

GENERATION AND MANAGEMENT OF RESIDUAL MATERIALS



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Petroleum Refining Performance

Generation and Management of Residual Materials

Petroleum Refining Performance 1991 Survey

Health and Environmental Affairs Department

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PREFACE

To improve the quality of the data collected, and its relevance to current developments, each year the American Petroleum Institute (API) reviews all data collected in this survey, and evaluates and revises, as necessary, the data collection forms and instructional materials. Consistent with this ongoing effort to promote the integrity of the survey findings and its utility to the industry, API has implemented a change in the terminology used in this survey. Beginning in 1990, API used the term “residual materials or residuals” instead of “wastes and secondary materials.” This change in terminology reflects industry practices—the use of many of these materials as feedstocks or for recycling, reuse, and reclamation. This change helps to reconcile the utilization of these materials in our industry with the regulatory usage of the term “waste.”

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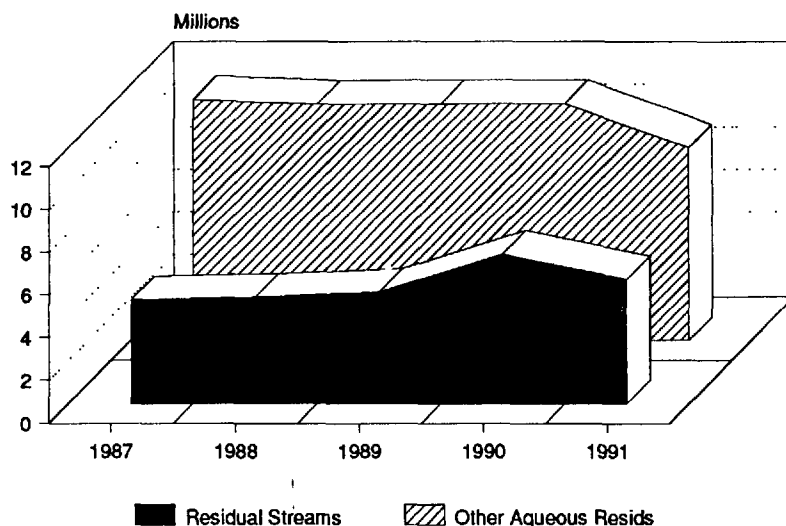
EXECUTIVE SUMMARY

In 1991, domestic refineries generated 14.8 million wet tons of residual materials. This population estimate was based on the American Petroleum Institute's survey on residual management practices. The survey has now amassed five years of consecutive data, with each cycle representing at least 70 percent of the refining capacity. This analysis of the 1991 data includes information from API's new question on pollution prevention activities, which when combined with the five years of data, provides a better understanding of trends in residual generation and management improvements.

The 14.8 million wet tons was the smallest quantity generated by the industry during the survey. The differences between the 1991 quantity and all previous years were statistically significant, even though the 16 million wet tons estimated for 1987-1989 were only slightly larger.

API makes a distinction between two classes of materials: there are 29 specific **Residual Streams** and another group of miscellaneous dilute materials, **Other Aqueous Residuals**. As illustrated below, Other Aqueous Residuals constitute the largest quantity of residuals. Rather than representing a typical industry generation pattern, however, these materials are generated by only several refineries that have deep-well injection capability. As displayed, the quantity of these Other Aqueous Residuals dropped in 1991.

Generation of Residual Streams and Other Aqueous Residuals: 1987-1991



Reductions were also observed in 1991 for several of the specific streams that make up the **Residual Streams** category. These include Pond sediments and Contaminated soils that dropped from the peak quantities reported in 1990, and the K-Wastes which have shown a more systematic downward trend over the survey period. The estimated quantity for several streams increased in 1991, including Spent caustics and the newly reported class of primary sludges (F037 and F038 listed wastes).

The trend analysis revealed distinct generation patterns for certain streams. For some, such as Spent FCCU and hydroprocessing catalysts, generation remained consistent over time. This would be expected since these streams are related to throughput. For others, like Spent caustics, the generation quantities have increased. It is believed that this reflects improved and more consistent reporting over the course of the survey.

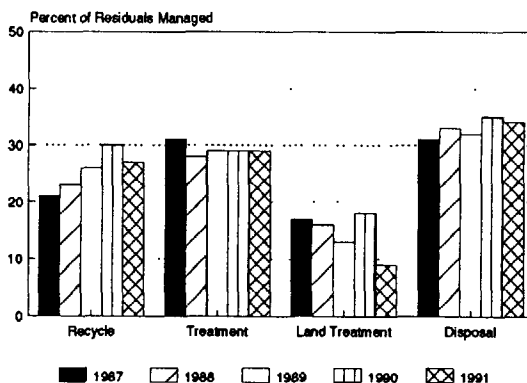
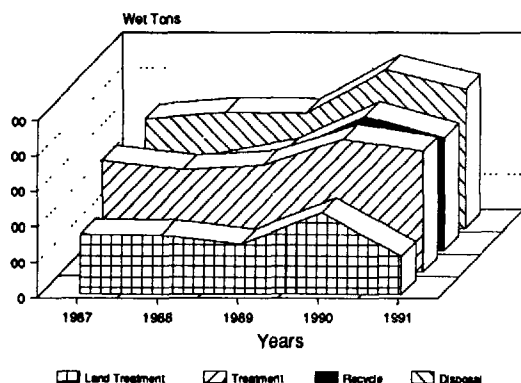
Another grouping of streams was based on the occurrence of pronounced, periodic spikes such as the peak quantities of pond sediments and contaminated soils generated in 1990. In these instances, larger quantities of waste equate to environmental progress, such as site remediation and construction of new process and residual management units.

API separator sludge and DAF float belong to a group of streams where progressively smaller quantities were generated over time. These reductions reflect the industry's concerted effort to minimize generation of these streams, largely through pollution prevention activities. Indeed, refiners reported that a variety of pollution prevention activities accounted for a reduction of over 300 thousand wet tons of API separator sludge and DAF float. (Note that unlike the estimates for the population of refineries that are presented in this report, the pollution prevention information are not U.S. totals and only represent the amount reported by those refineries that responded to the pollution prevention question).

API's survey is the only ongoing effort to document pollution prevention activities across an entire segment of industry. In 1991, approximately half of the refiners responded to the pollution prevention question indicating that they had performed at least one source reduction or beneficial recycling activity. This accounted for 715 thousand wet tons of material. Pollution prevention activities were reported for 26 of the 30 residual streams. In an effort to promote technology transfer, API includes narrative summaries of the various methods used with each stream in its report.

In addition to these pollution prevention achievements, 1991 also witnessed improvements in how the refining industry manages non-aqueous residual materials. This is graphically depicted below, with the quantities handled by each technique on the left and a percentage display on the right.

Summary of Residual Management Practices: 1987-1991



As illustrated by the graph on the left, the peak quantities generated in 1990 affected some of the prevailing patterns or trends in residual management. For example, the industry's use of land treatment has diminished over the five year period, although 1990 witnessed a temporary increase when this technology was used to handle the residuals that resulted from one-time construction and site remediation activities. Recycling, the most preferred handling technique in the waste management hierarchy, has increased since 1987, although 1991 saw a slight drop from the high noted in 1990. Treatment, which was not heavily relied on to manage the peak quantities generated in 1990, remained fairly constant, as did disposal.

The reduction in the use of land treatment and the increases in recycling reflect some of the management improvements instituted to meet the Resource Conservation and Recovery Act (RCRA) land disposal restrictions. As noted above, however, pollution prevention measures implemented by the industry significantly reduced generation of the K-wastes making compliance achievable. Thus, pollution prevention should be recognized as a crucial component of industry and regulatory plans to improve management of residual materials.

Section 1

INTRODUCTION

With this report for calendar year 1991, the American Petroleum Institute (API) has achieved its goal of collecting at least five years of data on residual material managed by domestic petroleum refineries. There are no plans to end this survey effort with this report; to the contrary, API is already collecting data for 1992 and 1993.

At this five-year mark, it seems appropriate to look back on the survey effort, and then, with this overview, proceed with the findings of the expanded analysis of the current data.

The five-year cycle for the survey was set for several reasons:

- to assure the availability of sufficient data to reliably characterize residual generation and management practices;
- to temper the interpretation of fluctuations observed between survey cycles; and
- to demonstrate the industry's commitment to voluntary efforts to monitor its environmental performance.

Reflecting some pragmatic concerns voiced by the refiners during the design phase of the study, these considerations have served as guideposts for the study. Refiners initially cautioned that trends would be difficult to determine because of the *unique considerations of each refinery*. Specifically, there are a variety of factors that influence residual generation: differences in the configurations of refineries, their age and capital improvements, geographic location, crude characteristics and product slates. Because of the multiplicity of interactions among these factors, refiners believe that efforts to control or influence residual management practices must give deference to site-specific considerations.

This five-year framework has likely enhanced the quality and utility of the data beyond the original plans for the survey. It has allowed successive refinements to be made in the survey questionnaire and data collection procedures, which, in turn, have improved the quality of the data collected, and the understanding of the data.

It is also important to note that there have been significant changes in the regulatory climate during the study interval. The survey was initiated in 1988, the height of the "command and control" approach to waste regulation, when more stringent prohibitions were being promulgated under the Resource Conservation and Recovery Act (RCRA). *Waste Minimization* was then the favored strategy for addressing waste generation.

By 1991, many of the proscriptive rules had become effective: there were three new streams listed as hazardous under RCRA and the new Toxicity Characteristic; land disposal restrictions precluded placement of hazardous wastes on the land without prior treatment to the Best Demonstrated Available Technology (BDAT); and *Source Reduction* was the preferred strategy for controlling waste generation.

As this report is published, a next generation of regulations is being contemplated: emphasis is placed on a more reasoned and holistic approach, wherein media-specific strategies are integrated, and site-specific flexibility is being discussed. *Pollution prevention*, which encompasses waste minimization and source reduction, is now the accepted term for waste management improvements.

The petroleum industry's environmental concerns, compliance strategies and management approaches have likewise evolved over the study period. Indeed, this survey is now part of a larger effort by the industry to publicly account for its environmental practices. The STEP program--a Strategies for Today's Environmental Partnership--was developed to implement API's guiding principles in 1991. STEP calls for a series of data collection efforts to enable a self-assessment of the industry's environmental practices.

Because the survey always included a reporting component, API viewed the effort as fulfilling its responsibility to promote technology transfer--one of the tenets of an effective waste minimization program. The survey reports, with the descriptive summaries of innovative activities undertaken by refiners, served as a vehicle to disseminate this information. A secondary benefit, not recognized at the outset, is that the survey instrument itself has become an important tool for the industry, providing direct technical guidance to refiners on measuring residuals generated and standardizing accounting of their subsequent management.

And again, this effort paved the way for other research. The success of the survey helped the industry to mount several projects that promote innovative techniques, such as the design of a new crude unit that minimizes multi-media releases.

