

GENERATION AND MANAGEMENT OF RESIDUAL MATERIALS



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Petroleum Refining Performance



One of the most significant long-term trends affecting the future vitality of the petroleum industry is the public's concerns about the environment. Recognizing this trend, API member companies have developed a positive, forward-looking strategy called STEP: Strategies for Today's Environmental Partnership. This program aims to address public concerns by improving our industry's environmental, health and safety performance; documenting performance improvements; and communicating them to the public. The foundation of STEP is the API Environmental Mission and Guiding Environmental Principles.

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- ❖ To operate our plants and facilities, and to handle our raw materials and products in a manner that protects the environment, and the safety and health of our employees and the public.
- ❖ To make safety, health and environmental considerations a priority in our planning, and our development of new products and processes.
- ❖ To advise promptly, appropriate officials, employees, customers and the public of information on significant industry-related safety, health and environmental hazards, and to recommend protective measures.
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- ❖ To commit to reduce overall emission and waste generation.
- ❖ To work with others to resolve problems created by handling and disposal of hazardous substances from our operations.
- ❖ To participate with government and others in creating responsible laws, regulations and standards to safeguard the community, workplace and environment.
- ❖ To promote these principles and practices by sharing experiences and offering assistance to others who produce, handle, use, transport or dispose of similar raw materials, petroleum products and wastes.

Generation and Management of Residual Materials

Petroleum Refining Performance 1992 - 1993 Survey

Health and Environmental Affairs Department

API PUBLICATION NUMBER 333

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At each refinery that participated in the survey, an individual(s) assumed the responsibility to complete the survey questionnaire. Their efforts deserve special recognition and thanks from the industry.



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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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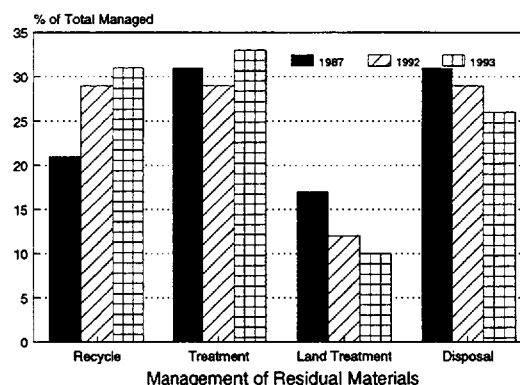
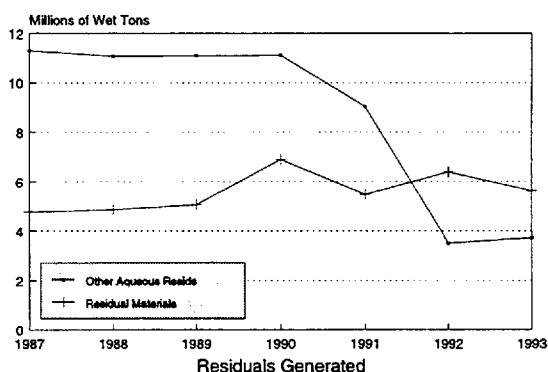
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EXECUTIVE SUMMARY

The addition of 1992 and 1993 information to API's database on refining performance strongly suggests that residual generation patterns and management practices have changed significantly from those observed in the late 1980's. Generation of Other Aqueous Residuals has dropped 69 percent since API's survey began in 1987, while the amount of other residual streams has fluctuated since 1990, due largely to unusual, one-time events. Over the seven year period, the industry has increased its reliance on recycling to manage residual materials, with 40 percent more material recycled in 1993 than in 1987 (1.8 and 1.1 million wet tons, respectively). At the same time, less material is managed in land treatment units and by disposal.



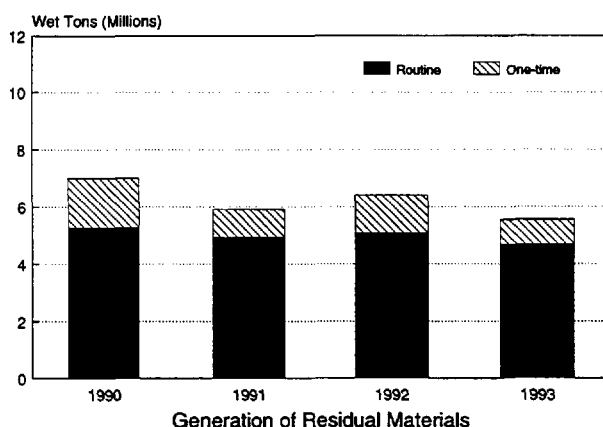
These observations are based on the responses to questionnaires API mailed to the population of 169 domestic refineries operating in 1992 and the 161 that remained in operation in 1993. Fewer refineries participated in the survey activity than ever before: 91 and 90 respectively, for each year. However, because these respondents represented 63 percent of the refining capacity and spanned the full range of refinery capacity classes (i.e., <10,000 - >400,000 barrels per stream day), the models previously used to create industry-wide estimates retained their validity.

API's survey continues to document how the industry has achieved compliance with the land disposal restrictions on RCRA listed hazardous K-wastes (K048-K052). It has also begun to trace the influence of the Primary Sludge rule and new Toxicity Characteristic criteria under RCRA. For K-waste residual streams, pollution prevention activities implemented by the

refiners should be credited with the 62 percent reduction in generation achieved: from approximately 760 thousand wet tons in 1987 to approximately 300 thousand wet tons in 1993. The types of pollution prevention activities performed include both those expected when such programs are initiated--procedural changes that quickly yielded substantial improvements--as well as secondary strategies to enhance recycling and sustain employee awareness.

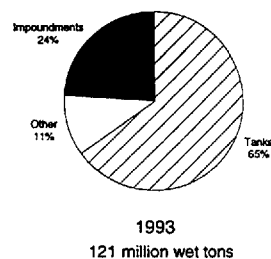
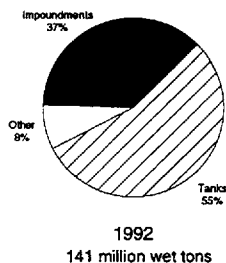
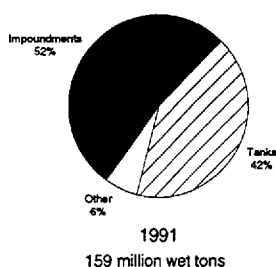
The three years of data on listed Primary Sludge wastes (F037) show an initial low generation quantity of 130 thousand wet tons in 1991 followed by successive increases to 209 and then 235 thousand wet tons in 1993. In 1992, refiners reported that one third of the amount generated was due to one-time events; this increased to over one half of the quantity reported in 1993. These spikes in generation are consistent with timing of variances EPA had provided to land ban requirements.

Similar spikes in generation have been noted for other residuals streams, such as **Contaminated soils/solids, Other inorganic residuals, Residual oils/spent solvents, Pond sediments, and Other residuals NOS**. Refiners have indicated that these reflect capital improvements (i.e., closure of units, construction and remediation activities). Such events occur infrequently, and as reported in the survey, are considered "one-time" incidences. The quantities of these residuals associated with these abnormal events are substantial, accounting for the increases in residuals noted since 1989, as well as the variability observed in residual generation between 1990 and 1993.



The pattern observed for TC wastewaters, however, was successive reductions, rather than increases in generation. The largest quantity was reported in 1991, followed by an 11 percent reduction for 1992, and a 24 percent drop by 1993 (based on the 41 refineries that provided TC data in all three survey cycles). The pie charts presented below illustrate the reduced reliance on surface impoundments to manage TC materials that has occurred over time.

Management of TC Wastewaters



INTRODUCTION

This report presents information on the generation and management of residual material in the petroleum refining industry during 1992 and 1993. This study differs from previous survey cycles and respective reports in that two years of data were collected and analyzed simultaneously.

The American Petroleum Institute (API) employed this strategy for several reasons. First, collection of the 1992 data had been delayed to avoid conflict with the refiners' completion of the Environmental Protection Agency's (EPA) survey conducted under the authority of Section 3007 of the Resource Conservation and Recovery Act (RCRA). This mandatory survey went to the field in September 1993--exactly when API had planned to send out the forms for collection of its own 1992 data. Recognizing that completion of EPA's 142 page questionnaire would require a substantial manpower effort, API opted to delay administration of its survey.

API, however, was concerned that a delay in collecting the 1992 data could undermine the utility of these data within the refining industry. Refiners had already expressed concern that the three year lag time in publishing the data made it less useful to them. For example, because the 1991 data were published in 1994, information on the first year of land disposal restrictions was released when refiners already had three years of experience with the prohibitions. Thus, while API's survey reports are viewed as the most comprehensive and current source of data on industry practices by those *outside* the industry, to some intimately involved in day-to-day refining operations, the information was too dated to assist in timely management decisions.

After discussing the issue with company representatives on API's General Refining Committee and the Committee on Refining Environmental Controls (CREC), agreement was reached that the 1992 and 1993 data should be collected simultaneously, but the time required to analyze and report results should be reduced substantially. The refiners would therefore shoulder an increased reporting burden, while API, the respective committees involved in the survey, and the contractor would be obligated to expedite handling and review of the survey data.

This report represents the accomplishment of these goals. The survey materials were mailed to refineries in March, 1994, less than one year ago. Publication of this report with 1993 data represents a substantial reduction in the lag time to publication. The refiners part in this collaborative effort is noteworthy for it represents the efforts of front line workers in a time when corporate downsizing already made their jobs more demanding.¹

¹ Between 1992 and 1994 when the data was collected, the number of employees in refining dropped from 121.8 thousand to 108.5 thousand--an 11 percent reduction (U.S. Department of Labor, *Employment Hours and Earnings*, August 1993, June 1994). This reflects the closing of 22 refineries between 1991 and 1993 and reductions in staff at the remaining 161 operating refineries. At the same time, manufacturing increased, from 593 to 618 billion barrels.

METHODOLOGY

The survey procedures used for the 1992 and 1993 cycles were the same as previously employed. The census design was based on the listings of operating refineries in the Department of Energy's *Petroleum Supply Annual for 1992 and 1993*. Survey materials were mailed in March 1994. The six week interval originally adopted for form completion was extended to almost seven months to maximize the response rate. Contact was maintained with all refineries during the field administration, with follow-up calls placed to refineries to encourage participation and through a "HELP-line" staffed by a refining expert.

The sections that follow provide more detail on the data collection forms and the estimation procedures used in the study.

Data Collection Forms

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.

The survey questionnaire had two sections. The first included nine short-answer questions that focused on refinery characteristics such as age, size, complexity of processing, and sewer configuration.

The second section of the questionnaire was a series of one-page "data sheets" that collect empirical information on:

- 1) the quantities of residual materials **generated**;
- 2) how they were **managed** (according to the waste management hierarchy steps of recycling, treatment, and disposal); and
- 3) the amount of materials that were reduced as a result of **pollution prevention** activities.

There were 30 of these *data sheets* for each year, one for each of the residual streams identified in Table 1. (Refer to Appendix A for an example of a data sheet).

The data sheets were virtually the same as used in the 1991 cycle of the survey. The two page format was retained, wherein codes for the management techniques and pollution prevention activities were printed on the back of the preceding page in a different color. The only modifications made to the forms were clarifications of various instructions, such as the inclusionary criteria for several streams (i.e., Residual oils and spent solvents, Spent acids, and High pH/low pH waters), and the selection of the most appropriate code for pollution prevention activities. These revisions were considered to be minor since edit checks had previously been performed on these same data elements.

