

The Transition to Ultra-Low-Sulfur Diesel Fuel: Effects on Prices and Supply

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.

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.

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.

The Transition to Ultra-Low-Sulfur Diesel Fuel: Effects on Prices and Supply

Table 1. Projected Fuel Expenditures for Heavy-Duty Diesel Vehicles, 2006-2020
(Billion 1999 Dollars)

Analysis Case	2007	2008	2009	2010	2011	2015	Total, 2007-2015
Total Fuel Expenditures							
Reference	39.45	40.46	41.46	42.19	42.98	45.96	385.63
Regulation	41.37	42.31	43.09	44.40	45.55	47.95	403.24
4% Efficiency Loss	41.37	42.31	43.09	44.58	45.92	48.44	406.21
Incremental Fuel Expenditures							
Regulation	1.92	1.85	1.63	2.21	2.57	1.99	17.62
4% Efficiency Loss	1.92	1.85	1.63	2.38	2.94	2.49	20.58

Source: National Energy Modeling System, runs DSUREF.D043001B, DSU7PPM.D043001A, and DSU7TRN.D043001A.

Table 2. Desulfurization Units Represented in the NEMS Petroleum Market Module

Unit	Capacity (Barrels per Day)	Feedstock	Capital Cost ^a (1999 Dollars per Barrel per Day)	Total Capital Cost per Unit ^a (Million 1999 Dollars)
HL1/HS2	25,000	All except coker gas oil and high-sulfur light cycle oil	1,331	33.3
HD1/HD2	10,000	All	1,849	18.5

^aOnly on-site costs for hydrotreaters are included in this table. See NEMS documentation for hydrogen and sulfur plant costs. Revamped unit costs are estimated to be 50 percent of new unit costs.

Source: Energy Information Administration, Office of Integrated Analysis and Forecasting.

Table 3. Range of Hydrotreater Units Represented in the Individual Refinery Analysis

Type	Throughput (Barrels per Day)	Straight-Run Feedstock (Percentage)	Capital Cost ^a (1999 Dollars per Daily Barrel)	Total Capital Cost per Unit ^a (Million 1999 Dollars)
New	50,000	100	995	49.8
New	10,000	68	1,807	18.1
Revamp	50,000	100	592	29.6
Revamp	10,000	68	1,210	12.1

^aIncludes only on-site costs.

Source: National Energy Technology Laboratory.

Table 4. Estimated Peak Engineering and Construction Labor Requirements for Gasoline and Diesel Desulfurization Projects
(Percent of Current Workforce)

Analysis Case	Front-End Design Workforce	Detailed Engineering Workforce	Construction Workforce
NPC Scenario A	42	32	—
NPC Scenario B	59	45	—
NPC Scenario C	62	56	—
NPC Scenario D	82	49	—
NPC Scenario E	82	49	—
EPA With No Temporary Compliance Option	46	27	10
EPA With Temporary Compliance Option	30	17	7

Sources: NPC: National Petroleum Council, *U.S. Petroleum Refining: Assuring the Adequacy and Affordability of Cleaner Fuels* (June 2000), Table 7-6. 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 IV, Table IV.B-5.

Table 5. EPA Estimates of Desulfurization Unit Startups, 2001-2010

Unit Type	2001-2003	2004	2005	2006	2007	2008	2009	2010
Gasoline Units								
After Promulgation of the Tier 2 Gasoline Sulfur Program . . .	10	37	6	26	9	9	—	—
After Promulgation of the ULSD Program	10	37	6	26	5	3	4	6
Diesel Units	—	—	—	63	—	—	—	58

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), Chapter IV, Table IV.B-2.

