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American Petroleum Institute

Management of Residual Materials: 1994

Petroleum Refining Performance

Health and Environmental Affairs Department
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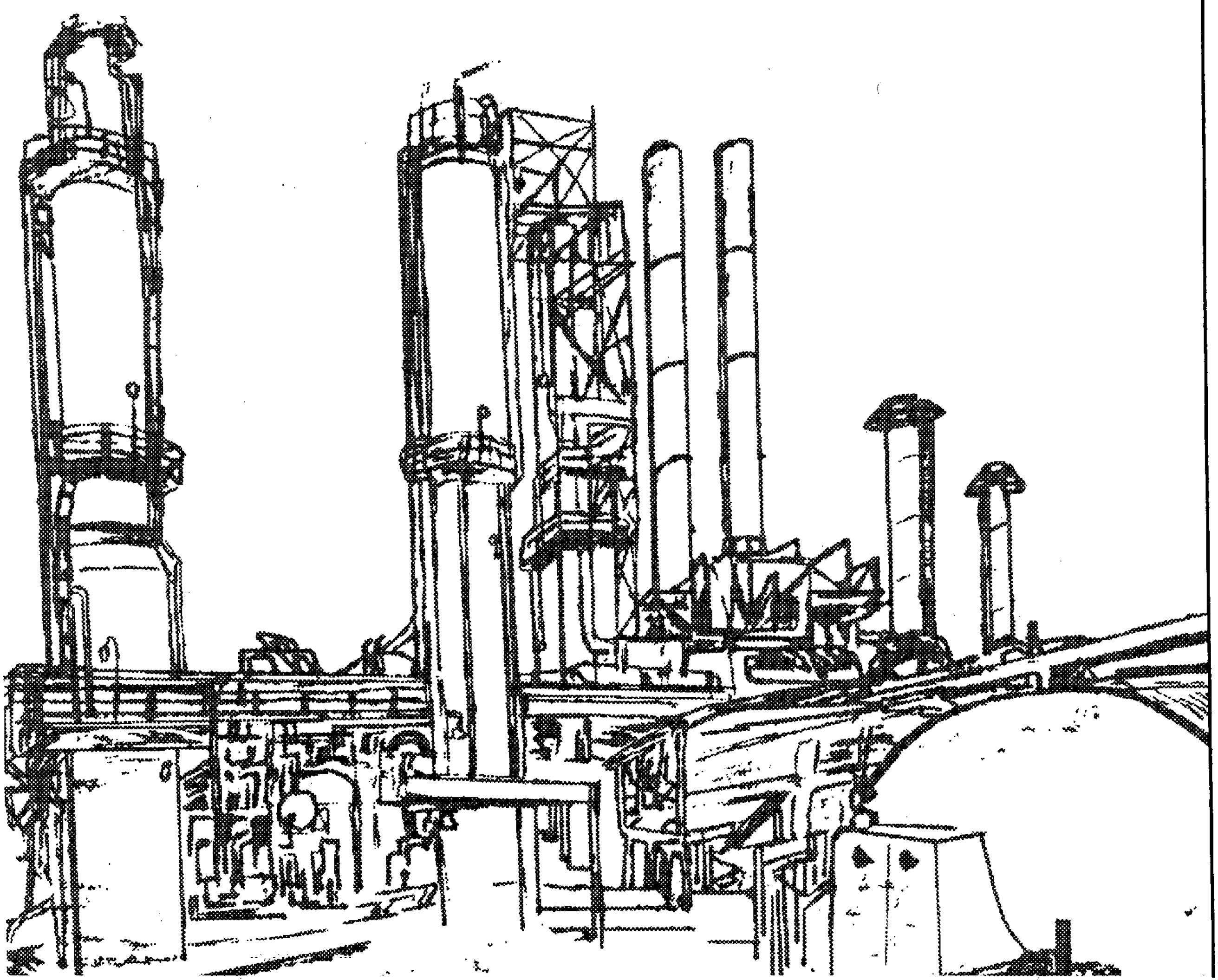

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Management of Residual Materials: 1994

Petroleum Refining Performance

Health and Environmental Affairs Department

API PUBLICATION NUMBER 336

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At each refinery participating in the survey, one or more individuals assumed the responsibility to complete the survey questionnaire. Their efforts deserve special recognition and thanks from the industry.

Carol Gosnell (API) is recognized for her contribution to the cover art for this publication.

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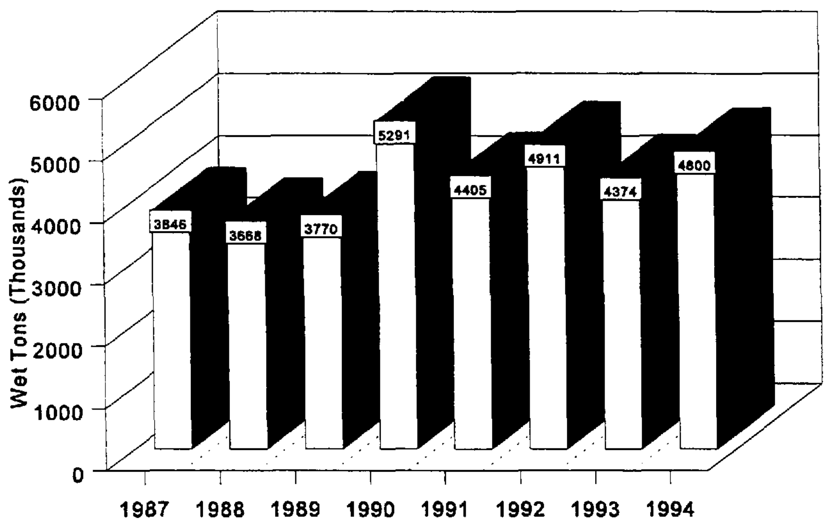
EXECUTIVE SUMMARY

The petroleum refining industry managed 4.8 million wet tons of 15 key residual materials in 1994. This was comparable to the quantity for these streams reported in 1992, and is somewhat less than the high observed in 1990. A peak in the Primary Sludge residual stream (associated with the regulatory deadlines to close or retrofit surface impoundments) and an increase in Hydroprocessing Catalysts overwhelmed the reductions observed for Pond Sediments and Contaminated Soils, and contribute to making this last cycle the third largest documented by the American Petroleum Institute's (API) annual refining survey.

Summary of Residual Generation: 1987 - 1994 (represents 15 residual streams[1])



Regarding the management of these streams, treatment continues to account for slightly more than 30 percent of the residuals. Since 1992, however, more material has been recycled than treated. Use of land treatment has diminished substantially and disposal, which peaked between 1990 and 1991, has stabilized at a low level comparable to that observed in 1989.

These findings were based on the data from 15 residual streams that were included in API's refining survey. API substantially reduced the number of streams included in its 1994 survey in order to curtail the burden associated with participating in the study. The streams selected for continued study include the most closely regulated residuals and other high volume streams that are generated by the majority of refineries. The 15 streams represent approximately 80 percent of all residuals generated and are the most costly streams to manage. Refiners responded positively to these changes, reporting that the new, abbreviated forms were much easier to complete. This was reflected in the response rate for the study, which continued to represent more than 60 percent of the domestic refining capacity.

Other modifications of the survey questionnaire were undertaken to improve the utility of the data. For example, the spent caustic stream was broken out to differentiate the three types of caustics: sulfidic,

[1] API's Petroleum Industry Environmental Performance (PIEP) report (API, 1996) lists 13 residuals. The numbers are comparable, however, since the PIEP report treated three caustic streams as one stream. These streams represent approximately 80% of all residuals generated.

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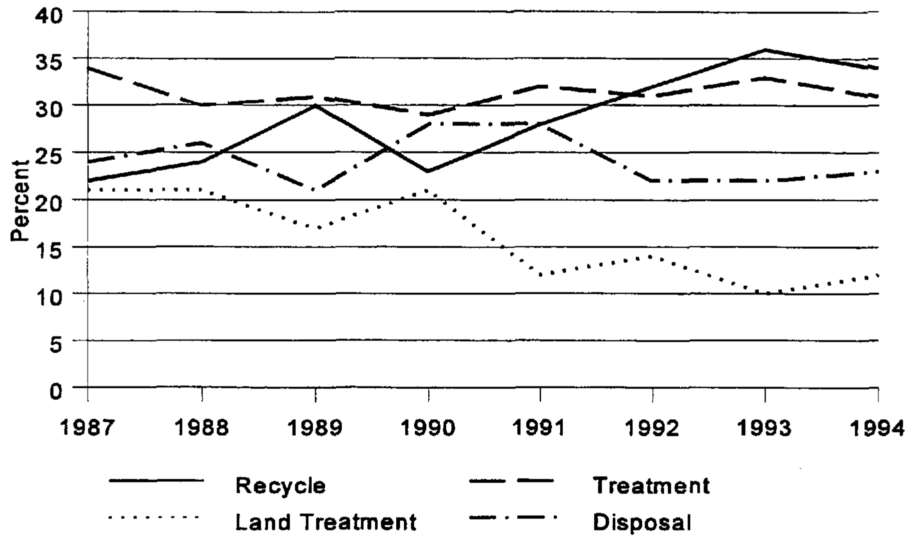
naphthenic and cresylic. This enabled a better comparison between Environmental Protection Agency's (EPA) and API's findings on the management of these materials. As noted in the report, both groups found that a substantial portion of the spent caustics are reclaimed, used as commercial feedstock, or reused as secondary materials in other manufacturing processes.

Trends in Management Practices



Other revisions included new questions on wastewater treatment systems and discharges and the inclusion of questions on the management costs for several of the streams. This information should expand the utility of the survey findings, enabling multi-media tracking of industry progress and practical experience with cost accounting strategies. A series of scatter plot charts summarizing the cost data are included following the discussions of API separator sludge, hydroprocessing catalysts, and spent sulfidic caustic.

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INTRODUCTION

For 1994, the American Petroleum Institute (API) substantially revised its annual refining survey. The scope of the survey was expanded from the single media (waste/residual) approach by the inclusion of new questions on wastewater treatment systems and discharges. A series of questions on the management costs for select residual streams was added to the basic survey items on generation quantities and handling practices. To reduce the burden associated with completing the survey, API limited the number of residual streams included in the survey. Using criteria that included regulatory status, quantity generated, and the magnitude of management costs, the number of streams included in the 1994 survey was reduced from 30 to 15. Data reported in the Executive Summary represents only the 15 streams surveyed for years 1987-1994.

These changes reflect API's ongoing critical review of the survey effort and its commitment to implement modifications that will improve the quality and utility of data collected. The reductions in the scope of the survey were born of necessity. Given the overarching economic considerations directing the streamlining of American industries in the 1990s, refiners view voluntary efforts critically. An important factor in their decision to participate in such efforts is the "value added" to their operations from participation in an external effort.

The *additions* to the 1994 survey are API's attempt to increase the value of the survey. The inclusion of information on capital improvements to the wastewater system and on management costs will be used to create benchmarks that refiners can use to evaluate their performance and the efficiency of their operations. The inclusion of these questions also reflects API's desire to keep abreast of current environmental performance monitoring trends: multi-media tracking systems and mechanisms to support total cost accounting.

The changes in the scope of the survey also have ramifications on the public reporting of the industry-wide *estimates*. Whereas the survey previously summarized *all* residuals generated by the industry, the 1994 effort provides a profile of *some* of the residuals. Accordingly, the format used in this report focuses on specific streams, in a section-by-section basis. The waste management hierarchy--which recognizes that prevention of waste by source reduction activities and recycling is preferred to treatment and disposal of wastes--has been retained, but is used now to structure the reporting on each of the residual streams.

Despite these changes, the procedures used to collect and analyze the data have remained consistent over time. The next chapter of this report will describe these methods.

METHODOLOGY

The listing of refineries published by the Department of Energy as *The Petroleum Supply Annual for 1994* was used to identify the census of 159 operating refineries. The revised questionnaires were mailed out in April, 1994 with instructions to return the completed forms within six weeks. This submission deadline was extended 10 additional weeks to maximize the response rate. As in all previous surveys, 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 describe the revisions to the data collection forms and the estimation procedures used in the study.

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Data Collection Forms

The two-section format was retained for the survey questionnaire. The first section was comprised of 12 short-answer questions that obtained information on refinery characteristics such as age, size, complexity of processing, sulfur content in the crude slate, sewer and wastewater treatment system configurations, and effluent characteristics.

The major revisions to the questionnaire focused on its second section, wherein data are collected on specific residual streams. As noted previously, the number of residual streams was reduced from 30 to the 15 streams listed below[1]:

API Separator Sludge
DAF Float
Slop Oil Emulsion Solids
Primary Sludge (F037)
Primary Sludge (F038)
Tank Bottoms
Pond Sediments
Contaminated Soils
Biomass
FCCU Catalyst or Equivalent
Hydroprocessing Catalysts
Other Spent Catalysts
Spent Sulfidic Caustic
Spent Naphthenic Caustic
Spent Cresylic Caustic

These streams actually correspond to 14 of the residuals used in previous surveys, because Tank Bottoms includes both Unleaded and Leaded Tank Bottoms, while the three Spent Caustic streams had previously been amalgamated into one Spent Caustic category.

To further minimize the effort required to complete the forms, the data sheets were streamlined. In the past, empirical data were collected on the amount of residual *generated* and the total amount that was *managed* in a given year. Because the industry had substantially reduced its use of additives to facilitate subsequent handling, and movement of residual material in and out of storage was extremely small, it was decided to drop the questions on generated quantities and the adjustments made for treatment additives and storage. This eliminated four items from the data sheet.

[1] The streams on which data were not collected in 1994 were: Waste Oils/Spent Solvents; Other Oily Sludges & Organic Wastes NOS; Heat Exchanger Bundle Cleaning Sludge; Waste Coke/Carbon/Charcoal; Waste Sulfur; Other Contaminated Soils; Oil Contaminated Waters (Not Wastewater); High pH/Low pH Waters; Spent Sulfite Solution; Spent Stretford Solution; Other Aqueous Wastes; TSD Leachate (F039); Spent Acids; Waste Amines; Other Inorganic Wastes; and Other Wastes. These residual streams were reported by fewer respondents and in smaller quantities that those streams retained for investigation in the 1994 survey. The 15 streams included in the survey represent about 80% of all residuals generated.

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The data sheets were also precoded to further reduce the respondent burden. The responses to the 1992 and 1993 questionnaires were reviewed to identify the most common recycle, treatment and disposal methods used for each residual stream. These methods were then used to customize and precode the data sheet for each stream, obviating the need to look up management techniques and transcribe the associated numeric codes. Spaces were provided for respondents to designate "other" handling techniques, in addition to those preprinted on the forms.

The question on pollution prevention activities previously included on each data sheet was moved to the first section of the questionnaire with the other short answer questions. This placement of the question gave recognition to the importance of the *descriptive* information obtained on innovative pollution prevention activities.

These changes to the data sheet enabled a substantial reformatting of the form to further increase the ease of completion.

As noted previously, new items were developed to obtain information on the costs associated with handling residual materials. In an effort to limit the burden of these new questions, while gaining experience with the cost data elements, the questions were placed on only three data sheets: API Separator Sludge, Hydroprocessing Catalysts and Spent Sulfidic Caustics. Two cost questions were asked. The first was directed at on-site management costs. Respondents were asked to indicate the total expenditures as well as the factors included in the estimates (e.g., capitalization of costs, operating expenses or contractual costs). The second question focused on off-site management costs, requesting a break-out that included recycling, treatment, disposal, analytical, transportation, and tax costs. Here respondents were asked to designate the basis of their response, either actual costs/receipts, estimates or rough estimates.

A copy of the questionnaire illustrating these revisions is presented in Appendix A.

Data Analysis

For the 1994 survey cycle, all data handling and analysis procedures were performed on a PC platform. This necessitated rewriting the statistical programs (which had previously been performed on a mainframe computer using the SAS programs), but even with this reprogramming, the overall data management costs were reduced by the reliance on PCs.

As in the past, the data verification and estimation procedures included 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.

A detailed description of the estimation procedures is presented in Appendix B. As discussed, preliminary analyses were performed with data sets from previous survey cycles to ascertain if the reduction in the number of residual streams and collection of data on the "managed" quantities (as opposed to "generated" quantities) would affect the use of regression analysis to create industry-wide estimates. Because very little change was noticed in the overall pattern of the abbreviated data set as compared to the scattergram containing all residuals, it was concluded that the 1994 survey would not require a new regression model.

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The general linear regression model used relates the square root of the residual quantity, R, for an individual refinery directly to throughput capacity, C, as shown in the following equation:

$$\sqrt{R} = b_o + b_1 C$$

where b_o is the intercept and b_1 is the slope of the regression line.

The specific regression equation developed for the 1994 data is:

$$\sqrt{R} = 46.284 + 8.9652 \text{ X } 10^{-4} C$$

with a coefficient of determination (COD), r^2, of 0.59. This COD is similar to values obtained in previous surveys. (It should be understood that this equation is used to develop an estimate for the *group* of refineries that did not participate in the survey. It is not intended for use with an individual refinery.)

As described in Appendix B, procedures similar to those used previously were developed to create a bias correction factor for the estimate and to calculate its variance and the percent error. The percent error for the 1994 estimate, 5.44 percent, was similar to that for previous survey cycles.

RESULTS

Response Rate

Of the 159 operating refineries in 1994, 84 (53 percent) completed and returned the survey forms. These refineries represented 64 percent of the domestic crude oil refining capacity.

Participation of refineries in the largest capacity classes was quite high, with more than half of all operating refineries greater than 10,000 barrel per stream day (bsd) responding. Also, as noted in the discussion of the estimation procedures, the six largest refineries all participated in the survey.

Respondent Characteristics

The location of the participating refineries is illustrated in Figure 2. The largest concentration of participating refineries was in the U.S. Department of Energy's Petroleum Administration for Defense (PAD) III, the Texas/Louisiana region. With 33 refineries, this was one more facility than responded in the last survey cycle. The number of refineries participating in PADs I, II, and IV were similar to those previously reported (11, 18 and 8, respectively). In contrast, the 14 refineries responding from PAD V represent a substantial drop in participation from the California region.

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Figure 1. Number of Respondents by Capacity Group

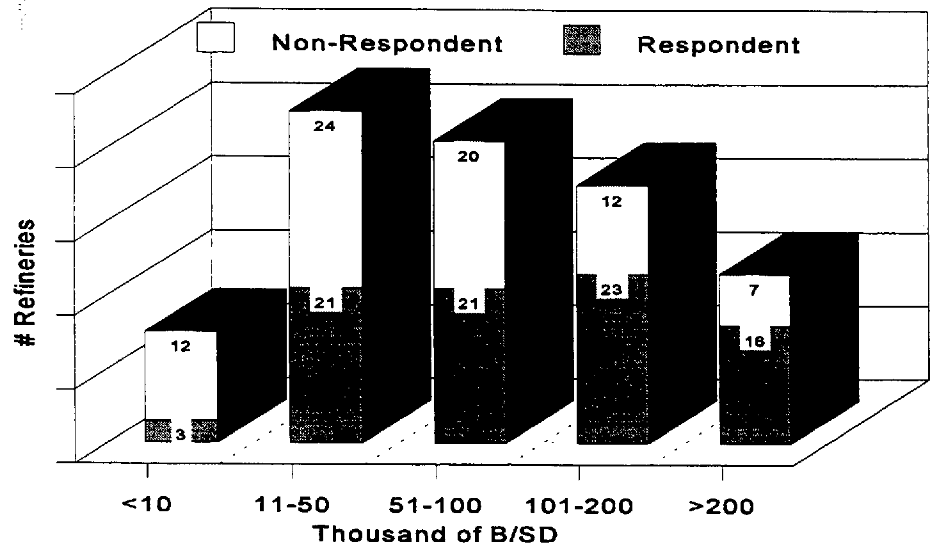
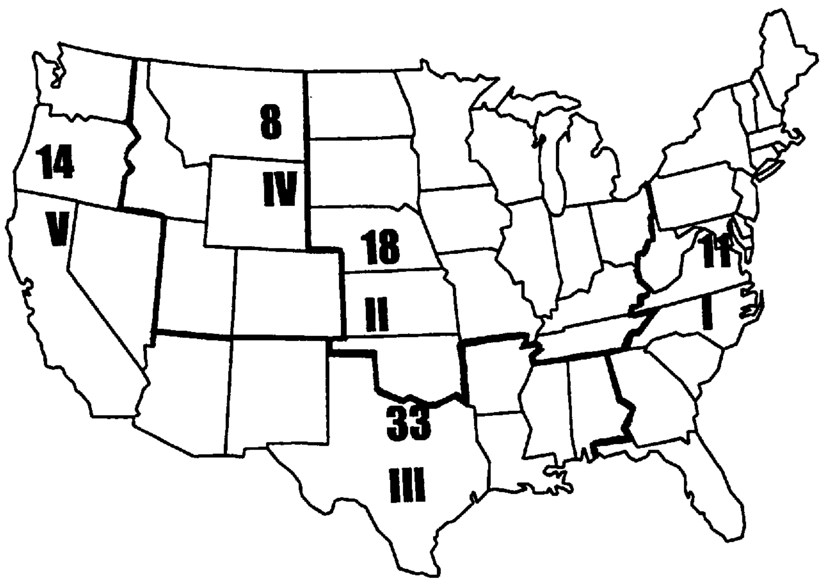


Figure 2. Location of Participating Refineries



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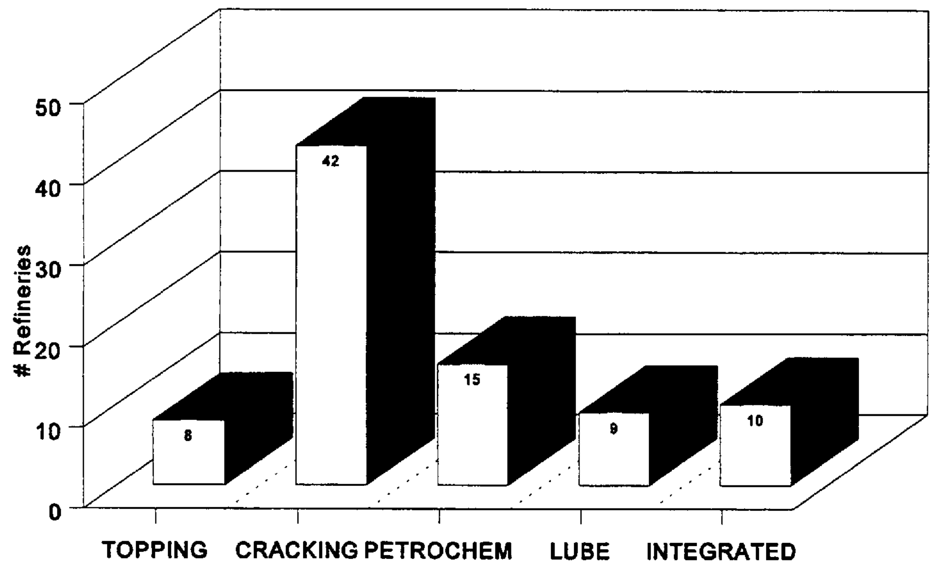
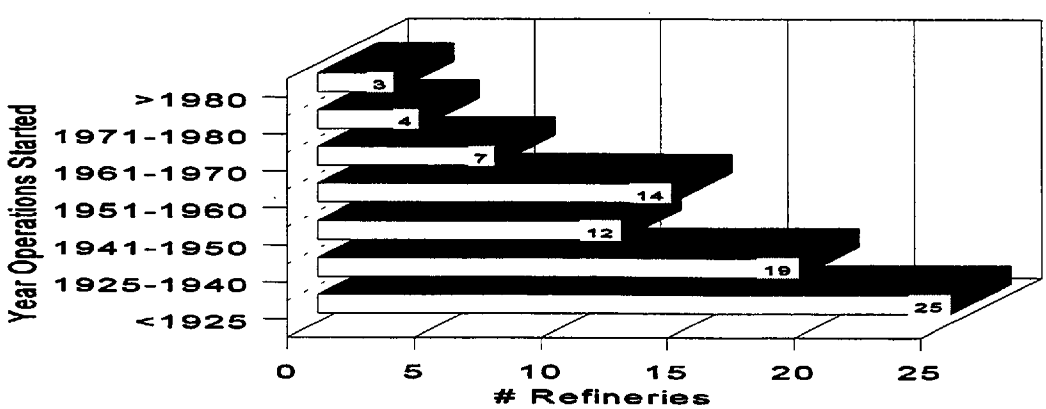
API uses the National Pollution Discharge Elimination System (NPDES) permit classifications to categorize the complexity of refineries (See Question 4 in Appendix A). The simplest form of crude processing is performed at facilities that exclusively rely on "Topping" operations, while the most complex processing configuration is an "Integrated" system that includes operations to catalytically crack hydrocarbons and to produce chemical and lubricating products. As shown in Figure 3, the "cracking" refineries were the most predominant group, with 42 refineries or approximately half of the respondent population. As depicted, there were slightly more petrochemical plants than topping, lube or integrated facilities.

