Executive Summary

This study was undertaken at the request of the Committee on Science, U.S. House of Representatives. The Committee asked the Energy Information Administration (EIA) to provide an analysis of the Final Rulemaking on Heavy-Duty Engine and Vehicle Standards and Highway Diesel Fuel Sulfur Control Requirements, which was signed by President Clinton in December 2000.[1]

The purpose of the rulemaking is to reduce emissions of nitrogen oxides (NO_x) and particulate matter (PM) from heavy-duty highway engines and vehicles that use diesel fuel. The new rule requires refiners and importers to produce highway diesel meeting a 15 parts per million (ppm) maximum requirement, starting June 1, 2006; however, pipelines are expected to require refiners to provide diesel fuel with an even lower sulfur content, somewhat below 10 ppm, in order to compensate for contamination from higher sulfur products in the system, and to provide a tolerance for testing. Diesel meeting the new specification will be required at terminals by July 15, 2006, and at retail stations and wholesalers by September 1, 2006. Under a "temporary compliance option" (phase-in), up to 20 percent of highway diesel fuel produced may continue to meet the current 500 ppm sulfur limit through May 2010; the remaining 80 percent of the highway diesel fuel produced must meet the new 15 ppm maximum.

The purpose of this study is to assess the possible impact of the new sulfur requirement on the diesel fuel market. The study discusses the implications of the new regulations for vehicle fuel efficiency and examines the technology, production, distribution, and cost implications of supplying diesel fuel to meet the new standards. In order to address both the short-term and mid-term supply issues identified by the Committee on Science, this analysis incorporates two different analytical approaches. Refinery cost analysis addresses the uncertainty of supply in the short term, during the transition to ultra-low-sulfur diesel fuel (ULSD) in 2006. Mid-term issues and trends (2007 through 2015) are addressed through scenario analysis using EIA's National Energy Modeling System (NEMS). The Committee on Science requested that these analyses use assumptions consistent with the Regulatory Impact Analysis published by the U.S. Environmental Protection Agency (EPA). Discussion of the key issues and uncertainties related to the distribution of ULSD is based on interviews with a number of pipeline carriers.

Although highway-grade diesel is the second most consumed petroleum product, gasoline is the most important product by far. In 1999 highway diesel accounted for 12 percent of total petroleum consumption and gasoline 43 percent.[2] Consumption of highway-grade diesel (500 ppm) accounted for 68 percent of the distillate fuel market in 1999, although 9 percent went to non-road (rail, farming, industry) and home heating uses.[3] Higher sulfur distillate (more than 500 ppm sulfur), used exclusively for non-road and home heating needs, accounted for the other 32 percent of the distillate market.

Assessment of Short-Term Effects of the Rule

Whether there will be adequate supply of diesel fuel as the new standard becomes effective in June 2006 is one of the key questions raised by the House Committee on Science in the request for analysis. To assess this possibility, cost increases for individual refineries to produce ULSD were estimated, the cost increases were arrayed from smallest to largest, and the resulting cost curves were matched against projected demand and imports. The cost curves reflect investment requirements and operating costs for refineries in Petroleum Administration for Defense Districts (PADDs) I through IV.[4] ULSD production costs were estimated for different groups of refineries based on size, sulfur content of feeds, fraction of cracked stocks in the feed,[5] boiling range of the feed, and fraction of highway diesel produced. Unlike ULSD analyses conducted by the EPA and others, the cost curves relied on proprietary stream data collected by

[1]U.S. Environmental Protection Agency, "Control of Air Pollution from New Motor Vehicles: Heavy-Duty Engine and Vehicle Standards and Highway Diesel Fuel Sulfur Control Requirements: Final Rule," *Federal Register*, 40 CFR Parts 69, 80, and 86 (January 18, 2001).

[2]Energy Information Administration, *Petroleum Supply Annual 1999*, DOE/EIA-0340(99)/1 (Washington, DC, June 2000), Table 3.

[3]Energy Information Administration, *Fuel Oil and Kerosene Sales 1999*, DOE/EIA-0525(99) (Washington, DC, September 2000), Tables 19-23.

[4]PADD V was not included in this analysis, because supply concerns are less of an issue in the transition period, and the requirement for California Air Resources Board diesel makes the PADD V market different from those in PADDs I-IV.

[5]Cracked stocks are previously processed streams that are more difficult to treat.

EIA.[6] The capital and operating costs for the different groups were developed for EIA by the staff of the National Energy Technology Laboratory (NETL), consistent with the EPA analysis. Return on investment was assumed to be 5.2 percent after taxes, consistent with the EPA's assumption of a 7-percent before-tax return on investment. 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.

