5. Short-Term Impacts on ULSD Supply

Background

This chapter addresses the transition to ultra-low sulfur diesel fuel (ULSD) when the ULSD Rule takes effect in 2006. Whether there will be adequate supply was one of the key questions raised by the House Committee on Science in its request for analysis. The Charles River Associates/Baker and O'Brien (CRA/BOB) study done for the American Petroleum Institute (API) estimated a shortfall of 320,000 barrels per day when the regulation is introduced in 2006. The issue of future supply of highway diesel fuel “received considerable attention during the comment period” on the Notice of Proposed Rulemaking (NPRM) published by the U.S. Environmental Protection Agency (EPA). The EPA noted that “numerous commenters to the proposed rule indicated that they believed that the 15 ppm sulfur cap would cause shortages in highway diesel fuel supply” but that “a number of commenters also thought otherwise (i.e., that future supplies would be adequate).”

While it is possible that some refiners may decide to shut down altogether because of this regulation, others might just abandon the highway diesel market. Few refineries can operate without producing gasoline because gasoline is a high-margin, high-volume product that provides significant revenue to refiners. On the other hand, it may be possible for some refineries to operate without producing ULSD. Some refineries could sell higher sulfur distillate products into the non-road, rail, ship, or heating oil markets. Some refiners could also decide to export distillate products if they are in the right location.

Because there are other markets for distillate products, some refiners may opt to delay upgrading their facilities to produce ULSD. Refiners’ recent experiences with investing to meet new fuel standards have not been encouraging. As the EPA pointed out in the Regulatory Impact Analysis for this regulation, both the 500 ppm diesel fuel and reformed gasoline standards resulted in overinvestment and oversupply of the fuels, and "of late, relatively poor refining margins have not allowed refiners to recoup the full cost of environmental standards." Overly aggressive expansion to produce ULSD could result in similar oversupply of product and reduced margins, and some refiners may therefore wait to see whether adequate margins develop.

Another uncertainty is possible regulation of non-road diesel fuel. In addition, some States are proposing their own regulations for highway diesel fuel, which may add to the EPA requirements. Some refiners may wait to see whether additional requirements are established for highway or non-road diesel before investing to upgrade their refineries to produce ULSD.

The EPA has taken steps to monitor the ULSD supply situation. Its Final Rulemaking requires refiners and importers to submit a variety of information to ensure a smooth transition, and to evaluate compliance once the program begins. Refiners and importers expecting to produce highway diesel in 2006 are required to register with the EPA by December 31, 2001. Annual pre-compliance reports are required from 2003 through 2005, containing estimates of ULSD and 500 ppm sulfur fuel that will be produced at each refinery and projections of the numbers of credits that will be generated or needed by each refinery. A time line for compliance is also required, as well as other information.

The EPA will produce an annual report summarizing information from the precompliance reports without disclosing individual company plans. This information will give refiners a better indication of the potential market for credits and the availability of credits in each region. The EPA will also require annual reports after the program takes effect, in order to monitor production of ULSD and 500 ppm sulfur diesel fuel. In addition, an independent advisory panel will be set up to look at issues of diesel supplies and related technologies, and to report to the EPA annually on the progress being made by industry to comply with the ULSD Rule.

98Diesel Fuel News (March 5, 2001), p. 3.

Energy Information Administration / Transition to Ultra-Low-Sulfur Diesel Fuel

14627

DOE017-1723

Obtained and made public by the Natural Resources Defense Council, March/April 2002
investment, which is estimated to be equivalent to the 7-percent before-tax return on investment assumed in the EPA’s analysis.

The cases in Table 6 were designed to represent the types of individual refinery situations that lie behind the cost curve results. Cases A and B represent refiners producing highway diesel fuel as a high fraction of their distillate pool. These refineries run a higher sulfur crude oil, do not have hydrocracking facilities, and have relatively large-scale highway diesel production. Thirty-two percent of the highway diesel they produce comes from cracked stock, which is about the average for Petroleum Administration for Defense District II (PADD II) (see Appendix D, Table D1). The cost of producing highway diesel at current production levels in the refineries of Cases A and B is 6.0 cents per gallon if a new hydrotreater is required and 5.0 cents per gallon if the current hydrotreater can be revamped. The cost of the incremental hydrogen to produce ULSD represents 28 percent of the added cost for Case A and 35 percent for Case B.

Cases C and D have the same volumes as A and B but use a lower sulfur crude oil. The cost of the added hydrogen is similar to the result for Cases A and B, because this analysis is estimating the cost to produce ULSD with 7 ppm sulfur rather than the current 500 ppm. Total costs, however, are just 0.1 cents per gallon lower for a revamped unit (Case D compared to Case B) and 0.6 cents per gallon lower for a new unit (Case C compared to Case A).

Case E shows a refinery producing ULSD only from straight-run distillate derived from a high-sulfur crude. The cost of production from a hydrotreater that has been revamped is only 2.7 cents per gallon. This is slightly more than half the cost of Case B, which has to handle 32 percent cracked stocks.

Cases G and H represent the same mix of hydrotreater feed as in Cases A and B, but the total feedstock volume is only 10,000 barrels per day, compared to 50,000 barrels per day in Cases A and B. This is the type of situation represented by comparing ULSD production in PADD IV with that in PADD II and PADD III. For a new hydrotreater unit, the ULSD cost would be 8.3 cents per gallon (2.3 cents per gallon higher than in Case A). If the unit can be revamped, the cost is 6.1 cents per gallon (1.1 cents per gallon higher than in Case B).

Some refineries currently produce high volumes of distillate product but no highway diesel. These refineries might consider entering the highway diesel market when the ULSD Rule takes effect if they anticipate that the price differential between ULSD and their other distillate products can more than offset the added investment and operating costs they would incur. Case I illustrates a non-road diesel producer converting to the production of highway diesel. The refinery runs a moderately high-sulfur crude oil and has substantial volumes of cracked distillates from the fluid catalytic cracker (FCC) and coker units. Because of quality requirements for non-road diesel products, cracked stocks still make up 45 percent of the feed to the hydrotreater for highway diesel production. The large percent of cracked stocks means a moderately high per-barrel investment and operating cost for the hydrotreater. Additionally, the per-barrel cost for hydrogen is quite high. Most of the refineries with high-volume distillate production and no highway diesel production had costs of highway diesel production in the higher portion of the cost range.

Cases J, K, and L provide an illustration of refineries achieving improved economics by reducing the volume of ULSD diesel below current highway production levels. As shown in Table 6, the cost of added hydrogen is generally a large component of the cost of producing ULSD. The cost for hydrogen grows as the fraction of cracked stocks increases, eventually requiring the construction of new hydrogen production capacity. However, if there is only a modest percent of cracked stock in the hydrotreater feed and the refiner reduces the input to the hydrotreater, then the incremental hydrogen requirement for ULSD production can be provided by existing refinery production sources.

Cases J and K show the costs for a new and revamped hydrotreater for a refinery running a medium-sulfur crude and with 22 percent cracked stock in the highway diesel production pool. Case J shows that if the input level is reduced from 32,400 barrels per day to 20,700 barrels per day when the unit is revamped, then the cost of ULSD production is reduced from 4.5 cents per gallon to 3.1 cents per gallon. Given the costs for Cases K and L, the preferred option for the refiner would be Case K if the price differential between highway and non-road diesel exceeds 6.9 cents per gallon and Case L if the differential is less than 6.9 cents per gallon.

These sample cases highlight several situations that can cause refineries to have potentially high ULSD production costs and discourage them from investing to produce ULSD. Small refineries with less than 10,000 barrels per day of highway diesel production will have very high relative costs unless they can revamp an existing unit. The fraction of cracked stocks in the ULSD hydrotreater feed is extremely important. The need for hydrogen increases with the fraction of cracked stocks and may require new hydrogen production capability. If a refinery’s other distillate products are primarily

1) Calculated by taking the difference in total cost (1.88 x 32.4 - 1.33 x 20.7) divided by the change in volume (32.4 - 20.7), expressed in cents per gallon.

Energy Information Administration / Transition to Ultra-Low-Sulfur Diesel Fuel

DOE017-1724

Obtained and made public by the Natural Resources Defense Council, March/April 2002
lowest proportion of revamps because of the large amount of cracked stocks that refineries in that region must process. PADD II has the highest percentage of revamps because of the extensive upgrading that took place in the early 1990s and the moderate levels of cracked stocks in the feed. The EPA assumed that 80 percent of ULSD production capacity would be revamped units.

**Supply Scenarios**

The first of the four supply scenarios was developed based on the rationale that there is a high probability that refineries will produce at least a moderate level of ULSD. In the other three scenarios there is decreasing probability that the additional volumes would be produced. The description of the specific scenarios follows:

- **Scenario 1—Competitive Investment.** The first scenario includes only those refineries who are likely to prepare to produce ULSD in 2006. They currently hold market share and are estimated to be able to produce ULSD at a competitive cost. Refiners with highway diesel as a relatively low fraction of their distillate production are assumed to abandon the market unless their cost per unit of production is competitive at current highway diesel production levels. Some refineries are assumed to reduce highway diesel production below current levels when they have a more competitive ULSD production at a reduced production rate.

