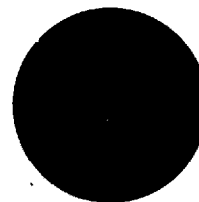


GENERATION AND MANAGEMENT OF RESIDUAL MATERIALS



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**Petroleum Refining
Performance**

Generation and Management of Residual Materials

Petroleum Refining Performance 1990 Survey

Health and Environmental Affairs Department

API PUBLICATION NUMBER 324

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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 is implementing a deliberate change in the terminology used in this survey. Henceforth, in this report and all future documents developed in conjunction with this survey, API will use "residual materials or residuals" to refer to what has 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 our industry with the regulatory usage of the term "waste."

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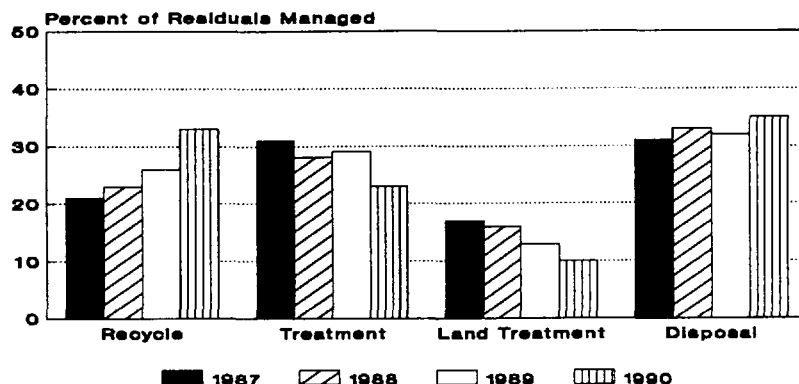
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EXECUTIVE SUMMARY

1990 Survey

In 1990, the petroleum refining industry reported that source reduction activities doubled over the last year, and that when combined with resource recovery initiatives, accounted for a reduction of close to a half a million wet tons of residual materials. Controlling for the statistical outliers, recycling rose to 33 percent, treatment and land treatment dropped to 23 and 10 percent respectively, while disposal accounted for 35 percent of the total quantity of residual material.



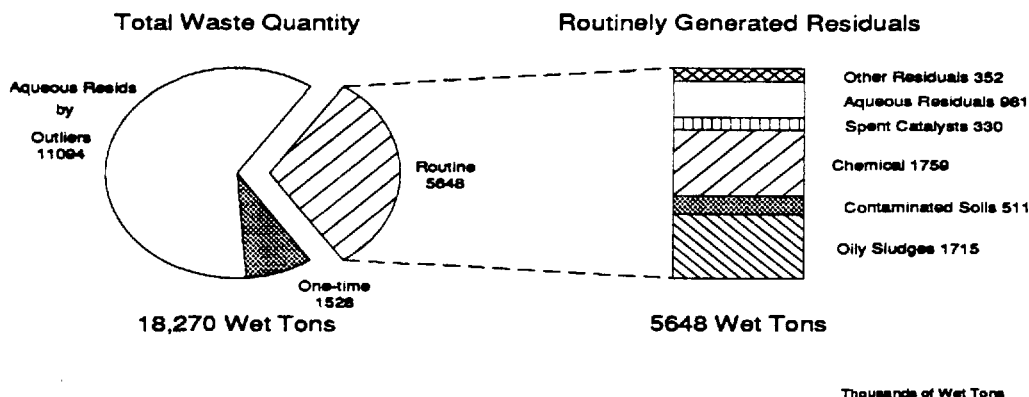
These findings were recorded by the American Petroleum Institute (API) in its fourth annual survey of refining practices. Responses from 103 refineries, representing 70 percent of the U.S. refining capacity, were used to develop industry-wide estimates. The procedures and data collection forms used in the survey were similar to those used previously. In an effort to emphasize that most materials resulting from petroleum refining processes have potential value as feedstocks and for recycling, reuse, reclamation or regeneration, API will discontinue using the term "waste", which had been used in previous surveys. Henceforth, API will use the term "residual materials" to refer to the materials that result from petroleum refining, both those derived from crude oil and those spent chemicals used in the process.

The changes in the management profile of residuals summarized above reflects several changes in the industry's generation and reporting of these materials. Waste minimization and source reduction activities improved recovery of oils and prevented creation of sludges by controlling solids entering the wastewater systems. This supported reduction in the generation of some streams, in particular, API separator sludge which decreased 40 percent from the 1989 level.

Overall, however, the quantity of residuals generated in 1990 increased to 18.2 million wet tons. Total residuals managed divided by crude oil throughput to refineries yields a ratio of 0.0277, compared with 0.0248 for 1989. When the statistical outliers are removed from the calculations, the ratio remains a low 0.008.

Much of the increased quantity of residuals was due to refiners closing surface impoundments, remediating sites, and building new process units—activities that lead to abnormal spikes in the generation of pond sediments and contaminated soils. Indeed, with the exception of the chemical category where increases in reporting of spent caustics and spent acids occurred, routinely generated wastes were approximately the same as previous years.

Residual Generation: 1990



The data for 1990 suggest that some practices in the industry are changing, while others may be more static. Two long term trends are noteworthy:

- o the amount of total residuals being **recycled** continues to rise--a 76 percent increase in total quantity compared with 1987; and
- o the amount of listed hazardous waste to **land treatment and disposal** continued to fall--a 57 percent decrease in quantity compared with 1987.

Thus, the 1990 results show indications of continued progress by the petroleum refining industry.

When API adds the fifth survey cycle to the database, additional analyses will be performed, which may enable further delineation of trends in the industry, perhaps even the identification of streams that are influenced largely by throughput, and others that fluctuate due to other factors.

INTRODUCTION

This report for calendar year 1990 marks the completion of four annual surveys of generation and management of residual materials within the refining segment of the petroleum industry. This fourth year is also the last year of the baseline period that API declared as it started this data collection effort. In light of the expected fluctuations in the generation of many residual materials—that some process units are serviced every three years and that maintenance turnarounds may occur at even longer intervals—this baseline period was imposed to ensure that information would be gathered on the natural fluctuation in generation rates. With this baseline data, subsequent between-year reductions (or increases) could be accurately attributed to either natural variation or to true changes in practices.

During this baseline period analytic efforts have been held primarily to descriptive statistics. This has allowed API to simply monitor and document how the industry handles residual materials, to learn more about how materials are managed, and to trace how regulatory events influence practices. During the baseline period several questionnaire items have been revised to improve the quality and consistency of the data collected, particularly with regard to the point of generation and its periodicity, and how the industry's recycling practices should be portrayed within the rubric of waste minimization, source reduction, and pollution prevention.

