

OFF-HIGHWAY TRANSPORTATION- RELATED FUEL USE

April 2004

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April 2004

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ACRONYMS AND ABBREVIATIONS

CNG	compressed natural gas
DOE	Department of Energy
DOT	Department of Transportation
EIA	Energy Information Administration
EPA	Environmental Protection Agency
FHWA	Federal Highway Administration
FOKS	Fuel Oil and Kerosene Sales
GGE	gasoline gallons equivalent
LNG	liquid natural gas
LPG	liquid petroleum gas
MBPD	million barrels per day
MPH	miles per hour
ORNL	Oak Ridge National Laboratory
SAE	Society of Automotive Engineers
SCC	Source Category Code
U.S.	United States
VIUS	Vehicle Inventory and Use Survey

EXECUTIVE SUMMARY

The transportation sector includes many subcategories – for example, on-highway, off-highway, and non-highway. Use of fuel for off-highway purposes is not well documented, nor is the number of off-highway vehicles. The number of and fuel usage for on-highway and aviation, marine, and rail categories are much better documented than for off-highway land-based use. Several sources document off-highway fuel use under specific conditions – such as use by application (e.g., recreation) or by fuel type (e.g., gasoline). There is, however, no single source that documents the total fuel used off-highway and the number of vehicles that use the fuel.

This report estimates the fuel usage and number of vehicles/equipment for the off-highway category. No new data have been collected nor new models developed to estimate the off-highway data – this study is limited in scope to using data that already exist.

In this report, unless they are being quoted from a source that uses different terminology, the terms are used as listed below.

- “On-highway/on-road” includes land-based transport used on the highway system or other paved roadways.
- “Off-highway/off-road” includes land-based transport **not** using the highway system or other paved roadways.
- “Non-highway/non-road” includes other modes not traveling on highways such as aviation, marine, and rail.

It should be noted that the term “transportation” as used in this study is not typical. Generally, “transportation” is understood to mean the movement of people or goods from one point to another. Some of the off-highway equipment included in this study doesn’t *transport* either people or goods, but it has utility in movement (e.g., a forklift or a lawn mower). Along these lines, a chain saw also has utility in movement, but it cannot *transport* itself (i.e., it must be carried) because it does not have wheels. Therefore, to estimate the transportation-related fuel used off-highway, transportation equipment is defined to include all devices that have wheels, can move or be moved from one point to another, and use fuel. An attempt has been made to exclude off-highway engines that do not meet all three of these criteria (e.g., chain saws and generators).

The following approach was used to determine the current off-highway fuel use. First, a literature review was conducted to ensure that all sources with appropriate information would be considered. Secondly, the fuel use data available from each source were compiled and compared in so far as possible. Comparable data sets (i.e., same fuel type; same application) were evaluated. Finally, appropriate data sets were combined to provide a final tally.

A comparison of the various data sources is difficult because of differences in time frames for the studies, definitions of the sectors, and types of equipment or fuels included. In addition, the studies must make assumptions about equipment populations and fuel “efficiency” because of the lack of registration requirements and reporting. Differences in the assumptions and methodologies contribute to discrepancies among the models.

A review of possible sources for off-highway fuel usage data revealed that there was no definitive source. Thus, to derive total off-highway fuel use, by fuel type, it was decided to combine data from two sources. The Environmental Protection Agency's (EPA's) NONROAD model was used to derive usage data for all transportation-related off-highway equipment that is covered by the model. The Census Bureau's 1997 Vehicle Inventory and Use Survey (VIUS) was used to derive usage data for all registered trucks used off-highway. (VIUS survey data are collected every 5 years and the 1997 data are the latest available at this time.)

VIUS data and NONROAD data are mutually exclusive. For the 1997 data year, the sum of the fuel use from the NONROAD model for the entire United States, less fuel use for those equipment types that are not transportation-related, plus VIUS off-highway fuel use for registered trucks equals the total fuel used, by sector (Table ES-1).

Table ES-1. Total estimated transportation-related off-highway fuel consumption, 1997 (millions of gallons)

Sector	Gasoline	Diesel	Other ^a	Total	Share by sector
Agriculture	319	2,994	5	3,318	19.4%
Industrial and commercial	1,761	1,579	1,854	5,193	30.4%
Construction	289	4,766	18	5,073	29.7%
Personal and recreational	3,425	37	7	3,469	20.3%
Other	2	48	2	52	0.3%
Total off-highway	5,797	9,424	1,885	17,106	100.0%

^aThe category of "Other" fuels includes compressed natural gas (CNG) [converted to gasoline gallons equivalent (GGE)], liquid petroleum gas (LPG), and other alternative fuels.

Thus, an estimated 17.1 billion gallons, or 1.1 million barrels per day (mbpd), of fuel was used for transportation-related purposes off-highway in 1997, 11% of on-highway fuel use. According to *Highway Statistics 1997*, the total fuel (gasoline plus special fuels) used on-highway during 1997 was 150.3 billion gallons.

To derive the total estimated off-highway fuel consumption for 2001, the VIUS fuel estimates for 1997 needed to be adjusted. This adjustment was made using a comparison of the outputs from the NONROAD model for 1997 and 2001, by sector and fuel type. After deriving the adjusted VIUS numbers for 2001, results of the two sources were summed. Table ES-2 shows total fuel use of 18.6 billion gallons, or 1.2 mbpd, for off-highway transportation-related purposes in 2001.

**Table ES-2. Total estimated transportation-related off-highway fuel consumption, 2001
(millions of gallons)**

Sector ^a	NONROAD ^b			VIUS			Total fuel use			Total	Share by sector
	Gasoline	Diesel	Other ^c	Gasoline	Diesel	Other	Gasoline	Diesel	Other		
Agriculture	51	3,250	0	287	102	4	338	3,352	4	3,694	19.9%
Industrial and commercial	1,351	1,426	2,103	382	368	6	1,733	1,794	2,108	5,636	30.3%
Construction	100	5,205	19	173	141	0	274	5,347	19	5,639	30.3%
Personal and recreational	1,816	13	1	1,708	29	6	3,524	42	7	3,573	19.2%
Other	2	61	2	0	0	0	2	61	2	65	0.3%
Total	3,321	9,955	2,125	2,550	641	16	5,870	10,596	2,141	18,607	100.0%

^aContents of each sector based on definitions from the original models are given in Table 9 of the full report.

^bFuel use for Source Category Codes (SCCs) not related to transportation was removed.

^cThe category of “Other” fuels includes CNG (converted to GGE), LPG, and other alternative fuels.

The proportion of fuel used off-highway by each sector is shown in Figure ES-1. The proportion of fuel by fuel type is shown in Figure ES-2.

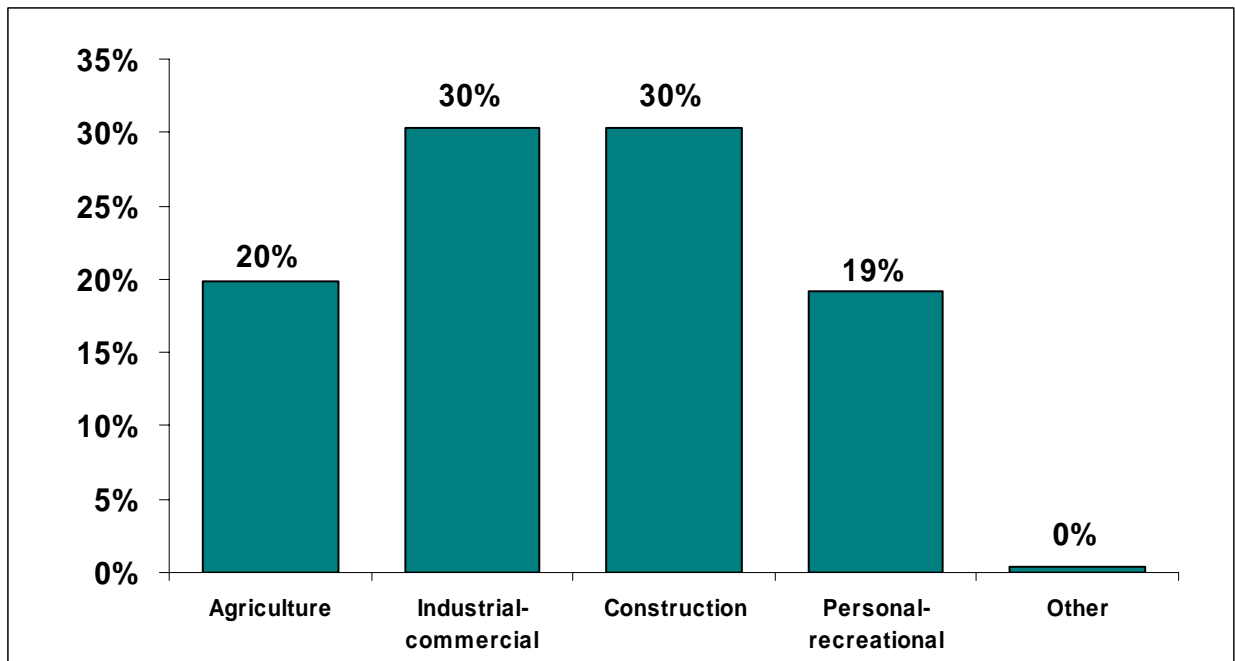


Figure ES-1. Proportion of transportation-related fuel used off-highway by sector, 2001.