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 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 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*** Residual 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.

API has used an equation on each data sheet as a quality control measure: the "inputs" of residual materials must balance the "outputs." Inputs include the quantities of residual material 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 depicted in the equation below, this is balanced by the quantities of the residual *recycled, treated, or disposed*.

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

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

Each data sheet also contains a section to capture information on pollution prevention activities that have been performed. In addition to indicating the quantity of waste reduced, respondents are asked to classify the pollution prevention activity according to the codes displayed below and to then briefly describe the activity performed.

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 used 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 all cases, any questionable data were verified by direct contact with the facilities to ensure their accuracy.

For each survey cycle, regression analysis has been used to estimate the quantity of residuals generated by the entire industry, based on the information submitted by survey respondents. A critical assumption in this approach is that the factor(s) influencing waste generation for respondents do not differ from those for non-respondents.

Similar to the approach used in 1991, a regression procedure was used to estimate the quantities of 29 residual streams that are generated by most refineries. As before, the regression model used for 1992 and was of the form:

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

where a and b were estimated based on the data from responding refineries that were not statistical outliers.

A separate modeling step was used to estimate Other Aqueous Wastes NOS since the generation and management pattern for this stream is quite atypical (with only a few facilities generating this stream, but with several reports of extremely large quantities).

To validate the continued applicability of the model used to estimate the 29 residual streams, the previous model assumption of operating capacity versus the square root of residual generation was examined. Specifically, scatterplots of the 1992 and 1993 data were made. Based on the visual fit of the data and the calculated R^2 values of 0.65 for each year, the existing regression model was considered adequate.

To improve regression, outliers that tend to have too much influence on the regression line were deleted. Confidence bands were drawn on the scatterplots of the 1992 and 1993 data to aid in visually identifying outliers. A 99.99 percent confidence interval was arbitrarily chosen to show the widest possible band which would highlight the most extreme, or outlying points. Using this technique, three refineries were identified as outliers for 1992 and two additional refineries were considered outliers for 1993 (i.e., a total of five for 1993). After removing these cases, the final R^2 value for 1992 was 0.68, while the 1993 statistic remained 0.65. The final regression equations are

for 1992:

$$G = \sqrt{40.04 + 0.0009872C}$$

and for 1993:

$$G = \sqrt{46.55 + 0.0009799C}$$

where, G = residual material generation (wet tons) and
 C = operating capacity (barrel per stream day).

This regression model was then used to estimate the total residual generated by each non-respondent by inputting its capacity obtained from statistics maintained by the U.S. Department of Energy into the model, squaring the result and then applying a standard statistical procedure to adjust that number so that the final estimate is unbiased.

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

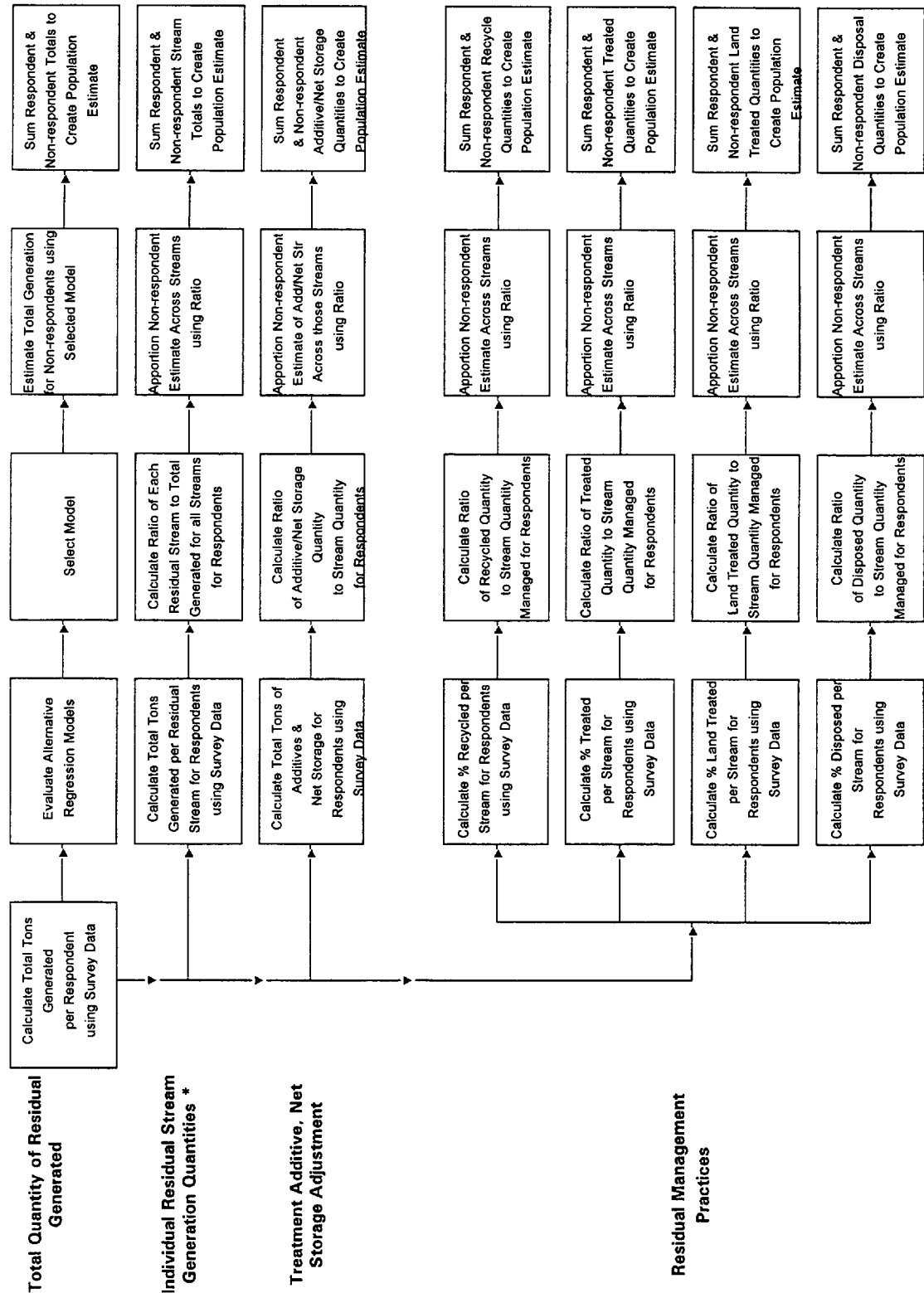
After deriving the total quantity of generated residual, calculations were performed to estimate the generation quantities for each of the 29 residual streams. This is illustrated in the flow chart presented in Figure A. A summary of the procedure used follows:

- 1) The total reported quantity of residuals was determined by summing, for each stream, 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 A.) 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. As depicted in the last four rows of the flow chart, a similar procedure was used to estimate the quantities of residuals recycled, treated and disposed.

To estimate the quantity of Other Aqueous Residuals generated, the simple ratio technique used in 1991 was employed. In 1992, 14 of the 91 respondents reported generating this stream, while only seven continued to report it in 1993. For each year, the quantity of this stream reported by these refineries was divided by the capacity represented by the group of refineries that responded to the survey. The resulting ratio was then applied to the capacity for all operating refineries.

Figure A - Statistical Estimation Procedures



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

RESULTS

Response Rate

In 1992, 91 refineries participated in the survey and 89 refineries provided data for 1993. These were the lowest response counts observed since the survey began. The survey continued to maintain, however, a sizeable core group of 56 refineries that participated in all seven survey cycles.

When the raw count of survey respondents is reviewed in the context of the number of operating refineries, the response rates for 1992 and 1993 are in the ranges previously reported. The overall number of operating refineries in 1992 and 1993 dropped substantially, to 169 and 161, from the 183 observed for the three previous survey cycles. Thus, when the 1992 and 1993 respondents are looked at as part of the population of refineries, the response rates are 54 and 55 percent, respectively. This is within 10 percent of the 64 and 65 percent rates achieved in 1989 and 1988, and comparable to the 56 percent reported for 1990.

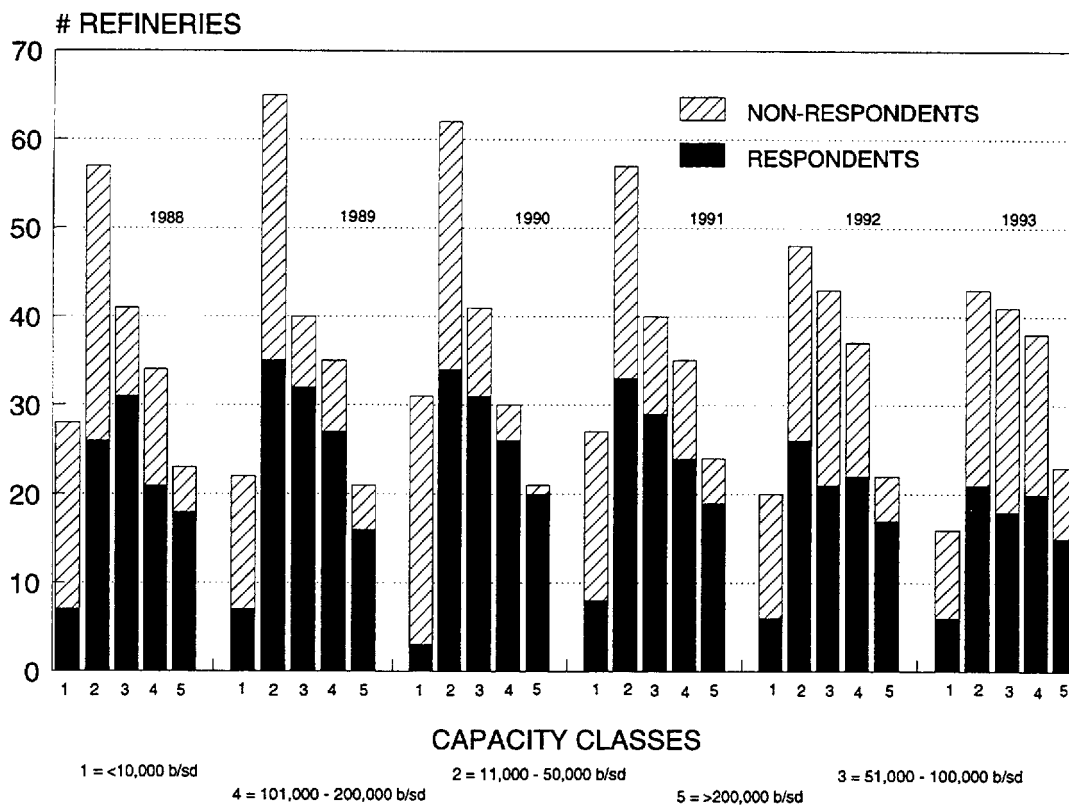
For both 1992 and 1993, the respondents represented 63 percent of the *domestic crude refining capacity* of 10.231 and 10.201 million barrels per stream day. This is lower than previously attained, but is still a substantial response and more than adequate to support the generation of reliable statistical estimates.²

This reduction in response rate for this survey appears to be related, in part, to the decrease in the number of operating refineries. The decrease in response between 1991 and 1993 was 21 percent, while the decrease in the number of operating refineries was 12 percent. However, the survey was administered in 1994, when even more closures and changes in operating status had taken place. Some refineries reported that they would not be able to participate because they were transitioning to new ownership and that attendant business issues took priority. Another related consideration is that refineries that closed in 1993 typically had no staff in place during 1994 and therefore could supply no data for 1992.