Cost representations of desulfurization units were used to develop four sets of cost curves, based on four different investment rationales (Table ES1). Within a given supply curve, the relative costs of different groups of refineries provide an indicator of possible supply shortfalls at the beginning of the ULSD requirement in the summer of 2006. Some refiners may be able to produce ULSD at a cost of about 2.5 cents per gallon; however, at the volumes needed to meet demand, costs are estimated at 5.4 to 6.8 cents per gallon,[7] and they could be higher if supply falls short of demand and consumers bid up the price. The behavior of refiners will be influenced by their expectation of what others will do and is therefore subject to considerable uncertainty.

The four refinery investment scenarios have progressively more volume and are defined as follows:

- The **Competitive Investment** scenario includes only those refiners that are very 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.
- In the **Cautious Expansion** scenario, current producers with competitive cost structures for ULSD production and high fractions of highway diesel production (greater than 70 percent) are assumed to maintain current production levels and, possibly, to push production of ULSD toward 100 percent of their distillate production if only minor increases in per-unit production costs occur for the increased volume.
- The **Moderate New Market Entry** scenario assumes that a selective number of refineries currently producing little or no highway diesel will enter the ULSD market. The underlying premise is that a limited number of companies would think that they would be able to gain market share without depressing margins to the extent of undercutting profits.
- The **Assertive Investment** scenario assumes that a larger number of refiners would make the requisite investments to either maintain or gain share in the highway diesel market. In this scenario, refiners would believe that most of their competitors were overly cautious, and that they could succeed by taking a contrary strategy (which in reality would be adopted by far more refiners than anticipated).

As a result of distribution limitations and non-road uses, the amount of ULSD actually needed to balance demand in 2006 is highly uncertain. Accordingly, a range of demand estimates was developed to account for some of the uncertainty (Table ES2 and Figure ES1). The Small Refiner and Temporary Compliance Options demand estimate was calculated as 80 percent of the estimated demand for transportation distillate for both highway and non-road uses in PADDs I-IV in 2006 (excluding production by small refineries, which are allowed to request waivers to delay production until 2010), representing the EPA's requirement to produce 80 percent ULSD after the regulation takes effect. The Small Refiner and Temporary Compliance Options with Imports

Table ES1. Short-Term Scenarios

Scenario	Number of Refineries Producing ULSD	Characteristics
(1) Competitive Investment	66	Current low-sulfur diesel producers maintain market share. Low-fraction producers drop out.
(2) Cautious Expansion	66	Some low-sulfur diesel producers in Scenario 1 expand production.
(3) Moderate New Market Entry	67	One refinery not currently producing low-sulfur diesel enters the ULSD market. Nine other producers in Scenario 2 expand production.
(4) Assertive Investment	74	A larger number of refineries not currently producing low-sulfur diesel enter the ULSD market. Some others expand production.

Notes: Current low-sulfur diesel contains 500 ppm sulfur. ULSD contains 7 ppm sulfur to compensate for contamination and to provide a tolerance for testing.
Source: Energy Information Administration, Office of Integrated Analysis and Forecasting.

[6]The EPA used EIA data on refinery capacity and diesel production in its refinery-by-refiney analysis.

[7]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.