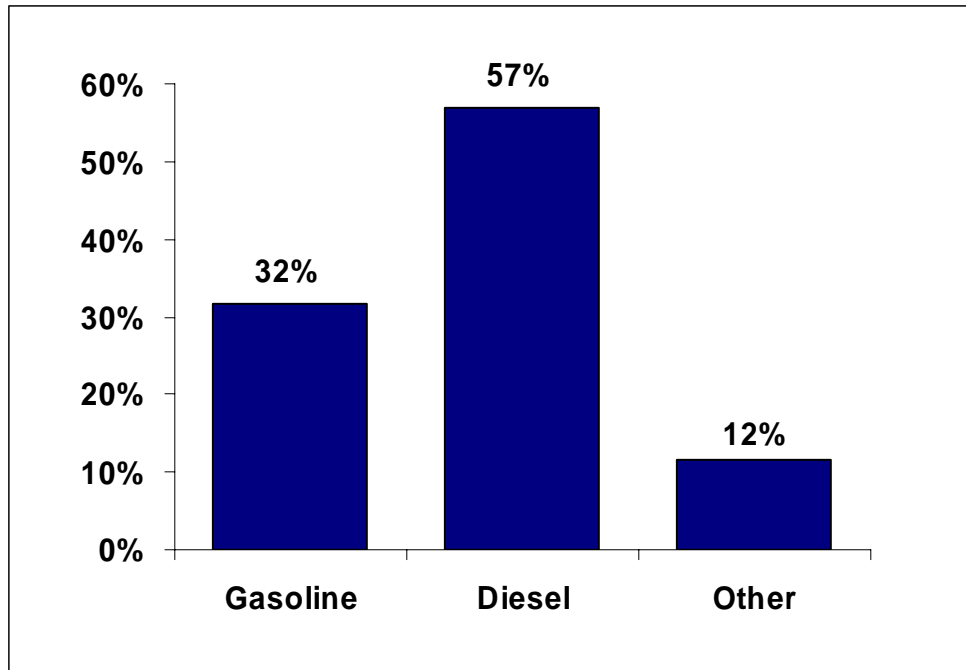


Figure ES-2. Proportion of transportation-related fuel used off-highway by fuel type, 2001.

Comparing the fuel use estimates for 1997 and 2001 shows the total off-highway use of fuel grew by 8.8%. The proportional use of fuel by fuel type stayed about the same between 1997 and 2001, as shown in Figure ES-3. The fuel type showing the greatest growth is the category containing alternative fuels (i.e., everything other than gasoline and diesel). Although this category has the smallest fuel use, it appears to be growing. Diesel is the fuel of choice for off-highway usage; about half of all fuel used off-highway is diesel.

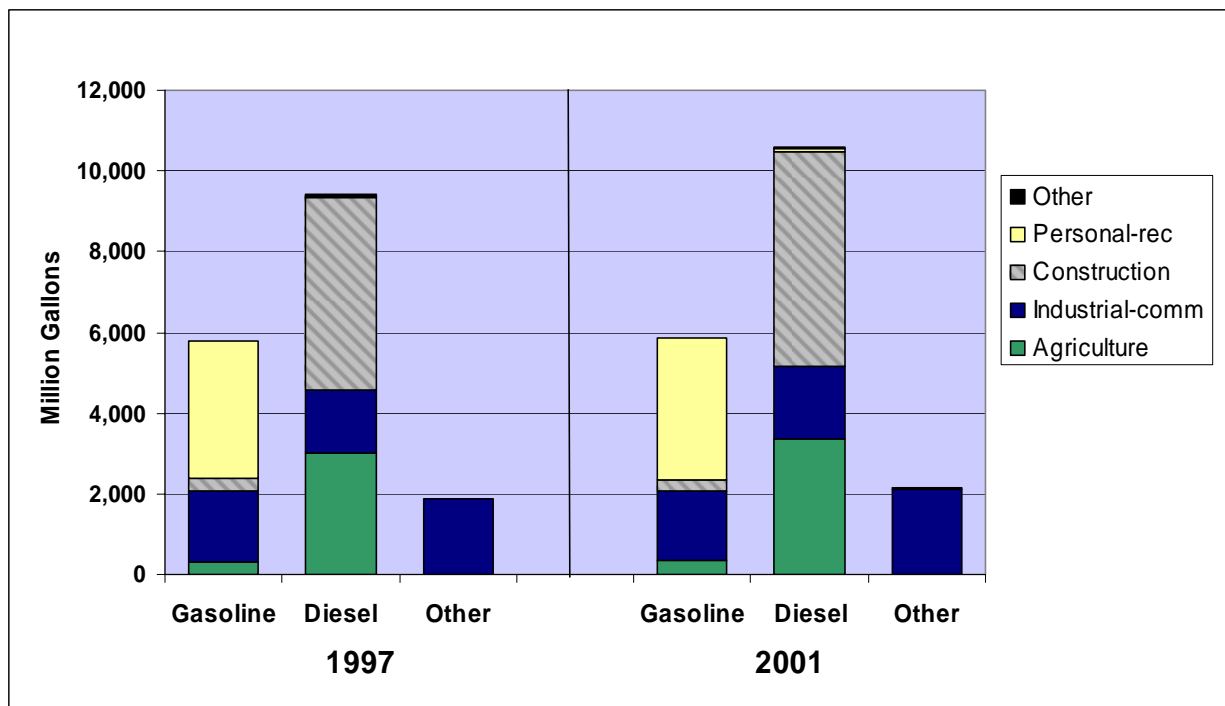


Figure ES-3. Comparison of fuel use, 1997 and 2001, by sector and fuel type.

Using the growth rate from 1997 to 2001, by sector and fuel type, a projection was calculated for the year 2005 which indicates that the total fuel use off-highway will be almost 20.5 billion gallons.

The number of off-highway vehicles and equipment is obtained from the same sources as the fuel use estimates (Tables ES-3 and ES-4). Population data from EPA's model show that diesel agricultural tractors are a large share of the agricultural off-highway population; commercial lawn and garden equipment make up the largest share of the industrial and commercial off-highway population; the construction sector has the most vehicle types which can run on alternative fuels; and the personal and recreational sector vehicles are nearly all gasoline vehicles (e.g., residential lawn mowers, off-highway motorcycles). Estimates of off-highway trucks from VIUS indicate that most off-highway trucks are personal vehicles which run on gasoline.

Table ES-3. Population of off-highway vehicles/equipment from NONROAD, 2001

	Gasoline	Diesel	Other
Agriculture	830,841	1,922,536	164
Industrial & commercial	5,383,462	1,117,345	533,397
Construction	858,138	1,618,431	12,774
Personal & recreational	63,632,842	34,700	4,535
Other	1,841	13,923	505

**Table ES-4. Population of off-highway trucks
from VIUS 1997**

	Gasoline	Diesel	Other
Agriculture	541,485	76,143	6,161
Industrial & commercial	492,438	100,268	2,206
Construction	169,333	62,659	461
Personal & recreational	2,353,810	59,793	12,917

The transport of fuel to large off-highway vehicles and other equipment is via tanker vehicles where it may be pumped directly into the equipment or into a storage tank, either above-ground or under-ground. Transport to small off-highway equipment is by portable equipment (e.g., a “gas can”).

Knowing the population of vehicles and the amounts and types of fuel used in off-highway applications is important for making decisions about the development and introduction of new technologies for small engines. When introducing additional alternative fuels into the off-highway marketplace or making investments in technologies to improve fuel efficiency of off-highway vehicles, data and information are needed about the off-highway sector to show where improvements can make the most impact. Unfortunately, there is no one data source that currently has information on all the off-highway vehicles. Oak Ridge National Laboratory (ORNL), however, was able to make estimations based on currently available data sources.

1. INTRODUCTION

In 2002 the transportation sector used over 13.1 million barrels of petroleum per day, which was over 67% of the total petroleum consumed in the United States. When comparing transportation energy use to total U.S. energy use in the year 2002, the transportation sector used 27.3% of the total (Davis and Diegel, 2003, Tables 1.14 and 2.3).

The transportation sector includes many subcategories – for example, on-highway, off-highway, and non-highway. These terms are not used consistently among agencies. In this report, unless they are being quoted from a source that uses different terminology, the terms are used as listed below.

- “On-highway/on-road” includes land-based transport used on the highway system or other paved roadways.
- “Off-highway/off-road” includes land-based transport **not** using the highway system or other paved roadways.
- “Non-highway/non-road” includes other modes not traveling on highways such as aviation, marine, and rail.

This report estimates the fuel usage for the off-highway category. In this report, the terms “off-highway” and “off-road” are synonymous. Use of fuel for off-highway purposes is not well documented, nor is the number of off-highway vehicles. The number of and fuel usage for on-highway and aviation, marine, and rail categories are much better documented than for off-highway land-based use.