The availability of this survey data has already helped the industry to engage in more meaningful dialogue about its practices with community and special interest groups, local and Federal regulatory agencies. API anticipates that these activities will increase with the issuance of this report and the industry's more comprehensive analysis of the data on the residual generation patterns, and the quantitative profile of how the industry is meeting the management challenges of the nineties.

Section 2

METHODOLOGY

For 1991, as with all previous years, the survey employed a census design. A listing of the 183 operating refineries was developed from the Department of Energy's *1991 Petroleum Supply Annual*. Survey materials were mailed in August, 1992—one month earlier than the typical September mailing date. As with previous years, the six week interval allowed for form completion was extended to increase the response rate. Contact was maintained with all refineries during the field administration, with three follow-up calls placed to refineries to encourage response and through a "HELP-line" staffed by a refining expert.

The questionnaire was revised for 1991 to reflect regulatory changes that affected the classification of refining residuals and to gather information on pollution prevention. The analytic procedures were also updated to improve the estimation for 1991, and to expand the analysis of the data beyond the simple summary statistics previously generated. The sections that follow describe the revisions of data collection forms and of the analytic procedures used to create the population estimates.

DATA COLLECTION FORMS

API's survey questionnaire for 1991 included nine short-answer questions focused on refinery characteristics and a series of "data sheets"—one-page forms that collect empirical information on the quantities of residual materials¹ generated and how they are managed. There were 30 data sheets for 1991. On each, "inputs" of residual materials are balanced against "outputs." Inputs include the Quantities Generated plus Treatment Additives and the Net Removed from Storage (i.e., the total amount of material removed from storage minus the amount placed into storage) and constitute the "Total Quantity Managed." As illustrated below, this is balanced according to the waste management hierarchy by the quantities of waste *recycled, treated, or disposed*.

Quantity Generated + Treatment Additives + Net From Storage = **Total Quantity Managed**

Total Quantity Managed = Quantity Recycled + Quantity Treated + Quantity Disposed

API used a two-page format for the data sheets in 1991. Rather than provide a "Code sheet" to which refiners had to refer for the various recycle, treatment and disposal codes, these codes were printed on the back of the preceding page in a different color. Survey participants no longer had to flip back and forth to code management practices, an activity that increased the respondent burden, and increased the likelihood of data coding errors.

¹ Beginning with publication of the Final Report for 1990, API has used the term "residual materials or residuals" to refer to what had previously been called "wastes and secondary materials." This change in terminology reflects industry practices—the use of many of these materials as feedstocks or for recycling, reuse, and reclamation. This change helps to reconcile the utilization of these materials in the petroleum industry with the regulatory usage of the term "waste."

The questionnaire was provided in both hard copy form and on an automated disk, written using Clipper, a commercially available compiler for dBase. A copy of the data collection form is presented in Appendix A.

Several changes in the forms were implemented for 1991:

- new questions on the impact of the *Toxicity Characteristic (TC)* were added to the short answer questions about the refinery characteristics;
- the listing of refinery streams was modified to incorporate the newly *listed "F wastes" under RCRA*.
- a *Pollution Prevention* question was added to each data sheet.

Two questions were developed on the **Toxicity Characteristic**. The first requested information on the amount of wastewater that failed the Toxicity Characteristic Leachate Procedure and its disposition. The second question focused on the amount of residuals considered "solid waste" under RCRA that was characteristically hazardous. (See Questions 8 and 9 in Appendix A.)

In 1990, three new streams were designated as **listed hazardous wastes** under RCRA:

- F037 - Primary sludge (Gravitational separation)
- F038 - Primary sludge (Physical/chemical separation)
- F039 - TSD Leachate

Data on these residuals had previously been captured by the survey, aggregated with other residual materials. Consequently, in addition to adding these three streams to the existing listing of 28 streams, all references to these residuals were deleted from the description of other residuals. Because **Other Separator Sludges** (API code 105) was now subsumed by F037 and F038, there remained a total of 30 waste streams. This listing of streams is presented in Table 1.

As the footnote to Table 1 suggests, the intent of the survey was to capture information on only residual materials—not wastewater that is directly treated and discharged under a NPDES permit or discharged to a POTW.

Table 1
Refining Residual Streams

Category	Constituents
Aqueous residuals	Biomass High pH/low pH waters Oil contaminated waters (not wastewaters)* Spent Stretford solution Spent sulfide solution TSD Leachate (F039)*** Other aqueous residuals NOS**
Chemicals/inorganic residuals	Spent acids Spent caustics Residual amines Other inorganic residuals NOS**
Contaminated soils/solids	Contaminated soils/solids Heat exchanger bundle cleaning sludge*** Residual coke/carbon/charcoal Residual/waste sulfur Other contaminated solids NOS**
Oily sludges/other organic residuals	API separator sludge*** DAF float*** Leaded tank bottoms*** Nonleaded tank bottoms Pond sediments Primary sludge (F037)*** Primary sludge (F038)*** Slop oil emulsion solids*** Waste oils/spent solvents Other oily sludges/organic residuals NOS**
Spent catalysts	Fluid cracking catalyst Hydroprocessing catalyst Other spent catalysts NOS**
Other residuals	Other wastes NOS**

* Does not include NPDES or POTW wastewaters.

** Not otherwise specified.

*** RCRA-listed hazardous wastes for petroleum refining.

The new **pollution prevention** question replaced the questions previously used to capture information on *source reduction* and *resource recovery*. Each year refiners have had difficulty applying the definition of source reduction to industry practices, in particular, distinguishing these from other improvements in residual management practices. To enable refiners to report beneficial recycle of residual materials *out-of-process on-site or by other users off-site*, in 1990 API developed a new question to obtain information on Resource Recovery activities. This question was placed immediately *before* the Source Reduction question, in an effort to force respondents to make a distinction between various beneficial activities, some of which are considered to be waste minimization, and others that are regarded as source reduction.

This strategy improved the reporting of this information, but did not totally resolve activity classification errors.

API believes that source reduction and beneficial recycling of materials are both critical elements in industry efforts to manage residuals. Moreover, API's survey experience suggests that the distinction between the two, or prioritization of one over the other, is not necessarily meaningful to refiners. Rather than perpetuate this somewhat arbitrary distinction, and as part of its continued effort to increase refiners' awareness of these activities and improve the quality of the data collected, API combined the two questions. The reporting format previously used for the source reduction question was retained, but the activity categories were expanded to include four new recycle codes. The question was labeled *Pollution Prevention* since this concept embraces both source reduction and beneficial recycling. Placed on each data sheet where refiners are asked to perform quantitative calculations, spaces were provided for up to three activities. The pollution prevention activity codes were placed on the facing worksheet. Both the question and codes are presented in Figure A.

Figure A
Pollution Prevention Question and Code Categories

POLLUTION PREVENTION	
Did your refinery initiate any activities, change any practices or modify any equipment that DECREASED the amount of this waste stream generated or requiring disposal capacity in 1991?	
☐	No
☐	Yes - Enter amount reduced, _____ wet tons, circle the appropriate waste prevention method code below and provide a brief description of the method used:
Code	Description:
1 2 3 4 5	Activity 1. Year 19 ____
6 7 8 9 10	_____
POLLUTION PREVENTION CODES	
1 = Equipment or Technology Modifications	
2 = Procedure Modifications	
3 = Reformulation or Design of Products	
4 = Substitution of Raw Materials	
5 = Improved Housekeeping, Training, or Inventory Control	
IN-PROCESS RECYCLE	
6 = In refining process units (e.g., crude unit; coker; desalter)	
7 = Recovering oil (& dewatering) by filter pressing/centrifugation	
8 = Other recycle	
OUT-OF-PROCESS RECYCLE	
9 = Reuse/reclamation	
10 = Other	

DATA ANALYSIS

The data verification and estimation procedures for 1991 were similar to those used previously. Data verification included 28 automated consistency checks for the variables on each data sheet, as well as final range checks across respondents and comparisons with the data previously submitted by the respective refinery. In cases that were identified in the edit, the data were verified by direct contact with the facilities to ensure its accuracy.

For each survey year, API develops an estimate of residuals generated by the entire industry based upon information submitted by survey respondents.² Implicit in this approach are the assumptions that the factor(s) influencing waste generation for respondents do not differ from those for non-respondents.

Regression analysis was used to estimate the residual quantity generated by the industry. In previous years, the regression model was based on all residual streams. For 1991, **Other Aqueous Residuals NOS** (Not Otherwise Specified) was not included in the model because it was the stream with the most aberrant responses. That is, few refineries report generating this stream, but those who did, reported extremely large quantities that were disposed by injection in wells. In all previous cycles, these cases had been identified as statistical outliers and were handled differently during model development. However, in 1991, this stream was handled separately throughout the modelling and estimation procedure as described in Appendix B.

Data on refinery characteristics (e.g., operating capacity, age, sewer system) was analyzed to evaluate the effect of the different factors on residual generation at a refinery. Scatter-plots were used to explore relationships between residual generation and the factors thought to be affecting it. Correlation analysis was performed and as in previous years, operating capacity of a refinery was found to be most significantly correlated with residual generation.

Scatter-plots were also used to quantify the form of capacity that best captured its relationship with residual generated. Regression models using different forms of capacity and residual quantity generated were evaluated based on performance criteria like R^2 and Root Mean Squared Error. Evaluation was also based on how closely model assumptions on normality of residuals and homogenous variance of residuals were followed.

In 1991, six outliers were identified during the modelling procedure. Outliers are influential observations that do not follow the general trend of the data and thus deleting them from the model results in a better fit. The six outliers were excluded only from the model used for estimating residual quantity generated by the non-respondents but were included at all other stages of the estimation procedure.

After examining regression models, scatter plots and correlations, it was found that the best relationship was between capacity and square root of total residual quantity generated at a refinery. Therefore, the regression model used for 1991 was of the form:

² A more technical summary of the estimation procedures is included in Appendix B.

$$\sqrt{\text{Total Generated Quantity}} = a + b(\text{Capacity})$$

or

$$\text{Total Generated Quantity} = [a + b(\text{Capacity})]^2$$

where a and b were estimated based on the data from the 107 responding refineries that were not statistical outliers. Because of the square-root transformation, this model yields a biased estimate of the residual quantity generated and a bias correction factor has to be applied. The regression model was then used to estimate the total residual generated by each non-respondent by (1) inputting its capacity into the model; (2) squaring the result; and, (3) applying a bias correction factor so that the final estimate is unbiased.

To estimate the total amount of residual materials generated in 1991 for all (183) of the U.S. refineries, estimates for the 70 non-respondent refineries were combined with: 1) the data obtained from the 113 survey participants (including the six outlier facilities); and 2) the quantity of **Other Aqueous Residuals** estimated for the population of refineries. This is illustrated in the first row of the flow chart presented in Figure B. All residual generation and management data shown in this report are estimates for all 183 refineries.

