption that non-respondents do not differ from respondents) was selected to develop the generation quantities for these non-respondents.

After calculating the total waste generated by each responding refinery, correlation coefficients were calculated for the refinery characteristics (e.g., capacity, age, sewer system) with total waste generation. In addition, scatterplots were made to help explore any relationships which could lead to development of models to estimate total waste generation.

The strongest correlation was between operable crude capacity (Question 3) and waste generation, with quantity of waste increasing as refinery capacity increased.

Simple linear, multiple regression and nonlinear models were considered. After examining all the model results for levels of significance, mean squared error, R-squared, and model complexity, the simple regression model using capacity as the independent variable was chosen.

Further examination of plots and sample statistics indicated that improvement in the regression results could be made by separately modeling refineries having capacities below 200,000 barrels per stream day (B/SD) and those with capacities above 200,000 B/SD. Specifically, the plots showed that unlike the smaller facilities, the relationship between total waste generation and capacity at large facilities was not linear. Consequently, separate regression models were developed for these two groups of data.

For the less than 200,000 B/SD facilities, waste generated was modeled as being directly related to capacity:

$$\text{Total Waste} = a_1(\text{capacity}) \quad (1)$$

At refineries having capacity greater than 200,000 B/SD, however, the increase in waste was modeled as a function of the square of the capacity:

$$\text{Total waste} = a_2(\text{capacity}^2) \quad (2)$$

Both a_1 and a_2 were estimated based on the data from 109 refineries².

To determine how well the models explained the variability in the data, R^2 was calculated. For 1987, R^2 values were 0.55 and 0.79 for the smaller and large facilities, respectively. For 1988 the R^2 values were 0.58 and 0.79. (The corresponding correlation coefficients were 0.75 and 0.89, respectively.) For this type of data, these R^2 values reflect a reasonably good fit.

² The six outliers discussed in Section 2.4.1 were not included in any of the calculations performed to derive values for non-respondents.

2.4.3 Estimation of Waste Generation Quantities

The models were used to estimate the total quantity of waste generated for each of the 61 non-responding refineries (based on their crude capacities) for both 1987 and 1988. To calculate the total amount of waste generated by all refineries, the estimate for the non-respondents was added to the responses from the 115 survey participants. All data shown in this report are estimates of waste for all 176 refineries.

After deriving the total waste generation quantity, calculations were performed to estimate the generation quantity for each of the 28 waste streams. As with the calculation of the total quantity of waste, the first step was to estimate the values for the non-respondents. A step by step summary of the procedure used follows:

- 1) The total waste generation quantity for each of the 109 non-outlier respondents was calculated.
- 2) The percentage contribution of each waste stream to the total quantity of wastes was calculated by dividing the individual waste stream generation quantity calculated in (1) by the summation of all 28 waste generation quantities.
- 3) These percentages were applied to the total waste generation quantity estimated for the 61 non-respondents (calculated in Section 2.4.2).

To obtain a total generation quantity for each of the 28 waste streams, the individual waste stream estimates for the non-respondents were added to the actual quantities reported for each waste stream by the 115 participants.

The margin of error (for sampling and modeling) for the total waste generation quantity and for the individual stream estimates were calculated. An approximate 2 percent margin of error was estimated for the total waste generation quantity. An approximate 10 percent margin of error value was estimated for the individual waste streams. These error estimates confirmed the expected high precision of the estimates which, in turn, reflect the excellent response rate.

3.0 RESULTS

3.1 RESPONSE RATE

A total of 115 refineries responded to the survey. When compared to the universe of 176 refineries active during 1987 and 1988, this represents a 65 percent response rate.

When response rate is viewed as a function of **refinery capacity**, the 115 respondents represent over 80 percent of the crude refining capacity in the country.

Figure 1 shows the distribution of the responses by refining capacity. As illustrated, the lowest response rate was observed in the 0 to 10 thousand barrel-per-day group. Slightly more than half of the 11 to 50 thousand barrel-per-day group responded, while response rates greater than 76 percent were achieved by each of the large refinery classes.