Table 6. Sample Results from the ULSD Cost Model

Refinery Characteristics and Costs	Case A	Case B	Case C	Case D	Case E	Case G	Case H	Case I	Case J	Case K	Case L
Hydrotreater Capacity Range^a	H	H	H	H	H	L	L	H	H	H	HR
Feed Sulfur Content Range^a	H	H	L	L	H	H	H	M	M	M	M
Percent Cracked Stock Range^a	H	H	H	H	L	H	H	H	M	M	M
Revamp or New Unit^d	N	R	N	R	R	N	R	N	N	R	R
Current Highway Diesel Production (Thousand Barrels per Day)	50.0	50.0	50.0	50.0	50.0	10.0	10.0	0.0	32.4	32.4	32.4
Hydrotreater Feeds (Thousand Barrels per Day)											
Straight-Run Distillate	34.0	34.0	34.0	34.0	50.0	6.8	6.8	33.0	25.3	25.3	18.4
Light Cycle Oil	8.0	8.0	8.0	8.0	0.0	1.6	1.6	4.0	2.1	2.1	0.0
Coker Distillate	8.0	8.0	8.0	8.0	0.0	1.6	1.6	23.0	5.1	5.1	2.3
Total	50.0	50.0	50.0	50.0	50.0	10.0	10.0	60.0	32.4	32.4	20.7
Hydrogen Consumption (Standard Cubic Feet per Barrel)	550	550	402	402	248	550	550	590	395	395	305
Feed Sulfur Content (Parts per Million)											
Straight-Run Distillate	9,000	9,000	1,100	1,100	9,000	9,000	9,000	6,000	6,000	6,000	6,000
Light Cycle Oil	25,000	25,000	3,800	3,800	0	25,000	25,000	15,000	13,000	13,000	13,000
Coker Distillate	22,000	22,000	5,700	5,700	0	22,000	22,000	14,000	14,000	14,000	14,000
ULSD Cost Components (1999 Dollars per Barrel)											
Hydrotreater											
Capacity Changes	0.73	0.55	0.70	0.55	0.36	1.21	0.74	0.72	0.81	0.55	0.49
Other	0.83	0.74	0.75	0.68	0.54	0.96	0.79	0.87	0.78	0.67	0.62
Hydrogen Production											
Capacity Changes	0.20	0.20	0.22	0.22	0.05	0.35	0.35	0.30	0.19	0.19	0.00
Other	0.52	0.53	0.55	0.54	0.12	0.56	0.57	0.88	0.40	0.41	0.13
Sulfur and Other	0.27	0.06	0.07	0.06	0.06	0.41	0.10	0.19	0.19	0.07	0.08
Total Cost (1999 Dollars per Barrel)	2.54	2.08	2.27	2.05	1.12	3.49	2.56	2.97	2.37	1.88	1.31
Total Cost (1999 Cents per Gallon)	6.0	5.0	5.4	4.9	2.7	8.3	6.1	7.1	5.6	4.5	3.1

^aH = refinery in the higher range; M = refinery in the middle range; L = refinery in the lower range.

^dN = new unit; R = revamped unit.

Note: Only refineries in Petroleum Administration for Defense Districts (PADDs) I-IV are included in the short-term analysis.

Source: Energy Information Administration, Office of Integrated Analysis and Forecasting.

Table 7. Estimate of Revamps and New Hydrotreaters for ULSD Production

Region	Number of Refineries			Percent Revamp	ULSD Production Volume (Thousand Barrels per Day)			Percent Revamp
	Revamp	New	Total		Revamp	New	Total	
PADD I	4	7	11	36	139	77	216	64
PADD II	14	13	27	52	442	158	599	74
PADD III	22	23	45	49	603	423	1,026	59
PADD IV	5	10	15	33	46	72	117	39
Total	45	53	98	46	1,229	729	1,957	63

PADD = Petroleum Administration for Defense District.

Note: Although 98 refineries are considered in this analysis, 87 are current producers of low-sulfur diesel. Not all of these refineries are expected to produce ULSD economically.

Source: Energy Information Administration, Office of Integrated Analysis and Forecasting.

Table 8. Supply and Demand Estimates in the Reference Case, 2006
(Thousand Barrels per Day)

	Demand	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Total Supply		1,763	1,823	1,952	2,143
Number of Refineries Producing ULSD.....		66	66	67	74
Differences Between Supply and Demand					
Small Refiner Option.....	2,533	-770	-709	-580	-389
Small Refiner and Temporary Compliance Options (Demand A).....	2,026	-264	-203	-74	117
Small Refiner and Temporary Compliance Options with Imports (Demand B)	1,946	-184	-123	6	197
Highway Use Only, Small Refiner and Temporary Compliance Options with Imports (Demand C)	1,662	100	161	290	481
Highway Use Only, Small Refiner and Temporary Compliance Options with Higher Imports (Demand D)	1,626	136	197	326	517

