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: a 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 refinery models were used. The Mathpro analysis used an LP model of a "notional refinery" that represented an average refinery in a given region. 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 that represent 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 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.

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.[125] 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.[126] 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.

Table 19. Methodologies Used To Estimate ULSD Refining Costs

Author	Client	Date	Methodology
Mathpro	Engine Manufacturers Association	October 1999; updated August 2000	LP, notional refinery Original study: PADDs I-III average cost (aggregated) Updated study: average cost U.S. excluding California
EPA		December 2000	Refinery-by refinery analysis, average cost after credit trading
NPC	U.S. Department of Energy	June 2000	Adjusted Mathpro's LP results from original study, average cost
CRA/BOB	American Petroleum Institute	August 2000	Constructed cost curves using industry interviews, refinery-by-refinery analysis, marginal cost of PADDs I-III aggregated, PADD IV, PADD V, and U.S.
EnSys	U.S. Department of Energy	August 2000	LP, aggregate PADD III refinery, average cost by each quartile of production, marginal costs provided for one scenario
ANL	U.S. Department of Energy	November 2000	Estimated weighted average costs based on EnSys costs
EIA	U.S. House of Representatives, Committee on Science	April 2001	(1) LP; aggregate regional refineries, PADDs I, II-IV aggregate, and V; marginal cost (2) Cost curves based on individual refinery data

Sources: **EPA:** U.S. Environmental Protection Agency, *Regulatory Impact Analysis: Heavy-Duty Engine and Vehicle Standards and Highway Diesel Fuel Sulfur Requirements*, EPA420-R-00-026 (Washington, DC, December 2000), Chapter V, web site www.epa.gov/otaq/regs/hd2007/frm/ria-v.pdf. **Mathpro:** Mathpro, Inc., *Refining Economics of Diesel Fuel Sulfur Standards: Supplemental Analysis of 15ppm Sulfur Cap* (Bethesda, MD, August 2000), Exhibit 8, Case 11. **NPC:** National Petroleum Council, *U.S. Petroleum Refining: Assuring the Adequacy and Affordability of Cleaner Fuels* (June 2000), Chapter 3. **CRA/BOB:** Charles River Associates, Inc., and Baker and O'Brien, Inc., *An assessment of the Potential Impacts of Proposed Environmental Regulations on U.S. Refinery Supply of Diesel Fuel*, CRA No. D02316-00 (August 2000). **EnSys:** EnSys Energy & Systems, Inc, *Modeling Impacts of Reformulated Diesel Fuel* (Flemington, NJ, August 2000). **ANL:** M.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). **EIA:** Energy Information Administration, Office of Integrated Analysis and Forecasting (Chapters 5 and 6 of this report).

Table 20. Characteristics of ULSD Cost Studies

Study	LP Model	Based on LP Results	Refinery-by-Refinery	Year-by-Year	Single Period	Multi-Region Results	Average Cost	End-Use Prices	Market Equilibrium Prices	Supply / Demand Analysis
Mathpro	X				X	X	X			
EPA			X	2006, 2010		X	X	X		
NPC		X[a]			X		X			
CRA/BOB.			X		X	X		X	Short-run	X
EnSys	X				X		X			
ANL		X[b]		2006-2015[c]			X	X		
EIA NEMS	X			2007-2015		X		X	Long-run	X
EIA Refinery by Refinery . . .			X		X	X	X			X

[a]Uses Mathpro results.
[b]Uses EnSys results.
[c]Phase-in of 8 percent ULSD to 100 percent.

Sources: **EPA:** U.S. Environmental Protection Agency, *Regulatory Impact Analysis: Heavy-Duty Engine and Vehicle Standards and Highway Diesel Fuel Sulfur Requirements*, EPA420-R-00-026 (Washington, DC, December 2000), Chapter V, web site www.epa.gov/otaq/regs/hd2007/frm/ria-v.pdf. **Mathpro:** Mathpro, Inc., *Refining Economics of Diesel Fuel Sulfur Standards: Supplemental Analysis of 15ppm Sulfur Cap* (Bethesda, MD, August 2000), Exhibit 8, Case 11. **NPC:** National Petroleum Council, *U.S. Petroleum Refining: Assuring the Adequacy and Affordability of Cleaner Fuels* (June 2000), Chapter 3. **CRA/BOB:** Charles River Associates, Inc., and Baker and O'Brien, Inc., *An assessment of the Potential Impacts of Proposed Environmental Regulations on U.S. Refinery Supply of Diesel Fuel*, CRA No. D02316-00 (August 2000). **EnSys:** EnSys Energy & Systems, Inc, *Modeling Impacts of Reformulated Diesel Fuel* (Flemington, NJ, August 2000). **ANL:** M.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). **EIA Refinery by Refinery:** Energy Information Administration, Office of Integrated Analysis and Forecasting (Chapter 5 of this report). **EIA NEMS:** National Energy Modeling System, runs DSUREF.D043001B, DSU7PPM.D043001A, DSU7HC.D043001A, DSU7INV.D043001A, DSU7DG10.D043001A, DSU7TRN.D043001A, DSU7BTU.D043001A, DSU7ALL.D050101A, DSU7IMP0.D043001A, DSUREF10.D043001A, and DSU7PPM10.D043001A.