1.1 BACKGROUND

Several sources document off-highway fuel use under specific conditions – such as use by application (e.g., recreation) or by fuel type (e.g., gasoline). There is, however, no single source that documents the total fuel used off-highway and the number of vehicles/equipment that use the fuel.

Several issues, which differ by fuel type, arise when “counting” gallons of fuel used off-highway. Total *gasoline* gallons sold in a state are determined through tax records and are reported by states to the Federal Highway Administration (FHWA). FHWA uses this information and various models to estimate the amount of non-highway and off-highway gasoline use. Off-highway *diesel* fuel is dyed red and is not legal for on-highway use. Since dyed diesel is not federally taxed, these gallons are not recorded by the FHWA. Not all dyed diesel fuel is used for transportation and not all diesel vehicles going off-highway use dyed diesel. Thus, obtaining total gallons of diesel fuel used off-highway for transportation presents a special set of problems. Finally, records for sales of *gasohol and alternative fuels* are inconsistent among the states in general, and the amount of these fuels used off-highway can only be estimated at best.

Categories (or sectors) of non-highway fuel use include agriculture, construction, commercial, industrial, marine, railroad, aviation, military, recreation, and small engines. Categories of interest in the current study of land-based, off-highway, transportation-related fuel use include agriculture, construction, commercial, industrial, and personal/recreational. Off-highway fuel types of interest in the current study include gasoline/gasohol, diesel, and all other fuels [compressed natural gas (CNG), liquid propane gas (LPG), and other alternative fuels].

1.2 ASSUMPTIONS

This study is bounded by the assumptions listed below.

- The primary interest is the energy use related to transportation; that is, fuel used in stationary applications will be included only if this use cannot be separated from transportation use.
- Uses such as personal and recreational will be included if easily available; fuel usage by small engines (e.g., lawn mowers) will be included only if easily available.
- All off-highway fuels, including gasoline, diesel, gasohol, and alternative fuels, are included.
- Excluded are gallons for aviation, marine, and railroad usage.
- Excluded are gallons for military use.
- The current usage (most recent year of available data) is of primary interest. Historical data or forecasted usage will be listed if easily acquired/available, but additional effort will not be spent in searching for these data.

It should be noted that the term “transportation” as used in this study is not typical. Generally, “transportation” is understood to mean the movement of people or goods from one point to another. Some of the off-highway equipment included in this study doesn’t *transport* either people or goods, but it has utility in movement (e.g., a forklift or a lawn mower). Along these lines, a chain saw also has utility in movement, but it cannot *transport* itself (i.e., it must be carried) because it does not have wheels. Therefore, to estimate the transportation-related fuel used off-highway, transportation equipment is defined to include all devices that have wheels, can move or be moved from one point to another, and use fuel. An attempt has been made to exclude off-highway engines that do not meet all three of these criteria (e.g., chain saws and generators).

It should be noted that this study is limited in scope to using data that already exist. No new data have been collected nor new models developed to estimate the total off-highway fuel usage.

2. METHODOLOGY

The following approach was used to determine the current off-highway fuel use. First, a literature review was conducted to ensure that all sources with appropriate information would be considered. Secondly, the fuel use data available from each source were compiled and compared in so far as possible. Comparable data sets (i.e., same fuel type; same application) were evaluated. Finally, appropriate data sets were combined to provide a final tally.

2.1 LITERATURE REVIEW

2.1.1 Overview

According to the Diesel Technology Forum (2003a, p. 23), 2.5 billion gallons of diesel distillate were used off-highway in 2001. Diesel distillate includes fuel oil for stationary (e.g., heating, crop drying, power generation) as well as mobile uses; therefore, these uses include more than just equipment used for transportation.

Carl T. Vuk (2001; 2003) of John Deere Power Systems noted that 16% of the total U.S. fuel oil usage (i.e., diesel distillate) was for off-highway (farm and industrial) uses. Vuk also concluded that turbo generation, electric auxiliaries, and integrated starter generators are means of increasing fuel and system efficiency.

In April 2001, the Society of Automotive Engineers (SAE) and DOE convened a workshop to address joint interests in reducing emissions of off-highway diesel engines. The joint venture resulted in a planning document, the *Off-Highway Vehicle Technology Roadmap* (U.S.DOE, 2001). This document provides an excellent overview of the off-highway engine sector – from the diverse functions (e.g., propelling the vehicle, lifting a load) to the wide range of engine sizes; from the volumes of new diesel engines sold to durability requirements; from emissions to fuel usage; from environmental requirements to economic costs. The Roadmap documents the status of off-highway technologies, sets goals for reducing fuel consumption and emissions, and identifies research needed to accomplish the Environmental Protection Agency's (EPA's) Tier 4 standards.

When EPA released the proposed Tier 4 regulations for off-highway equipment in April 2003, the Diesel Technology Forum (2003b) responded with a report on the diesel industry's progress in reducing emissions in off-highway equipment. The report includes a description of the off-highway market and discusses fuel needs in terms of applications. It should be noted that heavy equipment used off-highway operates under a wide variety of conditions. In general, most off-highway vehicles can be described as slow moving (usually <10 mph) with notable power requirements for accessories. Because of the conditions under which the equipment performs work, the cooling system consumes 10-20% of the total engine power (Diesel Technology Forum (2003a, p. 14). The Diesel Technology Forum noted that diesel is the predominate fuel used in many off-highway applications, including the following transportation-related functions:

- agriculture, 66%,
- construction, nearly 100%,
- mining, 72%,
- freight transport (including rail, shipping, and intermodal), 90%, and
- airport ground support equipment, 33%.

The problem of determining precise off-highway fuel usage is obviously difficult. Different sources use different criteria. The sources noted above were articles based on a particular point in time. Four sources that have long-term experience with collecting, analyzing, and reporting fuel data are reported in the sections below.

The FHWA collects data from the states and estimates missing data based on various statistical models to produce tabulations of highway usage. In addition to the on-highway fuel use, FHWA also maintains information on off-highway and non-highway gasoline use. The Energy Information Administration (EIA), EPA, and the U.S. Census Bureau also collect and maintain off-highway motor fuel data. Each of these sources had slightly different reasons for the data collection efforts.

2.1.2 Federal Highway Administration

The FHWA, part of the U.S. Department of Transportation (DOT), has a mission to create, maintain, and improve the nation’s highway system and its intermodal connections (U.S.DOT/FHWA, 2000). Related to this mission, FHWA collects information on fuel usage. Of primary importance is fuel used on the nation’s highways. Using State-provided data and computer models, the FHWA also estimates off-highway use of gasoline.

The models used by FHWA were originally developed by ORNL in 1986; these models were modified by ORNL in 1994. The 1986 study was conducted by Greene and Holcomb (1986) to estimate the off-highway and non-highway fuel consumption of gasoline for transportation using data from 1982. This study determined that, with the exception of aviation gasoline, state-level estimates of gallons of gasoline used off-highway were accurate within about $\pm 50\%$. This study, which was updated by Miaou and Lu (1994), included both gasoline and gasohol for data year 1992. Table 1 shows the results of both of these studies.

Table 1. Off-highway consumption of *gasoline* (1986 study) and *gasoline plus gasohol* (1994 study) (millions of gallons)

Date of study ^a	Agriculture	Commercial and industrial	Construction	Small equipment and recreation	Total off-highway	Total off-highway and non-highway consumption	% ^b
1986	1,500	250-500	200	250-500	1,975-2,700	4,800	56
1994	843	352	244	2,976	4,415	5,625	75

Sources: Greene and Holcomb (1986, p. i); Miaou and Lu (1994, p. ix).

^aThe data year used for the 1986 study was 1982; for the 1994 study, it was 1992.

^bThe percentage is calculated by dividing the off-highway gallons by the total off-highway plus non-highway gasoline use. Non-highway includes aviation, marine, and miscellaneous uses.

Most notable in the fuel use changes between the 1986 and 1994 studies are a 44% decrease in gasoline use for agricultural purposes (Section 2.2.4) and an approximately 700% increase in gasoline use for small equipment and recreation (Section 2.2.7). The 1994 version of the model was based on new surveys as well as other data. Basically, the 1994 model is still used by FHWA in its annual estimates of off-highway gasoline use. Minor revisions to the model, updated data sets, state-submitted data, and annual growth factors update the estimates each year. At the current time, the FHWA has no plans to develop a new off-highway/non-highway model.

While FHWA is primarily concerned with on-highway fuel use, determination of off-highway gasoline consumption is also important. Although all non-public-use gasoline is taxed, taxes paid on gasoline used off-highway should not be attributed to on-highway use. Table 2 shows the total gallons of gasoline and gasohol determined by FHWA to have been used for off-highway/non-highway purposes from 1997 through 2001. In addition to the categories of agriculture, industrial and commercial, construction, and miscellaneous shown in the table, FHWA estimates usage in aviation and marine categories, which are included in the total off-highway and non-highway column.