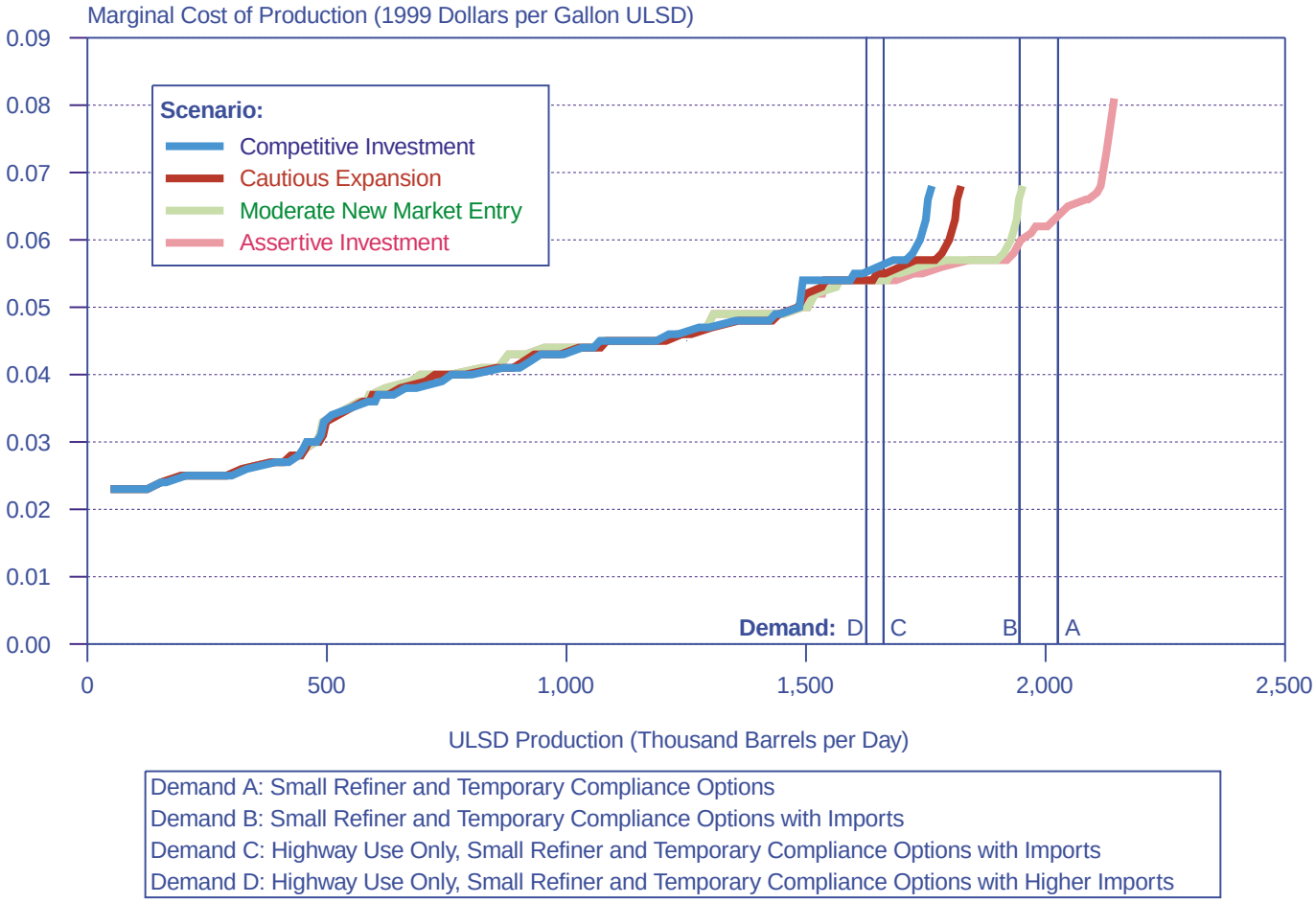
estimate assumes that imports from Canada and the Virgin Islands will continue at historical levels (Demand B, which matches the demand projection in the mid-term analysis described in Chapter 6). The Highway Use Only, Small Refiner and Temporary Compliance Options with Imports estimate (Demand C) assumes that ULSD will be used only to meet highway transportation demand, that the temporary compliance option will further reduce this demand by 20 percent, and that imports will remain at historical levels. Finally, the Highway Use Only, Small Refiner and Temporary Compliance Options with Higher Imports estimate (Demand D) assumes a higher level of ULSD imports.[8]

Table ES2. Short-Term Demand Estimates, 2006

Estimate	Demand Level (Thousand Barrels per Day)	Characteristics
Demand A: Small Refiner and Temporary Compliance Options	2,026	76 percent of transportation demand.
Demand B: Small Refiner and Temporary Compliance Options with Imports	1,946	Demand estimate A, less projected imports from Canada and the U.S. Virgin Islands.
Demand C: Highway Use Only, Small Refiner and Temporary Compliance Options with Imports	1,662	65 percent of transportation demand, less projected imports from Canada and the U.S. Virgin Islands.
Demand D: Highway Use Only, Small Refiner and Temporary Compliance Options with Higher Imports	1,626	Demand estimate C, less higher projected imports.

Source: National Energy Modeling System, run DSU7INV.D043001A.

Figure ES1. ULSD Cost Curve Scenarios with 2006 Demand Estimates



Sources: Cost curve scenarios: Appendix D. Demand estimates: National Energy Modeling System, run DSU7INV.D043001A.

[8]Additional demand estimates are analyzed in Chapter 5.

The combined cost curves for PADDs I-IV show that the total volume of ULSD production on the cost curves for the Competitive Investment and Cautious Expansion scenarios, production reaches the two lowest demand estimates, although at different costs (Figure ES1). In the Moderate New Market Entry scenario, production just reaches the Small Refiner and Temporary Compliance Options with Imports estimate. In the Assertive Investment scenario, production just reaches the Small Refiner and Temporary Compliance Options estimate.

The largest shortfall—estimated at 264,000 barrels per day relative to the Small Refiner and Temporary Compliance Options demand estimate (Demand A, the highest demand estimate in Table ES2)—occurs in the Competitive Investment scenario (which assumes the most cautious investment strategy and has the lowest production estimate). The largest surplus—517,000 barrels per day relative to the Highway Use Only, Small Refiner and Temporary Compliance Options with Higher Imports estimate (the lowest demand estimate)—occurs in the Assertive Investment scenario (which assumes the most aggressive investment strategy and has the highest production estimate).

