Industry Profile for Nonroad Diesel Tier 4 Rule

Final Report

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Section 1
Introduction and Overview of Results

This industry profile provides background information on the nonroad diesel industry and develops inputs for the economic impact analysis. The industry profile describes the nonroad diesel engine market, related equipment markets diesel fuel markets, and the affected downstream end-user markets. In each market, the producers and consumers are described along with product attributes and the effect of these attributes on production costs and demand.

As part of the market analysis, particular emphasis is placed on assessing suppliers' industrial organization and cost of production and demanders' price responsiveness and substitution possibilities. Baseline data for operationalizing the economic model are developed, including market prices, quantities, and other critical parameter estimates.

Figure 1-1 illustrates the links between the market segments of the diesel engine supply chain included in the industry profile. Although the proposed rule divides engines into seven classifications, technological and market similarities permit them to be grouped into three aggregate markets for the present purposes:

- small engines—less than 70 hp,
- medium engines—71 to 600 hp, and
- large engines—greater than 600 hp.

To match key data sources, nonroad diesel equipment manufacturers are grouped into seven equipment markets, differentiated by the type of customer or by equipment technology:

- agricultural,
- lawn and garden,
- construction,
- generators and welder sets,
- pumps and compressors,
- refrigeration and air conditioning, and
- general industrial.

Diesel equipment produced by these manufacturers are purchased by three aggregate economic sectors, referred to as application markets, each of which has its own set of product and service producers and consumers:

- agricultural,
- construction, and
- manufacturing.

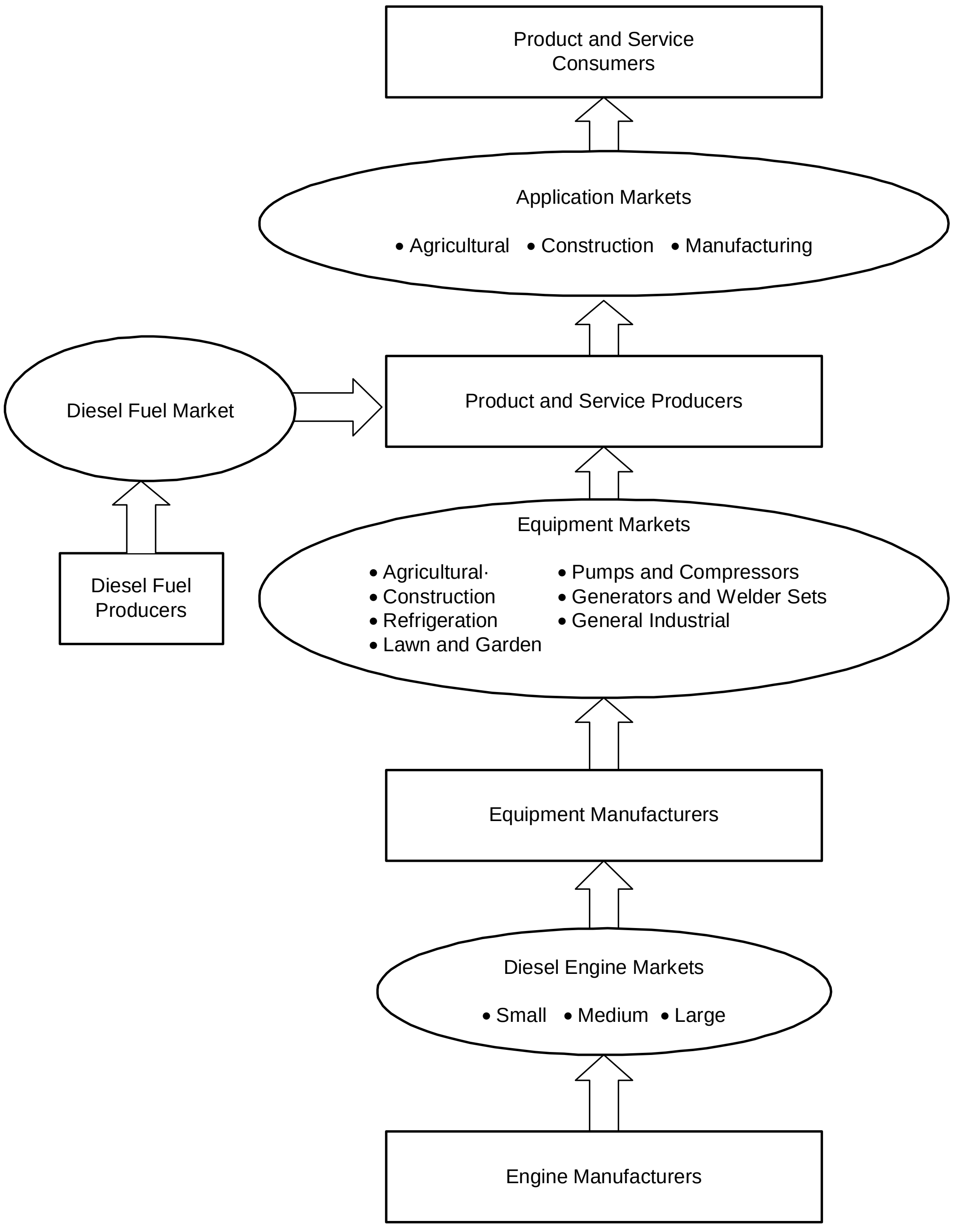

Figure 1-1. Diesel Engine Supply Chain

Finally, the producers in the three application markets using diesel equipment are also the consumers of nonroad diesel fuel. Four regional diesel fuel markets are discussed

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- PADD I&III: east and south,
- PADD II: midwest,
- PADD IV: mountain, and
- PADD V: west.

An example of the supply chain would be Cummins Engine Co. selling 100 hp engines to Deere & Company to be installed in tractors. These tractors are then sold to farmers who purchase fuel and use them to grow crops that are in turn sold to domestic and international consumers. In this way, some participants in the supply chain (such as equipment manufacturers) are both demanders (in the engines market) and suppliers (in the equipment market).

The following sections provide information on product characteristics, suppliers, demanders, and historical and future trends in the four groups of markets linking the diesel engine supply chain:

- nonroad diesel engines markets,
- equipment markets,
- application markets, and
- diesel fuel markets.

Section 2
Nonroad Diesel Engine Market

Diesel engines convert the chemical potential energy contained in a fuel into mechanical energy, which can then be used to do useful work, to provide locomotion, and/or to generate electricity. These machines are technologically similar to spark-driven engines powered by gasoline and other fuels, and they often compete in the same equipment and applications markets. Approximately 26 percent of the diesel engines produced in the United States are used in nonroad applications. These engines are inherently portable, in that they carry their power source with them, in fuel tanks that require refueling only occasionally. In contrast, electric motors, which are capable of performing many of the same tasks as diesel engines, must be connected to a power grid (or supplied with batteries that require frequent recharging). Diesel engines are, therefore, the power source of choice in remote applications, including agriculture, construction, mining, and freight transportation.

Diesel engines are built to be quite rugged, in part so that they can withstand the high temperatures and pressures inherent in sparkless combustion. As a result, they tend to be long lived, whether measured in operating hours or years of service. Diesel's efficiency in energy conversion leads to low operating costs, and simplicity of design allows high reliability and minimal maintenance costs. Each of these advantages becomes more important as the size of the engine increases, so diesel engines are dominant in all medium and large engine application markets.

The U.S. market for diesel engines is defined as all diesel engines incorporated into nonroad equipment sold in the United States. This includes engines made domestically, engines imported for use in U.S.-produced equipment, and those imported as a part of equipment made overseas. Excluded from our definition of the diesel engine market are U.S. exports. Because exported engines are designed to comply with foreign environmental regulations, they are not potential substitutes for engines used by U.S. equipment manufacturers. In addition, any costs incurred by exporters specifically to meet overseas regulations are not associated with this proposed regulation. As a result, domestic exports are considered a separate market and are not included in our analysis. This point will be discussed in greater detail in the methodology section.

In 2000, the U.S. produced approximately 300,000 nonroad diesel engines, of which 200,000 were consumed domestically and 100,000 were exported. An additional 550,000 engines were imported—primarily from Japan and western Europe. Domestic production dominates the supply of large engines, and foreign imports dominate the supply of smaller engines. About half of medium-sized engines are imported.

2.1 Diesel Engine Categories and Characteristics

Diesel engines in every size range find use in a diverse set of applications, making it very difficult to identify ‘typical’ applications. Nonetheless, diesel engines within a given hp range exhibit a high degree of technological similarity, regardless of the specific application for which they are intended. Therefore, throughout the industry profile, diesel engines are segmented into three hp size categories:

- Small: Engines in this category range from 1 hp to 70 hp and are characterized by low cost and high sales volumes. Small diesel engines are produced primarily for nonroad equipment applications and typically do not include electronics. They represent more than 50 percent of the diesel engines produced or imported each year in U.S. equipment manufacturing (see Table 2-1).

- Medium: Engines in this category range from 71 hp to 600 hp and are similar to most highway diesel products. This category has large sales volumes and high utilization (operating hours per year), and therefore is the source of the majority of nonroad emissions. The engines in this category represent between 40 and 50 percent of those produced or imported each year in the U.S. market.

- Large: This category covers all diesel engines larger than 600 hp. These engines are used primarily for nonroad equipment and have very low sales volumes. They represent about 1 percent of the engines produced or imported each year in the U.S. market. However, the size of these engines makes them a significant source of nonroad emissions.

Table 2-1. Nonroad Diesel Engine Market Share by Horsepower Category

Year	Small Engines Produced	Small Market Share	Medium Engines Produced	Medium Market Share	Large Engines Produced	Large Market Share
2000	426,863	56.6%	318,834	42.3%	8,751	1.2%
1999	482,048	59.5%	318,727	39.4%	8,723	1.1%
1998	340,098	52.3%	301,217	46.3%	9,085	1.4%
1997	299,078	52.0%	268,526	46.7%	7,767	1.3%
1996	262,495	52.1%	235,170	46.6%	6,501	1.3%

Note: Small = 1 to 70 hp; medium = 71 to 600 hp; large = over 600 hp.
Source: Power Systems Research (PSR). OELink™. <http://www.powersys.com/OELink.htm>.

Table 2-2 provides several engine characteristics for the different horsepower categories. The table uses the three engine size categories just described and shows the percentage of engines within each category that feature the several types of cooling systems, aspiration, fuel

Table 2-2. Engine Characteristics by Horsepower Category

	Small (1 to 70 hp)	**Medium (71 to 600 hp)**	**Large (> 600 hp)**
Cylinders	1–6	3–18	6–16
Weight (lbs)	23–413	115–2,650	1,214–16,715
Cooling			
Water-cooled	81.9 %	95.5%	100.0%
Air-cooled	13.2%	1.2%	0.0%
Oil-cooled	4.9%	3.3%	0.0%
Aspiration			
Natural	96.7%	27.9%	0.05%
Turbocharged	3.3%	72.1%	99.95%
Fuel Injection			
DI	49.0%	99.4%	100.0%
IDI	51.0%	0.6%	0.0%
Configuration			
Inline	92.8%	98.8%	5.7%
V-Block	0.1%	1.2%	94.3%
H-Block	7.1%	0.0%	0.0%

Source: Power Systems Research (PSR). OELink™. <http://www.powersys.com/OELink.htm>.

systems, and cylinder configurations. Also included is a range of the number of cylinders and range of weights for the engines in each horsepower size category.

2.2 The Supply Side

This section describes the supply side of the diesel engine industry, beginning with an overview of current engine design and production processes, including raw materials used. This overview is followed by a description of production costs. The supply-side section concludes with a description of potential control technologies for reducing sulfur and NO_x emissions.

2.2.1 Engine Design and Production Processes

Engine blocks are cast in a foundry, most often from gray iron. Depending on the size and complexity of the engine, the block may be formed by impression molding or two-piece sand-casting. Smaller, more complex parts, including cylinder heads, exhaust manifolds, and cylinder liners, are cast from ductile iron, typically using sand cores to allow formation of the complicated shapes. All castings must be cleaned and deburred prior to further processing; in addition, ductile iron parts will also usually be heat-treated to relieve stress and harden the alloys.

The cast block, cylinder head, and cylinder liners, along with crankshafts, gears, connecting rods, and other engine parts, are next machined to exact specifications in a machining center. Holes are drilled, parts reshaped, excess metal removed, and the metal surfaces polished in the machining area. The operation of the finished engine depends critically on the precision of the machining work at this stage.

The third major step in engine manufacturing is assembly. This area is usually physically isolated from the dirty upstream operations so that contaminants are not introduced into the completed engines, thus affecting their operation or shortening engine life. In a typical plant, subassemblies are first put together on separate lines or in separate bays, and then the subassemblies are brought together for final assembly. The completed engines are visually inspected and then evaluated on-line, on a test bench, or in a test cell to ensure their performance will meet expectations.

2.2.2 Costs of Production

Costs of production are divided into major input categories of labor, materials, and capital expenditures. Of these categories, purchased materials account for the largest share of total costs. Based on data from the most recent Economic Census, costs of materials represent about 60 percent of the value of shipments, followed by labor at about 10 percent, and capital expenditures at about 3 percent (see Table 2-3).

Table 2-4 lists the primary materials used in engine components. No breakdown of materials used in production is available from the 1997 Economic Census for the specific category of nonroad diesel engines (NAICS 3336183), but based on the broader engine equipment manufacturing category (NAICS 333618), materials costs are dominated by cast and formed metal. Iron and steel accounted for 15 percent of material costs and aluminum accounted for 7 percent; no other raw materials contributed more than 1 percent of material costs.

2.2.3 Diesel Engine Emission Control Technologies

Diesel emission control technologies are focused on modifying the engine to limit emissions leaving the combustion chamber (e.g., in cylinder and injection changes) and/or treating the exhaust gases to remove objectionable components (after treatment). In recent years, many advances have been made in particulate matter (PM) and NO_x emission control technologies. Consequently, exhaust emissions can be reduced to very low levels. These advanced technologies depend on the use of a low sulfur diesel fuel.

Table 2-3. Nonroad Engine Costs of Production in 1997

NAICS		Value of Shipments ($\$10^6$)	Labor ($\$10^6$)[a]	Cost of Materials ($\$10^6$)[a]	Capital Expenditures ($\$10^6$)[a]
333618	Other engine equipment manufacturing	$18,614.6	$2,326.1 (12.5%)	$10,473.4 (56.3%)	$632.0 (3.4%)
3336183	Nonroad diesel, semi-diesel, dual-fuel engines	$2,824.1	$261.0 (9.2%)	$1,734.4 (61.4%)	$80.6 (2.9%)
Materials Consumed by 333618		**Cost ($\$10^6$)**	**Share of Total Materials Cost (%)**		
Iron and steel		$1,562.7	14.9%		
Aluminum		$746.7	7.1%		

[a] Percentages in parentheses refer to percentage of the total value of shipments.

Source: U.S. Census Bureau. 1999. *1997 Economic Census—Manufacturing Industry Series.* EC97M-3241A, Tables 1, 6a, and 7.

Table 2-4. Engine Component Materials

Component	Primary Materials	Primary Process
Block	Iron Aluminum	Casting
Cylinder Head	Iron Aluminum	Casting Matching
Intake Manifold	Plastic Aluminum	Casting Matching
Connecting Rods	Powder Metal Steel	Molding Forging Matching
Pistons	Aluminum	Forging Matching
Carnshaft	Iron Steel Powder Metal	Molding Forging Matching
Valves	Steel Magnesium	Stamping Matching
Exhaust Systems	Stainless Steel Aluminum Iron	Extruding Stamping

Source: U.S. Environmental Protection Agency. 1995a. EPA Office of Compliance Sector Notebook Project: Profile of the Motor Vehicle Assembly Industry. EPA310-R-95-009. Washington, DC: U.S. Environmental Protection Agency.

Of the available advanced emission control devices that have been developed to control PM emissions, only the catalyzed diesel particulate filter (CDPF) is currently capable of providing the PM emissions control required by the proposed nonroad diesel regulation. The CDPF is a filter made of ceramic monolith or fiber-wound cartridge, positioned in the exhaust stream. It is designed to collect some of the particulate emissions while allowing exhaust gases to pass through. The collected PM is then burned off in a process referred to as "regeneration." CDPFs have the following characteristics:

- are highly effective at trapping all forms of diesel PM;
- reduce the temperature of regeneration by employing precious metals; and
- lower average back-pressure, which reduces potential fuel economy impacts, because they regenerate on a continuous basis.

Several ways exist for reducing NO_x emissions: selective catalytic reduction (SCR), lean-nitrous oxide catalysts, and plasma-assisted catalytic reduction. However, the most feasible and most widely applicable solution is the NO_x absorber catalyst—a three-way catalyst enhanced by adding storage materials to the catalyst that can absorb NO_x under such oxygen-rich conditions as are typical of diesel engines. This NO_x absorber catalyst must periodically release and reduce the emissions under fuel rich exhaust conditions. This can be accomplished either by an in-cylinder control system or an external control system.

2.3 Industry Organization of Diesel Engine Suppliers

To model the economic impact of the proposed regulation, it is important to characterize the overall diesel engine industry structure. Based on the PSR database, 61 parent companies were involved in manufacturing nonroad diesel engines in 2000. Of these 61 parent companies, 15 are considered U.S. companies.

2.3.1 Market Structure

The top 10 firms manufactured 80 percent of the engines used in nonroad diesel equipment produced in the United States in 2000. As shown in Figure 2-1, the top three companies account for 42.3 percent of units made in that year. The largest supplier by this measure is Kubota, a Japanese company that produces mostly small engines.

Figure 2-2 presents the market share by total hp sold. By this measure, which is highly correlated with the total value of engines produced, the top 10 firms account for 87 percent of the diesel engine market in 2000. Furthermore, the top three firms (Caterpillar, Deere, and Cummins), all U.S.-owned companies, comprise 60 percent of the total hp sold. Comparing Figures 2-1 and 2-2 shows that domestic firms dominate in sales of larger, more powerful engines, while foreign manufacturers make and sell into the U.S. market larger numbers of small engines.

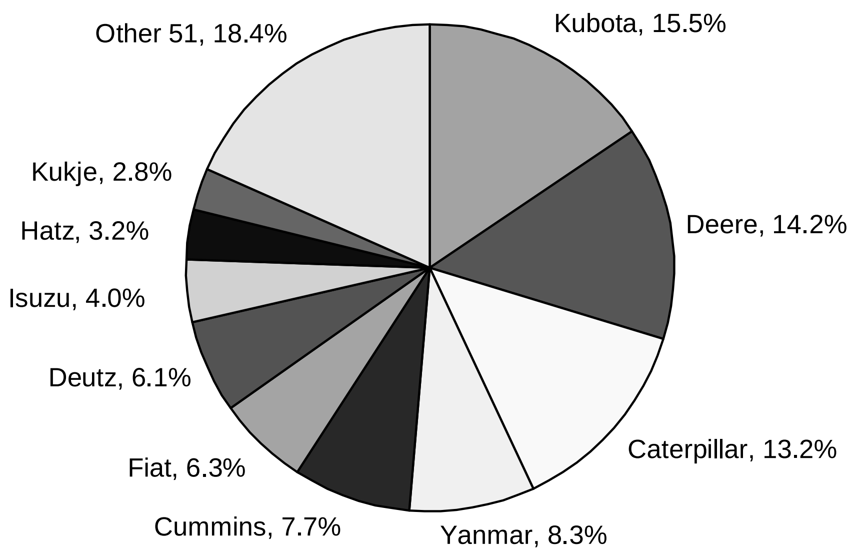

Figure 2-1. Top 10 Nonroad Engine Manufacturers by Units Sold (2000)

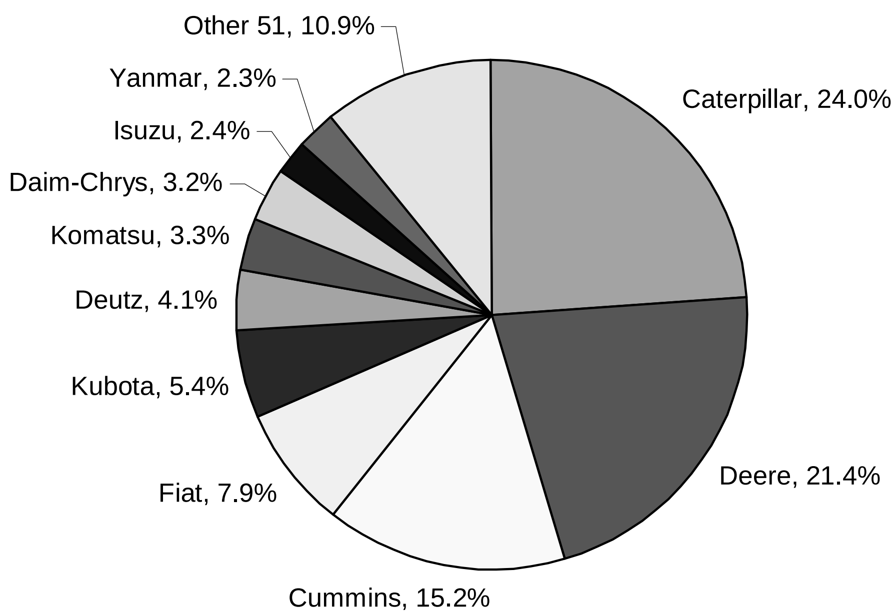

Figure 2-2. Top 10 Nonroad Engine Manufacturers by Total HP Sold (2000)
Source: Power Systems Research (PSR). OELink™. <http://www.powersys.com/OELink.htm>.

