

# Demand, Supply, and Price Outlook for Low-Sulfur Diesel Fuel

by Tancred Lidderdale\*

## Abstract

The Clean Air Act Amendments of 1990 established a new, sharply lower standard for the maximum sulfur content of on-highway diesel fuel, to take effect October 1, 1993. Only about one-third of the current output of on-highway diesel fuel, which is used mostly in diesel trucks, meets the new standard. Although it seems likely that the rising demand for low-sulfur diesel fuel can be met, the higher capital and operating costs of increasing low-sulfur diesel production could drive some refiners out of the on-highway diesel fuel business and will lead others to raise prices, probably by 3 to 4 cents per gallon above the price of high-sulfur diesel and other high-sulfur distillates.

## Introduction

To help ensure that sulfates in engine exhaust do not prevent manufacturers of heavy-duty diesel engines from meeting new particulate emissions standards for 1994 and later model years,<sup>1</sup> the Clean Air Act Amendments of 1990 (CAAA90) require refiners to reduce the sulfur content of on-highway diesel fuel from current average levels of 0.30 percent by weight to no more than 0.05 percent by weight. The new standard, which goes into effect October 1, 1993, also requires that

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<sup>1</sup>On March 15, 1985, the Environmental Protection Agency promulgated particulate standards for heavy-duty diesel engines in response to Section 202(a)(3) of the Clean Air Act as amended in 1977 (*Federal Register*, Vol. 50, No. 51, March 15, 1985, p. 10606). During the rulemaking process, heavy-duty diesel engine manufacturers expressed concern that sulfur in diesel fuel could either plug the trap-oxidizers that would be needed to meet the proposed particulate standards or generate significant particulate sulfate emissions that would make it difficult to meet the standards.

on-highway diesel fuel have a minimum cetane index of 40 or a maximum aromatic content of 35 percent by volume.<sup>2</sup> (See list of terms and definitions on the following page.) This provision is designed to prevent any future rises in aromatics levels.<sup>3</sup> Since the direct measurement of aromatics is complex, a minimum cetane index of 40 is specified as a surrogate for capping aromatics.<sup>4</sup> Except for California refineries, the level of aromatics does not appear to be a critical issue.

Home heating oil, a distillate product similar to diesel fuel, is not required to meet the new specifications. Off-highway diesel fuel and heating oil not meeting the new standards must be dyed in order to distinguish them from on-highway diesel fuel. The new diesel fuel standard applies nationwide and affects about 46 percent of the total domestic demand for distillate fuel oil (about 8.2 percent of total U.S. petroleum product demand).<sup>5</sup>

Refiners will incur higher operating and capital costs in adapting to the new demand pattern for low-sulfur diesel fuel. These increases will likely yield a price premium of 3 to 4 cents per gallon over heating oil and other high-sulfur distillate fuels. In California, the price premium will probably be higher because of a more restric-

<sup>2</sup>Public Law 101-549, Section 211(i), U.S.C. 42, "Clean Air Act Amendments of 1990," enacted on November 15, 1990. Final rule announced by the Environmental Protection Agency in *Federal Register*, Vol. 55, No. 162 (August 21, 1990), pp. 34120-34143, and revised in *Federal Register*, Vol. 57, No. 89 (May 7, 1992), pp. 19535-19539.

<sup>3</sup>The Environmental Protection Agency originally considered a cap on aromatics of 20 percent by volume. However, studies suggested that the benefits from particulate reductions (which did not include cancer benefits) did not justify the costs of reducing the level of aromatics in diesel fuel. *Federal Register*, Vol. 55, No. 162 (August 21, 1990), pp. 34128-34129.

<sup>4</sup>An approximate inverse relationship exists between cetane number and aromatics. A cetane number of 45 corresponds to an aromatics concentration of about 27 percent by volume, while a diesel fuel with a 40 cetane number would contain about 36 percent by volume aromatics. George H. Unzelman, "Higher Diesel Quality Would Constrict Refining," *Oil and Gas Journal* (June 29, 1987), pp. 55-59.

<sup>5</sup>Energy Information Administration, *Fuel Oil and Kerosene Sales 1991*, DOE/EIA-0535(91) (Washington, DC, November 1992), p. 28, and *Petroleum Supply Annual 1991*, DOE/EIA-0340(91)/1 (Washington, DC, May 1993), p. 31.

## Definitions

**API Gravity:** An arbitrary scale expressing the gravity or density of liquid petroleum products. The measuring scale is calibrated in terms of degrees API. A lighter, less dense product has a higher API gravity.

**Aromatics:** Hydrocarbons characterized by unsaturated ring structures of carbon atoms. Commercial petroleum aromatics are benzene, toluene, and xylene (BTX).

**Catalytic Hydrocracking:** A refining process that uses hydrogen and catalysts with relatively low temperatures and high pressures for converting middle boiling or residual material to high-octane gasoline, reformer charge stock, jet fuel, and/or high grade distillate fuel oil. The process uses one or more catalysts, depending upon product output, and can handle high sulfur feedstocks without prior desulfurization.

**Catalytic Hydrotreating:** A refining process for treating petroleum fractions from atmospheric or vacuum distillation units (e.g., naphthas, middle distillates, reformer feeds, residual fuel oil, and heavy gas oil) and other petroleum (e.g., cat cracked naphtha, coker naphtha, gas oil, etc.) in the presence of catalysts and substantial quantities of hydrogen. Hydrotreating includes desulfurization, removal of substances (e.g., nitrogen compounds) that deactivate catalysts, conversion of olefins to paraffins to reduce gum formation in gasoline, and other processes to upgrade the quality of the fractions.

**Cetane Number:** A measure of the ignition quality of diesel fuel oil. Cetane number is measured by comparing the ignition qualities of a diesel fuel in a test engine against those of a standard mixture of cetane and heptamethylnonane. The cetane "index" is calculated from the physical properties of the fuel, such as API gravity and mid-boiling point, and is a less expensive approximation of the cetane number.