With the Highway Use Only, Small Refiner and Temporary Compliance Options with Imports demand estimate (Demand C), all the production scenarios project sufficient supply (at least in the aggregate). For the Small Refiner and Temporary Compliance Options with Imports demand estimate (Demand B), the Moderate New Market Entry and Assertive Investment production scenarios provide supplies that are higher than demand by 197,000 barrels per day and 6,000 barrels per day, respectively. Supplies in the Competitive Investment and Cautious Expansion scenarios fall short of Demand B by 184,000 and 123,000 barrels per day, respectively. For the Small Refiner and Temporary Compliance Options demand estimate (Demand A), only the Assertive Investment production scenario provides sufficient supply.

Two sensitivity cases were used to examine the effects of assumptions about hydrotreater capital costs and about return on investment. The capital costs assumed in the initial set of four scenarios are similar to those used in the EPA analysis. When the capital costs for hydrotreater units are assumed to be about 40 percent higher than assumed in the initial set of scenarios, production of ULSD is projected to be 25,000 to 55,000 barrels per day lower, and the production costs are projected to be from 0.5 to 1.1 cents per gallon higher. When a 10-percent return on investment is assumed, as compared with 5.2 percent assumed in the initial set of scenarios, production is projected to be 40,000 to 66,000 barrels per day lower and costs 0.8 to 1.2 cents per gallon higher. Because of the reduced volumes, estimated production levels in the Moderate New Market Entry Scenario fall short of the demand level projected in the Small Refiner and Temporary Compliance Options with Imports estimate in both the higher capital cost and higher required return on investment sensitivity cases.

The scenarios indicate the possibility of a tight diesel market when the ULSD Rule is implemented. Supply scenarios that assume more cautious investment indicate inadequate supply compared with the demand levels projected in the *Annual Energy Outlook 2001*. Only more aggressive investment scenarios or lower demand scenarios show adequate supply to meet estimated demand. Furthermore, this analysis compares supply and demand at a very aggregate level. Maintaining a balance of supply and demand across regions and throughout the distribution system could be even more difficult.

If supplies fell short of demand, sharp price increases would likely occur to balance supply and demand. Sharply higher prices would curtail demand for diesel fuel. Truckers would reduce consumption to the extent possible and try to pass higher fuel costs on to customers, who would then look for alternative means to transport goods. In this situation 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. Additional imports of ULSD or jet fuel could be forthcoming if there were large price differentials between markets.

In 2006, little ULSD will actually be needed, because few new vehicles requiring ULSD will be on the road by then. If it becomes apparent that there will be inadequate supply, or if distillate markets are tight, the EPA could temporarily reduce the required proportion of ULSD production, which could make additional diesel supplies available. However, a temporary reduction would reduce the availability of ULSD supplies for new vehicles. In its final rulemaking the EPA required refiners and importers to submit a variety of reports to ensure a smooth transition, and the agency plans to establish an advisory panel to look at issues of diesel supply and monitor the progress of related technologies.

Assessment of Mid-Term Effects of the Rule

The mid-term analysis for this study was performed using the NEMS Petroleum Market Module (PMM) to assess the impact of new requirements for ULSD in the years 2007 through 2015. The PMM represents domestic refinery operations and the marketing of petroleum products to consumption regions. Refining operations are represented by a three-region linear programming formulation of the five PADDs. PADDs I (East Coast) and V (West Coast) are treated as single regions, and

PADDs II (Midwest), III (Gulf Coast), and IV (Rocky Mountains) are aggregated into one region. Each region is considered as a single firm, for which more than 80 distinct refinery processes are modeled. Refining capacity is allowed to expand in each region.

Unlike previous ULSD analyses, the PMM provides multi-year scenarios. These scenarios reflect market prices rather than average costs and implicitly include investment and import decisions. In contrast to the cost curves used in the short-term analysis, the NEMS projections reflect equilibrium market prices. That is, the results of the PMM scenarios assume that, in the long run, refiners will increase supply to meet demand. As a result, the NEMS analysis reflects more aggressive investment behavior than that portrayed for individual refiners in the short-term analysis.

The PMM was used to develop a ULSD Regulation case based on the provisions of the EPA's final ULSD Rule. A Severe case was developed to combine five sensitivity cases associated with greater uncertainty in industry operations and costs.[9] Finally, a No Imports case and a 10% Return on Investment case were developed.