Figure 3. Distribution of Respondents by NPDES Complexity Classification



As the distribution of refineries by age shows, half of the refineries began operations before 1940, and another third came on line between 1941 and 1960. Only eight of the participating refineries began operations in the last 25 years.

Figure 4. Distribution of Respondents by Refinery Age



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As previously noted, the 84 responding refineries represented 64 percent of the domestic refining capacity. They reported processing 3.34 million barrels of crude during 1994. Thirty-four (34) refineries charged crude every day during the year and another 12 were down for less than a week. All other refineries reported operating on 304 days or more. Regarding the crude run, 43 reported stock with less than 1 weight percent of sulfur, while 29 reported a slate between 1 and 2 weight percent sulfur. The remaining 12 refineries reported crudes with more than 2 weight percent of sulfur.

Eighty facilities answered the new question (Question 7) on the configuration of their wastewater system. None of these refineries indicated that they did not have wastewater treatment components. As indicated in the following table, 80 refineries reported having primary oil/water separation equipment, 60 had secondary oil/water separation components, 64 used secondary biological treatment, and 34 reported tertiary/polishing treatment. Most refineries reported having only one type of each stage of treatment, but 8 indicated that they had more than one type of secondary biological treatment and 5 had more than one type of tertiary/polishing treatment.

Table 1. Frequency of Reporting Wastewater System Components

WASTEWATER TREATMENT COMPONENT	# REFINERIES
PRIMARY OIL/WATER SEPARATION (n = 80)	
Oil/Water Separator (e.g., API separator; corrugated plate, etc.)	76
Other	3
SECONDARY OIL/WATER SEPARATION (n = 60)	
Gas Flotation (Dissolved or Induced Gas)	52
Filtration	2
Other	6
SECONDARY BIOLOGICAL TREATMENT (n = 64)	
Aerated Lagoon	11
Trickling Filter	4
Activated Sludge	52
Rotating Biological Contactor	4
Other	1
Anaerobic Filters or Contactors	0
Other	3
TERTIARY/POLISHING TREATMENT (n = 34)	
Filtration	17
Carbon Adsorbers	6
Biological Denitrification	3
Metals Removal Processes	3
Other	11

As would be expected by the reporting patterns, the most commonly reported combination of wastewater treatment components include primary oil water separation, dissolved/induced air flotation and activated sludge. As shown in Table 2, reporting such a combination of primary and secondary wastewater treatment components predominated in each capacity class. Note that 40 percent of the refineries with capacities greater than 100 BSD have upgraded their systems to include tertiary treatment.

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Table 2. Comparison of Wastewater Treatment Components by Capacity Class

TREATMENT TYPE/ CAPACITY CLASS	<10 BSD	10-50 BSD	51-100 BSD	101-200 BSD	>200 BSD
Primary Separation Only		2		3	
Primary & Secondary	3	16	13	11	9
Primary, Secondary & Tertiary		2	3	10	7

In response to the new Question 8, 35 refineries indicated that they exclusively use tanks to manage storm water and wastewater downstream of their primary oil/waste separation units, while 6 reported that they use only surface impoundments. The 32 other facilities that answered Question 8 use a combination of tanks and impoundments. Sixteen facilities reported having obtained Resource Conservation and Recovery Act (RCRA) permits for their impoundments (or the impoundments had interim status). These impoundments ranged in size from 1 to 44 acres. Combined, there were 249 acres of permitted impoundments. There was a total of 1178 acres of impoundments reported as not regulated under RCRA. The 31 facilities reporting these impoundments indicated that their size ranged from less than 1 acre up to 350 acres.

Another new question (Question 10) developed for the 1994 survey pertained to the quantity of water discharged daily from the refineries. The 72 facilities that answered the question reported values from 0 to 34 million gallons per day (MGD) for a total of 268 MGD. This resulted in an average of 3.3 MGD per refinery. The median value was 1.73 MGD.

The second part of the question on water discharges required the refiner to indicate the sources that contributed to the water discharged (e.g., the percentage that was process wastewater, non-contact once through cooling tower water, treated storm water, etc.) The table below summarizes these responses.

Table 3. Sources of Water Discharged by Refineries

SOURCE	# REPORTING	RANGE(MGD)	MEDIAN(MGD)
Process Wastewater	71	<0.01 - 14	1.2
Non-contact once through cooling water	47	<0.01 - 4.5	0.01
Treated storm water	42	<0.01 - 4.0	0.19
Untreated storm water	26	<0.01 - 2.6	0.14
Treated groundwater	23	<0.01 - 0.85	0.04
Other	20	<0.01- 2.9	0.12

As these values indicate, almost all refineries report that process wastewaters contribute to the water discharged under their NPDES permit. In fact, 18 refineries indicated that process wastewaters represent more than 90 percent of the water they discharge. More than half of the respondents indicated that non-contact cooling tower waters and treated storm water contribute to their effluent, while approximately one third reported discharging untreated storm water or treated groundwater.

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Another new question (Question 11) requested information on the annual water quality discharge parameters. To standardize the responses, the pounds of each parameter reported as discharged annually was divided by the wastewater flow reported in Question 10. The values for the five parameters that were most widely reported are presented below.

Table 4. Water Quality Discharge Parameters

PARAMETERS	# REFINERIES	RANGE	MEDIAN
Total Suspended Solids (TSS)	67	10 - 2143 lbs/MG	113 lbs/MG
Biochemical Oxygen Demand (BOD)	63	7 - 3730 lbs/MG	54 lbs/MG
Chemical Oxygen Demand (COD)	56	10 - 8338 lbs/MG	583 lbs/MG
Ammonia	59	10 - 1521 lbs/MG	31 lbs/MG
Oil & Grease	61	5 - 2023 lbs/MG	22 lbs/MG

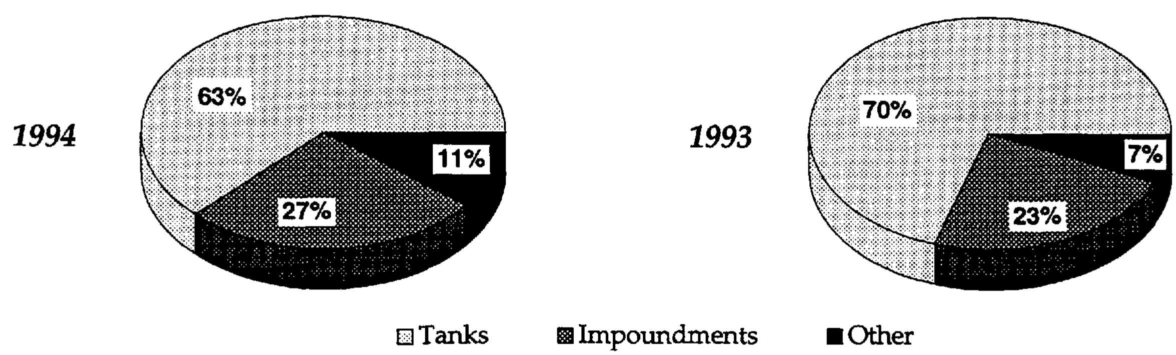
As the table entries indicate, the values vary substantially within a given parameter. Because of this, the median is used as a measure of central tendency since it provides a better understanding of the distribution of responses. Specifically, use of this middle most value as a benchmark highlights that the majority of responses are well below the high end of the range reported.

The survey also collected information on the amount of wastewater that failed the Toxicity Characteristic (TC). In 1994, a total of 143 million wet tons were reported by 46 facilities. Of this quantity, 77 percent was managed solely in tanks exempt from RCRA permitting prior to discharge. Eighteen percent was managed in RCRA permitted surface impoundments and 4 percent was managed in other ways.

To monitor the industry's progress on managing TC wastewater, API compares the quantities reported by refineries that participate in successive survey cycles. This procedure controls for the turnover in survey respondents or changes in the response rate that influence the reported quantity of TC wastewater. The total quantity reported in 1993 by the 29 refineries that reported TC wastewaters in both years was 116.0 million wet tons; for 1994, this dropped to 92.8 million wet tons.

Comparison of the management methods used by these refineries to handle TC wastewaters is graphically depicted in Figure 5. As indicated, the management practices remained fairly constant. More than 60 percent of TC wastewater was treated in tanks that are exempt from RCRA permitting requirements. Only one quarter of the TC wastewater was managed as a RCRA hazardous waste in surface impoundments and the remainder was reported as "Other" management techniques.

Figure 5. Management of TC Wastewater 9 (*Totals may not equal 100% due to independent rounding.*)



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As noted in the section on the instrument revision, the pollution prevention questions were moved to the first section of the questionnaire. The question format was similar to that previously used, with the exception that quantitative data were not requested. The responses are summarized in Table 5.

As indicated, the residuals with the highest number of responses were the API Separator Sludge stream and the Primary Sludges with 39 and 35 responses, respectively. This listing of pollution prevention activities highlights the industry's reliance on in-process recycling to minimize the generation of oily waste and its use of reclamation and regeneration to handle spent catalysts and chemicals. Refiners also continue to report housekeeping improvements and staff training programs to promote more efficient management practices.

Few source reduction activities were reported this year. This is not surprising given the subset of streams included in the 1994 survey. These streams were selected because they are more closely regulated and their management costs are higher. Consequently, these are the streams on which pollution prevention activities have focused in the past. Processes have already been modified, materials substituted wherever possible and external sources for residual reuse have already been identified. Thus, the "low hanging fruit," those pollution prevention activities most easily accomplished, have already been picked. Successive achievements for these streams will be driven by additional analyses and R&D efforts, both of which require time and funding to succeed.

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Table 5. Responses to Pollution Prevention Question

Residual Stream	# Responses	Pollution Prevention Techniques Reported
API Separator Sludge	39	Coking Filtering/dewatering/drying Housekeeping (sweeping, paving, covered API separator)
DAF Float	22	Coking Filtering/dewatering/drying Treated & recycled through wastewater treatment plant
Slop Oil Emulsion Solids	14	Coking Filtering/dewatering
Primary Sludges	38	Coker Filtering/dewatering Housekeeping (dust control, paving, replaced ponds w/ tanks, covered sewers, install silt fences in tank farm areas)
Tank Bottoms	28	Coker Crude unit Filtering/dewatering/centrifuge
Contaminated Soils	19	Thermal desorption Housekeeping/training (paving, spill/leakage control awareness, segregate wastes) Other reuse (use as road base, capping material at municiple landfill, stabilization agent for non-haz tank bottoms)
Pond Sediments	8	Recycle to LTU Replace ponds with tanks Thermal desorption for oil recovery Housekeeping (dust suppression, cleaned basins & segregated WW)
Biomass	9	Coker Filtering/centrifuging Recycle to LTU
FCCU Catalysts	24	Recycle to cement kilns Modified procedures to reduce catalyst loss Reuse as catalyst
Hydroprocessing Catalyst	30	Reclamation
Other Catalysts	21	Regeneration/Reclamation Cement kiln feed
Spent Caustics	28	Sold as feedstock/product (Merichem, paper mill) Reuse (corrosion inhibitor in crude oil charge, pH control in WWTS) Regeneration

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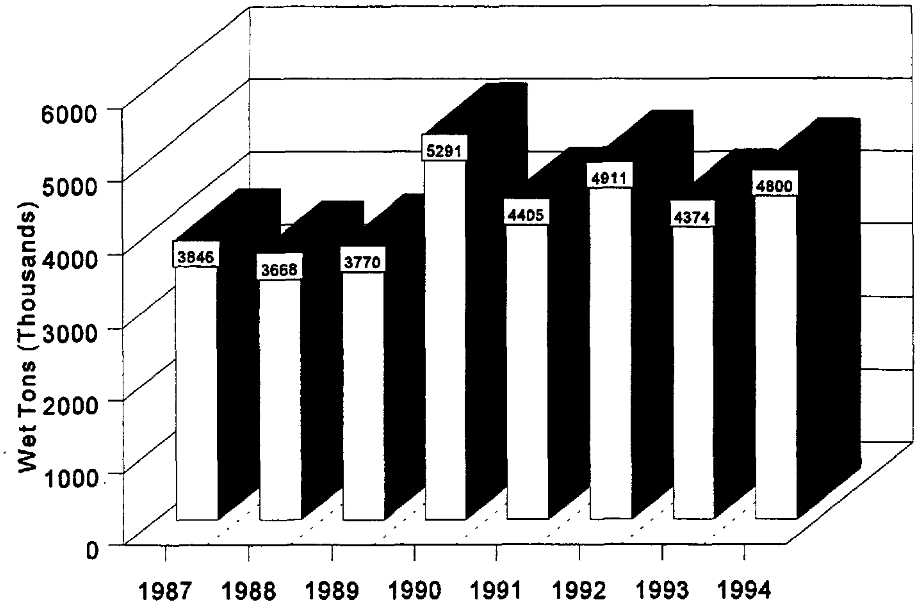
Residual Stream Profiles

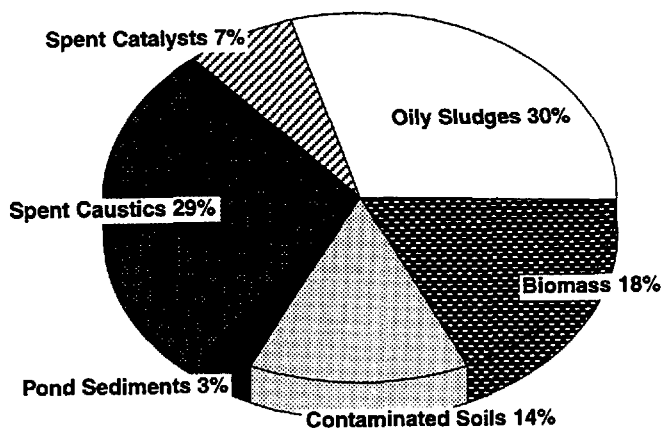
For 1994, the total industry estimate of residuals managed was 4.8 million wet tons. As graphically portrayed in Figure 6, this was intermediate in the range of quantities reported since 1990.

Figure 6. Summary of Residual Generation: 1987 - 1994 (represents 15 residual streams)



As shown in the pie chart, Oily Sludges (a broad group of residual streams that includes the RCRA listed K and F wastes) accounted for 30 percent of the total quantity managed. This was comparable to the 29 percent that was Spent Caustics (Sulfidic, Naphthenic and Cresylic). Biomass represented 18 percent of the total, while Contaminated Soils were 14 percent. Spent Catalysts were 7 percent of the total quantity of residuals, and Pond Sediments were just 3 percent .

Figure 7. Residuals Managed in 1994 (*Totals may not equal 100% due to independent rounding.)*



The remainder of this chapter will present information on the management of each of the residual streams. *It should be understood that the residual stream labels used in this survey are* ***NOT*** *used in a*

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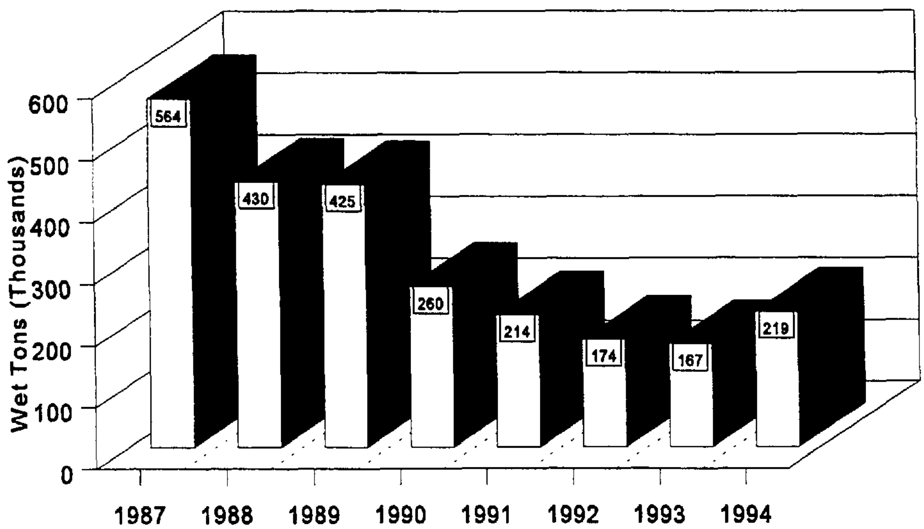
regulatory sense. Whereas the Environmental Protection Agency (EPA) regulations implementing RCRA have given these terms special meaning, our usage here is in a broader, more generic sense. API's intent is to have survey participants report the management of all residual type materials (e.g., materials that are byproducts or residuals of petroleum refining operations). This includes residuals that are beneficially recycled or reclaimed, as well as materials that are discarded.

Note that the computer print-outs, from which all the statistics presented in the text are derived, can be found in Appendix C.

API Separator Sludge[2]

The estimated quantity of API Separator Sludge residual stream for the entire refining industry was 219 thousand wet tons. As illustrated in Figure 8, this was somewhat higher than in 1991 and 1992, but substantially below the large quantities reported in the late 1980s.

Figure 8. Managed Quantities of the API Separator Sludge Residual Stream: Industry Estimates for 1987 - 1994



[2] As noted in the introduction of this section, API's use of the term "API Separator Sludge" is not in a regulatory sense. The API Separator Sludge residual stream includes materials--such as water and oil--which when recovered by dewatering and deoiling do not fall under the purview of RCRA.

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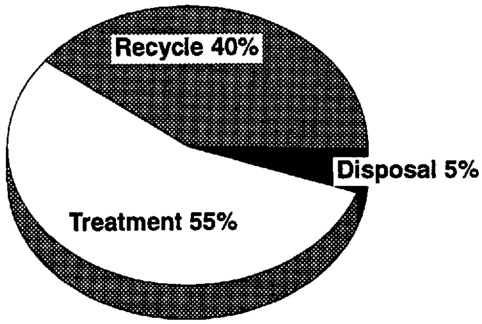
Figure 9 summarizes how the refiners handled the API Separator Sludge residual stream in 1994, highlighting the fact that the industry relies on recycling--primarily via cokers and crude units--to manage this material.

Figure 9. Management of the API Separator Sludge Residual Stream



Review of the data in Table 6 shows how the specific management practices have changed over time. Note that the amount of material recycled in cokers has fluctuated: in 1994 it was twice the quantity for 1993, but still less than that reported in 1988. Recycling of the API Separator Sludge residual stream as Cement Kiln Fuel and as Other Industrial Fuel both peaked in 1994, while its use as feed for cement kilns dropped substantially.

For treatment, Table 6 shows that the industry continues to use wastewater treatment to handle the separated aqueous portion of the residual material. This practice accounted for 84 percent of the residual that was treated. The fluctuations observed between years in the entries for incineration, heat and physical treatments are quite substantial, without any ready explanations.

A series of scatter plot charts summarizing the cost data for API separator sludge are included following Table 6.

Concerning disposal patterns, the 1994 responses reflect that several refineries successfully pretreated their API Separator Sludge which enabled them to landfill the material.