- **Scenario 2—Cautious Expansion by Competitive Producers.** In this scenario, refineries base ULSD production decisions on the assumption that the price differential between ULSD and non-road distillate products will remain wide. Current producers with competitive cost structures for ULSD production and high fractions of highway diesel production (greater than 70 percent of total distillate production) are assumed to maintain current production levels and may even push production of ULSD toward 100 percent of distillate production if only minor increases in per unit production costs occur at increased volume. Other refineries are also assumed to increase their fraction of highway production if the economics are only slightly poorer at higher volumes. Those whose current production is focused primarily on non-road markets are assumed to stay with those markets.

- **Scenario 3—Moderate New Market Entry.** While refineries that are currently producing little or no highway diesel may be hesitant to jump into the ULSD market, this scenario assumes that a select few will decide to take the risk. This is based on the belief that a limited number of refineries think they can gain market share without depressing the price differential between ULSD and non-road diesel to the extent of ruining margins and return on investment. These refineries are assumed to have favorable cost structures for ULSD production (probably in the lower third).

- **Scenario 4—Asseritive Investment.** The fourth scenario assumes that a larger number of refineries will compete to increase their shares of the ULSD market. In this scenario, refineries believe that most of their competitors are overly cautious, and that they can succeed by taking a contrary strategy (which in reality is adopted by far more refineries than anticipated).

**Imports**

Historically, imports have been a small part of low-sulfur diesel supply. The only significant volumes of low-sulfur diesel fuel have been imported into PADD I, which totaled 123,000 barrels per day in 1999 then declined slightly in 2000 to 106,000 barrels per day (Figure 4). Imports made up 5 percent of low-sulfur diesel product supplied for the United States as a whole in 2000 and 14 percent of product supplied in PADD I. The PADD I imports come from three main sources—Canada, the Virgin Islands, and Venezuela. Low-sulfur diesel imports from the Virgin Islands reached 62,000 barrels per day in 1996 and have fallen to 47,000 barrels per day in 2000. Imports from Canada, which have been fairly constant for the past few years, totaled 35,000 barrels per day in 2000. Imports from Venezuela grew sharply in 1998 and 1999, to 22,000 barrels per day in 1999, before falling to 8,000 barrels per day in 2000.
diesel fuel currently being consumed in the market is more than 15 percent higher than that required for highway vehicles. There are several reasons for this. The logistics of the distribution system dictate in some areas that only one type of fuel can be distributed. Because the price differential between low-sulfur diesel and other distillate products has been only 2 to 3 cents per gallon or less in recent years, the incentive to maintain separate product infrastructure has not been great. An important question is the extent to which the demand for ULSD will remain above that required for highway vehicles after the ULSD regulation takes effect in 2006. A larger price differential between ULSD and higher sulfur distillate products may provide some incentive to avoid consuming ULSD in markets where it is not required, but in some areas it may continue to be impractical to distribute more than one product.

It is also unclear how much 500 ppm sulfur diesel fuel will be in the market after the regulation takes effect. Refiners will be investing for the long term and not just to produce 80 percent ULSD in the transition period, and many refiners (if they invest to produce ULSD at all) may be producing 100 percent ULSD in the transition period. Some refiners could continue to supply 500 ppm diesel fuel by purchasing credits, and some small refiners could continue to produce 500 ppm sulfur fuel until 2010 (see box on page 45).

For the above reasons, the amount of ULSD actually needed to balance demand in 2006 is highly uncertain. A range of demand estimates has been developed to account for some of the uncertainty. In the mid-term analysis for this study, transportation distillate demand in PADDs I-IV in the 2/3 Revamp case (see Chapter 6) amounts to about 2.7 million barrels per day. At the U.S. level, transportation distillate demand is projected to be 3.0 million barrels per day in 2006, increasing by 3.2 percent per year from the 1999 level of 2.4 million barrels per day. This compares to an average rate of increase of 3.5 percent per year from 1982 to 1999. Transportation distillate demand rose sharply from 1982 to 1989 and again from 1991 to 1999, at annual average growth rates of 4.7 and 4.0 percent, respectively, but fell in 1990 and 1991, at the time of the Iraqi invasion of Kuwait.

The probable downgrading of some ULSD to 500 ppm sulfur diesel in the distribution system was not taken into account in this part of the analysis. The requirement to produce 80 percent ULSD is at the refinery gate, and
have much higher costs and could have concerns that margins in the marketplace would not be high enough to provide a satisfactory rate of return.

The cost curves in Figure 6 were developed using capital cost and return on investment assumptions consistent with those used in the EPA's analysis. Those assumptions were used in order to provide a comparison with the EPA's analysis results and should not be viewed as the assumptions that EIA considers the most likely. However, concerns about the adequacy of ULSD supply are based on the possible reluctance of higher cost producers to invest to produce ULSD in 2006. Because of the uncertainty of these assumptions, two additional sets of supply scenarios are provided, using higher capital cost assumptions and a higher required return on investment, as discussed later in this chapter.

Total ULSD production on the Scenario 1 (Competitive Investment) and Scenario 2 (Cautious Expansion) cost curves extends beyond the lower demand estimates (C and D) and would meet the highway demand estimates even if no ULSD imports were available. In Scenario 3 (Moderate New Market Entry), production just reaches the mid-term analysis demand estimate that includes imports (Demand B). In Scenario 4 (Assertive Investment), ULSD production surpasses the mid-term analysis demand estimate that does not include imports. None of the supply curves, however, provides enough supply to reach the demand estimate that does not include the temporary compliance option (see Table 8 below). Some refineries may be able to produce ULSD with a cost of about 2.5 cents per gallon; however, all the volumes needed to meet demand, costs are estimated at 5.4 to 6.8 cents per gallon. ULSD prices could show an even higher differential if supply falls short of demand.

The four factors that have the strongest influence on the cost of producing ULSD are the production volume of 500 ppm diesel, the fraction of cracked stocks in the feedstock, the scale of the hydrotreater unit, and whether a new or revamped unit is required.

### 500 ppm Diesel Supply Issues in 2006

In 2006, 500 ppm highway diesel could come from two sources: either from refineries which produce both 500 ppm and 15 ppm highway diesel or from refineries which are now producing highway diesel but who choose not to make investments to produce ULSD and purchase credits to sell 500 ppm diesel. Few refineries are assumed to fall into the first group. Possible candidates would be refineries with large current production of highway diesel who have multiple distillate hydrotreating units and decide to revamp or replace a large unit to produce ULSD and maintain a second unit to produce 500 ppm highway diesel. This would also mean that the refiner would anticipate selling the 500 ppm diesel as non-road diesel in 2011, because building one large hydrotreater in 2006 would be more economical than building a second hydrotreater for ULSD in 2010. If the decision is made to invest to produce ULSD, a refiner is likely to invest to produce the full volume of highway diesel as ULSD. Some product that fails to meet the ULSD specifications could be downgraded to 500 ppm diesel fuel and sold as highway diesel during the transition period, but few refineries are assumed to produce both 15 ppm and 500 ppm diesel.

Production of 500 ppm highway diesel can clearly come from refineries which are now producing low-sulfur highway diesel and decide not to convert their refinery facilities in 2006. In Scenario 2, the number of non-producers of ULSD in PADDs I-IV totals 21. The characteristics of the 21 refineries that are the potential sources of 500 ppm highway diesel production in 2006 in Scenario 2 differ across the various PADDs. PADD I has 5 refineries and PADD II has 5 refineries that are assumed not to invest to produce ULSD. None of these ten refineries currently produce less than 10,000 barrels per day of highway diesel, and the other is under 20,000 barrels per day.

The profile of the PADD III refineries is quite different from those in the other PADDs. While PADD III has some small refineries in this group, several moderately large refineries are also included, which accounts for the fact that PADD III represents 56 percent of the total volume of PADD I-IV production that is estimated not to convert low-sulfur diesel to ULSD in 2006. Most of these refineries are on the high end of the cost range and would have to build new units and/or deal with relatively high fractions of cracked stocks to produce ULSD.

Six refineries in PADD IV are estimated to have relatively high costs of ULSD production and are assumed not to invest to produce ULSD. The PADD IV refineries are relatively small. Most have some cracked stocks in the highway diesel feed stream and would need to build new units. The refineries not producing ULSD would need to obtain waivers or purchase credits to continue to sell 500 ppm diesel fuel into the highway market.

---

109 These are marginal costs on the industry supply curve, based on average refinery costs for producing ULSD. These cost estimates do not include additional costs for distribution, estimated at 1.1 cents per gallon in the mid-term analysis. Costs were not adjusted to take sulfur credit trading into account, because of the uncertainty about whether trading would occur and the value of the credits. If credit trading occurred, costs could be reduced.

Energy Information Administration / Transition to Ultra-Low-Sulfur Diesel Fuel

14631

DOE017-1727

Obtained and made public by the Natural Resources Defense Council, March/April 2002
higher. Second, five of the refineries entering the market were viewed in Scenario 3 as having too high a cost. The third and largest portion of additional volume comes from two refineries that currently are not producers of highway diesel. All of the additional volume in Scenario 4 comes from refineries with costs of ULSD production higher than 5 cents per gallon.