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
(1999 Cents per Gallon)

Period	Additional Refining	Lubricity Additive	Distribution[a]	Additional Distribution Tanks	Total Increase
Phase-in, 2006-2010	4.1	0.2	0.4	0.7	**5.4**
Fully Implemented Program, 2010	4.3	0.2	0.5	0.0	**5.0**

[a]Not including additional distribution tanks.

Source: U.S. Environmental Protection Agency, *Regulatory Impact Analysis: Heavy-Duty Engine and Vehicle Standards and Highway Diesel Fuel Sulfur Requirements*, EPA420-R-00-026 (Washington, DC, December 2000), p. V-103.

[127]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).

[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.

[129]U.S. Environmental Protection Agency, *Regulatory Impact Analysis: Heavy-Duty Engine and Vehicle Standards and Highway Diesel Fuel Sulfur Requirements*, EPA420-R-00-026 (Washington, DC, December 2000), Chapter V, p. V-106.

[130]Distribution costs include the capital cost of additional storage tanks, additional operating costs, yield losses, product downgrades, and testing costs.

[131]U.S. Environmental Protection Agency, *Regulatory Impact Analysis: Heavy-Duty Engine and Vehicle Standards and Highway Diesel Fuel Sulfur Requirements*, EPA420-R-00-026 (Washington, DC, December 2000), Chapter V, p. V-103, web site www.epa.gov/otaq/regs/hd2007/frm/ria-v.pdf.

Mathpro Analysis

In its original study for the Engine Manufacturers Association, Mathpro provided 5 sets of scenarios for 10 different combinations of heavy-duty, non-road, and light-duty diesel fuel standards. The scenarios were developed using a linear programming (LP) representation of a notional refinery in PADDs I through III.[132] The study was completed in October 1999 and reflected a range of uncertainty with regard to the eventual sulfur standard. The target sulfur level for highway diesel in the scenarios ranged from 150 ppm to 2 ppm. The scenarios also reflected varying assumptions about the ultimate sulfur level of non-road diesel, and about investment in upgrade (revamp) projects versus new (grassroots) projects. The scenarios resulted in an average increase in refining costs ranging from 2.5 to 9.0 cents per gallon for the 150 ppm and 2 ppm sulfur levels, respectively. The associated investment costs ranged between $0.8 billion and $3.9 billion for PADDs I through III.

In August 2000, Mathpro updated its analysis using the 15 ppm sulfur standard indicated in the June 2000 Notice of Proposed Rulemaking, assuming that the requirement would be met by producing diesel fuel with a pool average of 8 ppm or less.[133] The updated analysis provided estimates given three different assumptions about non-road diesel:

- Non-road diesel at current levels (3,500 ppm). This assumption most closely resembles the EIA and EPA cost analyses.
- Non-road diesel reduced to 350 ppm
- Non-road diesel reduced to 15 ppm.

For each of the non-road sulfur assumptions, the updated analysis provided five scenarios based on different investment and operating approaches by refineries:

- No Retrofitting-Inflexible, which requires only new unit investment
- No Retrofitting-Flexible, which requires only new unit investment but allows some flexibility in hydrocracking and jet fuel production
- Retrofitting-De-rate / Parallel, which allows modification of the existing desulfurization unit and building a parallel unit
- Retrofitting-Series, which allows expansion of the existing desulfurization unit by debottlenecking and adds a new unit in series
- Economies of Scale, which is similar to Retrofitting-Series but allows further economies of scale through inter-refinery processing arrangements.

The estimated increase in national average refining costs (excluding California) ranged between 4.0 and 7.6 cents per gallon and was associated with total investment costs between $1.8 billion and $3.3 billion (1999 dollars) over all of the non-road sulfur assumptions. Costs ranged from 4.5 to 7.1 cents per gallon and investments from $3.0 to $6.0 billion for the scenarios assuming current sulfur levels for non-road diesel (Table 22). The analysis assumed a 10-percent after-tax rate of return on investment. The scenarios with non-road diesel at 3,500 ppm were most similar to the EIA, EPA, and DOE analyses, and the scenario with non-road diesel at 350 ppm was more consistent with the CRA / BOB analysis. When non-road diesel was held at 3,500 ppm, the average cost of producing highway diesel increased by 7.1 cents per gallon in the No Retrofitting-Flexible case and by 4.5 cents per gallon in the Economies of Scale case.

