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# Historical Air Emissions from United States Petroleum Refineries

Analysis Prepared for:
American Fuel & Petrochemical Manufacturers

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## SECTION 1: Introduction

Sage Environmental Consulting, LP (Sage Environmental) was retained by American Fuel & Petrochemical Manufacturers (AFPM) to perform an analysis of the historical air emissions from United States petroleum refineries. The following sections present the source(s) of data that were used for the analysis, a graphical summary of the data observed and an analysis of the data which was collected from publically available sources as referenced herein.

## SECTION 2: Methods and Data Sources

US Environmental Protection Agency (USEPA) data on criteria air pollutant (CAP) emissions, including sulfur dioxide ($SO_2$), nitrogen oxides ($NO_x$), volatile organic compounds (VOC) and particulate matter (PM), was obtained from the National Emission Inventory (NEI) database[i] and then trended for the period of investigation. This data was obtained for petroleum refineries designated by Standard Industrial Classification (SIC) 2911 or North American Industrial Classification Systems (NAICS) 32411. This data set represents the most comprehensive record of petroleum refinery emissions over the period of 1990-2013.

The USEPA publishes the NEI database every three years and the following publication years were used in this investigation: 1990, 1996, 1999, 2002, 2005, 2008, and 2011 (no data was developed for 1993). Between NEI reporting years, USEPA refines and corrects the emissions data, and may update the database several times. USEPA notes that because the estimates originate from a variety of sources (state and local regulatory agencies, tribes, industry, and USEPA) and because estimation methods are used for differing purposes, the estimates will in turn vary in quality, pollutants included, level of detail, and geographic coverage.[ii] Emission data for filterable particulate emissions with a diameter of 10 microns or less ($PM_{10}$) is used as a surrogate for total particulate matter emissions. Although carbon monoxide (CO) emissions data is available, it is not considered an area of key interest to petroleum refineries, because all areas around US petroleum refineries are in attainment for the CO NAAQS.

The hazardous air pollutant (HAP) emission data used in this study was downloaded from the USEPA Toxic Release Inventory (TRI)[iii] and also trended for the period of investigation. HAPs are those 187 pollutants that are known or suspected to cause cancer or other serious health effects, such as reproductive effects or birth defects, or adverse environmental effects. Examples of hazardous air pollutants include benzene, dioxin, toluene, and metals such as cadmium, mercury, chromium, and lead compounds.[iv] TRI data should be interpreted carefully because there are various methodologies for estimating emissions and a corresponding variation within the release estimates[v]. HAP emissions were gathered for petroleum refineries listed under SIC 2911 or NAICS 32411.


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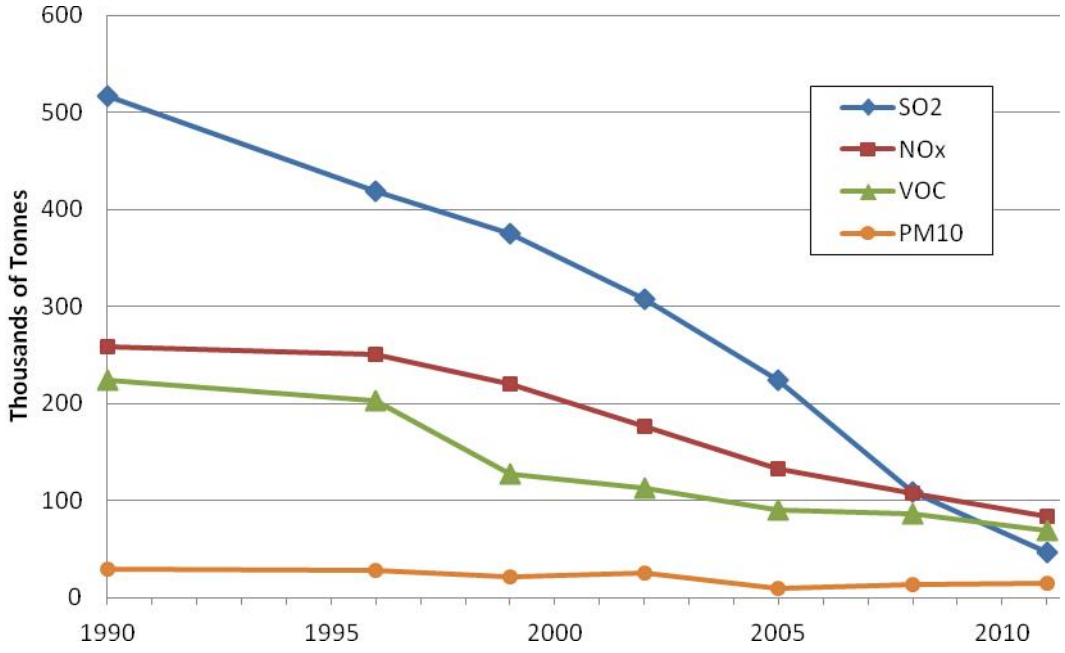
Data for total petroleum refining industry crude distillation capacity, gross crude feed, capacity utilization, crude oil sulfur content, crude oil density and refined products was obtained from the United States Energy Information Administration (USEIA)[vi] and trended from 1990 to 2010. Where feasible, the data were verified using other industry references including the Oil and Gas Journal Annual Worldwide Survey reports[vii] and the National United States Refining and Storage Capacity Report published by American Fuels & Petrochemical Manufacturers (AFPM), formerly known as National Petrochemical and Refining Association (NPRA). [viii] As with the USEPA data, USEIA information gathered in this study is for petroleum refineries under the NAICS 32411 or SIC 2911.