This separation of competition in the engine market is further illustrated in Table 2-5, which lists the three firms with the highest numbers of units sold within each engine hp category. In all three segments, the top four nonroad diesel engine manufacturers produced more than half of the engines used by U.S. diesel equipment manufacturers. Kubota produced the largest share of small engines in 2000, followed by Yanmar and Deutz, two other foreign-owned firms. In the case of medium engines, the top three producers are domestic companies, while the fourth, Case/New Holland, is controlled by Fiat. For large engines, the top four producers account for over 90 percent of the engines made. Caterpillar dominates the large engine market, with a market share of 56 percent, followed by Cummins, Komatsu, and the Detroit Diesel division of Daimler-Chrysler.

Table 2-5. Market Share of Top Four Nonroad Diesel Engine Manufacturers by Horsepower Category (2000)

Small	**% Share of Market (2000)**
Kubota Corp.	27.1%
Yanmar Diesel Corp.	14.7%
Deutz, AG	6.7%
Caterpillar Inc.	6.2%
Total	54.7%
Medium	
Deere & Company	28.7%
Caterpillar Inc.	21.4%
Cummins Engine Company, Inc.	17.9%
Fiat SPA (Case/New Holland)	12.4%
Total	80.4%
Large	
Caterpillar Inc.	56.2%
Cummins Engine Company, Inc.	14.2%
Komatsu Ltd.	12.8%
Daimler-Chrysler AG (Detroit Diesel, Mercedes)	11.6%
Total	94.8%

Note: Small = 0 to 70 hp; medium = 71 to 600 hp; large = over 600 hp.
Source: Power Systems Research (PSR). OELink™. <http://www.powersys.com/OELink.htm>.

Market concentration is measured in a variety of ways by antitrust regulators in the Department of Justice (DOJ) and Federal Trade Commission (FTC), including four-firm concentration ratios (CR4) and the Herfindahl-Hirschman Index (HHI). The CR4 is simply the combined market share of the four largest sellers in a given market, a very intuitive concentration measure. The HHI, which is currently used by the DOJ's Antitrust Division and the FTC, is constructed by summing up the squared market shares, in percentage terms, of all competitors in the market. According to these agencies' 1997 Horizontal Merger Guidelines, a market with an HHI under 1,000 is considered "unconcentrated," one with an HHI between 1,000 and 1,800 is "moderately concentrated," and one with a measure over 1,800 is "highly concentrated" (DOJ, 1997).

The merger guidelines assume that high concentration offers the potential for firms to influence prices through coordinated action on prices. Still it is possible for highly concentrated markets to behave competitively if firms are unwilling or unable to coordinate their actions or if potential entry can serve to limit price increases. For diesel engine markets, the following HHI values were calculated:

- Entire diesel engine market—all hp ranges 885 (unconcentrated)
- Small engines (1 to 70 hp) 1,202 (moderately concentrated)
- Medium engines (71 hp to 600 hp) 1,804 (highly concentrated)
- Large engines (over 600 hp) 3,662 (highly concentrated)

These data suggest that concentration in the small engine market is low enough that an assumption of competitive behavior is appropriate. In the medium range, the high level of concentration is mitigated by substantial competition from foreign manufacturers (see Table 2-6), who would be unlikely to coordinate actions with U.S. firms and may have strong incentives to compete vigorously on price. The over 600 hp engine category would seem to be more problematic, with Caterpillar selling more than half of the large diesel engines used in U.S.-produced nonroad equipment. Here too, however, competition from overseas firms may serve to keep the market competitive.

Table 2-6. Supply Side of Diesel Market (2000)

	Engines Produced by Integrated Manufacturers				
Engine Size Category	**Consumed Internally**	**Supplied to Market**	**Domestic Merchant Engines**	**Imported Engines**	**Total U.S. Market**
Small	—	—	3,468 (0.8%)	423,395 (99.2%)	426,863 (100.0%)
Medium	84,828 (26.6%)	77,536 (24.3%)	61 (0.0%)	156,409 (49.1%)	318,834 (100.0%)
Large	4,456 (50.9%)	1,811 (20.7%)	—	2,484 (28.4%)	8,751 (100.0%)
Total	89,284 (11.8%)	79,347 (10.5%)	3,529 (0.5%)	582,288 (77.2%)	754,448 (100.0%)

Note: Imported engines include units produced overseas by U.S. firms.
Source: Power Systems Research (PSR). OELink™. <http://www.powersys.com/OELink.htm>.

2.3.2 Firm Characteristics

In general, the nonroad diesel engine manufacturers are larger firms than the equipment manufacturers. As shown in Figures 2-3 and 2-4, the majority of these firms employ more than 1,000 employees and have total annual revenue of more than $1 billion. These figures include not only revenue from nonroad diesel engines but also revenue from other products the companies produce. Several companies, such as Fiat, Isuzu, and Daimler Chrysler, are involved in automobile production. This fact demonstrates a high degree of horizontal integration in the U.S. market. Other companies, such as Caterpillar and Deere, are vertically integrated and manufacture diesel equipment.

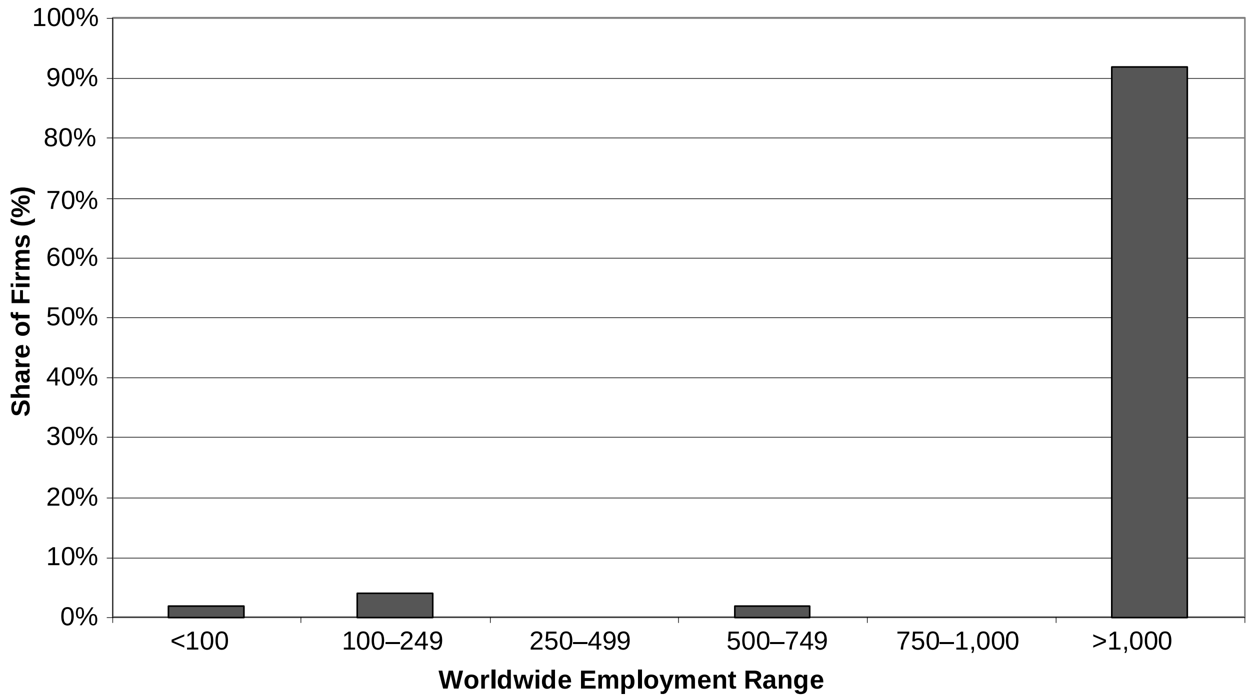

Figure 2-3. Employment Distribution of Engine Manufacturers in 2001 (N = 50)

Source: Business & Company Resource Center. ,http://www.gale.com/servlet/Item DetailServlet?region=9&imprint=000&titleCode=GAL49&type=1&id=115085>.
Hoover's Online. <http://www.hoovers.com/>.
Reference USA. <http://www.referenceusa.com/>.
Dun & Bradstreet. *Million Dollar Directory*. <http://www.dnb.com/dbproducts/ description/0,2867,2-223-1012-0-223-142-177-1,00.html>.

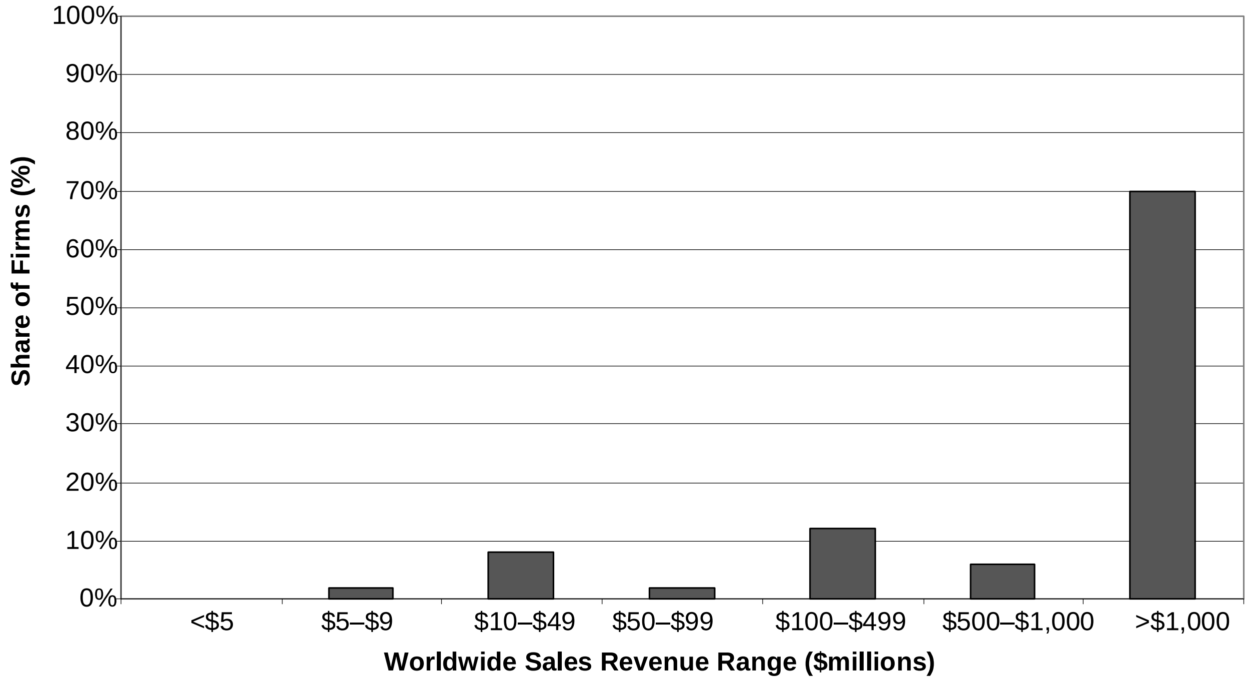

Figure 2-4. Sales Distribution of Engine Manufacturers in 2001 (N = 50)

Source: Business & Company Resource Center. <http://www.gale.com/servlet/ItemDetailServlet?region=9&imprint=000&titleCode=GAL49&type=1&id=115085>.

Hoover's Online. <http://www.hoovers.com/>.

ReferenceUSA. <http://www.referenceusa.com/>.

Dun & Bradstreet. *Million Dollar Directory*. <http://www.dnb.com/dbproducts/description/0,2867,2-223-1012-0-223-142-177-1,00.html>.

2.3.3 Integrated vs. Merchant Engine Manufacturers

The U.S. diesel engine industry can be divided into three producing sectors: integrated domestic manufacturers, merchant-market domestic manufacturers, and foreign-owned producers (importers). Integrated firms produce both diesel engines and diesel-powered equipment, while merchant-market firms sell all of the units they make to equipment-producing firms. Importers are foreign-owned firms that do not manufacture engines within the United States. About half of the engines produced by integrated manufacturers (referred to as captive production) are consumed internally. The other half of integrated manufacturers' engines are sold on the open market. Figure 2-5 illustrates the flow of engine production and consumption in the U.S. diesel engine market.

Table 2-6 provides the distribution of production broken out by small, medium, and large hp engines. Approximately 77.2 percent of the engines consumed in the United States are imported. Integrated manufacturers supply about 22.3 percent; 11.8 percent of their captive production is consumed internally and the remaining 10.5 percent is supplied to the U.S. engine market. Merchant producers supply the remaining 0.5 percent.

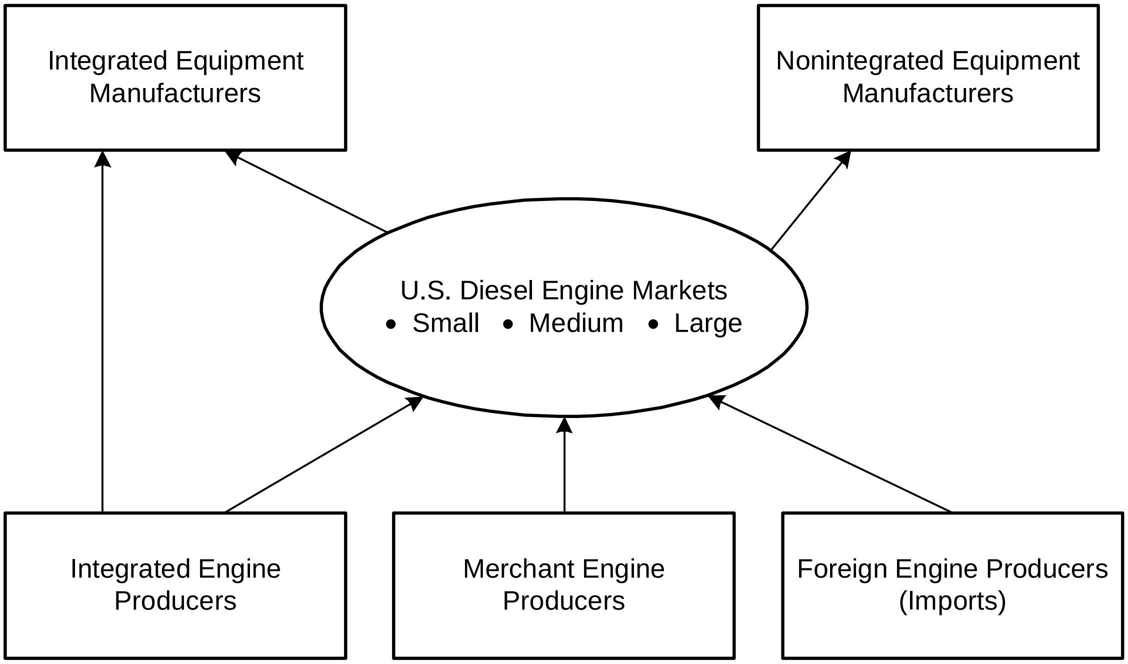

Figure 2-5. U.S. Diesel Engine Markets

Table 2-7 provides information on the integrated and merchant diesel engine producers. The engine production figures here exclude units produced outside the United States by domestic firms; for example, none of the integrated producers make small engines in the United States. Employment and sales are those of the parent companies. All of the companies have employment over 1,000 except for V&L Tools, with employment of 160.

2.4 The Demand Side

This section describes the aggregate demand for small, medium, and large nonroad diesel engines and considers the substitution possibilities available within each of these markets. The individual applications sectors' (e.g., agricultural, construction) demand characteristics are described as part of the equipment manufacturers market discussion in Section 2.2.

2.4.1 Derived Demand for Engines

Engines are an input into the production of diesel equipment, which in turn are inputs into a wide range of production processes that generate products and services. As a result, the demand for engines is linked through this supply chain to the final demand for products and services produced with diesel equipment. For example, if the demand for new highways is relatively price inelastic (i.e., increasing the cost of building roads does not affect construction plans), then increasing the cost of producing engines will have little or no impact on their demand. If, on the other hand, the demand for agricultural products is highly price elastic (due to foreign competition, for example), then increasing the cost of engines will have an impact on

Table 2-7. Domestic Integrated and Merchant Diesel Engine Producers in 2000

Name	Employment	Sales ($million)	Total Units	Small	Medium	Large
Integrated						
Deere & Company	45,100	$13,108	58,878	–	58,878	–
Cummins Engine Company, Inc.	24,900	$5,680	46,885	–	45,488	397
Fiat Spa	198,764	$54,661	28,861	–	28,861	–
Caterpillar Inc.	72,004	$20,450	28,094	–	23,246	4,848
Daimler Chrysler Ag	372,470	$136,256	3,846	–	2,843	1,003
Komatsu	32,002	$8,679	1,951	–	1,951	–
Volvo Ab	70,921	$17,614	54	–	54	–
General Motors Corp.	386,000	$177,260	41	–	26	15
Goodrich Corp.	19,200	$4,185	14	–	10	4
Dresser, Inc.	8,500	$1,546	7	–	7	–
Merchant						
V&L Tools	160	$15	3,529	3,468	61	–

Note: Production figures include only those units made at facilities within the United States.

Source: Power Systems Research (PSR). OELink™. <http://www.powersys.com/OELink.htm>.
Business & Company Resource Center. <http://www.gale.com/servlet/Item DetailServlet?region=9&imprint=000&titleCode=GAL49&type=1&id=115085>.
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ReferenceUSA. <http://www.referenceusa.com/>.
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their demand. The final product and service markets, as well as their price elasticities, are discussed in Section 2.3.

2.4.2 Substitution Possibilities in Consumption

A second factor that influences demand for engines is the potential for substitution throughout the supply chain. If a gasoline engine or electric motor can be used as a power source for a piece of equipment instead of a diesel engine, the demand response to regulation-induced prices change may be affected. Further along the supply chain, the ability to substitute a technologically dissimilar type of equipment in an application normally supported by diesel-powered equipment affects demand in the equipment markets. This section discusses substitution possibilities in the engine market, while equipment issues are addressed in later sections.

Diesel engines are inherently more efficient than gasoline engines, approximately 30 percent better at converting the fuel's energy into useful work. In addition to the operating cost and fuel refilling advantages that efficiency brings, the more complete energy conversion means that diesel engines reject less heat to the engine coolant. This allows smaller cooling fans and radiators to be specified for a given piece of equipment, decreasing purchase price and operating costs. The design robustness discussed earlier ensures that diesel-powered equipment is longer lived and simpler to maintain than similar units powered by gasoline engines.

For the medium and large engine categories in this profile, these efficiency and reliability considerations, along with requirements for high intensity and duration of usage, mean that diesel engines face little competition from gasoline engines. As long as the proposed rule generates changes that are small relative to the purchase price, one would not expect cost considerations to overwhelm diesel advantages in reliability, maintainability, and length of service that lead purchasers to pay a premium over prices of competing engine types. Furthermore, as the nonroad rule takes effect, similar emissions reductions will be required for gasoline-powered engines, which will add to their costs. As a result, makers and users of both types of engines will see increased costs. Finally, electric motors, which require connection to the power grid for extended operation, also do not offer the potential for substitution in any medium and large engine applications requiring portability or remote operation.

Low initial cost, along with ease of use and convenience of gasoline refueling, has made gasoline-powered engines dominant in equipment for household applications and for the smallest commercial equipment covered by this profile (specifically, those under 25hp). Several application categories, including lawn and garden care equipment, pumps and compressors, materials handling equipment, and generators and welders, show high percentages of gasoline power in the small engine segment. However, many cost and performance features of this small equipment are important to buyers besides purchase price. Those firms that produce diesel-powered equipment serve customers who willingly pay a price premium to obtain advantages in efficiency, reliability, and durability. A small increase in engine costs is highly unlikely to cause these firms to substitute away from diesel, forcing their consumers to give up these advantages. As a result, substitution does not appear to be a significant concern for any of the nonroad diesel engine size classes covered by this profile.

2.5 Historical Market Data and Trends

The historical market statistics are presented as a means to assess the future of nonroad diesel engine production. Information on production, consumption, and domestic prices is provided in this section, as well as a comparison of foreign production (imports) versus domestic production.

Domestic production of nonroad diesel engines has remained fairly constant since 1996. Domestic consumption data were not readily available, so apparent consumption was calculated from the known domestic production, import, and export data. As shown in Table 2-8, apparent consumption shows a slight upward trend. In 2000, exports represented about 37 percent of total domestic production, while imports have risen to about 77 percent of domestic consumption.