After deriving the total quantity of generated residual, calculations were performed to estimate the generation quantities for each of the 29 residual streams. A summary of the procedure used is as follows:

- 1) The total reported quantity of residuals for each stream was determined by summing the generated quantities from all respondents.
- 2) The relative contribution of each stream to the total reported quantity was obtained by dividing the individual residual stream generation quantity calculated in (1) by the total quantity of residuals for all 29 streams generated by respondents.
- 3) Each proportion calculated in (2) was multiplied by the total estimated residual quantity for all non-respondents to get residual quantities, by stream, for non-respondents.
- 4) Estimated generated quantity for a stream was obtained by summing the corresponding respondent and non-respondent quantities from (1) and (3). This is depicted in the second row of the flow chart.

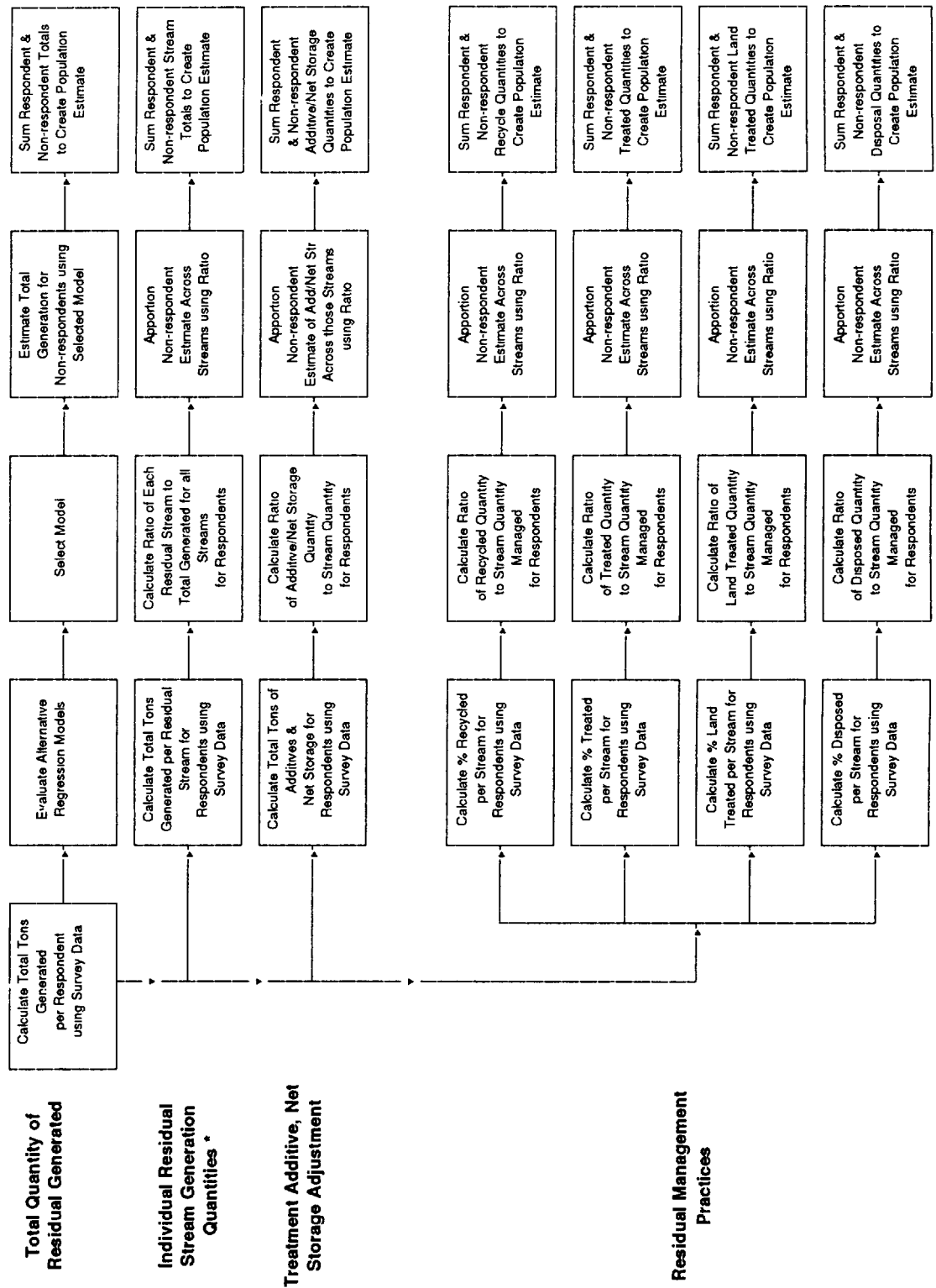
To obtain the managed quantity of residuals, the proportion of treatment additives and net quantity from storage to generated quantity in each stream was calculated. (Shown in the third row of Figure B.) These proportions were then multiplied by the non-respondent generated quantity for a stream to get estimated amounts of treatment additives and net from storage. Thus, the managed quantity of residuals was calculated by summing (a) generated quantity,

(b) treatment additives and (c) net from storage for respondents and non-respondents. A detailed explanation of the above procedure and that used for estimating recycled, treated and disposed amounts is given in Appendix B. The last four rows of the flow chart illustrate how the management estimations are performed.

Also, variances for the total estimated generated quantity and individual stream quantities were calculated. Using these variances, approximate 95% confidence intervals for the individual stream quantities were obtained.

Since 1991 is the fifth year of the Refining Residuals survey, longitudinal data was available to conduct a trend analysis. For each stream, the estimated generated quantity and its 95% confidence interval was plotted for all years. Significant differences in residual quantities over years can be evaluated by determining any overlap in the confidence intervals from one year to another.

Figure B - Statistical Estimation Procedures



* For this chart, STREAM refers to the 29 individual streams included in the analysis.

Section 3

RESULTS

RESPONSE RATE

In 1991, 113 refineries participated in the survey. This represented 62 percent of the population of 183 refineries, and accounted for 73 percent of the domestic crude refining capacity. This was the second highest response obtained, and continues the industry's achievement of at least 70 percent of the refining capacity participating in each survey cycle.

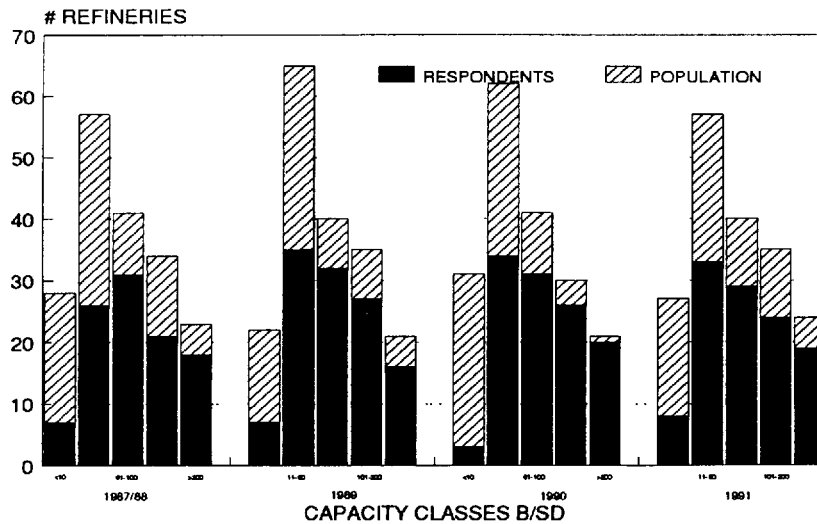
Of the 113 respondents, 70 had participated in all five years, which provided a sizeable cohort for covariance calculations. This was, however, 14 less than the 84 that had participated in all of the previous four surveys. The turnover in participants--particularly in this group of refineries that regularly respond--serves as a reminder that the population of refineries varies from year to year. Even though the total number of operating facilities has remained 183 for the last few years, each year there have been some closings and reactivations. In 1991, six refineries owned by majors, five of which had participated in each previous survey, either closed, converted to asphalt plants or marketing terminals (i.e., no longer met the inclusion criteria for this survey) or were sold. During the year, five other refineries were reactivated. As will be seen in the following discussion of refinery characteristics, the overall turnover of approximately 22 percent exerted some subtle, but detectable changes on the sample characteristics.

RESPONDENT CHARACTERISTICS

The 113 respondents reported an *operating capacity* of 12,073,851 barrels per stream day (b/sd). The total amount of crude charged in 1991 was 3,848 million barrels.

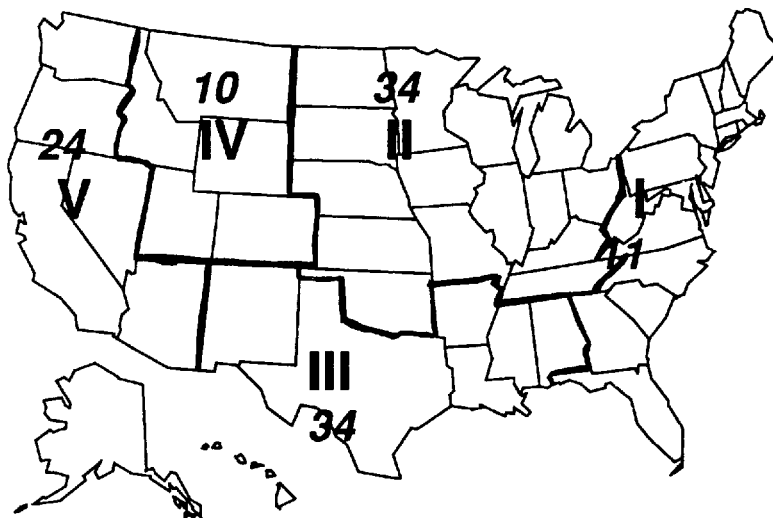
The profile of respondents by *capacity class* was very similar to that observed previously (See Figure C). There was an increase in the number of small refineries participating in the survey. Also, the distribution of operating refineries shifted slightly from 1990, with fewer in the 51-100 b/sd class, and several more in the 100-200 b/sd group.

Figure C
Number of Respondents by Capacity Group



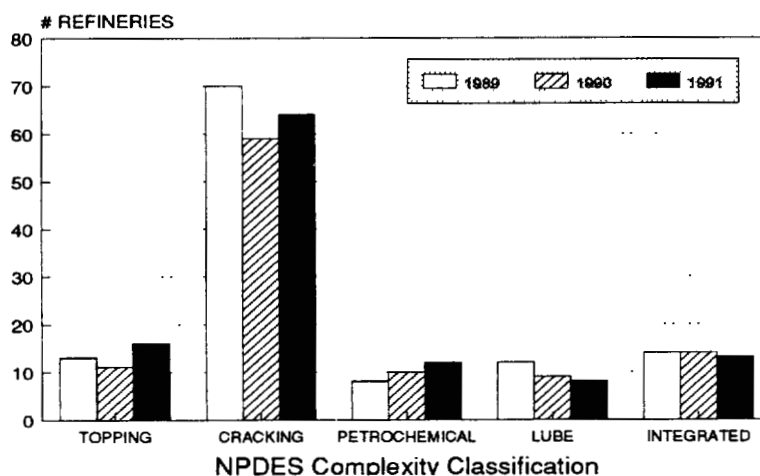
The distribution of refineries by *location* changed in 1991, departing from the direct relationship previously noted between the total number of refineries in each U.S. Department of Energy's Petroleum Administration for Defense (PAD) district and the number of refineries participating in each region. As shown in Figure D, the 34 respondents from PAD II (the third largest district) equalled the 34 refineries in the Texas/Louisiana region (PAD III), the district with the most operating refineries. The number of participants in PAD V increased by two, while one less refinery responded from PAD IV.