## SECTION 3: Historical Criteria Air Pollutant Emissions

Total US petroleum refining industry CAP emissions and their 20-year trend are shown in Figure 1. Annual emissions over the period of investigation show overall reductions of $SO_2$, $NO_x$, VOC and particulate matter (filterable $PM_{10}$). The historical data shows a marked and continuing downward trend with notable reductions in emissions of $SO_2$. The overall percent reduction in CAP emissions from the petroleum refining industry is summarized later in Table 1.

***Figure 1. Historical CAP Emissions for the US Petroleum Refining Industry Over Time***




To attempt to assess the reliability of the total industry emission estimates, the NEI $NO_x$ emissions were examined in more detail by comparing the annual normalized NEI reported NOx emissions as reported by each refinery to "boundary" estimates based on USEIA refinery fuels consumption data and EPA AP-42 emission factors. [ix] Normalized emissions are calculated using the NEI refinery specific total NOx emissions versus total crude throughput. As shown in Figure 2, the mean normalized NEI emission estimates (including standard deviation of the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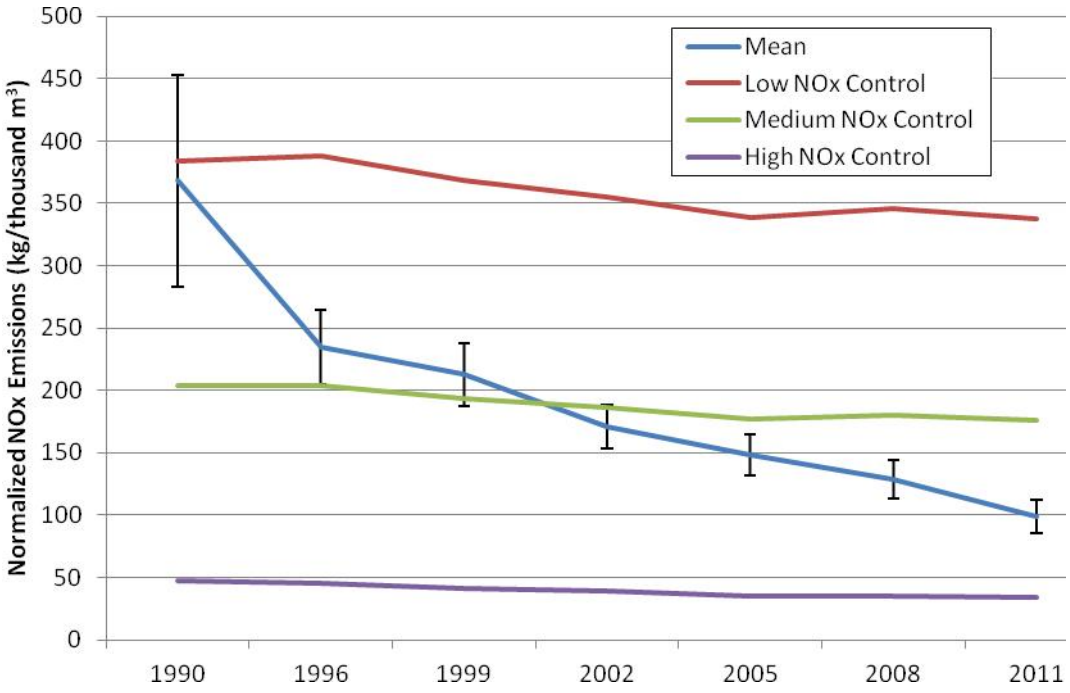
mean) is within the independently generated USEIA/AP-42 emissions "boundaries" where "Low NOx Control" is comparable to emission factor for standard burner technology, "Medium NOx Control" is comparable to first generation low NOx burner technology, and "High NOx Control" is comparable to 90 percent efficient selective catalytic reduction (SCR) or ultra low NOx burner technology. As can be seen from this comparison, normalized NOx emissions from US petroleum refineries is approaching the "High NOx Control" boundary (as calculated using AP-42 emission factors), thus indicating significant penetration of this type of technology.