Table 2-8. Nonroad Diesel Engine Market Trends (1996–2000)

	Domestic Production					
Year	**Consumed Domestically**	**Exports**[a]	**Export Percentage of Domestic Production (%)**	**Apparent Domestic Consumption**	**Imports**	**Import Percentage of Domestic Consumption**
2000	172,160	100,802	36.9%	754,448	582,288	77.2%
1999	172,827	102,034	37.1%	809,498	636,671	78.7%
1998	181,356	120,740	40.0%	650,400	469,044	72.1%
1997	166,680	102,767	38.1%	575,371	408,691	71.0%
1996	143,855	73,544	33.8%	504,166	360,311	71.5%

Primary Source: Power Systems Research (PSR). OELink™. <http://www.powersys.com/OELink.htm>.

[a]U.S. Census Bureau. 2001. "Internal Combustion Engines." *2000 Current Industrial Reports*. MA333L(00)-1. Table 8, p. 2-17. Washington, DC: U.S. Census Bureau.

The percentage of nonroad diesel engines produced domestically within the United States versus abroad differs by hp category. As shown in Table 2-9, less than 1 percent of small engines were produced domestically between 1996 and 2000. The percentage of medium engines produced domestically in those years varies from 50 to 60 percent. Large engines account for about 70 percent of domestic production between 1996 and 2000. Tables 2-10 through 2-12 provide information on the application use for small, medium, and large engines.

Price trends for the diesel engine manufacturing industry are shown in Figure 2-6. No data are available for the diesel engine industry specifically, but data for the internal combustion engine manufacturing industry are provided as an indicator of trends for diesel engine products. Over the last decade, the internal combustion engine U.S. producer price index (PPI) has been consistently higher than both the total manufacturing and the total industrial U.S. PPI.

Table 2-9. Nonroad Diesel Engine Market Trends by Horsepower Category (1996–2000)

Year	Horsepower Category	Domestic Production Consumed in U.S.	Percent Total	Foreign Production	Percent Total
2000	Small	3,468	0.8%	423,395	99.2%
	Medium	162,425	50.9%	156,409	49.1%
	Large	6,267	71.6%	2,484	28.4%
1999	Small	3,672	0.8%	478,376	99.2%
	Medium	163,084	51.2%	155,643	48.8%
	Large	6,071	69.6%	2,652	30.4%
1998	Small	3,004	0.9%	337,094	99.1%
	Medium	172,208	57.2%	129,009	42.8%
	Large	6,144	67.6%	2,941	32.4%
1997	Small	2,708	0.9%	296,370	99.1%
	Medium	158,887	59.2%	109,639	40.8%
	Large	5,085	65.5%	2,682	34.5%
1996	Small	2,590	1.0%	259,905	99.0%
	Medium	136,894	58.2%	98,276	41.8%
	Large	4,371	67.2%	2,130	32.8%

Note: Small = 0 to 70; medium = 71 to 600 hp; large = over 600 hp.
Source: Power Systems Research (PSR). OELink™. <http://www.powersys.com/OELink.htm>.

Table 2-10. Number of Small Nonroad Diesel Engines Produced Domestically versus Abroad, Displayed by Industry Sector (2000)

Industry	Domestic	(%)	Foreign	(%)	Total	(%)
Agriculture	29	0.0%	82,922	19.5%	82,951	19.5%
Lawn and Garden	176	0.0%	34,878	8.2%	35,054	8.2%
Construction	242	0.1%	90,634	21.2%	90,876	21.3%
Pumps and Compressors	–	0.0%	17,882	4.2%	17,882	4.2%
Refrigeration and Air conditioning	–	0.0%	43,657	10.2%	43,657	10.2%
General Industrial	745	0.2%	18,514	4.3%	19,259	4.5%
Generators and Welder Sets	2,276	0.5%	134,908	31.6%	137,184	32.1%
Total	3,468	0.8%	423,395	99.2%	426,863	100.0%

Source: Power Systems Research (PSR). OELink™. <http://www.powersys.com/OELink.htm>.

Table 2-11. Number of Medium Nonroad Diesel Engines Produced Domestically versus Abroad Displayed by Industry Sector (2000)

Industry	Domestic	(%)	Foreign	(%)	Total	(%)
Agriculture	42,729	13.4%	46,958	14.7%	89,687	28.1%
Lawn and Garden	3,044	1.0%	1,958	0.6%	5,002	1.6%
Construction	60,316	18.9%	61,022	19.1%	121,338	38.0%
Pumps and Compressors	13,910	4.4%	3,630	1.1%	17,540	5.5%
Refrigeration and AC	–	0.0%	–	0.0%	–	0.0%
General Industrial	23,240	7.3%	18,364	5.8%	41,604	13.1%
Generators and Welder Sets	19,186	6.0%	24,477	7.7%	43,663	13.7%
Total	162,425	51.0%	156,409	49.0%	318,834	100.0%

Source: Power Systems Research (PSR). OELink™. <http://www.powersys.com/OELink.htm>.

Table 2-12. Number of Large Nonroad Diesel Engines Produced Domestically versus Abroad Displayed by Industry Sector (2000)

Industry	Domestic	(%)	Foreign	(%)	Total	(%)
Agriculture	13	0.1%	–	0.0%	13	0.1%
Lawn and Garden	–	0.0%	–	0.0%	–	0.0%
Construction	2,822	32.3%	1,421	16.2%	4,243	48.5%
Pumps and Compressors	91	1.0%	–	0.0%	91	1.0%
Refrigeration and Air conditioning	–	0.0%	–	0.0%	–	0.0%
General Industrial	445	5.1%	50	0.6%	495	5.7%
Generators and Welder Sets	2,896	33.1%	1,013	11.6%	3,909	44.7%
Total	6,267	71.6%	2,484	28.4%	8,751	100.0%

Source: Power Systems Research (PSR). OELink™. <http://www.powersys.com/OELink.htm>.

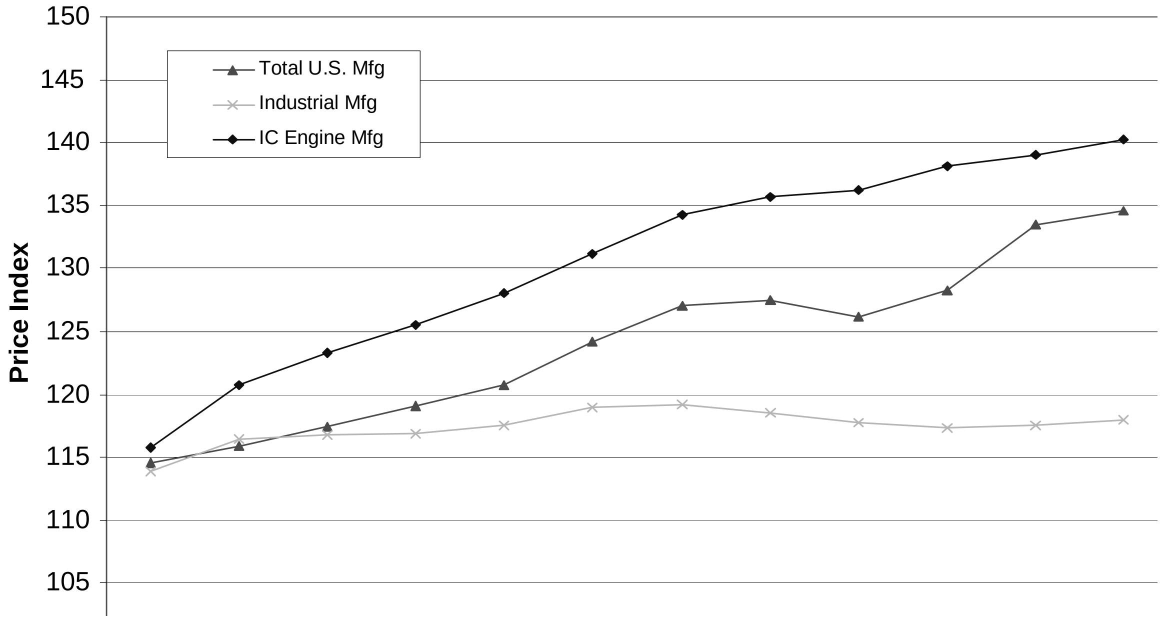

Figure 2-6. Comparison of Total U.S. Industrial and Internal Combustion Engine Manufacturing Producer Price Indexes

Source: U.S. Bureau of Labor Statistics. BLS LABSTAT Database: Producer Price Indices by SIC. <http://data.bls.gov/cgi-bin/surveymost?pc>.

Section 3
Equipment Manufacturers

This section describes general characteristics of the industries that produce nonroad equipment powered by diesel engines. Diesel equipment manufacturers are grouped into seven major equipment markets. In each of the market categories, supply- and demand-side considerations are presented, followed by an overview of the industrial organization and market trends.

With only a handful of exceptions, the demand for engines in these segments is unitary—there is a one-to-one correspondence between engines and equipment. Where subtitution with a different power-generation technology is possible, this potential will be treated in the demand-side analysis of the market. This section emphasizes the information that is needed to develop the multimarket economic model.

3.1 General Firm Characteristics

Unlike the nonroad diesel engine manufacturers, the majority (76 percent) of equipment manufacturers employ fewer than 1,000 employees. Furthermore, 86 percent of equipment manufacturers have sales revenues of less than $1 billion. It is important to remember that both of these counts include equipment manufacturers that also produce engines (see Figures 3-1 and 3-2).

3.2 Agricultural Equipment

The agricultural equipment manufacturing industry includes all machines and implements used in crop and livestock production. Activities supported by equipment in this category include preparing and plowing the soil; planting, cultivating, and harvesting crops; and spraying and irrigating fields.

Of the 770,000 nonroad engines incorporated into equipment in the year 2000, slightly more than 172,000 were used for agricultural machinery, as Table 3-1 details. Although gasoline or liquefied propane (LP) can be used to power most of the equipment in this category, diesel engines dominate in both the small- and medium-sized engine segments, because of their greater efficiency and lower operating costs. Based on 1997 data from the 1998 *Current Industrial Report* [MA333A(98)-1] and the 1997 Economic Census [EC97M-3331A], it is estimated that 87 percent of wheel tractors are equipped with a diesel engine, along with 63 percent of the agricultural equipment category.

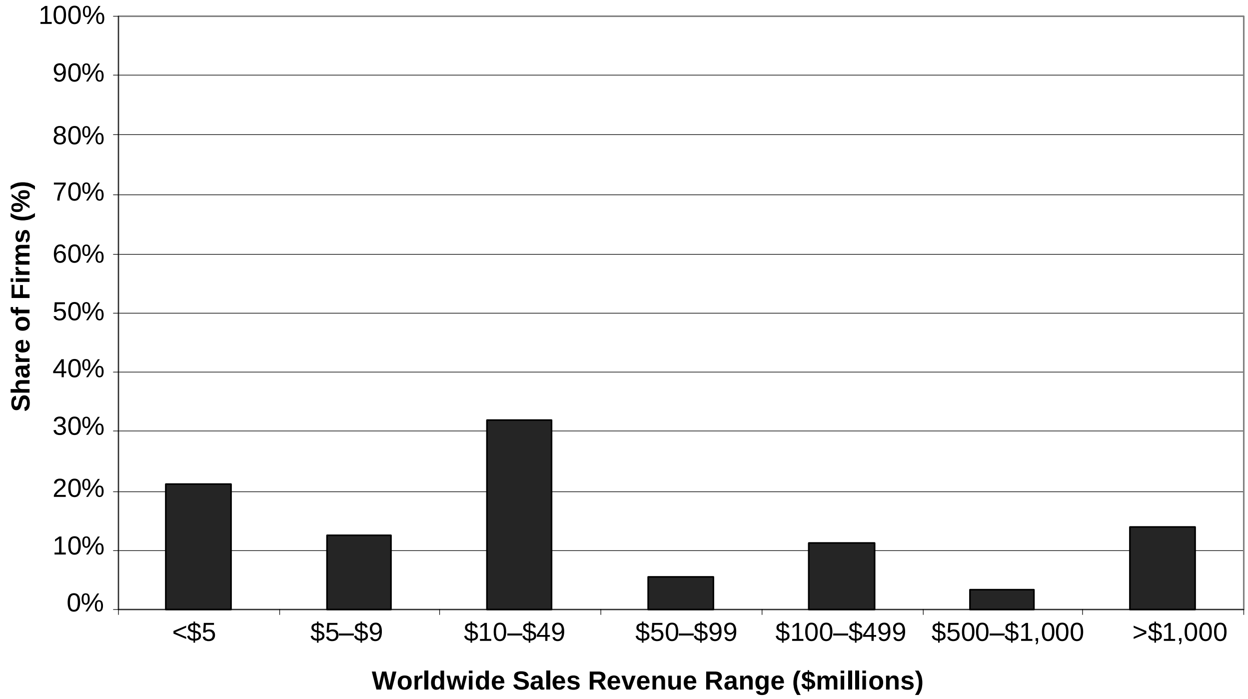

Figure 3-1. Sales Distribution of Equipment Manufacturers in 2001 (N = 487)

Source: Business & Company Resource Center. <http://www.gale.com/servlet/Item DetailServlet?region=9&imprint=000&titleCode=GAL49&type=1&id=115085>.
Hoover's Online. <http://www.hoovers.com/>.
ReferenceUSA. <http://www.referenceusa.com/>.
Dun & Bradstreet. *Million Dollar Directory*. <http://www.dnb.com/dbproducts/description/ 0,2867,2-223-1012-0-223-142-177-1,00.html>.

3.2.1 Agricultural Equipment Categories and Characteristics

Farm tractors dominate the agricultural equipment category, accounting for more than 98 percent of the small engine segment and three-quarters of the medium engine segment. Table 3-2 shows the number and percentages of each of the major types of equipment in the small- and medium-sized engine markets. The large engine classification is not important for farm equipment, with only 13 units sold in the year 2000.

The medium-sized tractors are the workhorse of agriculture, pulling implements that perform the bulk of plowing, planting, fertilizing, cultivating, and hauling chores. Smaller tractors are used for utility work and on smaller farms. Harvesting equipment includes combines for grain, windrowers and balers for hay, cotton pickers, corn pickers, and a variety of specialized equipment for other crops. Self-propelled sprayers are used for applying fertilizer, herbicides, and insecticides, while irrigation sets pump and spread ground water onto the growing crops.

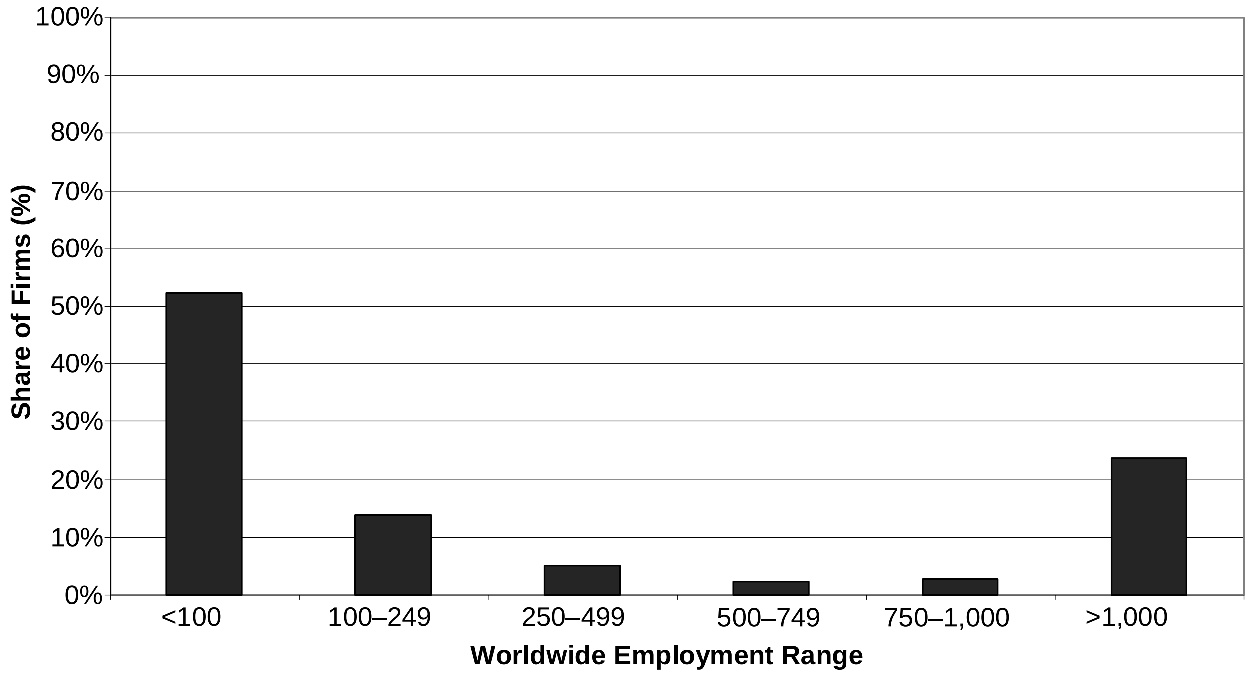

Figure 3-2. Employment Distribution of Equipment Manufacturers in 2001 (N = 494)

Source: Business & Company Resource Center. <http://www.gale.com/servlet/ItemDetailServlet?region=9&imprint=000&titleCode=GAL49&type=1&id=115085>.

Hoover's Online. <http://www.hoovers.com/>.

ReferenceUSA. <http://www.referenceusa.com/>.

Dun & Bradstreet. *Million Dollar Directory*. <http://www.dnb.com/dbproducts/description/0,2867,2-223-1012-0-223-142-177-1,00.html>.

These machines have several characteristics in common. They are operated in areas far from buildings and supporting infrastructure, so they must be self-sufficient for extended periods of time. The engine provides power for movement, performing work, and driving attachments and, in most cases, for generating electrical power to operate accessories. Tractors and harvesting machines have cabs or seats for operators, while irrigation sets and sprayers are normally unattended.

3.2.2 Supply-Side Considerations

Costs of Production. Key materials used in the production of agricultural machinery include plate and sheet steel, iron and steel castings, pneumatic and hydraulic systems, rubber tires, and diesel engines, each accounting for between 5 and 12 percent of delivered cost. Internally produced or purchased diesel engines comprised about 7.8 percent of the cost share of total agricultural equipment shipped in 2000. This cost share is projected to decrease over the next decade to 6.3 percent (see Table 3-3).

Table 3-1. Market Segments by Horsepower Categories—Units Sold (2000)

Application	Horsepower			Total
	Small	Medium	Large	
Agricultural Equipment	82,951	89,687	13	172,651
Lawn and Garden	35,054	5,002	0	40,056
Construction	90,876	121,338	4,243	216,547
Pumps and Compressors	17,882	17,540	91	35,513
Generator and Welder Sets	137,184	43,663	3,909	184,756
Refrigeration and Air	43,657	0	0	43,657
General Industrial	19,259	41,604	495	61,358
Total	426,863	318,834	8,751	754,448

Note: Small = 1 to 70 hp; medium = 71 to 600 hp; large = over 600 hp.
Source: Power Systems Research (PSR). OELink™. <http://www.powersys.com/OELink.htm>.

Substitution Possibilities. Substitution would be a concern if users of diesel-powered equipment might respond to price increases by choosing a different type of equipment or an alternate technique for their application. In the case of agricultural equipment, this is highly unlikely to occur. Each type of equipment in this category is highly specialized to the tasks for which it is designed and has effectively replaced competing technologies. As an example, self-propelled combines made pull-behind harvesters obsolete many years ago, because of their substantial advantages in productivity and cost-effectiveness. Likewise, draft horses are not economically feasible substitutes for diesel tractors' major functions of propelling and providing power to plowing, soil conditioning, and cultivating equipment.

3.2.3 Demand-Side Considerations

Demand for agricultural equipment is driven by farm operators' supply decisions, optimal replacement considerations, and improvements in performance and comfort features of new machines. Farmers will choose to cultivate additional acreage from year to year if population and export potential outpace yield increases, if government programs offer better support prices, or if improvements in their cost structure give them a competitive advantage. Over the past 20 to 30 years, overall acreage cultivated has not changed significantly in the United States, as yield and food demand have increased in step. Short-run changes in supply due to farm program influences have tended to balance out over a longer time horizon.

Tractors, combines, and other powered agricultural equipment are long-lived capital assets, so demand for new units is strongly tempered by competition from the large stock of existing units. For example, the 1997 Census of Agriculture reported almost 4 million wheel tractors in use on farms, 3.5 million of which were purchased prior to 1993. The fixed asset

Table 3-2. Diesel-Powered Agricultural Equipment by Horsepower Category (2000)

hp Category	Application	Nonroad Diesel Engines Purchased	Percentage Share of Total
Small	Agricultural Tractors	81,585	98.4%
	Two-Wheel Tractors	21	0.0%
	Other Agricultural Equipment	221	0.3%
	Sprayers	70	0.1%
	Irrigation Sets	953	1.1%
	Total	82,951	
Medium	Agricultural Tractors	69,476	77.5%
	Balers	114	0.1%
	Combines	6,668	7.4%
	Other Agricultural Equipment	1,702	1.9%
	Sprayers	4,212	4.7%
	Windrowers	2,356	2.6%
	Irrigation Sets	5,159	5.8%
	Total	89,687	
Large	Irrigation Sets	13	100.0%
	Total	13	

Note: Small = 0 to 70 hp; medium = 71 to 600 hp; large = over 600 hp.
Source: Power Systems Research (PSR). OELink™. <http://www.powersys.com/OELink.htm>.

tables produced annually by the Bureau of Economic Analysis (BEA) for their National Income and Product Accounts (NIPA) showed a current-cost average age of 5.7 years for farm tractors in 2000, indicating an economic life in excess of 11 years. Vintage capital theory suggests that these units are replaced when their operating and maintenance costs rise above the annual cost of new units, or when technological improvement reduces the total cost of the new machines (Salter, 1966). An increase in equipment cost and fuel expense could delay the replacement decision for any of the long-lived assets covered by this profile, if these increases outweighed higher operating and maintenance costs from retaining the other equipment.