**Table 2. Total off-highway and non-highway gasoline/gasohol use^a
(millions of gallons)**

Year	Agriculture	Industrial/ commercial	Construction	Miscellaneous	Total off-highway	Total off- highway and non-highway consumption	% ^b
1997	984.5	437.1	300.5	252.7	1,974.8	3,296.6	60
1998	906.9	479.1	234.7	221.7	1,842.4	3,149.7	58
1999	702.7	361.7	177.8	279.9	1,522.0	2,942.4	52
2000	652.3	380.0	191.5	266.8	1,490.5	2,910.8	51
2001	801.6	1,095.2	506.7	204.9	2,608.3	3,958.0	66

Source: FHWA, *Highway Statistics*, various years, Table MF-24.

^aGallons of gasohol, a blend of gasoline and fuel alcohol, are also included in this table. The large increase in total gallons between 2000 and 2001 are due to improved estimation procedures used by FHWA in 2001.

^bThe percentage is calculated by dividing the off-highway gallons by the total off-highway plus non-highway gasoline use. Non-highway includes aviation and marine.

FHWA derives the off-highway gasoline usage in several steps. Using data from the Vehicle Inventory and Use Survey (VIUS), growth rate factors, and averages for vehicle miles traveled and miles per gallon, off-highway gasoline used by trucks is estimated.

In addition to gasoline use by trucks operating off-highway, gasoline usage for other equipment is also estimated. The primary data source for the agriculture module is the *Census of Agriculture*; other data sources include the U.S. Department of Agriculture's *Farm Production Expenditures* summary report, EIA's *Petroleum Marketing Annual*, and FHWA's *Highway Taxes and Fees*. The construction module uses the *Statistical Abstract of the United States* and combines this data with VIUS data to derive gallons of gasoline. The industrial/commercial module uses VIUS data only; therefore, for this category, fuel usage is limited to gasoline used by trucks. The miscellaneous category contains gallons reported by the states that were not

reported in any other category. Fuel usage of off-highway mobile equipment such as forklifts, sweepers, and material handling equipment is not included in the FHWA estimates. While FHWA collects data on off-highway gasoline use, FHWA does not estimate the use of off-highway diesel fuel, which is exempt from Federal taxes. Taxes are applied only to undyed diesel, which is legal for use on-highway. It is likely that some undyed diesel fuel is used off-highway; however, FHWA does not attempt to estimate that usage.

2.1.3 Energy Information Administration

The EIA is a statistical agency of the U.S. Department of Energy (DOE). EIA provides energy-related data to assist government agencies with decision making. EIA collects and analyzes data and provides products such as reports and forecasts of energy use (U.S. DOE/EIA, 2004a). One such product is the *Annual Energy Outlook* (U.S. DOE/EIA, 2004b). This document contains tables and graphs on energy prices, consumption, production, trends, projections, and issues. It contains, for example, consumption data by industrial sector (supplemental tables, Table 32) and transportation-specific energy use by mode and type (supplemental tables, Table 33). Another EIA product, the *Annual Energy Review* (U.S. DOE/EIA, 2001, Table 5.12c), contains information by transportation sector, on petroleum consumption. Although there is an abundance of information, no specific data relates strictly to off-highway fuel used for transportation.

According to the Diesel Technology Forum (2003a, p. i), off-highway equipment is powered primarily by diesel. One major EIA product, therefore, that relates to off-highway use is the annual series of reports, *Fuel Oil and Kerosene Sales* (FOKS) (U.S. DOE/EIA, 2001), which is based on an annual survey of companies that sell distillate fuel to consumers. According to the 2001 version of this report, distillate fuel oil sales reached a high of 59.9 billion gallons in 2001, and the dominant user was the transportation sector (about 64% of the total, most of which was gallons used on-highway). Off-highway diesel sales in 2001 were a total of 2.7 billion gallons, up from a total of 2.6 billion gallons in 2000.

2.1.4 Environmental Protection Agency

The primary goals of the EPA are to protect human health and safeguard the environment. In general EPA classifies emissions into three categories – mobile, stationary, and area sources. EPA further subdivides mobile sources into on-highway and non-highway categories (EPA, 2002a, p. 1-1). (Note that the EPA uses the term non-highway or non-road to include land-based off-highway vehicles as well as rail and marine.) In early 2000, EPA issued the Final Rule on the new Tier 2 motor vehicle emissions standards for on-highway vehicles (EPA, 1999, 40 CFR 80, 85 and 86).

Because off-highway and non-highway engines have a significant impact on the total mobile emissions, EPA is proposing requirements to reduce emissions from off-highway and non-highway diesel engines; these requirements would be similar to the on-highway requirements and would be phased in for new engines. The proposed new emission standards would apply to four categories of off-highway and non-highway diesel engines – (1) land-based, (2) commercial marine, (3) locomotives, and (4) recreational marine. For the land-based, off-highway diesel

equipment, the new emission rules include standards that apply to both the equipment and the fuel.

2.1.4.1 EPA Estimates Based on EIA’s FOKS Report

In April 2003, EPA released a Draft Impact Analysis of the impact of the new emission regulations for off-highway and non-highway diesel engines. Table 3 shows off-highway distillate use, by end use category for calendar year 2000 derived by EPA based on the fuel sales volumes reported in EIA’s (2002) FOKS report. The EIA report estimates sales and does not directly represent fuel consumption by end-users. Thus, the EIA numbers represent all potential uses, including on-highway and off-highway, as well as mobile and stationary. To derive an estimate of off-highway mobile engines, EPA first estimated a proportion of the sales representing diesel fuel (i.e., not heating oil), and then estimated a second proportion for off-highway use. Then, using EIA energy use descriptors, EPA estimated fuel consumption for each end use category.

Table 3. Land-based off-highway distillate (*diesel*) usage for calendar year 2000 (millions of gallons)

End use	Consumption	Example equipment ^a
Farm	3,080	Tractors, irrigation equipment, milking machines
Off-highway (construction)	1,805	Earthmoving equipment, cranes, generators
Off-highway (other)	409	Logging, junk yards
Industrial	1,721	Manufacturing and mining equipment, producing and processing goods
Commercial	488	Nonmanufacturing equipment, service providers
Oil company	342	Drilling equipment, field and refinery operations
On-highway ^b	229	See footnote <i>b</i>
Total	8,074	

Source: EPA (2003, Table 7.1-6)

^aThese examples are extracted from the list in the U.S. DOE/EIA (2001, p. 53).

^bThis amount represents non-highway usage of low-sulfur highway diesel fuel that was taxed when purchased, for which no tax credit was claimed, and which was not accounted for in the U.S. DOE/EIA (2002) survey.

2.1.4.2 EPA Estimates Based on the NONROAD Model

In order to conduct a cost analysis for determining impacts of the new emission regulations related to the off-highway use of diesel fuel, EPA used data from the EIA FOKS report (U.S. DOE/EIA, 2002, as explained above). EPA also developed an off-highway and non-highway emissions model (NONROAD2002) to provide state and local agencies with a method to determine measurements of non-highway emissions. This model is available to the public from the EPA website and can be used to estimate vehicle population, fuel usage, and emissions, by sector and fuel type, for almost any geographic area.

Problems with estimating fuel use for off-highway vehicles include determining in-use equipment population and age, activity (steady state or transient), load, and emission rates since the equipment is not registered or permitted as it is for on-highway engines (Pollack et al., 1997).

In documenting the source and rationale of the engine population data for the NONROAD model (Lindhjem, 1998), EPA explained some of the difficulties in establishing an off-highway and non-highway engine inventory. The definition of a mobile off-highway or non-highway engine characterizes it as one that moves from one place to another within a 12-month period. Certain engines, such as generators, pumps, compressors, and welders, could therefore be stationary or mobile. In addition, in determining fuel use and emissions, certain small engines used in lawn and garden equipment have very different usage rates for residential vs commercial owners. These problems were addressed in the NONROAD model.

The NONROAD model includes the following vehicle and equipment types, not all of which are vehicles used in transportation. In addition, some of the transportation sectors, such as railroad and marine, are not within the scope of the current report (EPA, 2002, p. 1-1).

- Recreational vehicles, such as all-terrain vehicles and off-highway motorcycles
- Logging equipment, such as chain saws and skidders
- Agricultural equipment, such as tractors
- Construction equipment, such as graders and back hoes
- Industrial equipment, such as forklifts and sweepers
- Residential and commercial lawn and garden equipment, such as lawn mowers and leaf blowers
- Marine vessels
- Locomotive equipment
- Aircraft (EPA, 2002a)

Table 4 provides the fuel consumption for off-highway, land-based, diesel engines based on EPA's NONROAD model.

Table 4. Fuel consumption for land-based off-highway *diesel* engines, selected years

Year	Consumption (millions of gallons)
1996	9,304
1997	9,581
2000	10,496
2001	10,798

Source: EPA (2003c, Table 3.1-8)

Although Tables 3 and 4 are both EPA products, the methodologies for deriving the fuel consumption totals were different; thus, results of the two methodologies for estimating fuel use were not consistent. As can be seen by comparing the total fuel usages in Tables 3 and 4 for the year 2000, there is a difference of over 2 billion gallons. This discrepancy results from differences in definitions (e.g., usage categories) between the two studies.