***Figure 2. Crude Throughput Weighted Refinery NOx Emissions***




## SECTION 4: Historical Hazardous Air Pollutant Emissions

Petroleum refining industry HAP emissions trends using emissions estimated from the USEPA TRI database are shown in Figure 3. All refineries are required to report toxic emissions annually from air, water and waste through the TRI. In this analysis, if the reporting facility left a cell blank in its Form R submission, it was assumed that there were zero emissions of that TRI chemical for the reporting facility for that year. As with CAP emissions, the HAP emissions show a marked reduction during the period of investigation. In general, emissions of organic HAP compounds were reduced as a result of total VOC emission reductions and emissions of inorganic HAP compounds were reduced with PM reductions. The increases in the TRI releases from the period 1994 to 1996 were due to an increased number of chemicals being reported. In 1993, the TRI list of chemicals was increased with the addition of approximately 30 Resource Conservation and Recovery Act (RCRA) chemicals (58 FR 63500, December 1, 1993) and certain hydrochlorofluorocarbons (HCFCs) (58 FR 635496, December 1, 1993) and in 1994, a Chemical Expansion Final Rule (59 FR 61431, November 30, 1994) was promulgated expanding TRI by 286 new chemicals and categories.


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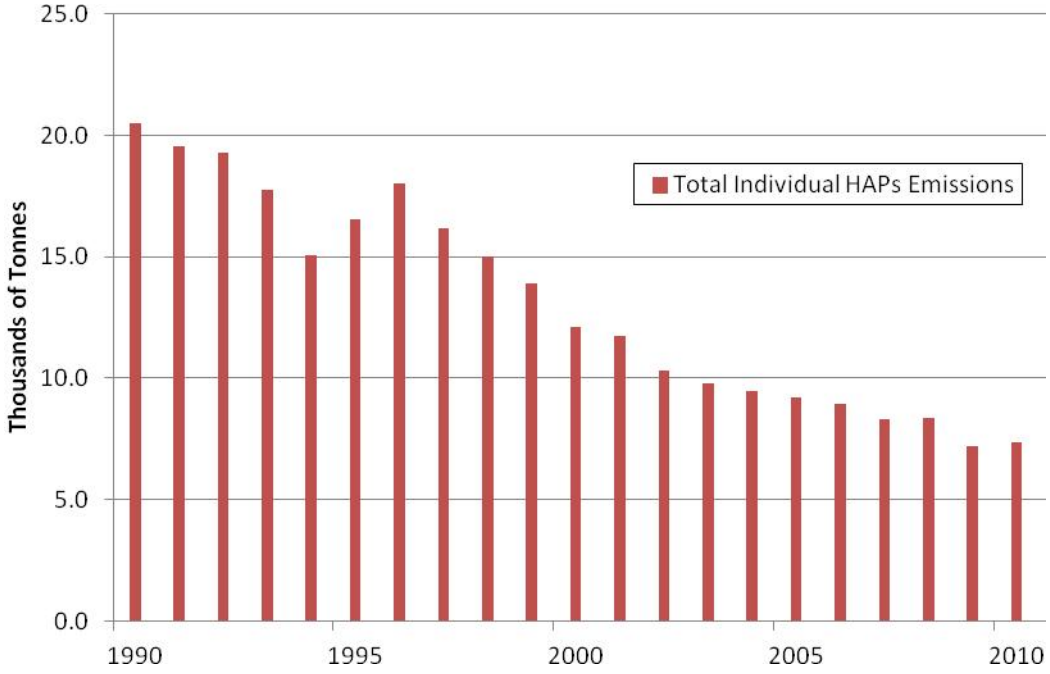
***Figure 3. Historical HAPs Emissions for the US Petroleum Refining Industry Over Time***