Figure D
Distribution of Respondents by Location



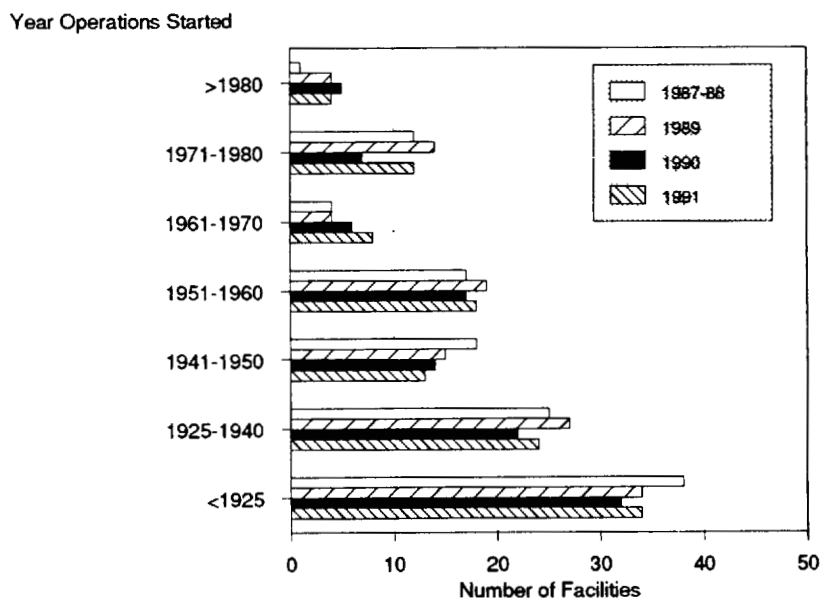
API uses the NPDES permit classifications to categorize the *complexity* of the refineries. Consistent with overall distribution of refineries, cracking facilities continued to predominate in 1991 (See Figure E). Several more topping facilities responded this year, a likely occurrence when one considers the increase in participation observed in the smallest capacity class.

Figure E
Distribution of Respondents by NPDES Complexity Classification



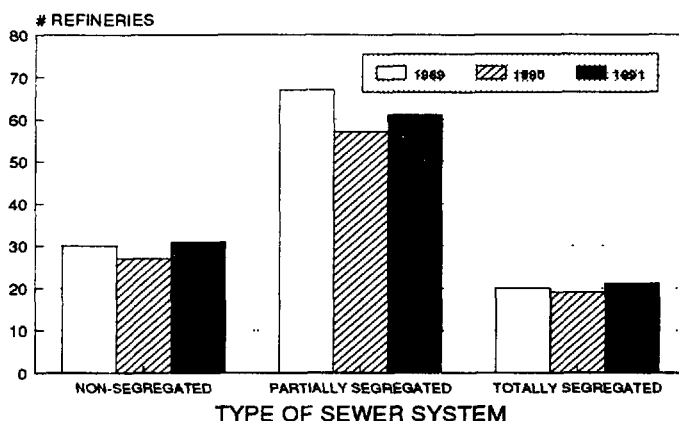
The data collected on the *age* of the refineries are presented in Figure F. The subtle differences across survey years reflect the turnover in the respondent sample. The largest between-year differences occur in refineries built between 1971-1980, relatively new facilities. The largest group continues to be the oldest, approaching 70 years in operation, since they were built before 1925.

Figure F
Distribution of Respondents by Refinery Age



As illustrated in Figure G, the data collected on the type of *sewer system* does not seem to change from year to year, with 73 percent of the refineries segregating some, if not all storm waters from process waters. The slight increases in the number of refineries with partially segregated sewers appears to reflect the increase in the response rate, rather than a shift among facilities from one sewer system type to another.

Figure G
Distribution of Respondents by Sewer Type

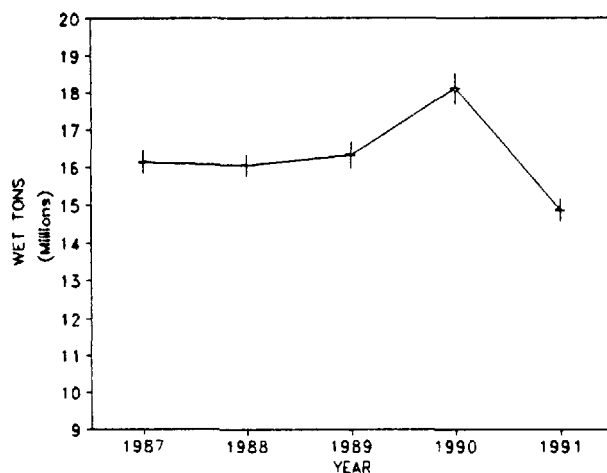


The survey also collected information on *RCRA Permit Status*, requiring participants to indicate their status, either as 1) Generators only with no RCRA permit required; 2) Interim Status (Part A filed) or 3) RCRA permit issued. The refineries were rather evenly distributed, with 38 that were only generators, 38 that had received their permit, and 29 facilities that were in Interim Status.

RESIDUAL GENERATION

The total amount of residual materials generated in 1991 by the 183 U.S. petroleum refineries was estimated to be 14.8 million wet tons--the smallest quantity estimated during the five years of this survey. As shown in Figure H, this was 2.9 million wet tons less than the 18.2 million wet tons generated in 1990 and substantially less than generated in 1987-1989. As the vertical variance bars on the estimates indicate, the difference between 1991 and 1990 was statistically significant (i.e., the vertical bars do not overlap). The amount of residuals generated in 1991 and 1990 differed significantly from the quantities estimated for 1987-1989, which, as shown by the overlap in the variance bars, were comparable.

Figure H
Residual Generation in the Petroleum Refining Industry: 1991 - 1987



What happened in 1991? The greatest change was observed in the generation of **Other Aqueous Residuals**, a stream generated by only a few refiners, but one that has accounted for more than two thirds of the residuals generated in each survey cycle. The amount of **Other Aqueous Residuals** generated in 1991 was over 2 million wet tons less than 1990. This reduction reflects movement by some refiners away from deep well injection of residuals, with concomitant changes in the pretreatment and handling of the dilute residuals that had been suitable for injection. In 1991, four refineries reduced their reliance on deep well injection and are planning total phase-out of this disposal technique. Another refinery obtained a "no-migration" permit for their Class I well, having demonstrated that continued use of the well presents no environmental hazards.

At the same time, the industry witnessed an increase in the amount of **primary sludges** generated, the newly listed "F wastes" under RCRA. Two hundred thousand additional wet tons of these materials were estimated as being generated in 1991. It is unclear whether this represents a true increase in generation, an artifact of the new classification and reporting requirement (e.g., the "F wastes" were reported for the first time in 1991 as individual streams), or even a peak in generation that resulted from refiners making an effort to remove

these materials before more costly management practices are required when LDR requirements become effective. Comparing the differences in the quantities of API Separator Sludge and DAF Float generated between 1990 and 1991, with the quantities of Primary Sludge reported in 1991, however, make it clear that with few exceptions, refiners did not reclassify K-wastes as F-wastes. The exceptions included a refinery that had previously reported the residual from an Induced Air Flotation unit as DAF float and was now correcting their reporting to show that this material was a Primary Sludge. In another case, a refinery reported taking an API Separator out of service and replacing it with an IAF unit (again appropriately reported as a Primary sludge).

The remaining 26 streams had an overall decrease of close to 1.4 millions wet tons, as illustrated in Table 2.

Table 2

Estimate of All Residuals Generated by the U.S. Refining Industry: 1991
(thousands of wet tons)

Residual Category	1991	1990	1989	1988	1987
Aqueous residuals NOS	9,036	11,107	11,100	11,076	11,296
RCRA F Wastes	327	97*	144*	104*	79*
Remaining 27 Residual Streams	5,482	6,902	5,067	4,864	4,769
Total	14,845	18,106	16,311	16,044	16,144

*The quantities for 1987-1990 for Primary Sludge were based on the estimates for "Other Separator Sludges," a stream that was subsumed in 1991 by the Primary sludge streams.

This pattern of an increase in one type of residual being offset by decreases in other streams is noted in Table 3, which presents the annual data for the 29 individual streams.

Increased quantities were estimated for the two largest streams, **spent caustics** and **biomass**. For both of these streams, the 1991 quantities were the largest ever generated. Other streams with increases were relatively low quantity streams: **residual coke/carbon/charcoal**, **residual amines**, **oil contaminated water** (not wastewater) and **spent sulfite solution**.

The largest decrease was noted for **pound sediments** which plummeted from its 1990 peak of over one million wet tons to 372 thousand wet tons. This was a return to a level comparable to the pre-1990 high when many refiners reported closures of surface impoundments that created the spike in the generation curve. Although the quantity of **Contaminated soils/solids** also dropped from the peak in 1990, this stream remained the third largest. Refiners continued to report substantial one-time generation quantities of this stream: for 1991, over 400 thousand wet tons or 67 percent of the total amount of **Contaminated soil/solids** generated resulted from "abnormal" events. Common knowledge of the industry's ongoing site remediation activities and construction to update refining process units corroborates this generation pattern.

Table 3**Estimate of Residual Materials Generated by the U.S. Refining Industry: 1991**

(thousands of wet tons)

Residual stream	1991	1990	1989	1988	1987
Spent Caustics	909	889	716	656	675
Biomass	855	782	642	786	757
Contaminated soils/solids	809	920	512	240	165
DAF float	406	553	496	655	652
Other inorganic residuals NOS	397	451	440	213	325
Pond sediments	372	1,017	313	266	337
Other residuals NOS	339	352	325	412	203
API separator sludge	210	251	419	355	400
FCC catalyst or equivalent	204	198	182	193	173
Primary sludge (F038)	177				
Slop oil emulsion solids	165	291	272	224	208
Residual coke/carbon/charcoal	138	92	129	67	43
Residual amines	136	75	51	14	13
Primary sludge (F037)	130				
Nonleaded tank bottoms	109	194	161	129	216
Spent acids	88	336	8	149	126
Oil contaminated waters (not wastewaters)	67	8	29	36	28
High pH/low pH waters	54	105	91	138	144
Other oily sludges/organic residuals NOS	54	53	47	61	38
Other contaminated soils NOS	37	69	53	68	82
Hydroprocessing catalysts	32	31	36	36	40
Spent Stretford solution	25	29	42	49	35
Other spent catalysts NOS	23	39	33	37	33
Residual oils/spent solvents	21	115	31	7	4
TSD Leachate (F039)	20				
Residual sulfur	19	35	52	22	17
Spent sulfite solution	9	1	8	40	42
Heat exchanger bundle cleaning sludge	3	13	2	5	3
Leaded tank bottoms	1	3	4	8	9
Other separator sludges	NA	97	114	104	79
Total	5,809	6,999	5,508	4,968	4,868

The decreases in the RCRA "K wastes" also contributed to the overall reduction in generation quantities. **DAF float** and **slop oil emulsion solids** both dropped by over 100 thousand wet tons, to 406 and 165 thousand wet tons, respectively. **API separator sludge** experienced a more modest decrease, but had already undergone some successive, substantial reductions.