Although the investment costs estimated by Mathpro were at least $195 million dollars higher when the sulfur limit for non-road diesel was assumed to decline to 350 ppm, the average costs were between 0.2 and 1.2 cents per gallon lower than in the scenarios assuming

Table 22. Mathpro Estimates of the Costs of Producing 15 ppm Highway Diesel, with Non-Road Diesel at 3,500 ppm Sulfur

Flexible	No Retrofit: Inflexible	No Retrofit: Flexible	Retrofit: De-rate	Retrofit: Series	Economies of Scale
Total Average U.S. Cost[a] (1999 Cents per Gallon)	6.8	7.1	6.7	4.6	4.5
Investment (Million 1999 Dollars)	5,950	5,900	5,370	3,330	3,040

[a]Excludes California.
Note: Costs have been converted to 1999 dollars from the 2000 dollars reported by Mathpro.
Source: Mathpro, Inc., *Refining Economics of Diesel Fuel Sulfur Standards: Supplemental Analysis of 15ppm Sulfur Cap* (Bethesda, MD, August 2000), Exhibit 8.

[132]Mathpro, Inc., *Refining Economics of Diesel Fuel Sulfur Standards: Supplemental Analysis of 15ppm Sulfur Cap* (Bethesda, MD, August 2000).

[133]Mathpro, Inc., *Refining Economics of Diesel Fuel Sulfur Standards: Supplemental Analysis of 15ppm Sulfur Cap* (Bethesda, MD, August 2000).

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.

[134] National 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 1998 dollars reported by NPC.

[135] Charles River Associates, Inc. and Baker and O'Brien, Inc., *An assessment of the Potential Impacts of Proposed Environmental Regulations on U.S. Refinery Supply of Diesel Fuel*, CRA No. D02316-00 (August 2000).

[136] U.S. Environmental Protection Agency, *Regulatory Impact Analysis: Heavy-Duty Engine and Vehicle Standards and Highway Diesel Fuel Sulfur Requirements*, EPA420-R-00-026 (Washington, DC, December 2000), Chapter V, web site www.epa.gov / otaq / regs / hd2007 / frm / ria-v.pdf.

[137] Turner, Mason & Company, *Costs/Impacts of Distributing Potential Ultra Low Sulfur Diesel* (Dallas, TX, February 2000); *Revised Supplement* (August 2000).

[138] Telephone conversation with Ray Ory of Baker and O'Brien, January 25, 2001.

EnSys Analysis

EnSys provided a set of cost estimates to the U.S. Department of Energy's Office of Policy, using an LP model that represents PADD III refiners in the aggregate.[139] The estimates reflected a 10-percent return on investment. Unlike the previously discussed studies, EnSys did not make an assumption of how many refiners would revamp units and how many would build new desulfurization units, but instead provided cost estimates for a refinery using revamps and cost estimates for a refinery building new units. The scenarios were also based on two sets of technologies: a conservative technology set and an optimistic technology set. In order to model a phase-in of the highway diesel standard, a series of cases were run assuming different percentages of highway diesel required to meet the new standard.

EnSys developed the scenarios discussed above for the production of highway diesel at various sulfur levels, ranging from 8 ppm to 30 ppm. The results of the 10 ppm scenarios are the focus of this discussion, because they were highlighted in the EnSys report and were provided in a more uniform manner. In general, the scenarios with diesel sulfur at 8 ppm were about 0.5 cent above the 10 ppm estimates. The average incremental cost estimates for producing 10 ppm diesel ranged from 4.4 to 6.0 cents per gallon for the first 50 percent of highway diesel produced at 10 ppm, 6.0 to 7.9 cents for the next 25 percent, and 7.6 to 10.1 cents per gallon for the final 25 percent of production. The lower estimate assumed that the product was produced by 100 percent revamped units; the higher estimate assumed 100 percent new units.

The cases assumed that 25, 50, 75, and 100 percent of highway diesel would be required to meet the 10 ppm standard, while non-road diesel was capped at 360 ppm. The 360 ppm assumption was negated by the fact that the cases were compared with a reference case that also assumed 360 ppm non-road diesel. Sensitivities of reaching 360 ppm for non-road diesel were performed with other assumptions varied. Cases that assumed 100 percent highway diesel at 10 ppm and non-road and heating oil at 360 ppm resulted in average costs that were between 1.6 cents per gallon and 2.1 cents per gallon higher than in the cases assuming non-road diesel and heating oil at current sulfur levels.