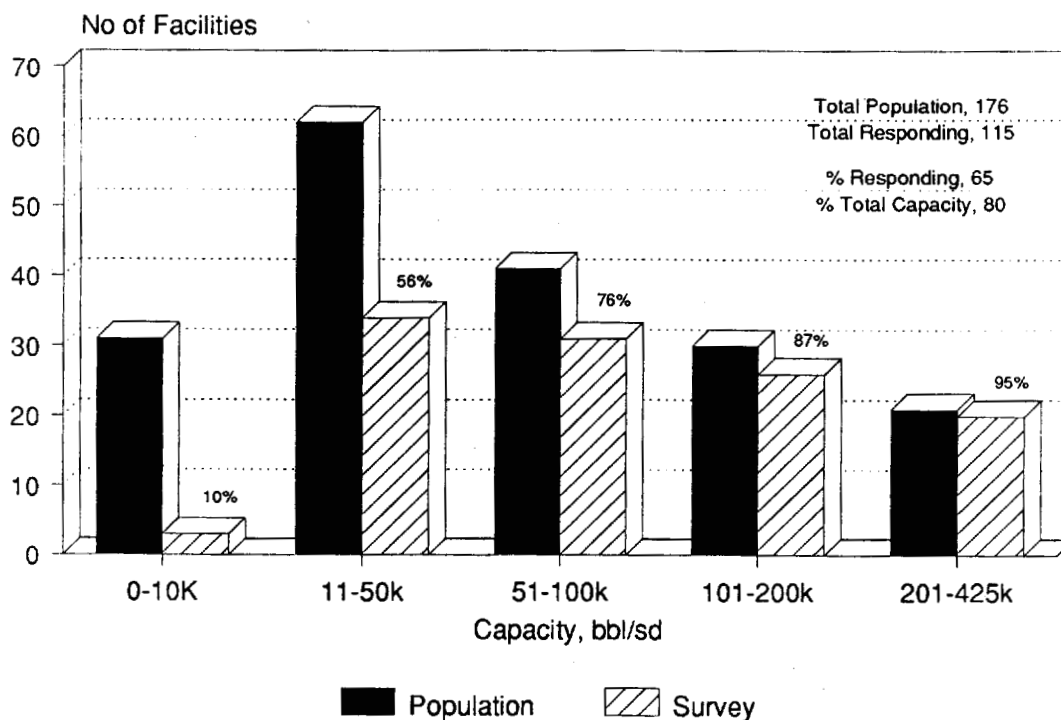


Figure 1. Number of Refineries Responding by Capacity Groups

Such a response pattern was expected: most of the larger refineries are owned by active members of API and NPRA. Also, smaller facilities have fewer employees and are less likely to maintain automated records. Consequently, completion of the survey for these smaller facilities may demand relatively large manpower commitments. Moreover, because these less than 10 thousand barrel-per-day refineries represent only 1 percent of the total refining capacity for the country, this lower response rate does not significantly affect the survey's overall representation of the industry's practices.

3.2 RESPONDENT CHARACTERISTICS

Information was obtained on the **location** and **complexity** of each refinery, its **age**, and its **type of wastewater sewer system**.

As anticipated the highest number of respondents (40) clustered in the historical oil producing region, the Department of Energy's Petroleum Administration for Defense (PAD) District III. The PAD II region followed with 29 respondents and the PAD V region with 21. As graphically depicted in Figure 2, PAD District I contributed 13 refineries and PAD Region IV contributed 12 responding refineries.

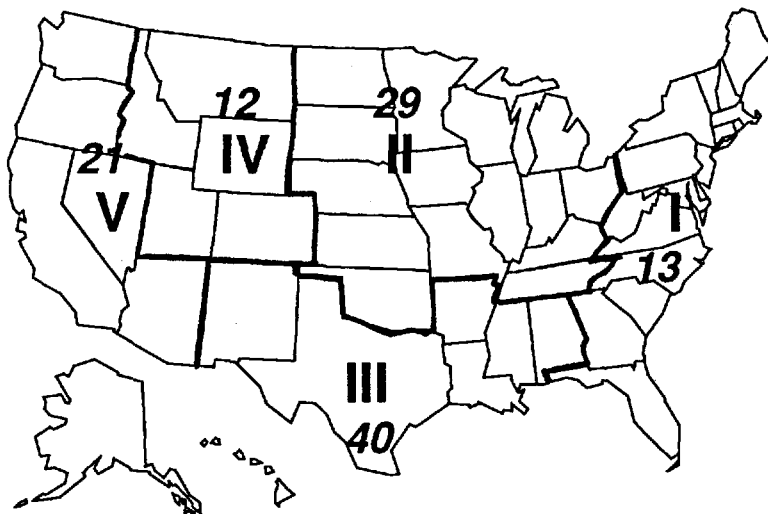


Figure 2. Distribution of Respondents by PAD Districts

The number of responding refineries by the complexity of their operations and capacity is presented in Figure 3. The complexity categories are those used by the EPA in the Effluent Guideline Limitations for Petroleum Refining Point Source Categories, often referred to as the National Pollutant Discharge Elimination System (NPDES) for wastewater permitting. The actual definitions for each category were included in Question 2 presented in Appendix A. Generally, a "Topping" refinery is the simplest type of facility and an "Integrated" refinery the most complex.