EPA's NONROAD model can be used to calculate local, county, regional, state, and national emissions and fuel consumptions by usage sector, fuel type, and year. These totals may be sorted by Source Category Code (SCC) for each sector. It should be noted that some off-highway fuel-using equipment included in these totals is not transportation related (e.g., chain saws) and does not fit the definition of transportation-related equipment as defined in Section 1.2. Although Table 5 data include these non-transportation-related gallons, they will not be included in the final results of this study. Total off-highway mobile fuel consumption for 2001 by fuel type is shown in Table 5.

Table 5. Total off-highway mobile fuel consumption by fuel type, including fuel usage from all SCCs, 2001

Fuel type	Fuel consumption (millions of gallons)	
CNG ^a	199,287 (actual gallons)	219 (converted)
Diesel		10,778
Gasoline		4,809
LPG		2,126
Total		17,932

Source: Derived from EPA (2002b) NONROAD2002 model.

^aThe gallons of CNG, which is a gas, are reported from the NONROAD model as actual gallons in the first column; in the second column, they have been converted to gasoline gallons equivalent (GGE) using 0.0011 as the conversion factor.

The NONROAD model also contains information about the size of the off-highway engines, measured in horsepower. Table 6 shows the fuel consumption by sector, fuel type, and horsepower category for all SCCs.

2.1.5 U.S. Census Bureau

The Census Bureau conducts the VIUS every five years to gather data on the truck population in the United States (U.S. Department of Commerce, 2000). The survey covers registered trucks that are used for both personal and business use, that are both light and heavy trucks, and that are used both on-highway and off-highway. It does not include equipment that would not be classified as a "truck." According to the 1997 VIUS, the most recent survey for which data are available, trucks that are used off-highway use the following amount of fuels, by fuel type and sector (Table 7).

2.1.6 Other Sources for Usage Data

Kean et al. (2000) published a study on off-highway diesel engines using data year 1996. To derive diesel fuel consumption, Kean, Sawyer, and Harley used data from the EIA FOKS (U.S. DOE/EIA, 2002) they then subtracted out diesel fuel used on-highway. The fuel usages for end-use categories of interest to the current study are shown in Table 8.

Table 6. Total off-highway mobile fuel consumption by sector, fuel type, and horsepower category, 2001 (millions of gallons)

	Gasoline	Diesel	Other ^a	Total
Agriculture				
100 hp or less	67	813	7	887
Over 100 hp	15	2,507	3	2,525
Industrial and commercial				
100 hp or less	2,615	1,219	1,444	5,278
Over 100 hp	60	818	864	1,741
Construction				
100 hp or less	146	1,086	21	1,252
Over 100 hp	3	4,263	3	4,268
Personal and recreational				
100 hp or less	1,869	4	1	1,874
Over 100 hp	33	9	0	42
Other				
100 hp or less	1	7	1	8
Over 100 hp	1	54	2	57

Source: Derived from EPA (2002b) NONROAD2002 model.

^aIncludes LPG and CNG. The gallons of CNG have been converted to gasoline gallons equivalent (GGE) using the conversion factor. 0.0011.

Table 7. Fuel used by off-highway trucks, 1997 (millions of gallons)

Sector	Gasoline	Diesel	Other ^a	All
Agriculture	271	91	5	367
Industrial and commercial ^b	388	324	5	718
Construction ^c	183	126	0	309
Personal	1,660	26	6	1,692
Total	2,502	567	16	3,086

Source: U.S. Department of Commerce (2000).

^aThe “other” category of fuel includes LPG, LNG, and other fuels.

^bThe “industrial and commercial” sector includes the following VIUS business uses: manufacturing, forestry or lumbering, mining and quarrying, utilities, daily rental, wholesale trade, retail trade, and business and personal services.

^cThe construction sector also includes contractor activities.

Table 8. Off-highway consumption of diesel fuel for data year 1996

	Usage by sector (millions of gallons)				Total off-highway and non-highway consumption	% ^a
	Farm	Industrial and commercial	Construction	Total off-highway		
Usage	3,237	2,278	1,644	7,159	12,950	53
Examples of engine applications	Tractors and combines	Forklifts, aerial lifts, mining equipment, other (logging equipment)	Cranes, paving, earth-moving equipment			

Source: Kean et al. (2000, pp. 1931-1932; data converted from liters to gallons).

^aThe percentage is calculated by dividing the off-highway gallons by the total off-highway plus non-highway diesel use.

The methodology used by Kean et al. (2000) to derive off-highway diesel fuel use is very similar to that explained in Section 2.1.4.1. The FOKS report (U.S.DOE/EIA, 2002) is a compilation of distillate fuel sales, not uses, and also includes all engine types, both mobile and stationary.

When considering off-highway fuel use, the growth of suburban America is resulting in a growth in the number of small engines, such as residential and commercial lawn and garden equipment. In addition, personal and recreational off-highway activities are increasing.

The *Washington State Nonhighway and Off-road Vehicle Activities Fuel Use Survey* (Herbert Research, Inc., 2003) was conducted over a one-year period ending December 2002. A stratified,¹ random sample of Washington State's 5.1 million street-licensed and registered off-highway (not street legal) vehicles was selected to measure the relative portion of motor vehicle fuel attributable to vehicles operating on back roads and off-roads. According to the survey, about 1% of the gasoline sold in Washington was used on back roads or off of roads for recreational purposes. (This fuel use excludes fuel consumed in snowmobiles.) It must be stressed that this survey concerned only fuel used for recreational purposes and did not relate to all off-highway uses.

If the results of the Washington State survey were extrapolated to the entire United States, the off-highway recreational fuel use for gasoline alone would equal 1,341 million gallons in 2001.²

2.1.7 Mechanisms for Transport and Delivery of Fuel

Refueling of off-highway equipment takes three basic approaches: on-site fuel storage tanks, on-site bulk fuel deliveries, and portable fuel containers. Each of these delivery mechanisms has the potential for fuel spillage.

¹ Stratified by county size and vehicle type.

² Total gasoline consumption in 2001 equal over 134,110 million gallons, according to *Highway Statistics 2001*, Table MF-21. Thus, 1% of total gallons equal about 1,341 million gallons.

On-site fuel storage tanks (diesel) are used for large operations at a particular site, such as farms or mines. When used off-highway, diesel must be dyed prior to removal from the terminal rack. There are rules concerning transport, delivery, licensing, and reporting of dyed diesel because of special tax provisions (Illinois Department of Revenue, 1999). Fuel is delivered to the on-site storage tanks by suppliers (as bulk fuel deliveries), usually by tank car or tank truck. Fuel storage tanks and pumps can also be rented.

On-site bulk fuel deliveries are used for operations that are not permanent at a particular site, such as construction sites. Oil companies provide this service and fuel many different types of equipment. Deliveries can be scheduled during normal vehicle downtime, and different types of fuel (e.g., diesel, kerosene) can usually be hauled in multi-compartment delivery trucks (Superior Oil Company of New Jersey, Inc., 1998). Because of the need for rapid refueling and the potential for spillage, there are markets for specialized refuel systems (e.g., nozzles and receivers) (Fluid Control Products, 2003).

Portable fuel containers are used for a broad range of small off-highway applications, such as lawn mowers. Portable containers may be used for either gasoline or diesel. Containers are privately owned and refilled as needed. These containers are sources of hydrocarbon emissions from both vapor displacement and spillage. The State of California proposed control measures through requiring use of a spill-proof nozzle and container (CARB, 2003).

2.2 DATA ANALYSIS

A comparison of the various data sources is difficult because of differences in time frames for the studies, definitions of the sectors, and types of equipment or fuels included. In addition, the studies must make assumptions about equipment populations and fuel “efficiency” because of the lack of registration requirements and reporting. Differences in the assumptions and methodologies contribute to discrepancies among the models. In an attempt to compare the different data sources, a “common” set of off-highway sectors was selected. Table 9 lists these sectors and the data from each data source that is included in each sector for purposes of this data analysis.

An effort to make a comparison of the models discussed in Section 2.1 is shown in Table 10. The results of Greene and Holcomb (1986) and Miaou and Lu (1994) are not included in this table. These two models were used to populate the FHWA off-highway database in the year they were developed. Because FHWA updates and reruns the models on an annual basis, only the FHWA values are reported in the table.