**Distillate Fuel Oil:** A general classification for one of the petroleum fractions produced in conventional distillation operations. It is used primarily for space heating, on- and off-highway diesel engine fuel (including railroad and agricultural machinery), and electric power generation. Distillate fuel oil is classi-

fied into three grades (No. 1, No. 2, and No. 4), which are differentiated by the boiling range of the fuel.

**No. 1 Distillate:** A volatile distillate fuel with a boiling range between 300 and 575° F that meets the specifications for No. 1 heating or fuel oil as defined in American Society for Testing and Materials (ASTM) Specification D396 and/or specifications for No. 1 diesel fuel as defined in ASTM Specification D975.

**No. 1 Diesel Fuel:** Used in high-speed diesel engines generally operated under wide variations in speed and load. Includes Type C-B diesel fuel used for city buses and similar operations.

**No. 1 Fuel Oil:** A light distillate fuel oil intended for use in vaporizing pot-type burners.

**No. 2 Distillate:** A gas oil type distillate of lower volatility with distillation temperatures at the 90 percent boiling point between 540 and 640° F. No. 2 distillate meets the specifications for No. 2 heating or fuel oil as defined in ASTM D396 and/or specifications for No. 2 diesel fuel as defined in ASTM Specification D975.

**No. 2 Diesel Fuel:** Used in high speed diesel engines generally operated under uniform speed and load conditions. Includes Type R-R diesel fuel used for railroad locomotive engines and Type T-T for diesel engine trucks.

**No. 2 Fuel Oil:** Used in atomizing type burners for domestic heating or for moderate capacity commercial-industrial burners.

**No. 4 Distillate:** This grade is a blend of distillate fuel oil and residual fuel oil stocks that conforms to ASTM Specification D396 or Federal Specification VV-F-815C and/or specifications for No. 4 diesel fuel as defined in ASTM specification D975.

**No. 4 Diesel Fuel:** Used as a bunker fuel for ships and for other low- and medium-speed diesel engines in sustained constant-speed service.

**No. 4 Fuel Oil:** Used for commercial burner installations not equipped with preheating facilities. It is used extensively in industrial plants.

tive aromatics specification, although no projection is attempted here.<sup>6</sup>

This article analyzes the new regulations' impact on distillate fuel markets and evaluates the constraints and costs faced by the petroleum refining industry in complying with them. The article reviews recent trends in demand and quality of on-highway diesel fuel oil and presents short- and long-term forecasts of diesel fuel demand. It discusses domestic and foreign sources of low-sulfur diesel supply and then moves on to an analysis of distillate fuel desulfurization economics, including diesel fuel price seasonality, desulfurization variable and capital costs, sulfur dioxide (SO<sub>2</sub>) emissions trading allowances, and the economics of blending lighter, more expensive petroleum fractions, such as kerosene, into diesel fuel. The article concludes with a brief review of events in Los Angeles in January 1985, when the California Air Resources Board reduced the sulfur specification for diesel fuel from 0.5 to 0.05 percent by weight.

## Distillate Fuel Oil Demand

Distillate fuel oil is classified into two primary types: diesel fuel and heating oil. On-highway diesel fuel represents about 46 percent of the total domestic demand for distillate fuel. The East Coast, Petroleum Administration for Defense (PAD) District I, and Midwest, PAD District II, account for about two-thirds of the total on-highway diesel fuel market (Table 1).

Since 1979, the average sulfur level in No. 2 diesel has ranged from about 0.25 to 0.30 percent by weight, according to annual surveys conducted by the National Institute for Petroleum and Energy Research

<sup>6</sup>The California Air Resources Board (CARB) has independently enacted more stringent diesel fuel regulations, also due to take effect October 1, 1993. The new CARB regulations require on- and off-highway diesel fuel sold in California to meet both the 0.05 percent sulfur specification and a standard limiting aromatics to no more than 10 percent by volume. The regulations provide an exemption from the latter requirement for certified diesel fuel blends that meet the low-sulfur requirements and achieve emissions equivalent to a standard 10-percent-by-volume-aromatics diesel.

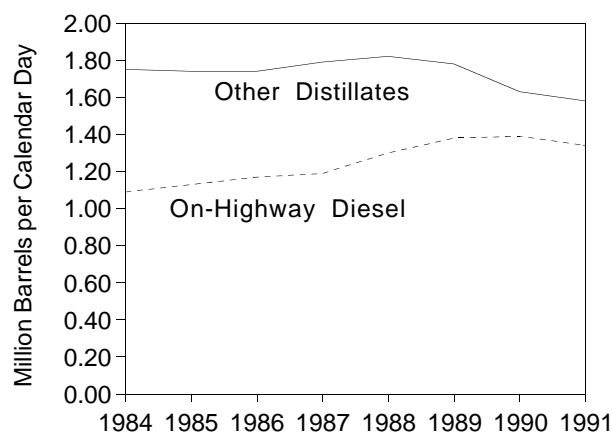
(NIPER).<sup>7</sup> About 0.45 million barrels per day of distillate fuel production already meet the 0.05-percent-by-weight sulfur standard, while about 1.8 million barrels per day fall in the 0.05- to 0.25-percent-by-weight range, and around 0.7 million barrels per day fall in the 0.25- to 0.50-percent-by-weight range.<sup>8</sup> The average cetane index of No. 2 diesel fuel produced in the United States has ranged between 45 and 47 from 1979 through 1992, according to the NIPER survey.

Demand for on-highway diesel fuel showed steady growth of about 4.1 percent per year in the 1980's, while demand for other distillates remained flat (Figure 1). Sales of diesel fuel for on-highway use increased

<sup>7</sup>The NIPER survey represents a nonrandom sample of U.S. refineries. In 1992, for example, analytical data for properties of 96 diesel fuel oil samples were submitted to NIPER. The samples were obtained during July and August 1992 from diesel product manufactured by 20 petroleum refining companies in 55 domestic refineries. National Institute of Petroleum and Energy Research, *Diesel Fuel Oils, 1992*, NIPER-177 PPS 92/5 (Bartlesville, OK, October 1992).

<sup>8</sup>Energy Information, Ltd., "U.S. Refiners Gear Up To Meet New Low-Sulfur Diesel Standards," *Oil Market Listener* (January 19, 1993), p. 2.