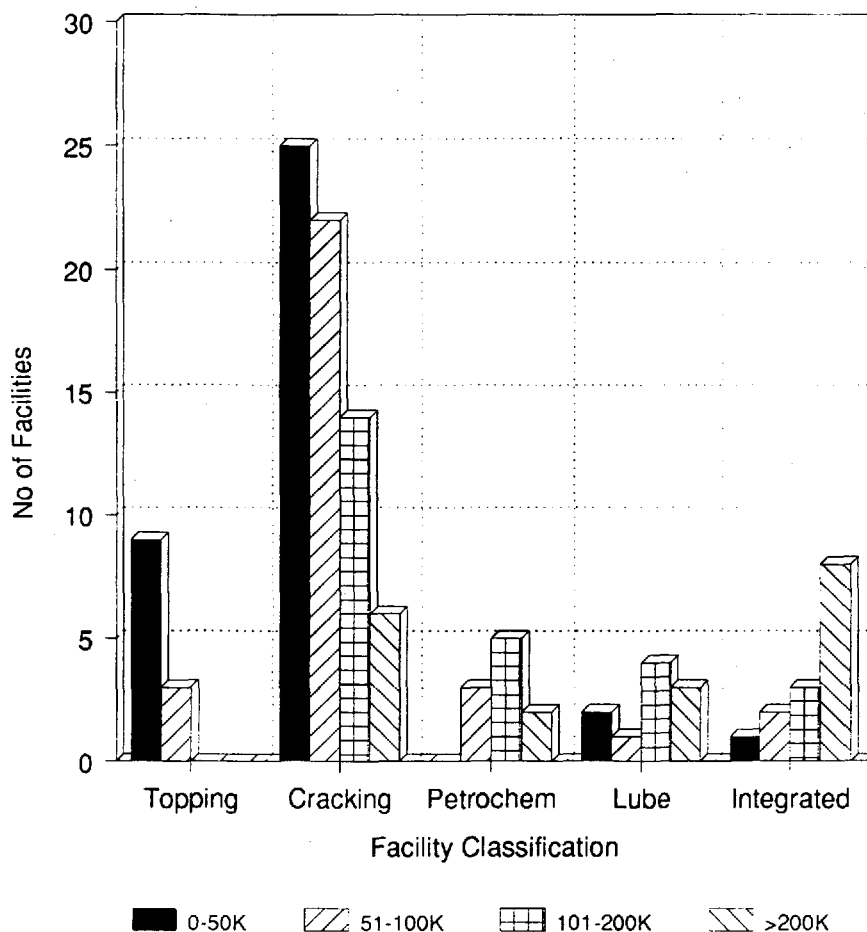


Figure 3. Distribution of Respondents by NPDES Classification and Refinery Capacity

As illustrated, there are approximately equal numbers of responding refineries in the simplest category — Topping — as there are in each of the more complex categories of Petrochemical, Lube, and Integrated. All four of those categories are dwarfed by the preponderance of facilities in the "Cracking" category.

Information was also obtained on refinery age as indicated by the year the refinery began operations. The distribution of respondents is given in Figure 4. Over half of the refineries began operations prior to 1940, and 85 percent were in operation before 1960.

Year Operations Started

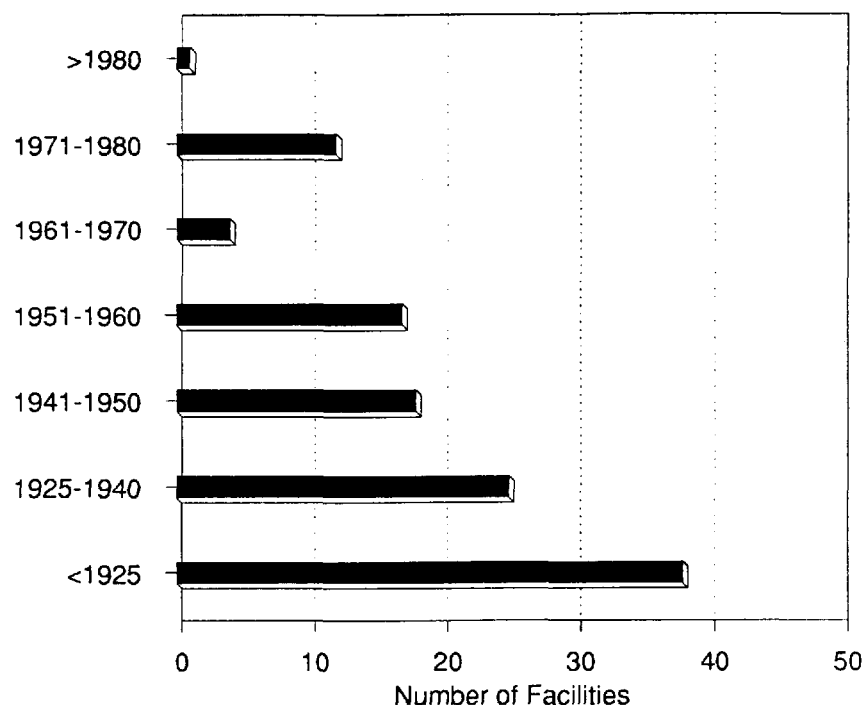


Figure 4. Distribution by Refinery Age (Year Operations Started)

The final characteristic on which information was obtained was the type of wastewater system used at each facility. Figure 5 and Figure 6 compare sewer system type with age and size of the refineries, respectively. Although it was anticipated that a higher proportion of the newer facilities would have totally segregated stormwater and process sewers, more of the intermediate age refineries (30 to 50 years of operation) have totally segregated sewer systems. In all age classes the partially segregated sewer systems predominate, while substantial numbers of non-segregated sewers are observed only in the two oldest groups of refineries.