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Table 6. Management Techniques Used for the API Separator Sludge Residual Stream (Industry Estimates)

	1994	1993	1992	1991	1990	1989	1988	1987
QUANTITY MANAGED	**218,517**	**167,296**	**174,147**	**214,031**	**259,600**	**424,499**	**430,045**	**563,774**
MANAGEMENT TECHNIQUES								
RECYCLE								
In-Process								
Coker	44,340	22,759	23,905	31,201	8,373	54,582	72,901	14,485
Crude Unit	16,794	11,265	10,542	10,992	10,015	23,821	13,236	17,963
Catalytic Cracker	82	200	1,790	148				
Other In-Process Recycle	10	1,120	796					
Sour Water Stripper						9	14	92
Out-of-Process								
Cement Kiln Fuel	15,969	14,086	8,208	15,681				
Other Industrial Fuel	3,392	492	127					
Reclamation	1,676	3,212	1,894	219	3,942	859	3,666	6,418
Cement Kiln Feedstock	295	1,829	79	3,400				
Regeneration		76						
Sold					1,426			
Industrial Furnace					864	502	39	411
Other Out-Of-Process Recycle		127	159					
Other Recycle	4,701	2	1		4,682	3,827	1,599	712
TOTAL	87,259	55,168	47,501	61,641	29,302	83,600	91,455	40,081
TREATMENT								
Wastewater Treatment	100,327	74,073	68,185	112,760	55,690	149,190	136,219	146,011
Incineration	8,615	11,965	25,687	29,098	4,639	7,417	5,290	4,131
Heat	5,672	662	7,531	3,695	2,336			
Physical	233	19,138	20,110	1,515	12,618	33,848	9,770	1,754
Chemical				24		1,299		
Stabilization					5,075	143		
Impoundment						3,280	1,968	10,597
Other Treatment	4,396							
TOTAL	119,244	105,838	121,513	147,092	80,358	195,177	153,247	162,493
LAND TREATMENT	1,442	1,320	363		65,496	60,562	85,395	210,829
DISPOSAL								
Landfill	10,298	4,741	4,550	5,297	79,342	76,598	51,210	53,886
Other Disposal	274	229	220		901	4,004		36,687
Impoundment				1	249	4	22,382	48,308
Landspread					3,952	4,554	26,356	11,490
TOTAL	10,572	4,970	4,770	5,298	84,444	85,160	99,948	150,371

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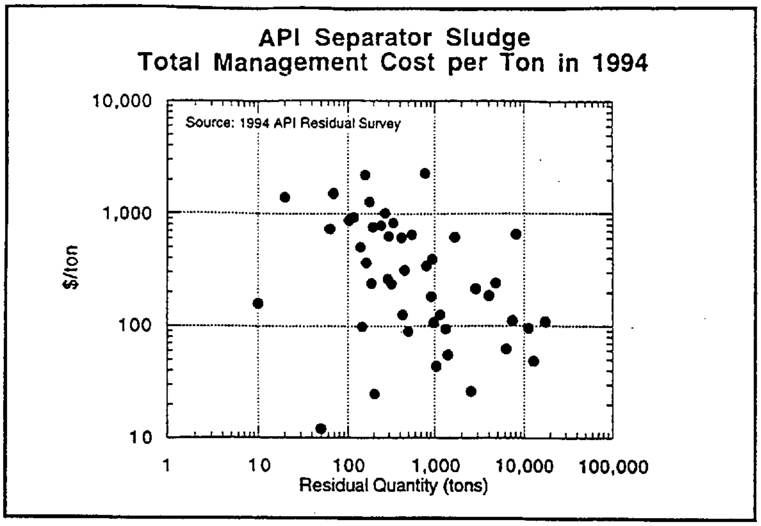

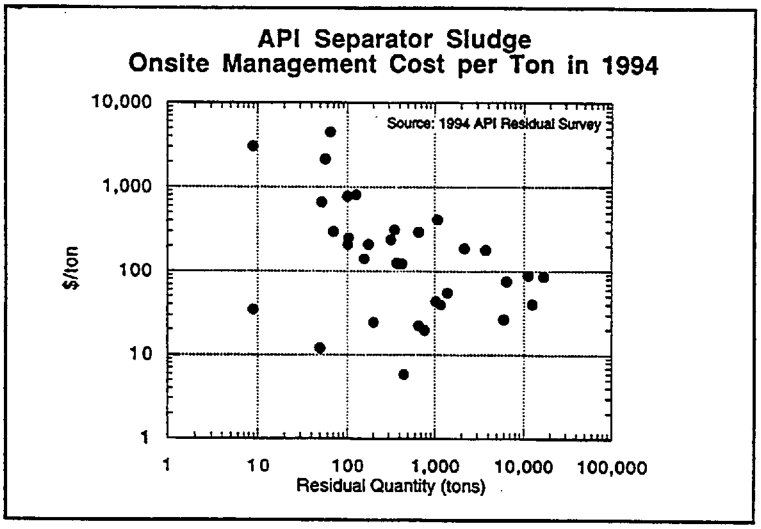

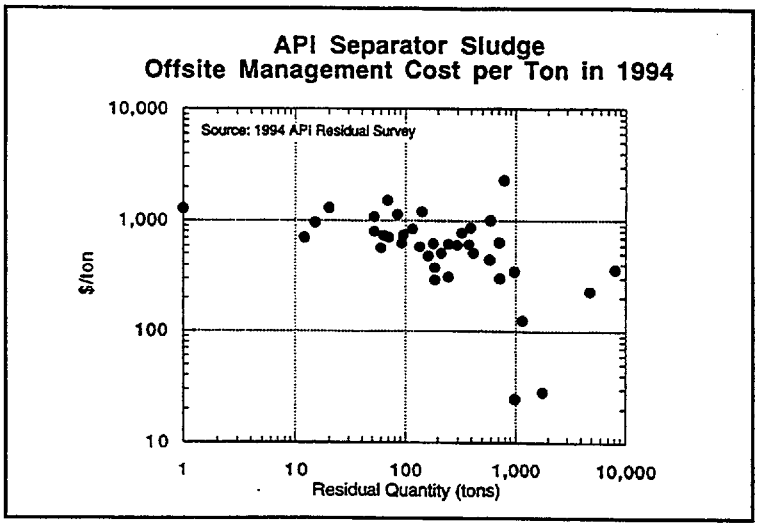

API Separator Sludge Cost Data

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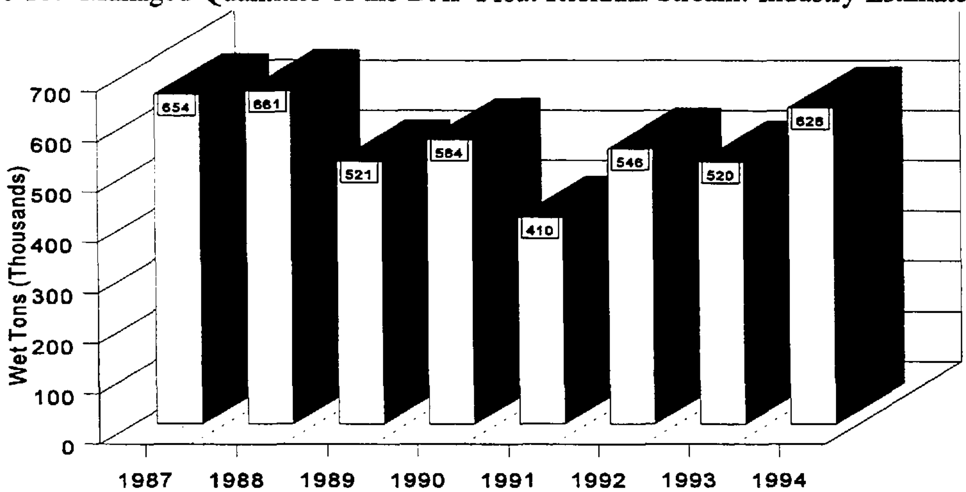
DAF Float [4]

The industry-wide estimate for the DAF Float residual stream was 628 thousand wet tons. This quantity was comparable to that observed in 1987 and 1988.

Figure 10. Managed Quantities of the DAF Float Residual Stream: Industry Estimates for 1987 - 1994



In 1994, slightly more than half of the DAF Float residual stream was recycled, while 48 percent was managed by treatment. Two thousand wet tons were land treated or disposed, but since this represents less than 1 percent of the total managed quantity, it is not graphically depicted on the following pie chart.

Figure 11. Management of the DAF Float Residual Stream

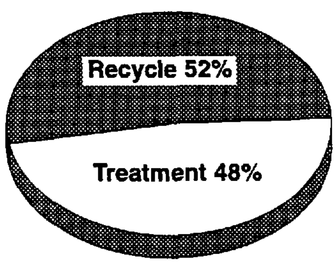


Table 7 displays the data on the management techniques used to handle the DAF Float residual stream. Review of the subtotals in the table indicates that the industry relied more on recycling in 1994 than ever before, while there was a reciprocal drop in the proportion of DAF Float that was treated.

Over half of the residual material that was recycled was handled by cokers, while another quarter went to crude units. For both recycling methods, the quantities reported in 1994 were substantially greater

[4] Recall that API uses labels such as DAF Float in the broader context of a *residual stream* which includes materials that are not subject to RCRA regulation.

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than ever reported before (i.e., the 170 wet tons that went to the coker were more than twice the previous high of 79 thousand wet tons reported in 1989, and the 85 thousand wet tons recycled in crude units were 10 thousand wet tons larger than the 75 thousand wet tons reported in 1992).

For out-of-process recycling, there was a marked drop in the quantity of material used as cement kiln fuel, while there was a sizeable quantity handled by "Other" methods.

Wastewater treatment, responsible for treatment of 91 percent of the DAF Float residual stream in 1994, continued to be the predominant treatment method. The 20 thousand wet tons sent to incinerators was the smallest quantity ever reported for this handling practice. For physical treatment there was a substantial increase over 1993, while there was a concomitant drop in the use of heat treatment.

Table 7. Management Techniques Used for the DAF Float Residual Stream (Industry Estimates)

	1994	1993	1992	1991	1990	1989	1988	1987
QUANTITY MANAGED	**627,773**	**520,118**	**546,136**	**409,551**	**564,300**	**520,797**	**660,515**	**653,899**
MANAGEMENT TECHNIQUES								
RECYCLE								
In-Process Recycle								
Coker	170,199	47,367	48,664	55,516	74,597	78,982	45,400	81,981
Crude Unit	84,829	52,268	74,967	71,866	21,625	34,037	19,007	16,190
Catalytic Cracker	36,748		1,339					
Other In-Process Recycle	19	30,899	27,641	9			7,942	5,999
Out-of-Process Recycle								
Cement Kiln Fuel	4,358	14,062	18,884	11,666				
Other Industrial Fuel	1,523	1,098			492		137	74
Cement Kiln Feedstock	945	684	1,191	43				
Reclamation		777	11	1,243	1,505	533	12,031	10,573
Regeneration		121	3					
Other Recycle	28,377	349	413		39,829	18,595	11,290	7,362
TOTAL	326,998	147,625	173,113	140,343	138,048	132,147	95,807	122,179
TREATMENT								
Wastewater Treatment	272,596	338,268	308,004	208,287	305,645	247,735	236,052	262,535
Incineration	20,327	24,479	54,308	57,615	32,199	25,572	47,281	35,312
Physical	5,253	329	273	83	2,433	6,949		
Heat	210	6,145	6,466	1,302				
Chemical/Stabilization					3,810	2,309		
Impoundment							18,917	15,005
TOTAL	298,387	369,221	369,051	267,287	344,087	282,565	302,250	312,852
LAND TREATMENT	1,148	1,616	444	4	60,464	71,637	202,570	159,418
DISPOSAL								
Landfill	1,240	1,656	3,528	1,168	20,910	29,014	51,214	30,936
Impoundment							6,925	25,853
Landspread					575	4,228	1,749	1,831
Other Disposal				749	216	1,206		830
TOTAL	1,240	1,656	3,528	1,917	21,701	34,448	59,888	59,450

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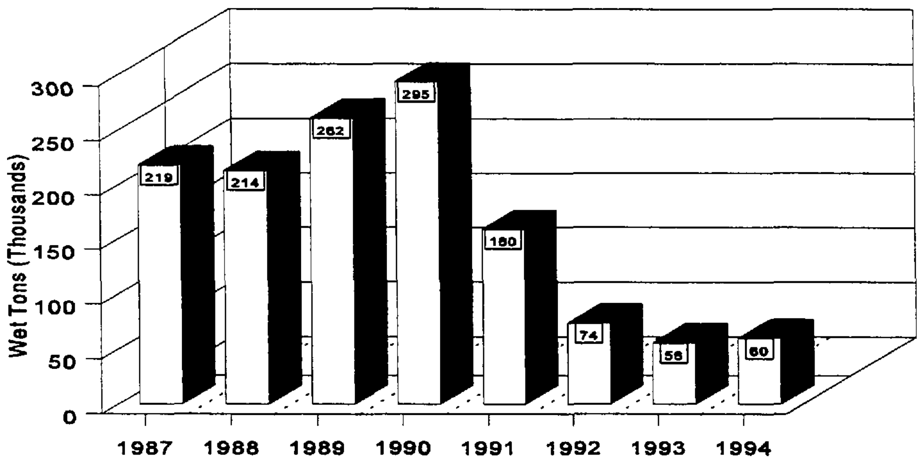
Slop Oil Emulsion Solids[5]

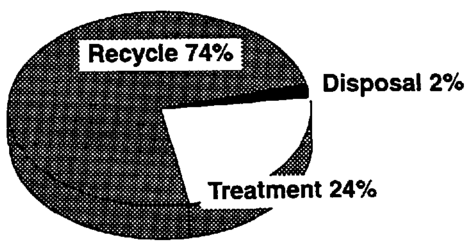
As the bar chart graphically depicts, the 60 thousand wet tons of the Slop Oil Emulsion Solids residual stream managed in 1994 was within the range reported in the two previous survey cycles. This was approximately 70 percent less than what was reported in 1987, and 80 percent below the peak quantity reported in 1990.

Figure 12. Managed Quantities of the Slop Oil Emulsion Solids Residual Stream: Industry Estimates for 1987 - 1994



Close to 75 percent of the Slop Oil Emulsion Solids stream was managed by recycling in 1995, while 23 percent was eliminated by treatment, as shown below.

Figure 13. Management of the Slop Oil Emulsion Solids Residual Stream



The specific handling practices used for the Slop Soil Emulsion Solids stream were similar to those reported for the API Separator Sludge and DAF Float streams: 60 percent of the recycled material was handled by cokers and crude units, while a smaller portion was sent off-site as cement kiln fuel. More material is eliminated by wastewater treatment than by any other treatment method. Overall, however, treatment of Slop Oil Emulsion Solids residuals has declined in the 1990s, as has Land Treatment and Disposal.

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[5] Recall that API uses labels such as Slop Oil Emulsion Solids in the broader context of a *residual stream* which includes materials that are not subject to RCRA regulation.

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Table 8. Management Techniques Used for the Slop Oil Emulsion Solids Residual Stream (Industry Estimates)

	1994	1993	1992	1991	1990	1989	1988	1987
QUANTITY MANAGED	**59,625**	**55,555**	**73,855**	**159,536**	**295,036**	**262,349**	**213,552**	**211,855**
MANAGEMENT TECHNIQUES								
RECYCLE								
In-Process Recycle								
Crude Unit	18,483	5,327	6,600	14,396	28,895	17,283	27,431	12,474
Coker	7,955	15,972	13,290	17,816	41,799	9,259	22,847	18,553
Catalytic Cracker	10	14	1,378	28,396				
Other In-Process Recycle	10,836						10,412	2,356
Out-of-Process Recycle								
Cement Kiln Fuel	6,398	8,668	9,802	19,136				
Other Industrial Fuel	279	1,611	1,470	1,079				
Industrial Furnace					3,698	861	226	326
Cement Kiln Feedstock		2,944	2,238	9				
Reclamation		1,176	341	92	4,999	2,955	9,723	13,547
Regeneration		556						
Other Recycle	187	2			59,250	62,657	78	181
TOTAL	44,148	36,270	35,119	80,924	138,048	93,015	70,717	47,437
TREATMENT								
Wastewater Treatment	10,809	11,808	22,589	57,782	107,851	98,347	56,563	98,499
Heat	1,819	4,671	6,897	975				
Incineration	1,649	2,127	7,702	19,468	734	354	4,494	1,210
Physical		176	224			387		
Chemical/Stabiliztion					5,675	3,788		
Other Treatment							124	
TOTAL	14,278	18,782	37,412	78,225	114,260	102,876	61,181	99,716
LAND TREATMENT	13				17,811	27,143	56,987	35,495
DISPOSAL								
Landfill	1,186	480	1,105	387	21,933	18,927	22,318	24,574
Injection					1,456			
Landspread					143	20,388	2,268	3,859
Other Disposal		23	219		792		81	774
TOTAL	1,186	503	1,324	387	24,324	39,315	24,667	29,207

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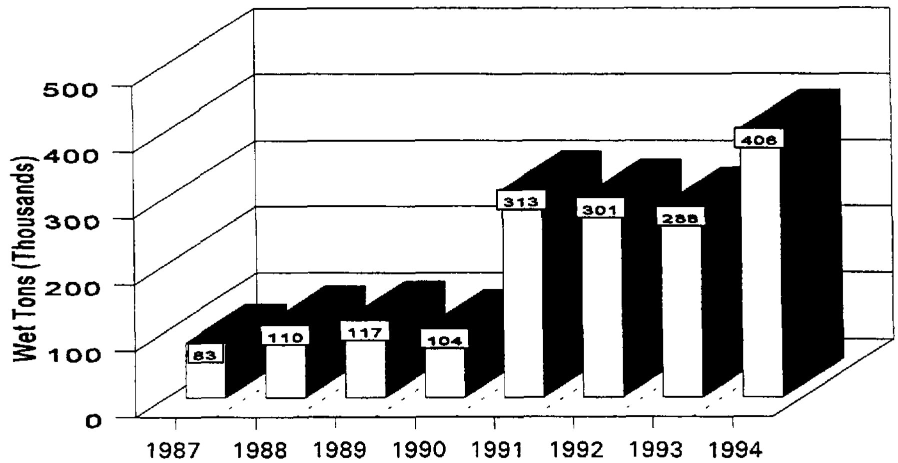
Primary Sludges[6]

The 406 thousand wet tons of the Primary Sludge residual stream managed in 1994 was the largest quantity ever reported. It is likely that this reflects the refiners efforts to meet the statutory deadlines to retrofit or close Primary Sludge or TC surface impoundments in 1994. Thus, just as the increases noted between 1991 and 1993 were related to regulatory actions--the phase-in of land disposal restrictions on Primary Sludges--the peak noted in 1994 may reflect the industry's effort to meet another regulatory mandate.

Figure 14. Managed Quantities of the Primary Sludge Residual Stream: Industry Estimates for 1987 - 1994



To obtain a better understanding of the 1994 peak, responses to the question on abnormal generation were explored. These responses suggest that 22 percent of the total quantity managed was related to an abnormal or one-time event. This is possibly an underestimate, because very few refiners answered this item. Specifically, of the 70 respondents, only 17 indicated that some quantity was due to abnormal or one-time events. However, half of these 17 refineries reported that 90 percent or more of their managed quantity was due to an abnormal occurrence. Consequently, some refiners who did not answer this question, may have generated Primary Sludge residuals as a result of one time activities.

The graphic depiction of the management practices employed in 1994 shows that one third of the Primary Sludge residual stream was recycled, similar quantities were treated and disposed (approximately 25 percent each), and just over 10 percent was placed in land treatment units.

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[6] The 1994 questionnaire included separate data sheets for F037and F038, the two residual streams from which the Primary Sludges designated as hazardous under RCRA are derived. Many refineries submitted a combined datasheet for the two streams because these residual materials are commingled for management and the relative contribution of each stream cannot be distinquished. Therefore, data for both streams were aggregated for all respondents and reported here as Primary Sludges. Similarly, the data for F037 and F038 for 1991 to 1993 have been aggregated. Before promulgation of the RCRA rule in 1990, data from the Other Separator Sludge category are used in longitudinal displays.

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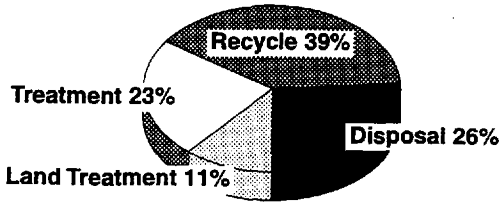
Figure 15. Management of the Primary Sludge Residual Stream

(Totals may not equal 100% due to independent rounding.)



As indicated in Table 9, most of the recycling of the Primary Sludge residual stream in 1994 was considered to be in-process, with 70 percent sent to cokers. The 113 thousand wet tons reported in 1994 was also a 70 percent increase over the quantity sent to cokers in 1993.

Table 9. Management Techniques Used For the Primary Sludge Residual Stream (Industry Estimates)

	1994	1993	1992	1991	1990	1989	1988	1987
QUANTITY MANAGED	405,644	288,194	300,643	312,554	103,861	116,947	110,251	82,798
MANAGEMENT TECHNIQUES								
RECYCLE								
In-Process Recycle								
Coker	112,710	30,371	20,484	1,333	772		6,662	6,707
Crude Unit	1,783	7,999	9,316	4,936	12,581	26,168	12,483	7,818
Other In-Process Recycle	33,442	613	298					
Out-of-Process Recycle								
Cement Kiln Fuel	9,046	5,622	487					
Reclamation	231	3,817	345	1,618			4,322	5,463
Other Industrial Fuel	199	2						
Cement Kiln Feedstock	120							
Other Out-of-Process Recycle	312			398				
Other Recycle	1,001				1,540	823	940	952
TOTAL	158,843	48,424	30,930	8,285	14,893	26,991	24,407	20,940
TREATMENT								
Wastewater Treatment	76,292	83,332	55,477	197,625	51,383	52,698	48,412	32,092
Heat	10,911	31						
Incineration	7,789	3,774	8,928	969	3			
Stabilization	44							
Physical		7,941				55	441	165
Chemical		53						
Impoundment								757
Other Treatment	117							
TOTAL	95,154	95,131	64,405	198,594	51,386	52,753	48,853	33,014
LAND TREATMENT	46,440	116,192	57,988	27,136	30,682	29,694	22,123	12,001
DISPOSAL								
Landfill	102,941	26,357	139,488	66,340	6,042	5,845	7,632	7,873
Impoundment	2,095	1,602	7,374	7,053			5,689	7,789
Landspread		76	352	4,173	858	1,664	1,514	1,181
Other Disposal	170	412	106	973			33	
TOTAL	105,207	28,447	147,320	78,539	6,900	7,509	14,868	16,843

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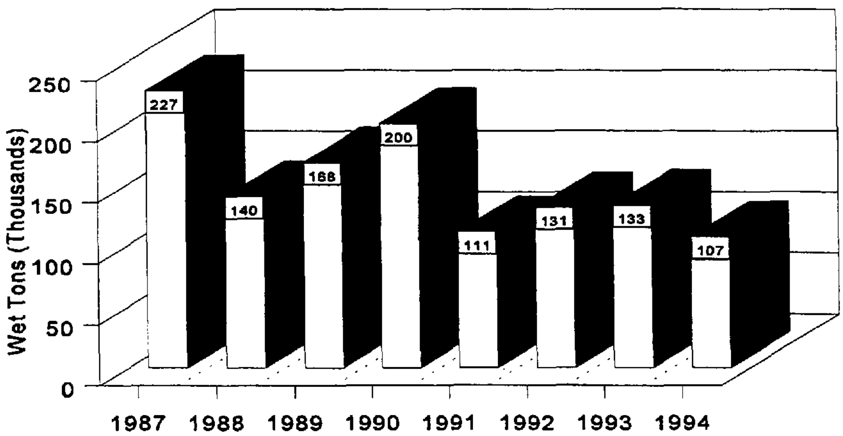
The amount of residual material sent to crude units dropped in 1994, while a sizeable quantity was reported as "Other In-Process Recycle." For out-of-process recycle, the largest quantity was sent to cement kiln as fuel.

As in the past, the vast majority of the Primary Sludge stream was subjected to wastewater treatment, although a sizeable quantity was eliminated by heat treatment in 1994. For disposal, most was accomplished in landfills.

Tank Bottoms

Tank Bottoms was a new category for 1994 replacing the leaded and nonleaded tank bottom streams previously distinguished in earlier surveys. The estimate for the entire industry was 107 thousand wet tons, which as shown below, was the smallest quantity ever reported.

Figure 16. Managed Quantities of Tank Bottoms: Industry Estimates for 1987 - 1994



As shown by the following pie chart, the majority of Tank Bottoms were disposed of in 1994, while the amount recycled was just slightly greater than that handled by treatment. Land treatment accounted for 10 percent of the total quantity managed.

Figure 17. Management of Tank Bottoms *(Totals may not equal 100% due to independent rounding.)*

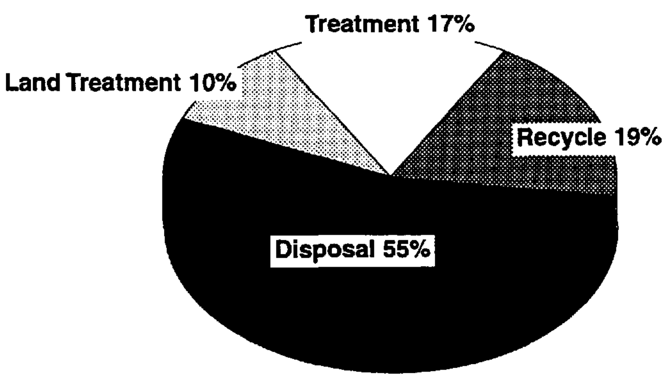


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Table 10, which summarizes the management practices used for Tank Bottoms since 1987, suggests that the industry's current reliance on disposal reflects general reductions in the use of wastewater treatment and land treatment technologies. Despite these overall trends, review of the specific entries does not suggest any systematic changes in how Tank Bottoms are handled. Note the variability between years for recycling in cokers. The vascillations in the quantities sent for reclamation, however, suggest a possible explanation: there is substantial turnover in refineries reporting management of Tank Bottoms across survey cycles, reflecting the cyclical nature of tank cleanouts.