Table 8 shows the differences between the demand and supply estimates. The largest shortfall, which occurs between Scenario 1 (assuming the most cautious investment strategy) and the highest demand estimate, is estimated at 770,000 barrels per day. The widest surplus, 517,000 barrels per day, is under Scenario 4 (the most aggressive investment strategy) and the lowest demand estimate that also accounts for import availability. Assuming the mid-term analysis demand estimate, which is similar to the AEO2001 projection, Scenarios 3 and 4 project sufficient supply.

Some analysts contend that demand could exceed the estimates in this analysis that assume the temporary compliance option of 80 percent ULSD production. Most refineries that invest to produce ULSD will plan to produce 100 percent ULSD unless they have a market for the higher sulfur product after 2010. Those producing 100 percent ULSD will generate credits which can then be sold to those who decide to delay investing to produce ULSD. Credit trading programs have been successful in the utility industry, but how well credit trading will work in a less-regulated industry remains unclear. Refiners may be less than enthusiastic about selling credits to their competitors that would allow them to sell product produced at a lower cost in the same market as ULSD, possibly at a price similar to the price of ULSD. Refiners who wait to invest can also take advantage of improvements in technology that could help them compete more effectively with those who invested early. Credits could increase sharply in value if markets were tight, but they would have less value if supplies were ample.

To provide a further range of demand estimates, Tables 9 and 10 show the projections for high and low macroeconomic growth cases along with the supply estimates from the cost curves. Transportation distillate demand is projected to increase by 4.0 percent per year from 1999 to 2006 in the high macroeconomic growth case and by 2.7 percent per year in the low macroeconomic growth case.

Table 9. Supply and Demand Estimates in the High Economic Growth Case, 2006
(Thousand Barrels per Day)

<table>
<thead>
<tr>
<th></th>
<th>Demand</th>
<th>Scenario 1</th>
<th>Scenario 2</th>
<th>Scenario 3</th>
<th>Scenario 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Supply</td>
<td></td>
<td>1.763</td>
<td>1.823</td>
<td>1.959</td>
<td>2.142</td>
</tr>
<tr>
<td>Number of Refineries Producing ULSD</td>
<td>66</td>
<td>56</td>
<td>56</td>
<td>67</td>
<td>74</td>
</tr>
<tr>
<td>Differences Between Supply and Demand</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Small Refiner Option</td>
<td></td>
<td>2.669</td>
<td>-906</td>
<td>-845</td>
<td>-716</td>
</tr>
<tr>
<td>Small Refiner and Temporary Compliance Options</td>
<td>2.135</td>
<td>-372</td>
<td>-311</td>
<td>-185</td>
<td>8</td>
</tr>
<tr>
<td>Small Refiner and Temporary Compliance Options with Imports</td>
<td>2.055</td>
<td>-292</td>
<td>-231</td>
<td>-103</td>
<td>88</td>
</tr>
<tr>
<td>Highway Use Only, Small Refiner and Temporary Compliance Options with Imports</td>
<td>1.756</td>
<td>7</td>
<td>68</td>
<td>196</td>
<td>387</td>
</tr>
<tr>
<td>Highway Use Only, Small Refiner and Temporary Compliance Options with Higher Imports</td>
<td>1.720</td>
<td>43</td>
<td>104</td>
<td>232</td>
<td>423</td>
</tr>
</tbody>
</table>


Table 10. Supply and Demand Estimates in the Low Economic Growth Case, 2006
(Thousand Barrels per Day)

<table>
<thead>
<tr>
<th></th>
<th>Demand</th>
<th>Scenario 1</th>
<th>Scenario 2</th>
<th>Scenario 3</th>
<th>Scenario 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Supply</td>
<td></td>
<td>1.763</td>
<td>1.823</td>
<td>1.952</td>
<td>2.143</td>
</tr>
<tr>
<td>Number of Refineries Producing ULSD</td>
<td>66</td>
<td>66</td>
<td>66</td>
<td>67</td>
<td>74</td>
</tr>
<tr>
<td>Differences Between Supply and Demand</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Small Refiner Option</td>
<td></td>
<td>2.447</td>
<td>-685</td>
<td>-624</td>
<td>-495</td>
</tr>
<tr>
<td>Small Refiner and Temporary Compliance Options</td>
<td>1.958</td>
<td>-195</td>
<td>-134</td>
<td>-6</td>
<td>185</td>
</tr>
<tr>
<td>Small Refiner and Temporary Compliance Options with Imports</td>
<td>1.878</td>
<td>-115</td>
<td>-54</td>
<td>74</td>
<td>266</td>
</tr>
<tr>
<td>Highway Use Only, Small Refiner and Temporary Compliance Options with Imports</td>
<td>1.604</td>
<td>159</td>
<td>220</td>
<td>349</td>
<td>540</td>
</tr>
<tr>
<td>Highway Use Only, Small Refiner and Temporary Compliance Options with Higher Imports</td>
<td>1.500</td>
<td>155</td>
<td>256</td>
<td>385</td>
<td>576</td>
</tr>
</tbody>
</table>


Many analysts contend that the prices of ULSD and 500 ppm diesel will converge in the phase-in period, because most trucks can use 500 ppm fuel but only 20 to 25 percent of production will be 500 ppm fuel. The higher demand than supply will tend to push the price to the same level as ULSD. The need to purchase credits to sell 500 ppm product will also tend to push up its price.

Energy Information Administration / Transition to Ultra-Low-Sulfur Diesel Fuel

DOE017-1728

Obtained and made public by the Natural Resources Defense Council, March/April 2002
this analysis, and/or if more imports were available. On the demand side, slower growth in the highway diesel market than these demand estimates and/or curtailing of ULSD consumption for non-road uses would also improve the situation.

If supplies fall short of demand, sharp price increases could occur to balance supply and demand. That type of situation could result in a number of responses, some of which could begin to occur as soon as the price differential between ULSD and other products started to widen—possibly even before it became clear that a market supply problem existed. Refiners would attempt to maximize ULSD production. Some additional production may be possible by, for example, shifting some non-road distillate or jet fuel streams into ULSD. This would be limited, however, because only the lower sulfur streams could be used and additional hydrotreating may be necessary. Imports of jet fuel or other products could then replace the lost production of those fuels. Additional imports of ULSD could be forthcoming if there were large price differentials between markets.

Such responses would require higher costs, however, because lower cost options would be exercised first.

Sharply higher prices would also curtail demand for diesel fuel. Truckers would reduce consumption to the extent possible and try to pass higher fuel costs to customers, who would then look for alternative means to transport goods.

In 2006, the quantity of fuel actually needed for vehicles requiring ULSD will be much less than the required 80 percent of diesel production. If it becomes apparent that the supply is inadequate, or that markets are becoming tight, additional low-sulfur diesel supplies could become available if the required proportion of ULSD production were reduced. Allowing more 500 ppm diesel into the highway market could alleviate some of the stress on the market. If the requirement were 70 percent instead of 80 percent, for example, the demand estimates shown in Table 8 would be reduced by 217,000 to 253,000 barrels per day, enough to eliminate the shortfalls indicated except for Demand A in Scenario 1 and the highest

Figure 8. ULSD 10% Return on Investment Sensitivity Case Cost Curve Scenarios with 2006 Demand Estimates

Marginal Cost of Production (1999 Dollars per Gallon ULSD)

Demand

D A: Small Refiner and Temporary Compliance Options
D B: Small Refiner and Temporary Compliance Options with Imports
D C: Highway Use Only, Small Refiner and Temporary Compliance Options with Imports
D D: Highway Use Only, Small Refiner and Temporary Compliance Options with Higher Imports

Sources: Cost curve scenarios: Appendix D. Demand estimates: National Energy Modeling System, run DSU7NV.0043001A.
6. Mid-Term Analysis of ULSD Regulations

Assumptions

The National Energy Modeling System (NEMS) was used to perform petroleum market analysis of the impact of new requirements for ultra-low-sulfur diesel fuel (ULSD) from 2007 through 2015. The Petroleum Market Module (PMM) of NEMS was modified to produce a ULSD Regulation case. Analysis of the Regulation case focuses on changes relative to a reference case using the oil price and macroeconomic assumptions of the Annual Energy Outlook 2001 (AEO2001) reference case but including some adjustments to provide a more accurate reflection of the diesel fuel market. The differences between the reference case for this study and the AEO2001 reference case are discussed in Appendix B.

The projected investment costs and average marginal prices resulting from the NEMS analysis represent the investment and price levels necessary to meet all demand requirements under the new ULSD Rule. As discussed in Chapter 3, some refineries may choose to drop out of the highway diesel market or even close down instead of investing for compliance with the Rule. ULSD supply could be inadequate in the short term if enough refineries chose to forgo investment. The NEMS analysis does not capture this uncertainty of supply, because NEMS is a long-run equilibrium model. By definition, the NEMS analysis projects the level of domestic production and imports necessary to meet all demand requirements. As a result, the NEMS analysis reflects more aggressive investment behavior than that portrayed for individual refineries in the short-term analysis.