Figure 1. On-Highway Diesel and Other Distillate Sales



Sources: • Energy Information Administration, *Fuel Oil and Kerosene Sales 1991*, DOE/EIA-0535(91) (Washington, DC, November 1992), p. 28, and *Petroleum Marketing Annual 1988*, DOE/EIA-0487(88) (Washington, DC, October 1989), p. 398.

Table 1. Distillate Fuel Oil Sales by PAD Sub-District, 1991 (Thousand Barrels per Day)

PAD Sub-District	On-Highway Diesel	Residential and Commercial	Industrial and Other	Total Distillate
IA — New England .....	42.7	153.3	20.4	216.4
IB — North Atlantic .....	163.8	238.3	63.1	465.3
IC — South Atlantic .....	218.0	50.9	97.3	366.2
II — Midwest .....	446.1	106.9	296.4	849.4
III — Gulf Coast .....	221.2	17.2	260.2	498.5
IV — Rocky Mountain .....	51.1	9.0	63.7	123.8
V — West Coast .....	193.5	41.7	166.0	401.3
<b>U.S. Total .....</b>	<b>1,336.3</b>	<b>617.4</b>	<b>967.1</b>	<b>2,920.8</b>

Note: Totals may not equal sum of components due to independent rounding.

Source: Energy Information Administration, *Fuel Oil and Kerosene Sales 1991*, DOE/EIA-0535(91) (Washington, DC, November 1992), pp. 30-33.

from an average of 1.09 million barrels per day in 1984 (38.4 percent of total distillate sales) to 1.34 million barrels per day in 1991 (45.8 percent of total distillate sales).

On-highway diesel fuel has also captured an increasing share of the on-highway fuel market (diesel plus motor gasoline). On-highway diesel fuel's share of the total U.S. market for motor gasoline and diesel fuel rose from 14.0 percent in 1984 to 16.2 percent in 1991.<sup>9</sup> Diesel fuel's increasing share of the on-highway fuel market results from slower gains in diesel vehicle fuel efficiency compared with motor gasoline vehicle fuel efficiency rather than from differences in highway mileage (Table 2).

Diesel fuel sales for automobile use are relatively inconsequential. Sales of diesel-powered cars in the United States grew rapidly from 0.35 percent of all new automobiles sold in 1977 to a peak of 6.10 percent in 1981. Since 1981, however, the diesel engine share of the U.S. new car market has declined steadily. The U.S. diesel new-car market share averaged only 0.9 percent over the 5 years of 1987 to 1991.<sup>10</sup> Diesel car sales in several European countries, on the other hand, continued to grow, exceeding 25 percent of 1988 new car sales in France and Belgium and over 10 percent in West Germany, Italy, and the Netherlands.<sup>11</sup>

The short-term forecast of distillate fuel demand prepared by the Energy Information Administration (EIA) and published quarterly in the *Short-Term Energy Outlook (Outlook)* represents the sum of distillate fuel de-

mand in four sectors of the economy: industrial, residential and commercial, electric utility, and transportation. Distillate demand in the transportation sector includes vessel bunkering, military use, railroad use, and on-highway diesel fuel. On-highway diesel fuel represents about 77 percent of transportation sector distillate demand. The third-quarter 1993 *Outlook* projects distillate demand in the transportation sector to grow by about 5.4 percent in 1993 and 2.2 percent in 1994 (Table 3).

The long-term (20-year) forecast of distillate fuel consumption in the transportation sector shows annual growth of 1.7 percent per year between 1990 and 2010 (42 percent total growth). Fuel consumption by freight trucks is projected to grow steadily at a rate of about 1.3 percent per year (total growth of about 30 percent between 1990 and 2010). Growth in truck travel follows trends in economic activity closely, although fuel consumption by trucks is projected to rise more slowly than real gross domestic product because fuel efficiency is expected to improve by about 11 percent between 1990 and 2010.<sup>12</sup> Diesel trucks are expected to capture a greater share of the short-haul market. In 1989, 54 percent of all energy consumed by freight trucks came from diesel fuel. By 2010, diesel-powered trucks are expected to represent 63 percent of freight truck fuel consumption.<sup>13</sup>

## Low-Sulfur Distillate Supply

Because diesel fuel and heating oil are currently so similar, most refineries produce a distillate product that satisfies both diesel and heating oil quality restrictions rather than incur the cost of segregating blend stocks and finished products. According to the National Petroleum

<sup>9</sup>Energy Information Administration, *Fuel Oil and Kerosene Sales 1991*, DOE/EIA-0535(91) (Washington, DC, November 1992), p. 28, and *Petroleum Supply Annual 1991*, DOE/EIA-0340(91)/1 (Washington, DC, May 1993), p. 17.

<sup>10</sup>Ward's Communications Inc., *Ward's 1992 Automotive Yearbook* (Detroit, MI, 1992), p. 57, and *Ward's 1988 Automotive Yearbook* (Detroit, MI, 1988), p. 58.

<sup>11</sup>Ward's Communications Inc., *Ward's 1989 Automotive Yearbook* (Detroit, MI, 1989), p. 86.

<sup>12</sup>Energy Information Administration, *Annual Energy Outlook 1993*, DOE/EIA-0383(93) (Washington, DC, January 1993), pp. 25, 82, and 96.

<sup>13</sup>Energy Information Administration, *Annual Energy Outlook 1992*, DOE/EIA-0383(92) (Washington, DC, January 1992), p. 22.

**Table 2. Automobile Versus Truck Highway Traffic, 1985-1991**

Year	Annual Miles Traveled (millions)		Annual Miles Traveled per Gallon Fuel	
	Personal Passenger Vehicles	Combination Trucks	Personal Passenger Vehicles	Combination Trucks
1985 .....	1,269,651	79,600	18.28	5.21
1986 .....	1,310,611	81,833	18.35	5.21
1987 .....	1,364,836	86,064	19.29	5.22
1988 .....	1,439,603	90,158	19.95	5.27
1989 .....	1,488,140	95,349	20.40	5.45
1990 .....	1,522,741	96,367	21.10	5.52
1991 .....	1,542,846	96,949	21.76	5.65
<b>Percent Change, 1985-1991</b>	<b>21.5</b>	<b>21.8</b>	<b>19.0</b>	<b>8.4</b>

Note: Personal passenger vehicles are primarily motor gasoline-powered automobiles. Combination trucks represent truck-tractors with semi-trailers and a majority of the heavy single-unit trucks used regularly in combination with full trailers; they are primarily diesel-powered.