While the quantities of **heat exchanger bundle cleaning sludge** and **leaded tank bottoms** were quite small, they nonetheless represented reductions of one third or more. As will be discussed later in this report, many refineries attributed these decreases to source reduction activities.

Sizeable reductions were also observed for **spent acids**, **nonleaded tank bottoms**, **other contaminated soils** and **residual oils/spent solvents**, streams that have some similarities in reporting patterns, but more interesting differences. As shown in Table 4, **nonleaded tank bottoms**, **other contaminated soils** and **residual oils/spent solvents** were reported by at least 59 refineries, a relatively high rate for this survey. **Spent acids**, on the other hand, was only reported by 20 refineries. What is interesting is that the decrease for **spent acids** and **residual oils/spent solvents** reflects a change in generation rate by only a few of the refineries participating in the survey, while the reductions in the other two streams appears to reflect a more systematic change by the group of refiners reporting each of these streams.

These frequency counts provide corollary information to the estimated quantity of residuals by the population of refiners, suggesting that there are *patterns* of generation. From Table 4 it is clear that no individual stream is generated by all refiners in any year. Yet some streams are generated by individual refiners every year, while other refiners generate these streams every other year, less frequently, or not at all. Because residual streams are generated periodically, no single year of data can provide a reliable snapshot of industry practices. Even with several years of data, effort must be exerted to control for this source of variability in the estimated quantity of residual material.

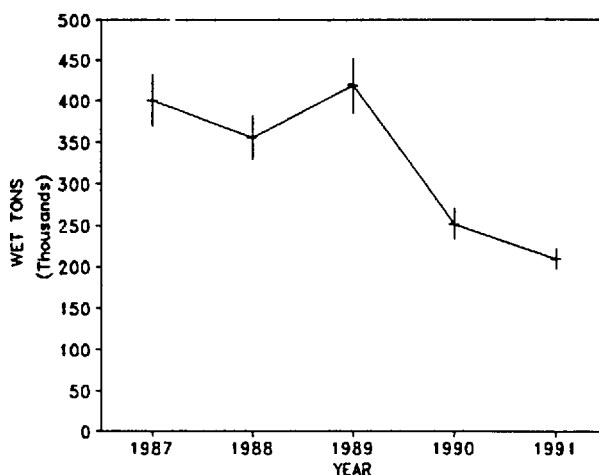
Table 4
Number of Refineries Reporting Each Stream

Residual stream Total number of refineries participating	1991 113	1990 103	1989 117	1988 115	1987 115
Contaminated soils/solids	90	87	88	77	77
Other residuals NOS	83	85	89	85	92
FCC catalyst or equivalent	76	79	84	86	85
API separator sludge	76	85	93	94	91
Nonleaded tank bottoms	69	72	72	75	72
Spent caustics	69	66	70	77	79
Residual oils/spent solvents	65	56	56	61	52
Other spent catalysts NOS	63	57	60	60	62
Other inorganic residuals NOS	62	65	73	73	77
Primary sludge (F037)	59				
Other contaminated soils NOS	59	56	61	71	70
Hydroprocessing catalysts	57	52	65	60	57
Residual coke/carbon/charcoal	55	50	51	47	48
Biomass	45	44	44	45	47
DAF float	44	50	47	50	53
Heat exchanger bundle cleaning sludge	43	51	49	48	49
Other oily sludges/organic residuals NOS	43	42	49	47	49
Residual sulfur	43	37	42	47	41
Slop oil emulsion solids	32	35	38	43	47
Residual amines	32	27	38	36	32
Pond sediments	25	34	31	29	26
Leaded tank bottoms	20	27	31	37	38
Spent acids	20	24	18	23	20
Other aqueous residues NOS	14	11	14	12	13
Primary sludge (F038)	14				
Oil contaminated waters (not wastewaters)	10	10	14	10	14
Spent Stretford solution	6	7	11	13	12
High pH/low pH waters	4	11	11	12	14
Spent sulfite solution	3	1	2	1	1
TSD Leachate	3				
Other separator sludges	NA	19	22	20	15

To gain a better understanding of the changes that have been observed in the generation rates, API performed two ancillary analytic procedures: a trend analysis was undertaken to identify statistically significant differences in the generation rates for individual streams between survey years; and, a covariance analysis was performed on the subset of refineries that had participated in all five years of the survey.

For the trend analysis, the approximate 95 percent confidence interval for each stream estimate was plotted and reviewed. The determination of statistically significant differences relies on a simple visual inspection of the graph: when the variance bars overlap, it is assumed that there is no statistically significant difference in the generation rates; conversely, when the bars do not overlap, the difference is considered to be statistically significant. The graph for API Separator Sludge (KO51) is presented below to illustrate the graphic output for each stream.

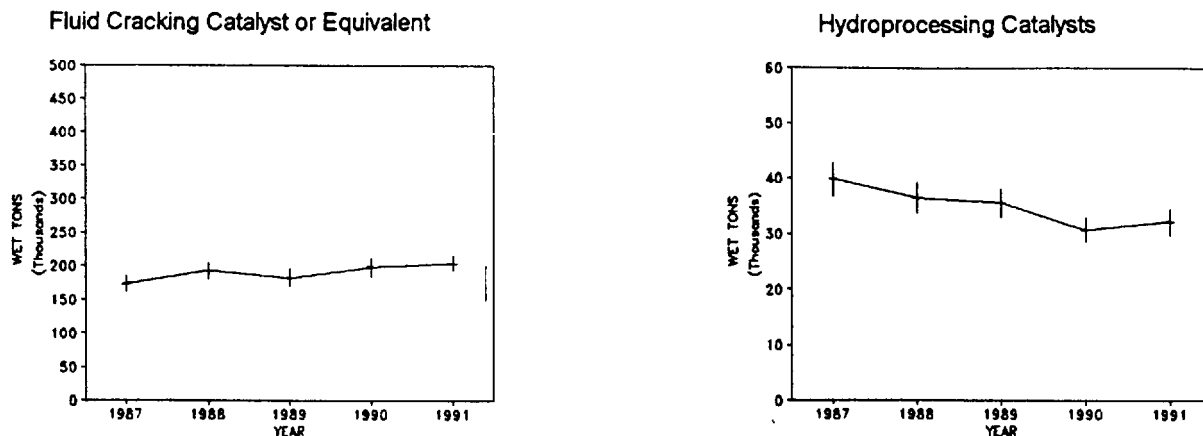
Figure I
Trend Analysis Plot for API Separator Sludge



This graph shows that from 1987 to 1989, the generation of API Separator Sludge varied between years, but no statistically significant difference was observed. In both 1990 and 1991, the amount generated dropped substantially, with the difference between 1990 and the three previous years being statistically significant. The amount generated in 1991 was also significantly different from all previous years. As the width of the error bars (Confidence interval) indicates, the error in the estimate has also diminished over time, with error for 1991 being the smallest.

Review of these trend graphs for each stream has provided some interesting observations about the variability in the generation rates across time. The streams that remained fairly static, as shown below, were the catalysts: **FCCU catalyst or equivalent** and **hydroprocessing catalysts**. Use of catalysts by the industry is largely a function of throughput, which has remained fairly constant over the survey period.

Figure J
Generation Trends for FCCU and Hydroprocessing Catalysts



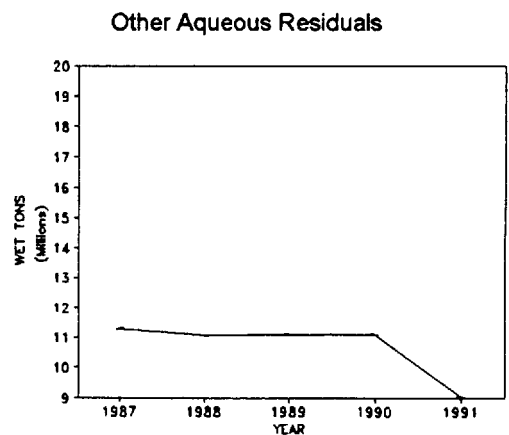
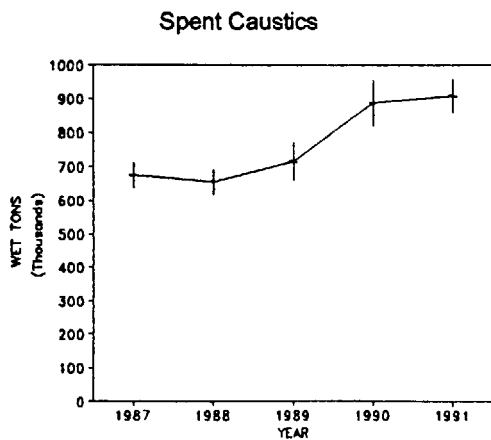
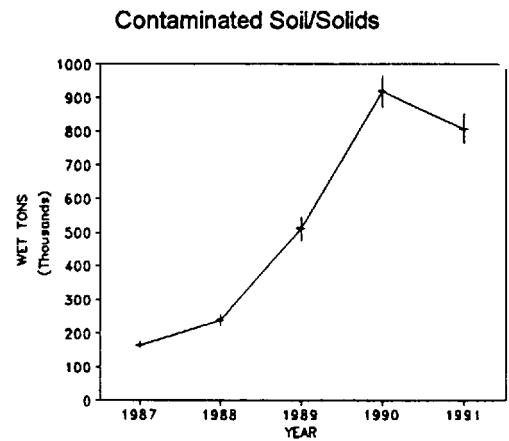
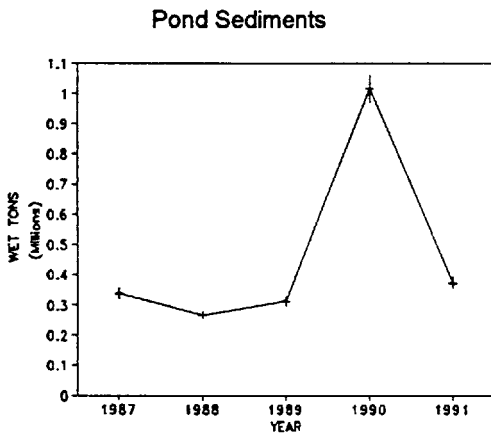
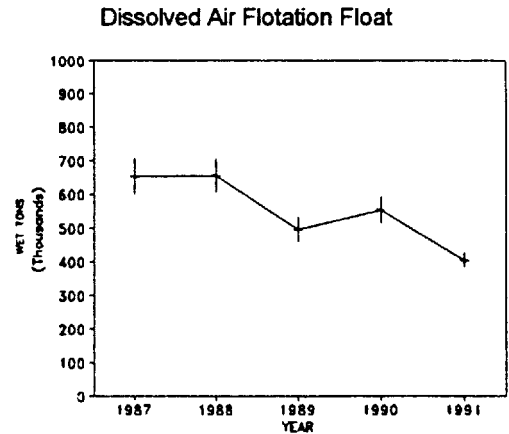
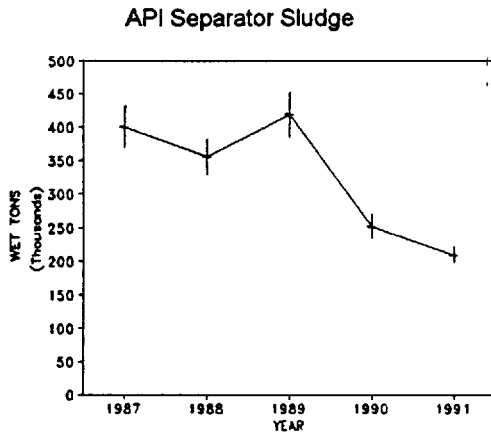
For other streams, when the 1987 generation estimates are compared with the 1991 estimates, the difference is statistically significant. For some streams, the quantity has decreased over time, while others have increased. When comparisons are made between two consecutive years, the differences are more subtle. Thus, observation of statistically significant differences between years must be critically reviewed and interpreted to determine if the difference is truly meaningful.