The NEMS analysis reflects the "80/20" rule, which requires the production of 80 percent ULSD and 20 percent 500 ppm highway diesel between June 2006 and June 2010, and a 100 percent requirement for ULSD after June 2010. Because each model region acts as a single unit, the provision of the ULSD Rule allowing small refineries, which account for about 5 percent of current highway diesel production, to delay investment until June 2010 is not modeled explicitly. However, the production requirements are adjusted downward by 4 percent to reflect an assumption that most small refineries will choose to delay investment.113

The requirement for 80 percent ULSD is not phased in and begins on June 1, 2006. Therefore, the full market impact of the requirement can be expected to occur at that time. Because NEMS is an annual average model, the full economic impact of the 80/20 rule cannot be seen until 2007. In the same manner, projections for 2011 represent the first full year of 100 percent ULSD compliance. The results for 2010 reflect a partial year at the 80 percent requirement and a partial year at the 100 percent requirement. For the purpose of assessing the market impacts of the new ULSD requirements, 2007 will be discussed as the first full year of the 80/20 requirement, and 2011 will be discussed as the 100 percent requirement.

The House Committee on Science requested that, if practical, the EIA analysis use the same assumptions as those used by the U.S. Environmental Protection Agency (EPA) in its Regulatory Impact Analysis (RIA). The assumptions are compared in Table 13. The Regulation case for this study is based on the following assumptions:

- Highway diesel at the refinery gate will contain a maximum of 7 parts per million (ppm) sulfur. Although sulfur content is limited to 15 ppm at the pump, there is a general consensus that refineries will need to produce diesel somewhat below 10 ppm in order to allow for contamination during the distribution process. The EPA assumed in its RIA that refineries would produce highway diesel at 7 ppm.

- The capital costs for the distillate hydrotreaters reflected in NEMS are $1,331 per barrel per day for a notional 25,000 barrel per day unit that processes low-sulfur feed streams with incidental desulfurization, and $1,849 per barrel per day for a second, 10,000 barrel per day unit that processes higher sulfur feed streams with greater aromatics improvement. A range of capital costs from a number of other studies is provided in Chapter 7. Because of differences in methodology, the sets of capital costs are not directly comparable. For instance, the EPA estimated the capital cost for a new distillate hydrotreater to range from $1,240 per barrel per day to $1,680 per barrel per day, but those estimates...
analysis, the revenue loss estimate is based on NEMS model results, at 0.3 cents per gallon of ULSD during the transition period and 0.2 cents per gallon after 2010.

- A cost of 0.2 cents per gallon is assumed for the addition of lubricity additives, consistent with estimates by the EPA and with industry analyses. Lubricity additives are needed to compensate for the reduction of aromatics and high-molecular-weight hydrocarbons stripped away by the severe hydrotreating used in the desulfurization process.

- The energy content of ULSD is assumed to decline by 0.5 percent, because undercutting and severe desulfurization will result in a lighter fuel composition than that for 500 ppm diesel. The EPA's analysis made no explicit adjustment to the energy content of diesel fuel but estimated a cost associated with a 1.3-percent (by weight) loss of yield. In the NEMS analysis, the yield loss is a variable model result (generally around 1.5 percent by volume). The National Petrochemical and Refining Association (NPRA) quoted a range of 1 to 4 percent energy loss in comments to the rulemaking docket. NPRA also estimated a yield loss of 1 to 5 percent.

- In accordance with the EPA's RIA, changes to engine after-treatment devices are assumed to result in no loss of fuel efficiency. Discussions with some engine and emission control technology manufacturers indicated considerable uncertainty about this assumption.

- No change in the sulfur level of non-road diesel is assumed. The EPA analysis of ULSD reflects no change in non-road standards, although the EPA is in the process of promulgating "Tier 3" non-road engine emission limits around 2003 or 2006, which are expected to be linked to sulfur reduction for non-road diesel fuel. The level of sulfur reduction required for Tier 3 vehicles is highly uncertain because of the diversity of the non-road market.

- No changes to other highway diesel specifications, such as aromatics or cetane, are assumed. Some refineries anticipate changes to these parameters in the future because of their relationship to emissions of particulate matter (PM). The State of California already limits aromatics to 10 percent by volume, which is reflected in this analysis. Proposals for similar requirements in other States are not included.

- Imports of diesel meeting the new ULSD standard are assumed to be available to U.S. markets, but the level of imports relative to the level of product supplied by refineries in the United States is a model result. Refineries in Canada, Northern Europe, and the Caribbean Basin (including Venezuela) are assumed to make upgrades to produce diesel fuel meeting the 15 ppm sulfur cap for 2006. Canada is moving forward with plans to harmonize with diesel regulations in the United States. European refiners will reduce diesel sulfur to 50 ppm for a new European standard in 2005. Some isolated European production of diesel meeting the ULSD standard is assumed, due to tax incentives for 10 ppm diesel in some markets. In order to divert ULSD from European markets, prices in the United States would have to exceed the tax incentives plus shipping costs. In 2000 less than 5 percent of U.S. imports of highway diesel came from Europe.

- In accordance with the EPA's RIA, the before-tax rate of return on investment is assumed to be 7 percent. Between 1977 and 1999 the combined before-tax return on investment for refiners and marketers averaged 7 percent, which is equivalent to a 5.2-percent after-tax rate. Because NEMS operates on an after-tax basis, the 5.2-percent rate is used in the model. Most of the studies compared in Chapter 7 assumed a 10-percent after-tax return on investment. The Committee indicated that this analysis was to be as consistent as possible with the assumptions underlying the EPA's RIA, and that sensitivity analysis should be provided for assumptions that diverge significantly from those in other studies or from expectations of industry experts. In addition to the Regulation case, this report provides sensitivity analyses for five assumptions associated with a greater uncertainty, for a Severe case that combines the assumptions of the five individual sensitivities, for a No Imports case, and for a 10% Return on Investment case:

- In the Higher Capital Cost case, the capital cost of the first notional hydrotreater is 24 percent higher than in the Regulation case, and the capital cost of the second notional unit is 33 percent higher.

- In the 2/3 Revamp case, two-thirds of upgrades at refineries are assumed to be accomplished by retrofitting existing equipment and one-third by construction of new units. With the exception of the

115U.S. Environmental Protection Agency. Reducing Air Pollution from Non-road Engines. EPA420-F-00-048 (Washington, DC, November 2000), p. 3
116Germany and the United Kingdom have proposed tax incentives for sales of 10 ppm diesel.
117Based on financial information from Form EIA-28 (Financial Reporting System).
118EIA did not assess the validity of these assumptions.
119The capital costs used in this case are based on recent work by EnSys, with revisions based on correspondence with Mr. Martin Tallett, April 21, 2001.

Energy Information Administration / Transition to Ultra-Low-Sulfur Diesel Fuel

14635
DOE017-1731

Obtained and made public by the Natural Resources Defense Council, March/April 2002
system. In other words, the additional downgrades must be offset by more ULSD production after 2010. The effect of downgrades is more pronounced in the 10% Downgrade case and the Severe case, where highway diesel demand is projected to increase by 2.9 percent and 3.1 percent per year, respectively, from 1999 to 2015.

Regulation Case

In the Regulation case, cumulative investment in distillate hydrotreating and hydrogen units is projected to be $4.2 billion higher than projected in the reference case in 2007 and $6.3 billion higher in 2011, when upgrades for meeting full compliance with the ULSD Rule will be complete (Table 14). In the early part of the transition period, upgrades for making ULSD may be constrained by specialized workforce and manufacturing limitations and access to capital, all of which will be in competition with projects for meeting the requirements for low-sulfur gasoline (see Chapter 3). The projected $2.1 billion in investment between 2007 and 2011 reflects expenditures for making expectations of growing demand for highway diesel, in addition to full compliance with the Rule. After 2011, incremental upgrades to meet future distillate demand are projected to continue, resulting in another $0.5 billion of investment in desulfurization equipment by 2015.

The Regulation case results in an increase in the marginal annual pump price for ULSD of 6.5 to 7.2 cents per gallon between 2007 and 2011 (Table 15). The peak differential is projected to occur in 2011, when all refiners must produce 100 percent ULSD. The projected differential declines after 2011, reaching 5.1 cents per gallon in 2015. About 0.7 cents of this decline is the result of no longer needing to include EPA’s estimate of additional capital investments for distribution and storage of a second highway diesel fuel during the transition period. A drop in capital expenses for distribution systems occurs after 2010 as a reflection of the EPA’s assumption that these investments will be fully amortized during the transition period. The remainder of the drop in the post-2011 differential occurs because refineries are expected to have completed the upgrades necessary for full compliance, and to be making incremental improvements that will make ULSD production less challenging. A similar decline in the price differential also occurs in all the sensitivity cases.

Through 2010, the Regulation case projections for highway diesel consumption exceed the reference case levels by up to 10,000 barrels per day, which can be attributed to the assumption of 0.3 percent loss in energy content. In 2011, the differential in consumption increases to 33,000 barrels per day, due mostly to the downgrading of 2.2 percent of ULSD to lower value non-road markets.

In a refinery, the impact of a change in the makeup or production level of a product can filter through to other products, because it changes the mix of total refinery production. The ULSD Rule is projected to result in slightly lower yields of higher sulfur distillate used for non-road and heating purposes, because its production is replaced by ULSD that is produced by refineries but is downgraded to higher sulfur products in the distribution system. The availability of the downgraded ULSD reduces the projected prices for high-sulfur distillate by about 1 cent per gallon relative to the reference case. The analysis revealed no clear trends for other distillate products as a result of the ULSD Rule.