Source: Federal Highway Administration, *Highway Statistics 1991*, FHWA-PL-92-025 (Washington, DC, 1992), p. 193, and previous annual issues.

Refiners Association (NPR A), if fuel distribution practices that were in place in 1986 are maintained, about 2.4 million barrels per day of distillate fuel oil would have to meet the low-sulfur requirement. However, only about one-half of this distillate fuel is required for the on-highway diesel fuel market.<sup>14</sup> Segregation of on-highway diesel fuel from other distillates within refineries is expected to reduce desulfurization plant investment and operating costs, although those savings could be more than offset by increased capital and operating costs for additional tankage and inventories in refineries, product distribution systems, and terminals.

Because providing low-sulfur fuel may be prohibitively expensive for some refineries, segregation of fuels between refineries is likely. Some refineries may produce only low-sulfur diesel fuel, while others may produce only high-sulfur distillates for the off-highway and heating oil markets. Refiners unable to produce low-sulfur diesel fuel may abandon the on-highway diesel market or exchange product with refineries producing low-sulfur diesel fuel.

Refiners have four primary options for supplying low-sulfur diesel fuel oil:

- Increase operating severity of existing or new catalytic hydrotreating units through use of more active catalysts or changes in unit operating conditions (temperature, pressure, space velocity, hydrogen-to-oil ratios, etc.).<sup>15</sup>
- Increase production of low-sulfur distillates from catalytic hydrocracking units. Catalytic hydrocracking units are normally operated to convert vacuum gas oil or light cycle oils to naphtha for catalytic reforming into motor gasoline. Selective

<sup>14</sup>National Petroleum Refiners Association, *U.S. Refining Industry Capability To Manufacture Ultra Low Sulfur Diesel Fuels* (Washington, DC, 1986), pp. 1 and 3. Refineries in the 1986 NPR A survey produced 428,000 barrels per day of segregated diesel fuel, 220,000 barrels per day of segregated No. 2 heating oil, and 1,934,000 barrels per day of unsegregated distillate fuel. The 139 refineries responding to the survey represented a total of 14.4 million barrels per day of crude oil distillation capacity (about 98 percent of operating capacity as of January 1, 1986).

<sup>15</sup>PennWell Publishing Co., "1990s Fuel Specifications Will Require Process Changes," *Oil and Gas Journal* (February 26, 1990), pp. 83-87.

production of distillate through use of different operating conditions and catalysts is also possible.

- Restrict diesel fuel blending operations to low-sulfur internal refinery streams. Some low-sulfur refinery streams not normally blended into distillate fuels, such as kerosene, could be used for on-highway diesel fuel blending.
- Import low-sulfur diesel fuel.

The refining industry's capability to produce low-sulfur on-highway diesel fuel remains uncertain. It is not clear how many refiners may abandon the on-highway diesel fuel market, what is the rated capacity of existing desulfurization equipment to produce low-sulfur diesel fuel, how strong is the demand for desulfurization capacity by other distillate fuel products, and how large is the capacity of new distillate desulfurization plants planned or under construction. However, most industry reports indicate that there will be sufficient supply of low-sulfur on-highway diesel by the October 1, 1993, CAAA90 deadline.<sup>16</sup>

**Hydrotreating and Hydrocracking Capacity:** Diesel fuel sulfur reduction is accomplished by either catalytic hydrotreating of distillate fuel or catalytic hydrocracking of heavy fuels, such as residual fuel oil, into low-sulfur distillate. The amount of desulfurization capacity available will affect the amount of capital investment required for compliance with the new sulfur regulations. However, the low-sulfur diesel production capacity of existing desulfurization units is highly uncertain. Some existing catalytic hydrotreating capacity must remain in kerosene or heating oil treatment service, while refiners will continue to maximize motor gasoline production from catalytic hydrocrackers. Furthermore, increasing the level of sulfur removal requires operating desulfurization units under more severe conditions (increased hydrogen volume, higher temperature and pressure, and lower reactor space velocities), which shorten catalyst life and reduce unit capacity. Thus, the increase in desulfurization unit operating severity needed to produce low-sulfur diesel fuel will significantly reduce the rated operating capacity of existing units.

<sup>16</sup>See, for example, Energy Information, Ltd., "Ample U.S. Refining Capacity Expected for New Low-Sulfur Diesel Needs," *Oil Market Listener* (March 4, 1993), p. 1.

**Table 3. Transportation Sector Distillate Fuel Demand Short-Term Forecast, 1991-1994**  
(Million Barrels per Day)

Year	First Quarter	Second Quarter	Third Quarter	Fourth Quarter	Annual Average
1991 .....	1.621	1.780	1.810	1.705	1.730
1992 .....	1.686	1.827	1.787	1.749	1.762
1993 .....	1.820	1.892	1.894	1.820	1.857
1994 .....	1.792	1.929	1.969	1.900	1.898

Note: On-highway diesel fuel represents about 77 percent of transportation sector distillate fuel demand.

Source: Energy Information Administration, Short-Term Integrated Forecasting System (STIFS) data base, "Transportation Sector Distillate Fuel Demand," series DFACPUS, extracted August 17, 1993.

NPRA estimated that full practical utilization of existing distillate hydrotreating capacity (of 1,675,000 barrels per day in their 1986 survey) could result in the production of only 315,785 barrels per day of 0.05-percent-by-weight-sulfur diesel fuel by 21 refineries.<sup>17</sup> Between January 1, 1987, and January 1, 1993, operable crude oil distillation capacity decreased by 3.2 percent while distillate hydrotreating capacity increased by 9.2 percent (or 238,667 barrels per stream day). Additional distillate hydrotreating capacity expansions of 705,720 barrels per day have been announced (Table 4).