In some cases, the changes are fairly easy to interpret:

- for **API Separator Sludge** and **DAF Float**, listed hazardous wastes, the 1991 quantity is substantially *less* than that generated in 1987 and reflects the conscientious effort by the industry to reduce the amount of these materials generated;
- for **Pond sediments**, a *peak* in generation occurred in 1990 as more refiners closed surface impoundments, prior to the effective dates for the TC and primary sludge regulatory initiatives;
- for **Contaminated soils**, the quantity generated *increased* significantly each year from 1987 to 1990 as more refineries initiated construction projects and remediated sites;
- for **spent caustics** there have been successive *increases* in the generation quantities that appear to reflect differences in the reporting of these materials (i.e., as more emphasis has been placed on beneficial reuse of residual materials, refiners have increased reporting spent caustics as a residual material, whereas previously this material had not been considered a residual because it was resold for subsequent use);
- for **Other aqueous residuals**, the generation quantity *dropped* in 1991 as some refiners phased out reliance on injection wells for these dilute materials.

Trend graphs for these streams are presented on the following page.

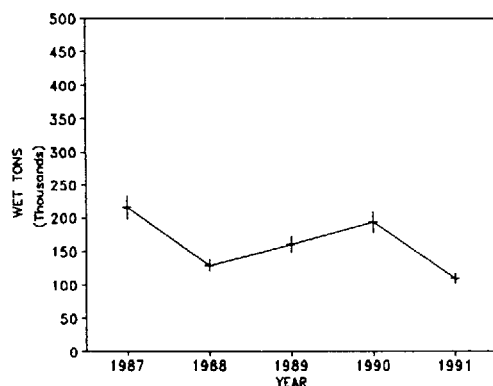
Figure K
Residual Generation Curves for Streams with Significant Trends



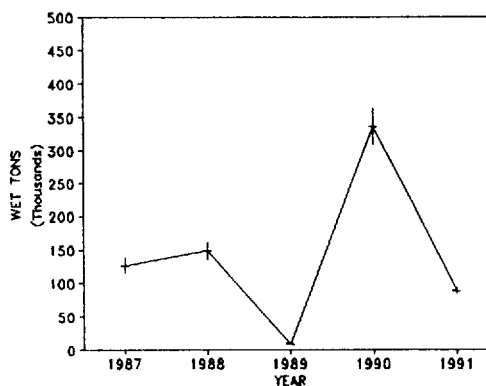
It appears that there is another grouping of streams--those for which there is no discernable pattern in generation, and for which there is no ready explanation of the variability. Note the graphs for **Nonleaded tank bottoms** and **Spent acids** in which the quantities generated each year fluctuate, as do the variances of each respective estimate.

Figure L
Residual Generation Curves for Streams with Unexplained Variability

Nonleaded Tank Bottoms



Spent Acids



The graphs for several other streams, **biomass**, **residual oils/spent solvents**, **residual coke/carbon/charcoal** also show substantial fluctuations between years that are statistically significant. For these streams, it appears that the variability can be attributed to fluctuations in the quantities reported by several, but not all refineries. Although it is unclear why the quantities reported by individual refineries varied so greatly, this pattern of reporting signaled the need for further analysis to more clearly understand these variations. Consequently, API performed a covariance analysis on the cohort of 70 refineries that had participated in all five survey years.

This covariance analysis was similar to that performed with the first three survey cycles of data in the 1989 report. Streams with five year industry-wide means of at least 100,000 wet tons were selected for study. Ten streams met this criteria. For the cohort of refineries, coefficients of variation (i.e., the standard deviation expressed as a percentage of the mean) were determined for both the industry-wide mean generation quantity for the 1987 - 1991 survey period and for each refinery reporting each waste stream. These data are arrayed in Table 5 in ascending order of the coefficient of variation for the industry; the median coefficient of variation for the individual refineries is presented in the next column.

Table 5**Covariance Data on Residual Generation Rates: 1987 - 1991 (Cohort of 70 refineries)**

Residual Stream	Mean Residual Managed by Cohort 1987-1991	Coefficient of Variation for Cohort	Median Coefficient of Variation for Individual Refineries
Biomass	455,540	11	109
DAF Float	280,414	14	77
Spent Caustic	508,084	17	85
FCC Catalyst or Equivalent	105,776	19	51
Other Residuals NOS	220,029	28	98
Other Inorganic Residuals NOS	225,172	27	93
Slop Oil Emulsion Solids	126,840	32	134
API Separator Sludge	213,221	50	91
Pond Sediments	303,949	58	199
Contaminated Soils/Solids	329,275	67	122

The industry-wide coefficient of variation ranged from 11 to 67 percent. The median coefficient of variation for refineries is consistently higher, ranging from 51 to 199. Moreover, the refinery specific coefficients of variation are two to ten times larger than the industry-wide coefficients. For example, for **biomass**, the industry-wide coefficient of 11 percent is 10 times smaller than the individual refinery median variation of 109 percent. Moving to the bottom of the table, the individual refinery coefficient for **contaminated soils/solids** is 122, but since this stream also has the second largest industry coefficient, the individual coefficient is only two times larger.

It is difficult to posit many meaningful interpretations of these data. It comes as no surprise that **pond sediments** and **contaminated soils/solids** exhibit the greatest variability. Both of these streams had large, abnormal/one-time generation peaks in 1990, which clearly contribute to the variability. Similarly, it is reasonable that **FCCU catalyst or equivalent** is intermediate in the table, since this stream is generated continually and has not varied substantially over time.

Even though it is hard to interpret the variability for individual streams, this covariance analysis makes it clear that site-specific considerations are critical in residual generation patterns. This source of variability must be factored into interpretations of the data, and any subsequent applications or inferences drawn from the data.

POLLUTION PREVENTION

As described in the Methodology section, a pollution prevention item was included on each data sheet. Refiners were asked to report, for each stream, activities that reduced the quantity of residual generated and/or the amount that might eventually require disposal. With the expanded listing of activity categories--both source reduction methods and codes to report in-process and out-of-process recycling--the number of refineries that reported any pollution prevention activities was 61, one less than the 62 that reported initiating source reduction activities in 1990. Most refiners reported more than one pollution prevention activity. The total number of activities reported was 274, close to 70 more than reported in 1990.

Refiners attributed a substantial reduction in residuals to pollution prevention activities: a total of 751,319 wet tons.

When comparing this with 1990, the revision in the question for 1991 must be kept in mind. The most valid comparison is to contrast the 751 thousand wet tons reported as pollution prevention in 1991 with the 315,524 wet tons of material reported in 1990 as prevented due to source reduction activities *summed* with the 143,841 thousand wet tons that were reported as reused or recycled under the resource recovery data item in the 1990 questionnaire. Comparison of the 751 thousand for 1991 with the total of 460 thousand for 1990 yields a 63 percent increase in the quantity of residuals reported by survey participants that were reduced at the source, recycled or otherwise reused or reclaimed.

Table 6 presents the frequency counts for each pollution prevention method.

Table 6
Number Refineries Reporting Each Pollution Prevention Activity

Pollution Prevention Activity	# Citations
Equipment or Technology Modifications	24
Procedure Modifications	23
Reformulation or Design of Products	3
Substitution of Raw Materials	13
Improved Housekeeping, Training, or Inventory Control	43
IN-PROCESS RECYCLE	
In refining process units (e.g., crude unit; coker; desalter)	42
Recovering oil (& dewatering) by filter pressing/centrifugation	50
Other recycle	5
OUT-OF-PROCESS RECYCLE	
Reuse/reclamation	66
Other	10

The most frequently reported activity was *reuse/reclamation* of materials, an out-of-process recycle method. As documented previously, the industry relies extensively on these methods to manage catalysts and chemicals used in the refining process. *Improving oil recovery operations* was the second highest activity cited, as might be expected in a year when land disposal restrictions on oily materials provided incentives to minimize the amount of these materials requiring disposal. *Housekeeping, training, and inventory control improvements*--the low hanging fruit of pollution prevention which can be readily implemented without large capital expense--was next, followed by *in-process recycle* of oily materials.

Procedure modifications and *equipment and technology modifications* received 23 and 24 responses, respectively. This was a substantial drop in the number of procedure modifications which was cited 73 times in 1990. Mentions of equipment and technology modifications were comparable with 18 in 1990 and 24 this year. Reporting *substitution of raw materials* doubled over the year, and although it remained a low frequency response--just 13--its increase attests to some of the toxics use reductions implemented by the industry: replacing chromates in cooling towers; using water-based solvents for cleaning operations; replacing asbestos insulation; and substituting other oils for PCBs in electrical equipment.

The fluctuations in these frequency counts serve as reminders of anticipated trends in pollution prevention and source reduction activities. Recycling of oily materials and spent chemicals/caustics is an ongoing activity that is reported each year. Hence the repeated, high frequency counts. As suggested above, some activities, typically the housekeeping improvements, can be implemented without much capital expense. Some of these improvements may be reported only once, like the paving of process areas to reduce dust and solids entering the sewer system, while others, like sweeping, may be ongoing and are reported successively.