3.2.4 Industry Organization

Understanding the structure of the industry is important in estimating the incidence of costs and how these increases will be passed from engine maker to equipment producer to farm operator and on to consumers. According to the 1997 Economic Census [EC97M31S-CR], farm machinery and equipment manufacturing is a moderately concentrated industry, with a four-firm concentration ratio (CR4) of 53.4 percent and an HHI of 1,707.

Table 3-3. Cost Share of Diesel Engines per Equipment Produced in Each Market Sector in 2000 and Projections for 2005 and 2010

	2000	2005	2010
Equipment Shipments (10^6)			
Agricultural	$16,400	$20,600	$25,900
Industrial/Other	$310,600	$389,000	$490,900
Construction and Mining	$24,300	$29,100	$34,900
Diesel Engine Demand (10^6)			
Agricultural	$1,275	$1,375	$1,630
Industrial/Other	$966	$1,320	$1,734
Construction and Mining	$2,023	$2,495	$3,151
Cost Share of Engines Produced			
Agricultural	7.8%	6.7%	6.3%
Industrial/Other	0.3%	0.3%	0.4%
Construction and Mining	8.3%	8.6%	9.0%

Source: The Freedonia Group (2001). Diesel Engines and Parts in the United States to 2005—Industry Structure. Freedonia Group. <http://www.freedoniagroup.com/scripts/cgiip.exe/WService=freedonia/abstract.html?ARTNUM=1153>.

Table 3-4 shows the leading producers of agricultural diesel equipment in the two engine size segments. Deere & Company is the largest producer in both segments, followed by the Case New Holland subsidiary of Fiat. In the small range, Kubota is the third-largest manufacturer; the three largest firms account for almost 80 percent of total production. In the medium-sized segment, the third-largest producer is Agco, a successor corporation to several large, integrated tractor firms, including Massey-Ferguson, Oliver, Minneapolis-Moline, and White. The top three producers in the medium-sized equipment category comprise more than 85 percent of this segment.

3.2.5 Markets and Trends

As Table 3-5 shows, the entire industry grew 10 percent from 1997 to 2000, with the important tractor segment logging a 13 percent increase. Irrigation sets sales grew at an even faster pace, adding 22 percent over the 4 years covered. The combines, balers, sprayers, and other equipment categories all declined over the period.

3.3 Lawn and Garden Equipment

The lawn and garden equipment industry manufactures commercial and consumer mowers; garden tractors; turf care products, such as mulchers, chippers, aerators, tillers,

Table 3-4. Diesel-Powered Agricultural Equipment Manufacturers by Horsepower Category (2000)

hp Category	Parent Company Name	Nonroad Diesel Engines Purchased	Percentage Share of Total
Small	Deere & Company	33,871	40.8%
	Fiat SPA	17,793	21.5%
	Kubota Corporation	14,216	17.1%
	AGCO Corporation	6,008	7.2%
	Ishikawajima-Harima Heavy Industries Co Ltd.	2,292	2.8%
	Sum of Top 5	74,180	89.4%
	Total	82,951	
Medium	Deere & Company	43,815	52.8%
	Fiat SPA	18,944	22.8%
	AGCO Corporation	9,154	11.0%
	Landini Spa	6,143	7.4%
	Caterpillar Inc.	1,844	2.2%
	Sum of Top 5	79,900	96.3%
	Total	89,687	

Note: Small = 0 to 70 hp; medium = 71 to 600 hp; large = over 600 hp.
Source: Power Systems Research (PSR). OELink™. <http://www.powersys.com/OELink.htm>.

shredders, and rakes; and miscellaneous equipment, such as leaf blowers and sweepers. Almost all pieces of equipment designed for households operate on gasoline, including push and riding mowers, lawn tractors, trimmers, and tillers. Diesel-powered machines are more commonly used on golf courses, municipal and amusement parks, cemeteries, and other commercial property.

3.3.1 Lawn and Garden Categories and Characteristics

Commercial mowers are the most important category in the lawn and garden industry, as can be seen by the figures in Table 3-6. Mowers account for almost three-quarters of production in the important small engine segment and comprise 10 percent of the over 70 hp class. Lawn and garden tractors are a significant fraction of the 70 hp and under segment as well, making up 21 percent of the total. Turf care equipment dominates the medium-sized segment, with 4,486 units manufactured in the year 2000, accounting for almost 90 percent of equipment produced. There are no lawn and garden machines using the largest class of engines.

Table 3-5. Production Trends for Diesel-Powered Agricultural Equipment

Category	1997	1998	1999	2000	Percentage Change 1997–2000
Ag Tractors	133,727	139,749	143,049	151,061	13%
Combines	8,705	9,700	6,605	6,668	–23%
Irrigation Sets	5,031	5,414	5,853	6,125	22%
Sprayers	4,401	4,514	4,235	4,282	–3%
Windrowers	2,354	2,512	2,229	2,356	0%
Other Ag Equip	2,153	2,253	2,049	1,923	–11%
Balers	230	254	211	215	–7%
2-Wheel Tractors	20	21	21	21	5%
Totals	156,621	164,417	164,252	172,651	10%

Source: Power Systems Research (PSR). OELink™. <http://www.powersys.com/OELink.htm>.

Table 3-6. Diesel-Powered Lawn and Garden Equipment by Horsepower Category (2000)

hp Category	Application	Nonroad Diesel Engines Purchased	Percentage Share of Total
Small	Commercial Turf	1,894	5.4%
	Leaf Blowers/Vacs	6	0.0%
	Lawn and Garden Tractors	7,366	21.0%
	Commercial Mowers	25,788	73.6%
	Total	35,054	
Medium	Commercial Turf	4,486	89.7%
	Commercial Mowers	516	10.3%
	Total	5,002	

Note: Small = 0 to 70 hp; medium = 71 to 600 hp; large = over 600 hp.
Source: Power Systems Research (PSR) OELink™. <http://www.powersys.com/OELink.htm>.

The characteristics of this class of machines are similar to the agricultural equipment discussed above but on a smaller scale. The engines are less likely to power separate implements, and fewer accessories are provided. An operator is required for all equipment, but enclosed cabs are less common.

3.3.2 Supply-Side Considerations

Costs of Production. Engines are a larger fraction of total delivered cost for lawn and garden equipment than for agricultural machines. According to the 1997 Economic Census [EC97M-3331B], which combines commercial and home equipment, the cost of purchased gasoline and diesel engines totaled $1.25 billion, making up 26.7 percent of the material cost, or 17 percent of the total value of shipments. Strip and sheet steel account for 12.5 percent of materials cost, with fabricated plastic products adding 5 percent and tires an additional 4 percent. Several other materials contribute lesser fractions of material cost.

Substitution Possibilities. Equipment in this application area is selected based on its ability to perform mowing, hauling, chipping, and similar tasks quickly, efficiently, and at a minimum cost. Diesel engine-powered equipment meets these criteria, and few if any alternatives exist in the market today. Manually operated tools cannot be substituted efficiently, because their capacity and speed limitations overwhelm any savings in purchase price and fuel cost.

3.3.3 Demand-Side Considerations

Although no industry-specific analyses are available, it is expected that demand for the services provided by lawn and garden equipment will increase in proportion to the level of general economic activity. Municipalities and recreational firms need to care for their grass, trees, and outside pedestrian areas regardless of the state of the economy.

3.3.4 Industry Organization

Because of the presence of a few dominant firms, the lawn and garden equipment industry (including commercial and home equipment) is one of the more concentrated in the nonroad equipment sector. Based on census data, the industry is moderately concentrated, with an HHI for the overall industry of 1,172, and a CR4 of 64.4 percent. Although census data are not available for the commercial sector alone, the PSR database indicated that home equipment applications are somewhat less concentrated than the commercial applications.

Table 3-7 details the leading manufacturers in each of the engine size segments. Deere produced 9,922 small units (70 hp or under), almost 30 percent of the total. This accounts for one-fifth of all lawn and garden equipment manufactured in 2000. Other major producers include Kubota, Textron, and Toro. In the medium engine category, the three leading firms produced around 20 percent of the total units; Bandit is the leading firm.

3.3.5 Markets and Trends

In contrast to the farm machinery industry, the three major categories in lawn and garden equipment grew strongly over the past 4 years. Table 3-8 shows that tractors made the most

Table 3-7. Top Five Diesel-Powered Lawn and Garden Equipment Manufacturers by Horsepower Category (2000)

hp Category	Parent Company Name	Nonroad Diesel Engines Purchased	Percentage Share of Total
Small	Deere & Company	9,922	28.3%
	Kubota Corporation	6,336	18.1%
	Textron Inc.	6,048	17.3%
	Toro Company	5,708	16.3%
	Grasshopper Company	1,406	4.0%
	Sum of Top Five	29,420	83.9%
	Total	35,054	
Medium	Bandit Industries, Inc.	1,112	22.2%
	Vermeer Manufacturing Company	1,078	21.6%
	Morbark Inc.	973	19.5%
	Wood Chuck Chipper Corp.	609	12.2%
	Textron Inc.	208	4.2%
	Sum of Top Five	3,980	79.6%
	Total	5,002	

Note: Small = 0 to 70 hp; medium = 71 to 600 hp; large = over 600 hp.
Source: Power Systems Research (PSR). OELink™. <http://www.powersys.com/OELink.htm>.

progress, increasing from 1,922 to 7,366 over the period 1997 to 2000. Mowers and turf care equipment grew at a more moderate pace but still fast enough to lead to a 53 percent overall increase in production volumes. The two smallest categories showed decreases, but their impact on the industry is minimal.

3.4 Construction Equipment

The construction equipment industry includes all machines, vehicles, and apparatus used to build highways and roads, commercial and residential buildings, factories, bridges, dams, and an impressive variety of other indoor and outdoor structures. Activities supported by equipment in this category include excavation and earth moving, materials handling and hauling, compacting, rolling, and paving. The machines in this sector contain engines for providing power for locomotion, doing work, and operating accessories.

Table 3-8. Production Trends for Diesel-Powered Lawn and Garden Equipment

	1997	1998	1999	2000	Percentage Change 1997–2000
Commercial Mowers	19,043	21,210	25,668	26,304	38%
Commercial Turf	5,112	5,603	6,024	6,380	25%
Lawn/Garden Tractors	1,922	1,220	5,024	7,366	283%
Leaf Blowers/Vacs	11	6	7	6	–45%
Other Lawn and Garden	19	0	0	0	–100%
Totals	26,107	28,039	36,723	40,056	53%

Source: Power Systems Research (PSR). OELink™. <http://www.powersys.com/OELink.htm>.

Of the approximately 750,000 nonroad engines produced in the year 2000, just under 216,000 were incorporated into construction equipment, making this the largest industry served. Table 3-1 shows the number of units accounted for by the construction industry, spanning all three hp classes. As in the agricultural industries, alternative fuels can potentially be used to provide power for most of the equipment in this category, and for a few types of equipment, electric power is a viable alternative. Nonetheless, diesel engines dominate in all three engine segments because of their high efficiency and lower operating costs.

3.4.1 Construction Equipment Categories and Characteristics

Table 3-9 details the large number of categories within the construction industry and lists the number of machines produced in 2000 in each size class. Skid-steer loaders lead the small and medium size categories, and account for 30 percent of the overall industry total. Medium-sized loader/backhoes, excavators, and wheel loader/dozers each account for 10 to 20 percent of that segment’s total; light and signal boards are also an important part of the small engine category. Other important machines in this segment are excavators, rollers, trenchers, and aerial lifts.

The construction equipment industry includes 4,243 pieces of equipment powered by engines over 600 hp, accounting for almost half of the large-engine segment overall. More than one-third of these powerful machines are nonroad trucks, which are used in mining and construction activities. Another quarter of the category (1,148 units) is made up of crawlers, while loader/dozers and scrapers constitute a significant fraction as well. Although the absolute numbers of machines are not huge, their large size makes them significant contributors to the total emissions of nonroad diesels.

Table 3-9. Diesel-Powered Construction Equipment by Horsepower Category (2000)

hp Category	Application	Nonroad Diesel Engines Purchased	Percentage Share of Total
Small	S/S Loaders	43,198	47.5%
	Tractor/Loader/Backhoes	2,586	2.8%
	Bore/Drill Rigs	2,040	2.2%
	Finishing Equipment	500	0.6%
	Forest Equipment	11	0.0%
	Mixers	1,146	1.3%
	Other Construction	182	0.2%
	Pavers	1,640	1.8%
	Plate Compactors	2845	3.1%
	Rollers	6,192	6.8%
	Tampers/Rammers	559	0.6%
	Trenchers	5,611	6.2%
	Wheel Loaders/Dozers	988	1.1%
	Aerial Lifts	6,705	7.4%
	Cranes	111	0.1%
	LT Plants/Signal BDS	9,902	10.9%
	Excavators	6,618	7.3%
	Total	90,876	
Medium	S/S Loaders	21,072	17.4%
	Tractor/Loader/Backhoes	22,778	18.8%
	Bore/Drill Rigs	3,723	3.1%
	Crawlers	10,204	8.4%
	Finishing Equipment	88	0.1%
	Forest Equipment	3,782	3.1%
	Graders	4,920	4.1%
	Mixers	247	0.2%
	Off-Hwy Trucks	1,241	1.0%
	Other Construction	1,141	0.9%
	Pavers	2,307	1.9%

(continued)

Table 3-9. Diesel-Powered Construction Equipment by Horsepower Category (2000) (continued)

hp Category	Application	Nonroad Diesel Engines Purchased	Percentage Share of Total
Medium	Rollers	7,060	5.8%
(cont)	Scrapers	872	0.7%
	Trenchers	2,318	1.9%
	Wheel Loaders/Dozers	15,456	12.7%
	Aerial Lifts	2,001	1.6%
	Cranes	4,081	3.4%
	Excavators	18,047	14.9%
	Total	121,338	
Large	Bore/Drill Rigs	106	2.5%
	Crawlers	1,148	27.1%
	Forest Equipment	39	0.9%
	Graders	8	0.2%
	Mixers	6	0.1%
	Off-Hwy Tractors	143	3.4%
	Off-Hwy Trucks	1,556	36.7%
	Other Construction	99	2.3%
	Scrapers	586	13.8%
	Trenchers	3	0.1%
	Wheel Loaders/Dozers	448	10.6%
	Cranes	13	0.3%
	Excavators	88	2.1%
	Total	4,243	

Note: Small = 0 to 70 hp; medium = 71 to 600 hp; large = over 600 hp.
Source: Power Systems Research (PSR). OELink™. <http://www.powersys.com/OELink.htm>.

3.4.2 Supply-Side Considerations

Costs of Production. Key materials used in the production of construction equipment include steel bars and plates, iron and steel castings, pneumatic and hydraulic systems, fabricated structural metal products, and diesel engines. According to the 1997 Economic Census [EC97M-3331C], the first four of these each account for between 5 and 6 percent of the total cost of materials, or about 3 percent of the value of shipments. Internally produced or purchased diesel engines made up the largest single material category, comprising more than 7 percent of materials cost, or 4 percent of shipment value. According to the Freedonia study cited earlier, diesel engines were 8.3 percent of the cost share of total construction and mining equipment shipped in 2000, a share that is projected to increase to 9.0 percent (see Table 3-3).

Substitution Possibilities. Construction equipment is highly specialized; each unit typically is designed for a single type of application. For example, excavators are used for digging, cranes lift heavy objects, and loaders pick up and transport material. Most of these pieces of equipment have no feasible substitutes, much less ones that might be economically viable if costs and prices were to increase. As a result, substitution is not a relevant concern in the construction application area.

3.4.3 Demand-Side Considerations

Demand for construction equipment is derived from the underlying demand for construction services, in the same way discussed previously for other industries. Construction activity is strongly pro-cyclical, and the booming economy of the past 10 years has provided significant growth in the demand for construction projects. Having decided to build a building, factory, or road, there are few if any substitutes for the highly specialized equipment needed.

3.4.4 Industry Organization

With a total of 222 equipment firms making construction equipment in the United States, this industry is not as concentrated as farm machinery, yet a few large firms dominate here as well. For example, the leading producer in the largest category, skid-steer loaders, made 43 percent of the 64,000 units manufactured in the year 2000. This firm, Ingersoll-Rand (I-R), is a major factor in the small and medium engine hp segments. Based on census data, the industry is moderately concentrated with an HHI of 1,020 and a CR4 of 49.6 percent.

Table 3-10 lists the five leading construction equipment manufacturers in each of the nonroad engine size segments. I-R machines accounted for 28 percent of the 70 hp and under equipment, and almost 10 percent of the medium range. Caterpillar led both medium and large equipment segments, with 19.5 percent and 58.6 percent, respectively. Other significant industry production leaders were Kubota and Fiat (through Case New Holland).

3.4.5 Markets and Trends

The strong market conditions noted earlier have led to steady growth in many of the industry categories listed in Table 3-11. Overall, the construction machinery market saw 20 percent growth from 1997 to 2000, with only a few categories showing declines. The slower growth categories include nonroad trucks and mining equipment, which may be a result of contraction in mineral extraction markets.

Table 3-10. Top Five Diesel-Powered Construction Equipment Manufacturers by Horsepower Category (2000)

hp Category	Parent Company Name	Nonroad Diesel Engines Purchased	Percentage Share of Total
Small	Ingersoll-Rand Company Ltd	25,606	28.2%
	Fiat SPA	11,324	12.5%
	Gehl Co.	6,664	7.3%
	Terex Corp.	4,376	4.8%
	Caterpillar Inc.	4,283	4.7%
	Sum of Top Five	52,253	57.5%
	Total	90,876	
Medium	Caterpillar Inc.	23,685	19.5%
	Fiat SPA	20,060	16.5%
	Deere & Company	14,689	12.1%
	Ingersoll-Rand Company Ltd.	11,743	9.7%
	Komatsu	7,365	6.1%
	Sum of Top Five	77,542	63.9%
	Total	121,338	
Large	Caterpillar Inc.	2,485	58.6%
	Komatsu	1,247	29.4%
	Rowan Companies, Inc.	75	1.8%
	Volvo AB	56	1.3%
	Terex Corp.	50	1.2%
	Sum of Top Five	3,913	92.2%
	Total	4,243	

Note: Small = 0 to 70 hp; medium = 71 to 600 hp; large = over 600 hp.
Source: Power Systems Research (PSR). OELink™. <http://www.powersys.com/OELink.htm>.

3.5 Generators and Welding Machines

Generators and welding machines are considerably different in many respects than the nonroad equipment discussed up to this point. The primary role of a generator is to convert chemical potential energy from a fuel into electrical potential, which can then be used to drive any electrical equipment desired. As a result, generators do not perform useful work directly. A

Table 3-11. Production Trends for Diesel-Powered Construction Equipment

Industry Category	1997	1998	1999	2000	Percentage Change 1997–2000
S/S Loaders	51,534	53,125	59,008	64,270	25%
Tractor/Loader/ Backhoes	20,490	28,148	22,458	25,364	24%
Excavators	19,850	22,328	22,927	24,753	25%
Wheel Loaders/Dozers	16,636	16,413	15,139	16,892	2%
Rollers	10,869	12,389	13,183	13,252	22%
Crawlers	13,247	14,747	11,765	11,352	–14%
LT Plants/Signal Bids	7,185	7,904	8,921	9,902	38%
Aerial Lifts	6,968	8,548	9,213	8,706	25%
Trenchers	6,383	6,911	7,825	7,932	24%
Bore/Drill Rigs	4,200	4,898	5,374	5,869	40%
Graders	4,545	5,008	4,881	4,970	9%
Cranes	2,569	3,068	3,190	4,205	64%
Pavers	2,936	3,188	3,534	3,947	34%
Forest Equipment	3,891	4,574	4,139	3,832	–2%
Plate Compactors	1,907	2,162	2,845	2,845	49%
Off–Hwy Trucks	2,707	2,685	2,663	2,797	3%
Scrapers	1,293	1,459	1,621	1,458	13%
Other Construction	1,086	1,247	1,326	1,422	31%
Mixers	1,212	1,303	1,376	1,399	15%
Finishing Equipment	907	653	577	588	–35%
Tampers/Rammers	276	540	553	559	103%
Off–Hwy Tractors	175	156	126	143	–18%
Totals	180,906	201,510	202,690	216,457	20%

Source: Power Systems Research (PSR). OELink™. <http://www.powersys.com/OELink.htm>.

welding machine is merely a generator with a simple apparatus attached to create a high-temperature electric arc. Although these machines are portable, they are not self-propelled, nor is it usually desirable for them to move while in operation. Finally, generators do not require an operator, except for starting and stopping, refueling, and maintenance activities.