The closings of these facilities exerted some distinct changes on the distribution of refineries as illustrated in Figure B.

² Although the number of refineries has diminished over time, the quality of the model used to create population estimates continues to be quite good as seen by the t-statistic of 13.8. It is anticipated that even if additional refineries choose not to participate in future cycles of the survey, appropriate models could be developed, assuming that the participating refineries continue to adequately represent the full range of capacity classes.

Figure B
Number of Respondents by Capacity Group



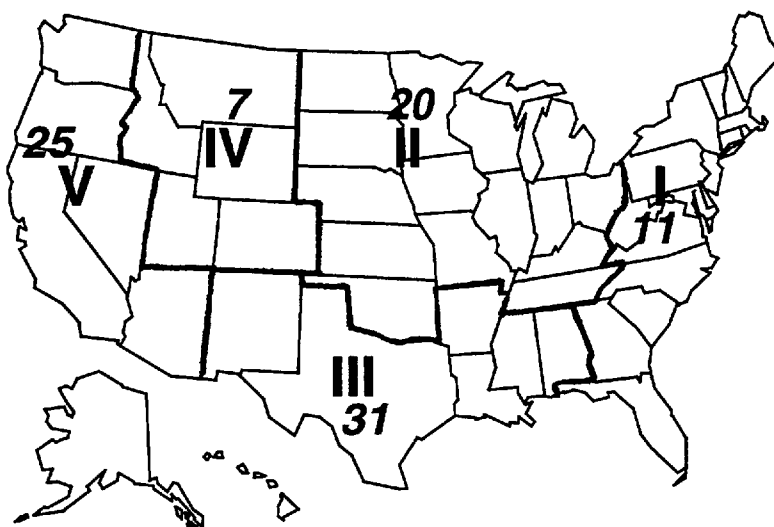
Note the substantial drop in the number of operating refineries (i.e., the combined area of both the respondent and non-respondent bars) in the 10 - 50 thousand barrels per stream day (b/sd) category and the increases, over time, in the two largest capacity classes. Given that no new refineries opened or were reactivated in 1992 and 1993, the increases in the number of operating refineries in the largest categories must reflect increases in capacity at existing facilities.

Regarding the participants in the survey, the graph shows that there were fewer responders in each capacity group, and that the greatest drop was in the 50 - 100 thousand b/sd capacity class. This observation comports with the information obtained during follow-up calls that some refineries and corporations decided not to respond because of the burden involved. In particular, a number of small refineries commented that they would be unable to participate because of the effort they had already devoted to complying with the RCRA 3007 survey. Several other companies, faced with the demands of downsizing, indicated that they could not complete the forms, especially since the two years of data increased the manpower effort required.

Respondent Characteristics

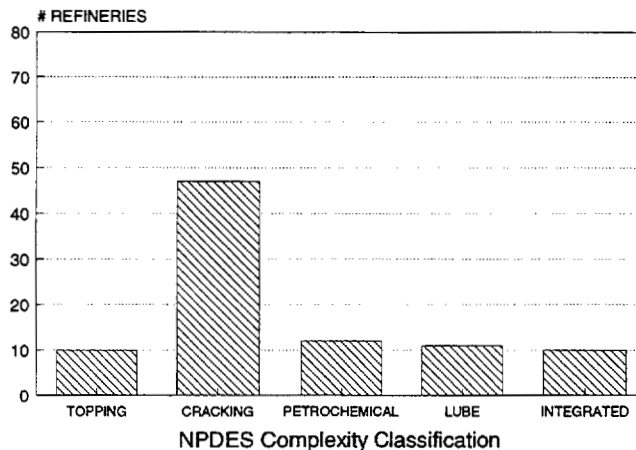
The location of the responding refineries is illustrated in Figure C. The only region with the same number of respondents as previously was PAD I. PAD II, with 20 refineries, had the greatest turnover in respondents, with 14 refineries that had participated in 1991 not participating in this survey. PAD III and PAD IV both had 3 fewer refineries participating, while the western PAD V had four less.

Figure C
Location of Participating Refineries



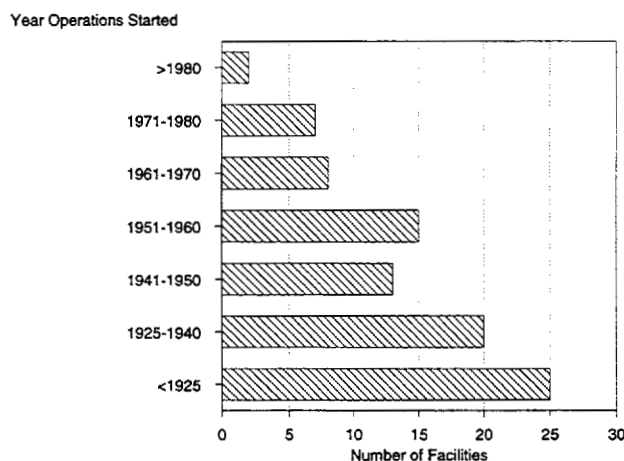
To categorize the complexity of refineries, API uses the NPDES permit classifications that range from the simplest "Topping" type of processing to the more complex "Integrated" system. As shown in Figure D, the "cracking" refineries were the most predominant group, representing 52 percent of the respondents ($n = 47$). As depicted, the 43 other refineries were fairly evenly distributed across the other complexity categories.

Figure D
Distribution of Respondents by NPDES Complexity Classification



As the distribution of respondents by the age of refinery shows, very few refineries are new (Figure E). Twenty-five refineries have been in operation for at least 70 years. Half of the refineries that participated in the 1992-93 survey began operations before 1940.

Figure E
Distribution of Respondents by Refinery Age



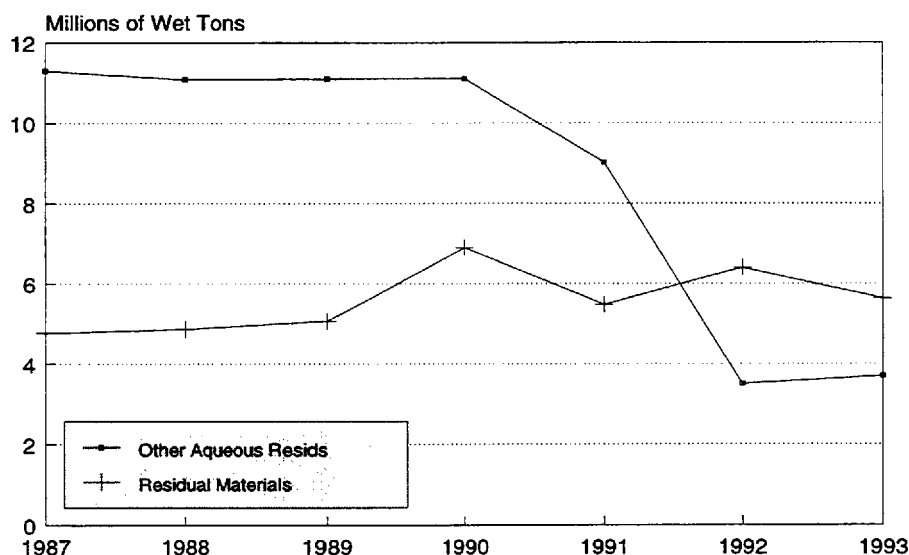
The final descriptive characteristic collected by the survey pertains to a refinery's sewer system and its separation of process water and stormwater. The majority of refineries (57 percent) that responded to the 1992/1993 survey have partially segregated sewer systems, while 23 percent have non-segregated systems and 19 percent have totally segregated systems.

Residual Generation

As described earlier, separate population estimates are performed for the grouping of 29 streams of residual materials and for the amount of Other Aqueous Residuals. For 1992 and 1993, the estimated quantity of residual material generated was 6.398 and 5.547 million wet tons, respectively. The amount of Other Aqueous Residuals generated was 3.510 million wet tons for 1992 and 3.717 million for 1993.

As illustrated in Figure F, the generation estimate for the group of 29 residual streams peaked in 1990, and has fluctuated since then. The overall quantity of these residual materials has remained fairly constant over time, particularly when compared with the generation pattern exhibited by the Other Aqueous Residuals. This stream dropped dramatically in 1990 and appears to have plateaued at a new lower level.

Figure F
Generation of Residual Materials and Other Aqueous Residuals
in the Petroleum Refining Industry: 1987 - 1993



From this graph it appears that 1990 was a pivotal year: the quantity of Other Aqueous Residuals has systematically dropped since then, while the quantity of Residual Materials, which was constant between 1987 and 1989, has fluctuated since it peaked in 1990. These trends can be explained, to a large extent, by regulatory requirements and planning activities undertaken in anticipation of other regulatory initiatives.

The drop in the generation of the Other Aqueous Residuals reflects the phasing out of deep well injection of these residuals by most refineries. EPA has approved a no-migration petition for one refinery that allows the continued use of deep well injection for the management of permitted liquid wastes. In addition, this same facility has dramatically reduced generation of these residuals to a level which is less than half the amount reported previously.

It should also be noted that the Other Aqueous Residual category was used to report a new type of material in 1992 and 1993: recovered groundwater from onsite remediation activity.

The fluctuations in the Residual Materials are contemporaneous with the 1990 RCRA land disposal restrictions for refinery K-wastes, the related specification of treatment standards for listed wastes, RCRA's new Toxicity Characteristic for determining characteristically hazardous wastes, and the Primary Sludge listings. As previously reported, the peak in 1990 was caused by one-time generation of **Contaminated soils and solids** and **Pond sediments**. Both of these materials are associated with site remediation and construction activities, such as the replacement of impoundments with tanks, undertaken by refiners as preparatory steps to comply with the Primary Sludge rule and BDAT standards.

The amount of Residuals reported 1990 included increased quantities of **Spent Caustics**--a trend which continued through 1991, and which has now extended through 1992, as shown in Table 2. The highest quantity of Spent Caustics--1436 thousand wet tons--was reported in 1993. This was more than twice the quantity reported in 1987 when the survey began. (Professional judgement within the industry maintains that this is not truly an increase in the generation of this material, but an improvement in the tracking and accounting of this material as more is reclaimed, regenerated, or sold for out-of-process recycling.)

Biomass also had a large quantity reported in 1993. The 801 thousand tons generated, however, was in the range previously reported. The three listed streams under RCRA, **Primary Sludges (F037 and F038)** and **TSD Leachate (F039)** edged upward in 1993.

The amount of **Contaminated soils and solids** generated in 1993 dropped substantially from its peak value of 1,063 thousand wet tons recorded in 1992 to 663 thousand wet tons. Over seventy percent of the material generated in 1992 was reported by 20 refineries that classified it as related to one-time events. The amount reported as due to abnormal events in 1993 dropped more than 300 thousand wet tons, but still constituted the majority of this material generated (58 percent).

In 1993, three of the residual streams that include RCRA K-wastes achieved the smallest generation quantity ever: **API Separator Sludge** at 175 thousand wet tons represented a 58 percent decrease from 1987; **Slop oil emulsion solids** decreased 74 percent from 1987 to 54 thousand wet tons; and three tons of **Leaded tank bottoms** were generated. The quantities of **DAF float** and **Heat exchanger bundle cleaning sludge** were within the ranges previously reported. It is important to note that **API separator sludge** remains one of the most frequently reported streams (n = 70 respondents as shown in Table 3), while the other K-waste streams are generated by less than half of the survey participants (e.g., DAF float was reported by 37 refineries). This suggests that the reduction in generation of API separator sludge is an industry-wide trend.