This baseline period has also allowed API to contemplate the nature of progress. When this survey was initiated, the underlying presumption was that *reductions* in the quantity of residual materials **generated** would serve as indicators of progress. In many situations this is true. The collection of four years of data has documented variations in the generation patterns for different streams, and led to an understanding that even the *detection* of significant change may be no small feat. Indeed, only ten of the 28 streams reported in the survey are generated routinely by the industry as indicated by the consistently high number of refineries reporting these streams in each survey year. These, then, are the streams for which it will be easiest to detect a systematic change over time. There can be substantial flux, however, in the quantities of these routinely generated streams. Thus, it may be difficult to detect reductions even in these streams. Consequently, other indicators of progress need to be identified.

In some circumstances, improvements in the way residual materials are handled constitute progress. Movement up the waste management hierarchy (source reduction, recycling, treatment, and finally disposal) should be recognized. Moreover, these changes address the entire continuum of the hierarchy: from disposal to treatment to recycling, in addition to source reduction.

Ironically, in some situations, progress may also be indicated by *increases* in generation quantities. For example, when refineries build new process units, or when they dismantle older units, they excavate soils. This increases the amount of contaminated soils and other waste generated. Similarly, while the installation of a segregated sewer system for process wastewaters and stormwaters will eventually decrease the amount of oily wastewaters and residues, construction of the sewer system, as measured by this survey, results in an increase in certain residual materials. Compliance with regulatory initiatives designed to improve the

protection of the environment, can also result in peak generation quantities. For example, many refineries have decided to limit their use of impoundments and ponds in an effort to minimize air emissions and reduce the generation of oily sludges. Closure of these ponds, many of which are quite large, has resulted in the removal of millions of tons of sediments—an abnormal spike in generated residuals.

Fortunately, the ongoing nature of this survey will provide an appropriate context for viewing the findings from an individual year. Beginning with the data for 1991, API will perform a more extensive analysis, testing to identify patterns in generation and to determine the strength of any trends observed. In addition to publishing this information in an annual project report, findings from the trend analysis will be incorporated in API's Environmental Performance Documentation Program (EPDP). As part of the Strategies for Today's Environmental Partnership, the EPDP program is designed to provide a public record of the industry's environmental performance. This longitudinal analysis of the data will enable the industry, and the public, to recognize residual generation patterns and to view these reductions, changes in practices, and peaks in generation quantities from an informed perspective that benefits from the serial analysis.

The chapters of this report which follow, are structured similarly to those of the previous reports from the baseline period. Following a brief description of the survey methodology, the results on generation quantities, source reduction practices, and handling procedures are presented and discussed. The appendices to the report contain copies of the data collection forms, summaries of qualitative data on source reduction practices, printouts from the estimation procedures, and graphics on the management practices for individual streams over time.

METHODOLOGY

The same design, administrative, and analytic procedures used to collect 1987 - 1989 data were used for 1990¹. Using a census listing of the 183 operating refineries (developed by updating the 1989 list from the Department of Energy's *1990 Petroleum Supply Annual*), survey materials were sent in September, 1991, to the respective corporate offices for the refineries. The six week interval originally allowed for form completion was extended to increase the response rate; the last survey form returned was accepted some six months later. 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 sections that follow briefly describe the data collection form and the analytic procedures used to create the population estimates. A copy of the data collection form is presented in Appendix A.

Data Collection Forms

API's survey questionnaire is comprised of a series of short-answer questions about the age, size, and complexity of the refinery, questions on resource recovery and source reduction activities, and a series of "data sheets"—one-page forms that collect empirical information on the quantities of residual materials² generated and how they are managed.

¹ For more detailed discussion of the survey procedures, consult API Publications 300 and 303, the final reports for the previous surveys.

² As noted in the Foreword, use of the "residual material" terminology was initiated with this report. When the 1990 data were collected, the "waste" terminology was used in all data collection materials and instructions. API did not explicitly define "waste and secondary materials" when it initiated the survey, hoping that this discretionary power would encourage broad reporting of actual practices. The Instruction Manual contained the following statement:

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)

The intent of this strategy was to encourage broad reporting of residual handling as it actually occurs, without introducing the potential bias of experimental or survey effects, such as arbitrary definitions of the point of generation.

The questionnaire was provided in both hard copy form and on an automated disk, written using Clipper, a commercially available compiler for dBase.

Few changes in the forms were implemented for 1990. In the *short-answer* series of questions, changes focused on improving the quality of information collected on **Source Reduction**. As noted in the reports on previous surveys, the refiners have had difficulty in applying the definition of Source Reduction to industry practices and distinguishing these from other improvements in residual management practices. Consequently, to assist refiners in classifying the types of management improvements they have instituted, a new question was developed to obtain information on **Resource Recovery** activities initiated in 1990. **Resource Recovery** was defined to include activities where residual materials are beneficially recycled in *out-of-process on-site or by other users off-site*. 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. To further emphasize the distinction used in the survey, the 1990 questionnaire used tabs (pre-labeled divider sheets), that provided visual cues to distinguish the two types of activities.

The **Source Reduction** question was in the same format as in 1989. Two changes were made requiring: 1) quantities reduced be reported by stream, as well as by source reduction method; and 2) the year the source reduction activity was initiated be specified.

Because the new Toxicity Characteristic (TC) under RCRA did not become effective until the last quarter of 1990, information was not collected on TC residuals in this survey. API plans to begin collecting information on TC residuals in the 1991 survey cycle.

The *data sheets* contained in the second part of the questionnaire were virtually the same as used before. There are 28 data sheets, one for each of the residual streams identified in Table 1. This listing of streams, and classification into six categories of residual materials that represent the typical grouping of materials in a refinery, has been used in each survey.

On the data sheets, "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

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 Other aqueous residues 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 Other separator sludges Pond sediments 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.

Data Analysis

The data verification and estimation procedures used in 1990 were the same as those used in previous survey cycles. 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.

During the range checking activity, statistical outliers were identified for separate handling during the model development³. The following 13 outliers were identified in the sample of 103 refineries that responded in 1990:

- o 4 refineries that generated no residuals;
- o 1 refinery which generated only 6 tons of residual material;
- o 4 refineries that deep well inject large quantities of dilute aqueous material;
- o 4 that were identified as aberrant during the data plotting phase of model development.

In all cases, 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 respondents⁴. To evaluate the relative impact of factors that may influence residual generation, correlation coefficients are calculated for a number of known refinery characteristics (e.g., capacity, age, sewer system) with total waste generation. In addition, scatterplots are developed to help explore any relationships which could lead to development of models to estimate total residual quantity generated. Individual factors are evaluated as well as combinations of factors. As with data from previous years, the strongest correlation observed in the 1990 data was a positive correlation between operable crude capacity (Question 3) and residual generation. Combining other factors with operable crude capacity did not significantly improve the predictable power of the model.

Thus, after examining all the model results for levels of significance, mean squared error, R-squared, and model complexity, a regression model with capacity as the explanatory variable was selected as most suitable. Additional regression diagnostics suggested that model assumptions were more closely followed with a square root transformation of the volume of generated residuals (the response or y-variable), and that such a model was statistically appropriate for 1990.