3.5.1 Generators and Welding Machines Categories and Characteristics

Generator sets and welding machines are the second largest of the nonroad equipment markets included in the analysis, with about 180,000 units produced in the year 2000. Table 3-1 indicates that generators and welders are important in all three hp classes, with small sets accounting for one-third of the 70 hp and under engine segment, while the largest units are second only to the diverse construction industry in the over-600 hp segment. These large generators are a little different technically than the smallest of the power generation and cogeneration units, which are operated and regulated as stationary sources.

Details on the production of this equipment in each size segment are presented in Table 3-12. Although significant numbers of welding machines appear in the small and medium engine classes, the category is dominated by the large numbers of generator sets. In fact, generators are the largest single nonroad equipment category according to the PSR database, both in terms of units and in total horsepower.

Table 3-12. Diesel-Powered Generator Sets and Welding Equipment by Horsepower Category (2000)

hp Category	Application	Nonroad Diesel Engines Purchased	Percentage Share of Total
Small	Welders	21,232	15.5%
	Generator Sets	115,952	84.5%
	Total	137,184	
Medium	Welders	1,254	2.9%
	Generator Sets	42,409	97.1%
	Total	43,663	
Large	Generator Sets	3,909	100.0%
	Total	3,909	

Note: Small = 0 to 70 hp; medium = 71 to 600 hp; large = over 600 hp.
Source: Power Systems Research (PSR). OELink™. <http://www.powersys.com/OELink.htm>.

3.5.2 Supply-Side Considerations

Costs of Production. The Economic Census [EC97M-3353B] includes generators and welders as part of the very large motor and generator manufacturing industry, which also includes electric motors, land transportation motors, and prime movers. The Census does not provide information on the purchase of diesel engines by this industry. As a result, there is little information on cost share of engines for generators and welders. Still, the nature of these products suggests that engines must be a substantial fraction of the total cost of materials, which are about one-half of the value of shipments across motor and generator manufacturing. The engine cost share for generator sets and welders is therefore estimated at 50 percent.

Substitution Possibilities. Because generators are little more than devices for converting liquid fuel to electrical power, supply-side substitution would not be likely if diesel engine prices increased substantially. Alternative fuels such as gasoline, compressed natural gas (CNG), or LP gas could in principle be used to fuel generators or welders, but it is more likely that demanders would adjust by switching to different devices to generate remote or backup power, as discussed below.

3.5.3 Demand-Side Considerations

There are several different applications for generators, with different demand-side considerations for each. Many of the largest diesel-powered generator sets are used for stand-by or emergency power in industrial, commercial, and communications facilities. This demand has been increasing quickly with the explosive growth of computer networks and the Internet, where electric power interruptions can be very costly unless a backup source of power is available. The demand for these units would be somewhat elastic, however, as many potential substitutes are available for facility-based use. These substitutes include natural gas-fired generation units, turbine generators, and the emerging fuel cell and photovoltaic technologies.

The same considerations would hold for facility-based auxiliary power, a second significant use of generators. Although the need for portability is much greater in this case, it still would be possible to tap into the facility's power supply to power equipment, if diesel generators increased in price. It is only in the remote, off-site application area that substitution is truly limited. As with agriculture and construction uses, remote power is still most efficiently provided by diesel-engine generators. As costs decline for photovoltaic and fuel cell devices, this calculus may change, but for the foreseeable future, demand for remote power will remain in the province of diesel engines.

Substitution is also a consideration in assessing the demand for welding machines. Just as in the case of generators, facility-based welding can be accomplished with electric (A/C or battery-operated) units, which is not possible for off-site uses. However, gas welders provide a third option, one that is not dependent on a local infrastructure.

3.5.4 Industry Organization

Taken as a whole, the motor and generator manufacturing industry is unconcentrated. Based on census concentration data, the HHI for the overall industry is 439, and the four leading sellers have only a 33 percent market share. The information from the PSR database confirms that the diesel-engine driven generators and welding machine markets are similar in terms of the numbers of competing manufacturers across engine size segments.

Sales for the leading manufacturers in the three engine size segments are presented in Table 3-13. The small and medium categories show a substantial penetration of Asian import firms. In the 70 hp and under segment, generator sets from Korea and China accounted for more than 30,000 units in 2000, or 25.6 percent of the total. Two Korean firms, Daewoo and Hyundai, contributed almost 18,000 medium-sized units, or 29 percent of that segment. Lincoln Electric, Cummins, and Caterpillar are other major generator- producing firms. Lincoln Electric and Illinois Tool Works lead in the production of diesel-powered welding machines.

Table 3-13. Top Five Diesel-Powered Generator Set and Welding Equipment Manufacturers by Horsepower Category (2000)

hp Category	Parent Company Name	Nonroad Diesel Engines Purchased	Percentage Share of Total
Small	Korean Gen-Sets	21,216	15.5%
	Honda Motor Company Ltd.	17,557	12.8%
	Thermadyne Holdings	17,003	12.4%
	Daewoo International Corp.	14,043	10.2%
	Lincoln Electric Holdings	11,548	8.4%
	Sum of Top Five	81,367	59.3%
	Total	137,184	
Medium	Cummins Engine Company, Inc.	6,709	15.4%
	Hyundai Heavy Industries Corp	5,901	13.5%
	Daewoo International Corp.	4,103	9.4%
	Caterpillar Inc.	3,245	7.4%
	Sunbeam Corporation	2,803	6.4%
	Sum of Top Five	22,761	52.1%
	Total	43,663	
Large	Caterpillar Inc.	1,775	45.4%
	Kohler Co.	485	12.4%
	Cummins Engine Company, Inc.	400	10.2%
	Multiquip Inc.	256	6.5%
	Dyna Technology Inc.	114	2.9%
	Sum of Top Five	3,030	77.5%
	Total	3,909	

Note: Small = 0 to 70 hp; medium = 71 to 600 hp; large = over 600 hp.
Source: Power Systems Research (PSR). OELink™. <http://www.powersys.com/OELink.htm>.

3.5.5 Markets and Trends

The growth in production of generator sets has been quite impressive over the past 4 years, as Table 3-14 shows. The influence of the Internet boom and Y2K concerns can be clearly seen in the large increase in 1999. By 2000, production had returned to the prior growth path, yet production more than doubled from 1997 to 2000. Welding machines showed less growth over the period, but a 38 percent increase still exceeded most of the categories in the nonroad market.

Table 3-14. Production Trends for Diesel-Powered Generators and Welders

	1997	1998	1999	2000	Percentage Change 1997–2000
Generator Sets	76,148	111,438	248,353	162,270	113%
Welders	16,266	19,348	23,736	22,486	38%
Totals	92,414	130,786	272,089	184,756	100%

Source: Power Systems Research (PSR). OELink™. <http://www.powersys.com/OELink.htm>.

3.6 Pumps and Compressors

Pumps and compressors, like generators, are relatively simple machines. Both use energy to pressurize a fluid, which then can do useful work in an application. In the case of pumps, the pressure of a liquid (or fluidized solid) is increased to move it through a piping or processing system, or simply to lift it to a more useful level. In the case of air and gas compressors, the fluid can be used to drive pneumatic equipment, circulate in an enclosed system, or to clean or cool applications. As with generators, pumps and compressors are designed to be stationary when in operation, although the units covered by this profile are all portable, or at least moveable. Most of these units are designed to function without an operator, although a person may manipulate the pressurized fluid.

3.6.1 Pumps and Compressors Categories and Characteristics

Table 3-15 lists the types of equipment included in the pumps and compressor industry in 2000. Air compressors account for about half of the units across all three hp classes and about two-thirds of the important medium segment. Pumps are the second most important category, with roughly equal numbers in the small and medium segments. Pressure washers, which operate like pumps but discharge liquids through a nozzle apparatus rather than into a piping system, are primarily concentrated in the small engine range. Gas compressors and hydraulic power units are included here for completeness, but their low volumes make them relatively unimportant for the economic analysis. There were only a handful of pumps and compressors provided in 2000 in the large engine range.

3.6.2 Supply-Side Considerations

Costs of Production. Diesel-powered pumps and compressors are each part of a larger industry as defined in the 1997 Economic Census. The pump and pumping equipment manufacturing sector [EC97M-3339A] includes liquid-fuel operated pumps along with those powered by an electric motor or generator. A total of $487 million was spent on power units for these pumps in 1997, $41.5 million (8.5 percent) of which was for purchased engines. With the total value of shipments at $6.8 billion in this category it is reasonable to estimate that $580

Table 3-15. Diesel-Powered Pump and Compressor Equipment by Horsepower Category (2000)

hp Category	Application	Nonroad Diesel Engines Purchased	Percentage Share of Total
Small	Air Compressors	7,207	40.3%
	Gas Compressors	17	0.1%
	Hydraulic Power Units	568	3.2%
	Pressure Washers	4,911	27.5%
	Pumps	5,179	29.0%
	Total	17,882	
Medium	Air Compressors	11,467	65.4%
	Gas Compressors	46	0.3%
	Hydraulic Power Units	390	2.2%
	Pressure Washers	927	5.3%
	Pumps	4,710	26.9%
	Total	17,540	
Large	Air Compressors	53	58.2%
	Hydraulic Power Units	3	3.3%
	Pressure Washers	14	15.4%
	Pumps	21	23.1%
	Total	91	

Note: Small = 0 to 70 hp; medium = 71 to 600 hp; large = over 600 hp.
Source: Power Systems Research (PSR). OELink™. <http://www.powersys.com/OELink.htm>.

million (also 8.5 percent) represents the value of diesel-powered pumps. It then follows that the diesel engine cost share can be estimated at 7 percent.

The air and gas compressor manufacturing industry [EC97M-3339B] includes diesel and gasoline-powered compressors as well as those using electric motors and generators. Using similar logic to that employed for pumps, the $67.6 million purchased engine cost suggests that diesel's share of power supplied is about 21 percent. With value of shipments at $5.6 billion in 1997, the cost share of compressor diesel engines can be estimated at around 6 percent.

3.6.3 Demand-Side Considerations

Process pumps are used heavily in process industries, including petroleum, chemicals, food processing, and pharmaceutical sectors. Lifting pumps are used to evacuate water from underground mines, in petroleum extraction, and in some construction activities. Mobile compressors are found in general industry as well but are perhaps more common in construction activities. It is expected that demand for all types of units in this industry would fluctuate with the overall level of manufacturing activity.

3.6.4 Industry Organization

Census concentration data show that neither the pump and pumping equipment manufacturing industry nor the air and gas compressor manufacturing industry is concentrated. The HHI for pumps is shown at a modest 267, while compressors have a 383 index. The CR4 is 24.3 percent for pumps and 30.9 percent for compressors.

Sales for the leading manufacturers in the two smaller pumps and compressor engine size segments are shown in Table 3-16. Ingersoll-Rand leads in unit sales for both groups, with a total of about 8,000 pieces of equipment produced in 2000. MI-T-M and Serfilco are the largest sellers in the small-engine category; between them, they produced about one-fifth of the total number of units. Atlas Copco and Hamilton Sunstrand are important producers of medium-sized pumps and compressors.

3.6.5 Markets and Trends

With the exception of pressure washers, the application categories in the pumps and compressor industry have shown slow growth over the past 4 years, as Table 3-17 shows. Air compressors, the largest category, increased by only 9 percent from 1997 to 2000. Overall, production increased by only about 5,000 units over the period, 40 percent of which were pressure washers.

3.7 Refrigeration and Air-Conditioning Equipment

The refrigeration and air-conditioning equipment covered by this profile makes up a small fraction of the large industrial cooling sector, which is dominated by electric-powered equipment in predominantly stationary applications. Diesel engines are used primarily in refrigerated trucks (reefers), as well as in externally mounted bus and RV air-conditioning units. The engines are typically fueled from the vehicle's main fuel tank or from a small auxiliary tank adjacent to the unit.

3.7.1 Refrigeration and Air-Conditioning Equipment Categories and Characteristics

Mobile refrigeration units are the only application category in this market. All of the units fall into the small engine category, with the largest units generating 64 hp. In operation, the engine drives a refrigeration compressor, which cools air that has been drawn from inside the trailer or vehicle, then returns it to the interior compartment.

Table 3-16. Top Five Diesel-Powered Pump and Compressor Manufacturers by Horsepower Category (2000)

hp Category	Parent Company Name	Nonroads Diesel Engines Purchased	Percentage Share of Total
Small	Ingersoll-Rand Company Ltd.	3,711	20.8%
	MI-T-M Corporation	2,503	14.0%
	Serfilco, Ltd.	1,314	7.3%
	Atlas Copco AB-North America, Inc.	801	4.5%
	Tuff Industrial Products	756	4.2%
	Sum of Top Five	9,085	50.8%
	Total	17,882	
Medium	Ingersoll-Rand Company Ltd.	4,293	24.5%
	Atlas Copco AB-North America, Inc.	2,411	13.7%
	Hamilton Sundstrand Corp.	2,011	11.5%
	Sullivan Industries, Inc.	1,661	9.5%
	Gorman-Rupp Company	764	4.4%
	Sum of Top Five	11,140	63.5%
	Total	17,540	

Note: Small = 0 to 70 hp; medium = 71 to 600 hp; large = over 600 hp.
Source: Power Systems Research (PSR). OELink™. <http://www.powersys.com/OELink.htm>.

Table 3-17. Production Trends for Diesel-Powered Pumps and Compressors

Application	1997	1998	1999	2000	Percentage Change 1997–2000
Air Compressors	17,163	17,955	18,759	18,727	9%
Pumps	8,799	9,156	9,604	9,910	13%
Pressure Washers	3,804	4,387	5,051	5,852	54%
Hydraulic Power Units	906	898	909	961	6%
Gas Compressors	61	63	63	63	3%
Totals	30,733	32,459	34,386	35,513	16%

Source: Power Systems Research (PSR) OELink™. <http://www.powersys.com/OELink.htm>.

3.7.2 Supply-Side Considerations

It is difficult to determine costs of production for the refrigeration and air- conditioning segment. This industry is not well identified in Census documents, and with only three firms competing in the market, no information would have been released. Nonetheless, technological similarity would suggest that the 5 to 6 percent engine cost share found for pumps and compressors might also apply here.

3.7.3 Demand-Side Considerations

Customers for mobile refrigeration units include manufacturers of trucks, buses, and recreational vehicles, and although the latter two sectors have been keeping pace with the growth rate of the economy as a whole, production of heavy trucks has declined significantly over the past couple of years. Diesel-powered reefers face no significant competition from alternate fuels; convenience and efficiency suggest that both the truck tractor and the reefer unit would use the same fuel. It seems reasonable to assume for this reason that these units are typically fueled with highway diesel fuel, rather than with nonroad diesel. For the smaller RV and bus units, diesel-powered refrigeration units compete with electric units run directly off of the vehicle's engine.

3.7.4 Industry Organization

Three firms currently compete in the under-70 hp segment. A breakdown by manufacturer is included in Table 3-18.

Table 3-18. Diesel-Powered Refrigeration and A/C Equipment Manufacturers (2000)

hp Category	Parent Company Name	Nonroad Diesel Engines Purchased	Percentage Share of Total
Small	Ingersoll-Rand Company Ltd.	24,551	56.2%
	United Technologies	18,230	41.8%
	Pony Pack, Inc.	876	2.0%
	Sum	43,657	100.0%

Note: Small = 0 to 70 hp; medium = 71 to 600 hp; large = over 600 hp.
Source: Power Systems Research (PSR). OELink™. <http://www.powersys.com/OELink.htm>.

3.7.5 Markets and Trends

The market for diesel-powered refrigeration equipment has picked up recently, after several years of stagnation. Still, growth over the 1997 to 2000 period has been slow, as Table 3-19 indicates.

Table 3-19. Production Trends for Diesel-Powered Refrigeration and A/C Equipment

	1997	1998	1999	2000	Percentage Change 1997–2000
Refrigeration/Air Conditioning	38,968	38,794	39,921	43,657	12%

Source: Power Systems Research (PSR). OELink™. <http://www.powersys.com/OELink.htm>.

3.8 General Industrial Equipment

General industrial equipment includes several classes of specialized machines used in a variety of industries. Included in this diverse collection are a number of nonroad vehicles, materials processing machines, and materials handling equipment. These machines contain an integral engine to provide power for doing work, operating accessories, and (for most) locomotion. A few, such as the materials processing machines, are stationary in operation and have to be transported to their location for use.

Of the 750,000 nonroad machines produced in the year 2000, just over 61,000 or about 8 percent are incorporated into general industrial equipment. Table 3-1 shows the units accounted for by general industrial sector, which are concentrated in the small and medium segments. With few exceptions, these machines are equipped with rubber tires or tracks to allow locomotion and transportation. Diesel engines are the overwhelming power source for all of the major categories in this sector with the exception of materials handling equipment, such as fork lifts.

3.8.1 General Industrial Equipment Categories and Characteristics

Table 3-20 details the categories and percentage shares in the general industrial equipment sector. Nonroad vehicles, including aircraft support, terminal tractors, and specialty and utility vehicles, made up 23 percent of the small engine segment (in 2000), 15 percent of the medium engine segment, and 16 percent of the large engine segment.

Materials handling equipment, including forklifts and dumpers and tenders, account for 38 percent of the small engine segment and 55 percent of the medium segment. Materials processing machines, of which chippers and grinders are the largest category, comprise 14 percent of the small segment, 5 percent of the medium segment, and 47 percent of the large engine segment. Finally, the scrubber and sweeper category makes up 18 percent of the small-engine category and 10 percent of the medium category.

Table 3-20. Diesel-Powered General Industrial Equipment by Horsepower Category (2000)

hp Category	Application	Nonroad Diesel Engines Purchased	Percentage Share of Total
Small	Aircraft Support Equipment	125	0.6%
	Chippers/Grinders	615	3.2%
	Concrete/Industrial Saws	1,232	6.4%
	Crushing/Proc Equipment	433	2.2%
	Oil Field Equipment	157	0.8%
	Other General Industrial	959	5.0%
	Railway Maintenance	126	0.7%
	Scrubbers/Sweepers	3,539	18.4%
	Special Vehicles/Carts	52	0.3%
	Surfacing Equipment	505	2.6%
	Utility Vehicles	3,794	19.7%
	Dumpers/Tenders	982	5.1%
	Forklifts	3,450	17.9%
	Other Material Handling	72	0.4%
	Rough Terrain Forklifts	2,830	14.7%
	Terminal Tractors	388	2.0%
	Total	19,259	
Medium	Aircraft Support Equipment	1,534	3.7%
	Chippers/Grinders	1,261	3.0%
	Concrete/Industrial Saws	226	0.5%
	Crushing/Processing Equipment	566	1.4%
	Oil Field Equipment	453	1.1%
	Other General Industrial	4,847	11.7%
	Railway Maintenance	399	1.0%
	Scrubbers/Sweepers	4,191	10.1%
	Special Vehicles/Carts	264	0.6%
	Surfacing Equipment	114	0.3%

(continued)

Table 3-20. Diesel-Powered General Industrial Equipment by Horsepower Category (2000) (continued)

hp Category	Application	Nonroad Diesel Engines Purchased	Percentage Share of Total
Medium	Utility Vehicles	74	0.2%
(cont)	Dumpers/Tenders	313	0.8%
	Forklifts	9,306	22.4%
	Other Material Handling	177	0.4%
	Rough Terrain Forklifts	13,403	32.2%
	Terminal Tractors	4,476	10.8%
	Total	41,604	
Large	Aircraft Support Equipment	79	16.0%
	Chippers/Grinders	207	41.8%
	Crushing/Processing Equipment	28	5.7%
	Oil Field Equipment	156	31.5%
	Other General Industrial	9	1.8%
	Railway Maintenance	14	2.8%
	Special Vehicles/Carts	2	0.4%
	Total	495	100.0%

Note: Small = 0 to 70 hp; medium = 71 to 600 hp; large = over 600 hp.
Source: Power Systems Research (PSR). OELink™. <http://www.powersys.com/OELink.htm>.

3.8.2 Supply-Side Considerations

The diversity of this industry grouping makes a detailed supply-side analysis problematic, but similarities in technology suggest some general observations. Manufacturers of nonroad vehicles and materials processing equipment do not have viable alternatives consider replacing diesel engines with alternative power sources, even in the face of significant price increases. The only categories in which a potential supply response is likely is in materials handling, whose applications tend to be facility based and therefore amenable to alternate fuel or power supply options.

3.8.3 Demand-Side Considerations

With one exception, one expects that demand and price response for the general industrial segment would mirror the closely related construction equipment industry. Much of this machinery is specialized to specific industries, such as mining, oil extraction, aviation support, and railway maintenance. The exception to the overall consideration of demand is for the forklift categories mentioned above. Diesel-powered forklifts compete with electric models and with those that operate on LP gas or CNG. The productivity and efficiency of a fleet of lift trucks is as dependent on convenience, fuel availability, and ease of use as it is on fuel efficiency. As a result, rechargeable electric and LP-gas-powered forklifts are competitive substitutes for diesel units in most facility-based applications.