In the **Regulation case**, highway diesel at the refinery gate is assumed to contain a maximum of 7 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. Revamping existing units to produce ULSD is assumed to be undertaken by 80 percent of refineries, while 20 percent build new units. The amount of ULSD that is to be downgraded to a lower value product because of sulfur contamination in the distribution system is assumed to total 4.4 percent. The energy content of the ULSD is assumed to decline by 0.5 percent, because undercutting and severe desulfurization will result in a lighter stream composition than 500 ppm diesel. The Rule is assumed to result in no loss in vehicle fuel efficiency. The actual after-tax return on investment is assumed to be 5.2 percent, which is equivalent to a 7-percent before-tax return on investment. As suggested by the Committee, the major assumptions in this case are consistent with those used by the EPA in its Regulatory Impact Analysis (RIA) of the Rule.[10]

The **Severe case** combines five sensitivities at variance with the above assumptions. In the "2/3 Revamp" sensitivity case, two-thirds of upgrades at refineries are assumed to be accomplished by retrofitting existing equipment and one-third by construction of all new units, consistent with the results of the individual refinery analysis. In the "10% Downgrade" case, 10 percent of the 15 ppm diesel produced is assumed to be downgraded to a lower value product because of contamination with higher sulfur products in the distribution system. In the "4% Efficiency Loss" case it is assumed that manufacturers will meet the emissions requirements of the ULSD Rule by installing after-treatment technology on new vehicles beginning in 2010, which would result in a 4-percent loss of fuel efficiency that is phased out as new technology emerges. In the "1.8% Energy Loss" case, a greater loss of energy content is assumed than in the Regulation case. In the "Higher Capital Cost" case, the capital costs of the hydrotreaters are 24 percent higher and 33 percent higher than in the Regulation case, based on a review of the most recent industry cost data.

The **No Imports case** assumes that foreign imports of ULSD will not be available. This assumption was not included in the Severe case because it was deemed to be less likely. Foreign supplies should be available from Canadian refiners, who likely will move to the U.S. standard at the same time as the United States, and from a large refinery in the U.S. Virgin Islands that is jointly owned by Armada Hess and Venezuela's national oil company, PdVSA. Both owners of the Virgin Islands plant see the United States as a strategic market. The greatest uncertainty for import availability is likely to occur in the early years of the program, because foreign refiners may delay investment until the market outlook for ULSD is more certain.

The **10% Return on Investment** case uses the after-tax rate of return assumed in most other studies, which is higher than the 5.2-percent after-tax rate used in the Regulation case and in the other sensitivity cases in this study, consistent with the EPA's assumption. At a rate of return less than 10 percent, investors may hesitate to put money into the refinery industry, especially for equipment designed for a new product.

In the Regulation case, the marginal annual pump price for ULSD is projected to range from 6.5 to 7.2 cents per gallon between 2007 and 2011 (Table ES3 and Figure ES2).[11] The peak differential is projected to occur in 2011, when oil refiners must produce 100 percent ULSD. In absolute terms, real marginal prices range from $1.29 to $1.35 per gallon in the Regulation and Severe cases from 2007 to 2011.[12] Refiners are projected to invest $6.3 to $9.3 billion to meet full compliance with the ULSD Rule through 2011.

[9]Results for the five sensitivity cases are provided in Chapter 6 and Appendix E.

[10]U.S. Environmental Protection Agency, *Regulatory Impact Analysis: Heavy-Duty Engine and Vehicle Standards and Highway Diesel Fuel Sulfur Control Requirements*, EPA420-R-00-026 (Washington, DC, December 2000).

[11]Analysis of 2006 is discussed above. As a partial year, 2006 is not included in the equilibrium analysis.

[12]These cases are based on variations from a reference case similar to that in EIA's *Annual Energy Outlook 2001*.

After 2011, the first full year of 100 percent ULSD, the projected differential of marginal prices is generally expected to decline, because of lower distribution and capital investment costs. About 0.7 cents of the projected decline results from using the EPA's assumption that the additional capital investments for distribution and storage of a second highway diesel fuel will be fully amortized during the transition period. The remainder of the drop in the post-2011 differential occurs because refineries are assumed to have completed the upgrades necessary for full compliance, to be making additional investment only to meet incremental demand, to be replacing and upgrading existing equipment, and to be making incremental operating improvements that make ULSD production less challenging. A similar decline in the price differential also occurs in all the sensitivity cases.