Table 2**Estimate of Residual Materials Generated by the U.S. Refining Industry: 1991**

(thousands of wet tons)

Residual stream	1993	1992	1991	1990	1989	1988	1987
Spent Caustics	1,436	1,428	909	889	716	656	675
Biomass	801	716	855	782	642	786	757
Contaminated soils/solids	693	1063	809	920	512	240	165
DAF float	517	544	406	553	496	655	652
Other inorganic residuals NOS	251	364	397	451	440	213	325
Primary sludge (F037)	235	209	130				
FCC catalyst or equivalent	204	203	204	198	182	193	173
Other oily sludges/organic residuals	193	38	54	53	47	61	38
API separator sludge	170	178	210	251	419	355	400
Other residuals NOS	143	488	339	352	325	412	203
Pond sediments	138	388	372	1,017	313	266	337
Nonleaded tank bottoms	127	128	109	194	161	129	216
Residual amines	116	142	136	75	51	14	13
Primary sludge (F038)	67	54	177				
Residual coke/carbon/charcoal	54	53	138	92	129	67	43
Slop oil emulsion solids	54	77	165	291	272	224	208
Residual oils/spent solvents	48	33	21	115	31	7	4
Hydroprocessing catalysts	47	55	32	31	36	36	40
Residual sulfur	44	53	19	35	52	22	17
TSD Leachate (F039)	40	13	20				
Other contaminated soils NOS	39	32	37	69	53	68	82
Spent sulfite solution	29	33	9	1	8	40	42
Other spent catalysts NOS	29	27	23	39	33	37	33
Oil contaminated waters (not	27	22	67	8	29	36	28
Spent Stretford solution	26	31	25	29	42	49	35
High pH/low pH waters	9	16	54	105	91	138	144
Spent acids	5	7	88	336	8	149	126
Heat exchanger bundle cleaning sludge	4	3	3	13	2	5	3
Leaded tank bottoms	3	<1	1	3	4	8	9
Other separator sludges	NA	NA	NA	97	114	104	79
Total	5,547	6,398	5,809	6,999	5,508	4,968	4,868

(The SAS output containing the data for this table is presented in Appendix B, pages B-1 and B-21).

Table 3
Number of Refineries Reporting Each Stream

Residual stream	1993	1992	1991	1990	1989	1988	1987
Total number of refineries participating	89	91	113	103	117	115	115
Contaminated soils/solids	80	84	90	87	88	77	77
API separator sludge	70	72	76	85	93	94	91
Other residuals NOS	69	74	83	85	89	85	92
Primary sludge (F037)	69	69	59				
Nonleaded tank bottoms	67	64	69	72	72	75	72
FCC catalyst or equivalent	63	69	76	79	84	86	85
Spent caustics	62	64	69	66	70	77	79
Other spent catalysts NOS	59	60	63	57	60	60	62
Residual oils/spent solvents	58	58	65	56	56	61	52
Other contaminated soils NOS	53	43	59	56	61	71	70
Hydroprocessing catalysts	55	58	57	52	65	60	57
Other oily sludges/organic residuals NOS	54	49	43	42	49	47	49
Heat exchanger bundle cleaning sludge	52	55	43	51	49	48	49
Residual coke/carbon/charcoal	51	51	55	50	51	47	48
Other inorganic residuals NOS	49	53	62	65	73	73	77
Biomass	45	44	45	44	44	45	47
Residual sulfur	40	37	43	37	42	47	41
DAF float	37	41	44	50	47	50	53
Slop oil emulsion solids	30	32	32	35	38	43	47
Residual amines	25	29	32	27	38	36	32
Leaded tank bottoms	15	12	20	27	31	37	38
Pond sediments	14	16	25	34	31	29	26
High pH/low pH waters	12	9	4	11	11	12	14
Primary sludge (F038)	11	11	14				
Spent acids	8	10	20	24	18	23	20
Other aqueous residues NOS	7	14	14	11	14	12	13
Oil contaminated waters (not wastewaters)	7	8	10	10	14	10	14
Spent Stretford solution	6	6	6	7	11	13	12
Spent sulfite solution	2	1	3	1	2	1	1
TSD Leachate	2	3	3				
Other separator sludges	NA	NA	NA	19	22	20	15

Several other streams had low values in 1993. **Pond sediments** and **Other residuals NOS** remained within the top ten streams based on generation quantities, although the quantities in 1993 were 64 and 71 percent less, respectively, than the reported quantities for 1992.

The reporting patterns for these streams were quite different (see Table 3). For **pond sediments**, the frequency count dropped to 14 in 1993, while **Other Residuals NOS** continued to be within the top three streams with 69 refiners reporting its generation. This suggests some different reasons for the reductions. Specifically, the reduction in the quantity of pond sediments may be linked to closure of a number of ponds used by the industry.

Reductions in the amount of **Other Residuals NOS** are harder to interpret, because this miscellaneous category is used to report a variety of lab wastes, used drums, batteries, barrels, PCBs, and asbestos. These reductions may reflect some of the progress made by pollution prevention activities. For example, refineries have instituted (and reported in previous survey cycles) programs to remove spent batteries and containers, replaced PCBs and asbestos with less hazardous or non-hazardous materials, and begun inventory controls with lab materials and office paper. It is therefore possible that the drop noted in 1993 reflects some of these activities.

Reductions observed in the reported amounts of **Spent acids** and **High pH/low pH waters** are likely due to the clarification in the inclusionary criteria for these streams which was placed directly on the respective data sheets. Previously, automated edit checks were performed to verify that materials reported in these categories were residuals that were intended to be captured by this survey. Specifically, in designing this survey, it was API's intention to exclude those materials that had specific exemptions under RCRA, such as spent acids targeted for regeneration and aqueous materials that are managed in accordance with other environmental statutes (e.g., NPDES permitted effluents). Use of automated edit checks in previous years enabled API to screen reports of the large quantities of these three streams, but not all reported quantities. Placing the instructions directly on the data sheets appears to have minimized the reporting of small amounts of these streams--the small quantities that it was not pragmatically possible to scrutinize previously.

As would be expected by the trend analysis previously performed with 1987 to 1991 data (published in the 1991 survey report), the quantities of **Hydroprocessing catalysts** continued to remain constant, while between-year fluctuations persisted in the generation of **Nonleaded tank bottoms, Residual coke/carbon/Charcoal, Residual sulfur, and Biomass**. Trend graphs that illustrate these patterns are presented in Appendix C.

Looking across all streams, these trend graphs enable the identification of a group of residual streams that have been reduced over time: **API Separator Sludge, Slop oil emulsion solids, Other contaminated soils, and High pH/low pH waters**. (DAF float had previously been identified as a member of this group, but the quantities in 1992 and 1993 suggest that the generation pattern may be more stable.)

There is also a group for which generation has increased since API's survey began: **Contaminated soils and solids, Spent caustics, and residual amines.** Another grouping worthy of mention are those streams that appear to be affected by periodic peaks, typically associated with abnormal events: **Pond sediments, Residual oils/spent solvents, Other oily sludges/organic residuals, Other contaminated soils, Oil contaminated water (not wastewater) and Spent Sulfite solution.**

Pollution Prevention

Pollution prevention refers to the reduction or elimination of pollutant discharges to air, water or land. It includes the development of more environmentally acceptable products, changes in processes and practices, source reduction, beneficial use and environmentally sound recycling.

For 1992 and 1993, approximately half of the survey participants reported at least one pollution prevention activity (44 and 46 refineries, respectively).³ They reported that 235 and 173 thousand wet tons of residuals were eliminated by source reduction activities or beneficial recycling activities.

Because no attempt is made to extrapolate the reports of pollution prevention activities to the population of refineries,⁴ these quantities must be reviewed in the context of the quantities of residuals *reported* by survey participants and not the estimated quantities for all U.S. refineries. In both survey years, the quantities attributed to pollution prevention represented 7 percent of the total amount of residual material generated.

Because the pollution prevention quantity is not a population estimate, it is also influenced by the reduced response rate for 1992 and 1993. Thus, it is difficult to interpret how the quantities reported by the 44 and 46 refineries in 1992 and 1993 compare with the 751 thousand wet tons reported by the 61 refineries in 1991.

³ One company that completed the forms centrally for all of its refineries did not complete the pollution prevention questions for 1993. Because most of these same refineries reported some pollution prevention activities in 1992, it is reasonable to assume that they probably would have continued such practices. Thus the number of refineries reporting pollution prevention activities and the amount of residual affected for 1993 is artificially low.

⁴ API has not developed a model to create industry-wide estimates of pollution prevention achievements because it is a relatively new concept for which there is little experience in tracking over time. Pollution prevention (including source reduction) have site specific considerations and are expected to vary significantly over time based on the implementation status of the individual facility (i.e., early efforts may achieve greater reductions than later incremental changes). In addition, API has noted substantial variability in the reporting patterns of these activities. Given these factors that complicate estimation, API has elected to present the reported values. Thus, it is clear that the information presented here underestimate the industry-wide pollution prevention achievements because coming from survey respondents only, they represent only a portion of the activities initiated by the industry.

Table 4 presents the frequency counts for each pollution prevention method. One similarity across years is that refiners report several pollution prevention activities, as indicated by the column totals. On average, refiners reported six pollution prevention activities in 1992 and 1993 compared with the five reported in 1991.

Table 4
Number of Refineries Reporting Each Pollution Prevention Activity

Pollution Prevention Activity	# Citations		
	1993	1992	1991
Equipment or Technology Modifications	20	14	24
Procedure Modifications	11	12	23
Reformulation or Design of Products	1	0	3
Substitution of Raw Materials	5	8	13
Improved Housekeeping, Training, or Inventory Control	22	24	43
IN-PROCESS RECYCLE			
In refining process units (e.g., crude unit; coker; desalter)	55	60	42
Recovering oil (& dewatering) by filter pressing/centrifugation	16	13	50
Other recycle	16	12	5
OUT-OF-PROCESS RECYCLE			
Reuse/reclamation	103	99	66
Other	14	22	10
TOTAL	263	264	279

The pollution prevention activities reported each year have varied. *Equipment and technology modifications* dipped in 1992, but still almost equalled the count observed in 1991, despite the small number of respondents in 1992. *Procedure modifications, substitution of raw materials, and improved housekeeping, training and inventory controls* have dropped with each successive cycle. Reciprocally, recycling in process units and out-of-process reclamation activities have both increased each year.

Tables 5a and 5b display the pollution prevention data, breaking it out across streams, providing the frequency counts for the number of times refineries indicated that they performed an activity, the quantity of residual that was affected by the activity, and showing the year that the activity was performed. **API separator sludge** had the highest number of citations in both years, followed by other K-wastes **DAF Float** and **Slop oil emulsion solids**, and other frequently reported streams, **Nonleaded tank bottoms** and **Contaminated soils and solids**.

The table entries for the quantities of residuals that were reduced at the source, recycled or otherwise reused or reclaimed range from extremely small values to many thousands of wet

tons. These actual reported values are presented here not to convey a sense of measurement precision, but to attest to the effort refiners devote to responding to this survey, and as an indicator of the refiner's attempts to provide accurate data.