Of the 187 refineries that were operable on January 1, 1993, 94 refineries did not have distillate hydrodesulfurization units. The 94 refineries represent about 19 percent of total domestic refining capacity.<sup>18</sup> Most of those refineries are not expected to produce low-sulfur diesel fuel. Only 12 have announced construction of new distillate hydrodesulfurization units.<sup>19</sup>

**Blending Kerosene into Diesel Fuel:** Small increases in low-sulfur diesel fuel can be obtained by blending in lighter, more expensive petroleum fractions, such as No. 1 distillate or kerosene. NIPER surveys show that the average sulfur contents of Jet-A and No. 1 diesel are close to 0.05 percent by weight. Kerosene-type jet fuel is the largest of these potential sources, with 1991 average sales of 1.3 million barrels per day. Kerosene or No. 1 distillate is routinely blended into diesel fuel during the winter to lower the cloud point (the temperature at which a cloud of wax crystals first appears) and prevent plugging of fuel

<sup>17</sup>National Petroleum Refiners Association, *U.S. Refining Industry Capability To Manufacture Ultra Low Sulfur Diesel Fuels* (Washington, DC, 1986), pp. 1-2.

<sup>18</sup>Energy Information Administration, *Petroleum Supply Annual 1992*, DOE/EIA-0340(92)/1 (Washington, DC, May 1993), pp. 82-105.

<sup>19</sup>Based on periodic industry announcements of plants under construction.

lines. In some cold northern States, distillate blends containing 30 to 50 percent kerosene are common.<sup>20</sup>

**Distillate Imports:** Distillate fuel imports into the United States come primarily from three sources: Canada, Venezuela, and the Virgin Islands. In 1992, those three sources accounted for over 93 percent of the average 216,000 barrels per day of distillate fuel imported into the United States. Over the last 6 years, those three sources accounted for over 80 percent of distillate fuel imports.<sup>21</sup>

The ability of the primary foreign distillate fuel oil suppliers to provide low-sulfur diesel fuel depends on their catalytic hydrotreating capacity (Table 5) and ability to segregate low-sulfur internal refinery distillate streams. The Virgin Islands (Hess) refinery is reported to have the largest ratio of distillate hydrotreating to crude oil distillation capacity and may be capable of supplying low-sulfur diesel to the U.S. East Coast. Venezuela, on the other hand, has the lowest ratio of hydrotreating to crude oil distillation capacity. However, Venezuela's U.S. exports of distillate represent only about 17 percent of its total distillate production compared with about 33 percent in the Virgin Islands.<sup>22</sup>

Because Europe has led the United States in increasing restrictions on diesel fuel quality in recent years, European refiners may also be unable to provide low-sulfur diesel for export. The maximum sulfur content for diesel and heating oil is 0.2 by percent by weight in eight countries (Belgium, Denmark, Finland, Germany, Luxembourg, Netherlands, Norway, and Sweden) and 0.3 percent by weight in seven (France, Greece, Ireland, Italy, Spain, Portugal, and the United Kingdom). Aus-

<sup>20</sup>Hunter Publishing Co., "Diesel Fuel Additives: Growing Business for Petroleum Marketers," *National Petroleum News* (February 1992), pp. 42-45.

<sup>21</sup>Energy Information Administration, *Petroleum Supply Monthly*, DOE/EIA-0109(93/02) (Washington, DC, February 1993), p. 80, and *Petroleum Supply Annual 1992*, DOE/EIA-0340(92)/1 (Washington, DC, May 1993), pp. 53-56, and earlier issues.

<sup>22</sup>Energy Information Administration, *International Energy Annual 1991*, DOE/EIA-0219(91) (Washington, DC, December 1992), p. 42.

**Table 4. U.S. Distillate Hydrotreating Capacity by PAD District, January 1, 1993**  
(Barrels per Stream Day, Percent of Atmospheric Distillation Capacity in Parentheses)

PAD District	Crude Oil Atmospheric Distillation		Existing Distillate Hydrotreating Capacity		Additional Planned Distillate Hydrotreating Capacity	
	Capacity	(Percent)	Capacity	(Percent)	Capacity	(Percent)
I — East Coast .....	1,425,000	(25.7)	366,600	(25.7)	20,000	(1.4)
II — Midwest .....	3,533,120	(13.0)	460,000	(13.0)	376,500	(10.7)
III — Gulf Coast .....	7,106,450	(21.9)	1,559,625	(21.9)	213,620	(3.0)
IV — Rocky Mountain .....	537,750	(17.9)	96,100	(17.9)	12,000	(2.2)
V — West Coast .....	2,958,679	(12.2)	360,200	(12.2)	83,600	(2.8)
<b>U.S. Total .....</b>	<b>15,560,999</b>	<b>(18.3)</b>	<b>2,842,525</b>	<b>(18.3)</b>	<b>705,720</b>	<b>(4.5)</b>

Notes: Existing distillate hydrotreating capacity includes kerosene and jet kero treaters.

Sources: Existing capacity from Energy Information Administration, *Petroleum Supply Annual 1992*, DOE/EIA-0340(92/1) (Washington, DC, May 1993). Planned capacity from PennWell Publishing Co., *Oil and Gas Journal* (April 12, 1993), pp.55-57; Gulf Publishing Co., *Hydrocarbon Processing* (October 1992), pp. 6-12; and company announcements in industry publications.

tria and Switzerland have a maximum sulfur content of 0.15 percent by weight in diesel fuel and 1 percent in heating oil.<sup>23</sup> The European community proposes to limit sulfur in all gas oils and distillates to 0.2 percent by weight by October 1, 1994. A further reduction in the sulfur level of on-highway diesel fuel to 0.05 percent will be required by October 1, 1996.