Therefore, the regression model used for 1990 was of the form:

$$\sqrt{\text{TotalGeneratedQuantity}} = a + b(\text{Capacity})$$

or

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

³ So that they do not unduly distort the statistical relationship between capacity and generated residual quantity, residual quantities from outlier facilities are temporarily separated from the sample during model development and then added back into the population estimates along with the non-respondent values.

⁴ Implicit in this approach are the assumptions that: 1) the factor(s) influencing waste generation for respondents do not differ from those for non-respondents; and, 2) no additional outliers exist in the non-respondent population.

where a and b were estimated based on the data from the 90 responding refineries that were not statistical outliers⁵. 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) using a standard statistical procedure to adjust that number so that the final estimate is unbiased.

To estimate the total amount of residual materials generated in 1990 for all (183) of the U.S. refineries, estimates for the 80 non-respondent refineries were combined with the data obtained from the 103 survey participants including outlier facilities. All residual generation and management data shown in this report are estimates for all 183 refineries.

Based on the model approach and assumptions, the margin of error for the total estimated residual quantity is approximately 2 percent. Thus the total residual generation is estimated between 18.6 million tons and 17.9 million tons at the 95 percent confidence level.

After deriving the total quantity of generated residual, calculations were performed to estimate the generation quantities for each of the 28 residual streams. A summary of the procedure used follows:

- 1) The total reported quantity of residuals was determined by summing the generated quantities from all non-outlier respondents.
- 2) Each individual residual stream generation quantity calculated in (1) was divided by the total quantity of residuals for the 28 streams to determine the relative contribution of each stream to the total reported quantity.
- 3) Each proportion calculated in 2) was multiplied by the total estimated residual quantity.

⁵This model form is different from the one used in 1987-1989 because, for 1990, it was found to satisfy model assumptions more closely. Nevertheless, a comparison between the 1990 estimates derived from the old and new approaches showed close agreement, i.e., within the margin of error.

RESULTS

Response Rate

For 1990, 103 refineries participated in the survey. Eleven refineries that had previously participated in the survey did not complete the questionnaire for 1990; reciprocally, four refineries submitted data for the first time in 1990.

The 103 refineries that participated in 1990 represented 56 percent of the population of 183 refineries, but accounted for 70 percent of the domestic crude refining capacity. This response rate was less than previously observed (74 percent of capacity was represented in 1989), but still outstanding for a survey conducted during 1991-1992, when economic considerations were dictating down-sizing of the industry and careful scrutiny of labor intensive, voluntary efforts.

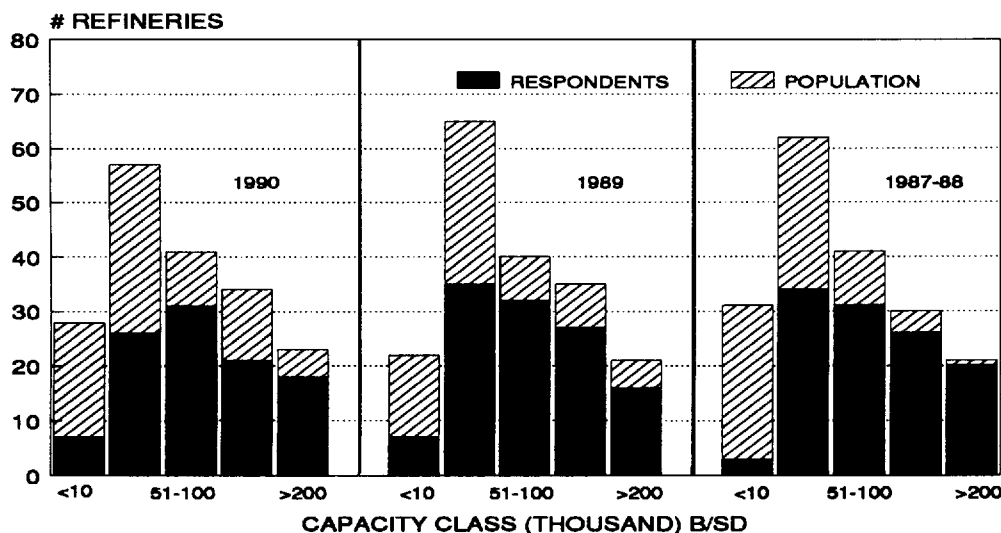
Of the 103 respondents, 84 have participated in all four years of the survey. These refineries represent 60 percent of the total refining capacity.

Respondent Characteristics

The 103 respondents reported an *operating capacity* of 11,793,750 barrels per stream day (b/sd). The total amount of crude charged was 3,748 million barrels. The modal number of days on which crude was charged was 365, which was reported by 57 refineries. With only three refineries reporting running less than 300 days, the total number of days on which crude was charged was 37,057 for the 103 respondents.

The profile of respondents by *capacity class* was generally similar to that observed previously. As depicted in Figure A, there have been some slight changes in the distribution of refineries at both ends of the spectrum.

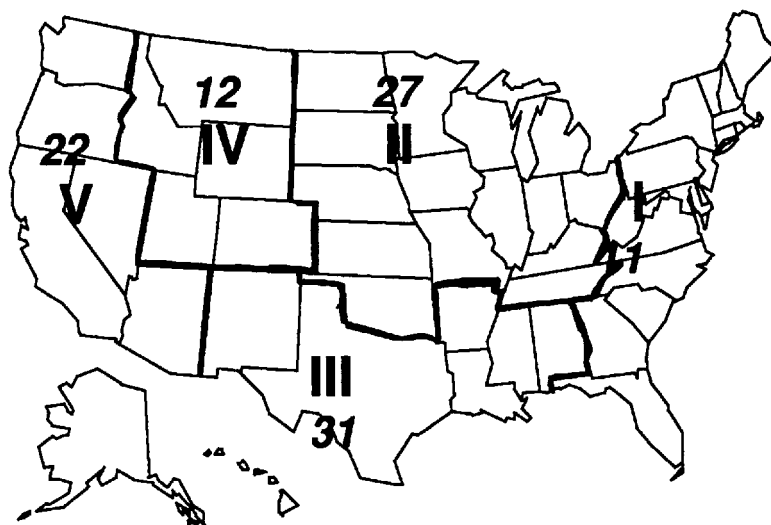
Figure A
Number of Respondents by Capacity Group



The population of small refineries, less than 10,000 b/sd, has fluctuated, increasing since 1989, but still less than the number operating in 1987-1988. The total number of refineries in the 11,000 - 50,000 b/sd class dropped from 1989, as did the number of participants in this size class. The number of refineries and participants in the 51,000 to 100,000 b/sd class remained constant since 1987, while a slight attenuation was observed in the next size class. Reciprocally, the group of refineries over 200,000 b/sd has increased over time. Only two refineries closed in 1990 and two others were reactivated, which kept the population a constant 183 for both 1989 and 1990.

The distribution of refineries by *location* was similar to that previously reported, with the highest number in U.S. Department of Energy's Petroleum Administration for Defense (PAD) III, the Texas/Louisiana region.