In both 1992 and 1993, refiners reported the largest pollution prevention quantities for **biomass**. This was followed by **DAF float** and **spent caustics**. **Residual oils/spent solvents** and **Contaminated soils and solids** had large quantities reported in 1992 only. The amount of **Pond sediments** and **Primary sludge** in 1993 was larger than for 1992.

The right side of the table shows whether an activity was performed only in 1992, in 1993 or in BOTH years. As this display shows, most activities were performed by at least one refinery in both years, particularly the recycling procedures. The presentation also highlights the new activities begun in 1993.

A major short-coming of these empirical displays on pollution prevention is that they do not convey *what* is being done to reduce generation and improve handling of residual materials. The stream-by-stream tables presented in Appendix D accomplish this goal. Construction of these tables, a manual process of updating the 1991 tables, enables several general observations about the specific pollution prevention activities.

First, most of the pollution prevention activities reported in 1992 and 1993 were new, and not duplicative of previously reported activity. The exceptions to this pattern involved recycling to cokers and crude units which were sometimes repeated.

Refiners have shifted their creative energies to new streams, introducing procedural modifications with **Primary sludge**, substitution of materials with **Oily residuals** and **spent solvents**, and finding outside markets for materials previously considered worthless: **Contaminated soils**, **Other inorganic residuals**, and **Other Residuals NOS**. In particular, note that refiners are sending a variety of streams--not just RCRA regulated streams--to cement kilns for reuse as fuel or feedstock.

Some of the procedural changes seem to run counter to what one might typically consider pollution prevention innovations. For example, rather than routinely adding lime feed to adjust boiler and water softening operations that affect generation of **Other Inorganic Residuals**, one refinery has instituted a monitoring system, so that lime is now added only when test results dictate. Thus, returning to manual procedures, is a step in the right direction.

Another procedural change reported involved the use of treatment chemicals that enhance filtration. Their use has been curtailed by some refiners in an effort to reduce the volumes of residuals requiring further management.

Table 5a
Summary of Pollution Prevention Activities

RECYCLE														
SOURCE REDUCTION					IN-PROCESS			OUT-OF-PROCESS						
Residual stream	1993		1992		1	2	3	4	5	6	7	8	9	10
API Separator Sludge	31	17,878	31	9,678	BOTH	BOTH			BOTH	BOTH	BOTH	BOTH	BOTH	
DAF Float	24	59,018	21	68,274	BOTH	1993			1993	BOTH	BOTH	BOTH	BOTH	
Slop Oil Emulsion Solids	18	10,884	18	10,069	1992				1992	BOTH	BOTH	BOTH	BOTH	
Leaded Tank Bottoms	5	39	1	25			1993						BOTH	
Pond Sediments	3	49,266	2	13,508		1993			BOTH	BOTH			1993	
Nonleaded Tank Bottoms	14	5,425	14	6,010	1993	1992				BOTH	BOTH	BOTH	BOTH	1992
Residual Oils/Spent Solvents	9	2,090	16	65,105	1993	1992		BOTH	1992	BOTH			BOTH	1992
Other Oily Sludges/Organic Wastes	10	2,342	6	3,776	BOTH					BOTH			BOTH	1992
Primary Sludge (F037)	18	20,562	13	16,278	BOTH	BOTH			BOTH	BOTH	1993		BOTH	
Primary Sludge (F038)	4	4,965	6	8,441	1992	1992			1993	BOTH	1992		BOTH	
Heat Exch Bundle Cleaning Sludge	6	53	5	358	1993	1993				BOTH	1992	1993	BOTH	
Contaminated Soil/Solids	3	109	12	32,017		1992			BOTH			1992	1992	1992
Residual coke/Carbon/Charcoal	9	155	6	255	BOTH			1992		1992			BOTH	BOTH
Residual sulfur	2	6	3	109				1992				BOTH	BOTH	
Other contaminated soils	6	662	6	872						BOTH			1992	1992

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 5b
Summary of Pollution Prevention Activities

Residual stream	SOURCE REDUCTION										RECYCLE			
	IN-PROCESS										OUT-OF-PROCESS			
	1	2	3	4	5	6	7	8	9	10				
FCC Catalyst or Equivalent	1993			BOTH	BOTH	BOTH		1993	BOTH	BOTH				
Hydroprocessing catalysts								BOTH	BOTH	1993				
Other Spent Catalysts					1993				BOTH	1993				
Biomass						BOTH		1993	BOTH					
Oil contaminated water (not WW)										1993				
High pH/low pH waters														
Other aqueous wastes NOS														
Spent Acids														
Spent caustics														
Residual amines														
Other inorganic residuals NOS														
Other residuals NOS														
TOTAL														

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

Total Quantity of Residuals Managed

API has coined the phrase *total quantity managed* to refer to the total amount of residual materials that refineries handle in a given calendar year. As indicated in the following equation, the total quantity managed equals the quantity generated plus treatment chemicals used to facilitate handling of some residuals and adjustments for materials that are placed into or removed from storage:

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

In both 1992 and 1993, the total quantity managed was less than the amount generated. Specifically, in 1992, 6,398 wet tons were generated, but due to the amount placed into storage, refiners managed 6,130 wet tons. Similarly for 1993, the generated quantity was 5,547 wet tons, while the managed quantity was 5,451. (The SAS output containing these data is presented in Appendix B, pages B-1 and B-21).

As shown in Tables 6a and 6b, two streams had large quantities placed into storage in both years: **Contaminated soils and solids** and **Biomass**. In addition, refiners placed over 100 thousand wet tons of **Other residuals NOS** into storage in 1992.

In 1992, **Primary sludge (F037)** had the largest quantity removed from storage (28 thousand wet tons), while in 1993 nine thousand wet tons were placed into storage.

For the remaining streams, the quantities that were moved into or removed from storage were very small, usually less than one ton.

Use of Treatment Additives in 1992 followed the expectation set by the responses to the pollution prevention question. Refiners minimized their use of treatment additives to 30 thousand tons compared with the 55 and 72 thousand wet tons reported in 1987 and 1988. Treatment additives increased to 79 thousand wet tons in 1993; however, over 62 percent of this was reported by one refiner that had an abnormal peak in generation of **Other oily sludges/organic residuals**.

The total quantity of residuals managed for each of the seven survey cycles is displayed in Table 7. As the totals for the columns indicate, quantities managed in 1992 and 1993 were within the range previously observed. The 1992 quantity was the second highest reported, while the 1993 quantity was the second lowest.

Table 6a**Estimates of Residual Materials Managed in 1992** (thousand wet tons)

Residual stream	Amounted Generated	Net From Storage	Treatment Additives	Total Amount Managed
Spent Caustics	1,428	(2)	0	1425
Contaminated soils/solids	1,063	(110)	0	953
Biomass	716	(79)	4	640
DAF float	544	(2)	5	546
Other residuals NOS	488	(107)	0	381
Pond sediments	388	0	3	391
Other inorganic residuals NOS	364	(5)	<1	359
Primary sludge (F037)	209	28	10	247
FCC catalyst or equivalent	203	(6)	0	197
API separator sludge	178	(8)	3	174
Residual amines	142	0	0	142
Nonleaded tank bottoms	128	<1	2	130
Slop oil emulsion solids	77	(4)	1	74
Hydroprocessing catalysts	55	(3)	0	51
Primary sludge (F038)	54	0	<1	54
Residual sulfur	53	(<1)	0	53
Residual coke/carbon/charcoal	53	<1	0	53
Other oily sludges/organic residuals NOS	38	<1	<1	38
Residual oils/spent solvents	33	0	0	33
Spent sulfite solution	33	0	0	33
Other contaminated soils NOS	32	(<1)	0	32
Spent Stretford solution	31	(<1)	0	31
Other spent catalysts NOS	27	(<1)	1	28
Oil contaminated waters (not wastewaters)	22	0	0	22
High pH/low pH waters	16	<1	0	16
TSD Leachate (F039)	13	0	0	13
Spent acids	7	0	<1	7
Heat exchanger bundle cleaning sludge	3	<1	<1	4
Leaded tank bottoms	<1	0	<1	<1
Total	6,398	-298	30	6,130

Table 6b**Estimates of Residual Materials Managed in 1993** (thousand wet tons)

Residual stream	Amounted Generated	Net From Storage	Treatment Additives	Total Amount Managed
Spent Caustics	1,436	(2)	0	1,434
Biomass	800	(83)	5	722
Contaminated soils/solids	693	(62)	<1	631
DAF float	517	(<1)	4	520
Other inorganic residuals NOS	251	(5)	1	247
Primary sludge (F037)	235	(9)	<1	226
FCC catalyst or equivalent	204	(6)	0	198
Other oily sludges/organic residuals NOS	193	0	49	242
API separator sludge	170	(7)	5	168
Other residuals NOS	143	(<1)	0	143
Pond sediments	138	0	7	145
Nonleaded tank bottoms	127	1	2	130
Residual amines	116	0	0	116
Primary sludge (F038)	67	(5)	0	62
Residual coke/carbon/charcoal	54	(<1)	3	57
Slop oil emulsion solids	54	1	1	56
Residual oils/spent solvents	48	0	0	48
Hydroprocessing catalysts	47	4	1	52
Residual sulfur	44	(<1)	<1	44
TSD Leachate (F039)	40	0	0	40
Other contaminated soils NOS	39	(<1)	<1	39
Spent sulfite solution	29			29
Other spent catalysts NOS	29	(<1)	1	29
Oil contaminated waters (not wastewaters)	27	0	0	27
Spent Stretford solution	26	0	0	26
High pH/low pH waters	9	0	<1	9
Spent acids	5	0	<1	5
Heat exchanger bundle cleaning sludge	3	<1	<1	4
Leaded tank bottoms	3	0	0	3
Total	5,547	-175	79	5,451

Table 7
Comparison of Residual Material Managed: 1993-1987 (Estimates in thousands of wet tons)