### Distillate Desulfurization Economics

The increase in operating costs and new capital investment required to produce low-sulfur diesel fuel should yield a price premium for low-sulfur diesel over heating oil and other high-sulfur distillate fuels. The significant factors in assessing the market price premium for low-sulfur diesel fuel are (1) the variable costs of operating desulfurization units; (2) the capital cost of new desulfurization capacity required to produce low-sulfur diesel fuel; and (3) the availability of other low-sulfur refinery streams that are not normally blended into distillate fuels (such as kerosene) but which could be used for on-highway diesel fuel blending.

Several industry studies have estimated the incremental cost of producing low-sulfur distillate fuel to be in the range of 1.2 to 7.0 cents per gallon.<sup>24</sup> The analysis presented here projects a low-sulfur diesel market price premium of 3 to 4 cents per gallon over heating oil on the basis of costs faced by the marginal producer. This premium covers higher variable costs of about 1 cent per gallon and capital recovery costs of 2 to 3 cents per gallon. This price premium is consistent with blending of incremental barrels of kerosene into the low-sulfur diesel pool and the observed market response to the low-sulfur diesel regulations imposed by California's South Coast Air Quality Management District (Los Angeles) in 1985.

<sup>23</sup>Energy Information, Ltd., "Low Sulfur Diesel Oil Moves to Center Stage in European Environmental Debate," *Oil Market Listener* (March 13, 1992), p. 2.

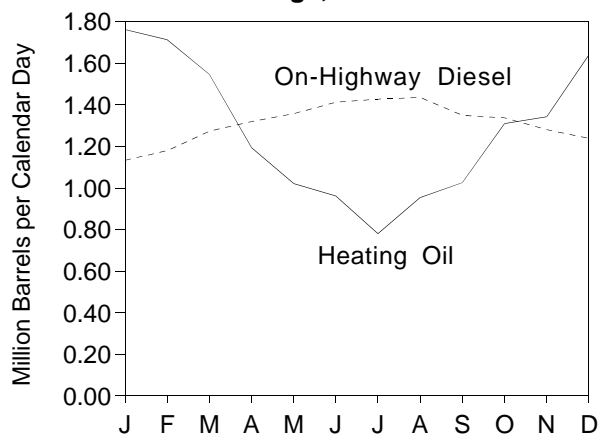
<sup>24</sup>Energy Resource Consultants, Inc., and Sobotka Consultants, Inc., *Diesel Fuel Quality Effects on Emissions, Durability, and Performance* (Washington, DC, September 30, 1985). National Petroleum Refiners Association, *U.S. Refining Industry Capability To Manufacture Ultra Low Sulfur Diesel Fuels* (Washington, DC, 1986). Environmental Protection Agency, *Federal Register*, Vol. 54, No. 163 (August 24, 1989), p. 35278. Cambridge Energy Research Associates, *The U.S. Refining Industry: Facing the Challenges of the 1990s* (Cambridge, MA, January 1992).

Not all refiners will respond the same way to the new low-sulfur market constraint. Some refiners may abandon production of low-sulfur diesel fuel completely. For example, even though the cost to small refiners may be lowered by the SO<sub>2</sub> trading allowances, the credits may not be enough to offset the higher production and capital costs they face. Desulfurization variable production costs are estimated to range from 0.7 cent per gallon for large refiners to 3.1 cents per gallon for small refiners. Capital service costs for new desulfurization capacity are projected to range from 1.1 cents per gallon for large refiners to 7.0 cents per gallon for small refiners. The net cost to small refiners with salable allowances for sulfur dioxide emissions may be lower by about 0.2 to 2.4 cents per gallon.

**Diesel Fuel Price Seasonality:** Although demand for diesel fuel is highest in the summer months, diesel fuel prices are expected to remain tied to prices for heating oil, a seasonal fuel with a winter peak in demand and prices (Figure 2).<sup>25</sup> Because a significant proportion of

<sup>25</sup>Differences in the average refiner prices for diesel fuel and heating oil are usually less than 1 cent per gallon. The reported price differences may result from averaging different regional prices and market shares or price premiums on special diesel fuel blends that include additives, such as pour-point and cloud-point depressants used in the winter.

**Figure 2. Diesel and Heating Oil Demand, 6-Year Average, 1986-1991**



Sources: • **Heating oil:** Energy Information Administration, Integrated Modeling Data System (IMDS) data base, "Distillate Fuel - Industrial Sector," series DFICPUS, and "Distillate Fuel - Residential and Commercial Sectors," series DFHCPUS, extracted June 18, 1993. • **On-highway diesel:** Federal Highway Administration, *Highway Statistics 1991*, FHWA-PL-92-025 (Washington, DC, 1992), p. 8, and previous annual issues.

**Table 5. Foreign Distillate Hydrotreating Capacity, January 1, 1993 (Barrels per Calendar Day)**

Country	Number of Refineries	Crude Oil Distillation Capacity	Distillate Hydrotreating Capacity	Hydrotreating as Percent of Crude Distillation Capacity
Canada .....	26	1,871,500	314,500	16.8
Venezuela.....	6	1,167,000	95,300	8.2
Virgin Islands.....	1	545,000	165,000	30.2

Source: PennWell Publishing Co., *Oil and Gas Journal* (December 21, 1992), pp. 52-95.

the winter supply of heating oil must come from inventory, an incentive must exist for refiners to store distillates produced during the low heating oil demand summer months for delivery during the winter heating season. The price of distillate fuel oil typically swings by about 10 cents per gallon from a June low to a December peak and provides the incentive.<sup>26</sup>

Because of the price swing, there will be no incentive for refiners to produce low-sulfur, on-highway diesel fuel during the winter for delivery in the high diesel fuel demand summer months (a course that would be equivalent to a buy high, sell low strategy). Thus, low-sulfur diesel fuel production capacity must be sufficient to meet the peak summer diesel fuel demand. This requirement implies that there may be excess low-sulfur diesel fuel production capacity during the winter. Under such conditions, refiners may be able to recover variable costs, but not capital costs, in the low-sulfur diesel fuel price premium. However, two factors will serve to reduce the potential winter excess capacity condition. First, since the swing in diesel fuel demand is only about 21 percent of peak summer demand (Figure 2), normal desulfurization unit turnarounds (e.g., catalyst replacement) would be scheduled for winter months, thereby minimizing excess capacity. Second, because total distillate fuel oil demand is lowest during the summer, some excess desulfurization capacity is already available during the summer months for low-sulfur diesel production.