When sewer type is viewed by size of facility, partially segregated systems dominate each size category. The greatest difference in the number of non-segregated and totally segregated systems is noticed in the largest size group with seven of the former and only one totally segregated facility. These age and size findings, when considered together, seem to indicate industry wide upgrading to at least partially segregated storm and process water systems.

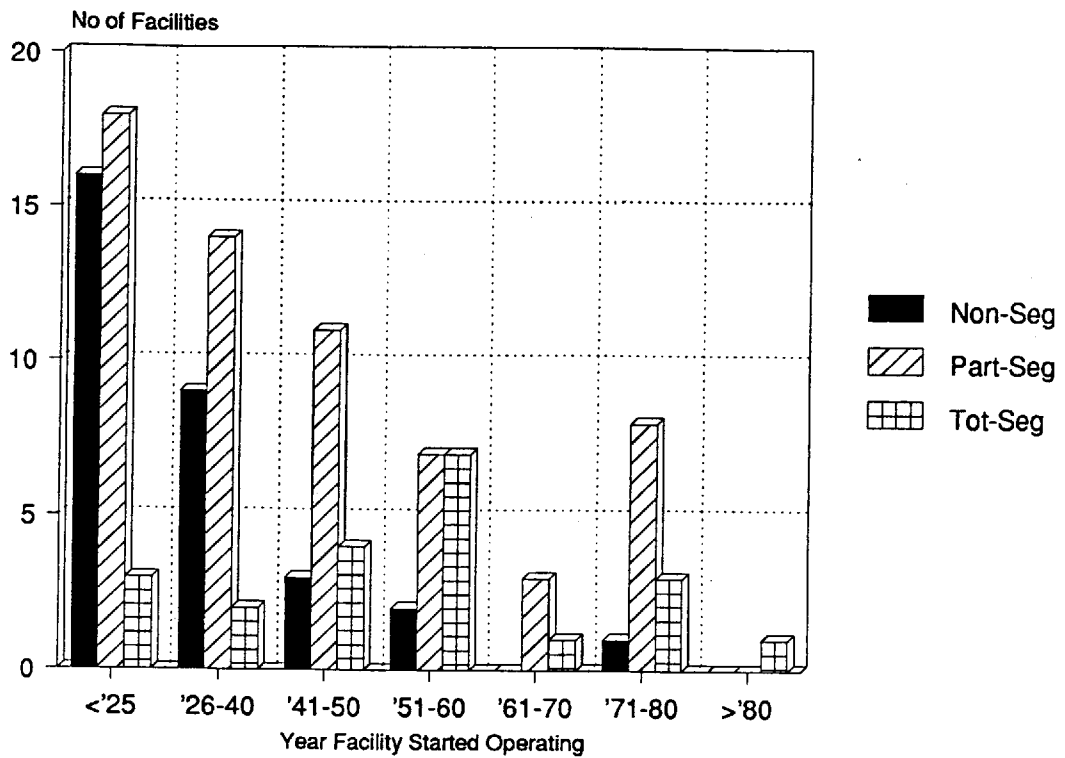


Figure 5. Refinery Age versus Sewer Type

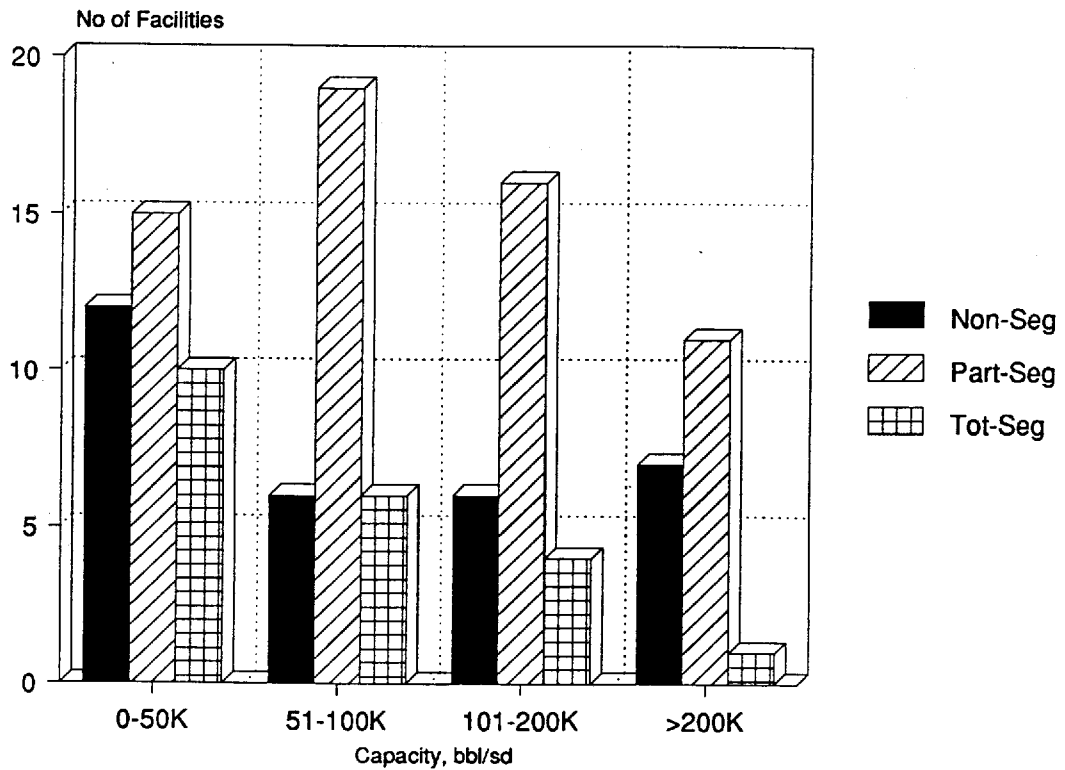


Figure 6. Refinery Capacity versus Sewer Type

3.3. TOTAL WASTE MANAGEMENT QUANTITY

The **Total Waste Management Quantity** refers to the initial waste handling practices that contribute to the amount of waste subsequently managed during the survey year. Specifically, it includes the summation of

Waste Generated
Treatment Additives, and
Net Waste Removed from Storage.

3.3.1 Waste Generation

To encourage the broadest reporting, the term "waste" was not specifically defined in the survey materials. Respondents were guided by the instructional materials that stated:

Although denominated as a "solid waste" survey, it should be understood that neither this title nor the references herein (e.g., "wastes" and "residuals") are used in a statutory or regulatory sense. Whereas EPA regulations implementing RCRA have given these terms special meaning, our usage here is in a broader, more generic sense. API wants survey participants to report the management of all residual type materials (e.g., materials that are byproducts or residuals of petroleum refining operations). This includes residuals that are beneficially recycled or reclaimed, as well as material that is discarded. This will allow reporting of industry data, wherever appropriate, according to the waste management hierarchy of source reduction, recycling, treatment, and disposal. (Instruction Manual)

For the petroleum refining industry, "waste generation" must refer to a broad range of activities. For example, many wastes are only collected periodically, when process units or tankage are taken out of service for maintenance. That could be less frequently than annually and includes annual, three-year, and in some cases, ten-year maintenance schedules.

Conversely, other wastes are created/generated in an ongoing manner. For example, some oil, water and solids separators are configured to include mechanisms for continuous sludge removal. In light of the broad range of potential waste generation activities and frequencies, explicit instructions were not provided to guide, limit, or consequently bias respondent application of the term "generation."