Table 10. Management Techniques Used for Tank Bottoms (Industry Estimates)

	1994	1993	1992	1991	1990	1989	1988	1987
QUANTITY MANAGED	106,658	133,046	130,835	111,187	199,551	168,172	140,469	227,134
MANAGEMENT TECHNIQUES								
RECYCLE								
In-Process Recycle								
Crude Unit	7,538	10,176	14,159	14,873	34,333	17,964	12,826	11,357
Coker	4,834	10,725	3,049	829	6,562	22,583	6,728	241
Catalytic Cracker	388							
Other In-Process Recycle	1,397	661	1,364					
Out-of-Process Recycle								
Reclamation	1,860	16,500	18		3,043	1,619	949	1,166
Cement Kiln Feedstock	1,726	186		3				
Cement Kiln Fuel	27	72	631	1,391				
Other Industrial Fuel		45	95					
Regeneration			3,414					
Other Out-Of-Process Recycle		163	225					
Other Recycle	2,338			1,123	356	498	545	
TOTAL	20,107	38,365	22,955	18,219	44,294	42,664	21,048	12,764
TREATMENT								
Wastewater Treatment	12,349	13,124	18,720	4,863	37,520	37,505	36,034	89,785
Incineration	2,705	684	610	360	250	39	4	
Stabilization	465	947	6,290	1,035	1,163			
Physical	356		209		1,182	692		
Chemical			106					
Weathering					316	69	52	
Heat				15				
Impoundment							21	16
Other Treatment	1,806							
TOTAL	17,681	14,755	25,935	6,273	40,431	38,305	36,111	89,801
LAND TREATMENT	10,650	14,215	11,612	8,978	22,901	36,584	34,801	61,583
DISPOSAL								
Landfill	54,874	60,582	70,285	75,040	84,521	49,105	44,353	55,720
Landspread	631	4,882	20	2,658	4,989	548	1,841	527
Impoundment		68			2,017	917	2,251	6,739
Other Disposal	2,715	16	28	19	398	49	22	
TOTAL	58,220	65,532	70,333	77,717	91,925	50,619	48,467	62,986

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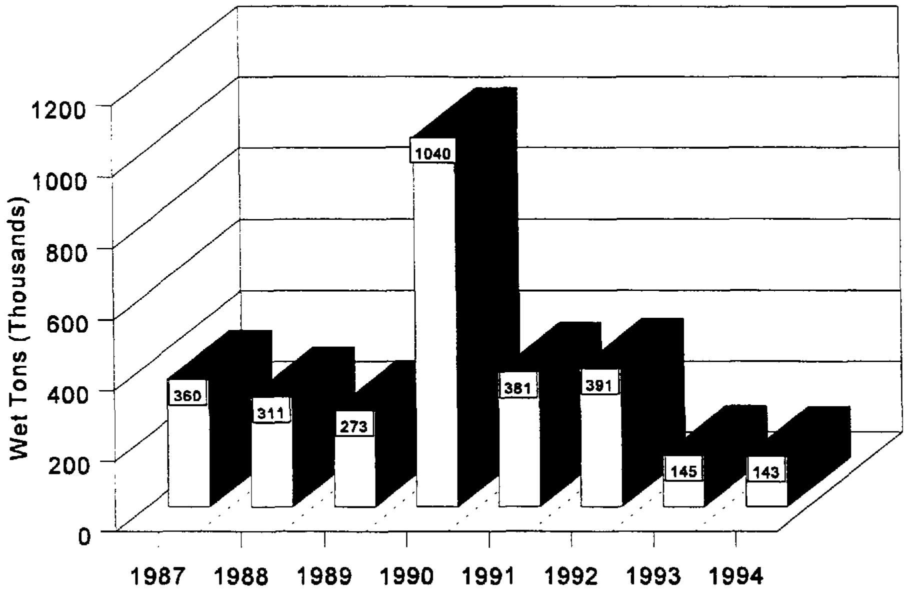
Pond Sediments

As the bar chart depicts, the managed quantity of Pond Sediments in 1994 was the lowest reported since the survey began. Consistent with previous observations, 92 percent of the total quantity managed was due to one-time events.

Figure 18. Managed Quantities of Pond Sediments: Industry Estimates for 1987 - 1994



Two-thirds of the pond sediments were disposed, 15 percent were eliminated by treatment and another 15 percent were managed in land treatment units (See Figure 19).

Figure 19. Management of Pond Sediments *(Totals may not equal 100% due to independent rounding.)*

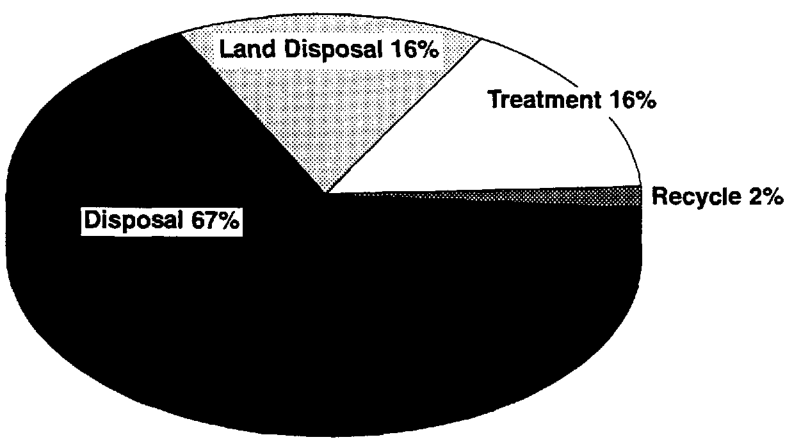


Table 11 shows that after landfilling, refiners relied on incineration in 1994 to manage Pond Sediments. Although the quantity incinerated in 1994 was only slightly greater than that reported in 1990, it represents 14 percent of the total quantity compared to the 5 percent incinerated in the 1990 peak year.

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The patterns of reporting are also interesting. Between 1993 and 1994, when the total managed quantities reported were similar, there are differences in the practices used to recycle and treat Pond Sediments. Recycling via cokers dropped, while incineration and heat treatment peaked. Most likely this variability is related to change/turnover in refineries reporting the management of Pond Sediments. (As noted above, 20 refineries indicated managing Pond Sediments in 1994, but only 14 reported in 1993).

Table 11. Management Techniques Used for Pond Sediments (Industry Estimates)

	1994	1993	1992	1991	1990	1989	1988	1987
QUANTITY MANAGED	143,205	144,661	391,095	380,652	1,039,645	273,216	311,269	359,996
MANAGEMENT TECHNIQUES								
RECYCLE								
In-Process Recycle								
Coker	474	10,783	1,662	1,741		4,923	2,854	233
Crude Unit		83	13,825	11	360	798	337	1,769
Out-of-Process Recycle								
Reclamation	1,915			1,450		162		
Cement Kiln Fuel		697		21				
Other Recycle	15							
TOTAL	2,405	11,563	15,487	3,223	360	5,883	3,191	2,002
TREATMENT								
Incineration	20,068	50		19,254				
Heat	1,954							
Wastewater Treatment	350	1,246	106,708	9,558	1,201	48,433	21,530	73,653
Stabilization					211,100			
Physical					1	7,095		
Chemical						3,760		
Weathering						16		
Other Treatment				681	27,412	10,003	21,194	87,902
TOTAL	22,372	1,296	106,708	29,493	239,714	69,307	42,724	161,555
LAND TREATMENT	22,401	20,488	230,187	10,692	348,855	126,520	64,372	66,525
DISPOSAL								
Landfill	96,027	111,314	38,713	327,783	404,887	59,842	49,827	77,014
Landspread				9,461	45,829	906	54,460	
Impoundment						1,348	96,695	34,462
Other Disposal						9,410		
TOTAL	96,027	111,314	38,713	337,244	450,716	71,506	200,982	111,476

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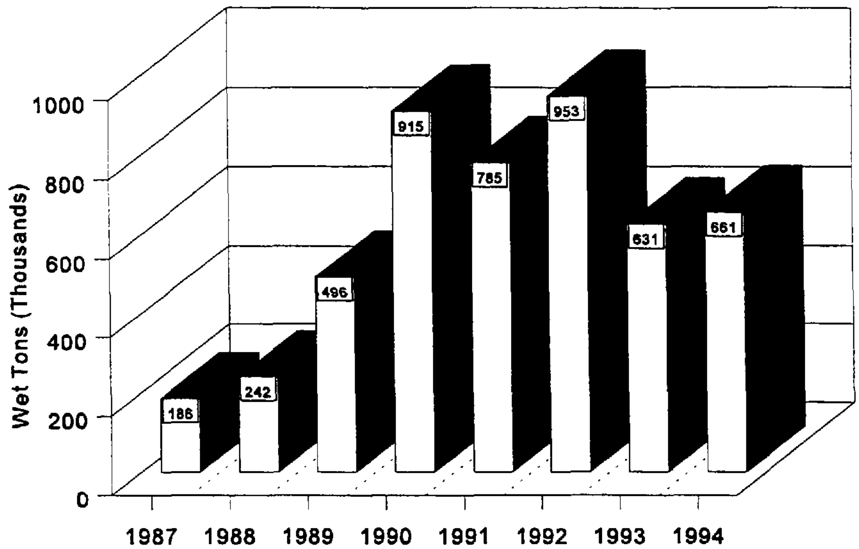
Contaminated Soils

The industry estimate of 661 thousand wet tons of Contaminated Soils was comparable to 1993, and as shown below, substantially lower than what was reported between 1990 and 1992.

Figure 20. Managed Quantities of Contaminated Soils: Industry Estimates for 1987 - 1994



Thirty-six refineries responded to the item regarding abnormal generation. Based on their answers, 14 percent of the managed quantity was due to one-time events.

To gain a better understanding of why Contaminated Soils are generated, API had included an additional question on the datasheet regarding the source of the residual material. Using the subset of respondents (n = 65) that answered this question correctly (i.e., their responses totalled 100 percent), the following profile was developed. As indicated, more than half of the contaminated soils managed in 1994 resulted from construction activities.

Table 12. Source of Contaminated Soils

Source	% of Quantity Managed
Spills	22
Construction	55
Remediation subject to Agency mandate	2
Voluntary remediation	15
Other	6

Figure 21 depicts how contaminated soils were managed in 1994. Less than 10 percent was recycled or treated, and only slightly more was placed in land treatment units. More than 75 percent was disposed.

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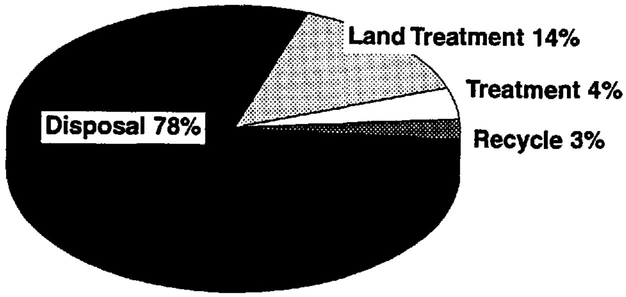
Figure 21. Management of Contaminated Soils *(Totals may not equal 100% due to independent rounding.)*



As shown in Table 13, although only a small percentage of Contaminated Soils was eliminated by recycling in 1994, substantially more was recycled in the preceding two years.

Table 13. Management Techniques Used for Contaminated Soils (Industry Estimates)

	1994	1993	1992	1991	1990	1989	1988	1987
QUANTITY MANAGED	661,125	631,122	953,179	785,418	914,926	495,517	242,073	185,818
MANAGEMENT TECHNIQUES								
RECYCLE								
In-Process Recycle								
Crude Unit	1,626				6			
Coker			22		2			
Other In-Process Recycle	4,163	53,630						
Out-of-Process Recycle								
Cement Kiln Feedstock	1,473	193	433	5,720				
Reclamation	980	145			6,961		6,182	5,235
Other Out-Of-Process Recycle	5,000	3,686	73,784	959				
Other Recycle	8,517	7,067	4	19,683	41,882	22,899	4,536	13,419
TOTAL	21,759	64,721	74,243	26,362	48,851	22,899	10,718	18,654
TREATMENT								
Heat	1,798	17,593	15,671				4	
Incineration	1,760	3,168	280	3,578	92	219	8	21
Wastewater Treatment	1,033				21			
Stabilization		274	164	611	55,070	4,172		17
Chemical		141	437					
Weathering		25		334	11	1		
Physical			32			207		
Other Treatment	22,001	3,342			8			
TOTAL	26,593	6,950	913	4,523	55,202	4,599	12	38
LAND TREATMENT	93,839	141,872	245,922	268,366	298,736	131,562	27,853	22,022
DISPOSAL								
Landfill	496,430	343,083	592,397	479,782	497,140	316,862	188,889	140,864
Impoundment	16,005					34	3,982	155
Landspread	6,499	56,901	24,031	6,385	14,770	16,463	10,619	4,085
Other Disposal		2	2		227	3,098		
TOTAL	518,934	399,986	616,430	486,167	512,137	336,457	203,490	145,104

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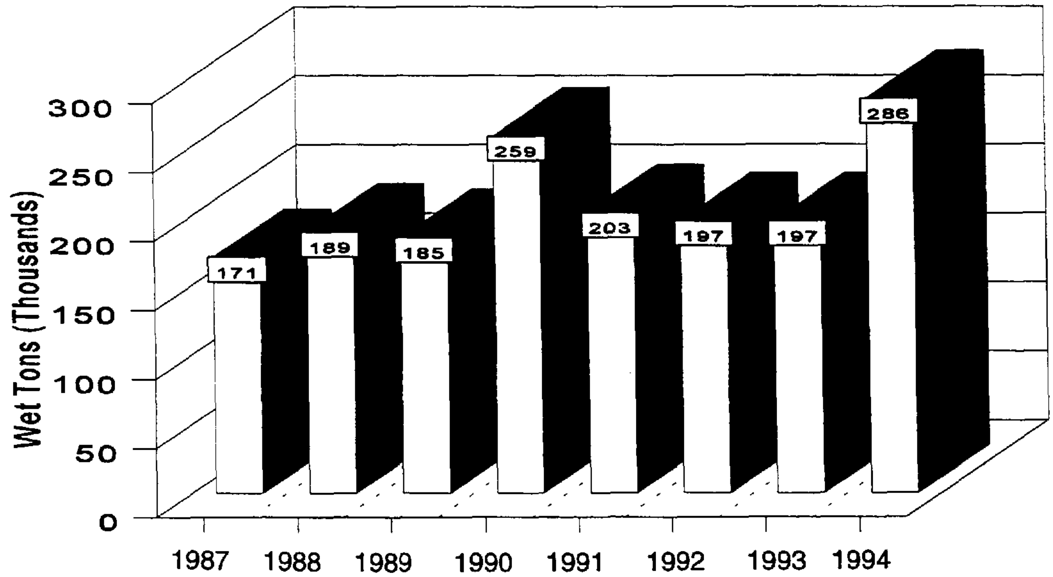
The table entries also show that refiners have used a great variety of recycling and treatment techniques over the years. Note the substantial drop in the quantities managed in land treatment units (a 68 percent drop between the peak in 1990 and the current reported quantity).

FCCU Catalysts

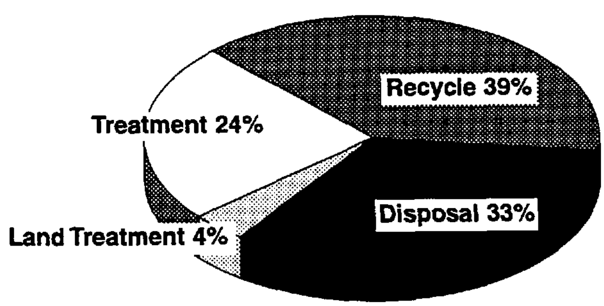
The industry estimate of 286 thousand wet tons of FCCU Catalysts for 1994 was the largest quantity ever recorded.

Figure 22. Managed Quantities of FCCU Catalysts: Industry Estimates for 1987 - 1994



As the pie chart of management practices shows, equal quantities of FCCU catalysts were recycled and disposed in 1994. Although the quantities eliminated by treatment and land treatment were the largest ever reported, these practices accounted for only 24 and 4 percent, respectively, of the total quantity managed.

Figure 23. Management of FCCU Catalysts



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From Table 14 it is clear that there have been some systematic changes in the management of FCCU Catalysts. Recycling has increased 300 percent since the survey began, while disposal rates have dropped. It appears that this may reflect the increased use of cement kilns, catalytic crackers and other out-of-process recycle methods that began in 1991.

Table 14. Management Techniques Used for FCCU Catalysts (Industry Estimates)

	1994	1993	1992	1991	1990	1989	1988	1987
QUANTITY MANAGED	286,150	197,292	196,732	203,806	259,310	185,380	189,191	170,854
MANAGEMENT TECHNIQUES								
RECYCLE								
In-Process Recycle								
Catalytic Cracker	4,869	6,548	6,360	3,807				
Crude Unit				2,334				
Other In-Process Recycle		11,223	8,590					
Out-of-Process Recycle								
Cement Kiln Feedstock	49,678	54,307	24,986	33,573				
Cement Kiln/Industrial Fuel	11,375	375	8,901	702	4,942	263	2,341	644
Regeneration	4,549	4,782	5,746	2,626	1,337	5,320	1,236	4,730
Reclamation	2,097	6,188	6,692	3,691	5,515	22,012	5,361	6,164
Sold					10,241	13,577	764	902
Other Out-Of-Process Recycle	10,205	10,022	22,186	2,488				
Other Recycle	27,653	456	2,075	6,918	40,303	9,791	13,944	12,686
TOTAL	110,425	93,901	85,536	56,140	62,338	50,963	23,646	25,126
TREATMENT								
Chemical				601				
Wastewater Treatment	68,873	17	13	1,484	52		3,046	6,182
Stabilization			13					
TOTAL	68,873	17	26	2,085	52	0	3,046	6,182
LAND TREATMENT	12,067	3,816	1,647	20	3,261	932	33,059	266
DISPOSAL								
Landfill	78,086	81,098	83,253	118,478	116,619	103,891	114,644	122,874
Impoundment	8,225	18,017	25,419	25,453	20,168	13,582	13,351	10,850
Landspread	825	410	851	1,631	56,844	13,188	875	5,311
Other Disposal	7,650	33			28	2,824	570	245
TOTAL	94,785	99,558	109,523	145,562	193,659	133,485	129,440	139,280

It should be noted that the relatively large quantity sent to wastewater treatment in 1994 reflects the management practice at one refinery whose configuration of cracking equipment enables recovery of suspended catalyst fines from wet gas scrubbers.

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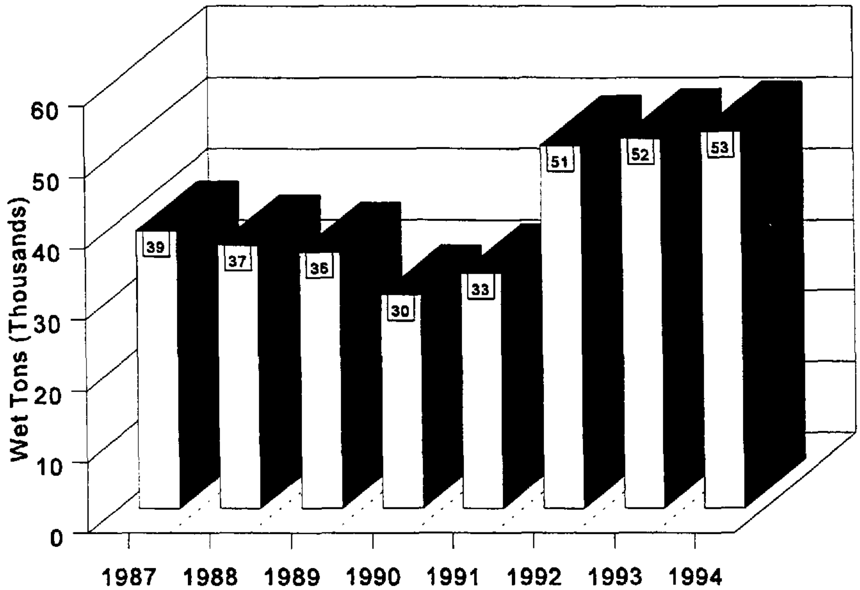
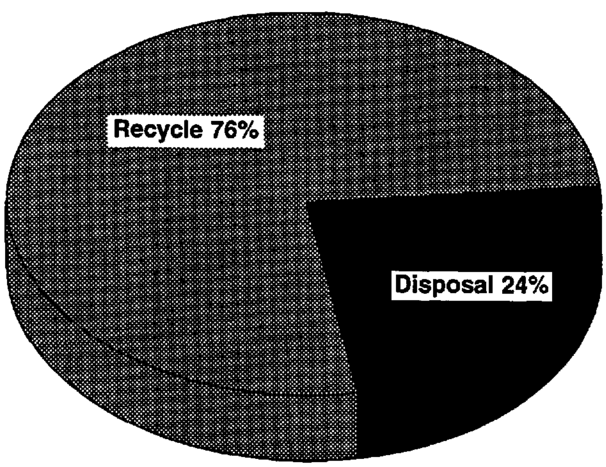
Hydroprocessing Catalysts
As shown in Figure 24, the 53 thousand wet tons of Hydroprocessing Catalysts managed in 1994 was comparable to the quantities reported in 1992 and 1993. These quantities continued to be higher than those reported in the first five survey cycles.

Figure 24. Managed Quantities of Hydroprocessing Catalysts: Industry Estimates for 1987 - 1994



In 1994, three quarters of the Hydroprocessing Catalysts were recycled, while the remainder was disposed.

Figure 25. Management of Hydroprocessing Catalysts



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Refiners use a combination of recycling and disposal to manage Hydroprocessing Catalysts, and as the data in Table 15 indicate, the actual percentages fluctuate over time. Note the differences in the recycled and disposed quantities for 1992 and 1994 compared to 1993. The very low percent of material disposed between 1989 and 1992 (6 to 13 percent) is also interesting, given that the total quantities managed during this period covered the range observed in the survey.

A series of scatter plot charts summarizing the cost data for Hydroprocessing Catalysts are included following Table 15.