**Desulfurization Variable Costs:** Increasing the level of sulfur removal from distillate fuel requires operation of hydrodesulfurization units under more severe operating conditions (increased hydrogen volume, higher temperature and pressure, and lower reactor space velocities) that increase operating costs.

Refineries responding to the 1986 NPRSA survey claimed that the increase in desulfurization variable costs would range from 0.7 to 3.1 cents per gallon of

<sup>26</sup>Author's calculation using regression analysis of diesel fuel price from 1982 to the present (controlling for changes in deseasonalized crude oil price).

low-sulfur distillate fuel, depending on capacity (Table 6). The average for the United States is closer to the lower end of this range (at 0.9 cents per gallon), with higher unit costs being characteristic of the smaller (and less complex) refineries. Small refineries are disadvantaged because they typically do not have access to inexpensive hydrogen (which is produced as a by-product from naphtha reformers) and cannot benefit from economies of scale because they do not have existing desulfurization capacity to build on.

**Desulfurization Capital Costs:** Estimated capital costs in the 1986 NPRSA survey ranged from \$660 per barrel of low-sulfur distillate for large refiners to \$4,328 per barrel of low-sulfur distillate for small refiners. Estimated capital service charges ranged from 1.1 cents per gallon of low-sulfur distillate fuel for large refiners to 7.0 cents per gallon of low-sulfur distillate for small refiners (Table 7). The average for the United States (2.2 cents per gallon) is again closer to the lower end of the range. The estimated capital service cost for large refineries is significantly lower than that for small refineries because of economies of scale and the availability of existing hydrogen production and sulfur recovery capacity, which reduces necessary capital investment.

Some refineries may not be able to make the needed investment in catalytic hydrogenation, hydrogen production, and sulfur recovery units. Those refineries may have to abandon the on-highway diesel fuel market. The National Petroleum Council (NPC) describes this as a niche strategy, focused on home heating oil and off-highway diesel fuel and most likely to be followed by small refineries.<sup>27</sup> Refineries that do not produce low-sulfur distillate may arrange for product exchanges of heating oil for low-sulfur diesel produced by refiners with excess desulfurization capacity, with appropriate value adjustments.

Thirty-seven refineries in the NPRSA survey, with a distillate production capacity of about 415,000 barrels

<sup>27</sup>National Petroleum Council, *Petroleum Refining in the 1990s: Meeting the Challenges of the Clean Air Act* (Washington, DC, June 1991), p. 55.

**Table 6. NPRSA Survey Estimates of Low-Sulfur Distillate Variable Production Cost**

Refinery Size Range (thousand barrels per day)	Number of Refineries	Potential Low-Sulfur Distillate Production (thousand barrels per day)	Hydrotreating as Estimated Operating Expense (cents per gallon)
0 to 30 .....	25	64	3.1
30 to 100 .....	67	821	1.0
100 to 200 .....	28	734	0.9
Over 200 .....	19	843	0.7
<b>U.S. Total .....</b>	<b>139</b>	<b>2,462</b>	<b>0.9</b>

Source: National Petroleum Refiners Association, *U.S. Refining Industry Capacity To Manufacture Ultra Low Sulfur Diesel Fuels* (Washington, DC, 1986), pp. 30 and 32.



per day, indicated that they could not make the needed improvements in diesel fuel quality because of investment capital or environmental permitting constraints. The small and medium refineries in the NPRA survey were reported to be the most susceptible to the constraints, with 33 out of 92 refineries unable to build new facilities. Fifty-six percent of small refineries (defined as having a capacity of less than 30,000 barrels per day crude oil) and 28 percent of medium-sized refineries (having a capacity of 30,000 to 100,000 barrels per day of crude oil) reported being unable to build new desulfurization units.

**Sulfur Dioxide Emissions Allowances:** Because small refineries would face greater capital and operating costs to meet the new low-sulfur standard than larger refiners, CAAA90 grants SO<sub>2</sub> allowances to small refiners that produce complying on-highway diesel fuel.<sup>28</sup> Small refiners may sell their SO<sub>2</sub> allowances to other sources affected by the CAAA90 (e.g., electric utilities that burn high-sulfur coal) or bank them for future use. CAAA90 defines small refiners as those companies with average 1990 crude oil throughput of 137,500 barrels per calendar day or less and further stipulates that the crude oil throughput of individual qualifying refineries be 50,000 barrels per calendar day or less. Based on data reported monthly to EIA, 90 refineries, which accounted for 12.9 percent of total U.S. distillate production in 1990, may qualify for allowances.<sup>29</sup>

One SO<sub>2</sub> allowance corresponds to 1 ton (2,000 pounds) of SO<sub>2</sub>. For typical diesel fuel (32.4 API gravity), about 1,478 barrels of low-sulfur diesel fuel would be awarded one SO<sub>2</sub> allowance.<sup>30</sup> The value of the

<sup>28</sup>Public Law 101-549, Section 410(h), U.S.C. 42, "Clean Air Act Amendments of 1990," enacted on November 15, 1990.

<sup>29</sup>Form EIA-810, "Monthly Refinery Report."

<sup>30</sup>Environmental Protection Agency, *Federal Register*, Vol. 57, No. 130 (July 7, 1992), p. 30031. The amount of sulfur removed in production of low-sulfur diesel is assumed by the EPA to represent the reduction in average sulfur content from 0.274 percent to 0.050 percent sulfur by weight.

allowances ranges from \$131 to \$1,500 each<sup>31</sup> and corresponds to a credit to small refiners of 0.2 to 2.4 cents per gallon of low-sulfur diesel fuel produced.

The maximum number of allowances that can be allocated annually to a small refiner is 1,500, which would correspond to low-sulfur diesel production of about 6,075 barrels per calendar day. In any given year, the total number of allowances awarded to all small refiners may not exceed 35,000 (about 141,750 barrels per day of low-sulfur diesel). Allowances may be allocated to small refiners from October 1, 1993, through December 31, 1999.