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

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

	Demand	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Total Supply		1,763	1,823	1,952	2,143
Number of Refineries Producing ULSD.....		66	66	67	74
Differences Between Supply and Demand					
Small Refiner Option.....	2,669	-906	-845	-716	-525
Small Refiner and Temporary Compliance Options	2,135	-372	-311	-183	8
Small Refiner and Temporary Compliance Options with Imports	2,055	-292	-231	-103	88
Highway Use Only, Small Refiner and Temporary Compliance Options with Imports	1,756	7	68	196	387
Highway Use Only, Small Refiner and Temporary Compliance Options with Higher Imports.....	1,720	43	104	232	423

Sources: Cost curve scenarios: Appendix D. Demand estimates: National Energy Modeling System, run HM2001.D101600A.

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

	Demand	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Total Supply		1,763	1,823	1,952	2,143
Number of Refineries Producing ULSD.....		66	66	67	74
Differences Between Supply and Demand					
Small Refiner Option.....	2,447	-685	-624	-495	-304
Small Refiner and Temporary Compliance Options	1,958	-195	-134	-6	186
Small Refiner and Temporary Compliance Options with Imports	1,878	-115	-54	74	266
Highway Use Only, Small Refiner and Temporary Compliance Options with Imports	1,604	159	220	349	540
Highway Use Only, Small Refiner and Temporary Compliance Options with Higher Imports.....	1,568	195	256	385	576

Sources: Cost curve scenarios: Appendix D. Demand estimates: National Energy Modeling System, run LM2001.D101600A.

Table 11. Supply and Demand Estimates in the Higher Capital Cost Sensitivity Case, 2006
(Thousand Barrels per Day)

	Demand	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Total Supply		1,721	1,782	1,897	2,118
Number of Refineries Producing ULSD		61	61	61	72
Differences Between Supply and Demand					
Small Refiner Option	2,533	-812	-751	-636	-415
Small Refiner and Temporary Compliance Options	2,026	-305	-244	-130	92
Small Refiner and Temporary Compliance Options with Imports	1,946	-225	-164	-50	172
Highway Use Only, Small Refiner and Temporary Compliance Options with Imports	1,662	58	119	234	455
Highway Use Only, Small Refiner and Temporary Compliance Options with Higher Imports	1,626	94	155	270	491

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

Table 12. Supply and Demand Estimates in the 10% Return on Investment Sensitivity Case, 2006
(Thousand Barrels per Day)

	Demand	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Total Supply		1,702	1,760	1,912	2,078
Number of Refineries Producing ULSD		61	61	63	71
Differences Between Supply and Demand					
Small Refiner Option	2,533	-831	-773	-621	-455
Small Refiner and Temporary Compliance Options	2,026	-325	-266	-114	51
Small Refiner and Temporary Compliance Options with Imports	1,946	-245	-186	-34	131
Highway Use Only, Small Refiner and Temporary Compliance Options with Imports	1,662	39	97	249	415
Highway Use Only, Small Refiner and Temporary Compliance Options with Higher Imports	1,626	75	133	285	451

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

Table 13. Comparison of EIA and EPA Assumptions

Parameter	EPA	EIA	Sensitivity Analyzed
Sulfur Content at Refinery	7 ppm	7 ppm	None
Capital Costs for New Diesel Hydrotreaters	\$1,240-\$1,680 per barrel per day ^a	\$1,331-\$1,849 per barrel per day ^b	\$1,655-\$2,493 per barrel per day ^b
Percent of Production from Revamped Equipment	80 percent	80 percent	66.7 percent
Total Percentage of Downgraded ULSD	4.4 percent total	4.4 percent total	10 percent total
Revenue Loss Associated with Downgrade	0.2 to 0.3 cents per gallon for all highway diesel	0.2 to 0.3 cents per gallon ULSD based on model results	0.7 cents per gallon ULSD based on model results for 10 percent downgrade
Capital Cost for Distributing Two Highway Diesels (Excluding Above Revenue Loss)	0.7 cents per gallon through 2010	0.7 cents per gallon through 2010	None
Lubricity Additives	0.2 cents per gallon	0.2 cents per gallon	None
Loss of Energy Content	0 percent	0.5 percent	1.8 percent
Yield Loss	1.3 percent yield loss (weight) at a cost of 0.1 to 0.2 cents per gallon	Variable model result (about 1.5 percent by volume)	Variable model result (about 1.5 percent by volume)
Loss of Fuel Efficiency	None	None	4 percent loss starting in 2010, phased out by 2015
Change in Non-Road Diesel Standards	None	None	None
Change in Other Highway Diesel Properties	None	None	None
Import Availability	Not studied	Same as reference	No imports
Return on Investment	7% before tax (estimated 5.2% after tax)	5.2% after tax	10% after tax