Higher Capital Cost Case

Because of limited experience in producing diesel containing less than 10 ppm sulfur, the capital costs for hydrotreaters able to mass produce ULSD are uncertain. The Higher Capital Cost case results in refinery investment for hydrogen and distillate hydrotreating units totaling $5.4 billion in 2007, which is $1.2 billion above the Regulation case level. By 2011 the Higher Capital Cost case is projected to require $7.8 billion of investment, $1.5 billion more than in the Regulation case. The higher investment costs translate to a higher projected price path for ULSD. Relative to the reference case, price differentials are projected to range from 7.5 to 7.8 cents per gallon between 2007 to 2010, peaking at 8.1 cents per gallon in 2011, the first full year of full compliance. These prices are 0.8 cents per gallon higher on average than those in the Regulation case.

2/3 Revamp Case

The 2/3 Revamp case results in a higher projected price path for ULSD, with price differentials ranging from 6.9 to 7.6 cents per gallon higher than in the reference case from 2007 to 2011. Prices are generally higher than in the Regulation case, with the differential between the two cases at its widest in 2011 at 0.4 cents per gallon. The 2/3


<table>
<thead>
<tr>
<th>Analysis Case</th>
<th>2007</th>
<th>2010</th>
<th>2015</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regulation</td>
<td>4.2</td>
<td>6.3</td>
<td>6.8</td>
</tr>
<tr>
<td>Higher Capital Cost</td>
<td>5.4</td>
<td>7.6</td>
<td>8.8</td>
</tr>
<tr>
<td>2/3 Revamp</td>
<td>4.6</td>
<td>6.9</td>
<td>7.6</td>
</tr>
<tr>
<td>10% Downgrade</td>
<td>4.2</td>
<td>6.7</td>
<td>7.3</td>
</tr>
<tr>
<td>4% Efficiency Loss</td>
<td>4.2</td>
<td>6.3</td>
<td>6.9</td>
</tr>
<tr>
<td>1.8% Energy Loss</td>
<td>4.2</td>
<td>6.3</td>
<td>6.9</td>
</tr>
<tr>
<td>Severe</td>
<td>5.9</td>
<td>9.3</td>
<td>10.5</td>
</tr>
<tr>
<td>No Imports</td>
<td>4.4</td>
<td>5.5</td>
<td>7.0</td>
</tr>
</tbody>
</table>

4% Efficiency Loss Case

The 4% Efficiency Loss case reflects an expectation, by some engine and emission technology manufacturers, that emission requirements for new heavy-duty vehicles in 2010 will be met by installing after-treatment technology, which could result in a 4-percent loss of fuel efficiency. Technological improvements are assumed to fully offset the loss in fuel efficiency of new vehicles by 2015. The combined impact of the ULSD requirement and less efficient new vehicles results in 19,000 barrels per day of additional highway diesel consumption in 2010 and 107,000 barrels per day in 2011 through 2015. The introduction of less fuel-efficient vehicles accounts for 11,000 barrels per day of the additional demand in 2010 and 24,000 barrels per day of demand after 2010. Refiners are projected to invest an additional $100 million dollars through 2015 relative to the Regulation case to provide for the slightly higher diesel demand.

The additional demand for highway diesel results in prices that are 5.7 cents per gallon above reference case prices on average between 2011 and 2015. This differential is 0.3 cents higher than when no fuel efficiency loss is assumed. Owners of vehicles purchased between 2010 and 2015 would see the greatest impact under this case, because diesel vehicles of that vintage would consume relatively more diesel fuel.

1.8% Energy Loss Case

Due to changes in refinery processing, ULSD is expected to have slightly less energy content than 500 ppm diesel. The 1.8% Energy Loss case reflects a greater loss of energy content than the Regulation case, which assumes a 0.5-percent loss per barrel. This case results in an average increase in ULSD consumption of 42,000 barrels per day between 2007 and 2010. Due to the 100 percent ULSD requirement, the impact of the lower energy content is greatest after 2010 when it widens to 128,000 barrels per day. Relative to the Regulation case, the 1.8% Energy Loss case results in an average of 33,000 barrels per day of additional demand through 2010 and 45,000 barrels per day after full compliance. This additional demand does not change refinery investment patterns relative to the Regulation case, because it can be provided through higher utilization rates.

The price differentials from the reference case average 7.0 cents per gallon between 2007 and 2010 and 5.5 cents per gallon between 2011 and 2015. In anticipation of higher demand, refineries are expected to build slightly more capacity in the transition period than they would in the Regulation case. Because of the slightly different investment pattern, prices in the 1.8% Energy Loss case are 0.2 cents per gallon higher than in the Regulation case on average through 2010 and comparable to Regulation case prices after 2010.

Severe Case

In the Severe case, the ULSD requirement in combination with the five sensitivity assumptions results in an average of 44,000 barrels per day of additional highway diesel consumption between 2007 and 2010 and an average of 366,000 barrels per day of additional demand between 2011 and 2015. The ULSD regulation by itself accounts for about 9,000 barrels per day of the additional consumption through 2010 and about 83,000 barrels per day after 2010. The combined effect of the five

Table 16. Variations from Reference Case Projections of Fuel Distribution Costs in the Regulation and 10% Downgrade Cases (1999 Cents per Gallon)

<table>
<thead>
<tr>
<th>Analysis Case and Cost Component</th>
<th>Average Annual Cost, June 2006 - June 2010</th>
<th>Average Annual Cost After June 1, 2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regulation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>1.2%</td>
<td>0.4%</td>
</tr>
<tr>
<td>Capital Costs</td>
<td>0.7</td>
<td>0.0</td>
</tr>
<tr>
<td>Operating Costs</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td>Downgrade Revenue Loss</td>
<td>0.3</td>
<td>0.2</td>
</tr>
<tr>
<td>10% Downgrade</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>1.6</td>
<td>0.9</td>
</tr>
<tr>
<td>Capital Costs</td>
<td>0.7</td>
<td>0.0</td>
</tr>
<tr>
<td>Operating Costs</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td>Downgrade Revenue Loss</td>
<td>0.7</td>
<td>0.7</td>
</tr>
</tbody>
</table>

*The additional annual diesel fuel distribution costs in the Regulation case differ slightly from the EPA estimates (see Table 26 in Chapter 7), because different revenue losses associated with product downgrade are assumed.


*This assumption is based on interviews with engine and technology manufacturers.

Energy Information Administration / Transition to Ultra-Low-Sulfur Diesel Fuel

DOE017-1733

Obtained and made public by the Natural Resources Defense Council, March/April 2002
cents per gallon between 2007 and 2011. Because this analysis is based on results from a long-run equilibrium model, it does not capture the uncertainty of supply discussed in Chapter 5. The NEMS analysis reflects more aggressive investment than is portrayed for individual refineries in the short-term analysis. In the Regulation case, which uses many of the EPA’s assumptions, prices are projected to increase by 6.5 to 7.2 cents per gallon between 2007 and 2011. The widest price differential—10.7 cents per gallon in 2011—is projected in the Severe case, which is based on assumptions more consistent with industry views. This peak price differential is associated with a requirement for additional ULSD supplies of 272,000 barrels per day above demand levels in the Regulation case, of which 206,000 barrels per day results from the 10-percent downgrade assumption.

Because NEMS is a long-run equilibrium model, it cannot address short-term supply issues; however, the No Imports case does provide some implications for short-term supply. When no availability of ULSD grade imports is assumed, the marginal price of ULSD is projected to exceed prices reflecting access to imports by about 1.2 to 1.6 cents per gallon between 2007 and 2011.