Table 15. Management Techniques Used for Hydroprocessing Catalysts (Industry Estimates)

	1994	1993	1992	1991	1990	1989	1988	1987
QUANTITY MANAGED	53,306	51,694	51,395	32,688	30,376	35,787	36,630	39,414
MANAGEMENT TECHNIQUES								
RECYCLE								
In-Process Recycle								
Coker		75						
Out-of-Process Recycle								
Reclamation	26,835	25,490	43,122	27,322	25,689	31,188	17,831	21,975
Regeneration	9,271	1,835	1,876	3,281	2,113	970	3,512	3,918
Cement Kiln Out of Process		27						
Cement Kiln Fuel		153	177					
Other Recycle	4,660			414	1		151	1,510
TOTAL	40,767	27,580	45,175	31,017	27,803	32,158	21,494	27,403
TREATMENT								
Incineration		188				93		
Impoundment							81	63
Other Treatment		2	3					
TOTAL		190	3	0	0	93	81	63
LAND TREATMENT					80	35	460	12
DISPOSAL								
Impoundment		105				4		7
Landfill	12,398	23,786	6,175	1,671	2,440	3,497	14,366	11,929
Other Disposal	142	33	42		53		229	
TOTAL	12,539	23,924	6,217	1,671	2,493	3,501	14,595	11,936

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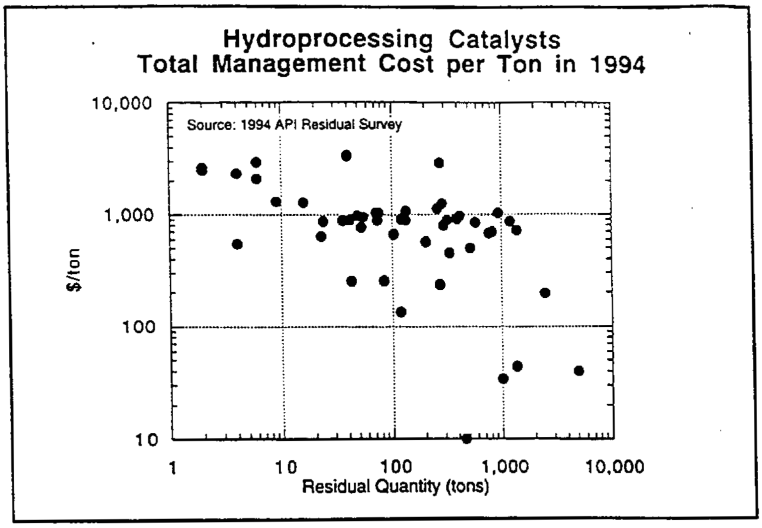

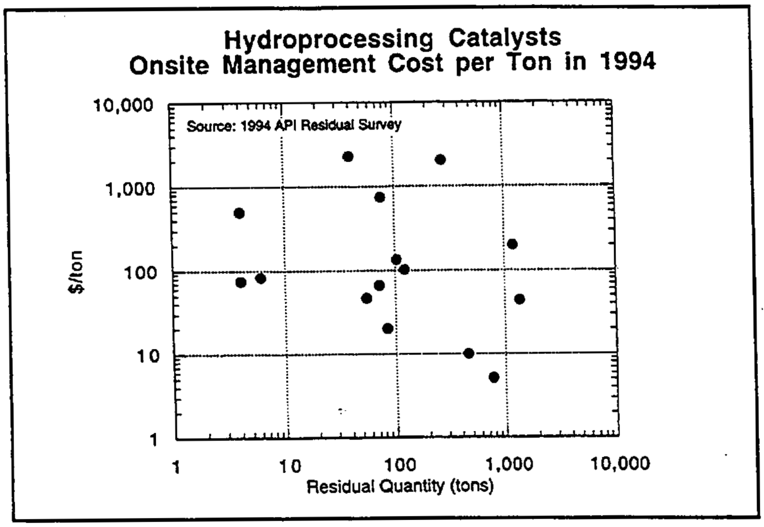

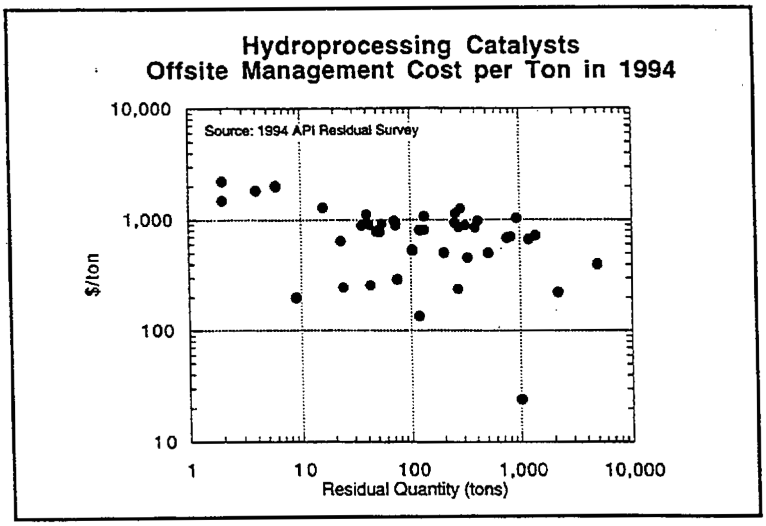

Cost Data for Hydroprocessing Catalysts

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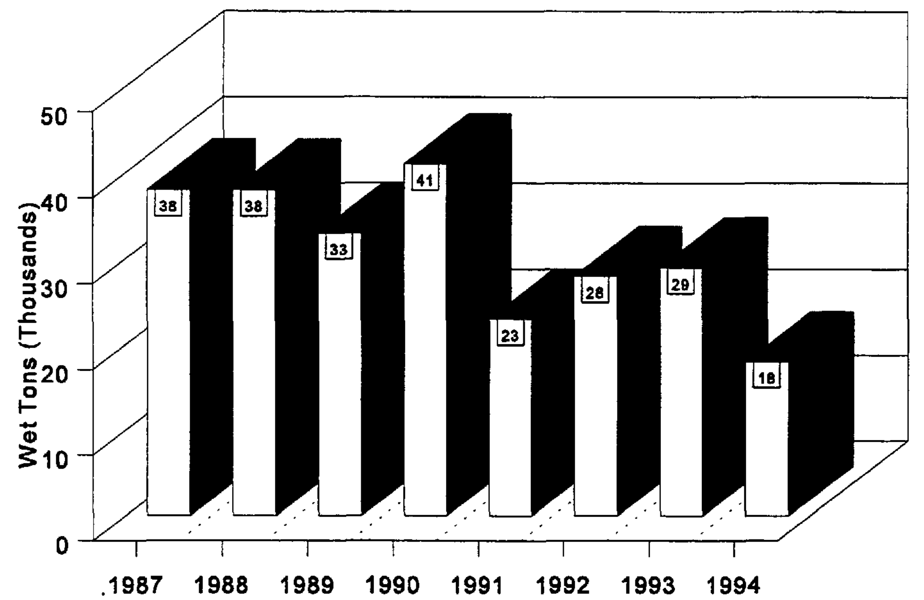
Other Spent Catalysts

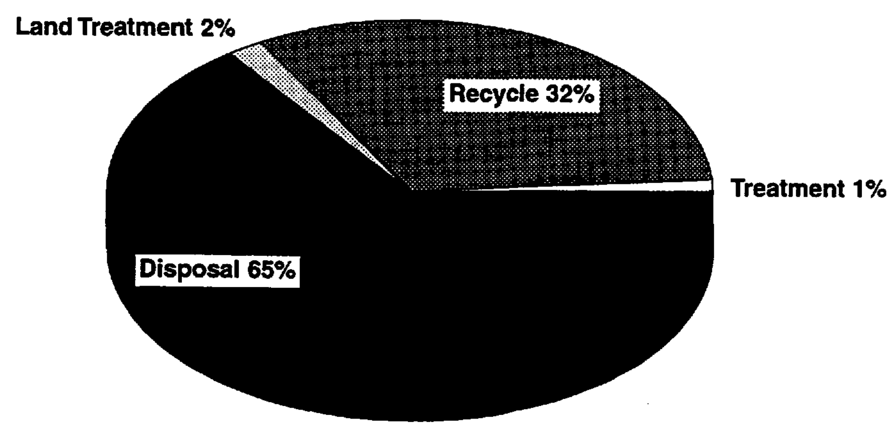
The Other Spent Catalyst stream is comprised of spent reformer, shift converter, other metallic, and not otherwise specified (NOS) catalysts. The 18 thousand wet tons estimated for the industry in 1994 was the smallest quantity ever reported. As illustrated in Figure 26, the amounts managed in more recent years are lower that than observed in the late 1980s.

Figure 26. Managed Quantities of Other Spent Catalysts: Industry Estimates for 1987 - 1994



As illustrated below, disposal is the predominant method used to manage these spent catalysts. Close to one third is recycled (primarily through reclamation and regeneration as shown in Table 16), and very small quantities undergo treatment and land treatment.

Figure 27. Management of Other Spent Catalysts



The variability in the data in Table 16 is interesting. Note how the quantities fluctuate between survey cycles. Given that the number of respondents have ranged from 59 to 63 over the survey timeframe, it does not appear that this is related to respondent turnover. Instead, it may reflect the variety of catalysts

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included in this category, each of which may have different changeout/renewal cycles that frustrate delineating a pattern when they are aggregated. There is, however, one clear reporting pattern: none of these materials has received wastewater treatment since 1991.

Table 16. Management Techniques Used for Other Spent Catalysts (Industry Estimates)

	1994	1993	1992	1991	1990	1989	1988	1987
QUANTITY MANAGED	18,085	29,246	27,642	23,201	40,589	33,396	37,905	38,239
MANAGEMENT TECHNIQUES								
RECYCLE								
In-Process Recycle								
Catalytic Cracker	1,276			136				
Other In-Process Recycle				21				
Out--of-Process Recycle								
Reclamation	2,204	15,402	5,885	5,288	9,873	8,067	8,715	15,398
Regeneration	1,613	357	516	379	771	546	84	482
Cement Kiln Feedstock	434	77	144					
Cement Kiln Fuel		30	33					
Sold					302	210		
Other Out-Of-Process Recycle	241	517	3,350	804				
Other Recycle	51	15	41	595	98	41	469	738
TOTAL	5,819	16,398	9,969	7,223	11,044	8,864	9,268	16,618
TREATMENT								
Incineration	46	33	51	3				
Chemical	40	165				462		
Stabilization	50							
Wastewater Treatment				2,213	11,746	11,095	9,217	36
Impoundment							16	10
Other Treatment	4					7		
TOTAL	140	198	51	2,216	11,746	11,564	9,233	46
LAND TREATMENT	444	452	430	1,149	2,892	829	1,302	1,585
DISPOSAL								
Landfill	11,100	12,198	17,101	12,215	14,830	11,034	18,064	19,892
Landspread					77	1,105		
Other Disposal	583		91	398			38	8
TOTAL	11,683	12,198	17,192	12,613	14,907	12,139	18,102	19,900

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Biomass

As the graphic portrayal suggests, the quantities of Biomass managed are quite comparable across the cycles.

Close to one half of the Biomass was land treated, while one quarter was recycled. Treatment and disposal both were less than 20 percent of the total quantity.

Figure 28. Managed Quantities of Biomass: Industry Estimates for 1987 - 1994

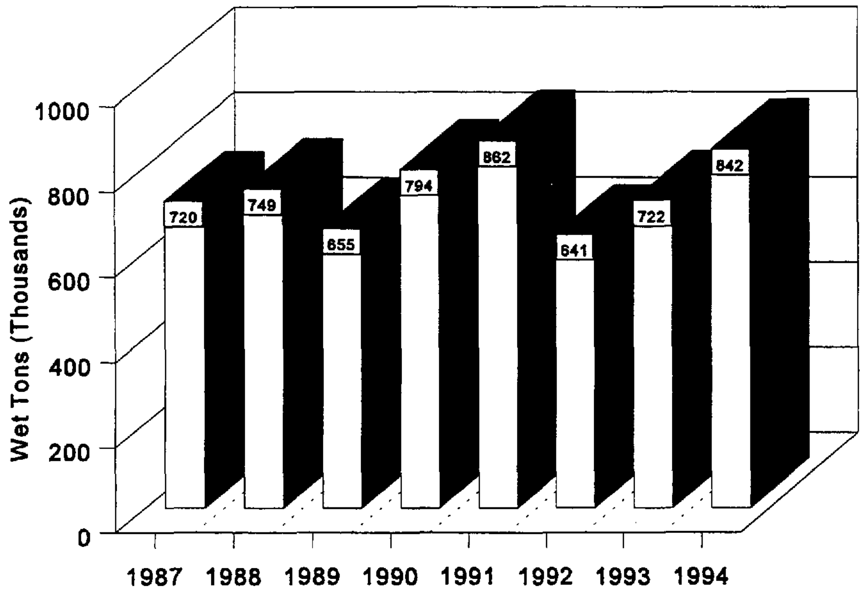
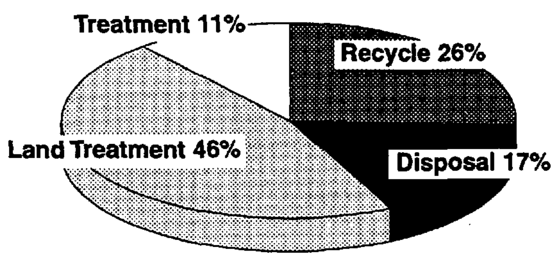


Figure 29. Management of Biomass



Review of the data in Table 17 suggests that the management practices in 1994 were different than previously observed. Reliance on land treatment was the highest ever reported. This is a break in the pattern of fairly systematic reductions in the use of land treatment previously observed. Biosolids are particularly suited to land treatment for they provide moisture and some of the nutrients that encourage growth of the organisms used to biodegrade organic materials. Since they are generated from the biological degradation of pollutants, biosolids have few pollutants themselves and any that are present are at trace or very low levels.

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For recycling, the amount sent to cokers was intermediate to previous reports. For the first time, refineries reported recycling biomass to catalytic crackers. Also, for the first time, biomass mixed with coke fines, was sent off-site as an industrial fuel.

For treatment, note that reliance on wastewater treatment in the last three years was significantly less than in the previous five survey cycles. Also, 1994 witnessed a substantial reduction in the use of incineration.

The rate of disposal was comparable to that observed between 1989 and 1992, even though the quantity sent to landfills was close to twice the previous high recorded in 1993.

Table 17. Management Techniques Used for Biomass (Industry Estimates)

	1994	1993	1992	1991	1990	1989	1988	1987
QUANTITY MANAGED	841,914	722,425	640,958	862,319	794,046	654,977	748,588	720,356
MANAGEMENT TECHNIQUES								
RECYCLE								
In-Process Recycle								
Coker	82,171	75,433	177,394	66,610	55,907	59,330	26,560	24,941
Catalytic Cracker	50,316							
Crude Unit		1,337	1,035	79,335		70		
Other In-Process Recycle	2,569	36,473	35,621					
Out-of-Process Recycle								
Other Industrial Fuel	46,989							
Reclamation	2,104	1,201	1,312	1,117	1,685	1,265	393	397
Cement Kiln Fuel		60						
Industrial Furnace					3			
Other Out-Of-Process Recycle		115,898						
Other Recycle	37,806	48,087	57,840			140		
TOTAL	221,955	278,489	273,202	147,062	57,595	60,805	26,953	25,338
TREATMENT								
Wastewater Treatment	69,087	33,887	89,505	354,490	288,341	249,423	221,854	234,478
Incineration	24,831	80,636	73,916	81,504	98,158	103,380	72,674	63,700
Heat	1,102					1,868		
Physical	143	12,022			20,290		16,963	18,462
Weathering		5,694						
Impoundment							8,057	6,350
Other Treatment			4,602	12,601	1,682		615	605
TOTAL	95,163	132,239	168,023	448,595	408,471	354,671	325,087	323,595
LAND TREATMENT	385,306	142,826	144,060	201,498	266,982	187,395	258,603	235,537
DISPOSAL								
Landfill	133,222	67,790	50,893	40,997	32,337	37,185	48,282	40,872
Landspread	4,471	101,081	4,780	22,565	26,412	14,640	48,018	51,082
Impoundment	84			1,602	2,249	281	41,645	42,193
Other Disposal	1,712							1,739
TOTAL	139,490	168,871	55,673	65,164	60,998	52,106	137,945	135,886

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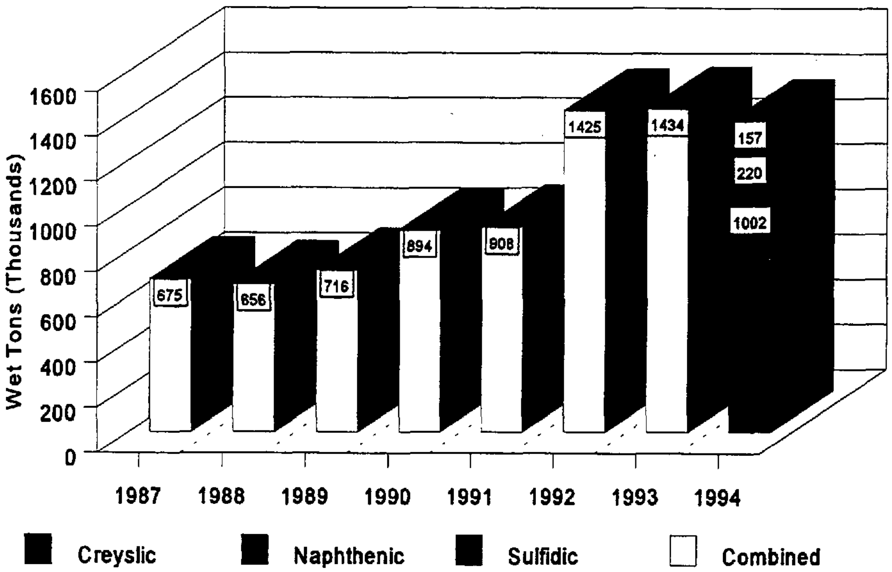
Spent Caustics
As noted earlier in this report, API elected to distinguish among three types of caustics for this survey cycle: sulfidic, naphthenic and cresylic. These break-outs for 1994 will be discussed in this section, but the data will also be aggregated to enable longitudinal comparisons to previous survey findings.

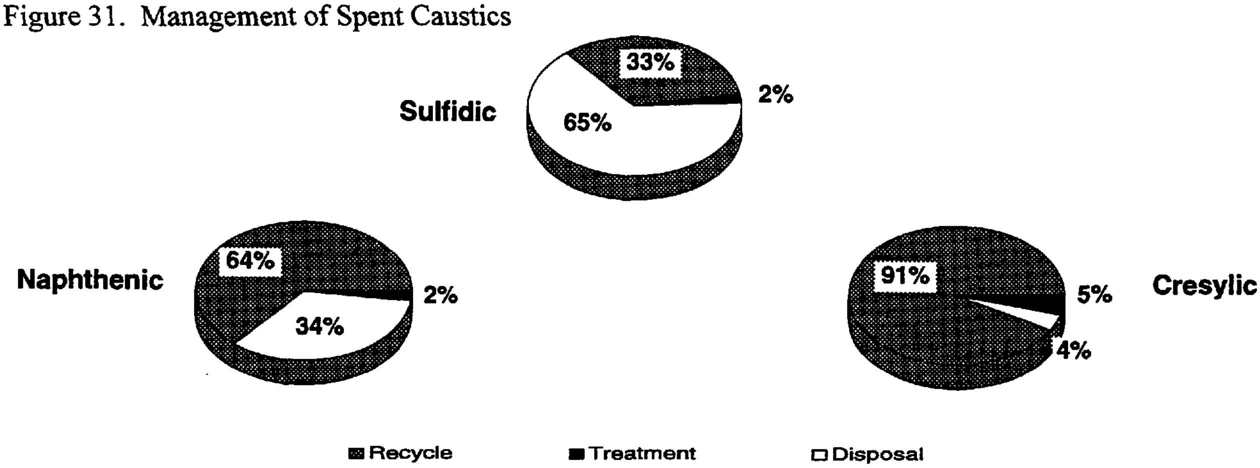
As graphically illustrated in Figure 30, the overwhelming majority of residual managed in 1994 was spent sulfidic caustics, totaling just over one million wet tons. The industry estimate for spent naphthenic caustic was 220 thousand wet tons, while the industry estimate was 157 thousand wet tons for cresylic caustics.

Figure 30. Managed Quantities of Spent Caustics: Industry Estimates for 1987 - 1994



The overall quantity managed in 1994 was comparable to that estimated for the two previous years. As hypothesized in earlier survey cycles, the general increase in the quantity of spent caustics managed may reflect increased reporting of the material, rather than an increase in its generation.

Figure 31. Management of Spent Caustics



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The pie charts depicting the types of management practices used (Figure 31) suggest different patterns for the three types of caustics. Two thirds of spent sulfidic caustics are treated, while recycling accounts for a similar proportion of the naphthenic type. Management of cresylic caustics is primarily through out-of-process recycling (i.e., off site reclamation).

Despite the seeming differences in the way the caustics are handled, when specific management practices are reviewed, as in Table 18, it is apparent that the practices used are similar. Note that the only differences among streams are the additional uses of regeneration, "other" recycle, treatment and disposal procedures of sulfidic caustics. Cresylic caustics were the only type disposed in a landfill (reported by only one refinery). Thus, it is the difference in the quantity of sulfidic caustic, compared to the naphthenic and cresylic caustics, that contributes to the view that the handling practices differ among the three types of caustics.

Following Table 18, a series of scatter plot charts summarize the cost data for spent sulfidic caustics, which are representative of the overwhelming majority of spent caustics.