^aThe low end of the range is for straight-run distillate; the high end is for light cycle oil.

^bThe low end of the range is for units processing low-sulfur feed with incidental dearomatization; the high end is for higher sulfur feeds with greater aromatics improvement.

Sources: 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), and Energy Information Administration, Office of Integrated Analysis and Forecasting.

**Table 14. Variation from Reference Case
Projections of Cumulative Capital
Expenditures for Hydrogen and Distillate
Hydrotreating Units in EIA Sensitivity
Cases, 2007, 2010, and 2015**
(Billion 1999 Dollars)

Analysis Case	2007	2010	2015
Regulation	4.2	6.3	6.8
Higher Capital Cost	5.4	7.8	8.8
2/3 Revamp	4.6	6.9	7.6
10% Downgrade	4.2	6.7	7.3
4% Efficiency Loss	4.2	6.3	6.9
1.8% Energy Loss	4.2	6.3	6.9
Severe	5.9	9.3	10.5
No Imports	4.4	6.5	7.0

Source: National Energy Modeling System, runs DSUREF.D043001B, DSU7PPM.D043001A, DSU7HC.D043001A, DSU7INV.D043001A, DSU7DG10.D043001A, DSU7TRN.D043001A, DSU7BTU.D043001A, DSU7ALL.D050101A, and DSU7IMP0.D043001A.

Table 15. 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)^a								
Regulation	7.0	6.7	6.5	6.8	7.2	5.1	6.8	5.4
Higher Capital Cost	7.8	7.6	7.5	7.6	8.1	5.8	7.6	6.2
2/3 Revamp	7.3	6.9	6.9	7.1	7.6	5.4	7.1	5.7
10% Downgrade	7.4	7.1	6.8	7.2	9.1	5.7	7.2	6.4
4% Efficiency Loss	7.0	6.7	6.5	6.9	7.3	5.3	6.8	5.7
1.8% Energy Loss	7.3	7.0	6.6	6.9	7.4	5.2	7.0	5.5
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
Higher Capital Cost	10	9	8	7	82	83	9	82
2/3 Revamp	10	10	8	8	82	84	9	82
10% Downgrade	10	10	8	8	289	303	9	295
4% Efficiency Loss	10	10	8	19	103	108	12	107
1.8% Energy Loss	41	41	39	47	127	131	42	128
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
Higher Capital Cost	-36	-1	-1	0	0	0	-10	0
2/3 Revamp	-36	-1	-1	0	0	0	-10	0
10% Downgrade	-36	-1	-1	0	0	0	-10	0
4% Efficiency Loss	-36	-1	-1	0	0	0	-10	0
1.8% Energy Loss	-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

^aEnd-use prices include marginal refinery gate prices, distribution costs, and Federal and State taxes but exclude county and local taxes.
 Source: National Energy Modeling System, runs DSUREF.D043001B, DSU7PPM.D043001A, DSU7HC.D043001A, DSU7INV.D043001A, DSU7DG10.D043001A, DSU7TRN.D043001A, DSU7BTU.D043001A, DSU7ALL.D050101A, and DSU7IMP0.D043001A.

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

Analysis Case and Cost Component	Average Annual Cost, June 2006 - June 2010	Average Annual Cost After June 1, 2010
Regulation		
Total	1.2 ^a	0.4 ^a
Capital Costs	0.7	0.0
Operating Costs	0.2	0.2
Downgrade Revenue Loss	0.3	0.2
10% Downgrade		
Total	1.6	0.9
Capital Costs	0.7	0.0
Operating Costs	0.2	0.2
Downgrade Revenue Loss	0.7	0.7

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

Sources: **Capital Costs and Operating Costs:** 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/fm/ria-v.pdf. **Operating Costs** include operating, existing mix, transmix, and testing cost estimates. **Downgrade Revenue Loss:** Energy Information Administration, Office of Integrated Analysis and Forecasting, based on projected price differentials for ULSD versus 500 ppm diesel.