## SECTION 5: Historical US Petroleum Refining Industry Crude Characteristics

Overall petroleum refinery CAP and HAP emissions have substantially decreased during the period of investigation despite processing crude oil with greater density and increasing sulfur content. The density of crude oil is measured using the API gravity, an inverse relationship to the specific gravity through the following equation[x]: API Gravity = 141.5/SG - 131.5. As reported by the USEIA and shown in Figure 4, the average API gravity for the crude oil used by the US petroleum refining industry has gradually decreased over time. Also as shown in Figure 4, annual average sulfur content of crude oil used by the US refining industry has increased from 0.9 percent in 1985 to 1.4 percent in 2005. It is important to note that density and sulfur content are not necessarily related and thus some individual crudes are relatively dense with low sulfur content, while others may have low density and high sulfur content. When compared to Figure 1 and Figure 3, it is apparent that the sulfur content in the crude (which has generally increased) is not related to the actual CAP and HAP emissions (which have significantly decreased).


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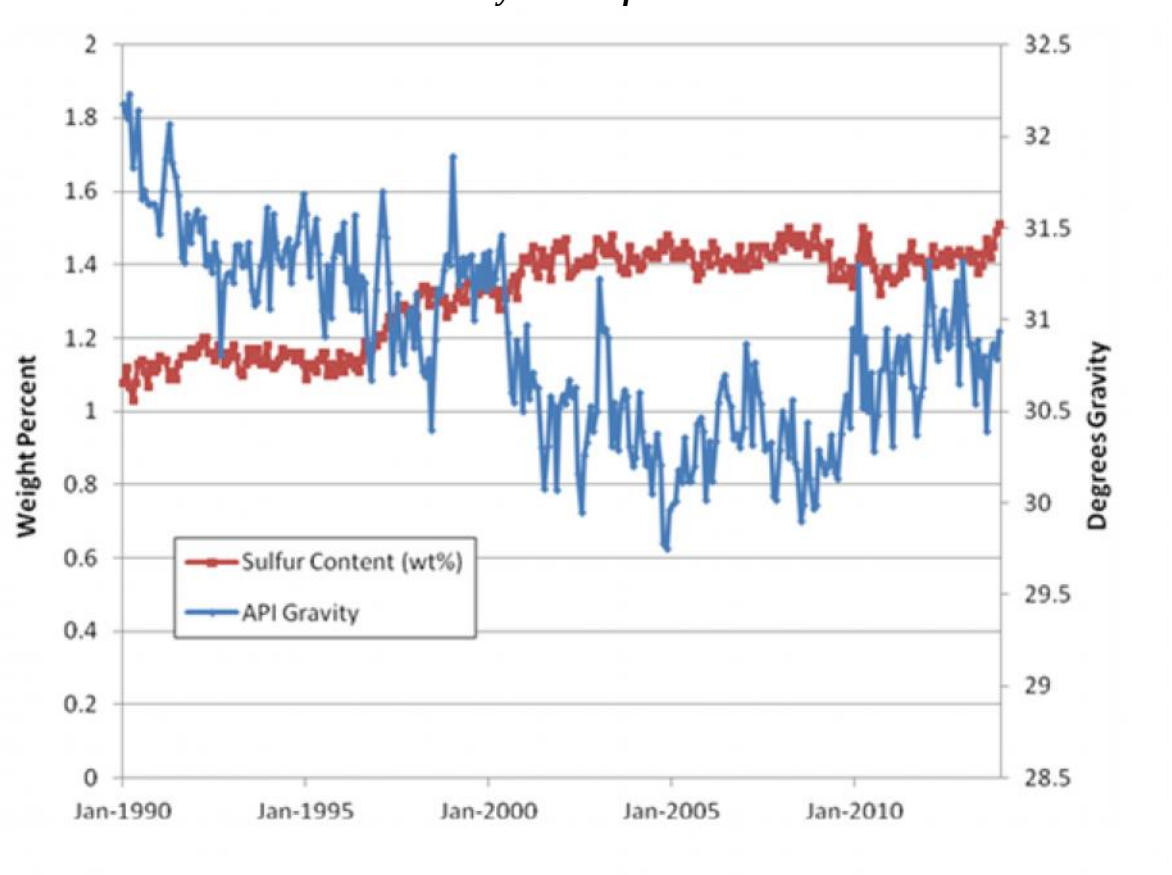
***Figure 4. Historical US Petroleum Refining Industry Average Crude API Gravity and Sulfur Content***