Table 18. Variations from Reference Case Projections of ULSD Marginal Refinery Gate Prices by Region in the Regulation and Sensitivity Analysis Cases, 2007-2015 (1999 Cents per Gallon)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Regulation</td>
<td></td>
<td></td>
<td>4% Efficiency Loss</td>
<td></td>
<td></td>
</tr>
<tr>
<td>U.S. Average</td>
<td>5.2</td>
<td>4.7</td>
<td>U.S. Average</td>
<td>5.2</td>
<td>5.1</td>
</tr>
<tr>
<td>PADD I</td>
<td>5.3</td>
<td>4.8</td>
<td>PADD I</td>
<td>5.3</td>
<td>5.3</td>
</tr>
<tr>
<td>PADDs II-IV</td>
<td>5.3</td>
<td>4.8</td>
<td>PADDs II-IV</td>
<td>5.3</td>
<td>5.2</td>
</tr>
<tr>
<td>PADD V</td>
<td>4.8</td>
<td>4.3</td>
<td>PADD V</td>
<td>4.8</td>
<td>4.5</td>
</tr>
<tr>
<td>Higher Capital Cost</td>
<td></td>
<td></td>
<td>1.8% Energy Loss</td>
<td></td>
<td></td>
</tr>
<tr>
<td>U.S. Average</td>
<td>6.4</td>
<td>5.2</td>
<td>U.S. Average</td>
<td>5.5</td>
<td>4.8</td>
</tr>
<tr>
<td>PADD I</td>
<td>6.0</td>
<td>5.5</td>
<td>PADD I</td>
<td>5.6</td>
<td>5.3</td>
</tr>
<tr>
<td>PADDs II-IV</td>
<td>6.6</td>
<td>5.3</td>
<td>PADDs II-IV</td>
<td>5.6</td>
<td>4.9</td>
</tr>
<tr>
<td>PADD V</td>
<td>5.4</td>
<td>4.9</td>
<td>PADD V</td>
<td>5.2</td>
<td>4.4</td>
</tr>
<tr>
<td>2/3 Revamp</td>
<td></td>
<td></td>
<td>Severe</td>
<td></td>
<td></td>
</tr>
<tr>
<td>U.S. Average</td>
<td>5.7</td>
<td>4.9</td>
<td>U.S. Average</td>
<td>7.0</td>
<td>6.4</td>
</tr>
<tr>
<td>PADD I</td>
<td>6.0</td>
<td>5.0</td>
<td>PADD I</td>
<td>7.4</td>
<td>6.8</td>
</tr>
<tr>
<td>PADDs II-IV</td>
<td>6.0</td>
<td>5.0</td>
<td>PADDs II-IV</td>
<td>7.4</td>
<td>6.3</td>
</tr>
<tr>
<td>PADD V</td>
<td>5.0</td>
<td>4.5</td>
<td>PADD V</td>
<td>5.9</td>
<td>5.2</td>
</tr>
<tr>
<td>10% Downgrade</td>
<td></td>
<td></td>
<td>No Imports</td>
<td></td>
<td></td>
</tr>
<tr>
<td>U.S. Average</td>
<td>5.2</td>
<td>5.2</td>
<td>U.S. Average</td>
<td>6.6</td>
<td>6.1</td>
</tr>
<tr>
<td>PADD I</td>
<td>5.3</td>
<td>5.4</td>
<td>PADD I</td>
<td>6.9</td>
<td>6.8</td>
</tr>
<tr>
<td>PADDs II-IV</td>
<td>5.3</td>
<td>5.3</td>
<td>PADDs II-IV</td>
<td>6.9</td>
<td>6.3</td>
</tr>
<tr>
<td>PADD V</td>
<td>4.8</td>
<td>4.7</td>
<td>PADD V</td>
<td>4.8</td>
<td>4.3</td>
</tr>
</tbody>
</table>

7. Comparison of Studies on ULSD Production and Distribution

This chapter compares the methodology and results of the Energy Information Administration's (EIA's) analysis with those from a number of other studies related to ultra-low-sulfur diesel fuel (ULSD) supply and costs. Refinery costs and investments are compared with other estimates from studies by the U.S. Environmental Protection Agency (EPA), Mathpro, the National Petroleum Council (NPC), Charles River and Associates and Baker and O'Brien (CRA/BOB), EnSys Energy & Systems, Inc. (EnSys), and Argonne National Laboratory (ANL). EIA's estimates of distribution costs are compared with estimates from the EPA, ANL, and Turner, Mason and Company (TMC). A review of an analysis of alternative markets for diesel fuel components by Muse, Stancil and Company (MSC) is also provided. All cost estimates in this chapter have been converted to 1999 dollars.

Analyses of Refining Costs

The refining cost studies reviewed here represent a range of methodologies and assumptions. An understanding of some key terms is important to differentiating between the methodologies of the various studies. The studies were based on two general types of methodologies: linear programming (LP) approach used by Mathpro, NPC, EnSys, DOE, and EIA; and a refinery-by-refinery approach used by CRA, EPA, and EIA. Within either approach, the studies used different methodologies and made different assumptions that make them difficult to compare. For instance, two different types of LP refiner models were used. The Mathpro analysis used an LP model of a "notional refinery" that represented an average refinery in the United States. In contrast, EnSys and EIA used refinery LP models that represented an aggregate refinery, or all the refineries in a region acting as one (Tables 19 and 20).

Costs estimated by the different studies are not easy to compare, because differences in estimation methodologies make them conceptually different. Both "average" and "marginal" costs can be based on LP models that operate as a single firm, or estimated from analysis of individual refineries. In general, marginal cost estimates reflect the cost of the last barrel of required supply can be seen as estimates of market prices. Much of the variation in investment and cost estimates reflects different assumptions about the cost of technologies; return on investment; the extent to which refiners will modify existing equipment or build entirely new hydrocrackers; the cost and quantity of additional hydrogen required; the extent to which some refineries may reduce highway diesel production; and the amount of highway diesel downgraded due to fuel contamination during distribution.

In EIA's refinery-by-refinery analysis (cost curves), the increased cost of producing ULSD in 2006 is estimated to be between 5.4 and 6.8 cents per gallon. Using the National Energy Modeling System (NEMS) Petroleum Market Module (PMM), the increased cost of producing ULSD is estimated to be between 4.7 and 7.3 cents per gallon from 2007 to 2010 and between 6.5 and 9.2 cents per gallon in 2011. The estimated additional production costs are associated with expected increases in average marginal price increases at the pump ranging from 6.5 to 8.8 cents per gallon in the transition period and 7.2 to 10.7 cents per gallon in 2011. In the Regulation case, which uses many of the EPA's assumptions, prices are projected to increase by 6.5 to 7.2 cents per gallon between 2007 and 2011. The widest price differential—10.7 cents per gallon in 2011—is projected in the Severe case, which is based on assumptions more consistent with industry views.

For consistency with the EPA's analysis, EIA estimates are based on a 7-percent before-tax return on investment, which is estimated to equate to a 5.2-percent after-tax rate of return. When a 10-percent after-tax rate of return, which was used in all the other analyses, is assumed, the refinery-by-refinery costs are about 0.8 to 1.2 cents per gallon higher than in the Regulation case, and the NEMS costs are about 0.8 to 1.1 cents per gallon higher than in the Regulation case.

125 In the NEMS PMM projections, the U.S. price is the average of the marginal prices in the three model regions.
126 According to financial information from Form EIA-28 (Financial Reporting System), refiners and marketers averaged a 7-percent before-tax return on investment between 1977 and 1999.

Energy Information Administration / Transition to Ultra-Low-Sulfur Diesel Fuel

14639

DOE017-1735

Obtained and made public by the Natural Resources Defense Council, March/April 2002
EPA Analysis

The EPA analysis was conducted in support of the final rulemaking published in December 2000.\(^{127}\) The EPA analysis used a refining cost spreadsheet that included refinery-specific estimates for meeting the new highway diesel standards and aggregated them to estimate fuel cost increases at the Petroleum Administration for Defense District (PADD) and national levels. The costs of meeting the final ULSD Rule were analyzed without including possible reductions in non-road diesel sulfur.

The EPA estimated that the ULSD Rule would increase average national production and distribution costs by 5.4 cents per gallon of 15 ppm diesel (4.5 cents per gallon for all highway diesel) during the temporary compliance period (2006 to 2010).\(^ {128}\) The total cost after full compliance in June 2010 was estimated at 5.0 cents per gallon (Table 21).

The largest component of the costs estimated by the EPA was increased refining costs (4.1 cents per gallon for 15 ppm diesel and 3.3 cents per gallon for all highway diesel between 2006 and 2010; 4.3 cents per gallon after June 1, 2010). The cost estimate for the compliance period was adjusted downward to reflect credit trading, assuming that low-cost refineries trade with high-cost refineries at the cost of production. Cost estimates for PADD IV were 30 to 40 percent higher than costs in other PADDs. The refining costs discussed above were based on a 7-percent before-tax return on investment, but the EPA also provided costs based on a 6-percent and 10-percent after-tax rate of return. The cost estimates for a 6-percent after-tax rate of return were 0.1 cents per gallon higher than the full compliance cost calculated with the 7-percent before-tax rate, and the estimates for a 10-percent after-tax rate were 0.4 cents per gallon higher.\(^ {129}\)

In addition to increased refining costs, the EPA estimated that the addition of lubricity additives would cost approximately 0.2 cents per gallon, and distribution costs were estimated to add another 1.1 cents per gallon during the temporary compliance period and 0.5 cents per gallon after full compliance.\(^ {130}\) The analysis behind the distribution cost estimates is discussed below.

Increased refining costs were expected to result from capital investment of $3.9 billion to meet the 2006 requirements and another $1.4 billion to reach full compliance in 2010, for a total investment of $5.3 billion.\(^ {131}\) The EPA estimated that the average refinery would spend $43 million dollars in capital expenditures and an additional $7 million per year in operating costs.

The EPA assumed that, in order to meet the 15 ppm highway diesel requirement, refiners would need to produce 7 ppm diesel fuel on average. It was assumed that 80 percent of diesel refining capacity would meet the new standards by modifications to existing hydrotreaters and the other 20 percent by building new hydrotreaters. The analysis included cost estimates under two scenarios. The first scenario assumed that all refiners currently producing highway diesel fuel would continue to do so. The second scenario assumed that some refiners would increase their production of highway diesel while making up for lost production from refiners that would drop out of the market. The EPA did not provide analysis assuming a net loss of production, but indicated that, with the inclusion of the 80/20 and small refiner provisions, no supply problems were anticipated. The EPA also performed an analysis of engineering and construction requirements and concluded that these factors should not be a problem due to the temporary compliance provisions (see Chapter 3 for more discussion).