Based on the procedure described previously, the total amount of waste generated by the population of 176 US petroleum refineries is estimated to have been:

16.1 million wet tons in 1987 and
16.0 million wet tons in 1988.

When the data are arrayed according to the refining waste stream categories (presented in Table I), it is apparent that the relative proportions of the various types of wastes remained fairly constant over the two survey years. As displayed in Figure 7, the **Aqueous Waste** category (which included all four of the outliers that generated wastes) represented approximately 76 percent of all wastes generated in both survey years. Among the other waste categories, **Oily Sludges/Other Organic Wastes** was the largest followed by **Chemicals/Inorganic Wastes**.

When the contributions of the different waste classes are compared over the two years, it is apparent that slightly less **Aqueous Wastes**, **Oily Sludges/Organic Wastes** and **Chemicals** were generated in 1988.

Table III lists the individual waste streams ordered by the amount generated in 1987. This clearly illustrates the strong influence of the outliers. The highest quantity waste stream, **Other Aqueous Wastes NOS**, was significantly affected by the outliers. In fact these facilities contributed over eleven million wet tons to the total amount of waste generated in 1987. Thus, the remaining 170 refineries (total population of 176 refineries) generated only 30 percent of the waste illustrated here.

Table IV, which lists the number of facilities reporting that the waste was generated, provides further insight into the variability in the survey data. For both years the streams most frequently reported to have been generated or managed were **API Separator Sludge**, **FCC Catalyst or Equivalent**, and **Other Wastes NOS**. Similarly, the **Other Aqueous Wastes NOS**, with only 13 responses in 1987 and 12 in 1988, was the highest quantity waste stream reported due to the influence of outlier data.

The median (middle value) and modal (most frequently reported) number of streams reported was only 13 — less than half of the full complement of 28 streams. Also, from a quantitative perspective, some refineries reported zero wet tons of waste generated for a specific stream, while others reported millions of wet tons for the same waste stream.

These differences in waste generation rates (and, as will be seen in the following section of this report, in waste management practices) reflect the variability among refineries. That is, while two refineries may have similar capacities and produce a comparable range of products, the actual refining methods may differ substantially based on the location and age of the refinery and the types of crude feedstock used.