Figure B
Distribution of Respondents by Location



The API survey has used the NPDES permit classifications to categorize the *complexity* of the refineries. The overall distribution of respondents for 1990 was similar to previous observations, with the number of "cracking" facilities predominating. Comparing the 1990 response to the 1989's as illustrated in Figure C, a decrease in the number of the cracking refineries occurred in 1990, while there were minor changes in the number of "topping", "petrochemical", and "lube" facilities.

The data collected on the *age* of the refineries attest to the maturity of the industry, with 85 percent of the refineries being built more than 30 years ago. As shown in Figure D, there are subtle differences among survey years that reflect different refineries participating and changes due to facility closures and reactivations.

Figure C
Distribution of Respondents by NPDES Complexity Classification

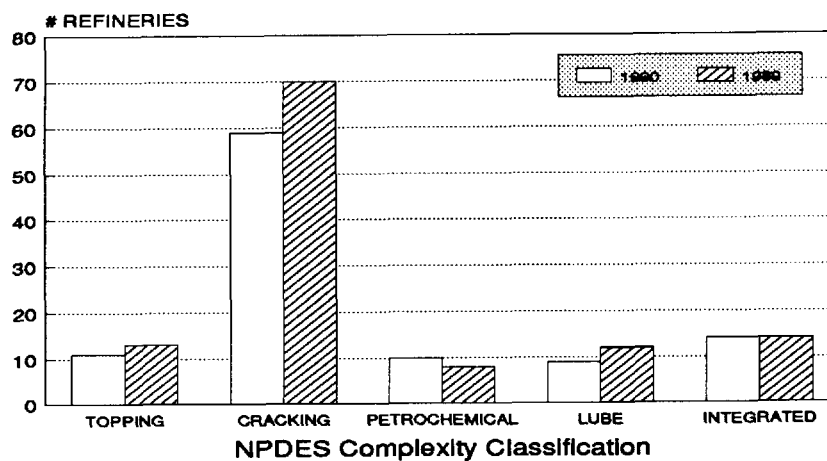
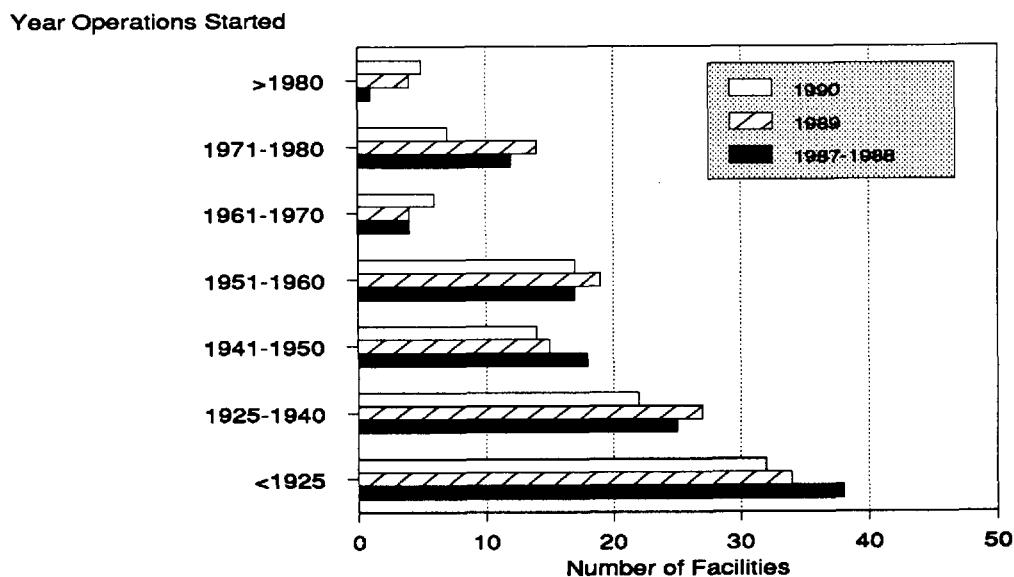
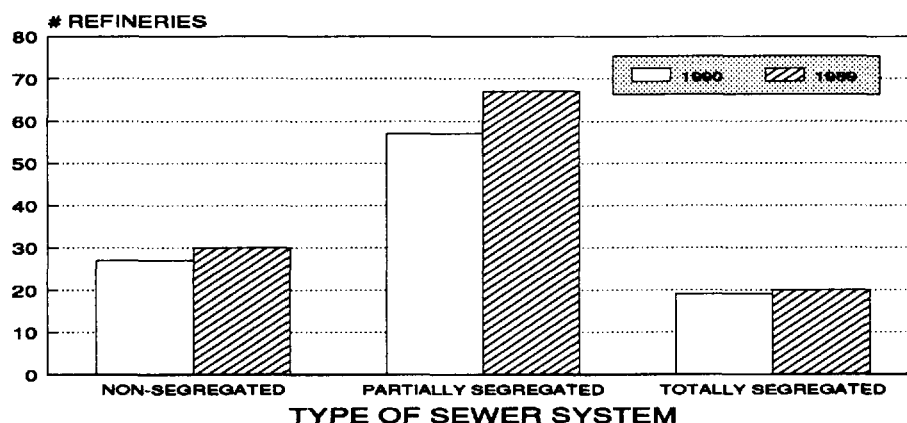


Figure D
Distribution of Respondents by Refinery Age



As illustrated in Figure E, the data collected on the type of *sewer system* seems constant from year to year. For 1990, 57 refineries, or 55 percent of the respondents, reported having sewer systems that partially segregate storm and process waters, which was comparable to the 57 percent reporting last year.

Figure E
Distribution of Respondents by Sewer Type



The survey also collected information on *RCRA Permit Status*, requiring participants to indicate their status before the September 25, 1990 effective date for the Toxicity Characteristic (TC), and thereafter. As presented in the Table 2 below, the number of refineries that filed permits and thus acquired "Interim Status" increased, drawing in refineries that had been considered generators only and not previously subject to RCRA permitting for on-site hazardous waste management.

Table 2
RCRA Permit Status

RCRA Permit Status	Before 9/25/90	After 9/25/90
Generator only; no RCRA permit required	40 (38%)	31 (30%)
Part A filed (interim status)	25 (24%)	34 (33%)
RCRA Permit issued	38 (37%)	38 (37%)

Total Management Quantity

The term "total management quantity" has been coined by API for this survey to refer to the amount of residual materials generated in a given year, plus the amount of material added to facilitate handling of the residuals, plus the amount of residuals removed from storage and handled in the target year. The following equation shows the various components.

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

The following sections of the report will describe each of these factors.

Residual Generation

Using the estimation procedure described previously, the total amount of residual materials generated in 1990 by the 183 U.S. petroleum refineries was estimated to be 18.2 million wet tons. This is an increase of 1.9 million wet tons over that generated in 1989. When divided by the amount of crude run in 1990, 658 million wet tons (as reported in the DOE Petroleum Supply Annual), the ratio is 0.0277, compared with the 0.0248 reported for 1989.