The EnSys analysis also included marginal cost estimates for producing 10 ppm diesel with base technology and no revamp (all new units). The marginal cost of production was 6.6 cents per gallon for the first 25 percent of production, 7.2 cents per gallon for the first 50 percent, 7.7 cents per gallon for the first 75 percent, 9.2 cents per gallon for the full phase-in, and 10.7 cents per gallon for an all-at-once approach. The highway diesel volumes produced did not reflect additional production for downgraded product.

ANL Analysis

ANL provided an analysis of total incremental refining and distribution costs for seven different phase-in scenarios to the U.S. Department of Energy (DOE) in August 2000 and updated the estimates in November 2000 based on EPA comments.[140] The most recent ANL estimates were based on average incremental production cost estimates from the EnSys 10 ppm production scenarios and distribution cost estimates for 15 ppm diesel extrapolated from TMC estimates for 5 ppm and 50 ppm diesel.

The ANL analysis used average per-gallon production cost estimates taken as the weighted average of the incremental cost for each quartile of highway diesel production, provided by EnSys. The scenarios had three parameters: the type of technology, the mix of new units versus modified units, and the percent of diesel production required to be 10 ppm. EnSys estimated costs for production under two different investment scenarios: all revamped equipment and all new units. For each investment scenario, EnSys provided cost estimates for both a base technology and an optimistic technology assumption.

The ANL analysis also provided cost estimates for 60 percent revamp / 40 percent no revamp given both base and optimistic technology assumptions, by blending the EnSys "all revamp" and "all new" scenarios.[141] The average estimated cost (undiscounted) of producing the first 25 percent ranged from 4.2 to 6.0 cents per gallon; the first 50 percent, 4.0 to 6.0 cents per gallon; the first 75 percent, 4.2 to 6.6 cents per gallon; for 100 percent after phase-in, 4.7 to 7.5 cents per gallon; and for 100 percent all-at-once, 6.0 to 8.1 cents per gallon.[142] Marginal costs were provided by an additional scenario resulting in a marginal cost of 6.6 cents per gallon for the first 25 percent of production, 9.2 cents per gallon for a full phase-in, and 10.7 cents per gallon if the production is required all at once. ANL developed phase-in cost series for the seven scenarios by interpolating between the cost estimates for the different levels of production mentioned above.

[139] EnSys Energy & Systems, Inc, *Modeling Impacts of Reformulated Diesel Fuel* (Flemington, NJ, August 2000).

[140] M.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).

[141] M.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 A.

[142] M.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), Table 1.

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 50 ppm diesel.[143] 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.[144]

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

Study	Sulfur Level (ppm)	Percentage of Highway Diesel That Is ULSD	Cost Change (1999 Cents per Gallon of ULSD)	Cost Basis	Refinery Capital Investment (Billion 1999 Dollars)
EPA (temporary compliance, 2006-2010)	7	75[a]	4.1[b]	Average, U.S.	3.9
EPA (full compliance, June 2010 forward)	7	100	4.3	Average, U.S.	5.3 total
CRA/BOB (August 2000 for 2006)	7[c]	100	6.7[d]	Average, U.S.[e]	7.7
EIA (cost curves, 2006)	7	76-100	5.4-6.8	Marginal, PADDs I-IV[f]	

[a]Small refiners accounting for 5 percent of production are eligible to delay, but only 2 percent are assumed to delay.
[b]Cost adjusted for credit trading at cost to low cost refiners.
[c]Correspondence with Ray Ory of Baker and O'Brien. Also reflects assumption of 350 ppm non-road diesel.
[d]Average cost to produce 7 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.
[e]Average based on marginal cost methodology.
[f]Marginal based on average refinery costs.

Sources: **EPA:** U.S. Environmental Protection Agency, *Regulatory Impact Analysis: Heavy-Duty Engine and Vehicle Standards and Highway Diesel Fuel Sulfur Requirements*, EPA420-R-00-026 (Washington, DC, December 2000), Chapter V, web site www.epa.gov/otaq/regs/hd2007/frm/ria-v.pdf. **CRA/BOB:** Charles River Associates, Inc., and Baker and O'Brien, Inc., *An assessment of the Potential Impacts of Proposed Environmental Regulations on U.S. Refinery Supply of Diesel Fuel*, CRA No. D02316-00 (August 2000). **EIA:** Energy Information Administration, Office of Integrated Analysis and Forecasting (Chapter 5 of this report).