Table 21. EPA Estimates of Increased Costs To Meet the 15 ppm Highway Diesel Standard

<table>
<thead>
<tr>
<th>Period</th>
<th>Additional Refining</th>
<th>Lubricity Additive</th>
<th>Distribution*</th>
<th>Additional Distribution Tanks</th>
<th>Total Increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phase-I, 2006-2010</td>
<td>4.1</td>
<td>0.2</td>
<td>0.4</td>
<td>0.7</td>
<td>5.4</td>
</tr>
<tr>
<td>Fully Implemented Program, 2010</td>
<td>4.3</td>
<td>0.2</td>
<td>0.5</td>
<td>0.0</td>
<td>5.0</td>
</tr>
</tbody>
</table>

*Not including additional distribution tanks.


\(^{128}\) Total cost per gallon of 15 ppm diesel is the sum of 4.1 cents per gallon refining cost and 1.1 cent per gallon distribution cost.


\(^{130}\) Distribution costs include the capital cost of additional storage tanks, additional operating costs, yield losses, product downgrades, and testing costs.


Energy Information Administration / Transition to Ultra-Low-Sulfur Diesel Fuel

14640

DOE017-1736

Obtained and made public by the Natural Resources Defense Council, March/April 2002
3,500 ppm non-road diesel. The lower average costs were the result of spreading the investments over a larger volume of product. The scenarios with non-road diesel sulfur capped at 15 ppm required the most investment and led to the highest costs. Relative to the 3,500 ppm non-road scenarios, the 15 ppm non-road scenarios required at least $1 billion more investment and resulted in average costs between 0.1 and 0.8 cents per gallon higher.

NPC Analysis

In its report, U.S. Petroleum Refining: Assuring the Adequacy and Affordability of Cleaner Fuels, the NPC included estimates of meeting a 30 ppm sulfur standard.134 The estimates were based on the 30 ppm scenarios included in Mathpro’s original report for the Engine Manufacturers Association in October 1999. The NPC combined the cost estimates from the “no retrofitting-inflexibility” and the “retrofitting-series” cases assuming that at 30 ppm, most refiners would retrofit. The NPC also made adjustments to the Mathpro estimates to reflect alternative assumptions of refinery economics. NPC adjusted the vendor-supplied estimates used in the Mathpro model upward by a factor of 1.2 for investments and a factor of 1.15 for hydrogen consumption and other operating expenses. The vendor data were adjusted to account for a perceived tendency of vendors to quote overly optimistic cost and performance information.

The NPC analysis estimated industry investment costs at $4.1 billion at a cost of 5.9 cents per gallon (1999 dollars) and assumed 50 percent revamped and 50 percent new units. The study indicated that a sulfur standard below 30 ppm would require greater reliance on new units, as opposed to retrofits, resulting in considerably higher investments.

The NPC analysis included a discussion of limitations on engineering and construction resources and, in contrast with the EPA analysis, concluded that the overlap with gasoline sulfur projects would result in delays in meeting the diesel standards. The study suggested that highway diesel supply shortfalls might occur if the standard were required before 2007 and that even more time would be required to meet a standard below 30 ppm. (See Chapter 3 of this report for more detail on engineering and construction.)

CRA/BOB Analysis

In a study for the American Petroleum Institute, CRA/BOB developed refinery-specific cost estimates for every U.S. refinery, using the Prism refinery model.135 The estimates and a survey of refiners intentions were used to construct a marginal cost curve that was used in an equilibrium supply and demand analysis. The initial supply and demand assumptions were from EIA’s Annual Energy Outlook 2000. The supply curve was shifted according to the marginal cost analysis, and the demand curve was shifted based on an elasticity assumption. In contrast to all but the EIA offline analysis, the CRA/BOB study provided an analysis of a short-term supply and cost outlook.

The analysis projected a reduction in highway diesel production of 320,000 barrels per day, resulting in a supply shortfall. The EPA has estimated that 75 percent of the shortfall estimated by CRA/BOB resulted from the underlying assumption that an additional 10 percent of the highway diesel produced would be downgraded because of product degradation from distribution and storage.136 In contrast, EIA and the EPA assumed an additional 2.2 percent of downgraded product, and TMC estimated that a total of 17.5 percent of ULSD would be downgraded.137 The estimated increase in average refining cost was 6.7 cents per gallon to produce ULSD from 500 ppm diesel. The estimated increase in the marginal price of ULSD needed to balance supply and demand was between 14.7 and 48.9 cents per gallon, depending on the availability of imports.

The CRA/BOB analysis assumed that, in order to meet the 15 ppm standard, refiners would produce highway diesel at an average of 7 ppm.138 The analysis also assumed that non-road diesel would be reduced to 350 ppm and jet fuel and heating oil sulfur would remain at 1999 levels. The cost estimates reflected an assumption that 40 percent of ULSD would be produced from new desulfurization units and 60 percent from revamped units, and that the return on investment would be 10 percent.

134National Petroleum Council, U.S. Petroleum Refining: Assuring the Adequacy and Affordability of Cleaner Fuels (June 2000), Chapter 3. Investment and cost estimates have been converted to 1999 dollars from 1996 dollars reported by NPC.

14641

Energy Information Administration / Transition to Ultra-Low-Sulfur Diesel Fuel

DOE017-1737
Each of the phase-in cost series provided by ANL was associated with a set of distribution costs, which varied slightly in the seven scenarios. The distribution cost analysis for 15 ppm highway diesel fuel was extrapolated from TMC (early) estimates for distributing 5 ppm and 30 ppm diesel. The costs included capital investment for the distribution and refueling system and for product downgrade. Distribution costs were provided for various levels of phase-in between 5 and 100 percent of the highway diesel market. The level of phase-in most consistent with the 80 percent required by the ULSD Rule for the initial years of the program was a supply of 83 percent of highway diesel, which was associated with undiscounted distribution costs between 1.5 and 2.2 cents per gallon. The costs associated with 100 percent of highway diesel at 15 ppm ranged between 1.2 and 2.1 cents per gallon.

The ANL analysis concluded that, depending on the case and the stage of phase-in, the total incremental costs of a phase-in would range from 6.1 to 11.2 cents per gallon, compared to a range of 7.1 to 12.7 cents per gallon for an all-at-once strategy. Estimates of total (undiscounted) costs to consumers for the various phase-in scenarios ranged from $15.2 to $25.4 billion ($10.1 to $17.3 billion net present value). Higher expenditures were estimated for an all-at-once strategy, with expected costs totaling $30.4 to $52.8 billion ($22.3 to $38.6 billion net present value). The relatively lower distribution costs under a phase-in approach were translated into an estimated savings of $14.2 to $27.4 billion.

### Summary of Investment Estimates

EPA estimated that, in order to meet the requirements of the ULSD Rule, the industry would invest a total of $5.3 billion. In comparison, DOE (by ANL) estimated between $8.1 and $13.2 billion of investment for ULSD. Mathpro estimated a range of $3.0 to $6.0 billion, CRA estimated $7.7 billion, and NPC estimated $4.1 billion to meet a 30 ppm standard and substantially higher but undefined amount to provide 15 ppm diesel (Tables 23 and 24). Because production of diesel in the appropriate sulfur range has been very limited, analysis of costs of the ULSD Rule depend heavily on vendor estimates and several critical assumptions, including refinery configuration, size, and crude oil inputs: the ratio of retrofitted units to new units, and the relative cost of retrofits versus new units.

The studies discussed above used different methodologies, economic approaches, levels of regional and annual detail, and assumptions (see Table 20). Many were completed before the Final Rule was issued and do not reflect the provisions for small refineries or the 80/20 rule. In addition, the studies were based on different assumptions about investment behavior and costs and the level of diesel demand. The capital investment estimates are difficult to compare not only because of their different methodologies and assumptions but also because their investment estimates reflect slightly different things. For instance, the EPA estimated the capital cost for a new distillate hydrotreater to range

### Table 23. Comparison of ULSD Production Cost Estimates: Individual Refinery Representation

<table>
<thead>
<tr>
<th>Study</th>
<th>Sulfur Level (ppm)</th>
<th>Percentage of Highway Diesel That Is ULSD</th>
<th>Cost Change (1999 Cents per Gallon of ULSD)</th>
<th>Cost Basis</th>
<th>Refinery Capital Investment (Billion 1999 Dollars)</th>
</tr>
</thead>
<tbody>
<tr>
<td>EPA (temporary compliance, 2006-2010)</td>
<td>2</td>
<td>75%</td>
<td>4.1%</td>
<td>Marginal, PAD0s I-V</td>
<td>3.9</td>
</tr>
<tr>
<td>EPA (full compliance, June 2010 forward)</td>
<td>7</td>
<td>100</td>
<td>4.3</td>
<td>Average, U.S.</td>
<td>5.3 total</td>
</tr>
<tr>
<td>CRA/BOB (August 2000 for 2006)</td>
<td>7</td>
<td>100</td>
<td>5.7%</td>
<td>Average, U.S.</td>
<td>7.7</td>
</tr>
<tr>
<td>(a) cost curves, 2006)</td>
<td>7</td>
<td>76-100</td>
<td>5.4-5.8</td>
<td>Marginal, PADDs I-V</td>
<td></td>
</tr>
</tbody>
</table>

*Correspondence with Ray G. Baker and O'Brien. Also reflects assumption of 350 ppm non-road diesel.
*Average cost to produce 2 ppm diesel from 500 ppm diesel. The marginal price to balance supply and demand was estimated to be between 14.7 and 48.9 cents per gallon, depending on the availability of imports.
*Average based on marginal cost methodology.
*Marginal based on average refinery costs.