As in previous years, over two thirds of the total quantity of residual generated can be traced to those refineries that have been identified as statistical outliers. For 1990, the residuals generated by the 9 refineries identified as outliers (that generated any residual material) was 12.6 million wet tons. Of this quantity, 11.1 million wet tons were primarily other aqueous wastes NOS generated on a routine basis. The remaining quantity of residuals generated by the facilities considered statistical outliers reflected either abnormal, one-time events (approximately 0.7 million wet tons), or routine generation of substantially more residual material by a refinery when compared with similar size refineries (approximately 0.8 million wet tons). The influence of these outliers is noticed in Table 3 which presents the total quantity generated by stream.

A substantial increase in the quantity of **pond sediments** generated is noted. This increase, as well as that for **contaminated soil/solids**, reflect abnormal situations, or generation peaks caused by closure of ponds, remediation of sites, or refinery construction that necessitates removal of soil. For **pond sediments**, the one-time quantity was 699,631 wet tons or 88 percent of the total amount generated. For **contaminated soils/ solids**, the quantity was 475,681 or 66 percent.

Spent acids and **waste oils/spent solvents** were two other streams with substantial increases in 1990. The generation pattern was very similar for these two streams, with four facilities contributing more than 70 percent of the amount generated in 1990.

It is harder to declare meaningful reductions in the generation quantities, due to fluctuations between survey years. The quantities of **API separator sludge** was the lowest ever reported, and begins to approximate a statistically significant reduction.

The number of refineries reporting each residual stream is presented in Table 4. The relative order of the streams has remained constant. The drop in the number of refineries reporting **FCC catalyst or equivalent** probably is due to the drop in survey participants this year, which as noted in Figure C, reduced the number of cracking facilities in the sample.

Table 3

Estimate of Residual Materials Generated by the U.S. Refining Industry: 1990
(thousands of wet tons)

Residual stream	1990	1989	1988	1987
Aqueous residuals NOS	11,107	11,100	11,076	11,296
Pond sediments	1,017	313	266	337
Contaminated soils/solids	920	512	240	165
Spent Caustics	889	716	656	675
Biomass	782	642	786	757
DAF float	553	496	655	652
Other inorganic residuals NOS	451	440	213	325
Other residuals NOS	352	325	412	203
Spent acids	336	8	149	126
Slop oil emulsion solids	291	272	224	208
API separator sludge	251	419	355	400
FCC catalyst or equivalent	198	182	193	173
Nonleaded tank bottoms	194	161	129	216
Waste oils/spent solvents	115	31	7	4
High pH/low pH waters	105	91	138	144
Other separator sludges	97	114	104	79
Residual coke/carbon/charcoal	92	129	67	43
Residual amines	75	51	14	13
Other contaminated soils NOS	69	53	68	82
Other oily sludges/organic residuals NOS	53	47	61	38
Other spent catalysts NOS	39	33	37	33
Residual sulfur	35	52	22	17
Hydroprocessing catalysts	31	36	36	40
Spent Stretford solution	29	42	49	35
Heat exchanger bundle cleaning sludge	13	2	5	3
Oil contaminated waters (not wastewaters)	8	29	36	28
Leaded tank bottoms	3	4	8	9
Spent sulfite solution	1	8	40	42
Total	18,106	16,311	16,044	16,144

Table 4
Number of Refineries Reporting Each Stream

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

Treatment Additives

Treatment additives are chemicals that facilitate subsequent management of residuals. For example, flocculants are used to expedite filtration that reduces the volume requiring subsequent handling. Other materials may be added to residuals like pond sediments to enable the residual to pass the paint filter test, the TC criteria. The use of treatment additives increased in 1990. Specifically, after dropping to 35 thousand wet tons in 1989, 88 thousand

wet tons were estimated for 1990. (In 1987, 55 thousand tons were used, while 72 thousand tons were used in 1988.) Treatment additives were reported for handling 19 residual streams, but 36 percent of the total amount used was with **pond sediments**—the stream with the highest one time quantity generated. Twelve thousand wet tons were used with **biomass** and **DAF float**; 8 thousand tons were used to pretreat **API separator sludge**; and **spent caustics** and **other separator sludges** required 7 thousand tons of additives.

Storage

API's data sheets provide spaces for refiners to designate the amount of material removed from storage and the quantity placed into storage. When added together, a "Net from Storage" quantity is derived, which then becomes a factor in the waste management equation.

Table 5 presents a listing of the five streams with the largest quantities removed from storage in 1990. Only one stream, **FCC catalyst or equivalent** had a significant quantity of material removed from storage: 61 thousand wet tons, which represented 15 percent of the total quantity generated for that stream. Two thirds of this amount was reported by one refinery that conducted a periodic clean-out of the pond in which FCC catalyst slurry was managed to allow gravity separation. For the remaining streams, the amount of material removed from storage was less than 1 percent of the total amount of managed.

Table 5
Top-five Residual Streams Removed from Storage
(thousands of wet tons)

Residual Stream	Total Managed	From Storage	% of Total
FCC catalyst or equivalent	259	39	15
DAF float	643	5	1
API separator sludge	260	4	<1
Biomass	794	4	<1
Other inorganic residuals NOS	453	4	<1

None of the streams placed into storage were large volumes. It is interesting to note that three of the five streams with the greatest tonnage removed from storage were also streams with the largest quantity placed into storage: **DAF float**, **biomass**, and **API separator sludge** (See Table 6.)

Table 6
Top-five Residual Streams Placed Into Storage
(thousands of wet tons)

Residual Stream	Total Managed	Into Storage	% of Total
Pond sediments	1091	6	<1
DAF float	643	6	<1
Biomass	794	4	<1
API separator sludge	260	4	1
Contaminated soils/solids	914	4	<1

Total Quantity Managed

Table 7 presents the estimates of generation quantities for each residual stream, the amount of treatment additives used, the net amount from storage, and the summation of these factors—the total amount of managed in 1990.