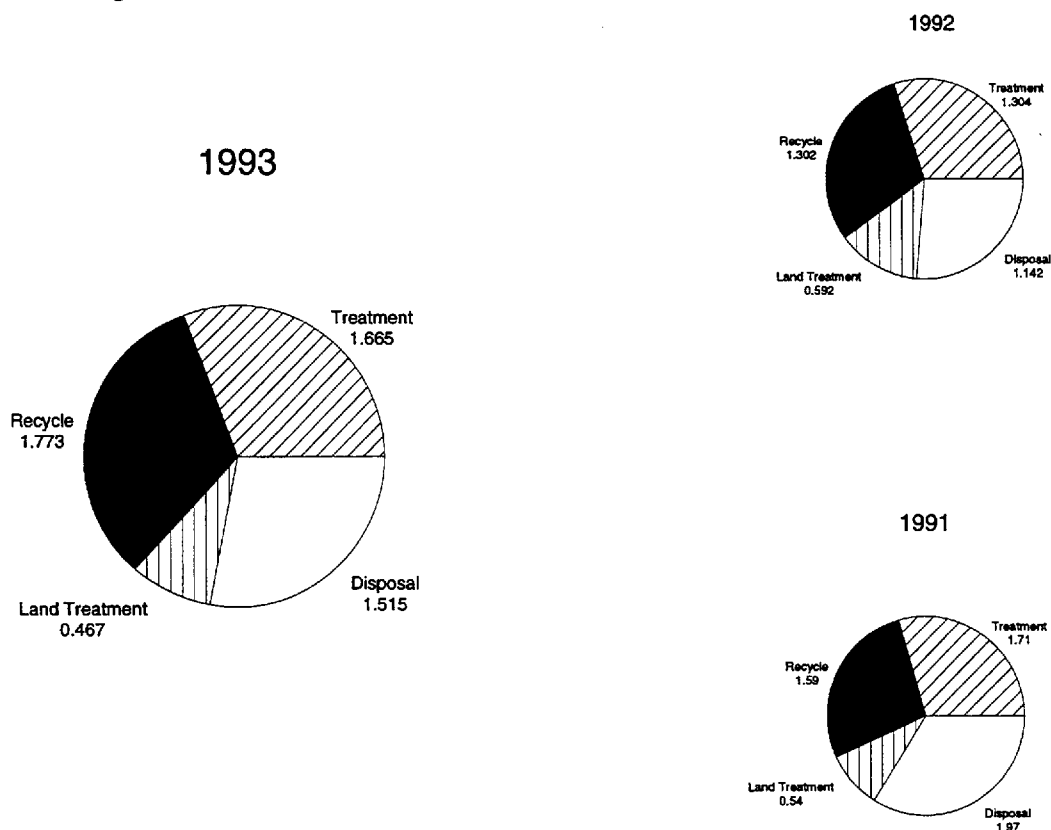
Residual streams	1993	1992	1991	1990	1989	1988	1987
Spent caustics	1434	1425	908	894	716	656	675
Biomass	722	641	862	794	655	749	720
Contaminated soils/solids	631	953	785	915	496	242	186
DAF float	520	546	410	564	521	661	654
Other Inorganic residuals NOS	247	359	393	453	441	221	323
Other Oily sludges/organic residuals NOS	242	38	54	54	47	61	40
Primary Sludge (F037)	226	247	133	NA	NA	NA	NA
FCC catalyst/equivalent	197	197	204	259	185	189	171
API separator sludge	167	174	214	260	425	430	564
Pond sediments	145	391	381	1,040	273	311	360
Other residuals NOS	143	381	339	353	325	412	203
Nonleaded tank bottoms	130	130	111	196	164	131	218
Residual amines	116	142	137	75	51	14	13
Primary Sludge (F038)	62	54	180	NA	NA	NA	NA
Residual coke/carbon/charcoal	57	53	138	92	137	67	43
Slop oil emulsion solids	56	74	160	295	262	214	212
Hydroprocessing catalysts	52	51	33	30	36	37	39
Residual oils/spent solvents	48	33	21	115	31	7	4
Residual sulfur	44	53	19	35	52	23	17
TSD Leachate (F039)	40	74	20	NA	NA	NA	NA
Other Contaminated soils NOS	39	33	37	69	53	77	88
Other spent catalysts	29	28	23	41	33	38	38
Spent sulfite solution	29	33	9	1	8	40	42
Oil contaminated waters (not wastewaters)	27	22	67	8	29	36	28
Spent Stretford solution	26	31	25	30	42	49	35
High pH/low pH waters	9	16	54	105	92	138	144
Spent acids	6	8	88	337	8	160	130
Heat exch bundle cleaning sludge	5	4	3	13	2	5	3
Leaded tank bottoms	3	<1	1	3	4	10	9
Other separator sludges	NA	NA	NA	104	117	110	83
Total	5,451	6,130	5,808	7,134	5,206	5,086	5,043

Management Practices for Residual Materials

API adopted the framework of the waste management hierarchy to structure the accounting of the handling practices used with residual materials generated by the refining industry. Source reduction activities, a subset of pollution prevention practices, have already been described. This section of the report will provide information on how the industry eliminates the residuals generated--a dynamic interaction between recycling of valuable constituents in the residuals, treatment to reduce volumes and/or neutralize materials, and ultimate disposal of remaining materials.

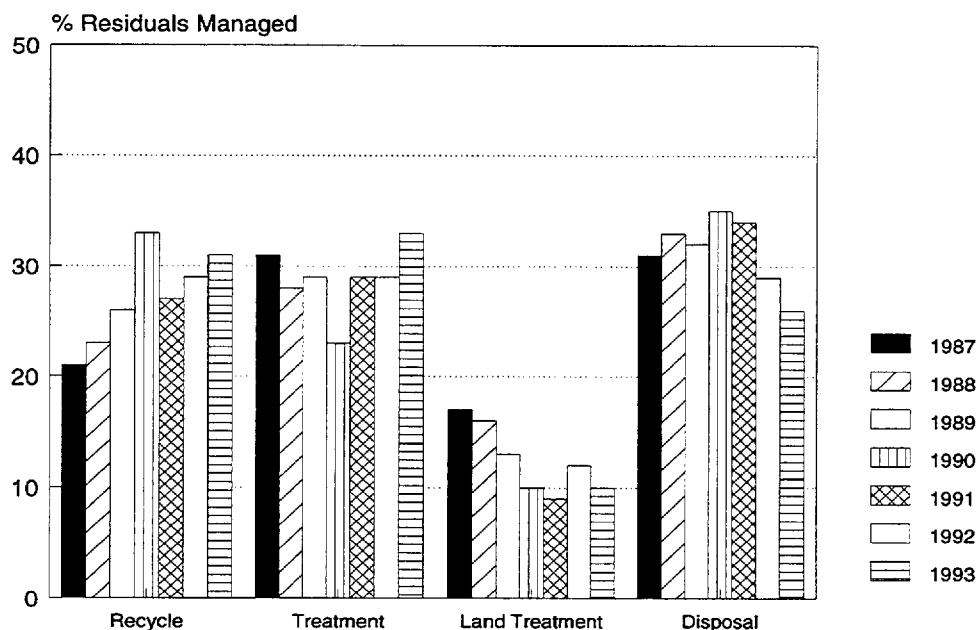
The pie charts presented in Figure G show the quantity of residuals handled by recycling, treatment, land treatment, and disposal for the last three survey cycles. (The SAS output containing these data is presented in Appendix B, pages B-2 and B-22). As indicated, handling practices have remained quite stable. If one looks closely, however, it is apparent that the proportion of residuals recycled in 1993 was slightly greater than that reported in 1991, while the proportion of material that was disposed has also been reduced.

Figure G
Residual Management Practices: 1993 - 1991 (Millions of wet tons)



These changes in handling practices are more pronounced when the data for each handling practice are displayed as a percentage of the total quantity managed in each survey cycle. As shown in Figure H, recycling has increased from just over 20 percent when the survey began to over 30 percent for 1993. Use of treatment has fluctuated, with a low observed in 1990 and a new peak in 1993. Land treatment decreased successively from 1987 to 1991, while disposal exhibited a similar step-wise decrease over the last three survey cycles.

Figure H
Longitudinal Comparison of Residual Management Practices: 1987 - 1993



The following sections of the report provide more detailed information on each handling practice, and, by describing the contributions of individual streams to the overall management profile, help to explicate the patterns observed in Figure H above.

Recycling

Among the methods for recycling residuals, *reclamation/regeneration* has remained the most commonly used throughout the seven years this survey has been conducted. In 1993, it accounted for 41 percent, as displayed in Table 8. When the 12 percent of material used in the *coker* (consistent with previous years), and 8 percent recycled to the *crude units* are added to the other in-process methods (including recycling to crude unit), *in-process recycling* accounts for over almost 30 percent of recycled residuals. (The SAS output containing these data is presented in Appendix B, pages B-4 - B-9 and B-24 - B-29.)

In the 1992-1993 cycle, *out-of-process recycling* methods accounted for 20 percent of recycled materials. This was a notable increase from the 5 percent reported in 1991 (the first year in which the survey included this category). Reciprocally, there was a decrease in "not specified" in the 1992-1993 cycle compared with the 1991 cycle.

Table 8

Summary of Recycling Practices(thousands of wet tons)

Method of Recycling	1993 Tons(%)	1992 Tons(%)	1991 Tons(%)	1990 Tons(%)	1989 Tons(%)	1988 Tons(%)	1987 Tons(%)
Coker	220 (12)	293 (16)	181 (11)	192 (10)	231 (17)	186 (16)	148 (14)
Crude unit	140 (8)	135 (7)	217 (14)	174 (9)	125 (9)	85 (7)	68 (0)
Reclamation/regeneration	732 (41)	788 (43)	772 (49)	872 (46)	611 (44)	434 (38)	447 (42)
Other recycling				655 (35)	408 (30)	474 (41)	410 (38)
In-process*	151 (9)	96 (3)	60 (4)				
Out-of-process*	356 (20)	368 (20)	84 (5)				
Fuel use*	60 (3)	61 (3)	78 (5)				
Not specified*	115 (7)	86 (5)	198 (12)				
Total	1774	1827	1590	1,893	1,376	1,179	1,073

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

Table 9 summarizes recycling methods by residual stream. As in other years, **Spent caustics** made the largest contribution to materials recycled by *reclamation/regeneration*, accounting for close to 90 percent. The 1992-1993 cycle continues the trend of increased amounts of spent caustics reclaimed/regenerated and decreased amounts of other streams. **Hydroprocessing catalysts** make the next largest contribution in 1993, followed by other spent catalysts and FCC catalysts. In 1992, **Residual oils/spent solvents** also contributed to the amount of residuals recycled by reclamation/regeneration, accounting for more than half of the All Other group.

Three streams made up the majority of residuals sent to the *coker* for in-process recycling: **Biomass**, **DAF float**, and **API separator sludge**. This was consistent with previous years, although the amounts from each stream show some variability, with more **Biomass** sent to the coker in 1992 than in 1993. These streams sent to the coker, however, still constitute only a small fraction, usually less than 5 percent, of the total coker feedstock.

Table 9**Estimated Quantities of Recycled Materials** (thousands of wet tons)

Recycling Method/Residual Stream	1993	1992	1991	1990	1989	1988	1987
RECLAMATION/REGENERATION							
Spent caustics	637	674	486	535	459	243	262
Hydroprocessing catalysts	27	45	31	28	32	21	26
Other spent catalysts	16	6	6	11	8	15	
FCC catalyst or equivalent	11	12	6	7	27	11	
All others	41	51	248	299	85	136	212
Total	732	788	772	872	611	378	390
IN-PROCESS RECYCLE-Coker							
Biomass	75	177	67	56	59	27	25
DAF float	47	49	56	75	79	45	82
API separator sludge	23	24	31	8	55	73	14
All others	75	43	27	53	38	41	27
Total	220	293	181	192	231	186	148
Crude unit							
DAF float	52	75	72	22	34	19	16
API separator sludge	11	11	11	10	24	13	18
All others	77	49	134	142	67	53	34
Total	140	135	217	174	125	85	68
Other In-Process Recycle	151	96	60	These recycle codes were new for 1991; consequently comparable data were not available for previous survey cycles			
Out-of-Process Kiln	64	43	51				
Other Out-of-process							
Biomass	116	0	0				
Spent caustic	68	63	20				
Residual coke	41	37	0				
Residual sulphur	31	26	<1				
Other inorganic	5	49	7				
Contaminated soils	3	74	1				
All Others	28	75	5				
Total	292	324	33				
Industrial Fuel	60	61	78				
Other*							
Spent caustics	33	21	137	123	138	254	232
Biomass	48	58	0	0	<1	0	0
All others	34	7	61	532	271	220	178
Total	115	86	198	655	409	474	410
Grand total	1,774	1,827	1,590	1,893	1,369	1,156	1,055

DAF float was by far the largest component of residuals sent to the *crude unit* for recycling, accounting for one third of the material in 1993. **API separator sludge** has the second largest quantity sent to the crude unit, although significantly less than DAF float. The large amount of **Biomass** sent to the crude unit reported in 1991 was not maintained in this survey cycle. Other streams that reported significant quantities recycled via crude units in previous years -- **Nonleaded tank bottoms** and **Slop oil emulsion solids** -- did not have large quantities in this survey cycle.