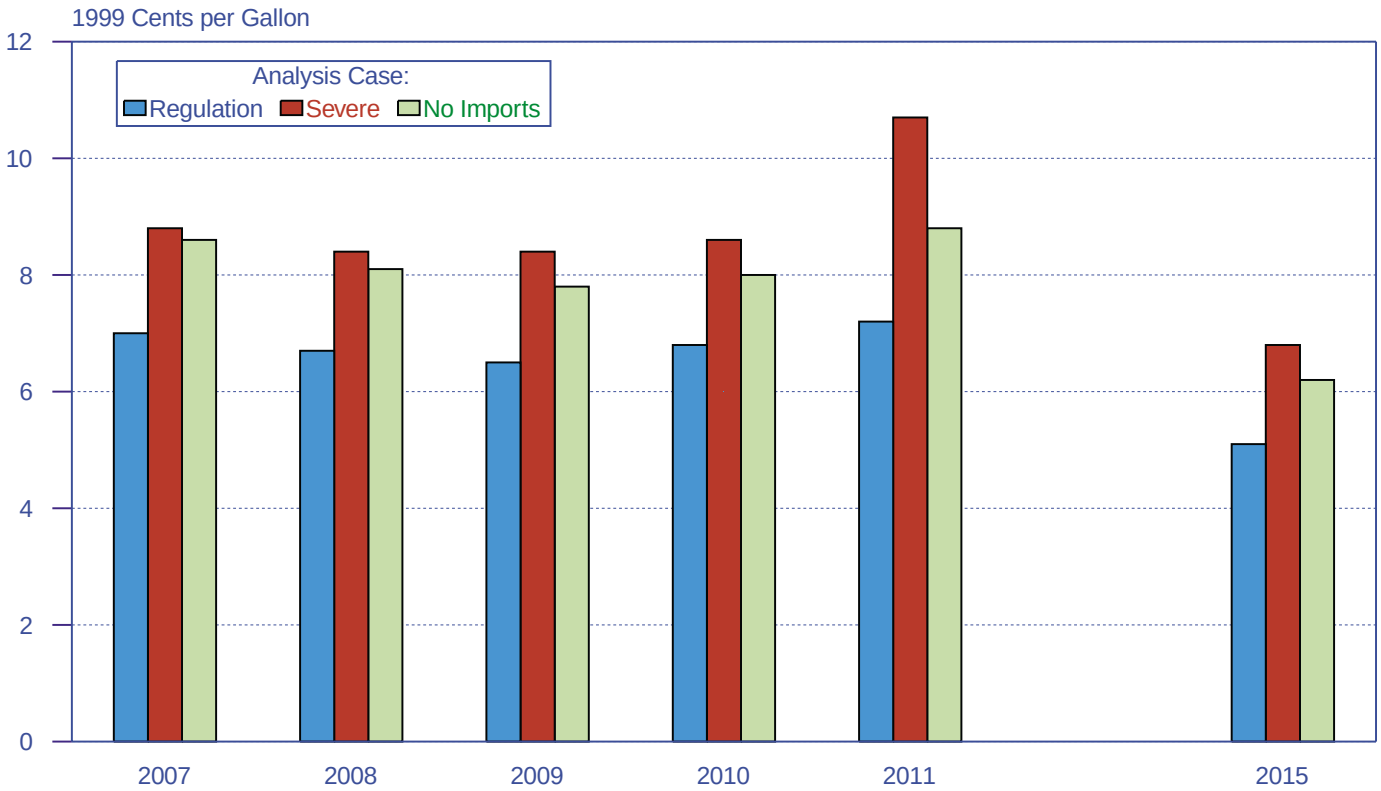
Through 2010, the Regulation case projections for highway diesel consumption exceed the reference case levels

Table ES3. Variations from Reference Case Projections in the Regulation and Sensitivity Analysis Cases, 2007-2015

Analysis Case	2007	2008	2009	2010	2011	2015	2007-2010 Average	2011-2015 Average
Difference Between End-Use Prices of ULSD and 500 ppm Diesel (1999 Cents per Gallon)								
Regulation	7.0	6.7	6.5	6.8	7.2	5.1	6.8	5.4
Severe	8.8	8.4	8.4	8.6	10.7	6.8	8.6	7.4
No Imports	8.6	8.1	7.8	8.0	8.8	6.2	8.1	6.8
Total Highway Diesel Fuel Consumption (Thousand Barrels per Day)								
Regulation	10	10	8	8	83	85	9	83
Severe	41	40	39	57	355	374	44	366
No Imports	10	9	7	7	81	83	8	81
Total Imports of Highway Diesel Fuel (Thousand Barrels per Day)								
Regulation	-36	-1	-1	0	0	0	-10	0
Severe	-36	-1	-1	0	0	0	-10	0
No Imports	-120	-125	-125	-125	-125	-125	-124	-125

Source: National Energy Modeling System, runs DSUREF.D043001B, DSU7PPM.D043001A, DSU7ALL.D050101A, and DSUIMP0.D043001A.

Figure ES2. Difference Between End-Use Prices of ULSD and 500 ppm Diesel in the Reference Case, 2007-2015



Source: National Energy Modeling System, runs DSUREF.D043001B, DSU7PPM.D043001A, DSU7ALL.D050101A, and DSUIMP0.D043001A.

by up to 10,000 barrels per day, which can be attributed to the assumption of 0.5-percent loss in energy content. In 2011 the differential in consumption increases to 83,000 barrels per day, because ULSD contaminated in the distribution system can no longer be downgraded to 500 ppm highway diesel, and refiners must therefore make more ULSD.