**Blending Kerosene into Diesel Fuel:** Small increases in low-sulfur diesel fuel supply can be obtained by blending in lighter, more expensive petroleum fractions, such as No. 1 distillate or kerosene. Over the last 5 years, the spot price of jet kerosene waterborne cargoes on the U.S. Gulf Coast (USGC) has averaged 2.9 cents per gallon higher than the spot USGC waterborne No. 2 fuel oil price (excluding the Iraq Desert Shield months).<sup>32</sup> This option should be viewed only as a spot or short-term solution to low-sulfur diesel fuel supply. Kerosene blend stocks are of lower quality than diesel fuel because of their lower heating values, which would yield lower diesel engine fuel efficiency. Furthermore, proposed U.S. military conversion from JP-4 naphthatype jet fuel to JP-8 or Jet-A jet kerosene will place greater demand pressure on the price of the kerosene cut of the crude oil barrel, tending to reduce the cost effectiveness of blending jet kerosene into diesel fuel.<sup>33</sup>

<sup>31</sup>Environmental Protection Agency, *Federal Register*, Vol. 58, No. 88 (May 10, 1993), pp. 27563-27567. The low end of the range corresponds to the low winning bid of \$131 by American Electric Power Service in the March 29, 1993, Phase 1 spot auction conducted by the Chicago Board of Trade for the EPA. The \$1,500 high end of the range represents the fixed price of allowances that the EPA will put up for direct sale on June 1, 1993, on a first-come, first-served basis.

<sup>32</sup>McGraw-Hill, Inc., *Platt's Oil Price Handbook and Oilmanac* (New York, NY, 1988-1992).

<sup>33</sup>Energy Information Administration, *Annual Energy Outlook 1993*, DOE/EIA-0383(93) (Washington, DC, January 1993), p. 35.

**Table 7. NPRA Survey Estimates of Low-Sulfur Distillate Capital Cost**

Refinery Size Range (thousand barrels per day)	Number of Refineries	Capital Investment New Facilities		Capital Service (cents per gallon low-sulfur diesel)
		Total Cost (million dollars)	Dollars per Barrel Low-Sulfur Distillate	
0 to 30.....	25	277	4,328	7.0
30 to 100 .....	67	1,628	1,983	3.2
100 to 200 .....	28	852	1,161	1.0
Over 200 .....	19	556	660	1.1
<b>U.S. Total .....</b>	<b>139</b>	<b>3,313</b>	<b>1,345</b>	<b>2.2</b>

Source: National Petroleum Refiners Association, *U.S. Refining Industry Capacity To Manufacture Ultra Low Sulfur Diesel Fuels* (Washington, DC, 1986), pp. 30 and 32. Capital service charge based on 15 percent discounted cash flow return on investment with a 13-year economic life.

**Transportation and Distribution:** NPC has noted that changing patterns of transportation and distribution could, in some regions, bring about relatively modest increases in the costs of moving product from supply to market. Cost increases could result from either having to move diesel fuel longer distances because fewer refineries will be producing on-highway diesel, or from having to build additional infrastructure to allow segregation of low-sulfur diesel fuel.<sup>34</sup>

The Petroleum Marketers Association of America argued that it would cost small marketers an average of \$40,000 to upgrade storage facilities to handle segregated fuel and an average \$60,000 to handle the delivery of segregated fuels, with the average cost to handle segregated fuels being about 1.5 cents per gallon.<sup>35</sup> A later study done by ICF Inc. for the Environmental Protection Agency estimated costs to marketers of 0.1 to 0.4 cent per gallon, depending on density of marketers, diesel share of distillate market, and population density.<sup>36</sup>

**The Los Angeles Experience:** One limited historical example of low-sulfur diesel fuel pricing is available. On January 1, 1985, the California Air Resources Board required all southern California refiners producing over

50,000 barrels per day to reduce sulfur in diesel fuel sold in the South Coast Air Quality Management District (Los Angeles) from 0.5 to 0.05 percent. During the first week of 1985, Chevron offered 0.05 percent diesel at 2 cents per gallon more than high-sulfur diesel, while ARCO priced its low-sulfur diesel at 4 cents per gallon above its high-sulfur diesel.<sup>37</sup> A comparison of Platt's refinery and terminal price reports for the Los Angeles and San Francisco No. 2 distillate terminals reveals a possible premium of over 3 cents per gallon for diesel fuel sold in Los Angeles. During the 4 years before January 1, 1985, diesel fuel in Los Angeles averaged 1.5 cents per gallon less than in San Francisco. In the 4 years after the regulation took effect, the price of diesel in Los Angeles was 1.7 cents per gallon more than the San Francisco price.<sup>38</sup> Examining daily diesel rack price postings reveals that on January 2, 1985, Los Angeles had a price advantage of 0.625 cents per gallon (72.5 cents per gallon in Los Angeles versus 73.1 cents per gallon in San Francisco), which became a 4-cent per gallon disadvantage by January 11, 1985 (75.6 cents per gallon in Los Angeles versus 71.6 cents per gallon in San Francisco). Although this is supportive evidence of the 3- to 4-cents-per-gallon market price premium for low-sulfur diesel fuel, it is not conclusive because of other unidentified market supply and demand forces that may have affected regional prices.

<sup>34</sup>National Petroleum Council, *Petroleum Refining in the 1990s: Meeting the Challenges of the Clean Air Act* (Washington, DC, June 1991), p. 56.

<sup>35</sup>*Federal Register*, Vol. 55, No. 162 (August 21, 1990), p. 34122.

<sup>36</sup>ICF Inc., "Impacts of Fuel Desulfurization on Distillate Marketers," March 13, 1990, cited in *Federal Register*, Vol. 55, No. 162 (August 21, 1990), pp. 34123-34125.

<sup>37</sup>United Communications Group, "ARCO, Chevron Peg Diesel Price," *Oil Express* (January 7, 1985), p. 3.

<sup>38</sup>McGraw-Hill, Inc., *Platt's Oil Price Handbook and Oilmanac* (New York, NY, 1981-1988).

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