The total amount of residuals recycled through *other out-of-process* methods in 1993 has increased significantly from the 1991 amount to about 292 thousand wet tons, approximately 16 percent of the total recycled. In 1993, **Biomass** accounted for 116 thousand wet tons, while the large contributors in 1992 were **Contaminated soils**, **Spent caustics**, and **Other inorganic residuals**.

Recycling methods that were not specified were reported for less than 6 percent of the recycled materials in 1992 and 1993, most coming from **Biomass**.

As shown in Table 10, activities performed on the ten recycled streams with the highest quantities are most often performed off-site. Exceptions are for oily residual materials: in 1993, **DAF float** with 68 percent performed on-site, and **API separator sludge** with 68 percent performed on-site.

Table 10
Location of Recycling Activities (thousands of wet tons)

1992 Residual Stream	Quantity	% On-Site	% Off-site
Spent caustics	764	48	52
Biomass	273	66	34
DAF float	173	72	28
FCC catalyst or equivalent ⁵	86	0	100
Contaminated Soils/Solids	74	0	100
Other inorganic residuals	65	3	97
API separator sludge	48	80	20
Hydroprocessing catalysts	45	1	99
Residual coke/carbon/charcoal	41	5	95
Slop oil emulsion solids	35	62	38

1993 Residual Stream	Quantity	% On-Site	% Off-site
Spent caustics	739	51	49
Biomass	278	28	72
DAF float	148	68	32
FCC catalyst or equivalent ⁵	94	0	100
API separator sludge	55	68	32
Residual coke/carbon/charcoal	45	1	99
Slop oil emulsion solids	36	62	38
Residual sulfur	34	0	100
Hydroprocessing catalysts	28	8	92
Other oily sludge	20	31	69

⁵ These data do not represent the continuous in-unit regeneration of catalyst that occurs throughout the refining process, but refer only to the location of recycling activities after the catalyst is spent.

Treatment

As in other years, *wastewater treatment* accounted for the largest quantity of residuals treated, with 87 percent in 1993. The 1992-1993 survey cycle continued the trend begun in 1990 and 1991 with increased quantities of Aqueous chemical wastes/inorganics undergoing wastewater treatment.

Consistent with previous years, *incineration* was next most commonly reported treatment method, but still it accounts for a very small quantity of residuals (8 percent in 1993). This profile is displayed in Table 11. After a significant decrease in 1991, quantities of residuals treated by *chemical/physical* methods increased, although not to the levels of surveys in years before 1991. (The SAS output containing these data is presented in Appendix B, pages B-10 - B-13 and B-30 - B-33.)

Table 11
Summary of Treatment Methods (thousands of wet tons)

Method of Treatment	1993 Tons (%)	1992 Tons (%)	1991 Tons (%)	1990 Tons (%)	1989 Tons (%)	1988 Tons (%)	1987 Tons (%)
Wastewater	1452 (87)	1,547 (86)	1,464 (86)	1,265 (68)	1,176 (78)	1,045 (72)	1,167 (74)
Incineration	130 (8)	175 (10)	215 (13)	165 (9)	143 (9)	131 (9)	107 (7)
Chemical/physical	42 (3)	33 (2)	3 (<1)	131 (7)	143 (9)	148 (10)	117 (7)
Stabilize/Fixation	2 (<1)	7 (<1)	3 (<1)	276 (15)	4 (<1)	5 (<1)	<1 (<1)
Other	39 (2)	41 (2)	22 (1)	37 (2)	45 (3)	117 (8)	186 (12)
Total	1,665	1,805	1,707	1,874	1,511	1,446	1,577

Table 12 shows that **DAF float** remained the largest oily stream that was dewatered, but in general, other dewatered oily streams showed a decrease in their reliance on wastewater treatment compared with previous years. There was, however, a notable quantity, 107 thousand wet tons, of **Pond sediments** reported (in the "Others" category) in 1992, although this dropped to only 1 thousand wet tons in 1993. Among the aqueous chemical streams, **Spent caustics** increased sharply in its contribution to wastewater treatment. This increase in Spent caustics was accompanied by an equally sharp decrease in the volume of Biomass that was treated in refining wastewater treatment systems. Another difference reported in this survey cycle was the 22 thousand wet tons of **TSD leachate** that was wastewater treated in 1993.

Quantities of residuals treated through *incineration* continue to come primarily from three streams: **Biomass**, **DAF float**, and **API separator sludge**. As would be expected with incineration specified as BDAT, the slightly higher quantities of API separator sludge that occurred in 1991 were maintained in the 1992-1993 survey cycle. Compared to 1991, there was a notable decrease in **Pond sediments** and **Slop oil emulsion solids** quantities treated by incineration, although the 1993 quantities are similar to those reported before 1991.

The only stream that had a significant quantity treated by *chemical or physical* methods continues to be **API separator sludge**, returning in this survey cycle to quantities that were consistent with amounts compared with 1991. In three out of the seven survey years, including 1993, small quantities of **Biomass** were reported as being treated by chemical/physical methods.

Table 12**Estimated Quantities of Residuals Treated (thousands of wet tons)**

Treatment Method/Residual stream	1993	1992	1991	1990	1989	1988	1987
Wastewater treatment							
<i>From dewatered oily materials</i>							
DAF Float	338	308	208	306	248	236	263
Primary Sludge (F037 & F038)*	83	56	197	51	53	48	32
API separator sludge	74	68	113	56	149	136	146
Slop oil emulsion solids	12	23	58	108	98	57	98
Others	20	114	110	29	10	472	161
Subtotal	527	589	576	559	633	529	700
<i>Aqueous chemical wastes/inorganics</i>							
Spent caustics	660	630	229	132	93	74	87
Residual amines	113	139	133	71	46	2	2
Other inorganic residuals NOS	39	39	70	50	23	39	33
Biomass	34	90	354	288	249	222	234
TSD Leachate (F039)	22	1					
Oil contaminated waters (not wastewaters)	21	21	59	1	19	35	26
Spent Stretford solution	21	22	18	16	29	39	17
All others	15	18	25	58	31	594	735
Total	1,452	1,547	1,464	1,265	1,176	1,045	1,167
Incineration							
Biomass	81	74	82	98	103	73	64
DAF float	24	54	58	32	26	47	35
API separator sludge	12	26	29	5	7	5	4
All others	13	21	46	29	7	6	4
Total	130	175	215	164	143	131	107
Chemical/physical							
API separator sludge	19	20	2	13	35	10	2
Biomass	12	0	0	20	0	17	0
All others	11	13	<1	98	128	104	115
Total	42	33	3	131	143	131	117
Thermal/Heat							
Contaminated Soils	18	16	0	0	0	0	0
DAF float	6	6	1	0	0	0	0
Slop oil emulsion solids	5	7	1	0	0	0	0
Other	<1	7	5	2	6	0	0
Total	29	36	7	2	6	0	0
Stabilize/Fixation	2	7	3	276	4	0	<1
Weathering/Other							
Biomass	6	5	13	0	0	0	0
Others	4	<1	9	36	49	122	186
Total	10		22	36	49	122	186
Grand total	1,665	1,805	1,707	1,877	1,511	1,446	1,577

*Quantities reported for 1987 - 1990 were for Other Separator Sludge

Table 13 displays the location of treatment activities. As in previous years, most treatment of residuals is performed on-site. In fact, in 1993, all of the top ten streams contributing to residual treatment have 89 percent or more of the quantities processed on-site.

Table 13

Location of Treatment Activities (thousands of wet tons)

1992 Residuals Stream	Quantity	% On-Site	% Off-site
Spent caustics	632	98	2
DAF float	369	95	5
Biomass	168	80	20
Residual amines	140	100	0
API Separator sludge	122	80	20
Pond sediments	107	100	0
Other inorganic	48	88	12
Primary sludge (F037)	41	69	31
Slop oil emulsion	37	79	21
Nonleaded tank bottoms	25	99	1

1993 Residuals Stream	Quantity	% On-Site	% Off-site
Spent caustics	661	99	1
DAF float	369	96	4
Biomass	132	91	9
Residual amines	113	100	0
API Separator	106	89	11
Primary sludge (F037)	56	94	6
Other inorganic	40	98	2
Primary sludge (F038)	39	99	1
TSD leachate	22	100	0

Land Treatment

Land treatment appears on the survey data sheets as a treatment methodology, but is presented separately here because it is considered to occupy an intermediate status between residual treatment technologies and waste disposal practices.

Land treatment has been subjected to some of the land disposal restrictions that began in 1990 (i.e., wastes regulated as hazardous under Subtitle C of RCRA can no longer be land treated or disposed in landfills without meeting treatment standards or unless a no-migration variance has been granted). The decrease in the use of land treatment observed in 1991, continued in the 1992-1993 survey cycle. The 1992 amount was substantially higher than the 1991 amount, but in 1993 the amount returned to 497 thousand wet tons land treated. (The SAS output containing these data is presented in Appendix B, pages B-14 - B-16 and B-34 - B-36.)

Three residual streams make up the majority of this quantity: **Biomass**, **Contaminated soils**, and **F037 Primary sludge**. In 1992, when a peak in generation was reported, **Pond**

sediments also contributed to the land treated quantity. In fact, the difference in total quantity of residuals land treated between 1992 and 1993 can be attributed to the difference in the quantities of Pond sediments land treated (230 thousand wet tons in 1992 compared with only 20 thousand wet tons in 1993).

Table 14

Estimated Quantities of Land Treated Residuals (thousands of wet tons)

Residual stream	1993	1992	1991	1990	1989	1988	1987
Contaminated soils/solids	142	246	268	299	132	28	22
Biomass	143	144	201	267	187	259	236
Primary sludge (F037)	116	58	27	NA	NA	NA	NA
Pond sediments	20	230	11	349	127	64	67
All others	76	32	31	233	263	351	525
Total	497	710	538	1,148	709	832	850

Disposal

Table 15 shows that the refining industry reported the smallest quantity of residuals eliminated by disposal in 1993--1,515 thousand wet tons. This continued the trend of decreased disposal quantities which followed the peak in that occurred in 1990. (The SAS output containing these data is presented in Appendix B, pages B-17 - B-20 and B-37 - B-40.)

Table 15

Summary of Disposal Practices (thousands of wet tons)

Method of Disposal	1993 Tons (%)	1992 Tons (%)	1991 Tons (%)	1990 Tons (%)	1989 Tons(%)	1988 Tons(%)	1987 Tons (%)
Impoundment	43 (3)	51 (3)	110 (6)	129 (6)	113 (7)	245 (15)	280 (18)
Landfills	1,265 (84)	1,665 (93)	1,703 (84)	1,889 (84)	1,375 (85)	1,200 (73)	1,070 (69)
Landsread	170 (11)	33 (2)	66 (3)	174 (8)	95 (6)	160 (10)	109 (7)
Injection	36 (2)	36 (2)	35 (2)	36 (2)	15 (1)	30 (2)	40 (3)
Other	1 (<1)	3 (<1)	60 (3)	8 (<1)	21 (1)	1 (<1)	41 (3)
Total	1,515	1,788	1,974	2,236	1,619	1,636	1,540

As in all other survey years, landfills were used to handle the majority of the disposed residuals, accounting for 84 percent of the total 1,515 thousand wet tons disposed. The trend of decreasing quantities of residuals placed in disposal impoundments continued to an all time low in 1993. The quantity of residuals disposed by landspreading increased in 1993 to 170 thousand wet tons, a level comparable to that reported in 1990.