[143]Turner, Mason & Company, *Costs/Impacts of Distributing Potential Ultra Low Sulfur Diesel* (Dallas, TX, February 2000).

[144]M.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.

from $1,240 per barrel per day to $1,680 per barrel per day, whereas those in EIA's refinery-by-refinery analysis ranged from $1,043 to $1,807, and in EIA's NEMS Regulation case they were $1,331 to $1,849 per barrel per day (Table 25).

The sets of capital costs used in the EIA and EPA analyses are not directly comparable. The lower-bound of EPA's capital costs represents a 25,000 barrel per day hydrotreater processing 100 percent straight-run feedstock, and the upper-bound reflects the same unit processing 100 percent light cycle oil. The EPA's upper and lower bound costs encompass a third estimate for a unit processing entirely coker distillate. The capital costs for individual refineries in the EPA analysis vary across this range, depending on the assumptions about proportions of straight-run distillate, coker distillate, and light cycle oil processed at each refinery and the size of the hydrotreater unit. The capital cost range for EIA's refinery-by-refinery analysis also varies for the quality of the feedstock and size of each unit. EIA's short-term analysis reflects actual data about the quality of crude oil and feed streams at individual refineries. In contrast, EIA's mid-term NEMS analysis does not use refinery-specific information about feed steams but aggregates feed and crude quality information at a regional level.

Table 24. Comparison of ULSD Production Cost Estimates: LP Model or Based on LP Results

Study	Sulfur Level (ppm)	Percent of Highway Diesel That Is ULSD	Cost Change (1999 Cents per Gallon of ULSD)	Cost Basis	Refinery Capital Investment (Billion 1999 Dollars)
Mathpro (August 2000)	8	100	4.5-7.1[a]	Average U.S.	3.0-6.0[a]
NPC (June 2000)	30	100	5.9	Average PADDs I-III	4.1
EnSys (August 2000), first 50 percent of production at 10 ppm	10[b]	50	4.4-6.0[c]	Average PADD III	
EnSys (August 2000), next 25 percent of production at 10 ppm	10[b]	75	6.0-7.9[c]	Average incremental cost of next 25% PADD III	
EnSys (August 2000), final 25 percent of production at 10 ppm	10[b]	100	7.6-10.1[c]	Average incremental cost of final 25% PADD III	
EnSys (August 2000), 25% to 100%	10[b]	25-100	6.6-10.7[d]	Marginal PADD III	
ANL (November 2000), up to 50% of production at 10 ppm	10	50	4.0-6.0[d]	Average PADD III	
ANL (November 2000), 75% of production at 10 ppm	10	75	4.2-6.6[c]	Average PADD III	
ANL (November 2000), 100% of production at 10 ppm	10	100	4.7-7.5[c]	Average PADD III	8.1-13.2 (August 2000 estimate)[e]
ANL (November 2000), 100% of production at 10 ppm, all-at-once	10	100	6.0-8.1[c]	Average PADD III	
ANL (November 2000), 25% to 100%	10	25-100	6.6-9.2[d]	Marginal PADD III	
EIA (NEMS, 2007-2010)	7	76[f]	4.7-7.3[g]	Marginal, U.S. average	4.2-5.9 through 2007
EIA (NEMS, 2011)	7	100	6.5-9.2[g]	Marginal, U.S. average	6.3-9.3 through 2011

[a]Non-road 3500 ppm.
[b]Reflects assumption of 360 ppm non-road diesel but the cost impact is negated because it is compared with a reference case with non-road diesel at the same sulfur level.
[c]The higher end of the cost range reflects base technology while the lower end reflects more optimistic technology.
[d]Marginal costs at 25 percent and 100 percent 10 ppm production with base technology and all new units.
[e]U.S. Department of Energy, "Comments of the Department of Energy on the Environmental Protection Agency's May 16, 2000 Notice of Proposed Rulemaking on Heavy-Duty Engine and Vehicle Emission Standards and Highway Diesel Fuel Sulfur Control" (Washington, DC, September 2000), Enclosure 1.
[f]Small refiners accounting for 5 percent of production are eligible for the small refinery provision, but only 4 percent of production is assumed to be delayed.
[g]Average refinery gate price for individual years.