Procedure modifications usually optimize operations, and are dependent on formalized analysis of current procedures. These innovations and any related reductions in residuals are reported for the year they were initiated. Although these modifications become part of ongoing operating procedures, they may only be counted the year they came online. Equipment and technology modifications, like efforts to reformulate products or substitute raw materials, generally require research and monetary investments to develop and implement. Because they take longer to achieve, frequency counts for these activities are expected to remain low.

The summary statistics in Table 6 provide an overview of the industry's continuing efforts to improve its operating practices. Looking at this same pollution prevention data, but arrayed by residual stream, reinforces the view that the industry dedicates substantial effort to optimizing management practices. As Table 7 reveals, refiners reported some pollution prevention activity for 26 of the 29 residual streams. Moreover, for 24 streams, there were two or more different pollution prevention activities performed.

Table 7
Summary of Pollution Prevention Activities

	# Refineries	Wet Tons	SOURCE REDUCTION					IN-PROCESS					RECYCLE	
			1	2	3	4	5	6	7	8	9	10		
Residual stream														
API Separator Sludge	36	103,291	✓	✓			✓	✓	✓		✓			
DAF Float	20	195,411	✓	✓			✓	✓	✓	✓	✓			
Slop Oil Emulsion Solids	16	20,489	✓				✓	✓	✓		✓			
Leaded Tank Bottoms	5	41			✓				✓					
Pond Sediments	4	6,348		✓				✓						
Nonleaded Tank Bottoms	9	22,257						✓	✓		✓			
Residual Oils/Spent Solvents	8	373	✓			✓	✓	✓		✓	✓			
Other Oily Sludges/Organic Wastes	4	148	✓				✓	✓	✓					
Primary Sludge (F037)	10	38,602	✓	✓			✓	✓	✓					
Primary Sludge (F038)	4	495						✓			✓			
Heat Exch Bundle Cleaning Sludge	5	179						✓	✓					
Contaminated Soil/Solids	12	16,470	✓	✓			✓				✓			
Residual coke/Carbon/Charcoal	4	311					✓				✓			
Residual sulfur	2	223	✓				✓							
Other contaminated soils	7	470		✓			✓					✓		

POLLUTION PREVENTION CODES

1 = Equipment or Technology Modifications

2 = Procedure Modifications

3 = Reformulation or Design of Products

4 = Substitution of Raw Materials

5 = Improved Housekeeping, Training, or Inventory Control

IN-PROCESS RECYCLE

6 = In refining process units (e.g., crude unit; coker; desalter)

7 = Recovering oil (& dewatering) by filter pressing/centrifugation

8 = Other recycle

OUT-OF-PROCESS RECYCLE

9 = Reuse/reclamation

10 = Other

Table 7 (contd)
Summary of Pollution Prevention Activities

Residual stream	# Refineries	Wet Tons	SOURCE REDUCTION					IN-PROCESS RECYCLE					OUT-OF-PROCESS RECYCLE	
			1	2	3	4	5	6	7	8	9	10		
FCC Catalyst or Equivalent	14	16,159	✓					✓			✓			
Hydroprocessing catalysts	7	6,214						✓			✓			
Other Spent Catalysts	8	1,215	✓	✓							✓			
Biomass	8	212,595	✓	✓			✓	✓	✓	✓				
Oil contaminated water (not WW)	1	431	✓											
High pH/low pH waters	2	10,548		✓									✓	
Other aqueous wastes NOS	1	113									✓			
Spent caustics	12	63,954	✓	✓				✓			✓			
Residual amines	4	15,853					✓				✓			
Other inorganic residuals NOS	4	6,515						✓	✓		✓			
Other residuals NOS	10	12,614		✓		✓	✓	✓			✓		✓	
TOTAL	274	751,319												

POLLUTION PREVENTION CODES

1 = Equipment or Technology Modifications

2 = Procedure Modifications

3 = Reformulation or Design of Products

4 = Substitution of Raw Materials

5 = Improved Housekeeping, Training, or Inventory Control

IN-PROCESS RECYCLE

6 = In refining process units (e.g., crude unit; coker; desalter)

7 = Recovering oil (& dewatering) by filter pressing/centrifugation

8 = Other recycle

OUT-OF-PROCESS RECYCLE

9 = Reuse/reclamation

10 = Other

The greatest reduction, 213 thousand wet tons, was reported for biomass. The eight refiners with biomass reductions implemented a variety of pollution prevention activities:

- improving equipment by installing a steam dryer;
- optimizing procedures by using chemicals for dewatering and stopping use of an impoundment;
- improving housekeeping to avoid contamination of the wastewater system;
- recycling biomass by injecting it into the crude conversion unit, by improving deoiling or by using it to re-seed the refinery's land biotreatment unit.

DAF float had the second greatest reduction, followed by **API separator sludge** (195 and 103 thousand wet tons, respectively). When these RCRA listed hazardous wastes are combined with the other regulated streams (**Slop oil emulsion solids, leaded tank bottoms, heat exchanger bundle cleaning sludge** and the **primary sludges**), they total 359 thousand wet tons or 48 percent of the total quantity that was prevented.

As the check marks in Table 7 indicate, refineries used a variety of pollution prevention activities with these five streams. As might be expected for these oily materials, in-process recycling to either process units (e.g., crude units or cokers) or via improved deoiling/dewatering, were cited for all these streams. Technology/equipment improvements included installing thermal dryers to maximize deoiling/dewatering, segregating the sewer system, installing new feed equipment to the filter press, or installing zero sample valves at all units. Procedure improvements ranged from use of safe-t-caps during hot work, to segregating residuals (particularly biosludge), to optimizing decanting. The housekeeping improvements focused on suppressing dust and soil from entering the sewers, either by paving, regrading or sweeping process and tank areas, or by "dry" cleaning process areas. More information on the pollution prevention methods reported for each stream can be found in Appendix C.

The other residual stream for which refiners reported a substantial pollution prevention quantity was **spent caustics** (64 thousand wet tons). Recycling, particularly out-of-process reuse by paper and chemical manufacturers, or on-site at bio-ponds for pH control, accounted for much of the spent caustics. As shown in Appendix C, in-process recycle methods involved use of prewash caustics by other treaters or "captive" use within a company, but at another refinery.

The amount of material attributed to pollution prevention activity was much smaller for the remaining residual streams. Refiners reported the in-process recycle of 22 thousand tons of **nonleaded tank bottoms. FCCU catalyst or equivalent** and **contaminated soils/solids** both had 16 thousand wet tons reported, by 14 and 12 refineries, respectively. The pollution prevention activities for **FCCU catalyst or equivalent**, a residual generated on a continuous basis, represented 8 percent of the total amount of this stream generated. The reductions reflect engineering changes in the cyclones, as well as out-of-process regeneration or recycling of the residual to steel and cement manufacturers.

In contrast, the amount of **contaminated soil/solids** prevented represented barely 2 percent of the total amount generated. As would be anticipated for a stream that is not methodically generated (i.e, contaminated soils result from abnormal, one time events such as spills or from infrequent, periodic initiatives such as construction of new units or remediation of a site), housekeeping improvements were cited to avoid future contamination. In addition, some of this contaminated material was recycled via cement kilns. An interesting procedure modification reported was the use of recyclable steel grit with a containment system which reduced the amount of sand blast grit generated (and disposed).

For more information on the pollution prevention activities conducted on other residual streams, readers should refer to the respective tables in Appendix C.

TOTAL QUANTITY OF RESIDUALS MANAGED

API has used *total quantity managed* to refer to the total amount of residual materials which refineries must handle in a given calendar year. This phrase makes an explicit reference to the waste management hierarchy, wherein residual materials are eliminated from further handling by a combination of recycling, treatment, and/or disposal³. The quantity managed is usually larger than the quantity generated, because refiners add treatment materials to facilitate subsequent handling of some residuals, while additional material that had been in storage can be removed for final disposition. The following equation shows the various components.

$$\text{Total Quantity Managed} = \text{Quantity Generated} + \text{Treatment Additives} + \text{Net From Storage}$$

As described earlier, a total of 5,809 thousand wet tons of residuals were *generated* in 1991. After accounting for the use of treatment additives and movement of materials in and out of storage, it was estimated that the industry *managed* a total of 5,808 thousand wet tons of residual material. This difference of only 1 thousand tons was the smallest ever observed between these two measures. In the past, treatment additives plus the removal of residuals from storage have created a larger increase in the 100 thousand wet tons range.

Table 8 presents a listing, by stream, of the wet tons generated plus treatment additives and the net from storage. As the summary row at the bottom of the table indicates, the amount of treatment additives used was offset by residuals placed into storage in 1991. The 42 thousand wet tons placed into storage included 24 thousand of **contaminated soils/solids**, eight thousand of **slop oil emulsion solids**, six thousand of **DAF float**, and 4 thousand of **Inorganic residuals NOS**.

The use of treatment additives has fluctuated over the five years, reaching a high of 88 thousand wet tons in 1990, when the peak in generation of pond sediments necessitated use of more additives. One year earlier, in 1989, the low of 35 thousand wet tons was reported. The 42 thousand for 1991 is the second lowest ever reported, and represents reductions in the use of additives for **spent caustics**, and, as would be expected when regulatory constraints emphasized minimizing the quantity of listed hazardous wastes, **DAF float**, **API separator sludge** and **slop oil emulsion solids**.

³ As described previously, **Other Aqueous Residuals NOS** are typically deep well injected without any prior effort to minimize the quantity by recycling or treatment. Because of this, this stream was handled separately in 1991 and is not included in the total quantity of residuals discussed in this section.

Table 8**Estimates of Residual Materials Managed in 1991 (thousand wet tons)**

Residual streams	Amount Generated	Treatment Additives	Net From Storage	Total Amount Managed
Spent caustics	909		(1)	908
Biomass	855	7	<1	862
Contaminated soils/solids	809	<1	(24)	785
DAF float	406	9	(6)	410
Inorganic residuals NOS	397	<1	(4)	393
Pond sediments	372	8	0	381
Other residuals NOS	339	0	<1	339
API separator sludge	210	5	(1)	214
FCC catalyst/equivalent	204	0	0	204
Other separator sludges				
Primary Sludge (F038)	177	3	(<1)	180
Primary Sludge (F037)	130	2	<1	133
TSD Leachate (F039)	20	0	0	20
Slop oil emulsion solids	165	3	(8)	160
Residual coke/carbon/charcoal	138	0	(<1)	138
Residual amines	136	0	<1	137
Nonleaded tank bottoms	109	2	(<1)	111
Spent acids	88	<1	0	88
Oil contaminated waters (not wastewaters)	67	0	0	67
High pH/low pH waters	54	0	0	54
Oily sludges/organic residuals NOS	54	<1	(<1)	54
Contaminated soils NOS	37	<1	(<1)	37
Hydroprocessing catalysts	32	0	<1	33
Spent Stretford solution	25	0	(<1)	25
Other spent catalysts	23	<1	<1	23
Residual oils/spent solvents	21	0	(<1)	21
Residual sulfur	19	0	<1	19
Spent sulfite solution	9	0	<1	9
Heat exch bundle cleaning sludge	3	<1	(<1)	3
Leaded tank bottoms	1	0	(<1)	1
Total	5,809	42	(43)	5,808

Table 9 compares the total quantity of residuals managed in 1991 with the data for the preceding four years. As shown, 1991 weighed in with the second largest quantity of residuals to manage, substantially lower than the high of 1990, and generally comparable to the quantities reported prior to that peak. Given that the influence of treatment additives and storage activity was negligible, the patterns observed in generation rates remained valid: the largest increase was noted for **biomass** and the quantity of **primary sludge** increased. Sizeable reductions were recorded for **pond sediments**, the **listed hazardous wastes**, and **contaminated soils/solids**.