Table 7**Estimated Quantities of Residual Materials: 1990 (wet tons)**

Residual stream	Amount Generated	Treatment Additives	From Storage	Total Amount Managed
Aqueous residuals NOS	11,106,421	0	0	11,106,421
Pond sediments	1,016,597	31,987	(8,939)	1,039,645
Contaminated soils/solids	920,444	11	(5,529)	914,926
Spent caustics	888,511	5,951	(204)	894,258
Biomass	782,000	12,347	(302)	794,045
DAF float	552,938	11,709	(344)	564,303
Inorganic residuals NOS	451,464	542	1,157	453,163
Other residuals NOS	352,114	459	(23)	352,550
Spent acids	336,259	398	(66)	336,591
Slop oil emulsion solids	290,862	4,428	(254)	295,036
API separator sludge	251,183	7,801	617	259,601
FCC catalyst/equivalent	198,295	0	61,016	259,311
Nonleaded tank bottoms	193,694	3,203	(412)	196,485
Waste oils/spent solvents	114,611	0	(2)	114,609
High pH/low pH waters	105,238	0	0	105,238
Other separator sludges	96,511	7,350	0	103,861
Residual coke/carbon/charcoal	91,798	0	0	91,789
Residual amines	74,861	0	0	74,861
Contaminated soils NOS	69,310	86	(16)	69,380
Oily sludges/organic residuals NOS	53,199	373	(72)	53,500
Other spent catalysts	39,165	1,231	194	40,590
Residual sulfur	34,614	0	(70)	34,544
Hydroprocessing catalysts	30,658	0	(282)	30,376
Spent Stretford solution	29,334	180	0	29,514
Heat exch. bundle cleaning sludge	12,775	245	(45)	12,975
Oil contaminated waters (not wastewaters)	8,281	16	2	8,299
Leaded tank bottoms	3,066	34	398	3,066
Spent sulfite solution	1,173	0	0	1,173
Total	18,105,376	88,351	46,824	18,240,110

Table 8 presents the total amount of residuals managed in 1990 along with that reported for the preceding survey years.

Table 8

Total Amount of Residual Material Managed (Estimated Quantities) (wet tons)

Residual streams	1990	1989	1988	1987
Aqueous residuals NOS	11,106,421	11,100,221	11,076,251	11,296,230
Pond sediments	1,039,6457	273,217	311,268	359,996
Contaminated soils/solids	914,926	495,511	242,074	185,819
Spent caustics	894,258	715,540	655,528	674,522
Biomass	794,045	654,977	748,589	720,355
DAF float	564,303	520,798	660,514	653,899
Inorganic residuals NOS	453,163	440,809	220,503	322,702
Other residuals NOS	352,550	325,212	412,380	202,645
Spent acids	336,591	8,424	160,399	130,436
Slop oil emulsion solids	295,036	262,349	213,551	211,854
API separator sludge	259,601	424,501	430,042	563,733
FCC catalyst/equivalent	259,311	185,380	189,191	170,853
Nonleaded tank bottoms	196,485	163,700	130,851	217,869
Waste oils/spent solvents	114,609	30,896	7,346	4,453
High pH/low pH waters	105,238	91,513	138,269	144,015
Other separator sludges	103,861	116,945	110,251	82,797
Residual coke/carbon/charcoal	91,798	137,103	66,549	42,712
Residual amines	74,861	51,053	13,798	13,107
Contaminated soils NOS	69,380	53,266	76,698	88,002
Oily sludges/organic residuals NOS	53,500	47,219	61,336	40,024
Other spent catalysts	40,590	33,396	37,904	38,238
Residual sulfur	34,544	51,705	22,714	17,299
Hydroprocessing catalysts	30,376	35,787	36,630	39,415
Spent Stretford solution	29,514	42,449	49,264	34,881
Heat exchanger bundle cleaning sludge	12,975	2,455	4,643	2,977
Oil contaminated waters (not wastewaters)	8,299	28,907	35,867	28,156
Leaded tank bottoms	3,066	4,471	9,615	9,264
Spent sulfite solution	1,173	7,937	40,274	42,262
Total	18,240,114	16,305,741	16,162,299	16,338,555

As previously noted, a substantial contribution to the overall quantity of residual material managed in 1990 was due to the closure of surface impoundments (which resulted in the creation of **pond sediments**) and remediation and construction at the refineries that spiked the generation of **contaminated soils/solids**.

Figure F illustrates the relative contributions to the total quantity of waste managed in 1989 and 1990 by contrasting the overwhelming quantity of other aqueous residuals reported as generated routinely by the statistical outliers, with the quantities of pond sediments and contaminated soils that were reported as abnormal, one-time events, and with all other residuals. This graph highlights that the 1990 spike in pond sediments and contaminated soils was four times the amount reported as one-time quantities for these same streams in 1989.

Figure F
Comparison of Managed Quantities: 1989 - 1990

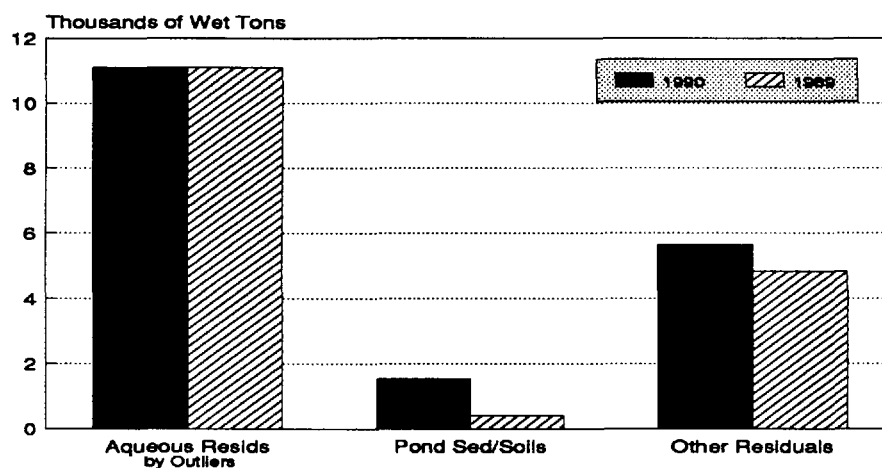
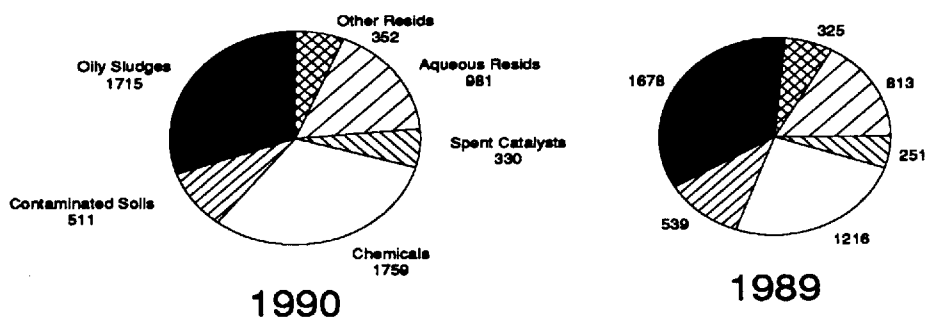


Figure F also shows that there was a slight increase in the other residuals streams, most of which are generated on a routine basis.

Figure G summarizes the differences in management quantities for these residuals, grouped according to the six residuals classes discussed previously. The largest increase was in the Chemicals category, which includes the **Spent acid** and **spent caustic** streams. As the pieces of the pie charts indicate, the remaining categories remained quite constant, ranging from a drop of 37 tons for Contaminated Soils to an increase of 168 tons for the category that includes **biomass**, among the other Aqueous Residuals.