3.8.4 Industry Organization

The machinery in the general industrial category are spread across the Census NAICS codes, so no comprehensive concentration measure is available. Industrial machinery manufacturing as a whole has a very low HHI of 89.4, but because equipment is not substitutable across diverse industry sectors, that figure does not provide much guidance. The industrial truck, tractor, trailer, and stacker machinery market is included, however, and it shows a low level of concentration: the HHI is 503 and the top CR4 is only 38.5 percent. In the mining machinery and oil and gas field equipment categories, the HHIs are 516 and 392, respectively, both of which are considered unconcentrated.

Sales for the five leading manufacturers in the small and medium size segments are shown in Table 3-21. It is interesting to note that no single firm accounts for more than 5,000 units or for more than 20 percent of the overall total, a finding that is consistent with Census concentration data. The firm with the highest share in each size segment is Textron, maker of small utility vehicles and medium-sized rough-terrain forklifts. The other major manufacturers in both engine segments concentrate on forklifts and small wheeled vehicles as well.

3.8.5 Markets and Trends

Overall, the categories in the general industrial equipment sector have seen slow growth over the past 4 years (see Table 3-22). None of the large categories showed exceptional growth during this period, and the 10,000-unit increase for the category as a whole mirrored the growth across the entire nonroad equipment sector.

Table 3-21. Top Five Diesel-Powered General Industrial Equipment Manufacturers by Horsepower Category (2000)

hp Category	Parent Company Name	Nonroad Diesel Engines Purchased	Percentage Share of Total
Small	Textron Inc.	1,826	9.5%
	Terex Corp.	1,099	5.7%
	Kawasaki Heavy Industries, Ltd.	1,003	5.2%
	Tennant Company	929	4.8%
	Daewoo International	913	4.7%
	Sum of Top Five	5,770	30.0%
	Total	19,259	
Medium	Textron Inc.	3,056	7.3%
	Caterpillar Inc.	2,946	7.1%
	Partek Corporation	2,538	6.1%
	Toyota Motor Corporation	2,505	6.0%
	Fiat SPA	2,228	5.4%
	Sum of Top Five	13,273	31.9%
	Total	41,604	

Note: Small = 0 to 70 hp; medium = 71 to 600 hp; large = over 600 hp.
Source: Power Systems Research (PSR). OELink™. <http://www.powersys.com/OELink.htm>.

Table 3-22. Production Trends for Diesel-Powered General Industrial Equipment

Application	1997	1998	1999	2000	2001	Percentage Change 1997–2001
Aircraft Support Equipment	1,733	1,767	1,877	1,488	1,738	0.3%
Chippers/Grinders	1,835	1,771	1,927	2,018	2,083	13.5%
Concrete/Ind Saws	723	754	849	1,306	1,458	101.7%
Crush/Proc Equipment	946	956	1,018	1,034	1,027	8.6%
Dumpers/Tenders	107	621	712	948	1,295	1,110.3%
Forklifts	9,090	10,406	11,656	11,654	12,756	40.3%
Oil Field Equipment	766	822	863	801	766	0.0%
Other Material Handling	201	224	222	236	249	23.9%
Other General Industrial	5,024	5,182	4,690	5,374	5,815	15.7%
Railway Maintenance	550	560	585	586	539	–2.0%
Rough Trn Forklifts	11,429	12,697	15,218	17,272	16,233	42.0%
Scrubbers/Sweepers	5,942	6,162	6,751	6,992	7,730	30.1%
Spec Vehicles/Carts	238	257	280	282	318	33.6%
Surfacing Equipment	288	367	510	582	619	1,114.9%
Terminal Tractors	3,758	3,974	4,334	4,671	4,864	29.4%
Utility Vehicles	3,315	3,102	2,899	4,192	3,868	16.7%
Totals	45,945	49,622	54,391	59,436	61,358	33.5%

Source: Power Systems Research (PSR). OELink™. <http://www.powersys.com/OELink.htm>.

Section 4
Application Markets

Nonroad diesel-powered equipment, such as tractors, earth movers, and generators, is used to produce a wide range of products and services. For the purpose of this study, final products and services were grouped into three broad application market: agricultural products, construction products, and manufactured products.

Within these markets, several factors influence diesel equipment users' (purchasers') ability to pass along the increased costs of the regulations through increased prices:

- equipment purchase, operating, and maintenance cost as a share of total production costs;
- price elasticity of demand for products and services; and
- availability and competitiveness of imports.

These factors determine how consumers react to increases in prices and hence how increases in price feed back through the supply chain (referred to as derived demand) influencing the price and quantity of diesel equipment and diesel engines sold.

As shown in Figure 1-1, the suppliers into these markets (farmers, construction companies, and manufacturers) are the demanders of diesel equipment. These diesel equipment users will face not only increased equipment costs associated with the regulation but will incur increased fuel costs associated with reducing sulfur content to 15 ppm. Because the resulting increased cost per gallon of diesel fuel may vary across regional fuel markets, some of the product market data provided are disaggregated by Petroleum Administrative Defense Districts (PADDs).

4.1 Agricultural Product Market

For purposes of this analysis, the agricultural product market is defined as production of crops and livestock and commercial lawn and garden care. The diesel engines used in this equipment are fairly evenly distributed between small- and medium-sized engines, as discussed in the previous section.

Table 4-1 lists agricultural production, imports, and exports from 1993 to 2000. In 2000, total U.S. agricultural production was valued at $218.6 billion. This amount was slightly below the 1997 peak of $231.0 billion. U.S. exports have historically been between 20 and 30 percent of total production. As seen in Table 4-1, the United States is a net exporter of agricultural goods. However, over the past 5 years, the United States's trade surplus has decreased from $27.4 billion to $11.9 billion.

Table 4-1. Agricultural Production

Year	U.S. Production ($ millions)	Export ($ millions)	Imports ($ millions)
2000	218,636	50,798	38,864
1999	213,787	49,106	37,306
1998	219,455	53,711	36,848
1997	231,012	57,338	35,665
1996	228,424	59,867	32,452
1995	203,484	54,729	29,795
1994	208,168	43,967	26,570
1993	191,646	42,887	24,616

Source: U.S. Department of Agriculture, National Agricultural Statistics Service (USDA-NASS). 2002. *Agricultural Statistics 2002*. Washington, DC: U.S. Department of Agriculture.

In determining the impact of nonroad diesel regulations on the U.S. agricultural industry, it is necessary to look at all diesel equipment-related costs as a share of agriculture expenditures. These costs include annual diesel equipment expenses, diesel equipment maintenance expenses, and diesel fuel expenses. Diesel equipment maintenance costs were estimated by multiplying the total annual repair and maintenance costs (reported in the Census) by the percentage of diesel equipment (42 percent). Total diesel-related costs, listed in Table 4-2, represent 6.2 percent of total agricultural production costs.

Table 4-2. Agricultural Diesel-Equipment Related Expenses as a Share of Total Production Costs (1997)

Expenditure Categories	Cost/Share ($ millions)
Annual Diesel Equipment Expenditures	$5,539
Maintenance Expenditures on Diesel Equipment ($8,638 x 0.42)	$3,640
Diesel Fuel Expenditures	$2,846
Total Diesel Equipment-Related Expenses	$12,025
Total Production Costs	$195,089
Share of Total Costs	6.2%

Source: U.S. Census Bureau. *1997 Census of Agriculture*, Volume 1: Part 51, Chapter 1 “United States Summary and State Data.” Tables 3, 14. Washington, DC: U.S. Census Bureau.

Because fuel prices are likely to be affected differently in different regions of the country, it is important to know which areas of the United States have the highest concentration of agricultural production because this will influence the economic impact of the proposed regulation. Information is not available on the geographic distribution of equipment. However, this information can be proxied by either agricultural fuel use or by acres farmed by PADDs. PADD I represents the East Coast, PADD II represents the Midwest, PADD III represents the Gulf Coast, PADD IV represents the Rocky Mountains, and PADD V represents the West Coast.

Table 4-3 shows farm use of diesel fuel by PADD. The Midwest (PADD II) accounts for over half of the diesel fuel used for farming. Table 4-3 also shows the number of acres farmed in each PADD. Again, the Midwest represents over half of total U.S. acres.

Table 4-3. Farm Diesel Usage and Land Utilization by PADD (2000)

District	Diesel Fuel Usage (1,000 gallons)	Share of Diesel Fuel Used	Land Cultivated (1,000 Acres)	Share of Land Cultivated
PADD I	388,534	12.6%	26,595	8.6%
PADD II	1,571,971	51.0%	203,300	65.7%
PADD III	548,885	17.8%	38,652	12.5%
PADD IV	218,977	7.1%	22,628	7.3%
PADD V	351,297	11.4%	18,224	5.9%
Total	3,079,664	100.0%	309,399	100.0%

Note: Diesel fuel usage includes highway and nonroad grades of fuel.
Source: U.S. Census Bureau. 2002. "Historical C30 Value of Construction Put in Place Data." <http://www.census.gov.const/C30/c30_hist.html>. Washington, DC: U.S. Census Bureau.

4.2 Construction Market

Construction machinery is used for constructing buildings and power and manufacturing plants, and for adding or renovating infrastructures. Construction equipment uses engines from all hp categories but is primarily focused on medium and large engines. The value of construction work in the United States has been steadily increasing over the past decade at a rate of approximately 7 percent each year. The value of construction work in 2001 was $842.5 billion (Table 4-4).

As with agriculture, information on the geographic distribution of construction equipment is not available. Therefore, construction equipment use by PADD is estimated by fuel usage and value of work. The fuel use and value of construction work divided by PADD shows that it is much more evenly distributed compared to agricultural production. PADD I (the East Coast) and PADD II (Midwest) each account for over one-fourth of distillate fuel consumption for construction activities. As seen in Table 4-5, PADD I (the East Coast) has the highest percentage of construction at 37.1 percent. The lowest percentage of construction work is found in PADD IV (the Rocky Mountains).

Table 4-4. Value of Construction Work

Year	U.S. Production ($ millions)
2001	842,539
2000	820,345
1999	765,876
1998	705,685
1997	653,429
1996	615,900
1995	557,818
1994	539,193
1993	491,003
1992	463,661

Source: U.S. Census Bureau. 2000. *1997 Economic Census-Construction Subject Series* EC97C235-15. Table 9. Washington, DC: U.S. Census Bureau.

Table 4-5. Value of Construction Work by PADD (1997)

	Distillate Usage (1,000 gallons)	Share of Construction	Value of Work ($ millions)	Share of Value of Work
PADD I	510,876	26.9%	313,356	37.1%
PADD II	549,299	28.9%	229,263	27.1%
PADD III	394,367	20.8%	99,986	11.8%
PADD IV	150,060	7.9%	35,755	4.2%
PADD V	295,235	15.5%	167,181	19.8%
Total	1,899,834	100.0%	845,541	100.0%

Source: U.S. Census Bureau. 2000. *1997 Economic Census-Construction Subject Series* EC97C235-15. Table 9. Washington, DC: U.S. Census Bureau.

4.3 Manufactured Products Market

Nonroad equipment supporting the manufactured products market includes generator sets, refrigeration and A/C units, materials handling equipment, and pumps and compressors. This industrial equipment uses engines from all hp size categories, but its highest concentration of products uses small- and medium-sized engines.

U.S. production of manufactured goods has increased by 4 to 5 percent annually over the past decade. In 2000, total U.S. manufactured products were valued at $2,003 billion (see Table 4-6).

Table 4-6. Manufacturing Value Added

Year	**U.S. Production ($ billions)**
2000	2,003
1999	1,954
1998	1,891
1997	1,826
1996	1,750
1995	1,711
1994	1,606
1993	1,483
1992	1,425
1991	1,341

Source: U.S. Census Bureau. 2002. *Annual Survey of Manufactures. 2000 Statistics for Industry Groups and Industries.* M00(AS)-1. Table 1. Washington, DC: U.S. Census Bureau.

Table 4-7 shows the distribution of manufacturing activity across PADDs as represented by diesel fuel use and value added. In the absence of specific data on regional use of diesel equipment in manufacturing, these measures should help illustrate the spatial allocation across the country. U.S. manufacturing is primarily concentrated in PADD I (the East Coast) and PADD II (Midwest), with 24.1 percent and 28.0 percent of diesel fuel usage and 32.6 percent and 35.6 percent of value added, respectively. As demonstrated in Table 4-7, the lowest value added producers of manufacturing products are located in PADD IV (the Rocky Mountains). However, PADD IV accounts for a larger share of fuel use.

Table 4-7. Manufacturing Value Added by PADD (2000)

District	Diesel Fuel Usage (1,000 gallons)	Share of Fuel Use	Mfg Value Added ($ million)	Share of Value Added
PADD I	396,453	24.1%	653,874	32.6%
PADD II	460,676	28.0%	713,018	35.6%
PADD III	357,412	21.7%	241,742	12.1%
PADD IV	220,765	13.4%	50,758	2.5%
PADD V	209,877	12.8%	343,288	17.1%
Total	1,645,183	100.0%	2,002,680	100.0%

Source: U.S. Census Bureau. 2002. *Annual Survey of Manufactures*. *Geographic Area Statistics: 2000.* M00(AS)-3RV. Table 1. Washington, DC: U.S. Census Bureau.

Section 5
Petroleum Refining and Distribution Operations

In considering new regulations of nonroad compression ignition engines and equipment, EPA plans to include changes to fuel requirements that will directly reduce nonroad sulfate emissions from all engines and support anticipated future nonroad engine emissions control technologies. As a result, it is important to develop an understanding of the petroleum refining industry, with a special emphasis on the portion that produces distillate fuels, including highway and nonroad diesel fuel and home heating oil. This industry profile describes U.S. petroleum refineries and their associated downstream fuel distribution and storage systems.

This section discusses critical aspects of supply and demand for the industry as a whole and for each of the separate PADDs. A description of industry structure and market trends provides the context for the likely producer response to the proposed regulations. In addition, this section provides baseline data, including supply and demand elasticities, market prices, and quantities, which are needed for the economic impact model. Section 5.1 covers refinery operations, which will be directly affected. Section 5.2 treats refined products distribution and storage more briefly because these businesses will be less directly affected. Crude oil transportation and distribution, which should be unaffected, are not discussed here.

5.1 Refinery Operations

5.1.1 Supply-Side Considerations

This section describes the supply side of the petroleum refining industry, including the current refinery production processes and raw materials used. It also discusses the need for potential changes in refinery production created by the new EPA rule. Finally, it describes the three primary categories of petroleum products affected by the rule and the ultimate costs of production currently faced by the refineries.

Refinery Production Processes/Technology. Petroleum refining is the thermal and physical separation of crude oil into its major distillation fractions, followed by further processing (through a series of separation and chemical conversion steps) into finished petroleum products. Although refineries are extraordinarily complex and each site has a unique configuration, this section describes a generic set of unit operations that are found in most medium and large facilities. A detailed discussion of these processes can be found in EPA's sector notebook of the petroleum refining industry (EPA, 1995); simplified descriptions are available on the web sites of several major petroleum producers (Flint Hills Resources, 2002; Chevron, 2002).

Figure 5-1 shows the unit operations and major product flows in a typical refinery. After going through an initial desalting process to remove corrosive salts, crude oil is fed to an atmospheric distillation column that separates the feed into several fractions. The lightest boiling range fractions are processed through reforming and isomerization units into gasoline or diverted to lower-value uses such as LPG and petrochemical feedstocks. The middle-boiling fractions make up the bulk of the aviation and distillate fuels produced from the crude. In most refineries, the undistilled liquid (called bottoms) is sent to a vacuum still to further fractionate this heavier material. Bottoms from the vacuum distillation can be further processed into low-value products such as residual fuel oil, asphalt, and petroleum coke.

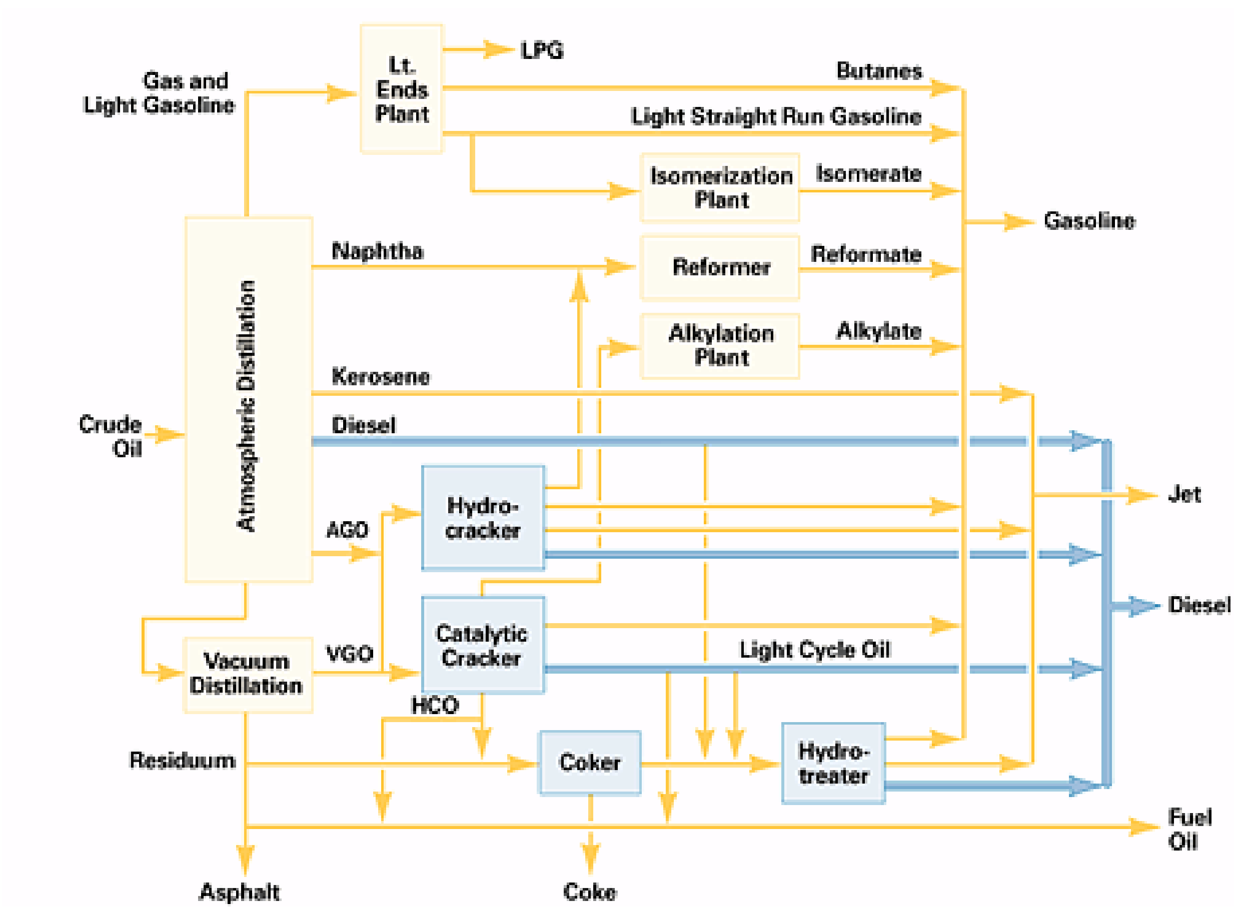

Figure 5-1. The Modern Refinery

Source: Chevron. 2002. Diesel Fuel Refining and Chemistry. As accessed on August 19, 2002. <www.chevron.com/prodserv/fuels/bulletin/diesel/L2_4_2rf.htm>.

A portion of the bottoms from the atmospheric distillation, along with distillate from the vacuum still, are processed further in a catalytic cracking unit or in a hydrocracker. These operations break large hydrocarbon molecules into smaller ones that can be converted to high-value gasoline and middle distillate products. Bottoms from the vacuum still are increasingly processed in a coker to produce saleable coke and gasoline and diesel fuel blendstocks. The cracked molecules are processed further in combining operations (alkylation, for example), which combine small molecules into larger, more useful entities, or in reforming, in which petroleum molecules are reshaped into higher quality species. It is in the reforming operation that the octane rating of gasoline is increased to the desired level for final sale. A purification process called hydrotreating helps remove chemically bound sulfur from petroleum products and is critically important for refineries to process their refinery streams into valuable products and to achieve the low sulfur levels that the proposed regulations will mandate.

For each of the major products, several product streams from the refinery will be blended into a finished mixture. For example, diesel fuel will typically contain a straight-run fraction from crude distillation, distillate from the hydrocracker, light-cycle oil from the catalytic cracker, and hydrotreated gas oil from the coker. Several auxiliary unit operations are also needed in the refinery complex, including hydrogen generation, catalyst handling and regeneration, sulfur recovery, wastewater treatment, and blending and storage tanks. Table 5-1 shows average yields of major products from U.S. refineries.