## SECTION 6: Historical US Petroleum Refining Capacity Utilization

During the period of investigation, there has been modest net growth in US crude distillation capacity due to expansion of existing refineries. On January 1, 1990, the Oil and Gas Journal identified 188 operating refineries with a total crude distillation capacity of approximately 2.5 million cubic meters per calendar day (or 15.6 million barrels per calendar day).[xi] On January 1, 2013, there were 143 operable petroleum refineries in the United States (excluding Puerto Rico and the US Virgin Islands)[xii] and the USEIA estimated the total crude refining capacity in the United States at 2.8 million cubic meters per calendar day (or 17.8 million barrels per calendar day), which is an increase of 16 percent from 1990. Therefore, the net growth in US crude distillation capacity at existing refineries has compensated for the loss in capacity from refineries that were permanently shutdown because no new refineries have been constructed. During the entire reported period, the capacity utilization has remained relatively stable although a decline is seen in the 2004 to 2009 period which has been compensated with an increase in utilization in the last four years. Figure 5 summarizes capacity utilization over the period of analysis.


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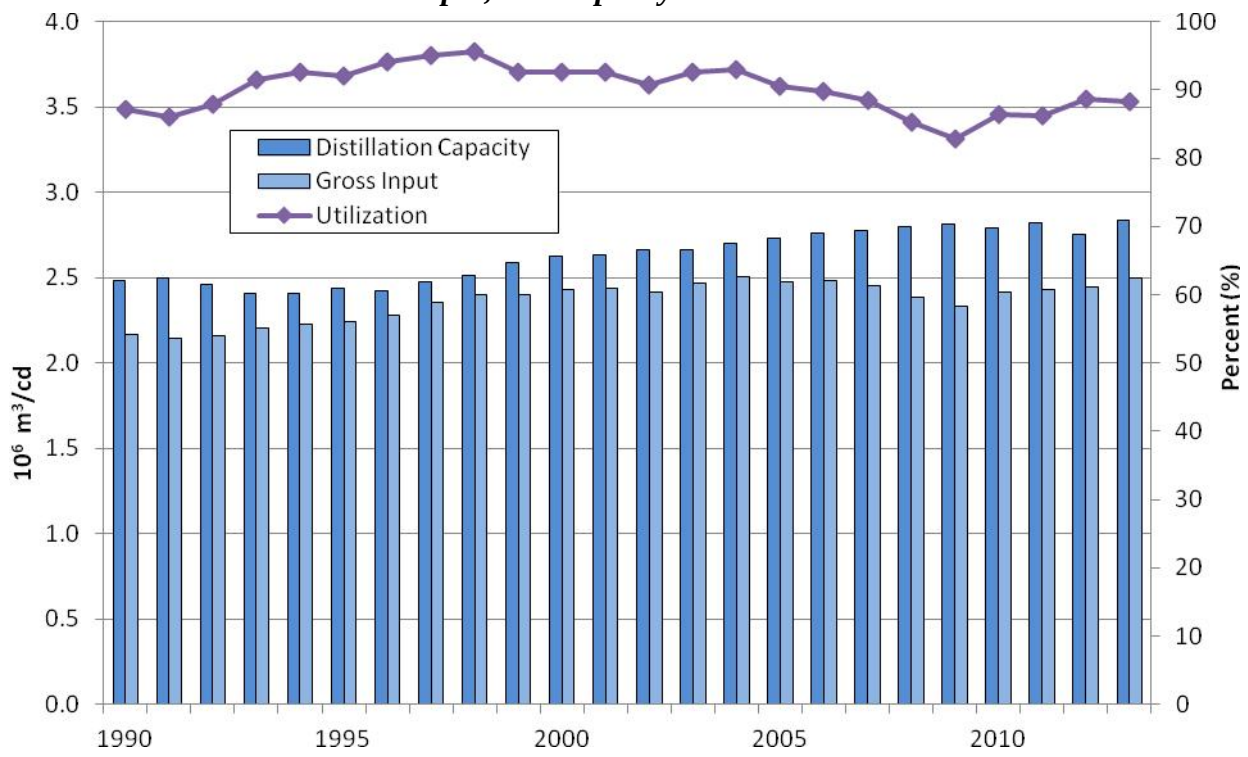
***Figure 5. Historical US Petroleum Refining Crude Distillation Capacity, Gross Refinery Input, and Capacity Utilization***