FIGURE 7. COMPARISON OF WASTE GENERATION: 1987 - 1988

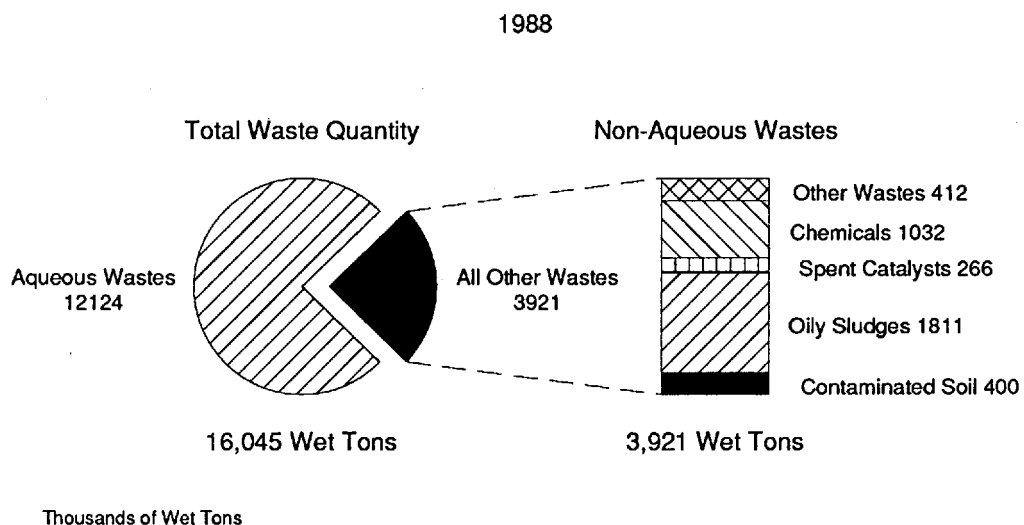
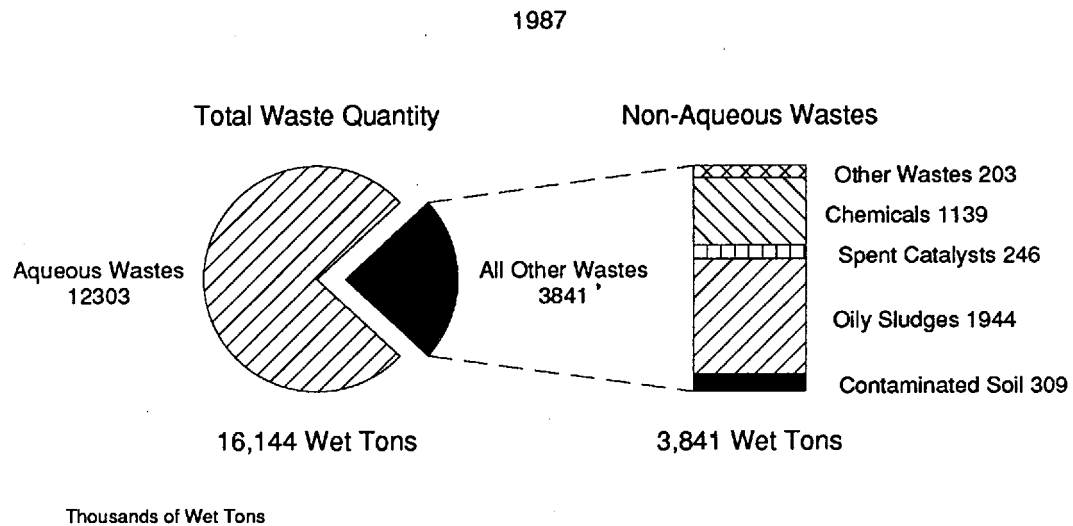


Table III. Estimates of Wastes Generated for the Total US Refining Industry
(Thousands of Wet Tons)

	1987		1988	
	Generated Quantity	Outliers	Generated Quantity	Outliers
Other Aqueous Wastes NOS	11,296	11,267	11,076	11,048
Biomass	757		786	
Spent Caustics	675		656	
DAF Float	652		655	
API Separator Sludge	400		355	
Pond Sediments	337		266	
Other Inorganic Wastes NOS	325		213	
Nonleaded Tank Bottoms	216		129	
Slop Oil Emulsion Solids	208		224	
Other Wastes NOS	203		412	
FCC Catalyst or Equivalent	173		193	
Contaminated Soil/Solids	165		240	
High pH/Low pH Waters	144		138	
Spent Acids	126		149	
Other Contaminated Soils NOS	82		68	
Other Separator Sludges	79		104	
Waste Coke/Carbon/Charcoal	43		67	
Spent Sulfite Solution	42		40	
Hydroprocessing Catalysts	40		36	
Other Oily Sludges/Inorg Wastes	38		61	
Spent Stretford Solution	35		49	
Other Spent Catalysts NOS	33		37	
Oil Contam Water NOT Wastewater	28		36	
Waste Sulfur	17		22	
Waste Amines	13		14	
Leaded Tank Bottoms	9		8	
Waste Oils/Spent Solvents	4		7	
Heat Exch Bundle Cleaning Solids	3		5	

Table IV. Number of Refineries Responding to the Survey that Reported Generating Each Waste Stream