Table 9
Comparison of Residual Material Managed: 1991-1987
(Estimates in thousands of wet tons)

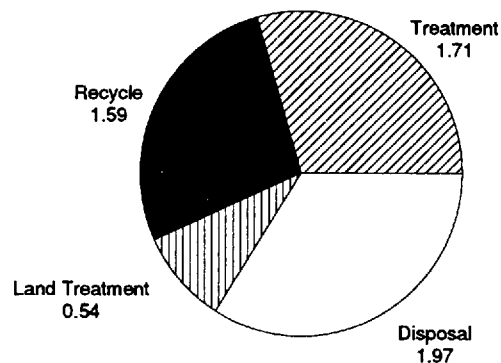
Residual streams	1991	1990	1989	1988	1987
Spent caustics	908	894	716	656	675
Biomass	862	794	655	749	720
Contaminated soils/solids	785	915	496	242	186
DAF float	410	564	521	661	654
Inorganic residuals NOS	393	453	441	221	323
Pond sediments	381	1,040	273	311	360
Other residuals NOS	339	353	325	412	203
API separator sludge	214	260	425	430	564
FCC catalyst/equivalent	204	259	185	189	171
Other separator sludges	NA	104	117	110	83
Primary Sludge (F038)	180	NA	NA	NA	NA
Primary Sludge (F037)	133	NA	NA	NA	NA
TSD Leachate (F039)	20	NA	NA	NA	NA
Slop oil emulsion solids	160	295	262	214	212
Residual coke/carbon/charcoal	138	92	137	67	43
Residual amines	137	75	51	14	13
Nonleaded tank bottoms	111	196	164	131	218
Spent acids	88	337	8	160	130
Oil contaminated waters (not wastewaters)	67	8	29	36	28
High pH/low pH waters	54	105	92	138	144
Oily sludges/organic residuals NOS	54	54	47	61	40
Contaminated soils NOS	37	69	53	77	88
Hydroprocessing catalysts	33	30	36	37	39
Spent Stretford solution	25	30	42	49	35
Other spent catalysts	23	41	33	38	38
Residual oils/spent solvents	21	115	31	7	4
Residual sulfur	19	35	52	23	17
Spent sulfite solution	9	1	8	40	42
Heat exch bundle cleaning sludge	3	13	2	5	3
Leaded tank bottoms	1	3	4	10	9
Total	5,808	7,134	5,206	5,086	5,043

MANAGEMENT PRACTICES FOR RESIDUAL MATERIALS

As described in the Methodology section, the data sheets require respondents to categorize the disposition of each waste stream according to the waste management hierarchy of recycle, treatment and disposal. (Even though it was collected under the broader category of treatment, API breaks out land treatment data and reports it separately.)

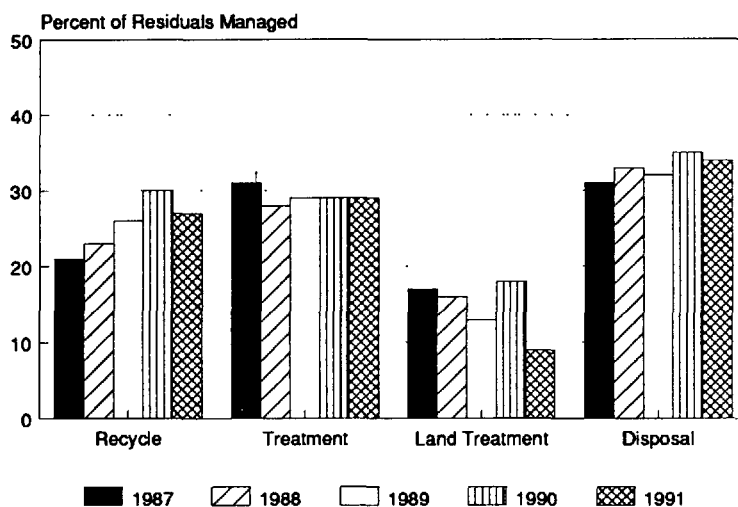
Figure M illustrates how the industry manages its residuals. As the filled portions of the pie chart show, approximately two thirds are either recycled, treated or land treated, while one third is disposed.

Figure M
Summary of Residual Management Practices for 1991 (millions of wet tons)



As shown in Figure N, this distribution of handling practices is similar to that reported in previous years.

Figure N
Longitudinal Comparison of Residual Management Practices: 1987-1991



The amount of residuals recycled has increased since the survey began, while the use of treatment has remained fairly constant.⁴ Use of land treatment has diminished over the last five years, although 1990 witnessed an increase due to the industry's use of this modality to handle the peak quantities of pond sediments and contaminated soils generated from construction and site remediation activities undertaken in 1990. Disposal needs have remained constant, particularly when one considers that refiners had to resort to disposal technology to handle the large quantities of contaminated soils generated during the last two survey cycles.

The following sections of the report describe how recycling, treatment, land treatment and disposal were used by the industry. The data on the amount of each stream handled by the various management methods provide an interesting picture of how the industry handles its wastes, and alludes to the multiplicity of factors that affect how a residual will be handled. The SAS print-outs that support the following analysis are presented in Appendix D.

⁴This graphic presentation is based on the estimation procedures used for the 1991 data, wherein: 1) a separate model was used for Other Aqueous Residuals and 2) observations determined to be statistical outliers were included in the calculations that apportion the total quantity of residual managed across the various handling procedures. This has resulted in a change in the data for 1990 which had previously been presented without the influence of the Other Aqueous Wastes and any other statistical outliers. Specifically, the graphic portrayal of the data in the 1990 report showed decreases in treatment and land treatment which several of the outliers used to handle the peak quantities of pond sediments and contaminated soils.

Recycling

The general pattern of recycling residuals has remained constant over the five year survey period. As shown in Table 10, **reclamation/regeneration** continues to account for almost one half of the material recycled. When summed, in-process recycling, either to the **coker**, the **crude unit**, or to the new category used in the 1991 questionnaire that includes desalter, catalytic cracker and other, represents 29 percent. The other new categories, **out-of-process** that includes non-fuel reuse, such as cement kiln feed, were used with 5 percent of the residuals. Similarly, use as **industrial fuels**, also accounted for 5 percent.

Table 10
Summary of Recycling Practices

(thousands of wet tons)

Method of Recycling	1991 Tons	%	1990 Tons	%	1989 Tons	%	1988 Tons	%	1987 Tons	%
Coker	181	11	192	10	231	17	186	16	148	14
Crude unit	217	14	174	9	125	9	85	7	68	6
Reclamation/regeneration	772	49	872	46	611	44	434	38	447	42
Other recycling			655	35	408	30	474	41	410	38
In-process*	60	4								
Out-of-process*	84	5								
Fuel use*	78	5								
Not specified*	198	12								
Total	1590	100	1,893	100	1,376	100	1,179	100	1,073	100

*These categories were new for 1991; data were not available for previous years.

Table 11 shows the contributions made by stream, to the total quantity of residual managed by each recycling method. As in previous years, **spent caustics** accounts for over half of the residual that is *reclaimed or regenerated*. From the pollution prevention data, it is known that much of this was sold to paper mills and chemical manufacturers. An increase in the quantity of **residual coke/carbon/charcoal** regenerated was reported and reflects the new pollution prevention practice reported whereby carbon was sent off-site for regeneration. Note that the amount of spent acids that is regenerated or reclaimed has varied substantially over the survey period, while the amount of **hydroprocessing catalysts** has remained constant.

Looking at the residuals that are sent to the coker for recycling, it appears that refiners are using this method to handle more **biomass**. The coker is also used for residuals that if disposed, would be listed hazardous wastes, namely **API separator sludge**, **DAF float** and **slop oil emulsion solids**. The quantities handled each year vary substantially.

In 1991, refiners sent 79 thousand wet tons of **biomass** to the crude unit; in previous years the quantity had been negligible. The amount of **DAF float** going to the crude unit was the highest ever reported. The variability noted with **residual oils/spent solvents** may reflect reporting by different refineries in each year that employ various methods of handling these materials.

Overall, the out-of-process recycle categories used in 1991 accounted for 162 thousand wet tons or approximately 10 percent of the materials recycled. Thirty three thousand wet tons or 65 percent of the out-of-process recycle to cement kilns was **FCCU catalyst**; 7 percent was **API separator sludge**. Listed residual material accounted for 86 percent of the 51 thousand wet tons recycled out-of-process as fuel for cement kilns.

The amount of residuals handled by "Other" methods represented 12 percent of the total (198 thousand wet tons), most of which was **spent caustics**.

Table 11
Estimated Quantities of Recycled Materials (thousands of wet tons)

Recycling Method/Residual Stream	1991	1990	1989	1988	1987
RECLAMATION/REGENERATION					
Spent caustics	486	535	459	243	262
Residual coke/carbon/charcoal	100	48	40	43	27
Spent acids	80	200	0	56	57
Hydroprocessing catalysts	31	28	32	21	26
Other Residuals NOS	45				
All others	30	54	35	120	212
Total	772	872	611	378	390
IN-PROCESS RECYCLE-Coker					
Biomass	67	56	59	27	25
DAF float	56	75	79	45	82
API separator sludge	31	8	55	73	14
Slop oil emulsion solids	18	42	9	23	19
All others	9	4	6	11	8
Total	181	192	231	186	148
Crude unit					
Biomass	79				
DAF float	72	22	34	19	16
Residual Oils/Spent Solvents	15	64	0	0	0
Nonleaded tank bottoms	15	34	18	13	11
Slop oil emulsion solids	14	29	17	27	12
API separator sludge	11	10	24	13	18
All others	11	2	6	0	3
Total	217	174	125	85	68
Other In-Process Recycle	60	These recycle codes were new for 1991; consequently comparable data were not available for previous survey cycles			
Out-of-Process Kiln	51				
Other Out-of-process	33				
Industrial Fuel	78				
Other*					
Spent caustics	137	123	138	254	232
Contaminated soil	20				
Other inorganic residuals NOS	13	102	6	14	18
Other residuals NOS	13				
All others	15	218	141	220	178
Total	198	655	409	474	410
Grand total	1,590	1,893	1,369	1,156	1,055