Sources: **Mathpro:** Mathpro, Inc., *Refining Economics of Diesel Fuel Sulfur Standards: Supplemental Analysis of 15ppm Sulfur Cap* (Bethesda, MD: August 2000). **NPC:** National Petroleum Council, *U.S. Petroleum Refining: Assuring the Adequacy and Affordability of Cleaner Fuels* (June 2000). **EnSys:** EnSys Energy & Systems, Inc, *Modeling Impacts of Reformulated Diesel Fuel* (Flemington, NJ, August 2000). **ANL:** M.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). **EIA:** National Energy Modeling System, runs DSUREF.D043001B, DSU7PPM.D043001A, DSU7HC.D043001A, DSU7INV.D043001A, DSU7DG10.D043001A, DSU7TRN.D043001A, DSU7BTU.D043001A, DSU7ALL.D050101A, DSU7IMP0.D043001A, DSUREF10.D043001A, and DSU7PPM10.D043001A.

The lower end cost in EIA's NEMS analysis reflects a notional unit that processes low-sulfur feed with incidental dearomatization, 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.[145] 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.[146] The NPC characterized vendor estimates as inherently over-optimistic;[147] 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 $80 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 Hydrotreator Investment Assumptions for Various Refinery Models

Model	Capital Cost of New Hydrotreater (1999 Dollars per Barrel per Day, ISBL)	Revamp Cost as a Percentage of New Unit Cost	Unit Size (Barrels per Day)	Percent of ULSD Production from Revamped Units Versus New Units
Refinery-by-Refinery Models				
CRA/BOB	1,622[a]	55	25,000	60/40
EPA	1,240-1,680[b]	50	25,000	80/20
EIA Cost Curve	1,043-1,807[c]	Variable	50,000-10,000	Not an assumption
EIA Cost Curve, High Capital Cost Scenario	1,465-2,548c	Variable	50,000-10,000	Not an assumption
LP Models				
EnSys (August 2000)	2,350-3,296[d]	60	25,000	NA
EIA NEMS Regulation Case	1,331-1,849[d]	50	25,000-10,000	80/20
EIA NEMS 2/3 Revamp Case	1,331-1,849[d]	50	25,000-10,000	66.7/33.3
EIA NEMS Higher Capital Cost Case	1,655-2,493[d]	50	25,000-10,000	80/20

[a]Feedstock composed of 65 percent straight-run distillate, 10 percent cracked stock, and 25 percent light cycle oil.
[b]Low end of range is for straight-run distillate and high end is for light cycle oil.
[c]Costs varied depending on unit size and feedstock.
[d]Low end of range is for units processing low-sulfur feed streams with incidental dearomatization. High end is for higher sulfur feed streams with greater aromatics improvement.

Sources: **CRA/BOB:** Correspondence with Mr. Ray Ory, April 19, 2001. **EPA:** U.S. Environmental Protection Agency, *Regulatory Impact Analysis: Heavy-Duty Engine and Vehicle Standards and Highway Diesel Fuel Sulfur Requirements*, EPA420-R-00-026 (Washington, DC, December 2000), Chapter V, Table V.C-9, web site www.epa.gov/otaq/regs/hd2007/frm/ ria-v.pdf. **EIA Cost Curve and Cost Curve High Capital Cost Scenario:** National Energy Technology Laboratory, in conjunction with Mr. John Hackworth, energy consultant. **EnSys:** EnSys Energy & Systems, Inc, *Modeling Impacts of Reformulated Diesel Fuel* (Flemington, NJ, August 2000). **EIA/NEMS Regulation and 2/3 Revamp Cases:** Office of Integrated Analysis and Forecasting. **EIA/NEMS High Capital Cost Case:** Revised EnSys costs based on correspondence with Mr. Martin Tallett, April 23, 2001.

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

[146]M.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), p. 132.

[147]National Petroleum Council, *U.S. Petroleum Refining: Assuring the Adequacy and Affordability of Cleaner Fuels* (June 2000), p. 77.

The EIA NEMS analysis produced estimates for the refinery capital investment required to comply with the ULSD Rule for 2007 and 2010. The cumulative refinery capital investment estimated through 2007 ranged between $4.2 billion and $5.9 billion. The NEMS analysis produced an estimate of refinery capital investment between $6.3 billion and $9.3 billion through 2011.

Distribution Cost Analyses

EPA, ANL, and TMC have published estimates of distribution costs given different assumptions about the phase-in requirements for highway diesel. In general, the cost estimates for distributing a smaller percentage of 15 ppm fuel were higher than estimates assuming that 100 percent of the highway diesel market would be at 15 ppm, because a phase-in approach requires the distribution system to handle an extra product (Table 26).

Distribution cost estimates from the EPA, ANL, and TMC analyses included the capital incurred in the distribution and refueling system, as well as costs resulting from downgraded product. The EPA estimated that distribution costs would increase by 1.1 cents per gallon during the temporary compliance period, with 0.4 cents of the cost associated with the distribution and energy loss of the ULSD relative to 500 ppm diesel and 0.7 cents associated with capital expenses for handling two grades of highway diesel. EPA assumed that the capital costs would be fully amortized during the transition period (by 2010), and that revenue losses from product downgrade and other operating costs would increase distribution costs by 0.5 cents per gallon.