## SECTION 7: Conclusions

The Clean Air Act requirement for USEPA to review and update NSPS and NESHAP regulations will maintain and potentially augment air emissions controls in the future as noted earlier. Therefore, emissions have actually been inversely related to increases in distillation capacity and crude oil density and sulfur content over the last 23 years. Figure 6 provides a comparison of the criteria pollutants versus annual production rates of the major petroleum refining product types. Based on the comparisons, the US petroleum refining industry has been able to increase production of finished motor gasoline (an approximate 33 percent increase from 1990 to 2011) and kerosene-type jet fuel, and distillate fuel oil (an approximate 40 percent increase from 1990 to 2011), while reducing emissions of criteria pollutants during the same period of time.

Table 1 summarizes trends in US refining processing and CAP and HAP emissions over the period of investigation. Even though US petroleum refining crude distillation capacity has increased 16 percent and the associated crudes have increased in density and sulfur content, industry $SO_2$ emissions have decreased 91 percent and total HAP emissions have decreased 66%. These reductions in emissions are closely related to industry compliance with federal and state air pollution control rules. As refineries install equipment to process heavier crudes and/or increase sulfur processing capacity, emissions are likely to continue to decline due to both technology improvements and increased stringency of existing regulations.


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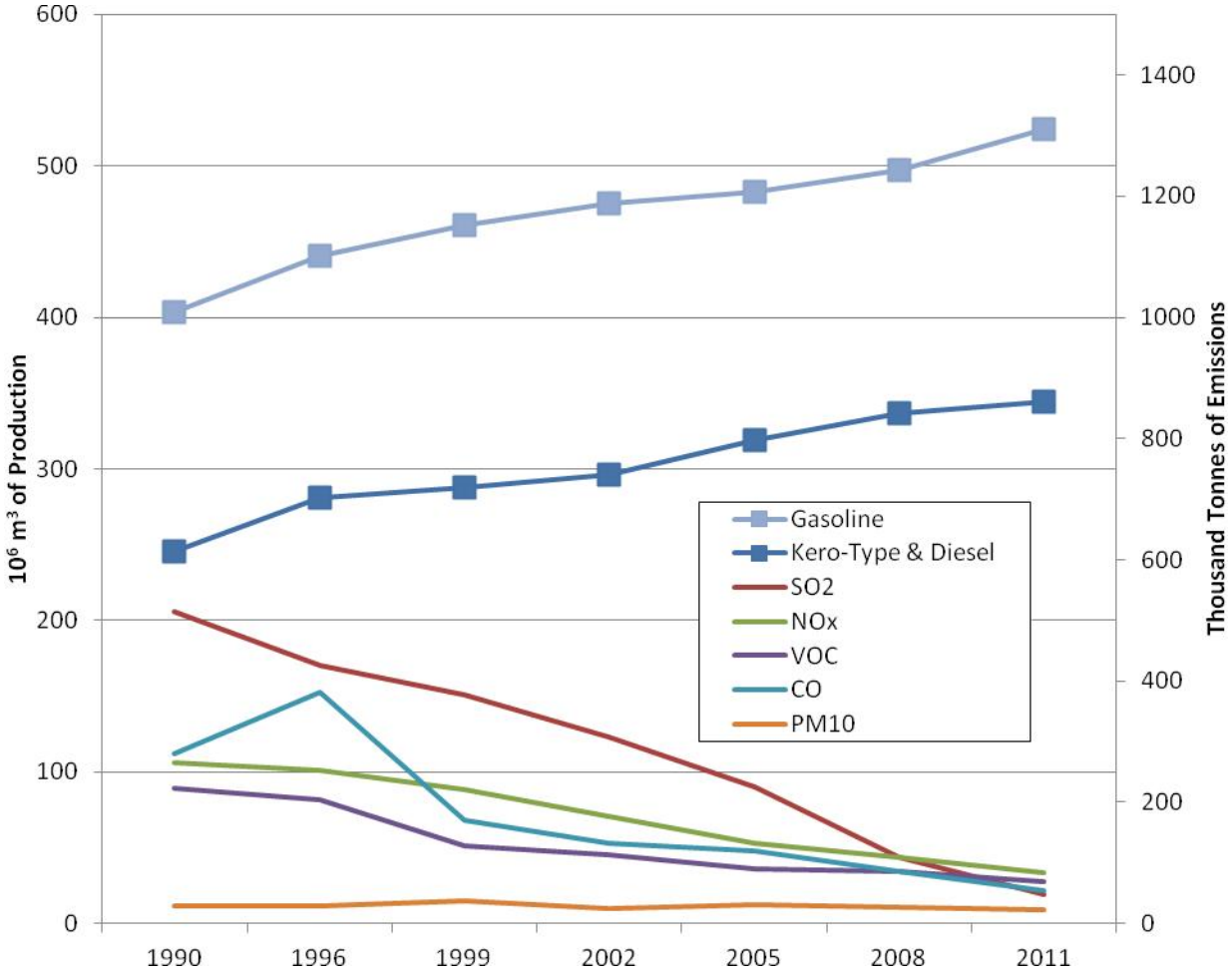
***Figure 6. Gasoline and Kerotype/Diesel Production and Refinery CAP Emissions***



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| Table 1. Summary of US Petroleum Refining Statistics for 1990 vs. 2013 | | | | |
|---|---|---|---|---|
| **US Refining Industry** | **Units** | **1990** | **2013** | **Difference** |
| Number of Operating Refineries | NA | 188 | 143 | -24% |
| Crude Capacity | $10^6$ $m^3/d$ | 2.5 | 2.9 | 12% |
| Crude Throughput | $10^6$ $m^3/d$ | 2.2 | 2.4 | 14% |
| Capacity Utilization | Percent | 87 | 84 | -3% |
| Crude API Gravity | Deg API | 31.9 | 30.8 | -3% |
| Crude Sulfur Content | Wt% | 1.1 | 1.4 | 27% |
| **Criteria Air Pollutant Emissions** | **Units** | **1990** | **2013** | **Difference** |
| SO2 | $10^6$ tonnes/yr | 516 | 46 | -91% |
| NOx | $10^6$ tonnes/yr | 258 | 84 | -67% |
| VOC | $10^6$ tonnes/yr | 225 | 70 | -69% |
| PM10 (filterable) | $10^6$ tonnes/yr | 30 | 16 | -46% |
| **Hazardous Air Pollutants Emissions** | **Units** | **1990** | **2013** | **Difference** |
| Total HAP | $10^3$ tonnes/yr | 21 | 7.1 | -66% |

## SECTION 8: Literature Cited


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[xi] Worldwide Refinery 1990 Survey. *Oil and Gas Journal*. Vol. 88, No. 13, March 26, 1990.

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