Table 18. Management Techniques Used in 1994 for Sulfidic, Naphthenic and Cresylic Caustics (Industry Estimates)

	SULFIDIC	NAPHTHENIC	CRESYLIC	TOTAL
QUANTITY MANAGED	1,001,630	219,736	156,801	1,378,167
MANAGEMENT TECHNIQUES				
REYCLE				
In Process Recycle				
Crude Unit	10,714	6,072	8,820	16,786
Desalter				
Catalytic Cracker				
Other In-Process Recycle	15,860			15,860
Out-of-Process Recycle				
Industrial Furnace				
Reclamation	125,043	41,990	73,295	240,328
Regeneration	116,057			116,057
Other Out-of-Process Recycle	10,459			10,459
Other Recycle	54,004	92,393	60,781	207,178
TOTAL	332,137	140,455	142,896	615,488
TREATMENT				
Chemical	1,773		180	1,953
Wastewater Treatment	648,505	74,016	6,342	728,863
Other Treatment	1,144			1,144
TOTAL	651,422	74,016	6,522	731,960
LAND TREATMENT				
DISPOSAL				
Landfill			1,682	1,682
Injection	16,324	5,265	5,702	27,291
Other Disposal	1,747			1,747
TOTAL	18,071	5,265	7,383	30,719

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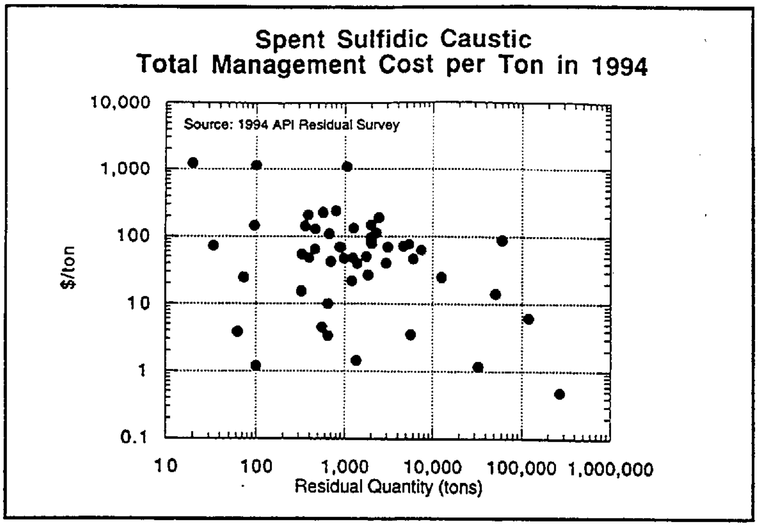

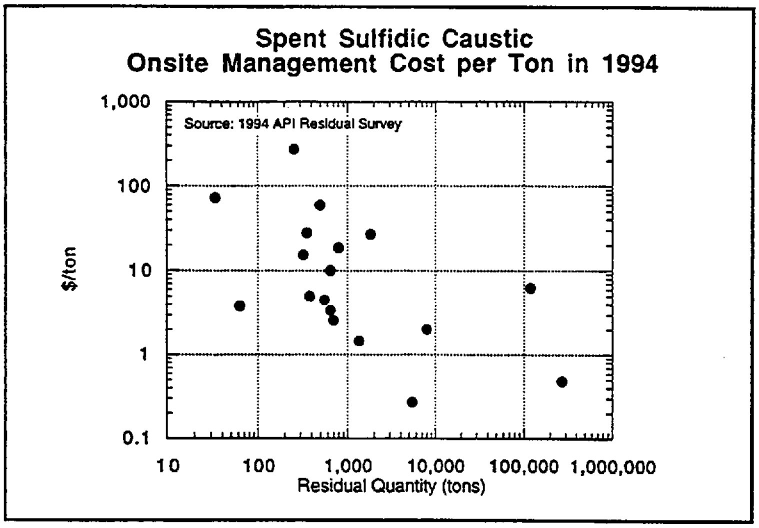

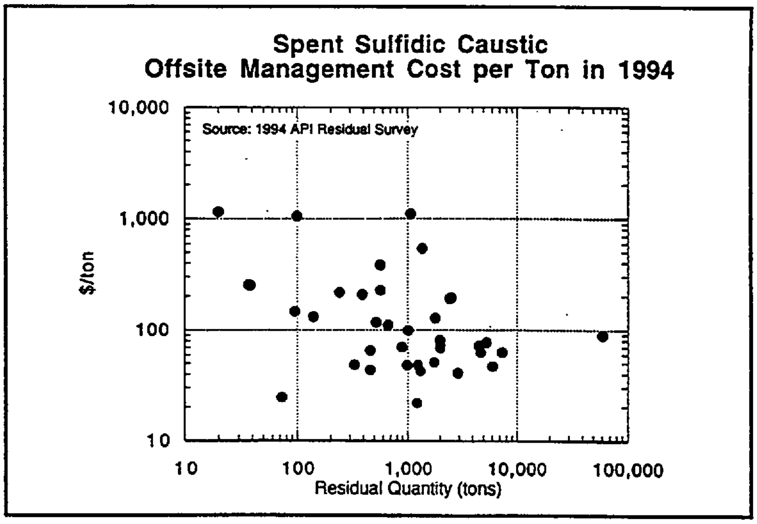

Cost Data for Management of Spent Sulfidic Caustics

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The handling practices reported in Table 18 were very similar to those observed by EPA in its RCRA 3007 survey (60 Federal Register 57747; November 20, 1995). A substantial portion of the spent caustics is reclaimed or otherwise used as a commerical feedstock. Others are reused as secondary materials in other manufacturing processes (e.g., paper milling, chemical and fertilizer production). Smaller, but comparable, portions were sent to wastewater treatment or deepwell injected.

Regarding the treatment of spent caustics, reliance on the wastewater system has increased since 1991. For disposal, injection continues to account for the largest quantity. This is not a widespread practice, however, with only seven refineries reporting injection in 1994.

Table 19 presents the 1994 data aggregated for all caustic types as well as the data from previous survey cycles. In this longitudinal context, the quantities recycled in crude units and other in-process methods reported in 1994 are noteworthy. Exploring this further, however, reveals these practices were performed by only one refinery.

Table 19. Management Techniques Used for Spent Caustics: 1987 - 1994 (Industry Estimates)

	1994	1993	1992	1991	1990	1989	1988	1987
QUANTITY MANAGED	1,378,167	1,434,128	1,427,544	908,055	894,258	715,541	655,528	674,524
MANAGEMENT TECHNIQUES								
RECYCLE								
In Process Recycle								
Crude Unit	16,786	618	1,199	267	43	13		
Desalter						3,068	231	225
Catalytic Cracker			1,429					
Other In-Process Recycle	15,860	761	2,808	3,418				
Out-of-Process Recycle								
Reclamation	240,328	472,203	484,086	204,681	235,667	172,974	147,181	172,294
Regeneration	116,057	164,809	189,674	281,545	299,164	286,277	95,365	89,536
Other Out-of-Process Recycle	10,459	67,871	63,121	19,728				
Industrial Furnace					1,786			
Other Recycle	207,178	32,836	21,423	136,724	92,840	99,543	169,428	153,080
TOTAL	615,488	739,098	763,740	646,363	629,500	561,875	412,205	415,135
TREATMENT								
Chemical	1,953	27	1,667	37	69,953	8,024	17,634	16,601
Wastewater Treatment	728,863	660,292	630,088	228,835	132,680	93,823	74,057	87,080
Incineration		20				82	409	442
Stabilization								
Other Treatment	1,144	307					38,888	38,256
TOTAL	731,960	660,646	631,755	228,872	202,633	101,929	130,988	142,379
LAND TREATMENT				7			237	2,239
DISPOSAL								
Impoundment					90	248	1,945	1,376
Landfill	1,682			75	925	409	588	422
Injection	27,291	33,908	29,057	31,575	32,213	13,664	23,989	32,811
Other Disposal		476	524	1,163	577	308	337	463
TOTAL	28,973	34,384	29,581	32,813	33,805	14,629	26,859	35,072

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It is interesting that the quantities recycled by reclamation between 1992 and 1994 were greater than those reported as regenerated. This pattern reversed itself between 1989 and 1991, while reclamation predominated in 1987 and 1988. This may simply be another instance where respondent bias affects the data (i.e., individuals completing the forms do not use consistent definitions of reclamation and regeneration).

DISCUSSION

API has now accumulated eight years of consecutive data on the management of residual materials in the petroleum refining industry. Each new year of data has improved understanding of the factors that influence residual generation patterns and trends in handling practices. For example, the survey allowed API to track abnormal or one-time generation of residuals that result from non-routine activities such as construction or remediation projects. These data helped to demonstrate how beneficial activities can produce overall increases in the amount of residuals handled by the industry. These spikes, as witnessed with pond sediments in 1990 or contaminated soils in 1992 and 1993, can overwhelm reductions, such as those achieved with the RCRA regulated K-wastes.

The 1994 data enabled some new observations:

- The generation rates for Pond Sediments and Contaminated Soils have dropped from the peaks observed in the early 1990s. These streams continue to be some of the most widely reported residuals across the industry, but the amounts reported by each refinery are now quite small.

- Since 1992, the industry has used substantially more hydroprocessing catalysts than used previously. This may reflect that refineries are running higher sulfur content crudes.

- The managed quantity of the Primary Sludge residual stream reached a new high in 1994, with at least 20 percent due to one-time events (associated with the deadlines to close or retrofit surface impoundments that handle TC wastewaters or Primary Sludges). As in 1992 and 1993 when refiners reported increased quantities from one-time events prior to the effective dates of the land disposal restrictions, 1994 witnessed the effect of another new regulation. That is, managed quantities increased as part of the preparatory activities necessary to come into compliance with the new surface impoundment regulation.

- Based on a comparison of refineries that reported both in 1994 and 1993, it appears that generation of TC wastewater continues to decrease, with the majority of these waters (63 percent in 1994) managed solely in tanks.[7]

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[7] It should be noted that with the availability of 1993 RCRA Biennial Survey data, API attempted to replicate its analysis comparing the information on residual streams and TC wastewater compiled in the API survey to the values published by EPA. For 1993, comparison of the values for the 10 refineries, identified by EPA as large quantity generators and were participants in the API survey, indicated a difference greater than the 4.5 percent difference observed with the 1991 data. Review of the 1993 data revealed that there were several cases with large discrepancies between the EPA and API values. Subsequent discussions with these refineries clarified the differences which included one case where the value reported to EPA had been inexplicably doubled, inconsistent reporting of TC wastewaters managed in tanks (i.e., sometimes this quantity was not subtracted from the quantity reported as hazardous by EPA), and variability between the two surveys regarding the point of generation of the TC wastewaters. Taking this into consideration, a re-analysis of the 1993 data revealed a

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When the managed quantities of all residual streams reported in 1994 are aggregated, the resulting total is 4.8 million wet tons. As shown in Figure 32, this is comparable to the quantity reported in 1992, and is somewhat less than the high observed in 1990. The one-time quantity of Primary Sludges and the increase in Hydroprocessing Catalysts contribute to making this last cycle the third largest documented by this survey.

Figure 32. Summary of Residual Generation: 1987 - 1994 (represents 15 residual streams)

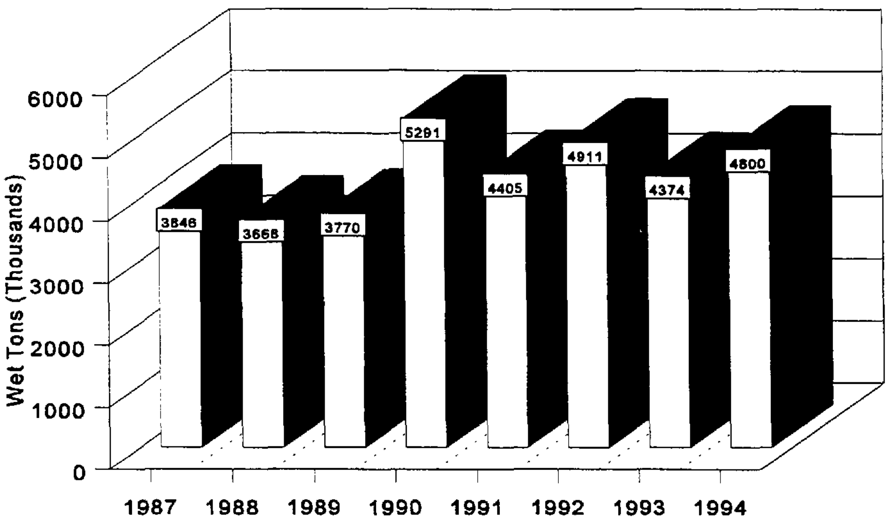
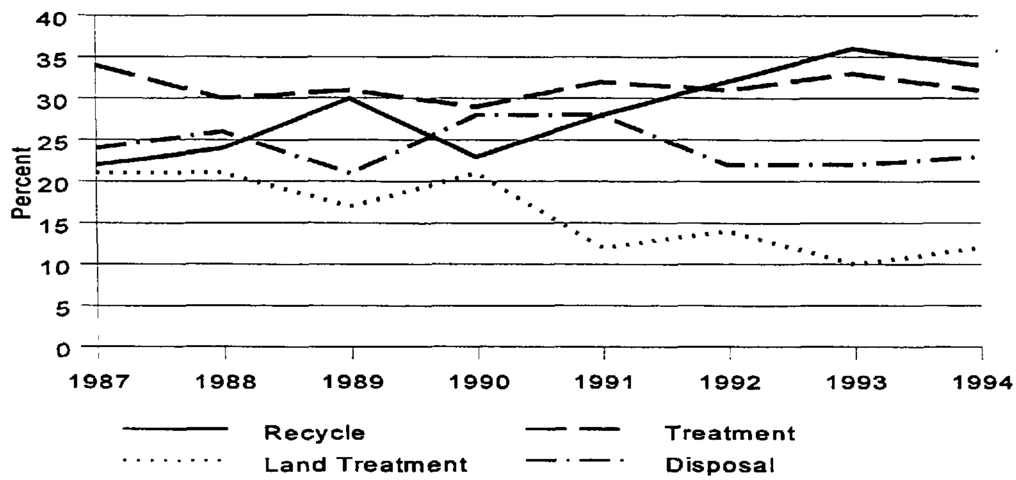


Figure 33 shows how these streams were managed. Since 1990, the industry has increased its reliance on recycling. Treatment continues to account for slightly more than 30 percent of the residuals, but since 1992 more material has been recycled than treated. At the same time, use of land treatment has diminished substantially. Disposal, which peaked between 1990 and 1991, seems to have stabilized at a low level comparable to that observed in 1989.

Figure 33. Trends in Management Practices



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4 percent difference between the two surveys. Thus, its appears that the large numbers reported by the EPA Biennial Survey as hazardous wastes continue to be dominated by TC wastewaters which are decharacterized and managed under the strict requirements of the Clean Water Act and therefore pose little, if any, threat to human health or the environment.

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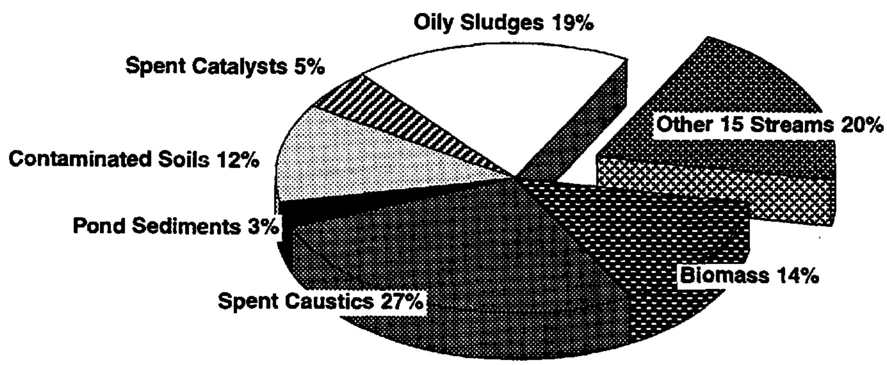
In viewing these graphic summaries, one must also consider that theses are representations of a *sub-set* of the residuals managed by the refining industry. Recall that API reduced the number of streams included in the survey from 30 to 15. Consequently the data used to create Figures 32 and 33 were based on the 15 streams that were retained for 1994.

To provide a better understanding for viewing these industry totals, the managed quantities observed in 1993 for the complete dataset of 30 streams are graphically presented below. As indicated, the 15 streams that were not included in the 1994 questionnaire (labelled "15 Other Streams" below) constituted only 20 percent of the total quantity managed in 1993. It is reasonable to assume that this remained constant in 1994.

Figure 34. Managed Quantities of All Residual Materials: 1993



Thus, API has been able to continue the collection and analysis of data on the overwhelming majority of residual materials, but by reducing the number of streams, has minimized the survey effort. Refiners responded positively to these changes, reporting that the new, abbreviated forms were much easier to complete.

Another benefit of revising the survey has been a significant reduction in the overall cost and time required to complete the analysis and reporting of the data. Moving to the PC platform has also facilitated the analysis and the development of the benchmarking reports for survey participants. These new feedback reports, combined with the stream by stream reporting format adopted in this report, should enhance the utility of the data to the refiners and sustain this survey effort in future years.

API will also continue to collect information on the management costs for selected streams in future surveys. As would be expected with a first attempt to collect data on a complex parameter such as cost, API noted substantial variability in the data reported. Some of this variability was related to the management practices utilized and the quantity of residuals managed. For example, refineries that recycled API Separator Sludge in their cokers and sent filter cake to cement kilns incurred lower unit costs than refineries that sent the material to commercial incinerators. Similarly, refineries that managed large quantities of a residual, incurred lower costs per ton.

The range of *on-site* management costs was broad, with the sources of variability more difficult to isolate. In part, this was related to the question format. Refiners were asked to report the total cost for all on-site activities as a single variable. Thus, this estimate reflected an aggregation of the costs calculated for different management techniques, (e.g., the unit costs for in-process recycling, filter

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pressing, and wastewater treatment), as well as the inclusion (or omission) of cost factors to cover operating and maintenance expenses. Review of the data across streams also suggests that on-site cost components were considered differentially, based on the residual under consideration. For example, refiners that managed hydroprocessing catalysts off-site were more likely to include some estimate of associated on-site costs than were refiners that managed API Separator Sludge off-site. Modification of the question for the 1995 survey cycle should help standardize the responses.

Despite the imprecision of the responses, the inclusion of these questions on management costs in the survey has already benefited the industry. API has gained a better understanding of the magnitude of costs associated with managing residual streams. At the same time, an appreciation of the complexity, and inherent difficulty of total cost accounting procedures has developed. API anticipates that its efforts to improve collection of cost information in the future will result not only in more accurate estimates of residual management expenditures, but also, as the information is circulated among survey participants as benchmark reports, refiners will glean an increased awareness of the relative efficiencies of the various handling practices.

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Appendix A - Copy of the Questionnaire

NOTE:

The datasheet for API Separator Sludge contains the questions on management costs; this same form was used to collect data on Hydroprocessing Catalysts and Sulfidic Caustics.

The datasheet for DAF Float was used to collect information on all other residual streams except those that had a unique section on the sources of the soil.

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API REFINING RESIDUAL SURVEY - 1994

Company Name: ______________________________

Facility Name: ______________________________

Street: ______________________________

City: ______________________________

State: ______ **Zip:** __________

Contact Name: ______________________________

Title: ______________________________

Phone: ____________________ x ________

Alternative Contact

Name: ______________________________

Phone ____________________ x ________

Completed surveys should be returned to:
Brad Jones
American Petroleum Institute
Health and Environmental Affairs Department
1220 L Street NW
Washington, D.C. 20005

If you have any questions on the **purpose** of this survey or how the data will be used, please contact Brad Jones at (202) 682-8343.

If you have any **technical questions** on how to respond to the survey, please contact Wendall Clark at (914) 227-6304.

Please return completed survey by JUNE 20, 1995

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1) What was the approximate year this facility began operations? Check the appropriate box.

- ☐ Before 1925
- ☐ 1925 - 1940
- ☐ 1941 - 1950
- ☐ 1951 - 1960
- ☐ 1961 - 1970
- ☐ 1971 - 1980
- ☐ After 1980

2) Which of the following USEPA National Pollutant Discharge Elimination System (NPDES) - Permit Fact Sheet Classifications best describes this refinery?

Check the appropriate box

- ☐ **Topping** - Refinery uses topping and catalytic reforming, but not thermal processes or cracking.
- ☐ **Cracking** - Refinery uses topping and cracking, but none of the operations designated in the categories below.
- ☐ **Petrochemical** - Refinery uses topping and cracking, and 1) **at least 15%** of refinery production is first-generation petrochemicals and isomerization products (e.g., BTX, olefins), or 2) the refinery produces second-generation petrochemicals (e.g., alcohols, cumene), and 3) there is **no** lube oil manufacturing.
- ☐ **Lube** - Refinery uses topping, cracking, and lube oil manufacturing processes, but **not** petrochemical operations.
- ☐ **Integrated** - Refinery uses topping, cracking, lube oil, and petrochemical manufacturing processes.

(NOTE: If your facility does NOT fit one of these categories, please call Wendall Clark at (914) 227-6304 to clarify the types of operations performed at your facility.)

3) In 1994, what was this facility's operable crude oil capacity in BARRELS PER STREAM DAY as reported in the Oil & Gas Journal?

☐ Barrels per **Stream** Day

4) What was the **TOTAL AMOUNT** of crude processed (throughput) in 1994?

☐ Million Barrels

5) On how many days was crude charged in 1994?

☐ Days

6) What was the average weight percent of sulfur in the crude run at this refinery in 1994?

- ☐ <1 wt %
- ☐ 1 - 2 wt %
- ☐ > 2 wt %

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7) What types of equipment do you use at your refinery to manage process wastewater? (Note: You may check multiple boxes in each category.)

☐ No treatment prior to discharge (Go on to Question 9)

PRIMARY OIL/WATER SEPARATION
- ☐ Oil/water separator (e.g., API Separation, corrugated Plate Separator or Interceptor)
- ☐ Other

SECONDARY OIL/WATER SEPARATION
- ☐ Gas floatation (Dissolved or Induced Gas)
- ☐ Filtration (Dual or multi media)
- ☐ Other

SECONDARY BIOLOGICAL TREATMENT
(Do **NOT** include units used exclusively to manage sanitary wastewater)

Aerobic Processes
- ☐ Aerated lagoon
- ☐ Trickling filter
- ☐ Activated sludge
- ☐ Rotating biological contactor (RBC)
- ☐ Other

Anaerobic Process
- ☐ Anaerobic filters or contactors
- ☐ Other

TERTIARY/POLISHING TREATMENT
- ☐ Filtration (Dual or multi media)
- ☐ Carbon adsorbers (carbon columns)
- ☐ Biological denitrification
- ☐ Metals removal processes (ion exchange, precipitation, reverse osmosis)
- ☐ Other

8) What type of units do you use downstream of a Primary Oil/Water Separator (API separator) to manage stormwater and/or wastewater? (Note: "TANK" has the normal refinery definition, not the RCRA exemption definition.)

Check only one type:
- ☐ Tanks only
- ☐ Tanks & Surface Impoundments
- ☐ Surface Impoundments ONLY

If you use surface impoundments, indicate their acreage.

☐ Acres of RCRA permitted or interim status impoundments

☐ Acres of non-RCRA regulated impoundments

9) Use spaces below to report the amount of **WASTEWATER** (in WET TONS) that failed the Toxicity Charactersitic (TC) and that was:

TC Hazardous Wastewater

☐ Managed SOLELY in tanks exempt from RCRA permitting prior to discharge.
(TC wastewater reported here should NOT be reported in any of the following categories)

☐ Treated as a TC hazardouse waste in a RCRA permitted surface impoundment prior to discharge

☐ Deep well injected

☐ Other

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10) How much water is discharged daily from your facility either through your NPDES permit, to a POTW or is deep-well injected? **(EXCLUDE once through cooling tower water that is NOT treated prior to discharge)**

☐ Million gallons/day (mgd)

Of this quantity, what percent is:

☐ % Process wastewater

☐ % Non-contact once through cooling tower water

☐ % *Treated* Stormwater

☐ % *Untreated* Stormwater

☐ % Treated groundwater

☐ % Other. Specify:__________

11) Characterize your refinery's effluent by providing the actual amount of each of the following discharge parameters.