143 Turner, J.M., and Company, Costs/Impacts of Distributing Potential Ultra Low Sulfur Diesel (Dallas, TX, February 2000).
144 K. Singh, Analysis of the Cost of a Phase-in of 15 ppm Sulfur Cap on Diesel Fuel, Revised (Argonne, IL: Center for Transportation Research, Argonne National Laboratory, November 2000), Appendix C.
The lower end cost in EIA's NEMS analysis reflects a notional unit that processes low-sulfur feed with incidental deasphaltization, while the higher end cost reflects a different notional unit that processes higher sulfur feed with greater aromatics improvement. EIA also provided sensitivity analysis using higher capital cost assumptions for both the refinery-by-refinery and NEMS analyses. The Higher Capital Cost sensitivity case for EIA's refinery-by-refinery analysis is based on capital costs that are about 40 percent higher than those in the initial analysis. Both sets of capital costs were developed by the National Energy Technology Laboratory, in conjunction with Mr. John Hackworth, energy consultant. The capital costs used in the NEMS Higher Capital Cost case were provided by recent work from EnSys and are 24 percent higher for the first notional unit and 33 percent higher for the second notional unit, relative to the Regulation case.

The EPA analysis was based on estimates from two technology vendors, providing costs based on retrofits and new units. EPA assumed that 80 percent of ULSD will be produced from diesel hydrotreaters that are revamped at a cost of $40 million each. These estimates reflected an assumption that new units would cost twice as much as revamps. The net result was an estimated average cost of $50 million per refinery, which equates to a little more than 4 cents per gallon of highway diesel on average.

The NPC analysis did not estimate costs for producing diesel with less than 10 ppm sulfur but indicated that even a 30 ppm sulfur standard would require reactor pressures in the range of 1,100 to 1,200 psi, which is well above the vendor estimates used by the EPA. The NPC characterized vendor estimates as inherently over-optimistic; however, several new technologies are under development that may reduce costs (see Chapter 3).

The ANL estimates blended the EnSys 100 percent new and 100 percent revamp refinery analysis, based on the assumption that 60 percent of ULSD would be produced from revamped units that cost an average of $40 million per unit, and the other 40 percent would come from new units at an average cost of $50 million per unit. Instead of making an assumption about the split between revamped and new units, Mathpro developed scenarios for different types of choices. Assuming no change in the non-road diesel standards, Mathpro estimated that the total investment cost would range from $6.0 billion if refineries required all new units with minimum operating flexibility to $3.0 billion if all refineries were retrofitted and economies of scale from trading were realized.

| Table 25. Comparison of Key Hydrotreater investment Assumptions for Various Refinery Models |
|----------------------------------|-----------------|-----------------|-----------------|-----------------|
| Model                           | Capital Cost of New Hydrotreater (1999 Dollars per Barrel per Day: ISH) | Revamp Cost as a Percentage of New Unit Cost | Unit Size (Barrels per Day) | Percent of ULSD Production from Revamped Units Versus New Units |
| EnSys (August 2000)             | 2,350-3,295$^2  | 60              | 25,000          | NA              |
| EIA NEMS Regulation Case       | 1,331-1,845$^3  | 60              | 25,000          | 80/20           |
| EIA NEMS 2/3 Revamp Case       | 1,331-1,845$^3  | 50              | 25,000-10,000   | 67.7/33.3       |
| EIA NEMS Higher Capital Cost Case | 1,655-2,495$^3 | 50              | 25,000-10,000   | 80/20           |

$^2$Feedstock contains 65 percent straight-run diesel, 10 percent cracked stock, and 25 percent light cycle oil.

$^3$Low end of range is for units processing low-sulfur feed streams with incidental deasphaltization. High end is for higher sulfur feed streams with greater aromatics improvement.


145EPA corroborated the vendors' cost estimates in discussions with two other vendors. E-mail from Lester Wyborny, U.S. Environmental Protection Agency: March 30, 2001.


Energy Information Administration / Transition to Ultra-Low-Sulfur Diesel Fuel

DOE017-1739

Obtained and made public by the Natural Resources Defense Council, March/April 2002
produced was projected to be downgraded to a lower value product.

The ANL estimates, which were extrapolated from previous TMC estimates for delivering 5 ppm and 50 ppm diesel, ranged from 6.2 cents to 1.2 cents per gallon for delivery of 5 percent and 100 percent, respectively. In August 2000, TMC provided supplemental estimates reflecting downgrade costs associated with distributing 15 ppm diesel fuel. Presumably, the capital costs would remain the same as for the 5 ppm case in the previous TMC analysis. When the original TMC 5 ppm estimates are adjusted to reflect 15 ppm diesel, the total distribution cost estimates are 6.9 cents per gallon to supply 5 percent of the market; 4.1 cents per gallon to supply 20 percent of the market, and 1.4 cents per gallon to supply the entire highway diesel market.

The extent to which product contamination will occur in the distribution system (and how much product must be downgraded as a result) is very uncertain. The analyses included strikingly different estimates of how much of the 15 ppm product would be downgraded in the distribution system. EIA’s NEMS analysis assumed 4.4 percent downgrade for consistency with the EPA assumptions but also provided a sensitivity case assuming 10 percent downgrade. Downgrade estimates ranged from 4.4 percent of production (EPA) to 17.5 percent (TMC). Part of the uncertainty stems from not knowing the present level of downgrade occurring in the distribution system, because there is no current reporting requirement. The EPA assumed a doubling of product downgrade from current downgrade levels, which were estimated at 2.2 percent. The methodology used by the EPA to estimate current downgrade levels was highly speculative and was not based on a scientific survey. The EPA’s estimation methodology was loosely based on a survey of the Association of Oil Pipelines, in which six respondents provided estimates of the current diesel fuel downgrade ranging from 0.2 percent to 10.2 percent (see Chapter 4). In the same survey some respondents expressed an expectation that the downgrade amount might be expected to double under the ULSD Rule.

The TMC analysis was based on a survey of 14 refiners (representing 38 percent of U.S. petroleum refining capacity), 3 pipeline operators (representing approximately 40 percent of U.S. highway diesel shipping capacity), and 11 terminal operators (representing 25 percent of U.S. petroleum product storage capacity). A wide range of responses was noted in the responses of pipeline operators. In the survey, some terminal operators indicated that they would not handle ULSD. Terminal operators generally anticipated a higher rate of downgrade than did pipeline operators. Terminal operators indicated that, to handle ULSD, dedicated transport trucks or compartments in transport trucks would be required to avoid sulfur contamination.

The TMC analysis projected 17.5 percent downgrade when 100 percent of the highway diesel market was assumed to require the 15 ppm diesel, and slightly lower levels of downgrade were expected when smaller segments of the market were required. Although the ANL analysis did not provide the downgrade assumptions used, it was based on the TMC assumptions for downgrade of 5 ppm and 50 ppm diesel and tracked closely with the TMC assumptions. Different downgrade assumptions resulted in different cost estimates associated with downgrade. The EPA estimated a total downgrade cost of 0.2 cents per gallon for all highway diesel in the initial years and 0.3 cents per gallon after full implementation. In contrast, the ANL analysis (based on the TMC assumptions of higher downgrade volumes) estimated a total downgrade cost of about 1 cent per gallon when more than half of the market was required to meet the 15 ppm standard.

The TMC, EPA, and ANL analyses also used different sets of assumptions about capital investment requirements. During the initial years of the program, when the distribution system must handle two highway diesel fuels, the EPA estimated tankage costs at refineries, terminals, pipelines, and bulk plants at $0.81 billion. In addition, investments at truck stops to handle the extra product were estimated at $0.24 billion. These costs were amortized over total highway diesel volumes (both 500 ppm and 15 ppm) during the initial 4 years at 7 percent per year, resulting in a cost of 0.7 cents per gallon. EIA used EPA’s capital cost estimate of 0.7 cents per gallon in all NEMS analysis scenarios.

The ANL analysis assumed that, given a phase-in, 50 percent of terminals would add tanks or reconfigure. Of those terminals that were modified, it was assumed that

14644

DOE017-1740

Obtained and made public by the Natural Resources Defense Council, March/April 2002
Bibliography


Bjorklund, B.L. and others. The Lower It Goes, The Tougher It Gets (The Practical Implications of Producing Ultra-Low Sulfur Diesel), NFRA 2000 Annual Meeting Report, AM-00-16.


Federal Register, U.S. Environmental Protection Agency, 40 CFR Parts 80, 85, and 89, "Control of Air Pollution from New Motor Vehicles: Tier 2 Motor Vehicle Emissions Standards and Gasoline Control Requirements" (February 10, 2000).


U.S. Environmental Protection Agency, Reducing Air Pollution from Non-road Engines, EPA420-F-00-048 (Washington, DC, November 2000).