In the Severe case, up to 57,000 barrels per day of additional highway diesel is projected to be consumed between 2007 and 2010, and an average of 366,000 barrels per day of additional consumption is projected between 2011 and 2015. The ULSD Rule by itself accounts for an average of 9,000 barrels per day of the additional consumption through 2010 and an average of 83,000 barrels per day after 2010. The combined effects of the 2/3 Revamp, 10% Downgrade, 4% Efficiency Loss, 1.8% Energy Loss, and Higher Capital Cost cases raise consumption beyond that in the Regulation case by at least 30,000 barrels per day through 2010, primarily because of energy losses and higher capital cost, and by an average of 283,000 barrels per day after 2010 because of energy losses, downgrading, and efficiency losses. The higher downgrade assumption accounts for about 210,000 barrels of the additional demand after 2010. ULSD-related investments in the Severe case are projected to total $9.3 billion through 2011, $3 billion more than in the Regulation case. Higher demand in the Severe case generally results in marginal prices 1.7 to 1.9 cents per gallon above those in the Regulation case, although costs range up to 3.5 cents per gallon higher in 2011.

The No Imports case explores the impact of the ULSD Rule by assuming that foreign imports will not be available to meet the new sulfur standard. In the Regulation case, projected imports of highway diesel are lower than in the reference case in the first few years, because foreign refiners are expected to be more hesitant to invest to meet a U.S. regulation. The No Imports case assumes that no imports of ULSD are available, and that imports of highway diesel are reduced by 120,000 to 125,000 barrels per day between 2007 and 2015, relative to the reference case. The lack of imports means that domestic refineries must produce more ULSD. The requirement for more production results in marginal prices 1.1 to 1.6 cents per gallon higher than in the Regulation case. The higher prices in the No Imports case result in a slight dampening of demand compared with the Regulation case.

Because the Regulation case assumes a 5.2-percent after-tax return on investment, the 10% Return on Investment case must be compared with an alternative base case that assumes the same return on investment. The resulting price differentials range from 7.5 to 8.0 cents per gallon between 2007 and 2011 and are 0.9 cents per gallon higher on average than when the 5.2-percent after-tax rate is assumed.

Differences between regional end-use prices in the analysis cases relative to those in the reference case reflect variations in the marginal costs of producing ULSD between regions. The cost curve analysis described in Chapter 5 indicates that PADD IV, which is made up of relatively small refineries, can be expected to be the highest cost region. The relatively high cost in PADD IV is obscured in the mid-term analysis (Chapter 6), because PADD IV is aggregated with both PADD II and the largest and lowest cost refining region, PADD III. In the transition years of the Regulation case, regional refining costs range from an average of 4.8 to 5.3 cents per gallon. PADD I is the highest cost region, PADD V is the lowest cost region, and PADDs II-IV (and average U.S.) costs fall in between. Average marginal refining costs generally narrow by about 0.5 cents per gallon in the post-2010 period, as refineries make incremental improvements that allow them to produce ULSD more efficiently.

Additional Uncertainties

Uncertainties about the pace of engine, refinery, and pipeline testing technology development; the availability of personnel, thick-walled reactors, and reciprocating compressors; the behavior of ULSD in the oil pipeline system; and cost recovery by oil pipelines further cloud the outlook for the transition to very low levels of sulfur in diesel fuel. The new ULSD Rule requires not only that the sulfur content of transportation diesel fuel oil produced by domestic refineries be drastically reduced by 2007, but also that emission controls on heavy-duty diesel engines be imposed to reduce emissions of NO_x, PM, and hydrocarbons (HC).

Historically, engine manufactures have met new emissions standards through modifications to engine design. To meet the 2007 standard, manufacturers will have to rely heavily on component and system development by emission control equipment manufacturers. In particular, engine manufacturers must implement an exhaust after-treatment catalyst technology to control NO_x emissions. Currently, the EPA expects NO_x adsorbers to be the most likely emission control technology applied by the industry. Using current catalyst technology, the fuel-rich cycle could reduce fuel efficiency by 4 percent. To date, no NO_x adsorber system has proven feasible. Although NO_x adsorbers have demonstrated compliance using ULSD (7 ppm), the systems show losses in conversion efficiency after 2,000 miles of operation. In order to meet the 2007 emission standards for heavy-duty diesel engines, conversion efficiencies must be improved, and exhaust gas recirculation equipment must be optimized. The considerable time available for research and development, however, may provide government and industry ample time to resolve the fuel efficiency loss issues associated with advanced emission control technologies.

Beyond traditional hydrotreating to remove sulfur from diesel streams, new technologies are under development that could reduce the cost of desulfurization. They include sulfur adsorption, biodesulfurization, sulfur oxidation, gas-to-liquids, and biodiesel. Each of these technologies is in the first stages of commercialization. Although they are being spurred by the EPA Rule, it is uncertain whether any of the new technologies will make a significant contribution to meeting the requirements of the ULSD Rule in 2006, although they may have some impact later in the decade.