EIA's NEMS analysis assumed the EPA's estimated capital costs of 0.7 cents per gallon and portions of EPA's other distribution costs, including operating, transmix, and testing costs, which totaled 0.2 cents per gallon. EIA estimated the cost associated with the revenue loss of the downgraded product at 0.3 cents per gallon through 2010 and 0.2 cents per gallon after 2010 (see Chapter 6). The EIA revenue loss estimates were based on model results. A higher revenue loss estimate of 0.7 cents per gallon for all years was associated with EIA's 10% Downgrade sensitivity case, because more of the ULSD

Table 26. Comparison of ULSD Distribution Cost Estimates and Assumptions

Study	Sulfur Level (ppm)	Year	Distribution Cost Change (1999 Cents per Gallon)	Investment (Billion 1999 Dollars)	Downgrade Estimates
TMC	5		7 at 5% 4.1 at 20% 1.5 at 100%	0.215 1.05 1.08	10.0% 12.0% 19.5%
TMC	15		6.9 at 5% 4.1 at 20% 1.4 at 100%	0.215 1.05 1.08	9.5% 11.0% 17.5%
TMC	50		Costs 15% to 35% less than 5 ppm costs		8.0% 10.0% 13.5%
ANL	15		6.2 at 5% 1.6-2.2 at 74%-100% 1.2-2.1 all-at-once Costs are undiscounted and include refueling costs	50% of terminals reconfigure split between new tankage at $1 million per terminal and modified tankage at $100,000 per terminal	Same as TMC 5 ppm and 50 ppm
EPA (temporary compliance)	15	2006-2010	1.1	0.5	4.4%
EPA (full compliance)	15	Post-2010	0.5	0.3	4.4%
CRA/BOB	15				10.0% above current
EIA Regulation Case (temporary compliance)	15	2007-2010	1.2		4.4%
EIA Regulation Case (100% ULSD)	15	Post- 2010	0.4		4.4%
EIA 10% Downgrade Case (temporary compliance)	15	2007-2010	1.6		10%
EIA 10% Downgrade Case (100% ULSD)	15	Post- 2010	0.9		10%

Sources: Sources: **EPA:** U.S. Environmental Protection Agency, *Regulatory Impact Analysis: Heavy-Duty Engine and Vehicle Standards and Highway Diesel Fuel Sulfur Requirements*, EPA420-R-00-026 (Washington, DC, December 2000), Chapter V, web site www.epa.gov/otaq/regs/hd2007/frm/ria-v.pdf. **CRA/BOB:** Charles River Associates, Inc., and Baker and O'Brien, Inc., *An assessment of the Potential Impacts of Proposed Environmental Regulations on U.S. Refinery Supply of Diesel Fuel*, CRA No. D02316-00 (August 2000). **ANL:** M.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). **TMC:** Turner, Mason & Company, *Costs/Impacts of Distributing Potential Ultra Low Sulfur Diesel* (Dallas, TX, February 2000). **EIA:** National Energy Modeling System, runs DSUREF.D043001B, DSU7PPM.D043001A, DSU7HC.D043001A, DSU7INV.D043001A, DSU7DG10.D043001A, DSU7TRN.D043001A, DSU7BTU.D043001A, DSU7ALL.D050101A, DSU7IMP0.D043001A, DSUREF10.D043001A, and DSU7PPM10.D043001A.

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,[148] ranged from 6.2 cents to 1.2 cents per gallon for delivery of 5 percent and 100 percent, respectively.[149] In August 2000, TMC provided supplemental estimates reflecting downgrade costs associated with distributing 15 ppm diesel fuel.[150] 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.[151]

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.[152]

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.[153] 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

[148]Turner, Mason & Company, *Costs/Impacts of Distributing Potential Ultra Low Sulfur Diesel* (Dallas, TX, February 2000).

[149]M.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.

[150]Turner, Mason & Company, *Costs/Impacts of Distributing Potential Ultra Low Sulfur Diesel* (Dallas, TX, February 2000); *Revised Supplement* (August 2000).

[151]Total distribution and retail cost estimates for 5 ppm from *Costs/Impacts of Distributing Potential Ultra Low Sulfur Diesel* were adjusted based on update of downgrade costs for 15 ppm diesel provided in the *Revised Supplement*.

[152]Telephone conversation with Bob Cunningham of Turner Mason, March 21, 2001.