Table 9. Definition of contents of off-highway sectors by data source

Source	Agriculture	Industrial and commercial	Construction	Personal and recreational	Other
VIUS	Agricultural/ farming/ fisheries	Manufacturing, mining/quarrying, utilities, forestry/lumbering, daily rental, wholesale trade, retail trade, business/personal services	Construction, contractor	Personal	
NONROAD	Agricultural	Industrial, commercial, logging, lawn and garden (commercial)	Construction and mining	Recreational, lawn and garden (residential)	Airport
EPA (using FOKS)	Farm	Industrial, commercial, oil company, other (logging)	Construction		On-highway
FHWA	Agriculture	Industrial and commercial	Construction		Miscellaneous
Kean et al.	Farm	Industrial, commercial, oil company, other (logging equipment)	Construction		

Table 10. Comparison of data sources for gallons of off-highway fuel by fuel type and sector^a (millions of gallons)

Data year	Source	Agriculture	Industrial and comm.	Construction	Personal and rec.	Other	Total off-highway
<i>Gasoline (including gasohol)</i>							
1997	VIUS (trucks only)	271	388	183	1,660	0	2,502
1997	NONROAD ^b	78	2,603	156	1,850	18	4,706
1997	FHWA	985	437 ^c	300	0	253	1,975
2001	NONROAD ^b	82	2,656	149	1,902	21	4,809
2001	FHWA	802	1,095 ^c	507	0	205	2,608
<i>Diesel</i>							
1996	Kean et al.	3,237	2,278	1,644	0	0	7,159
1997	VIUS (trucks only)	91	324	126	26	0	567
1997	NONROAD ^b	2,965	1,789	4,768	11	48	9,581
2000	EPA (using FOKS)	3,080	2,960	1,805	0	229	8,074
2001	NONROAD ^b	3,320	2,037	5,348	12	61	10,778
<i>Other (CNG, LPG, alternative fuels)^d</i>							
1997	VIUS (trucks only)	5	5	0	6	0	16
1997	NONROAD ^b	LPG = 0 CNG =11,881 CNG equi=13	LPG = 1,829 CNG = 173,009 CNG equi=190	LPG = 21 CNG = 43 CNG equi=0	LPG = 1 CNG = 0	LPG = 2 CNG = 0	LPG = 1,854 CNG = 184,933 CNG equi=203
2001	NONROAD ^b	LPG = 0 CNG =8,469 CNG equi=9	LPG =2,099 CNG =190,772 CNG equi=210	LPG = 24 CNG = 46 CNG equi=0	LPG = 1 CNG = 0	LPG = 2 CNG = 0	LPG = 2,126 CNG = 199,287 CNG equi=219

^aExcludes aviation, marine, and locomotive. For definitions of the contents of each sector, see Table 9.

^bThe total gallons in the NONROAD model are derived using all SCC, which implies that some land-based, non-transportation-related engines are included.

^cIncludes only data for fuel use by registered trucks; data are from VIUS, with annual growth rates based on models.

^dFor CNG, which is a gas, the use of “gallons” as a unit of measure is not comparable with gallons of gasoline or diesel, both of which are liquid fuels. Therefore, for the NONROAD values, three values are given, one for LPG (in gallons, as provided by the model), one for CNG (in gallons, as provided by the model), and one for CNG equivalence (i.e., CNG has been converted to GGE, using the conversion factor 0.0011).

2.2.1 Gasoline

The “total” gallons of gasoline used off-highway vary by source, as shown in Table 10. The sources, however, do not always measure the same usage. The VIUS, for example, estimates off-highway fuel usage from registered trucks. The NONROAD model, on the other hand, does

not include fuel usage from any of these trucks. Therefore, these two sources for off-highway fuel usage are mutually exclusive.

In Table 10, the fuel usage as reported by the NONROAD model includes all SCCs, which implies that some non-transportation-related engines are included. The NONROAD model estimates the highest total off-highway gasoline consumption.

The FHWA-reported fuel usage for the industrial and commercial sector is limited to data based on VIUS; hence, it includes only trucks. Since VIUS is only conducted every five years, the FHWA model includes an annual growth factor. The fuel usage reported in 1997 is based on the 1992 VIUS (plus incremental annual growth) and therefore does not precisely match the data provided by the 1997 VIUS, which had not been published at the time FHWA's *Highway Statistics 1997* was prepared. In addition, FHWA data does not include any fuel usage for personal and recreational activities. According to both VIUS (only trucks) and the NONROAD models, this is an area for large gasoline use.

2.2.2 Diesel

Diesel is a liquid, and gallons are reported as gallons of diesel without conversion to GGE.

FHWA does not report diesel gallons used off-highway. Diesel is, however, the fuel of choice for off-highway work. Two additional sources, Kean et al. (2000) and EPA, both of which use the EIA FOKS report (U.S.DOE/EIA, 2002) as starting points, provide fuel estimates for diesel. The VIUS data, again, refer only to registered trucks used off-highway. Heavy equipment is not registered; therefore, the VIUS data are much lower than that of the other sources. Excepting VIUS, the data sources are more in agreement with each other for diesel than they are for gasoline usage. As noted above, the NONROAD model does not include registered trucks.

The EPA (using FOKS) reports 229 million gallons of diesel used off-highway which had been purchased as on-highway (low sulfur) diesel (Table 10, "Other" category). This undyed diesel fuel has met certain EPA criteria to ensure that it was used off-highway and was not counted in any other category.

2.2.3 Other Fuels

This category contains all fuels other than gasoline/gasohol and diesel. When VIUS asks respondents to mark the fuel used by the truck identified for the survey, they are given two "other" options – LPG and LNG (a single option) and other, with the request to specify the meaning of other.

The NONROAD model separately calculates fuel use for LPG and LNG. In the model, both are reported in gallons. In Table 10, LPG, a liquid, is reported in gallons and is not converted to GGE. CNG, a gas, is given in two units – gallons of CNG as a gas and in GGE. The factor for converting CNG gallons to GGE was obtained from personal communication with the U.S. EPA Office of Transportation and Air Quality.

2.2.4 Agriculture

As noted in Tables 1 and 2, gasoline used in agriculture has generally decreased over time. In the United States, as farms have decreased in number and increased in average acreage, the machinery used for agricultural production has changed from using gasoline to using diesel fuel (Figure 1).

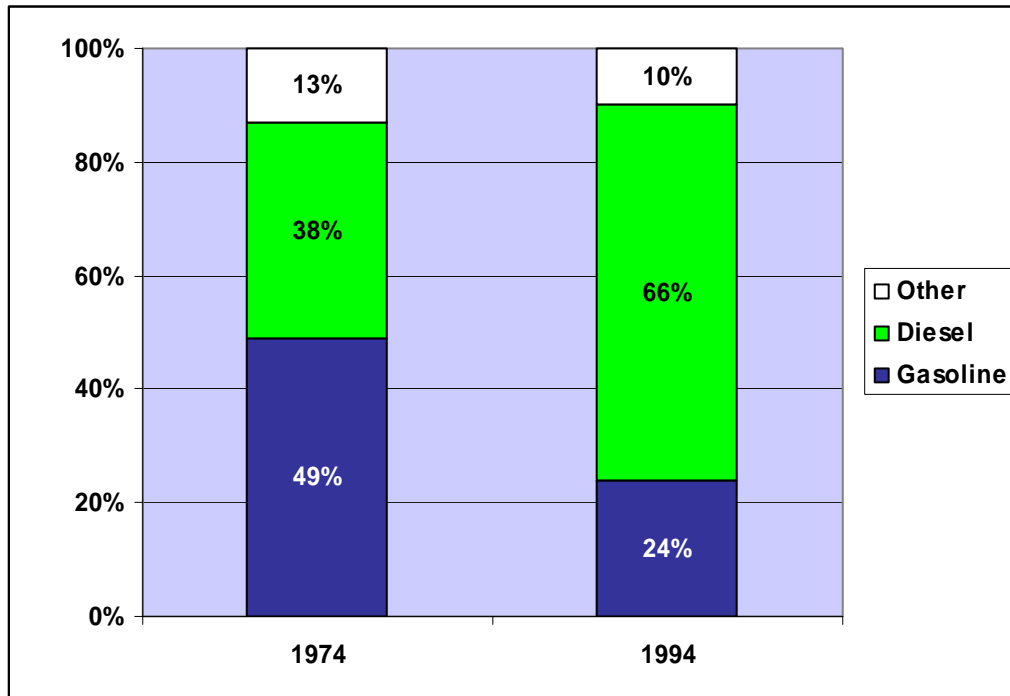


Figure 1. Changes in the percentages of fuel types used in agriculture between 1974 and 1994. Source: Diesel Technology Forum (2003a, p. 6).

The differences in the gallons of gasoline attributed to agricultural usage by FHWA and the NONROAD model are of concern. While it is true that the NONROAD model does not include registered trucks that might be used off-highway, this does not explain the total discrepancy, because when VIUS and NONROAD totals are added together, they still are only about one-third of the gallons reported by FHWA for 1997.

The sources agree fairly closely on diesel gallons used for agricultural purposes. Agriculture is not a big user of alternative fuels.

2.2.5 Industrial and Commercial

The industrial-commercial category is the category with the largest use of alternative fuels, particularly CNG. The equipment that is the predominant user of CNG, according to the NONROAD model, is forklifts.

In VIUS, the industrial-commercial sector is the category with the largest use of diesel fuel. For the NONROAD model, this sector has the largest use of gasoline for off-highway purposes.

2.2.6 Construction

FHWA's estimates of gasoline use in the construction category are double those of the NONROAD model. If the gasoline usages from VIUS and NONROAD are combined, the total is almost equal to the FHWA estimate. Construction is the largest consumer of diesel fuel according to the NONROAD model, using about half of all diesel used off-highway.

2.2.7 Personal and Recreational

This sector is difficult to estimate. While usage of diesel and other fuels is insignificant, use of gasoline is, according to VIUS and to the NONROAD model, very large. This is, in fact, the largest sector of gasoline use as reported by VIUS. It is the second largest sector for the NONROAD model, following the industrial/commercial category. This category includes the off-highway use of trucks and motorcycles, as well as smaller equipment such as residential lawn mowers.