Table 5-1. Yields of Major Petroleum Products from Refinery Operations

Product	Gallons per Barrel of Crude	Percentage of Total Feed
Crude Feed	42.0	100.0%
Gasoline	19.4	46.0%
Distillate, of which:	8.7	21.0%
Highway diesel	6.3	15.0%-
Home heating oil	1.6	4.0%
Nonroad diesel	0.8	2.0%
Jet Fuel	4.3	10.0%
Petroleum Coke	2.0	5.0%
Residual Fuel Oil	1.9	4.5%
LP Gas	1.9	4.5%
Asphalt	1.4	3.0%
Other Products	4.0	9.5%
Total	43.6	104.0%

Note: Total exceeds 100 percent due to volume gain during refining.
Source: Calculated from EIA data in *Petroleum Supply Annual 2001*. U.S. Department of Energy, Energy Information Administration (EIA). 2002a. *Petroleum Supply Annual 2001*. Tables 16, 17, and 20. Washington, DC.

Potential Changes in Refining Technology Due to EPA Regulation. Over the next few years, EPA regulations will come into effect that require much lower levels of residual sulfur for both gasoline and highway diesel fuel. To meet these challenges, refineries are planning to add hydrotreater units to their facilities, route more intermediate product fractions through existing hydrotreaters, and operate these units under more severe conditions to reduce levels of chemically bound sulfur in finished products. As has been documented in economic impact analyses for the gasoline and highway diesel rules, these changes will require capital investments for equipment, new piping, and in-process storage; increased use of catalyst and hydrogen; and modifications to current operating strategies.

The addition of lower sulfur limits for nonroad diesel fuel will result in additional refinery changes similar in nature to those required for highway diesel fuel. Product streams formerly sent directly to blending tanks will need to be routed through the hydrotreating operation to reduce their sulfur level. In addition, because an increasing fraction of the total volumetric output of the facility must meet ultra-low sulfur requirements, flexibility will be somewhat reduced. For example, it will become more difficult to sell off spec products if errors or equipment failures occur during operation.

Types of Products. The major products made at petroleum refineries are unbranded commodities, which must meet established specifications for fuel value, density, vapor pressure, sulfur content, and several other important characteristics. As Section 5.2 describes, they are transported through a distribution network to wholesalers and retailers, who may attempt to differentiate their fuel from competitors based on the inclusion of special additives or purely through adroit marketing. Gasoline and highway diesel are taxed prior to final sale, whereas nonroad fuel is not. To prevent accidental or deliberate misuse, nonroad diesel fuel must be dyed prior to final sale.

A total of $158 billion of petroleum products were sold in the 1997 census year, accounting for a nontrivial 0.4 percent of GDP. Table 5-2 lists the primary finished products produced; as one might expect, the percentages are quite close to the generic refinery output shown in Table 5-1. Motor gasoline is the dominant product, both in terms of volume and value, with almost three billion barrels produced in 1997. Distillate fuels accounted for less than half as much as gasoline, with 1.3 billion barrels produced in the U.S. in the same year. Data from the Energy Information Administration (EIA) suggest that 60 percent of that total is low-sulfur highway diesel, with the remainder split between nonroad diesel and heating oil. Jet fuel, a fraction slightly heavier than gasoline, is the third most important product, with a production volume of almost 600 million barrels.

Primary Inputs. Crude oil is the dominant input in the manufacture of refined petroleum products, accounting for 74 percent of material cost, or about $95 billion in 1997, according to the latest Economic Census (U.S. Census Bureau, 1999). The census reported almost equal proportions of imported and domestic crude in that year, with 2.5 billion barrels imported and 2.8 billion barrels originating from within the U.S. More recent data published by the EIA show

Table 5-2. Types of Petroleum Products Produced by U.S. Refineries (2001)

Products	Total Produced (thousand barrels)	Percentage of Total
Liquified Refinery Gases	243,322	3.9%
Finished Motor Gasoline	2,928,050	46.4%
Finished Aviation	6,522	0.1%
Jet Fuel	558,319	8.8%
Kerosene	26,679	0.4%
Distillate Fuel Oil	1,348,525	21.4%
Residual Fuel Oil	263,017	4.2%
Naphtha for Feedstock	60,729	1.0%
Other Oils for Feedstock	61,677	1.0%
Special Naphthas	18,334	0.3%
Lubricants	63,961	1.0%
Waxes	6,523	0.1%
Petroleum Coke	280,077	4.4%
Asphalt and Road Oil	177,189	2.8%
Still Gas	244,432	3.9%
Miscellaneous	21,644	0.3%
Total	**6,309,000**	**100.0%**

Source: Calculated from EIA data in *Petroleum Supply Annual 2001*. U.S. Department of Energy, Energy Information Administration (EIA). 2002a. *Petroleum Supply Annual 2001*. Table 17. Washington, DC.

a higher import dependence in the most recent year, with 3.4 billion barrels, or 61.7 percent, imported out of a total of 5.5 billion barrels used by refineries during 2001 (EIA, 2002a).

Crude oil extracted in different regions of the world have quite different characteristics, including the mixture of chemical species present, density and vapor pressure, and sulfur content. The cost of production and the refined product output mix vary considerably depending on the type of crude processed. A light, sweet crude oil, such as that found in Nigeria, will process very differently from a heavy, sulfur-laden Alaska or Arabian crude. The ease of processing any particular material is reflected in its purchase price, with sweet crudes selling at a premium. The result of these variations is that refineries are frequently optimized to run only certain types of crude; they may be unable or unwilling to switch to significantly different feed materials.

In addition to crude oil, refineries may also feed to their refineries hydrocarbon by-products purchased from chemical companies and other refineries and/or semiprocessed fuel oils imported from overseas. In 1997, the Census reported that these facilities purchased $11 billion of hydrocarbons and imported $2.4 billion of unfinished oils. Other significant raw materials purchased include $600 million for precious metal catalysts and more than $800 million in additives.

Costs of Production. According to the latest Economic Census, there were 244 petroleum refining establishments in the United States in 1997, owned by 123 companies and employing 64,789 workers. Data from EIA using a more stringent definition shows 164 operable refineries in 1997, a number that fell to 153 by January 1, 2002. As seen in Table 5-3, value of shipments in 2000 was $216 billion, up from $158 billion in the 1997 census year. The costs of refining are divided into the main input categories of labor, materials, and capital expenditures. Of these categories, the cost of materials represents about 80 percent of the total value of shipments, as defined by the Census, varying from year to year as crude petroleum prices change (see Table 5-4). Labor and capital expenditures tend to be more stable, each accounting for 2 to 4 percent of the value of shipments.

Table 5-3. Description of Petroleum Refineries—Census Bureau Data

NAICS 324110—Petroleum Refineries	**Establishments**	**Companies**	**Employment**	**Value of Shipments ($$10^6$)**
2000	(NA)	(NA)	62,229	$215,592
1999	(NA)	(NA)	63,619	$144,292
1998	(NA)	(NA)	64,920	$118,156
1997	244	123	64,789	$157,935
1992 (reported as SIC 2911)	232	132	74,800	$136,239

Sources: 1992 data from: U.S. Census Bureau. *1992 Census of Manufactures, Industry Series.* MC92-I-29A. Table 1A.

1998-2000 data from U.S. Census Bureau. 2002. *Annual Survey of Manufactures. 2000 Statistics for Industry Groups and Industries* M00(AS)-1. Table 2.

1997 data from U.S. Census Bureau. 1997. "Petroleum Refineries." *1997 Economic Census—Manufacturing, Industry Series* EC97M-3241A. Table 1.

Refinery Production Practices. Refining, like most continuous chemical processes, has high fixed costs from the complex and expensive capital equipment installed. In addition, shutdowns are very expensive, because they create large amounts of off-specification product that must be recycled and reprocessed prior to sale. As a result, refineries attempt to operate 24 hours per day, 7 days per week, with only 2 to 3 weeks of downtime per year. Intense focus on

Table 5-4. Petroleum Refinery Costs of Production, 1997–2000

Petroleum Refinery Costs of Production	1997	1998	1999	2000
Cost of Materials (10^6)	$127,555	$92,212	$114,131	$178,631
as % of shipment value	80.4%	78.0%	79.1%	82.9%
Cost of Labor (10^6)	$3,885	$3,965	$3,983	$3,995
as % of shipment value	2.4%	$127,555	2.8%	1.9%
Capital Expenditures (10^6)	$4,244	80.4%	$3,943	$4,453
as % of shipment value	2.7%	$3,885	2.7%	2.1%

Source: U.S. Census Bureau. 2002. *Annual Survey of Manufactures*. *2000 Statistics for Industry Groups and Industries*. M00(AS)-1. Tables 2 and 5. Washington, DC: U.S. Census Bureau.

cost-cutting has led to large increases in capacity utilization over the past several years. A Federal Trade Commission (FTC) investigation into the gasoline price spikes in the Midwest during the summer of 2000 disclosed an average utilization rate of 94 percent during that year, and EIA data from 2001 show that a 92.6 percent utilization rate was maintained in 2001 (FTC, 2001; EIA, 2002a).

Because of long lead times in procuring and transporting crude petroleum and the need to schedule pipeline shipments and downstream storage, refinery operating strategies are normally set several weeks or months in advance. Once a strategy is established for the next continuous run, it is difficult or impossible to change it. Exact proportions of final products can be altered slightly, but at a cost of moving away from the optimal cost profile established initially. The economic and logistical drivers combine to generate an extremely low supply elasticity. One recent study estimated the supply elasticity for refinery products at 0.24 (Considine, 2002). The FTC study discussed above concluded that refiners had little or no ability to respond to the shortage of oxygenated gasoline in the Midwest in the summer of 2000, even with some advance warning that this would occur.

5.1.2 The Demand Side

This section describes the demand side of the market for refined petroleum products, with a focus on the distillate fuel oil industry. It discusses the primary consumer markets identified and their distribution by end use and PADD. This section also considers substitution possibilities available in each of these markets and the feasibility and costs of these substitutions. Figure 5-2 is a map of the five PADD regions.

Uses and Consumers. Gasoline, jet fuel, and distillate fuel oils account for almost 80 percent of the value of refinery product shipments, with gasoline making up about 51 percent (U.S. Census Bureau, 1999). Actual and relative net production volumes of these three major products, along with residual fuel oils, are shown in Table 5-5, broken out by PADD and for the country as a whole. PADD III, comprising the states of Texas, Louisiana, Arkansas, Alabama,

Petroleum Administration Defense Districts (PADDs)

Figure 5-2. PADDs of the United States

Mississippi, and New Mexico, is a net exporter of refined products, shipping them through pipelines to consumers on the East Coast and also to the Midwest. Compared to gasoline production patterns, distillate production is slightly lower in PADD V (the West Coast) and higher in PADD II (the Midwest).

The primary end-use markets for distillate and residual fuel oils are divided by EIA as follows:

- residential—primarily fuel oil for home (space) heating;
- commercial—high-sulfur diesel (HSD), low-sulfur diesel (LSD), and fuel oil for space heating;
- industrial—LSD for highway use, HSD for nonroad fuels, and residual fuel oil for operating steam boilers and turbines (power generation);
- oil companies—mostly fuel oil and some residual fuel for internal use;
- farm—almost exclusively HSD;
- electric utility—residual fuel and distillate fuel oil for power generation;
- railroad—HSD and LSD used for locomotives;
- vessel bunking—combination of fuel oil and residual fuel for marine engines;

Table 5-5. Refinery Net Production of Gasoline and Fuel Oil Products by PADD (2001)

PADD	Motor Gasoline Quantity (1,000 bbl)	Motor Gasoline Percent (%)	Distillate Fuel Oil Quantity (1,000 bbl)	Distillate Fuel Oil Percent (%)	Jet Fuel Quantity (1,000 bbl)	Jet Fuel Percent (%)	Residual Fuel Oil Quantity (1,000 bbl)	Residual Fuel Oil Percent (%)
I	369,750	12.6%	170,109	12.6%	30,831	5.5%	38,473	14.6%
II	641,720	21.9%	316,023	23.4%	80,182	14.4%	24,242	9.2%
III	1,306,448	44.6%	629,328	46.7%	288,749	51.7%	132,028	50.2%
IV	97,869	3.3%	54,698	4.1%	9,787	1.8%	4,151	1.6%
V	512,263	17.5%	178,367	13.2%	148,770	26.6%	64,123	24.4%
Total	**2,928,050**	**100.0%**	**1,348,525**	**100.0%**	**558,319**	**100.0%**	**263,017**	**100.0%**

Source: U.S. Department of Energy, Energy Information Administration (EIA). 2002a. *Petroleum Supply Annual 2001*. Tables 16, 17, and 20. Washington, DC.

- on-highway diesel—LSD for highway trucks and automobiles;
- military—HSD sales to the Armed Forces; and
- off-highway diesel—HSD and LSD used in construction and other industries.

As Table 5-6 indicates, the highway diesel fuel usage of 33.1 billion gallons represents the bulk of distillate fuel usage (58 percent) in 2000. Residential distillate fuel usage, which in the majority is fuel oil, accounts for 11 percent of total usage in 2000. Nonroad diesel fuel is primarily centered on industrial, farm, and off-highway diesel (construction) usage. In 2000, these markets consumed about 13 percent of total U.S. distillate fuels.

To determine the regional consumption of distillate fuel usage, 2000 sales are categorized by PADDs. As shown in Table 5-7, PADD I (the East Coast) consumes the greatest amount of distillate fuel at 20.9 billion gallons. However, residential, locomotive, and vessel bunking consumers account for 6.4 billion gallons of the distillate fuel consumed, which means that at least one-third of the total consumed in PADD I is due to fuel oil and not to diesel fuel consumption.

Table 5-8 presents a closer look at on-highway consumption of distillate fuel, which is entirely LSD fuel. PADD I (the East Coast) and PADD II (the Midwest) consume almost 65 percent of all U.S. distillate fuel sold for on-highway use.

Table 5-9 shows that residential consumption of distillate fuel (primarily fuel oil) is centered in PADD I (the East Coast). Fuel-oil-fired furnaces and water heaters in New York and New England consume most of this heating oil; in most of the rest of the country, residential central heating is almost universally provided by natural gas furnaces or electric heat pumps. A

Table 5-6. Distillate Fuel Oil by End Use (2000)

End Use	2000 Usage (thousand gallons)	Percentage Share (%)
Residential	6,204,449	10.8%
Commercial	3,372,596	5.9%
Industrial	2,149,386	3.8%
Oil Company	684,620	1.2%
Farm	3,168,409	5.5%
Electric Utility	793,162	1.4%
Railroad	3,070,766	5.4%
Vessel Bunking	2,080,599	3.6%
On-Highway Diesel	33,129,664	57.9%
Military	233,210	0.4%
Off-Highway Diesel	2,330,370	4.1%
Total	**57,217,231**	**100.0%**

Source: U.S. Department of Energy, Energy Information Administration (EIA). 2001b. *Fuel Oil and Kerosene Sales, 2000*. Tables 19-24. Washington, DC.

Table 5-7. Distillate Fuel Oil by End Use and PADD (2000)

	PADD (Thousand Gallons)				
End Use	**I**	**II**	**III**	**IV**	**V**
Residential	5,399,194	628,414	1,117	38,761	136,962
Commercial	2,141,784	568,089	346,578	102,905	213,240
Industrial	649,726	600,800	420,400	241,146	237,313
Oil Company	19,101	41,727	560,905	29,245	33,643
Farm	432,535	1,611,956	552,104	220,437	351,377
Electric Utility	304,717	133,971	194,786	8,492	151,196
Railroad	499,787	1,232,993	686,342	344,586	307,059
Vessel Bunking	490,150	301,356	1,033,333	173	255,586
On-highway Diesel	10,228,244	11,140,616	5,643,703	1,474,611	4,642,490
Military	70,801	36,100	9,250	4,163	112,895
Off-highway Diesel	669,923	608,307	516,989	180,094	355,056
Total	**20,905,962**	**16,904,329**	**9,965,507**	**2,644,613**	**6,796,817**

Source: U.S. Department of Energy, Energy Information Administration (EIA). 2001b. *Fuel Oil and Kerosene Sales, 2000*. Tables 19-24. Washington, DC.

Table 5-8. Sales for On-Highway Use of Distillate Fuel by PADD (2000)

PADD	Distillate Usage (Thousand Gallons)	Share of Distillate Fuel Used
I	10,228,244	30.9%
II	11,140,616	33.6%
III	5,643,703	17.0%
IV	1,474,611	4.5%
V	4,642,490	14.0%
Total	**33,129,664**	**100.0%**

Source: Data in Table 5-7.

Table 5-9. Sales for Residential Use of Distillate Fuel by PADD (2000)

PADD	Distillate Usage (Thousand Gallons)	Share of Distillate Fuel Used
I	5,399,194	87.0%
II	628,414	10.1%
III	1,117	0.0%
IV	38,761	0.6%
V	136,962	2.2%
Total	**6,204,448**	**100.0%**

Source: Data in Table 5-7.

comparison of Tables 5-5 and 5-9 reveals that PADD I produces far less distillate fuel oil than it consumes. The balance is made up by shipments from PADD III and imports from abroad.

Tables 5-10, 5-11, and 5-12 focus on diesel sales for industrial, agricultural, and construction use. Industrial use of diesel fuel is fairly evenly spread across PADDs. PADD II (the Midwest) has the highest percentage of diesel usage at 28 percent, while PADD V (the West Coast) has the lowest percentage at 11 percent. In contrast, agricultural purchases of diesel are in the great majority (51 percent) centered in PADD II (the Midwest). For construction only, distillate fuel sales are available, but these sales are assumed to be principally diesel fuel. Construction usage of diesel fuel, as with industrial usage, is fairly evenly spread across PADDs, with the exception of PADD IV. PADD IV represents only 8 percent of total construction usage.

Table 5-10. Industrial Use of Distillate Fuel by PADD (2000)

PADD	Distillate Usage (Thousand Gallons)	Share of Distillate Fuel Used
I	649,726	30.2%
II	600,800	28.0%
III	420,400	19.6%
IV	241,146	11.2%
V	237,313	11.0%
Total	**2,149,385**	**100.0%**

Source: Data in Table 5-7.

Table 5-11. Adjusted Sales for Farm Use of Distillate Fuel by PADD (2000)

PADD	Distillate Usage (Thousand Gallons)	Share of Distillate Fuel Used
I	432,535	13.6%
II	1,611,956	50.9%
III	552,104	17.4%
IV	220,437	7.0%
V	351,377	11.1%
Total	**3,168,409**	**100.0%**

Source: Data in Table 5-7.

Table 5-12. Sales for Construction Use of Off-Highway Distillate Fuel by PADD (2000)

PADD	Distillate Usage (Thousand Gallons)	Share of Distillate Fuel Used
I	510,876	26.9%
II	549,299	28.9%
III	394,367	20.8%
IV	150,060	7.9%
V	295,235	15.5%
Total	**1,899,837**	**100.0%**

Source: Data in Table 5-7.

Substitution Possibilities in Consumption. For engines and other combustion devices designed to operate on gasoline, there are no practical substitutes, except among different grades of the same fuel. Because EPA regulations apply equally to all gasoline octane grades, price increases will not lead to substitution or misfueling. In the case of distillate fuels, it is currently possible to substitute between LSD, HSD, and distillate fuel oil, although higher sulfur levels are associated with increased maintenance and poorer performance.

With the consideration of more stringent nonroad fuel and emission regulations, substitution will become less likely. Switching from nonroad ultralow-sulfur diesel (ULSD) to highway ULSD is not financially attractive, because of the taxes levied on the highway product. Misfueling with high-sulfur fuel oil will rapidly degrade the performance of the exhaust system of the affected engine, with negative consequences for maintenance and repair costs.

5.1.3 Industry Organization

To determine the ultimate effects of the EPA regulation, it is important to have a good understanding of the overall refinery industry structure. The degree of industry concentration, regional patterns of production and shipment, and the nature of the corporations involved are all important aspects of this discussion. This section addresses market measures for the United States as a whole and by PADD region.

Market Structure—Concentration. There is a great deal of concern among the public about the nature and effectiveness of competition in the refining industry. Large price spikes following supply disruptions and the tendency for prices to slowly fall back to more reasonable levels have created suspicion of coordinated action or other market imperfections in certain regions. The importance of distance in total delivered cost to various end-use markets also means that refiners incur a wide range of costs in serving some markets; because the price is set by the highest cost producer serving the market as long as supply and demand are in balance, profits are made by the low-cost producers in those markets.

There is no convincing evidence in the literature that markets should be modeled as imperfectly competitive, however. Although the FTC study cited earlier concluded that the extremely low supply and demand elasticities made large price movements likely and inevitable given inadequate supply or unexpected increases in demand, their economic analysis found no evidence of collusion or other anticompetitive behavior in the summer of 2000. Furthermore, the industry is not highly concentrated on a nationwide level or within regions. The 1997 Economic Census presented the following national concentration information: CR4 of 28.5 percent, eight-firm concentration ratio (CR8) of 48.6 percent and an HHI of 422.

Two additional considerations were important in making a determination as to whether one can safely assume that refineries act as price-takers in their markets. First, with greater concentration in regional or local markets than at the national level, as well as with significant transport costs, competition from across the country will not be effective in restraining prices.

Secondly, several large mergers have occurred since the 1997 Economic Census was conducted, all of which have prompted action by the FTC to ensure that effective competition was retained.

To investigate these issues, concentration measures were estimated that are not based on refinery-specific production figures (which are not available), but rather on crude distillation capacity, which is the industry's standard measure of refinery size. The total capacity controlled by each corporate parent was aggregated, both at the PADD level and nationwide, and then CR4, CR8, and HHI figures were calculated. The results are presented in Table 5-13.