[153]U.S. Environmental Protection Agency, *Regulatory Impact Analysis: Heavy-Duty Engine and Vehicle Standards and Highway Diesel Fuel Sulfur Requirements*, EPA420-R-00-026 (Washington, DC, December 2000), Chapter V, p. V-124,

half would add tankage at $1 million per terminal and the other half would reconfigure at a cost of $100,000 per terminal. Bulk terminals were not assumed to make conversions for a second highway diesel fuel, because they were assumed to enter into exchange agreements with marketers during a phase-in period, rather than investing in tankage. In addition, all truck stops were assumed to be modified to provide two fuels during the phase-in, at a cost of $75,000 per truck stop.

The original TMC report provided investment estimates for distributing 5 ppm fuel to supply, 5, 20, and 100 percent of the highway diesel market. Investments at terminals and pipelines were estimated at $295 million when supplying 20 percent of the highway market and $325 million for 100 percent of the market. Retail investments were estimated at $755 million for both 20 percent and 100 percent of supply. Unlike the other two analyses, which reflected the cost of conversion to truck stops only, TMC assumed that some gasoline stations would invest to carry a second diesel fuel.[154]

Downgrade Analysis

The MSC study, *Alternative Markets for Highway Diesel Fuel Components*, conducted at the request of the EPA, provided an analysis of the potential for diverting sub-specification highway diesel to non-road or foreign markets.[155] The study compared 2007 projections for supply and demand of distillate products to assess the outlook for non-road distillate market growth and used relative relationships of highway diesel to non-road distillate prices to estimate the economic consequences of diverting to other products.

The analysis used historical industry-level distillate demands for each PADD from EIA's *Fuel Oil and Kerosene Sales* as a starting point.[156] These industry level demands were projected out to 2007, using national annual growth rates from the *Annual Energy Outlook 2000*.[157] PADD-level supply balances for distillate fuel were projected for 2007, starting with historical data from the *Petroleum Supply Annual 1999*[158] and applying growth rates from the *Annual Energy Outlook 2000*. Import and export levels were held constant in PADDs II and IV. In PADD V, inter-PADD transfers were held to historical levels and imports and exports were used as a balancing item. The study concluded that there was little potential to divert highway diesel to non-road distillate markets, and that the potential for severe market dislocations and / or price depression in the non-road markets was greatest in PADD IV and least in PADD I.

The price consequences of diverting product from the highway diesel market to non-road markets were assessed using estimated price relationships for these products derived from historical price data from various industry pricing agencies (e.g., Platts), combined with relevant transportation costs.[159] The price implications of downgrading 5 percent, 10 percent, and 15 percent of the current highway diesel supply were estimated for each PADD (Table 27). The price impact of diverting 5 percent of the highway diesel supply to other uses ranged from -3.0 cents per gallon in PADD I to -6.0 cents per gallon in PADD IV. The range widened to -3.5 to -20.0 cents per gallon in PADDs I and IV, respectively, for 10 percent of diverted product and to -3.5 to -22.0 cents per gallon for 15 percent of diverted product. The study concluded that except in PADD IV, a 5-percent diversion of product would have modest market impact. In addition, a 10- to 15-percent diversion would have a significant market impact in all areas except PADD I.

Table 27. Projected Relative Price Decrease by PADD and Percentage of Diverted Diesel
(1999 Cents per Gallon)

Diversion Level (Percent)	PADD I	PADD II	PADD III	PADD IV	PADD V
5	3.0	2.5	4.0	6.0	5.0
10	3.5	14.0	4.5	20.0	5.0
15	3.5	16.0	4.5	22.0	6.0

Source: Muse, Stancil & Co., *Alternative Markets for Highway Diesel Fuel Components* (September 2000), p. 4.

[154] Turner, Mason & Company, *Costs/Impacts of Distributing Potential Ultra Low Sulfur Diesel* (Dallas, TX, February 2000), p. 6.
[155] Muse, Stancil & Co., *Alternative Markets for Highway Diesel Fuel Components* (September 2000).
[156] Energy Information Administration, *Fuel Oil and Kerosene Sales*, DOE / EIA-0535 (Washington, DC, 1995-1998).
[157] Energy Information Administration, *Annual Energy Outlook 2000*, DOE / EIA-0383(2000) (Washinton, DC, December 1999).
[158] Energy Information Administration, *Petroleum Supply Annual 1999*, Volume 1, DOE / EIA-0340(99 / 1) (Washington, DC, June 2000).
[159] Muse, Stancil & Co., *Alternative Markets for Highway Diesel Fuel Components* (September 2000), pp. 19-32.