2.2.8 Other

This sector is included only for those fuel uses that did not fit in the other more specific categories. For the NONROAD model, it contains airport vehicles; for the FHWA, it is entitled "miscellaneous" (see also Section 2.1.2); for the EPA (using FOKS) data set, it includes on-highway diesel used off-highway and not counted elsewhere.

3. FUEL USE RESULTS

A review of possible sources for off-highway fuel usage data revealed that there was no definitive source. FHWA reported only gasoline gallons. VIUS covered all fuel types of interest to this study; however, it was limited to the off-highway fuel usage of registered trucks. The FOKS report contained both mobile and stationary engines. The NONROAD model seemed to be the most complete and useful fuel use data set for the purposes of this study, except it did not include registered trucks and it included some non-transportation-related engines.

Thus, to derive total off-highway transportation-related fuel use, by fuel type, it was decided to combine data from two sources. EPA’s NONROAD model was used to derive usage data for all off-highway transportation-related equipment that is covered by the model. VIUS was used to derive usage data for all registered trucks used off-highway.

Because EPA’s definition for mobile equipment in the NONROAD model includes equipment that is not transportation-related, fuel used by some sources (e.g., chainsaws) had to be subtracted. A listing of SCCs applied in the final estimation of off-highway fuel use for this report is provided in Appendix A. It should be noted that fuel for vehicles such as pavers and curbers, which may be USED on-highway, but not for transportation, have been included in this analysis. Fuel used in these vehicles is not captured in any on-highway fuel use category.

To derive the fuel used by registered trucks when driven off-highway, VIUS data were used. VIUS data and NONROAD data are mutually exclusive. For the 1997 data year, the sum of the fuel use from the NONROAD model for the entire United States, less fuel use for those SCCs that are not transportation-related, plus VIUS off-highway fuel use for registered trucks equals the total fuel used, by sector (Table 11).

Table 11. Total estimated transportation-related off-highway fuel consumption, 1997^a (millions of gallons)

Sector ^b	Gasoline	Diesel	Other ^c	Total	Share by sector
Agriculture	319	2,994	5	3,318	19.4%
Industrial and commercial	1,761	1,579	1,854	5,193	30.4%
Construction	289	4,766	18	5,073	29.7%
Personal and recreational	3,425	37	7	3,469	20.3%
Other	2	48	2	52	0.3%
Total off-highway	5,797	9,424	1,885	17,106	100.0%

^aFuel use for SCCs not related to transportation was removed.

^bContents of each sector based on definitions from the original models are given in Table 9.

^cThe category of “Other” fuels includes CNG (converted to GGE), LPG, and other alternative fuels.

Thus, an estimated 17.1 billion gallons, or 1.1 mbpd, of fuel was used for transportation-related purposes off-highway in 1997, 11% of on-highway fuel use. According to *Highway Statistics 1997*, the total fuel (gasoline plus special fuels) used on-highway during 1997 was 150.3 billion gallons.

3.1 OFF-HIGHWAY FUEL USE FOR 2001

To derive the total estimated off-highway fuel consumption for 2001, the VIUS fuel estimates for 1997 needed to be adjusted. This adjustment was made using a comparison of the outputs from the NONROAD model for 1997 and 2001, by sector and fuel type. After deriving the adjusted VIUS numbers for 2001, results of the two sources were summed as described above for 1997. Table 12 shows total fuel use of 18.6 billion gallons, or 1.2 mbpd, for off-highway transportation-related purposes in 2001.

Table 12. Total estimated transportation-related off-highway fuel consumption, 2001 (millions of gallons)

Sector ^a	NONROAD ^b			VIUS			Total fuel use			Total	Share by sector
	Gasoline	Diesel	Other ^c	Gasoline	Diesel	Other	Gasoline	Diesel	Other		
Agriculture	51	3,250	0	287	102	4	338	3,352	4	3,694	19.9%
Industrial and commercial	1,351	1,426	2,103	382	368	6	1,733	1,794	2,108	5,636	30.3%
Construction	100	5,205	19	173	141	0	274	5,347	19	5,639	30.3%
Personal and recreational	1,816	13	1	1,708	29	6	3,524	42	7	3,573	19.2%
Other	2	61	2	0	0	0	2	61	2	65	0.3%
Total	3,321	9,955	2,125	2,550	641	16	5,870	10,596	2,141	18,607	100.0%

^aContents of each sector based on definitions from the original models are given in Table 9.

^bFuel use for SCCs not related to transportation was removed.

^cThe category of "Other" fuels includes CNG (converted to GGE), LPG, and other alternative fuels.

The proportion of fuel used off-highway by each sector is shown in Figure 2. The proportion of fuel by fuel type is shown in Figure 3.

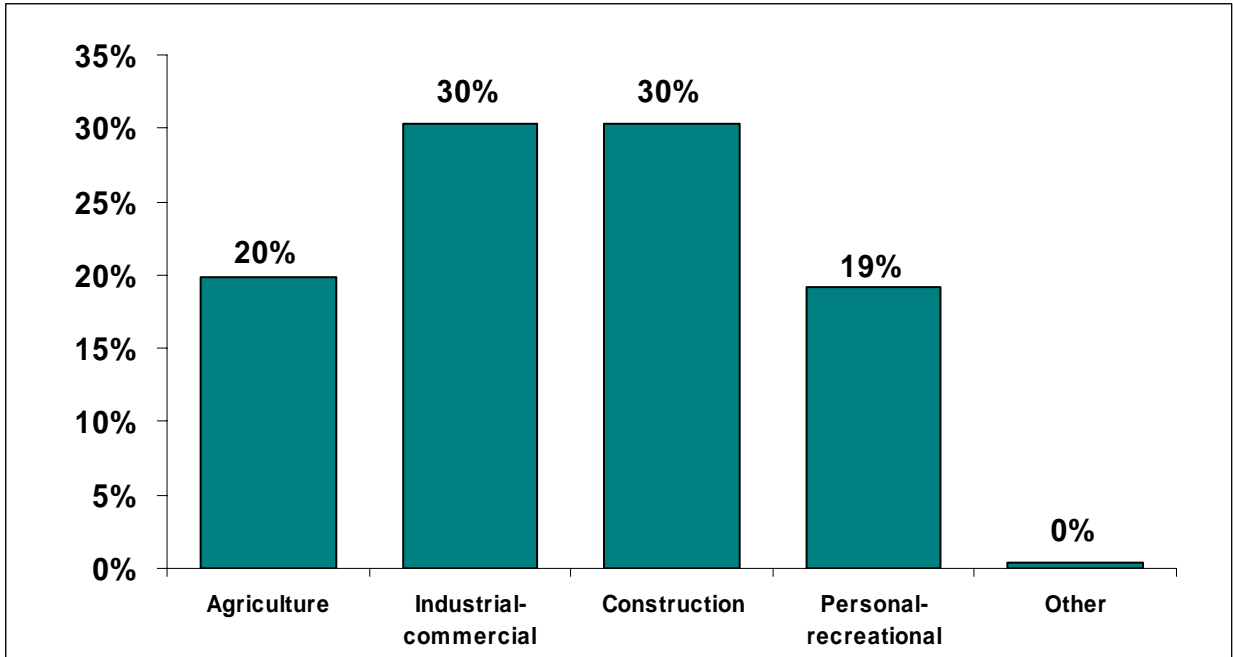


Figure 2. Proportion of transportation-related fuel used off-highway by sector, 2001.

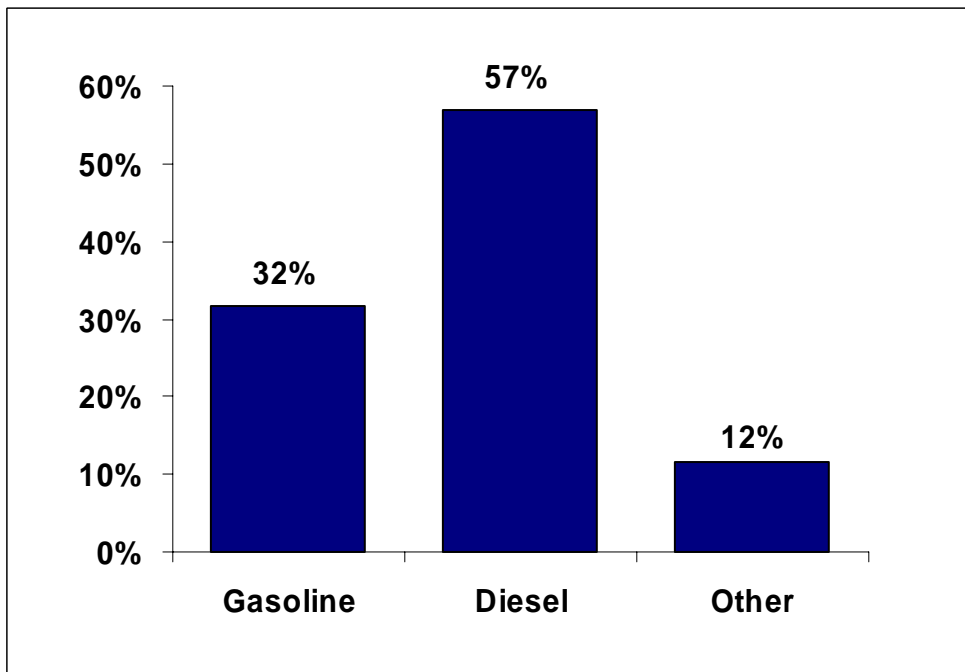


Figure 3. Proportion of transportation-related fuel used off-highway by fuel type, 2001.