Pounds/Year	
☐	TSS
☐	BOD
☐	COD
☐	Ammonia
☐	Oil & Grease
☐	Chromium
☐	Nickel
☐	Selenium

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12) The following question requests information on the **POLLUTION PREVENTION** (P2) activities that were performed during 1994. Spaces have been provided for you to indicate if you performed any pollution prevention activity for specific residual streams and to categorize the type of activity performed according to the codes listed below. Use the spaces to provide a brief description of 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

CHECK IF P2 ACTIVITIES PERFORMED	STREAM	CIRCLE ONE CODE	
☐	**API SEPARATOR SLUDGE**	1 2 3 4 5 6 7 8 9 10	DESCRIBE P2 ACTIVITY: ______
☐	**DAF FLOAT**	1 2 3 4 5 6 7 8 9 10	DESCRIBE P2 ACTIVITY: ______
☐	**SLOP OIL EMULSION SOLIDS**	1 2 3 4 5 6 7 8 9 10	DESCRIBE P2 ACTIVITY: ______
☐	**PRIMARY SLUDGE (F037)**	1 2 3 4 5 6 7 8 9 10	DESCRIBE P2 ACTIVITY: ______
☐	**PRIMARY SLUDGE (F038)**	1 2 3 4 5 6 7 8 9 10	DESCRIBE P2 ACTIVITY: ______
☐	**TANK BOTTOMS**	1 2 3 4 5 6 7 8 9 10	DESCRIBE P2 ACTIVITY: ______

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12) **P2** (CONTINUED)

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

CHECK IF P2 ACTIVITIES PERFORMED	STREAM	CIRCLE ONE CODE	
☐	**CONTAMINATED SOILS**	1 2 3 4 5 6 7 8 9 10	DESCRIBE P2 ACTIVITY: ________
☐	**POND SEDIMENTS**	1 2 3 4 5 6 7 8 9 10	DESCRIBE P2 ACTIVITY: ________
☐	**BIOMASS**	1 2 3 4 5 6 7 8 9 10	DESCRIBE P2 ACTIVITY: ________
☐	**FCCU CATALYSTS**	1 2 3 4 5 6 7 8 9 10	DESCRIBE P2 ACTIVITY: ________
☐	**HYDRO PROCESSING CATALYSTS**	1 2 3 4 5 6 7 8 9 10	DESCRIBE P2 ACTIVITY: ________
☐	**OTHER CATALYSTS**	1 2 3 4 5 6 7 8 9 10	DESCRIBE P2 ACTIVITY: ________
☐	**SPENT CAUSTICS**	1 2 3 4 5 6 7 8 9 10	DESCRIBE P2 ACTIVITY: ________

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DID YOUR FACILITY GENERATE/MANAGE: **API SEPARATOR SLUDGE - K051 (CODE 101)** ? YES / NO

MANAGED QUANTITY	1994 RESIDUAL MANAGEMENT PRACTICES								
	ELIMINATED BY RECYCLE			ELIMINATED BY TREATMENT			ELIMINATED BY DISPOSAL		
This refers to the amount of residual generated + treatment additives + materials taken out of storage (minus any residual placed into storage). Report the QUANTITY MANAGED in the box at bottom of this column. Note this should equal the amount Recycled + Treated + Disposed	TECHNIQUE	WET TONS ON-SITE	WET TONS OFF-SITE	TECHNIQUE	WET TONS ON-SITE	WET TONS OFF-SITE	TECHNIQUE	WET TONS ON-SITE	WET TONS OFF-SITE
	COKER	______	______	WASTEWATER TREATMENT	______	______	LANDFILL	______	______
	CRUDE UNIT	______	______	HEAT	______	______	OTHER Code: D____	______	______
	CEMENT KILN FUEL	______	______	INCINERATION	______	______			
	CEMENT KILN FEEDSTOCK	______	______	PHYSICAL	______	______			
TOTAL QUANTITY MANAGED	OTHER Code: R____	______	______	OTHER Code: T____	______	______			
[ ]	=	[ ]		+	[ ]		+	[ ]	

% ABNORMAL/ONE-TIME GENERATION
If any of the residual material generated this year resulted from an abnormal or unusual event (e.g., closure of a unit, construction, site remediation or other one-time event), report this as a percentage of the Total Quantity Managed in the box to the right. [ ] %

TOTAL 1994 COST OF RESIDUAL MANAGEMENT PRACTICES Provide as many cost components as possible; *at the very least*, estimate the **Total** on-site and off-site costs.

ON-SITE MANAGEMENT COSTS

TOTAL $

What factors were included in this estimate? (Check all that apply) ☐ Capitalization of equipment ☐ Operating expenses (maintenance, labor, utilities) ☐ Contractual costs (equipment lease, labor)

OFF-SITE MANAGEMENT COSTS

RECYCLE $ + TREATMENT $ + DISPOSAL $ + ANALYTICAL $ + TRANSPORTATION $ + TAXES $ = TOTAL $

BASIS OF COST DATA: (Check only one) ☐ Actual costs/receipts ☐ Estimates/professional judgement ☐ Rough Guess

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DID YOUR FACILITY GENERATE/MANAGE: **DAF FLOAT - K048 (CODE 102)?** YES / NO

MANAGED QUANTITY	1994 RESIDUAL MANAGEMENT PRACTICES								
This refers to the amount of residual generated + treatment additives + materials taken out of storage (minus any residual placed into storage). Report the QUANTITY MANAGED in the box at bottom of this column. Note this should equal the amount Recycled + Treated + Disposed.	ELIMINATED BY RECYCLE			ELIMINATED BY TREATMENT			ELIMINATED BY DISPOSAL		
	TECHNIQUE	WET TONS ON-SITE	WET TONS OFF-SITE	TECHNIQUE	WET TONS ON-SITE	WET TONS OFF-SITE	TECHNIQUE	WET TONS ON-SITE	WET TONS OFF-SITE
	COKER	____	____	WASTEWATER TREATMENT	____	____	LANDFILL	____	____
	CRUDE UNIT	____	____	HEAT	____	____	OTHER Code: D____	____	____
	CEMENT KILN FUEL	____	____	INCINERATION	____	____			
	CEMENT KILN FEEDSTOCK	____	____	PHYSICAL	____	____			
TOTAL QUANTITY MANAGED	OTHER Code: R____	____	____	OTHER Code: T____	____	____			
[ ]	=	[ ]	+		[ ]	+		[ ]	

% ABNORMAL/ONE-TIME GENERATION
If any of the residual material generated this year resulted from an abnormal or unusual event (e.g., closure of a unit, construction, site remediation or other one-time event), report this as a percentage of the Total Quantity Managed in the box to the right. [ ] %

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DID YOUR FACILITY GENERATE/MANAGE: **CONTAMINATED SOILS (CODE 202)?** YES / NO

MANAGED QUANTITY	1994 RESIDUAL MANAGEMENT PRACTICES								
	ELIMINATED BY RECYCLE			ELIMINATED BY TREATMENT			ELIMINATED BY DISPOSAL		
This refers to the amount of residual generated + treatment additives + materials taken out of storage (minus any residual placed into storage). Report the QUANTITY MANAGED in the box at bottom of this column. Note this should equal the amount Recycled + Treated + Disposed.	TECHNIQUE	WET TONS ON-SITE	WET TONS OFF-SITE	TECHNIQUE	WET TONS ON-SITE	WET TONS OFF-SITE	TECHNIQUE	WET TONS ON-SITE	WET TONS OFF-SITE
	IN-PROCESS RECYCLE	______	______	INCINERATION	______	______	LANDFILL	______	______
	OTHER Code: R____	______	______	HEAT	______	______	OTHER Code: D____	______	______
				OTHER Code: T____	______	______			
TOTAL QUANTITY MANAGED [ ]	=	[ ]		+	[ ]		+	[ ]	

↪ **% ABNORMAL/ONE-TIME GENERATION** [ ] %

If any of the residual material generated this year resulted from an abnormal or unusual event (e.g., closure of a unit, construction, site remediation or other one-time event), report this as a percentage of the Total Quantity Managed in the box to the right.

SOURCE OF CONTAMINATED SOILS

To help API characterize the contaminated soils generated by the industry, indicate the percentage of the total quantity of contaminated soil that was managed in 1994 that was generated as a result of the following types of activities:

- [ ] % from Spills
- [ ] % from Construction
- [ ] % from Remediation subject to Agency mandate
- [ ] % from Remediation (voluntary)
- [ ] % from Other activities. Specify:______________

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Appendix B - Description of Statistical Procedures

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DATA ANALYSES

This is a summary of the analytical techniques that were used with the 1994 survey data. It describes the selection of a regression model to project residual quantities reported by refineries in this survey to the entire refining industry. It also explains the statistical techniques used to estimate the variance and prediction limits for the residual quantities and how estimates for individual residual streams (e.g., API separator sludge) were made.

REGRESSION MODEL

Model Selection

One of the objectives of this survey is to estimate residual quantities for the entire refining industry based on the data from the subset of refineries responding to the survey. API has conducted this type of survey since 1987 and has consistently found that throughput capacity to be the best predictor of residual quantity. The general linear model that has been used in the previous surveys relates the square root of the residual quantity, *R*, for an individual refinery directly to throughput capacity, *C*, as shown in the following equation:

$$\sqrt{R} = b_0 + b_1 C$$

where b_0 is the intercept and b_1 is the slope of the regression line. The goodness-of-fit of this model to the 1994 data is discussed in the following sections.

Changes in Data Collection

Two changes were made to the 1994 survey that had the potential to impact the data analyses. The first change was in the types of residual streams that were reported. In previous surveys, facilities were required to report all residual streams, subdivided into approximately 30 categories. In 1994, API decided to focus the survey on those streams that were of significant volume or regulatory importance; 14 streams were identified. Although representing less than half of the types of residuals that are generated by the refining industry, these 14 residuals account for more than 75% of the total quantity.[1]

Prior to sending out the 1994 survey, data from the 1993 survey for these 14 residuals were plotted in a scattergram versus throughput capacity to determine if the above regression model would be impacted by this change. Very little change was noticed in the overall pattern of the data when compared to the scattergram containing all residuals. Therefore, it was concluded that this change in the 1994 survey would not require a new regression model.

The second change that was made to the 1994 survey concerned generation versus managed quantities. Until the 1994 survey, both generated and managed quantities were reported; in 1994,

[1]These 14 residuals account for 75% of all residual quantities in the 1991 survey, 79% in the 1992 survey, and 84% in the 1993 survey.

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only managed quantities were reported. Generation may differ from management because management can include additional quantities from treatment additives or change when residuals are placed into or taken out of storage. Often, the differences between generation and management are small and do not affect trends. In previous surveys, error estimates had been calculated for the individual residual streams to help in judging the precision of the residual quantities and in deciding whether trends were real or just part of the natural variability in the data. However, analysis of the 1994 data showed that there were enough differences in some streams to make the trend graphs questionable. Therefore, the error estimates for 1994 are only presented as precision estimates for the 1994 data and not for the purpose of analyzing trends. Changing from generated to managed quantities, fortunately, did not affect the choice of regression model which, prior to 1994, had always been applied to generated quantities. The 1994 managed quantities are represented by the linear regression model well, as demonstrated in the following section.

Fitting Model to 1994 Data

Data from the present survey (82 plants) were plotted in a scattergram (square roots of residuals vs. capacity) as a visual check to see if the model used in previous surveys was still a good fit. The regression line drawn through the data indicated that the model was acceptable. There was, however, a distinct break in the data around 300,000 barrels per stream day (bsd) with six plants in the higher capacity group widely separated from the smaller capacity plants. The variability in residual quantities of these six plants was also much greater than the other plants as shown by the dispersion of the data points around the regression line. Because the regression equation is used to estimate residual quantities for plants that do not respond to the survey, it is important that the regression not include plants that are unrepresentative. To help in deciding whether these six plants were representative of the nonrespondents, the capacities of the nonrespondents were reviewed. Since the highest capacity of the nonrespondent group was 310,000 bsd, it was decided to leave these six plants out of the regression analyses. No outliers were identified for the smaller capacity plants; all 76 plants were used in the regression analyses.

The regression equation developed from these 76 plants is:

$$\sqrt{R} = 46.284 + 8.9652 \times 10^{-4} C$$

with a coefficient of determination (COD), r^2, of 0.59. This COD is similar to values obtained in the previous surveys. The test of the correlation coefficient, r, by the following statistic:[2]

$$t = \frac{r\sqrt{n-2}}{\sqrt{1-r^2}} = \frac{0.77\sqrt{74}}{\sqrt{1-0.59}} = 10.3$$

shows that the correlation coefficient is significant at the 99% level.

Both the slope and intercept of the regression equation were tested for significance using Student's t test. A parameter value is considered significant in the regression model if it is found to be significantly different from zero. The t value for the slope and intercept are calculated by the

[2]Bhattacharyya, Gouri K. and Richard A. Johnson, 1977, *Statistical Concepts and Methods*, John Wiley & Sons, New York, pg. 411.

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following equation:[3]

$$t = \frac{x}{SE}$$

where x is the value of the parameter to be tested and SE is the standard error of the value. The standard errors for the slope and intercept are 8.6525×10^{-5} and 10.208, respectively. The t values for the slope and intercept are 10.36 and 4.53, respectively. The critical t value at a significance level of 95% (two-tailed test) with 74 degrees of freedom is 1.99. Both values are greater than the critical t, so both the slope and intercept values are considered significant.

INDUSTRY ESTIMATES

The first step in calculating residual quantities for the refining industry is to estimate the residual quantity for each facility that did not respond to the survey, using the above regression equation. However, the regression equation operates with the square root of the residual quantity, so it is a biased estimator and requires a correction factor to yield an unbiased estimate. After the bias correction is made to each facility estimate, the nonrespondent quantities are summed and added to the sum of the respondent quantities. This yields the total residual estimate for the refining industry. The reliability of this estimate can be stated as a percent error. In statistical terms, a prediction interval is calculated from the variance of the estimate and translated to a percent error. Both the bias correction and variance calculations are explained below.

Nonrespondent Estimates

Biased Estimate

The biased estimate for each nonrespondent is calculated as follows:

$$\sqrt{R} = b_0 + b_1 C$$

$$\sqrt{R} = 46.284 + 8.9652 \times 10^{-4} C$$

$$R = (\sqrt{R}\,)^2$$

For example, for a throughput capacity of 72,000 bsd, the biased estimate of residual quantity would be 12,284 tons as shown below:

$$\sqrt{R} = 46.284 + 8.9652 \times 10^{-4}(72{,}000)$$
$$= 110.83$$

$$R = (110.83)^2$$
$$= 12{,}284$$

[3]Neter, John and William Wasserman, 1974, *Applied Linear Statistical Models: Regression, Analysis of Variance, and Experimental Design*, Richard D. Irwin, Inc., Homewood, IL, pp. 53-62.

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Bias Correction

The bias correction factor is derived from the following relationship:[4]

$$V(\sqrt{R}) = E(R) - [E(\sqrt{R})]^2$$

where V is the variance and E is the expected value. Rearranging the above equation to solve for $E(R)$ and using R^* to represent $E(R)$, the expected or unbiased value, the following equation is obtained:

$$E(R) = [E(\sqrt{R})]^2 + V(\sqrt{R})$$
$$R^* = R + V(\sqrt{R})$$

The variance in the above equation is calculated from the equation[5] below for an individual facility i. This equation represents the variance of a *new* observation, independent of the values from which the regression analysis is based.

$$V(\sqrt{R_i}) = MSE\left[1 + \frac{1}{n} + \frac{(C_i - \overline{C})^2}{\Sigma(C - \overline{C})^2}\right]$$

The *MSE* is the mean square error of the original data. An example calculation is shown below for the same 72,000 bsd facility. The average capacity and sum of squares from the original 76 values upon which the regression is based are 94,793 and 374,920,064,673, respectively. The *MSE* is 2,807.

$$V(\sqrt{R_i}) = 2807\left[1 + \frac{1}{76} + \frac{(72{,}000 - 94{,}793)^2}{374{,}920{,}864{,}673}\right]$$
$$= 2848$$

Therefore, the unbiased residual estimate for a 72,000 bsd facility is 15,132 tons, as show by the following calculation:

$$R^* = 12{,}284 + 2{,}848$$
$$= 15{,}132$$

Variance of the Unbiased Estimate

Each residual estimate for a nonrespondent has a variance associated with it. This variance is the variance of the *unbiased* estimate which is different from the variance discussed previously (i.e., the variance associated with the regression value, or the square root of the biased value). The variance of

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[4]Meyer, Paul L., 1970, *Introductory Probability and Statistical Applications*, 2nd ed., Addison-Wesley Publishing Company, Reading, Massachusetts, pp. 134-135.

[5]*Op. cit.*, *Applied Linear Statistical Models*, pp. 69-74.

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the unbiased estimate, based on the equation for R^*, is:

$$V(R') = V(R) + V[V(\sqrt{R})]$$

The first term in the above equation, the variance of R or $V(R)$, can be derived from the following relationship:[6]

$$V(R) \cong \left[\frac{\partial R}{\partial\sqrt{R}}\right]^2 V(\sqrt{R}) = \left[\frac{\partial(\sqrt{R})^2}{\partial\sqrt{R}}\right]^2 V(\sqrt{R})$$
$$= [2\sqrt{R}]^2 V(\sqrt{R})$$
$$= 4R \times V(\sqrt{R})$$

The second term is the variance of a variance. If σ^2 represents a variance, then the variance of σ^2 is:[7]

$$V(\sigma^2) = \frac{2\sigma^4}{n-1}$$

Rewriting the above equation in terms of R, the second term becomes:

$$V[V(\sqrt{R})] = \frac{2[V(\sqrt{R})]^2}{n-1}$$

Putting both the first and second terms together, the variance of the unbiased estimate can now be stated as:

$$V(R^*) = 4R \times V(\sqrt{R}) + \frac{2[V(\sqrt{R})]^2}{n-1}$$

For the 72,000 bsd facility, the variance of the estimated residual quantity (15,132 tons) is therefore:

$$V(R^*) = 4(12{,}284)(2{,}848) + \frac{2(2{,}848)^2}{76-1}$$
$$= 140{,}155{,}624$$

Total Residuals For Industry

The total estimated residual quantity for the refining industry is the sum of the residual quantities

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[6] *Op. cit.*, *Introductory Probability and Statistical Applications*, pg. 139.

[7] Bury, Karl V., *Statistical Models in Applied Science*, Wiley-Interscience, New York, pp. 249-250.

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reported by facilities in the survey and the nonrespondent estimates. For the 1994 survey, the sum of the respondents' residuals is 3,139,513 tons. The estimated residual total for the nonrespondents is 1,660,656 tons. Therefore, the total estimate for the refining industry is 4,800,169 tons.

Variance of the Total Residual

The variance of the total residual estimate for the refining industry is the sum of the variances associated with the individual facilities. The residual quantities of the respondents are taken as known values which have no variance. Therefore, only the nonrespondents contribute to the variance of the total estimate. Since the total residual quantity for the industry, T, is a linear combination (sum) of the individual facility quantities, the total variance is calculated by the following equation:[8]

$$V(T) = V(R_1^*) + V(R_2^*) + \ldots + V(R_n^*)$$

The sum of the nonrespondent variances for the 1994 survey is 17,050,312,772.

Prediction Interval for Total Residuals Estimate

The prediction interval for the industry residuals estimate is based on the total variance and the confidence level chosen for the estimate. For a 95% confidence coefficient, the prediction interval is calculated by the following equations:[9]

$$T_U = T + 2\sqrt{V(T)}$$
$$T_L = T - 2\sqrt{V(T)}$$

where T_U and T_L are the upper and lower limits, respectively. Using the above equations, the prediction interval for the total industry estimate is 4,539,015 to 5,061,322 tons.

The prediction interval can also be stated as a percent error, $E\%$. The percent error is calculated by the following equation:

$$E\% = \frac{2\sqrt{V(T)}}{T} \times 100\%$$

The percent error for the 1994 estimate is 5.44%.

RESIDUAL STREAM ESTIMATES

Allocation from Total Managed

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[8]Box, George E.P., William G. Hunter, and J. Stuart Hunter, 1978, *Statistics for Experimenters: An Introduction to Design, Data Analysis, and Model Building*, John Wiley & Sons, New York, pg. 87-88.

[9]*Op. cit.*, *Applied Linear Statistical Models*, pp. 71-74.

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The total industry residual estimate was subdivided into individual residual streams and management practices based on the proportion of each in the respondents' total. Proportions or ratios were calculated using the respondents' data without the higher capacity plants that had been excluded from the regression analysis. These ratios were multiplied by the nonrespondents total residual quantity to get the nonrespondents' contribution in each category.

An example with API separator sludge will illustrate this allocation method. The total quantity of residuals reported in the 1994 survey is 3,139,513 tons of which 119,827 tons are API separator sludge. The six higher capacity facilities that had been previously excluded from the regression analysis reported 1,320,899 tons of residuals, of which 11,750 tons are API separator sludge. The proportion of API separator sludge reported by the remaining 76 facilities is calculated as follows:

$$\frac{119{,}827-11{,}750}{3{,}139{,}513-1{,}320{,}899}=0.05943$$

The quantity of API separator sludge attributed to the nonrespondents was the above ratio multiplied by the total nonrespondent quantity (1,660,656 tons). The quantity of API separator sludge for nonrespondents was therefore:

$$0.05943(1{,}660{,}656)=98{,}690$$

The estimate for API separator sludge for the entire industry was therefore, 119,827+98,690, or 218,517 tons.

Stream Variances

Error or precision estimates for individual residuals are based on the variance for each stream which is derived from the equation used to estimate the residual quantity:

$$T_s=rT_N+T_{R,s}$$

where T_s is the total for the stream, r is the ratio or proportion of this stream relative to the respondents' total residuals (excluding the higher capacity plants), T_N is the nonrespondents' total, and $T_{R,s}$ is the respondents' total for the stream (including all plants). For the API separator sludge, this calculation as discussed previously is:

$$\begin{aligned}T_s&=0.05943(1{,}660{,}656)+119{,}827\\&=218{,}517\end{aligned}$$

The variance associated with T_s is:

$$V(T_s)=V(rT_N)+V(T_{R,s})$$

The stream residual total for the respondents is taken as a known value that has no variance, thus the above equation reduces to the first term.

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The first term, which is the product of two variables, can be estimated by the following equation:[10]

$$V(rT_N) = r^2 \times V(T_N) + T_N^2 \times V(r) + V(r) \times V(T_N)$$

The variance of T_N is 17,050,312,772 as shown previously. To determine the variance of the ratio, r, the ratio can be thought of as the sum of individual stream quantities for the respondents divided by the total residual quantities of the respondents. The total residual quantity of the respondents, T_R, is assumed to be a known value with no variance. Thus, the ratio can be written as:

$$r = \frac{q_1 + q_2 + \ldots + q_n}{T_R}$$

The variance of r can be written as:

$$V(r) = \left(\frac{1}{T_R}\right)^2 V(q_1 + q_2 + \ldots q_n)$$

The variance of a sum, assuming equal variances of the individual terms, is:

$$V(q_1 + q_2 + \ldots q_n) = nV(q)$$

Thus, the variance of the ratio is:

$$V(r) = \frac{nV(q)}{T_R^2}$$

In the above equation, the value of n represents the number of respondents that actually reported the stream. Thus, n may be different for each stream.

The percent error for each stream is calculated in the same fashion as described previously for the total industry estimate.

An example will help illustrate these calculations. In the 1994 survey, the ratio for API separator sludge is 0.05943 based on a total of 1,818,614 tons from the 76 plants used in the regression analysis. The variance of the quantities of API separator sludge reported in the survey (55 values) is 13,672,042.

The variance of the ratio of API separator sludge with respect to the total reported by the respondents is:

$$V(r) = \frac{55(13,672,042)}{1,818,614^2}$$
$$= 2.2736 \times 10^{-4}$$

[10]Benjamin, Jack R. and C. Allin Cornell, *Probability, Statistics, and Decision for Civil Engineers*, McGraw-Hill Book Co., New York, pp. 169-170.