	Number of Refineries *	
	1987	1988
Other Wastes NOS	92	85
API Separator Sludge	91	94
FCC Catalyst or Equivalent	85	86
Spent Caustics	79	77
Contaminated Soils/Solids	77	77
Other Inorganic Wastes NOS	77	73
Nonleaded Tank Bottoms	72	75
Other Contaminated Soils NOS	70	71
Other Spent Catalysts NOS	62	60
Hydroprocessing Catalysts	57	60
DAF Float	53	50
Waste Oils/Spent Solvents	52	61
Heat Exch Bundle Cleaning Solids	49	48
Other Oily Sludges & Inorg Wastes	49	47
Waste Coke/Carbon/Charcoal	48	47
Biomass	47	45
Slop Oil Emulsion Solids	47	43
Waste Sulfur	41	47
Leaded Tank Bottoms	38	37
Waste Amines	32	36
Pond Sediments	26	29
Spent Acids	20	23
Other Separator Sludges	15	20
High pH/Low pH Waters	14	12
Oil Contaminated Water NOT Wastewater	14	10
Other Aqueous Wastes NOS	13	12
Spent Stretford Solution	12	13
Spent Sulfite Solution	1	1

* The number of refineries responding to the survey was 115.

3.3.2 Treatment Additives

After wastes are generated, chemicals or treatment additives are sometimes added to facilitate subsequent handling. For example, alum may be added to **DAF Float** to increase flocculation. For other wastes, chemicals can be added to control pH or to stabilize organics for subsequent treatment.

The amount of treatment additives used in the refining industry is quite small, less than 0.5 percent of the total wet tons of waste generated.

In both 1987 and 1988, additives were reported as being used with 19 of the 28 waste streams. The amount of additives used with **Biomass** was the largest observed in 1987; **API Separator Sludge** had the greatest use of additives in 1988. However, the additives represented less than 1 percent of the total quantity of **Biomass** in 1987 and 4 percent of **API Separator Sludge** in 1988. The highest proportion of additives used--5 percent

in 1987 and over 6 percent in 1988--was with the **Other Separator Sludges** waste stream.

3.3.3 Storage

Respondents were asked to indicate the net quantity of wastes placed into storage or removed from storage each year. The responses for 1987 differed significantly from those in 1988. Specifically, when the "positive" and "negative" quantities of stored wastes were added together, 14 streams had net amounts placed into storage in 1987, and 8 waste streams had net amounts removed from storage. In contrast, in 1988 only 5 streams had net amounts placed into storage, and 17 streams had net amounts removed from storage.

As shown in Table V, the **API Separator Sludge** was the highest quantity stream removed from storage. In fact, the amount removed from storage in 1987 was more than one quarter of the total amount managed. As will be seen, this storage quantity significantly influenced the overall trend in the amounts of hazardous wastes managed between 1987 - 1988.

Table V. Estimated Net Waste Quantities Removed From Storage for the Total US Refining Industry (Thousands of Wet Tons)

	1987			1988		
	Total Managed	From Storage	%	Total Managed	From Storage	%
API Separator Sludge	564	151	27	430	60	14
Pond Sediment	360	21	9	311	44	14
Contaminated Soil/Solids	186	21	11	242	2	<1
Other Contaminated Soil NOS	88	6	7	77	9	12
Other Catalysts NOS	38	4	11	38	<1	<1

The other high-quantity waste streams removed from storage were the same over the two survey years: **Pond Sediments, Contaminated Soils/Solids, Other Contaminated Soils NOS, and Other Catalysts NOS**. While the proportion of waste removed from storage compared with the total input quantity fluctuated over the two year survey period, the percentages remained relatively low (less than 14 percent), with the exception of **API Separator Sludge**.

As shown in Table VI, the greatest net amount of waste put into storage for both years was for the **Biomass** waste stream, which remained a constant 7 percent. That was primarily because biomass was allowed to accumulate in secondary wastewater treatment ponds/impoundments.

Table VI. Estimated Net Waste Quantities Placed Into Storage for the Total US Refining Industry (Thousands of Wet Tons)

	1987			1988		
	Total Managed	Into Storage	%	Total Managed	Into Storage	%
Biomass	720	50	7	749	50	7
DAF Float	654	8	1	661	8	1
Other Inorganic Wastes	323	3	1	—	—	—
FCC Catalyst or Equivalent	171	3	2	189	4	2
Slop Oil Emulsion Solids	212	<1	<1	214	15	7

3.3.4 Total Quantity of Waste Managed/Input

As displayed below, the total waste management quantity equals the summation of the estimated quantity of waste generated, the treatment additives used, and the net waste into/from storage.

$$\begin{array}{rclclcl} \text{Total Quantity} & = & \text{Quantity} & + & \text{Treatment} & + & \text{Net From} \\ \text{Waste Managed} & & \text{Generated} & & \text{Additives} & & \text{Storage} \end{array}$$

This information for each waste stream, for both 1987 and 1988, is presented in Table VII.

As anticipated, addition of the treatment and storage factors to the generated quantity barely affects the ordering of the waste streams compared with the order based on Generation amounts alone (See Table III).

Table VII and this discussion clarify the derivation of all of the waste management statistics subsequently presented in this report. Consistent with the "input = output" approach incorporated in each data sheet, the total waste management quantity presented here serves as the basis for the estimation of waste quantities subsequently managed by recycling, treatment or disposal.