Table 5-13. 2001 Concentration Measures for Refineries Based on Crude Capacity

PADD	Quantity	CR-4	CR-8	HHI
I	1,879,400	71.6%	91.3%	1,715
II	3,767,449	54.6%	78.2%	1,003
III	8,238,044	48.8%	68.0%	822
IV (current)	606,650	59.6%	90.1%	1,310
IV (future)	606,650	45.4%	80.5%	918
V	3,323,853	61.3%	90.9%	1,199
National	17,815,396	41.89%	65.50%	644

Note: Quantity is crude distillation capacity in thousands of barrels per stream day.
Source: U.S. Department of Energy, Energy Information Administration (EIA). 2002b. Refinery Capacity Data Annual. As accessed on September 23, 2002. <http://www.eia.doe.gov/oil_gas/petroleum/data_publications/refinery_capacity_data/refcap02.dbf>. Washington, DC.

The data in this table provide several interesting conclusions:

- The current and future state of PADD IV shows the impact of FTC oversight to maintain competition. As part of approving the Phillips-Conoco merger, the FTC ordered the merged company to divest two refineries in PADD IV—Commerce City, Colorado, and Woods Cross, Utah. Once those divestitures take place, the concentration levels will drop below 1,000, a level that is not generally of concern.
- The only region that is moderately concentrated is PADD I, which is generally dominated by two large refineries. In this case, however, imports of finished petroleum products, along with shipments from PADD III, should prevent price-setting behavior from emerging in this market. Table 5-14 shows imports of refined products for PADD I and the entire country. About 90 percent of total U.S. imports of gasoline and distillate fuels come into PADD I, aided by inexpensive ocean transport. It is reasonable to assume that any attempts to set prices by the dominant refineries would be defeated with increased imports.

Table 5-14. PADD I and Total U.S. Imports of Gasoline and Fuel Oil Products by Top Five Countries of Origin (2001)

Top Five Countries of Origin	Finished Motor Gasoline		Distillate Fuel Oil		Residual Fuel	
	PADD I Import	**Total U.S. Import**	**PADD I Import**	**Total U.S. Import**	**PADD I Import**	**Total U.S. Import**
Venezuela	21,017	21,257	16,530	16,530	17,667	18,341
Brazil	8,286	8,286	1,472	1,832	8,361	9,105
Canada	41,711	43,778	30,350	35,165	9,483	11,723
Russia	869	968	10,345	10,345	174	1,051
Virgin Islands, USA	38,135	38,882	30,810	31,540	13,412	13,502
Sum of Top Five	110,018	113,171	89,507	95,412	49,097	53,722
Total	**153,633**	**165,878**	**112,318**	**125,586**	**91,520**	**107,688**
Percentage of Total U.S. Imports	**92.6%**		**89.4%**		**85.0%**	

Source: U.S. Department of Energy, Energy Information Administration (EIA). 2002a. *Petroleum Supply Annual 2001*. Table 20. Washington, DC.

Markets in PADDs II and III, which are not overly concentrated or geographically isolated, should be expected to behave competitively, with little potential for price-setting among its refineries.

- The four large mergers (Exxon-Mobil, BP-Amoco, Chevron-Texaco, and Phillips-Conoco) have not increased nationwide concentration to a level that would be a concern for competitive reasons.

Market Structure—Firms and Facilities. PADD III has the greatest number of refineries affected by the EPA nonroad regulation and will account for the largest volume of new ULSD nonroad fuel. Tables 5-15 and 5-16 present the number of operating refineries and the number of crude distillation units in each PADD; output volumes were presented in Table 5-5. PADD III also accounts for 45 to 50 percent of U.S. refinery net production of finished motor gasoline, distillate fuel oil, and residual fuel oil. Similarly, PADD IV contains the fewest number of affected facilities and accounts for the smallest share of distillate production. Still, because compliance costs per unit of output are likely to depend on refinery scale, the small size and geographic isolation of the PADD IV refineries suggest that the financial impact may be greatest on these operations.

According to the EIA Petroleum Supply Annual 2001, the top three owners of crude distillation facilities are ExxonMobil Corp. (11 percent of U.S. total), Phillips Petroleum Corp. (10 percent), and BP PLC (9 percent). Table 5-17 gives an overview of the top refineries in each

Table 5-15. Number of Petroleum Refineries by PADD (2001)

PADD	Number of Facilities	Percentage of Total
I	16	11.1%
II	28	19.4%
III	54	37.5%
IV	14	9.7%
V	32	22.2%
Total	**144**	**100.0%**

Source: U.S. Department of Energy, Energy Information Administration (EIA). 2002a. *Petroleum Supply Annual 2001*. Table 36. Washington, DC.

Table 5-16. Number of Crude Distillation Facilities by PADD (2001)

PADD	Number of Facilities	Percentage of Total
I	12	8.6%
II	26	18.7%
III	50	36.0%
IV	16	11.5%
V	35	25.2%
Total	**139**	**100.0%**

Source: U.S. Department of Energy, Energy Information Administration (EIA). 2002a. *Petroleum Supply Annual 2001*. Table 40. Washington, DC.

PADD, in descending order of total crude distillation capacity. As operating refineries attempt to run at full utilization rates, this measure should correlate directly to total output. Information is not available on actual production of highway diesel, nonroad diesel, and other distillate fuels for each refinery. It should be noted that PADD III has more than 50 percent of the total crude distillation capacity as well as the three largest single facilities.

Firm Characteristics. Many of the large integrated refineries are owned by major petroleum producers, which are among the largest corporations in the United States. According to *Fortune Magazine's* Fortune 500 list, ExxonMobil is the second largest corporation in the world, as well as in the U.S. Chevron Texaco ranks as the eighth largest U.S. corporation, placing it fourteenth in the world. The newly merged Phillips and Conoco entity will rank in the top 20 in the United States, and six more U.S. petroleum firms make the top 500. BP Amoco (fourth worldwide) and Royal Dutch Shell (eighth worldwide) are foreign-owned, as is Citgo (owned by Petroleos de Venezuela).

Table 5-17. Top Refineries in Each PADD by Total Crude Distillation Capacity (2001)

	Name of Company	Location of Facilities		Crude Distillation Capacity (barrels/day)	Percentage of Total PADD Crude Distillate Capacity	Percentage of Total U.S. Crude Distillate Capacity
PADD I	Sunoco Inc. (R&M)	Philadelphia	PA	330,000	20.9%	2.0%
	Phillips 66 Co.	Linden	NJ	250,000	15.9%	1.5%
	Phillips 66 Co.	Trainer	PA	180,000	11.4%	1.1%
	Motiva Enterprises LLC	Delaware City	DE	175,000	11.1%	1.1%
	Sunoco Inc.	Marcus Hook	PA	175,000	11.1%	1.1%
	TOTAL			**1,576,600**	**100.0%**	**9.7%**
PADD II	BP Products North America, Inc.	Whiting	IN	410,000	12.0%	2.5%
	Phillips 66 Co.	Wood River	IL	288,300	8.4%	1.8%
	Flint Hills Resources LP	Saint Paul	MN	265,000	7.7%	1.6%
	ExxonMobil Refg & Supply Co.	Joliet	IL	235,500	6.9%	1.4%
	Marathon Ashland Petro LLC	Catlettsburg	KY	222,000	6.5%	1.4%
	Conoco Inc.	Ponca City	OK	194,000	5.7%	1.2%
	Marathon Ashland Petro LLC	Robinson	IL	192,000	5.6%	1.2%
	Williams Refining LLC	Memphis	TN	180,000	5.3%	1.1%
	TOTAL			**3,428,053**	**100.0%**	**21.1%**

(continued)

Table 5-17. Top Refineries in Each PADD by Total Crude Distillation Capacity (2001) (continued)

	Name of Company	Location of Facilities		Crude Distillation Capacity (barrels/day)	Percentage of Total PADD Crude Distillate Capacity	Percentage of Total U.S. Crude Distillate Capacity
PADD III	ExxonMobil Refg & Supply Co.	Baytown	TX	516,500	6.8%	3.2%
	ExxonMobil Refg & Supply Co.	Baton Rouge	LA	488,500	6.4%	3.0%
	BP Products North America, Inc.	Texas City	TX	437,000	5.8%	2.7%
	ExxonMobil Refg & Supply Co.	Beaumont	TX	348,500	4.6%	2.1%
	Deer Park Refg Ltd Ptnrshp	Deer Park	TX	333,700	4.4%	2.1%
	Citgo Petroleum Corp.	Lake Charles	LA	326,000	4.3%	2.0%
	Chevron U.S.A. Inc.	Pascagoula	MS	295,000	3.9%	1.8%
	Flint Hills Resources LP	Corpus Christi	TX	279,300	3.7%	1.7%
	Lyondell Citgo Refining Co. Ltd.	Houston	TX	274,500	3.6%	1.7%
	Premcor Refg Group Inc	Port Arthur	TX	255,000	3.4%	1.6%
	Conoco Inc.	Westlake	LA	252,000	3.3%	1.6%
	Phillips 66 Co.	Belle Chasse	LA	250,000	3.3%	1.5%
	Motiva Enterprises LLC	Port Arthur	TX	245,000	3.2%	1.5%
	Marathon Ashland Petro LLC	Garyville	LA	232,000	3.1%	1.4%
	Motiva Enterprises LLC	Norco	LA	228,000	3.0%	1.4%
	Motiva Enterprises LLC	Convent	LA	225,000	3.0%	1.4%
	Phillips 66 Co.	Sweeny	TX	213,000	2.8%	1.3%
	Valero Refining Co. Texas	Texas City	TX	204,000	2.7%	1.3%
	Chalmette Refining LLC	Chalmette	LA	182,500	2.4%	1.1%
	Atofina Petrochemicals Inc.	Port Arthur	TX	178,500	2.4%	1.1%
	Total			**7,583,080**	**100.0%**	**46.7%**

(continued)

Table 5-17. Top Refineries in Each PADD by Total Crude Distillation Capacity (2001) (continued)

	Name of Company	Location of Facilities		Crude Distillation Capacity (barrels/day)	Percentage of Total PADD Crude Distillate Capacity	Percentage of Total U.S. Crude Distillate Capacity
PADD IV	Conoco Inc.	Commerce City	CO	62,000	2.0%	0.4%
	Sinclair Oil Corp.	Sinclair	WY	62,000	2.0%	0.4%
	Conoco Inc.	Billings	MO	60,000	1.9%	0.4%
	TOTAL			**567,370**	**18.4%**	**3.5%**
PADD V	BP West Coast Products LLC	Los Angeles	CA	260,000	8.4%	1.6%
	Chevron U.S.A. Inc.	El Segundo	CA	260,000	8.4%	1.6%
	BP West Coast Products LLC	Cherry Point	WA	225,000	7.3%	1.4%
	Chevron U.S.A. Inc.	Richmond	CA	225,000	7.3%	1.4%
	Williams Alaska Petro Inc.	North Pole	AK	197,928	6.4%	1.2%
	TOTAL			**3,091,198**	**100.0%**	**19.0%**
Total U.S.	**(excluding Virgin Islands)**			**16,246,301**		**100.0%**

Source: U.S. Department of Energy, Energy Information Administration (EIA). 2002b. Refinery Capacity Data Annual. As accessed on September 23, 2002. <http://www.eia.doe.gov/oil_gas/petroleum/data_publications/refinery_capacity_data/refcap02.dbf>. Washington, DC.

Many of the smallest refineries are certified as small businesses by EPA. A total of 21 facilities owned by 13 different parent companies qualify or have applied for small business status (EPA, 2002). These small refineries are concentrated in the Rocky Mountain and Great Plains region of PADD IV, and their conversion to ULSD is likely to require significant flexibility on the part of EPA.

5.1.4 Markets and Trends

There is considerable diversity in how different markets for distillate fuels have been growing over the past several years. Table 5-18 shows that residential and commercial use of fuel oil has been dropping steadily since 1984, while highway diesel use has nearly doubled over the same period. Farm use of distillate has been flat over the 15-year period, while off-highway use, mainly for construction, has increased by 40 percent.

5.2 Distribution and Storage Operations

Refined petroleum products, including gasoline, distillates, and jet fuel, are transported by barge and truck and through pipelines from refineries to the wholesale and retail networks in the major markets of the United States. The most important of these routes is the 86,500-mile pipeline network, operated by nearly 200 separate companies (AOPL, 2000; FERC, 2002). Terminals and other storage facilities are located near refineries, along pipelines at breakout stations, and at bulk plants near major consumer markets. There are currently more than 1,300 terminals for refined products in the U.S. (API, 2002).

5.2.1 Supply-Side Considerations

Pipelines are constructed of large-diameter welded steel pipe and typically buried underground. Pumps at the source provide motive force for the 3 to 8 miles per hour flow in the piping network (API, 1998; AOPL, 2000). Periodically, the line pressure is boosted at strategically placed pumping stations, which are often located at breakout points for intermediate distribution of various components. The product is moved rapidly enough to ensure turbulent flow, which prevents back-mixing of components. Figure 5-3 shows a typical configuration of several refined components on the Colonial Pipeline, a major artery connecting East Texas producing sites to Atlanta, Charlotte, Richmond, and New Jersey.

The pipelines do not change the physical form of the petroleum products that they carry and only add value by moving the products closer to markets. Operating costs of transporting products in a pipeline are quite small, so most of the cost charged to customers represents amortization of capital costs for construction. According to the 1997 Economic Census, revenues for pipeline transportation, NAICS code 48691, were $2.5 billion, of which only $288 million represented wags and salaries (U.S. Census Bureau, 2000). Almost all pipeline companies act as a common carrier (they do not take ownership of the products they transport), so their revenues and economic value added are equivalent. Census data for storage operations are not broken down in enough detail to permit estimation of revenues or value added.

Table 5-18. Sales of Distillate Fuel Oils to End Users 1984-1999 (thousands of barrels per day)

Year	Resi-dential	Com-mercial	Indust-rial	Oil Comp-any	Farm	Electric Utility	Rail-road	Vessel Bunkering	On-Highway Diesel	Military	Off-Highway Diesel	All Other	Total
1984	450	319	153	59	193	45	225	110	1,093	45	109	44	2,845
1985	471	294	169	57	216	34	209	124	1,127	50	105	12	2,868
1986	476	280	175	49	220	40	202	133	1,169	50	111	9	2,914
1987	484	279	190	58	211	42	205	145	1,185	58	113	5	2,976
1988	498	269	170	57	223	52	212	150	1,304	64	119	4	3,122
1989	489	252	167	55	209	70	213	154	1,378	61	107	2	3,157
1990	393	228	160	63	215	48	209	143	1,393	51	116	(s)	3,021
1991	391	226	152	59	214	39	197	141	1,336	54	110	(s)	2,921
1992	406	218	144	51	228	30	209	146	1,391	42	113	(s)	2,979
1993	429	218	128	50	211	38	190	133	1,485	31	127	(s)	3,041
1994	413	218	136	46	209	49	200	132	1,594	34	130	(s)	3,162
1995	416	216	132	36	211	39	208	129	1,668	24	126	—	3,207
1996	436	223	137	41	217	45	213	142	1,754	24	134	—	3,365
1997	423	210	141	41	216	42	200	137	1,867	22	136	—	3,435
1998	367	199	147	37	198	63	185	139	1,967	18	142	—	3,461
1999	381	196	142	38	189	60	182	135	2,091	19	140	—	3,572

Source: U.S. Department of Energy, Energy Information Administration (EIA). 2001a. *Annual Energy Review, 2000.* Table 5.13. Washington, DC.

Figure 5-3. Typical Sequence in which Products are Batched While in Transit on Colonial System

The most important impact of additional EPA regulation on the distribution network has been to increase the number of different products handled by each pipeline. Although some concern has been expressed by these firms in relation to the gasoline and highway diesel regulations, the incremental effect of reducing sulfur content for nonroad diesel should be minor. The Colonial Pipeline mentioned previously currently handles 38 grades of motor gasoline, 16 grades of distillate products, 7 grades of kerosene-type fuels (including jet fuel), and an intermediate refinery product, light cycle oil (Colonial, 2002).

As Figure 5-3 shows, these pipelines are shipping low-sulfur gasoline, LSD fuel, and high-sulfur nonroad fuel in the same pipeline. In most cases, the interface (mixing zone) between products is degraded to the poorer quality material. When they begin handling ULSD and gasoline, they may be forced to downgrade more interface material to nonroad or fuel oil and will need to carefully prevent contamination in storage tanks and pumping stations.

Importantly, changeover to ULSD for nonroad applications will not add additional complexity to their operations. EPA expects that there will be no physical difference between 15 ppm diesel fuel destined for the highway market and 15 ppm diesel fuel destined for the off-highway market prior to the terminal level when dye must be added to off-highway diesel fuel to denote its untaxed status. This will allow pipeline operators to ship such fuels in fungible batches. Consequently, the introduction of 15 ppm off-highway diesel should not result in increased difficulty in limiting sulfur contamination during the transportation of ultra-low sulfur products. Pipeline operators will continue to have a market for the downgraded mixing zone material generated during the shipment of 15 ppm diesel fuel by pipeline. After the implementation of EPA's 15 ppm highway diesel requirement and the envisioned off-highway diesel fuel controls, the pipelines that transport the majority of the nation's diesel fuel are projected to continue to carry HSD fuel and/or 500 ppm diesel fuel. These pipelines would blend their downgraded 15 ppm diesel into the 500 ppm and/or HSD fuel that they ship. A fraction of the pipelines are projected to carry only a single grade of diesel fuel (15 ppm fuel) after the EPA's highway program is implemented. These pipelines currently carry only 500 ppm highway diesel fuel. In EPA's highway diesel final rule, EPA projected that these pipelines would install an additional storage tank to contain the relatively low volumes of downgraded 15 ppm diesel fuel generated during pipeline transportation of the product. EPA projected that this downgraded material would be sold into the off-highway diesel market. The implementation of the envisioned nonroad diesel fuel controls would not change this practice. One expects that these pipeline operators would continue to find a market for the downgraded 15 ppm fuel, either as 500 ppm off-highway diesel fuel or for use in stationary diesel engines.

5.2.2 Demand-Side Considerations

Demand for distribution through pipelines (versus barge or truck movement) is driven by cost differentials with these alternate means of transportation. The National Petroleum Council estimated in a comprehensive 1989 report that water transport of a gallon of petroleum products was about three times as expensive per mile as transport via pipeline, and truck transportation was up to 25 times as expensive per mile (National Petroleum Council, 1989). A recent pipeline industry publication shows that pipelines account for around 60 percent of total ton-miles of refined petroleum product movements, with 31 percent by water, 5.5 percent by truck, and 3.5 percent by rail (AOPL, 2001). It should be noted that shipments often move by more than one mode of transport from refinery to end user.

Pipeline transport charges make up only a small portion of the delivered cost of fuels. Industry publications cite costs of about 1$ per barrel, equal to 2.5 cents per gallon, for a 1600 mile transfer from Houston to New Jersey, and about 2 cents per gallon for a shipment of 1100 miles from Houston to Chicago (AOPL, 2002; Allegro, 2001). Although average hauls are shorter and somewhat more expensive per mile, average transport rates are on the order of 0.06 to 0.18 cents per barrel per mile.

5.2.3 Industry Organization

Just as it has with other transportation modes defined by site-specific assets and high fixed costs, the federal government has traditionally regulated pipelines as common carriers. Unlike railroad and long-haul trucking, however, pipeline transport was not deregulated during the 1980s, and the Federal Energy Regulatory Commission (FERC) still sets allowable tariffs for pipeline movements. A majority of carriers, therefore, compete as regulated monopolies.

Most pipelines are permitted small annual increases in rates without regulatory approval, typically limited to 1 percent less than the increase in the producer price index (PPI). If regulatory changes caused significant cost increases, for instance from the addition of tankage to handle two grades of nonroad diesel fuel, pipeline operators would have to engage in a rate case with FERC to pass their increased costs along to consumers. If they chose not to request rate relief, the pipelines would absorb any costs above the allowable annual increases.

5.2.4 Markets and Trends

Pipeline firms have seen slowly rising demand for their services over the past several years. The latest available data, from the 1996 to 1999 period, are displayed in Table 5-19. Pipelines have not only captured almost all of the overall increase in total product movements, but they have taken some share away from water transport during the period. Railroad shipments have grown as well, but from a very small base.

Table 5-19. Trends in Transportation of Refined Petroleum Products

					Percentage Change
	1996	**1997**	**1998**	**1999**	**1996-1999**
Pipelines	280.9	279.1	285.7	296.6	5.6%
Water Carriers	154.1	148.3	147.1	147.5	–4.3%
Motor Carriers	28.0	26.0	26.7	27.6	–1.4%
Railroads	16.0	16.2	16.2	18.2	13.8%
Totals	479.0	469.6	475.7	489.9	2.2%

Note: All figures, except percentages, in billions of ton miles.
Source: Association of Oil Pipe Lines (AOPL). 2001. Shifts in Petroleum Transportation. As accessed on November 20, 2002. <www.aopl.org/pubs/facts.html>.

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