Figure G
Distribution of Routinely Generated Residuals: 1989 - 1990 (excluding outliers)
 (thousands of wet tons)



Source Reduction and Resource Recovery

API uses the waste management hierarchy to structure its collection of information on refining practices. Placed at the top of the hierarchy, source reduction is the most desirable approach to managing residuals: preventing their creation in the first place. Both EPA and API have learned through their respective survey efforts, however, that it is difficult to capture information on such practices because of the variety of potential activities involved, many of which result in residual reductions as a secondary benefit. Another, and perhaps the central problem with collecting reliable data is that source reduction involves counting a negative: the residual material which was *not* produced as a result of the source reduction activity. As the API survey has demonstrated, the quantities of residuals generated vary from year to year, creating a "noisy" background against which to calculate source reduction benefits.

To help clarify what is meant by source reduction, and to promote the development of more reliable estimates of residual prevented, API revised its form for 1990 to distinguish between

- 1) **Resource Recovery** activities that minimize residuals, and
- 2) **Source Reduction** activities.

In particular, resource recovery activities were defined as those which involve *out-of-process* recycling, while source reduction encompassed a variety of procedure and equipment modifications, as well as *in-process* recycling activities. In addition to classifying the activities as either source reduction or resource recovery, refiners were asked to categorize quantities reduced by stream and by activity. The descriptive information obtained from these questions, and the quantitative information obtained is summarized below.

Source Reduction

In 1990, 62 refineries reported source reduction activities. This increase from 55 refineries in 1989 seems nominal, but actually represents a 10 percent increase in the reporting rate. The amount of material reported—315,524 wet tons—is nearly twice that reported previously.

Table 9 summarizes the source reduction information according to the six activity categories that have been recognized by EPA in guidance materials. Procedure modifications were reported most frequently and resulted in 177,387 wet tons of residual prevented or 33 percent of all source reduction activity. A greater variety of activities were considered procedure modifications: improvements in separation techniques, changes in how and when clean-outs and changeouts are performed, and modification of cokers to accept different residuals.

Within process recycling accounted for 31 percent of the source reduction activity (98,200 wet tons), reflecting the recycling of recovered oils to crude units and cokers.

Table 9
Summary of Source Reduction Methods

Source Reduction Method	# Citations	Wet Tons Reported
Procedure modifications	73	177,387
Within process recycling activities	64	98,200
Improved housekeeping, training, or inventory control activities	41	25,330
Equipment and technology modifications	18	13,864
Activities to substitute materials	6	698
Activities to reformulate or design products	5	45
TOTAL	207	315,524

Improved housekeeping, training and inventory controls were reported by 41 refiners and resulted in a reduction of 25,330 wet tons of residual. The industry continued to improve its procedures for minimizing solids entering the sewer systems, installing concrete drains, ditches and sump pads, reducing reliance on sand bags for hot work, as well as improving grounds keeping, particularly by increases in sweeping and paving.

The number of refineries reporting **equipment and technology modifications** was slightly less in 1990, but likely reflects more accurate and consistent use of this source reduction category. The types of modifications reported included upgrading separators, changing piping systems and replacing units (kerosene Merox heaters, Stretford units, cyclones, isomerization units).

Given the nature of the industry and the performance specifications for fuel products, few refineries reported **activities to reformulate or design products** or to **substitute materials**. Phase out of leaded gasolines accounts for most of the changes in products, while the substitution of materials involves use of less hazardous substances, such as non-solvent cleaners.

The source reduction methods were categorized by stream. As shown in Table 10. At least one type of source reduction activity was reported for 25 of the 28 residual streams.

Activities to prevent the creation of listed hazardous wastes—**API separator sludge, DAF float, slop oil emulsion solids, leaded tank bottoms, and heat exchanger bundle cleaning sludge**—summed to 139,126 wet tons or 30 percent of the total. Other streams with substantial quantities eliminated include **spent caustics, biomass, and nonleaded tank bottoms**.

Table 10
Summary of Source Reduction Activities - 1990

SOURCE REDUCTION METHOD

Residual stream	Wet Tons	1	2	3	4	5	6
API Separator Sludge	17,920	✓	✓			✓	✓
DAF Float	87,871		✓			✓	✓
Slop Oil Emulsion Solids	33,040		✓			✓	✓
Leaded Tank Bottoms	74		✓	✓			
Other Separator Sludges	6,452		✓			✓	✓
Pond Sediments	9,345		✓				✓
Nonleaded Tank Bottoms	30,020	✓	✓			✓	✓
Waste Oils/Spent Solvents	8,013	✓			✓	✓	✓
Other Oily Sludges/Organic Wastes	855	✓	✓			✓	✓
Heat Exch Bundle Cleaning Sludge	221	✓				✓	✓
Contaminated Soil/Solids	4,251	✓		✓	✓		✓
Residual coke/Carbon/Charcoal	14					✓	
Other Contaminated Soils NOS	599	✓	✓			✓	✓
FCC Catalyst or Equivalent	3,202	✓	✓		✓		
Hydroprocessing catalysts	60		✓				
Other Spent Catalysts	10	✓	✓				
Biomass	34,351		✓			✓	✓
Oil Contaminated Waters/not WW	315					✓	
High pH/Lo pH Waters	9,102		✓				
Spent Stretford Solution	160	✓					
Other Aqueous Waste NOS	4,882	✓	✓				✓
Spent Caustics	43,672	✓	✓			✓	
Residual amines	19,328		✓				✓
Other inorganic residuals NOS	2,109		✓		✓	✓	
Other Residuals NOS	295		✓		✓	✓	✓
TOTAL	315,524						

SOURCE REDUCTION METHOD CODES

1 = Equipment or Technology Modifications

2 = Procedure Modifications

3 = Reformulation or Design of Products

4 = Substitution of Raw Materials

5 = Recycling Within a Process

6 = Improved Housekeeping, Training, or Inventory Control

There were a number of changes in the types of source reduction methods reported by stream. In 1990, procedure modifications were reported most frequently (for 19 streams), followed by recycling and housekeeping improvements (both 15 streams). In 1989, equipment modification and recycling led reporting by streams with 15 each, followed by housekeeping improvements (12 streams) and procedure modifications (11 streams).

These changes in the activities undertaken affected all but two streams, **other separator sludges and waste oils/spent solvents**, where procedures remained constant. In all, there were 38 changes between the two years, including: (1) four new streams with equipment/technology modifications; (2) nine different streams with procedural changes; (3) five streams with new housekeeping improvements. Reciprocally, seven streams for which equipment modifications had been reported in 1989, did not report modifications in 1990. There were also five fewer reports in 1990 of substitution of materials.

Appendix B contains a summary of the raw data collected on source reduction which supports the foregoing discussion. Refer to these tables for a slightly more detailed presentation of the actual methods performed on each stream to prevent the generation of residual material.

The survey also included questions on the *incentives* for implementing source reduction, and the *barriers* that impeded these activities. As shown in Table 11, the most frequently cited reason for implementing source reduction activities was economic: to reduce treatment and disposal costs. It is not surprising with land disposal restrictions for listed hazardous wastes becoming effective in 1990, the percentage of refineries citing this reason rose. Refineries citing other process cost reductions also rose in 1990 to 43% of respondents. The percentage of refineries reporting the remaining reasons remained fairly constant, with less than a third reporting occupational safety or concerns with public opinions as motivating factors.