Table VII. Estimated Waste Quantities in Wet Tons for 1987 & 1988

Waste Stream	1987				1988			
	Managed	Generated	Treatment Additives	Net From Storage	Managed	Generated	Treatment Additives	Net From Storage
Other Aqueous Wastes NOS	11,296,230	11,295,981	0	249	11,076,251	11,076,100	0	151
Biomass	720,355	757,240	13,115	(50,000)	748,589	785,530	13,059	(50,000)
Spent Caustics	674,522	674,639	102	(219)	655,528	655,556	15	(43)
Dissolved Air Flotation Float	653,899	652,346	9,208	(7,655)	660,514	655,370	13,575	(8,431)
API Separator Sludge	563,773	399,940	12,885	150,948	430,042	355,361	15,160	59,521
Pond Sediments	359,996	337,419	1,481	21,096	311,268	266,227	1,271	43,770
Other Inorganic Wastes NOS	322,702	325,474	181	(2,953)	220,503	213,756	277	6,470
Nonleaded Tank Bottoms	217,869	215,761	1,810	298	130,851	128,744	2,026	81
Slop Oil Emulsion Solids	211,854	207,916	4,231	(293)	213,551	224,224	4,571	(15,244)
Other Wastes NOS	202,645	202,694	0	(49)	412,380	412,345	0	35
Contaminated Soil/Solids	185,819	165,148	0	20,671	242,074	240,004	0	2,070
Fluid Cracking Catalyst or Equivalent	170,853	173,353	19	(2,519)	189,191	193,078	13	(3,900)
High pH/Low pH Waters	144,015	143,947	68	0	138,269	138,199	70	0
Spent Acids	130,436	126,149	4,287	0	160,399	148,639	11,760	0
Other Contaminated Soils NOS	88,002	81,810	169	6,023	76,698	67,629	108	8,961
Other Separator Sludges	82,797	78,617	4,180	0	110,251	103,606	6,645	0
Waste Coke/Carbon/Charcoal	42,712	42,705	0	7	66,549	66,548	0	1
Spent Sulfite Solution	42,262	42,262	0	0	40,274	40,274	0	0
Other Oily Sludges & Inorganic Wastes	40,024	38,496	1,552	(24)	61,336	61,121	188	27
Hydroprocessing Catalysts	39,415	39,774	0	(359)	36,630	36,336	0	294
Other Spent Catalysts NOS	38,238	33,216	619	4,403	37,904	37,034	639	231
Spent Stretford Solution	34,881	34,881	0	0	49,264	47,621	1,643	0
Oil Contaminated Water NOT Wastewater	28,156	28,258	0	(102)	35,867	35,859	0	8
Waste Sulfur	17,299	16,550	749	0	22,714	21,735	979	0
Waste Amines	13,107	13,121	2	(16)	13,798	13,790	0	8
Leaded Tank Bottoms	9,264	9,140	219	(95)	9,615	8,167	29	1,419
Waste Oils/Spent Solvents	4,453	4,468	0	(15)	7,346	7,291	0	55
Heat Exchanger Cleaning Bundle Sludge	2,977	2,957	35	(15)	4,643	4,597	38	8
Total	16,338,555	16,144,262	54,912	139,381	16,162,299	16,044,741	72,066	45,492

3.4 WASTE MANAGEMENT

In the context of this survey, and in the petroleum refining industry, **Waste Management** refers to all the waste handling practices that are performed after pretreatment with additives, or movement into or out of storage. Thus the waste quantities managed in 1987 and 1988 are estimated to have been the "Managed" amounts listed in Table VII.

The waste management practices of

Recycling,
Treatment,
Land Treatment, and
Disposal

all involve the elimination of wastes from the management system.

For instance, a waste is "eliminated" by recycling it (or a portion of it) to some useful purpose. Thus, the recycled amount of waste is eliminated from the waste management system and no longer requires handling. For a partially recycled waste, the remaining material is further managed by a "Treatment" or "Disposal" technique.

3.4.1 Recycling

The petroleum industry has long prided itself on its extensive recycling practices. Efforts are exerted throughout the industry to recapture hydrocarbons that might be lost to the system whether in waste oils, off-specification products, or used oils. Such recovered oils can be inserted into various process units for additional refining into products.

Most hydrocarbons are recycled through the refinery's oil recovery system **prior** to consideration of the materials as waste. The major portion of that recovery is from the skimming of oil from the surface of the water in the wastewater treatment system. Thus, a significantly larger amount of hydrocarbon recycling takes place than indicated by this survey, since those materials are not regarded as wastes or secondary materials within the context included in this survey and consequently were not captured.

Within the waste management hierarchy such recycling activities are appropriately considered "source reduction" (i.e., activities that prevent the generation of additional waste). As is described in Appendix B of this report, API (as well as EPA) have had difficulty in obtaining reliable information on source reduction activities, largely due to the recent advent of the concept and the technical difficulty in measuring a "negative"--the avoidance of waste.