Table 17. Variations from Alternative Reference Case Projections in the 10% Return on Investment Case, 2007-2015

Year	Difference Between End-Use Prices of ULSD and 500 ppm Diesel (1999 Cents per Gallon) ^a
2007	7.9
2008	7.5
2009	7.6
2010	7.7
2011	8.0
2015	5.7
2007-2010 Average	7.7
2011-2015 Average	6.0

^aEnd-use prices include marginal refinery gate prices, distribution costs, and Federal and State taxes but exclude county and local taxes.

Source: NEMS runs DSUREF10.D043001A and DSU7PPM10.D043001A.

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

Analysis Case and Producing Region	2007-2010 Average	2011-2015 Average	Analysis Case and Producing Region	2007-2010 Average	2011-2015 Average
Regulation			4% Efficiency Loss ...		
U.S. Average	5.2	4.7	U.S. Average	5.2	5.1
PADD I	5.3	4.8	PADD I	5.3	5.3
PADDs II-IV	5.3	4.8	PADDs II-IV	5.3	5.2
PADD V	4.8	4.3	PADD V	4.8	4.5
Higher Capital Cost			1.8% Energy Loss		
U.S. Average	6.4	5.2	U.S. Average	5.5	4.8
PADD I	6.6	5.5	PADD I	5.6	5.3
PADDs II-IV	6.6	5.3	PADDs II-IV	5.6	4.9
PADD V	5.4	4.9	PADD V	5.2	4.4
2/3 Revamp			Severe		
U.S. Average	5.7	4.9	U.S. Average	7.0	6.4
PADD I	6.0	5.0	PADD I	7.4	6.8
PADDs II-IV	6.0	5.0	PADDs II-IV	7.4	6.3
PADD V	5.0	4.5	PADD V	5.9	5.2
10% Downgrade			No Imports		
U.S. Average	5.2	5.2	U.S. Average	6.6	6.1
PADD I	5.3	5.4	PADD I	6.9	6.8
PADDs II-IV	5.3	5.3	PADDs II-IV	6.9	6.3
PADD V	4.8	4.7	PADD V	4.8	4.3

Source: NEMS runs DSUREF.D043001B, DSU7PPM.D043001A, DSU7HC.D043001A, DSU7INV.D043001A, DSU7DG10.D043001A, DSU7TRN.D043001A, DSU7BTU.D043001A, DSU7ALL.D050101A, and DSU7IMP0.D043001A.

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/fm/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*			X		X			
CRA/BOB			X		X	X		X	Short-run	X
EnSys	X				X		X			
ANL		X*		2006-2015*			X	X		
EIA NEMS	X			2007-2015		X		X	Long-run	X
EIA Refinery by Refinery			X		X	X	X			X

*Uses Mathpro results.

†Uses EnSys results.

*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/fm/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.

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

^aNot 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.

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

^aExcludes 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.

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	

^aSmall refiners accounting for 5 percent of production are eligible to delay, but only 2 percent are assumed to delay.

^bCost adjusted for credit trading at cost to low cost refiners.

^cCorrespondence with Ray Ory of Baker and O'Brien. Also reflects assumption of 350 ppm non-road diesel.

^dAverage 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.

^eAverage based on marginal cost methodology.

^fMarginal 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).

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

^aNon-road 3500 ppm.

^bReflects 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.

^cThe higher end of the cost range reflects base technology while the lower end reflects more optimistic technology.

^dMarginal costs at 25 percent and 100 percent 10 ppm production with base technology and all new units.

^eU.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.

^fSmall 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.

^gAverage 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.

Table 25. Comparison of Key Hydrotreater 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	1,465-2,548 ^c	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

^aFeedstock composed of 65 percent straight-run distillate, 10 percent cracked stock, and 25 percent light cycle oil.

^bLow end of range is for straight-run distillate and high end is for light cycle oil.

^cCosts varied depending on unit size and feedstock.

^dLow 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/fm/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.

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: **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/fm/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.

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.