Table 16 displays the methods of disposal by residual streams. *Disposal impoundments* were used principally for handling **FCC catalyst** and **TSD leachate** in 1992 and 1993. The quantities of **Other inorganic residuals** placed in disposal impoundments decreased significantly from previous years.

As in other years, several residual streams have significant quantities disposed in *landfills*. **Contaminated soils/solids** remained the largest stream. The amount of **Pond sediments** fluctuated, with a low of 39 thousand wet tons in 1992 and 111 wet tons in 1993. Although there was an increase in the use of landfills for **Other residuals NOS** in 1992, it returned to an all time low in 1993. This was also true of **Primary sludge** (F037).

The increase in **Biomass** eliminated by *landspreading* in 1993 to 101 thousand wet tons accounts for almost 60 percent of the total landspread quantity, the largest amount in the seven survey years. **Contaminated soils/solids** account for another 34 percent landspread in 1993. The relatively small amount of residual disposed by deep well injection was primarily **Spent caustics**, as in all previous survey years.

Most disposal activity occurs off-site, as shown in Table 17. Two exceptions are disposed **Biomass** and **Spent caustics**. Two-thirds of the quantities of each are disposed on-site.

Table 16

Estimated Quantities of Wastes Eliminated by Disposal (thousands of wet tons)

Disposal Method/Residual stream	1993	1992	1991	1990	1989	1988	1987
Disposal impoundment							
FCC catalyst or equivalent	18	25	25	20	14	13	11
TSD Leachate (F039)	18	11	18	NA	NA	NA	NA
Other inorganic residuals NOS	5	7	53	86	65	25	56
All others	2	8	14	22	34	207	211
Total	<u>43</u>	<u>51</u>	<u>110</u>	<u>129</u>	<u>113</u>	<u>245</u>	<u>280</u>
Landfill							
Contaminated soils/solids	343	592	480	497	317	189	141
Other inorganic residuals NOS	170	230	210	162	227	77	155
Other residuals NOS	133	356	272	336	315	384	195
Pond sediments	111	39	328	405	60	50	7
FCC catalyst or equivalent	81	83	118	117	104	115	123
Biomass	68	51	41	32	37	48	41
Nonleaded tank bottoms	61	70	75	82	45	42	53
Other contaminated soils NOS	24	20	31	46	38	69	82
Primary sludge (F037)	21	138	40	NA	NA	NA	NA
All others	253	84	108	218	212	226	362
Total	<u>1265</u>	<u>1665</u>	<u>1703</u>	<u>1889</u>	<u>1375</u>	<u>1200</u>	<u>1070</u>
Landspread							
Biomass	101	5	23	26	15	48	51
Contaminated soils/solids	57	24	6	15	16	11	4
All others	12	4	37	133	64	101	54
Total	<u>170</u>	<u>33</u>	<u>66</u>	<u>174</u>	<u>95</u>	<u>160</u>	<u>109</u>
Injection							
Spent caustics	34	29	32	32	14	24	33
All others	2	7	3	4	1	6	7
Total	<u>36</u>	<u>36</u>	<u>35</u>	<u>36</u>	<u>15</u>	<u>30</u>	<u>40</u>
Other methods							
Total	<u>1</u>	<u>3</u>	<u>60</u>	<u>8</u>	<u>21</u>	<u>2</u>	<u>41</u>
Grand total	<u>1515</u>	<u>1788</u>	<u>1974</u>	<u>2236</u>	<u>1619</u>	<u>1636</u>	<u>1540</u>

Table 17**Location of Disposal Activities (thousands of wet tons)**

1992 Residual Stream	Quantity	% On-site	% Off-site
Contaminated soils/solids	616	8	92
Other residual NOS	358	28	72
Other inorganic residuals NOS	238	8	92
Primary sludge (F037)	140	39	61
FCC catalyst or equivalent	109	39	61
Nonleaded tank bottoms	70	5	95
Biomass	56	28	72
Pond sediments	39	0	100
Spent caustics	30	66	34
Residual sulfur	27	1	99

1993 Residual Stream	Quantity	% On-site	% Off-site
Contaminated soils/solids	400	19	81
Other inorganic residuals NOS	176	9	91
Biomass	169	66	34
Other residual NOS	133	14	86
Pond sediments	111	0	100
FCC or equivalent	100	38	62
Nonleaded tank bottoms	65	9	91
Spent caustics	34	62	38
Other contaminated soils NOS	25	8	92
Primary sludge (F037)	23	8	92

Aqueous Residuals

API's survey does not attempt to capture extensive information on refinery wastewater treatment systems. Because many refinery wastewater treatment systems are regulated under the Clean Water Act NPDES permit system and are historically not subject to full regulation under RCRA, a decision was made during the development of the survey not to request information on these aqueous materials.

Since that time, RCRA rulemakings, in particular promulgation of the new Toxicity Characteristic (TC), have affected some refinery wastewaters. Accordingly, beginning with the 1991 cycle of the survey, API incorporated questions in its survey to obtain data on these residuals. The sections that follow provide data on these TC Wastewaters, as well as the miscellany of aqueous materials that constitute the category of **Other Aqueous Residuals**.

Other Aqueous Residuals NOS

As described in the Methodology section, the data collected on this residual stream was not included in the modeling of the other 29 residual streams. Instead, because of the great variability in the generation quantities, a separate ratio model was used to develop the industry estimates.

In 1992, 14 of the 91 respondents reported generating **Other Aqueous Wastes NOS**, while only seven continued its generation in 1993. The industry wide estimates were 3.510 million wet tons for 1992 and 3.718 million wet tons for 1993. These estimates reflect the influence of one refinery that deep well injects sour waters resulting from processing high sulfur content crude oils. This refinery accounted for 97 percent of the amount of **Other Aqueous Wastes NOS** reported in 1992 and for 94 percent in 1993. Another refinery used this category to report groundwater recovered from site remediation activities, accounting for an additional 2 percent of 1992 quantity and 5 percent for 1993. Thus, the generation pattern previously observed for **Other Aqueous Residuals NOS** has persisted, with large quantities generated by just a few refineries.

The management practices have also remained constant over time, with deep well injection accounting for 99 percent of the material in 1992 and 97 percent in 1993.

TC Wastewaters

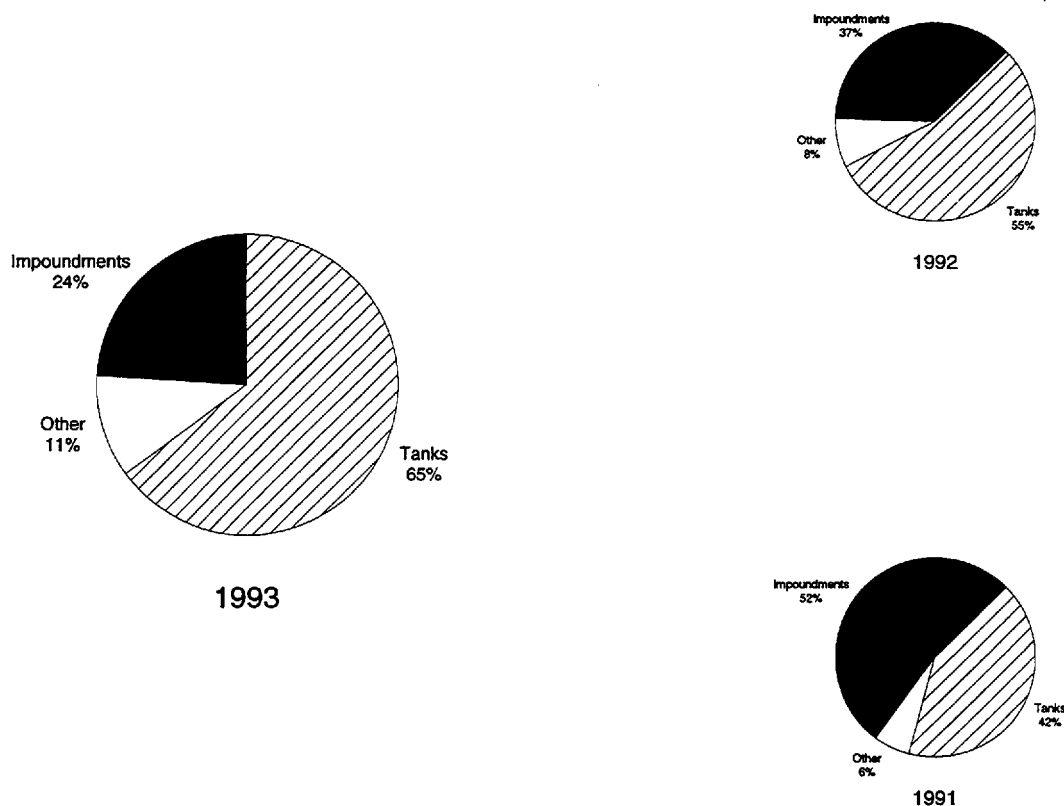
Question 8 in the first section of the questionnaire (refer to the copy of API's questionnaire in Appendix A) requests information on the amount of refinery wastewater that was identified as characteristically hazardous under RCRA. In 1992, 53 respondents reported that 157.75 million tons of their wastewater failed the Toxicity Characteristic Leachate Procedure (TCLP). Similarly, for 1993, 52 respondents reported 128.42 million wet tons.

Because these are reported quantities, and not nationally extrapolated estimates, one cannot compare the total quantities generated in 1992 and 1993 with that reported in 1991 without first controlling for the effect of the drop in overall survey response rates. Consequently, the cohort of 41 refineries that participated in all three survey cycles was examined to gain insight into the generation pattern for TC wastewater. This comparison revealed a systematic reduction over time: from 159 million wet tons in 1991, to 141 million wet tons in 1992, to 121 wet tons in 1993.

Similarly, the management of TC wastewaters has changed over time. As shown in Figure 1, in 1991 over half of the material was handled in RCRA permitted surface impoundments, but by 1993, only one quarter was managed in this manner. A reciprocal shift has taken place in the proportion of TC wastewater managed in tanks: increasing from a low of 42 percent in 1991 to 65 percent in 1993.

Deep well injection of TC wastewaters is included in the "Other" management category. Use of this disposal method has remained very low, accounting for only 2 percent of the total amount of TC wastewater in 1992 and 3 percent in 1993.

Figure I
Techniques Used to Manage TC Hazardous Wastewater (% of total quantity managed)



DISCUSSION

API's database on refinery residuals now spans seven years. The addition of data from 1992 and 1993 strongly suggest that residual generation patterns and management practices for the 1990's differ significantly from those observed during the late 1980's.

Although fluctuations in residual generation patterns were noted in 1990 and 1991, it was the graphic portrayal of the seven years of data that illustrated the differences between decades. As presented earlier in this report (as Figure F) and shown again below, the generation of Residual Materials and Other Aqueous Residuals was relatively static between 1987 and 1989. Since that time, generation of Residual Materials has fluctuated, while Other Aqueous Residuals has decreased, achieving an ultimate cumulative reduction of approximately 10 million tons or 69 percent.