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The variance of the stream estimate (218,517 tons) is:

$$V(rT_N) = 0.05943^2(17,050,312,772) + 1,660,656^2(2.2736\times10^{-4}) + (2.2736\times10^{-4})(17,050,312,772)$$
$$= 691,102,902$$

The percent error for the stream estimate is thus:

$$E\% = \frac{2\sqrt{691,102,902}}{218,517}\times100\%$$
$$= 24\%$$

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1994 API Residuals Survey
Stream Variances

Stream	Ratio	Var(Ratio)	Tons	Variance(Tons)	StdErr(Tons)	2*StdErr	%Error
101	0.05943	0.00000413	218,517	71,687,481	8,467	16,934	8%
102	0.14582	0.00010719	627,773	659,998,592	25,690	51,381	8%
103	0.01703	0.00000149	59,625	9,092,579	3,015	6,031	10%
106	0.00947	0.00000064	143,205	3,314,195	1,820	3,641	3%
110	0.08114	0.00001121	385,194	143,350,515	11,973	23,946	6%
111	0.00588	0.00000116	20,450	3,814,159	1,953	3,906	19%
112	0.02816	0.00000049	106,658	14,881,044	3,858	7,715	7%
202	0.14311	0.00001393	661,125	387,834,238	19,694	39,387	6%
301	0.07280	0.00001236	286,150	124,657,390	11,165	22,330	8%
302	0.01200	0.00000023	53,306	3,093,510	1,759	3,518	7%
303	0.00503	0.00000001	18,085	467,611	684	1,368	8%
401	0.20149	0.00002866	841,914	771,750,708	27,780	55,561	7%
501a	0.13527	0.00003648	1,001,630	413,219,791	20,328	40,656	4%
501b	0.05015	0.00011130	219,736	351,712,870	18,754	37,508	17%
501c	0.03322	0.00000184	156,801	23,921,297	4,891	9,782	6%
Total	1.00000		4,800,169	2,982,795,981			2%

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Appendix C - Data Tables

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Estimate of Residuals Managed by U.S. Refining Industry
(thousands of wet tons)

Code	Residual	1994	1993	1992	1991	1990	1989	1988	1987
101	API separator sludge (K051)	219	167	174	214	260	425	430	564
102	Dissolved air flotation float (K048)	628	520	546	410	564	521	661	654
103	Slop oil emulsion solids (K049)	60	56	74	160	295	262	214	212
106	Pond sediments	143	145	391	381	1,040	273	311	360
105	Other separator sludges					104	117	110	83
110	Primary sludge (F037)	385	226	247	133	*	*	*	*
111	Primary sludge (F038)	20	62	54	180	*	*	*	*
112	Tank bottoms (unleaded, leaded)	107	133	130	112	199	168	141	227
202	Contaminated soils and solids	661	631	953	785	915	496	242	186
301	FCC catalyst or equivalent	286	197	197	204	259	185	189	171
302	Hydroprocessing catalysts	53	52	51	33	30	36	37	39
303	Other spent catalysts	18	29	28	23	41	33	38	38
401	Biomass	842	722	641	862	794	655	749	720
501	Spent caustics (total)	1,378	1,434	1,425	908	894	716	656	675
501a	Spent sulfidic caustics	1,002	**	**	**	**	**	**	**
501b	Spent naphthenic caustics	220	**	**	**	**	**	**	**
501c	Spent cresylic caustics	157	**	**	**	**	**	**	**
	Total	4,800	4,374	4,911	4,405	5,395	3,887	3,778	3,929

* Not identified as specific residual category prior to 1991; included with other separator sludges.
** Not identified as specific residual category prior to 1994; included in total spent caustics.

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Number of Respondents Reporting Each Type of Residual

Code	Residual Total number of respondents	1994 (82)	1993 (89)	1992 (91)	1991 (113)	1990 (103)	1989 (117)	1988 (115)	1987 (115)
101	API separator sludge (K051)	60	70	72	76	85	93	94	91
102	Dissolved air flotation float (K048)	38	37	41	44	50	47	50	53
103	Slop oil emulsion solids (K049)	26	30	32	32	35	38	43	47
106	Pond sediments	20	14	16	25	34	31	29	26
105	Other separator sludges	—	—	—	—	19	22	20	15
110	Primary sludge (F037)	70	69	69	59	*	*	*	*
111	Primary sludge (F038)	11	11	11	14	*	*	*	*
112	Tank bottoms (unleaded, leaded)	67	**	**	**	**	**	**	**
104	Leaded tank bottoms	**	15	12	20	27	31	37	38
107	Nonleaded tank bottoms	**	67	64	69	72	72	75	72
202	Contaminated soils and solids	77	80	84	90	87	88	77	77
301	FCC catalyst or equivalent	60	63	69	76	79	84	86	85
302	Hydroprocessing catalysts	57	55	58	57	52	65	60	57
303	Other spent catalysts	61	59	60	63	57	60	60	62
401	Biomass	51	45	44	45	44	44	45	47
501	Spent caustics (total)	—	62	64	69	66	70	77	79
501a	Spent sulfidic caustics	64	***	***	***	***	***	***	***
501b	Spent naphthenic caustics	10	***	***	***	***	***	***	***
501c	Spent cresylic caustics	36	***	***	***	***	***	***	***

* Not identified as specific residual category prior to 1991; included with other separator sludges.
** Starting with 1994 survey, reported as combined residual stream.
*** Not identified as specific residual category prior to 1994; included in total spent caustics.

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Number of Respondents Reporting Each Type of Residual

Code **Residual** Total number of respondents	**1994** (82)	**1993** (89)	**1992** (91)	**1991** (113)	**1990** (103)	**1989** (117)	**1988** (115)	**1987** (115)
101 API separator sludge (K051)	60	70	72	76	85	93	94	91
102 Dissolved air flotation float (K048)	38	37	41	44	50	47	50	53
103 Slop oil emulsion solids (K049)	26	30	32	32	35	38	43	47
106 Pond sediments	20	14	16	25	34	31	29	26
110 Primary sludge (F037)	70	69	69	59	*	*	*	*
111 Primary sludge (F038)	11	11	11	14	*	*	*	*
112 Tank bottoms (unleaded, leaded)	67	**	**	**	**	**	**	**
104 Leaded tank bottoms	**	15	12	20	27	31	37	38
107 Nonleaded tank bottoms	**	67	64	69	72	72	75	72
202 Contaminated soils and solids	77	80	84	90	87	88	77	77
301 FCC catalyst or equivalent	60	63	69	76	79	84	86	85
302 Hydroprocessing catalysts	57	55	58	57	52	65	60	57
303 Other spent catalysts	61	59	60	63	57	60	60	62
401 Biomass	51	45	44	45	44	44	45	47
501 Spent caustics (total)	***	62	64	69	66	70	77	79
501a Spent sulfidic caustics	64	***	***	***	***	***	***	***
501b Spent naphthenic caustics	10	***	***	***	***	***	***	***
501c Spent cresylic caustics	36	***	***	***	***	***	***	***

* Not identified as specific residual category prior to 1991; included with other sludge-type residuals.
** Starting with 1994 survey, reported as combined residual stream.
*** Not identified as specific residual category prior to 1994; included in total spent caustics.

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Management Estimates for U.S. Refining Industry
(wet tons)

Code	Residual	Recycled	Treated	Land Treated	Disposed	Total
101	API separator sludge (K051)	87,259	119,244	1,442	10,572	218,517
102	Dissolved air flotation float (K048)	326,998	298,387	1,148	1,240	627,773
103	Slop oil emulsion solids (K049)	44,148	14,278	13	1,186	59,625
106	Pond sediments	2,405	22,372	22,401	96,027	143,205
110	Primary sludge (F037)	144,558	93,314	46,440	100,881	385,194
111	Primary sludge (F038)	14,285	1,839	-	4,326	20,450
112	Tank bottoms (unleaded, leaded)	20,107	17,681	10,650	58,220	106,658
202	Contaminated soils and solids	21,759	26,593	93,839	518,934	661,125
301	FCC catalyst or equivalent	110,425	68,873	12,067	94,785	286,150
302	Hydroprocessing catalysts	40,767	-	-	12,539	53,306
303	Other spent catalysts	5,819	140	444	11,683	18,085
401	Biomass	221,955	95,164	385,306	139,490	841,914
501a	Spent sulfidic caustics	332,137	651,422	-	18,071	1,001,630
501b	Spent naphthenic caustics	140,455	74,016	-	5,265	219,736
501c	Spent cresylic caustics	142,896	6,522	-	7,383	156,801
	Total	1,655,973	1,489,843	573,750	1,080,602	4,800,169

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Management Estimates for U.S. Refining Industry
(as percentage of quantity managed)

Code	Residual	Recycled	Treated	Land Treated	Disposed	Total Tons
101	API separator sludge (K051)	40%	55%	1%	5%	218,517
102	Dissolved air flotation float (K048)	52%	48%	0%	0%	627,773
103	Slop oil emulsion solids (K049)	74%	24%	0%	2%	59,625
106	Pond sediments	2%	16%	16%	67%	143,205
110	Primary sludge (F037)	38%	24%	12%	26%	385,194
111	Primary sludge (F038)	70%	9%	0%	21%	20,450
112	Tank bottoms (unleaded, leaded)	19%	17%	10%	55%	106,658
202	Contaminated soils and solids	3%	4%	14%	78%	661,125
301	FCC catalyst or equivalent	39%	24%	4%	33%	286,150
302	Hydroprocessing catalysts	76%	0%	0%	24%	53,306
303	Other spent catalysts	32%	1%	2%	65%	18,085
401	Biomass	26%	11%	46%	17%	841,914
501a	Spent sulfidic caustics	33%	65%	0%	2%	1,001,630
501b	Spent naphthenic caustics	64%	34%	0%	2%	219,736
501c	Spent cresylic caustics	91%	4%	0%	5%	156,801

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Estimated Recycle Techniques Used by U.S. Refining Industry
(wet tons)

Code	Residual	Coker	Crude Unit	Desalter	Cat Cracker	Recla-mation	Regen-eration	Cement Kiln Feedstock	Cement Kiln Fuel	Other In-Process Recycle	Other Out-of-Process Recycle	Other Ind. Fuel Reuse	Other Recyle	Total
101	API separator sludge (K051)	44,340	16,794	-	82	1,676	-	295	15,969	10	-	3,392	4,701	87,259
102	Dissolved air flotation float (K048)	170,199	84,829	-	36,748	-	-	945	4,358	19	-	1,523	28,377	326,998
103	Slop oil emulsion solids (K049)	7,955	18,483	-	10	-	-	-	6,398	10,836	-	279	187	44,148
106	Pond sediments	474	-	-	-	1,915	-	-	-	-	-	-	15	2,405
110	Primary sludge (F037)	99,850	1,389	-	-	231	-	107	8,692	33,442	312	153	383	144,558
111	Primary sludge (F038)	12,860	394	-	-	-	-	13	354	-	-	46	618	14,285
112	Tank bottoms (unleaded, leaded)	4,834	7,538	-	388	1,860	-	1,726	27	1,397	-	-	2,338	20,107
202	Contaminated soils and solids	-	1,626	-	-	980	-	1,473	-	4,163	5,000	-	8,517	21,759
301	FCC catalyst or equivalent	-	-	-	4,869	2,097	4,549	49,678	11,375	-	10,205	-	27,653	110,425
302	Hydroprocessing catalysts	-	-	-	-	26,835	9,271	-	-	-	-	-	4,660	40,767
303	Other spent catalysts	-	-	-	1,276	2,204	1,613	434	-	-	241	-	51	5,819
401	Biomass	82,171	-	-	50,316	2,104	-	-	-	2,569	-	46,989	37,806	221,955
501a	Spent sulfidic caustics	-	10,714	-	-	125,043	116,057	-	-	15,860	10,459	-	54,004	332,137
501b	Spent naphthenic caustics	-	6,072	-	-	41,990	-	-	-	-	-	-	92,393	140,455
501c	Spent cresylic caustics	-	8,820	-	-	73,295	-	-	-	-	-	-	60,781	142,896
	Total (tons)	422,684	156,658	-	93,689	280,230	131,491	54,671	47,172	68,295	26,217	52,382	322,485	1,655,973

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Recycle Techniques Used by Respondents
(number of respondents reporting each residual)

Code	Residual	Coker	Crude Unit	Desalter	Cat Cracker	Recla-mation	Regen-eration	Cement Kiln Feedstock	Cement Kiln Fuel	Other In-Process Recycle	Other Out-of-Process Recycle	Other Ind. Fuel Reuse	Other Recyle
101	API separator sludge (K051)	14	21	-	1	1	-	1	19	1	-	4	4
102	Dissolved air flotation float (K048)	13	13	-	2	-	-	1	12	1	-	3	3
103	Slop oil emulsion solids (K049)	7	8	-	1	-	-	-	9	2	-	1	1
106	Pond sediments	1	-	-	-	1	-	-	-	-	-	-	1
110	Primary sludge (F037)	9	8	-	-	2	-	2	17	2	1	2	2
111	Primary sludge (F038)	2	2	-	-	-	-	1	3	-	-	1	1
112	Tank bottoms (unleaded, leaded)	6	8	-	1	4	-	2	2	1	-	-	1
202	Contaminated soils and solids	-	1	-	-	2	-	1	-	2	1	-	3
301	FCC catalyst or equivalent	-	-	-	5	2	1	22	5	-	3	-	7
302	Hydroprocessing catalysts	-	-	-	-	40	22	-	-	-	-	-	2
303	Other spent catalysts	-	-	-	1	21	11	2	-	-	2	-	2
401	Biomass	3	-	-	1	1	-	-	-	1	-	1	2
501a	Spent sulfidic caustics	-	1	-	-	20	3	-	-	1	4	-	11
501b	Spent naphthenic caustics	-	1	-	-	4	-	-	-	-	-	-	2
501c	Spent cresylic caustics	-	1	-	-	18	-	-	-	-	-	-	10

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Estimated Recycling (On-Site, Off-Site) for U.S. Refining Industry
(wet tons)

Code	Residual	Tons	On-Site %	Off-Site %
101	API separator sludge (K051)	87,259	70%	30%
102	Dissolved air flotation float (K048)	326,998	97%	3%
103	Slop oil emulsion solids (K049)	44,148	58%	42%
106	Pond sediments	2,405	20%	80%
110	Primary sludge (F037)	144,558	70%	30%
111	Primary sludge (F038)	14,285	93%	7%
112	Tank bottoms (unleaded, leaded)	20,107	75%	25%
202	Contaminated soils and solids	21,759	20%	80%
301	FCC catalyst or equivalent	110,425	23%	77%
302	Hydroprocessing catalysts	40,767	4%	96%
303	Other spent catalysts	5,819	0%	100%
401	Biomass	221,955	79%	21%
501a	Spent sulfidic caustics	332,137	11%	89%
501b	Spent naphthenic caustics	140,455	4%	96%
501c	Spent cresylic caustics	142,896	15%	85%
	Total	1,655,973		

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Estimated Treatment Techniques Used by U.S. Refining Industry
(wet tons)

Code	Residual	Weather-ing	Chemical	Heat	Impound-ment	Physical	Waste-water Treatment	Incin-eration	Land Treatment	Stabili-zation	Other Treatment	Total
101	API separator sludge (K051)	-	-	5,672	-	233	100,327	8,615	1,442	-	4,396	120,686
102	Dissolved air flotation float (K048)	-	-	210	-	5,253	272,596	20,327	1,148	-	-	299,535
103	Slop oil emulsion solids (K049)	-	-	1,819	-	-	10,809	1,649	13	-	-	14,291
106	Pond sediments	-	-	1,954	-	-	350	20,068	22,401	-	-	44,773
110	Primary sludge (F037)	-	-	10,911	-	-	74,773	7,523	46,440	44	63	139,755
111	Primary sludge (F038)	-	-	-	-	-	1,519	266	-	-	54	1,839
112	Tank bottoms (unleaded, leaded)	-	-	-	-	356	12,349	2,705	10,650	465	1,806	28,331
202	Contaminated soils and solids	-	-	1,798	-	-	1,033	1,760	93,839	-	22,001	120,432
301	FCC catalyst or equivalent	-	-	-	-	-	68,873	-	12,067	-	-	80,940
302	Hydroprocessing catalysts	-	-	-	-	-	-	-	-	-	-	-
303	Other spent catalysts	-	40	-	-	-	-	46	444	50	4	584
401	Biomass	-	-	1,102	-	143	69,087	24,831	385,306	-	-	480,469
501a	Spent sulfidic caustics	-	1,773	-	-	-	648,505	-	-	-	1,144	651,422
501b	Spent naphthenic caustics	-	-	-	-	-	74,016	-	-	-	-	74,016
501c	Spent cresylic caustics	-	180	-	-	-	6,342	-	-	-	-	6,522
	Total (tons)	-	1,993	23,467	-	5,986	1,340,580	87,789	573,750	559	29,468	2,063,593

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Treatment Techniques Used by Respondents
(number of respondents reporting each residual)

Code	Residual	Weather-ing	Chemical	Heat	Impound-ment	Physical	Waste-water Treatment	Incin-eration	Land Treatment	Stabili-zation	Other Treatment
101	API separator sludge (K051)	-	-	4	-	2	22	26	3	-	3
102	Dissolved air flotation float (K048)	-	-	1	-	1	13	9	1	-	-
103	Slop oil emulsion solids (K049)	-	-	1	-	-	7	12	1	-	-
106	Pond sediments	-	-	2	-	-	2	5	6	-	-
110	Primary sludge (F037)	-	-	8	-	-	11	35	6	1	1
111	Primary sludge (F038)	-	-	-	-	-	2	3	-	-	1
112	Tank bottoms (unleaded, leaded)	-	-	-	-	3	7	22	11	1	2
202	Contaminated soils and solids	-	-	1	-	-	1	12	13	-	1
301	FCC catalyst or equivalent	-	-	-	-	-	1	-	2	-	-
302	Hydroprocessing catalysts	-	-	-	-	-	-	-	-	-	-
303	Other spent catalysts	-	2	-	-	-	-	2	2	1	1
401	Biomass	-	-	1	-	1	8	3	14	-	-
501a	Spent sulfidic caustics	-	3	-	-	-	24	-	-	-	2
501b	Spent naphthenic caustics	-	-	-	-	-	2	-	-	-	-
501c	Spent cresylic caustics	-	1	-	-	-	8	-	-	-	-

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Estimated Treatment (On-Site, Off-Site) for U.S. Refining Industry
(wet tons)

Code	**Residual**	**Tons**	**On-Site %**	**Off-Site %**
101	API separator sludge (K051)	119,244	90%	10%
102	Dissolved air flotation float (K048)	298,387	99%	1%
103	Slop oil emulsion solids (K049)	14,278	88%	12%
106	Pond sediments	22,372	10%	90%
110	Primary sludge (F037)	93,314	90%	10%
111	Primary sludge (F038)	1,839	83%	17%
112	Tank bottoms (unleaded, leaded)	17,681	71%	29%
202	Contaminated soils and solids	26,593	87%	13%
301	FCC catalyst or equivalent	68,873	100%	0%
302	Hydroprocessing catalysts	-	N/A	N/A
303	Other spent catalysts	140	0%	100%
401	Biomass	95,164	61%	39%
501a	Spent sulfidic caustics	651,422	99.7%	0.3%
501b	Spent naphthenic caustics	74,016	100%	0.0%
501c	Spent cresylic caustics	6,522	99.9%	0.1%
	Total	1,489,843		

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Estimated Land Treatment (On-Site, Off-Site) for U.S. Refining Industry
(wet tons)

Code	Residual	Tons	On-Site %	Off-Site %
101	API separator sludge (K051)	1,442	100%	0%
102	Dissolved air flotation float (K048)	1,148	100%	0%
103	Slop oil emulsion solids (K049)	13	100%	0%
106	Pond sediments	22,401	99%	1%
110	Primary sludge (F037)	46,440	100%	0%
111	Primary sludge (F038)	-	N/A	N/A
112	Tank bottoms (unleaded, leaded)	10,650	100%	0%
202	Contaminated soils and solids	93,839	89%	11%
301	FCC catalyst or equivalent	12,067	100%	0%
302	Hydroprocessing catalysts	-	N/A	N/A
303	Other spent catalysts	444	86%	14%
401	Biomass	385,306	100%	0%
501a	Spent sulfidic caustics	-	N/A	N/A
501b	Spent naphthenic caustics	-	N/A	N/A
501c	Spent cresylic caustics	-	N/A	N/A
	Total	573,750		

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Estimated Disposal Techniques Used by U.S. Refining Industry
(wet tons)

Code	Residual	Impound-ment	Land-fill	Land-spread	Injection	Other Disposal	Total
101	API separator sludge (K051)	-	10,298	-	-	274	10,572
102	Dissolved air flotation float (K048)	-	1,240	-	-	-	1,240
103	Slop oil emulsion solids (K049)	-	1,186	-	-	-	1,186
106	Pond sediments	-	96,027	-	-	-	96,027
110	Primary sludge (F037)	86	100,624	-	-	170	100,881
111	Primary sludge (F038)	2,009	2,317	-	-	-	4,326
112	Tank bottoms (unleaded, leaded)	-	54,874	631	-	2,715	58,220
202	Contaminated soils and solids	16,005	496,430	6,499	-	-	518,934
301	FCC catalyst or equivalent	8,225	78,086	825	-	7,650	94,785
302	Hydroprocessing catalysts	-	12,398	-	-	142	12,539
303	Other spent catalysts	-	11,100	-	-	583	11,683
401	Biomass	84	133,222	4,471	-	1,712	139,490
501a	Spent sulfidic caustics	-	-	-	16,324	1,747	18,071
501b	Spent naphthenic caustics	-	-	-	5,265	-	5,265
501c	Spent cresylic caustics	-	1,682	-	5,702	-	7,383
	Total (tons)	26,409	999,484	12,426	27,291	14,992	1,080,602

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Estimated Disposal (On-Site, Off-Site) for U.S. Refining Industry
(wet tons)

Code	**Residual**	**Tons**	**On-Site %**	**Off-Site %**
101	API separator sludge (K051)	10,572	30%	70%
102	Dissolved air flotation float (K048)	1,240	0%	100%
103	Slop oil emulsion solids (K049)	1,186	0%	100%
106	Pond sediments	96,027	4%	96%
110	Primary sludge (F037)	100,881	53%	47%
111	Primary sludge (F038)	4,326	46%	54%
112	Tank bottoms (unleaded, leaded)	58,220	1%	99%
202	Contaminated soils and solids	518,934	11%	89%
301	FCC catalyst or equivalent	94,785	25%	75%
302	Hydroprocessing catalysts	12,539	22%	78%
303	Other spent catalysts	11,683	28%	72%
401	Biomass	139,490	16%	84%
501a	Spent sulfidic caustics	18,071	34%	66%
501b	Spent naphthenic caustics	5,265	100%	0%
501c	Spent cresylic caustics	7,383	53%	47%
	Total	1,080,602		

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Disposal Techniques Used by Respondents
(number of respondents reporting each residual)

Code	**Residual**	**Impound-ment**	**Land-fill**	**Land-spread**	**Injection**	**Other Disposal**
101	API separator sludge (K051)	-	14	-	-	1
102	Dissolved air flotation float (K048)	-	5	-	-	-
103	Slop oil emulsion solids (K049)	-	4	-	-	-
106	Pond sediments	-	10	-	-	-
110	Primary sludge (F037)	1	20	-	-	1
111	Primary sludge (F038)	1	3	-	-	-
112	Tank bottoms (unleaded, leaded)	-	49	2	-	2
202	Contaminated soils and solids	1	64	5	-	-
301	FCC catalyst or equivalent	1	43	1	-	1
302	Hydroprocessing catalysts	-	18	-	-	1
303	Other spent catalysts	-	40	-	-	3
401	Biomass	2	25	2	-	1
501a	Spent sulfidic caustics	-	-	-	7	2
501b	Spent naphthenic caustics	-	-	-	1	-
501c	Spent cresylic caustics	-	1	-	2	-

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