Table 11
Incentives for Source Reduction Activities (% of refineries reporting)

Reasons	1990	1989
Reduction of treatment/disposal cost	93%	84%
Self-initiated review	69%	67%
Regulatory requirement for waste	43%	44%
Other process cost reduction	43%	26%
Occupational safety	31%	33%
Concern over public reactions	25%	31%
Pressure from public or environmental groups	5%	9%

Cost was also the most frequently cited *barrier* to implementing source reduction. Sixteen refineries or 34 percent of the 47 refineries that did not implement source reduction activities reported that source reduction was not economically feasible.

Resource Recovery

Significant editing was required to make the resource recovery reports conform to the intent of the question: to capture information on the reuse of residual materials, either on-site or for other uses off-site that were *initiated in 1990*. For example, many refiners initially reported in-process recycling of oily materials under this question, rather than as a source reduction activity. These responses were recategorized as source reduction during the data cleaning process. In this editing process, care was exerted to assure that activities were not reported under both resource recovery and source reduction.

Twenty eight (28) refiners reported some type of resource recovery activity. Because many refiners reported multiple conservation activities this resulted in a total frequency of 60 reports, involving 19 streams.

As shown in Table 12, the number of refineries reporting initiating resource recovery activity for any individual stream was low. The stream with the highest frequency of resource recovery reports was **other residuals NOS** with eight reports. This was followed by **FCC catalyst or equivalent** and **hydroprocessing catalysts** with seven each, and **other inorganic residuals** with 6 refineries.

A total of 143,841 wet tons of residual materials were reported as reused. This is less than 1 percent of the total quantity of waste managed in 1990. This suggests that most of the off-site or out-of-process recycling reported on the data sheets, but not captured here, reflected industry practices that predated the 1990 initiation criteria of this question.

Table 12 also presents a brief narrative description of the resource recovery activities reported. Reuse on-site of **spent acids** and **caustics** to adjust the pH of the wastewater system was reported by four refiners, but constituted close to 70 percent of all residuals reused. Reuse in cement kilns, an off-site activity, was cited for six streams: **contaminated soils/solids**, **other inorganic residuals NOS**, **API separator sludge**, **residual coke/carbon/charcoal**, **FCC catalyst or equivalent**, and **waste oils/spent solvents**. This accounted for approximately 25 percent of the material reused. The resource recovery question was not designed to capture information regarding the purpose of materials reused in cement kilns. However, those residues with a high hydrocarbon content would be used for fuels to a kiln, while inorganic residuals would be used as an ingredient in the cement production process.

The stream that had the greatest variety of activities reported—**other residuals NOS**—represents a large variety of materials: batteries, lab wastes, paper products etc. The variety of recovery methods for **other residuals NOS** reflects the inherent diversity of the category and underscores the need tailor reuse activity to the residual under consideration.

Table 12
Summary of Resource Recovery Data

Residual stream	# Citations	Wet Tons	DESCRIPTION OF ACTIVITIES
Spent Acids	1	67,000	Reuse to adjust pH of wastewater system
Contaminated Soils/Solids	3	30,499	Reused in asphalt & cement kilns
Spent Caustics	3	29,768	Reuse to adjust pH of wastewater system
Nonleaded Tank Bottoms	4	6,804	Centrifuge tank bottoms; recycle recovered oil
Other inorganic residuals NOS	6	3,893	Lime solids/slurry sold as raw material for cement kilns Pretreatment recycle or stabilize
FCC Catalyst or Equivalent	7	1,329	Reuse in cement kilns Reuse as road base filler Sold for recycle
Residual coke/Carbon/Charcoal	4	1,087	Fines sold for reuse Regenerated Reused in cement kilns
Other Spent Catalysts NOS	4	925	Off-site recovery Reuse as fertilizer feed
Hydroprocessing Catalysts	7	871	Off-site reclamation Metals recovery
Slop Oil Emulsion Solids	1	818	Oil recovered used as fuel off-site
API Separator Sludge	5	335	Use as fuel for cement kiln Coke fine recovery system used Thicken in storage tanks
Oil Contaminated Waters	1	300	Recycle toluene unit cooling water
Other Contaminated Soils NOS	1	125	Centrifuge filter clay to recover kerosene
Other Residuals NOS	8	68	Send batteries to reclaimer Send white & computer paper to pulp mill Send aluminum cans to recycler Metal reclamation off-site Waste paint used in fuel blend
Waste Oils/Spent Solvents	2	9	Reuse as fuel for cement kiln Off-site reclamation
Other Oily Sludges/Organic Residuals NOS	1	5	Anti-freeze to recycler
Residual sulfur	1	4	Recover sulfur spill
Heat Exch. Bndl Clean Sludge	1	1	Treated water reused
Pond Sediments	1	1	Pond not used; water recycled
TOTAL	60	143,841	

Management of Residual Materials

The remaining steps of the waste management hierarchy—recycling, treatment, and disposal—were used on API's data sheets to categorize the practices used to handle wastes and residual materials. In the data collection phase of this survey, Land Treatment is classified under the broader category of Treatment; however, as in previous reports, Land Treatment practices are described in a separate section. The SAS printouts that support the following discussion of the handling practices are presented in Appendix C.

Recycling

In 1990, 1.9 million wet tons of waste and residual materials were recycled by petroleum refiners. This is about 10 percent of the total amount of waste managed—an increase of 2 percent over the total recycled in 1989. After adjustment to correct for the outliers—the percentage of materials recycled is 33 percent of the total residuals managed. Tracing this statistic over time, the industry is steadily increasing its reliance on recycling: from 21 percent in 1987, to 23 percent in 1988, to 26 percent in 1989 to 33 percent in 1990. Indeed, over the four survey years, over 76 percent more material is managed by recycling.

Table 13 summarizes how materials are recycled. As in previous years, more waste and residual materials were reported as being reclaimed or regenerated, followed by the "Other" recycling category. A drop in the amount of materials sent to the coker was observed in 1990. A small, but steady increase in utilization of crude units has been reported over time.

Table 13
Summary of Recycling Practices
(thousands of wet tons)

Method of Recycling	1990		1989		1988		1987	
	Tons	%	Tons	%	Tons	%	Tons	%
Coker	192	10	231	17	186	16	148	14
Crude unit	174	9	125	9	85	7	68	6
Reclamation/regeneration	872	46	611	44	434	38	447	42
Other	655	35	408	30	474	41	410	38
Total	1,893	100	1,376	100	1,179	100	1,073	100

Table 14 provides a more detailed presentation of these data, showing the recycling methods used with each stream. **Chemicals/inorganic residuals** and **spent catalysts** contribute the biggest quantities of materials for reclamation and regeneration. As in previous years, **spent caustics** accounted for more than half of the material recycled in this category.