Before the ULSD Rule takes effect in 2006, sulfur testing methods must also be improved. The designated method, ASTM 6428-99, was developed for testing sulfur in aromatics and has not yet been adapted or evaluated by industry as a test for sulfur in diesel fuel. Because the diesel methodology has not yet been developed for the designated method, it has not yet been tested by multiple laboratories. There is also no readily available and appropriate test for sulfur that will permit the precise cuts between batches that will be required in handling ULSD. Most oil pipeline operators will probably want or need to perform in-line monitoring of sulfur content, because degradation of ULSD will easily and, possibly, frequently occur in as little as a minute's time. However, current instruments for testing sulfur do not have adequate sensitivity, accuracy, or speed for the job. Current machines require 5 to 10 minutes to complete one analysis of a passing product stream—far too long to permit a pipeline operator to make a correctional response if off-specification material is detected in a batch of ULSD.

The deployment of diesel desulfurization technologies will hinge not only on the ability and willingness of refiners to invest and the timing of investment and permitting but also on the ability of manufacturers to provide units for all U.S. refineries at once, and the availability of engineering and construction resources. In addition to providing diesel hydrotreaters, the same contractors will be designing and building gasoline desulfurization units for the Tier 2 gasoline sulfur reduction requirements that will be phased in between 2004 and 2007. The EPA's breakout of the expected startup of gasoline and diesel desulfurization units reflects an overlap of 26 gasoline units and 63 diesel units in 2006, more than any other year except 2004. The EPA estimates that 30 percent more workers will be required for the gasoline and diesel programs together than for the gasoline program alone. If thick-walled reactors are required for deep hydrotreating, delivery lead times will be longer, because only one or two U.S. companies produce thick-walled reactors. Another type of critical equipment is reciprocating compressors. Two reciprocating compressors will be required for each diesel desulfurization project. Reciprocating compressors will also be required for gasoline desulfurization projects. Excluding the former Soviet Union, there are only five manufacturers of reciprocating compressors in the world.

The exact sulfur level at which refineries will be required to produce ULSD is not certain, because there is no experience with distributing ULSD in a non-dedicated or common transportation system. Residual sulfur from high-sulfur material could contaminate subsequent pipeline material beyond the interface between the two products. Recently, Buckeye Pipe Line conducted a test of possible sulfur contamination from one product batch to another. Buckeye carefully measured the sulfur content in batches of highway diesel fuel following a batch of high-sulfur diesel fuel and found that the sulfur content of the second batch of highway diesel fuel increased. Exact sulfur levels have implications for the amount of material downgraded during pipeline and terminal operations.

If no other application or action were taken by an oil pipeline company, the existing tariff rates covering diesel fuel would apply to ULSD when that material is distributed to markets; however, oil pipelines will incur large incremental capital and operating costs in distributing the new diesel fuel. If an oil pipeline carrier is operating under the Federal Energy Regulatory Commission's commonly approved index method and applies its existing tariff rate to ULSD, there will be no basis for the carrier to recover its incremental costs in the approved rate. A carrier might file a new tariff rate expressly covering ULSD.

Comparison with Other Studies

Earlier studies related to ULSD supply and costs included analyses by the U.S. Environmental Protection Agency (EPA), Mathpro, the National Petroleum Council (NPC), Charles River and Associates with Baker and O'Brien, EnSys Energy & Systems, Inc., and Argonne National Laboratory (ANL). The studies were based on two general types of methodologies: a linear programming (LP) approach used by Mathpro, NPC, EnSys, ANL, and EIA; and a refinery-by-refinery approach used by Charles River, EPA, and EIA.

Cost estimates from 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 that represent the cost of the last barrel of required supply can be seen as estimates of market prices. Average cost estimates usually reflect refinery investment, but they are not good estimates of market prices. Much of the variation in investment and cost estimates reflects

different assumptions about the cost of technologies; unit size; contingency factors; the extent to which refiners will modify existing equipment or build entirely new hydrotreaters; 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. Nevertheless, the studies using LP models reported cost increases ranging from 4.0 to 10.7 cents per gallon, excluding distribution costs and taxes. The marginal refinery gate prices reported in this study for the post-2006 period, which exclude distribution costs and taxes, range from 4.7 to 9.2 cents per gallon.

Likewise, the costs derived from refinery-by-refinery analysis included average costs for the industry and average costs for the marginal firm, different estimates of the penetration of ULSD, different consumption estimates, different assumptions about the cost of technologies, different assumptions about the extent to which refiners will modify existing equipment or build entirely new hydrotreaters, different assumptions about the cost and quantity of additional hydrogen required, and different regions. The range of estimated cost increases reported in the studies using refinery-by-refinery analysis was 4.1 to 6.8 cents per gallon. This study's range for the 2006 analysis is at the higher end, because it leaves out the lower cost PADD V, is based on marginal industry costs rather than average refinery costs, and has 63 percent of refineries revamping their hydrotreaters, as compared with 80 percent in the studies with lower cost estimates.