As can be seen in Figures 2 and 3, the industrial/commercial and construction sectors consume 60% of the fuel used off-highway, and the most commonly used fuel is diesel.

3.2 COMPARISON OF 1997 AND 2001 OFF-HIGHWAY USE

Based on the current analysis, the total off-highway use of fuel grew 8.8% between 1997 and 2001. Every sector experienced growth; however, the greatest percentage growth was in the “other” sector as shown in Table 13. (See Table 9 for examples of the contents of this sector.)

Table 13. Growth in off-highway fuel use by sector, 1997-2001 (millions of gallons)

Sector	Total 1997	Total 2001	Percent change
Agriculture	3,318	3,694	11.3%
Industrial-commercial	5,193	5,636	8.5%
Construction	5,073	5,639	11.2%
Personal-recreational	3,469	3,573	3.0%
Other	52	65	24.7%
Totals	17,106	18,607	8.8%

The proportional use of fuel by fuel type stayed about the same between 1997 and 2001, as shown in Figure 4. The fuel type showing the greatest growth is the category containing alternative fuels (i.e., everything other than gasoline and diesel). Although this category has the smallest fuel use, it appears to be growing. Diesel is the fuel of choice for off-highway usage; about half of all fuel used off-highway is diesel (Table 14).

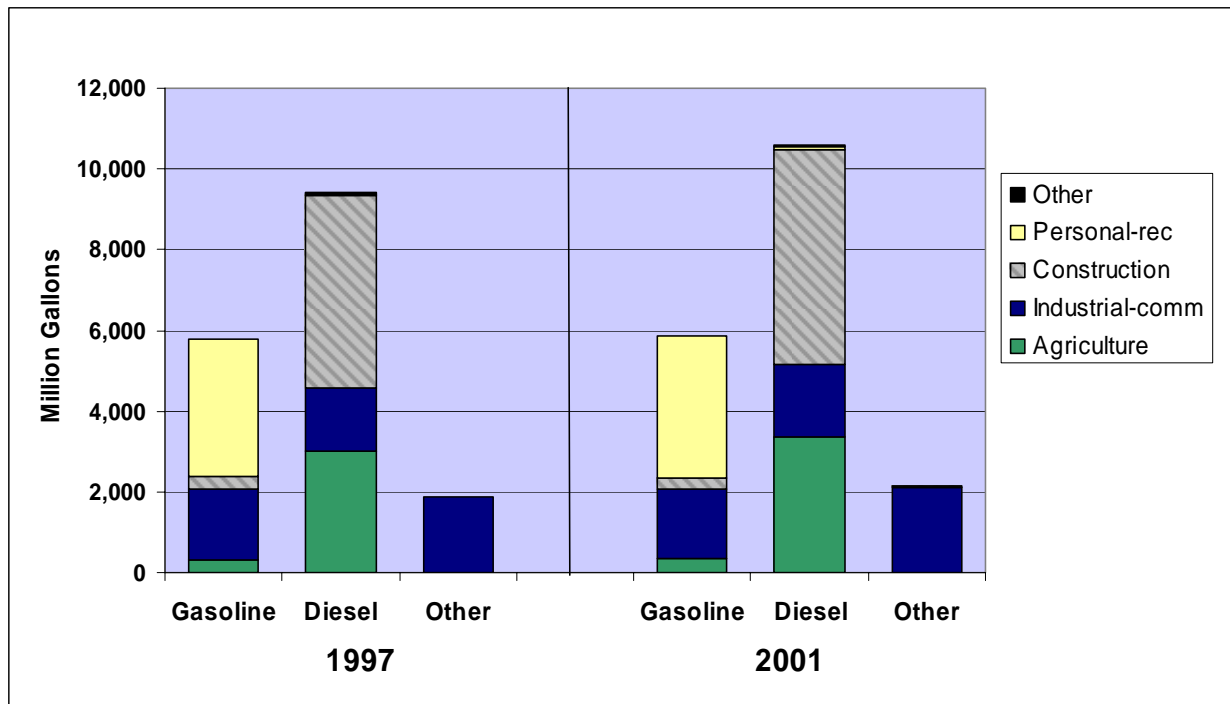


Figure 4. Comparison of fuel use, 1997 and 2001, by sector and fuel type.

Table 14. Growth in off-highway fuel use by fuel type, 1997-2001 (millions of gallons)

Fuel type	Total 1997	Total 2001	Percent change
Gasoline	5,797	5,870	1.3%
Diesel	9,424	10,596	12.4%
Other	1,885	2,141	13.6%
Totals	17,106	18,607	8.8%

3.3 PROJECTED OFF-HIGHWAY FUEL USE IN 2005

Using the growth rate from 1997 to 2001, by sector and fuel type, a projection was calculated for the year 2005 which indicates that the total fuel use off-highway will be almost 20.5 billion gallons. The results of the projection are shown in Table 15.

Table 15. Projection of off-highway fuel consumption in the year 2005 (millions of gallons)

Sector	Gasoline	Diesel	Other	Total
Agriculture	357	3,753	4	4,114
Industrial-commercial	1,705	2,039	2,398	6,143
Construction	259	5,998	21	6,278
Personal-recreational	3,626	47	7	3,680
Other	2	76	3	81
Totals	5,949	11,914	2,433	20,296

4. VEHICLE POPULATION

Knowing the vehicle population is essential for estimating fuel use. The EPA NONROAD model, which was used in the previous section of this report to estimate off-highway fuel use, contains detailed levels of vehicle population. The model uses vehicle population to derive the fuel use estimates. Sections 4.1-4.5 contain the detailed 2001 vehicle population data from the NONROAD model. Section 4.6 contains information on off-highway trucks from the 1997 VIUS (the latest available VIUS).

4.1 AGRICULTURE

The transportation-related off-highway agricultural vehicles include tractors, mowers, combines, balers and other farm-related equipment which has utility in its movement. There are twice as many diesel vehicles as gasoline vehicles in this category (Table 16).

Table 16. Transportation-related off-highway agricultural vehicles, 2001 (number of vehicles)

	Gasoline	Diesel	LPG & CNG
2-Wheel Tractors	5,092	731	0
Agricultural Tractors	2,757	1,609,362	0
Combines	32	224,358	0
Balers	18,954	6,173	0
Agricultural Mowers	8,644	2	0
Tillers > 6 HP	759,337	0	0
Swathers	12,229	52,841	0
Other Agricultural Equipment	23,796	29,068	164
Total	830,841	1,922,536	164

Source: Derived from EPA (2002b), NONROAD2002 model.

4.2 INDUSTRIAL AND COMMERCIAL

Lawn and garden equipment used for commercial purposes make up a large share of the industrial and commercial off-highway vehicle total (Table 17). Because many of the mowers use gasoline, the ratio of gasoline to diesel vehicles is almost 5:1. Most of the alternative fuels used off-highway are used in the industrial sector. The EPA estimates almost 500,000 LPG and CNG forklifts in 2001.

Table 17. Transportation-related off-highway industrial and commercial vehicles, 2001 (number of vehicles)

	Gasoline	Diesel	LPG & CNG
Aerial Lifts	31,550	67,332	21,559
Forklifts	17,318	43,112	494,477
Sweepers/Scrubbers	21,256	41,469	7,416
Other General Industrial Equipment	77,510	57,344	1,630
AC\Refrigeration Trucks	978	225,821	174
Terminal Tractors	1,182	22,170	1,504
Front Mowers	176,646	506,724	0
Lawn mowers	1,671,000	0	0
Rotary Tillers < 6 HP	613,359	0	0
Rear Engine Riding Mowers	51,253	0	0
Shredders < 6 HP	321,756	0	0
Lawn & Garden Tractors	350,243	72,318	0
Chippers/Stump Grinders	29,796	19,735	6,638
Commercial Turf Equipment	1,021,977	39,671	0
Other Lawn & Garden Equipment	768,305	941	0
Shredders > 6 HP	228,810	0	0
Forest Equip. - Feller/Bunch/Skidder	524	20,709	0
Total	5,383,462	1,117,345	533,397

Source: Derived from EPA (2002b), NONROAD2002 model.

4.3 CONSTRUCTION

Nearly two-thirds of all transportation-related off-highway construction vehicles are powered by diesel fuel (Table 18). Alternative fuels are used in many types of construction vehicles, though the share of alternative fuel vehicles to conventional fuel vehicles is small.

Table 18. Transportation-related off-highway construction vehicles, 2001 (number of vehicles)

	Gasoline	Diesel	LPG & CNG
Pavers	8,753	20,245	712
Tampers/Rammers	156,143	0	0
Plate Compactors	115,849	19,193	0
Rollers	9,923	75,215	709
Scrapers	0	20,552	0
Paving Equipment	120,055	8,969	577
Surfacing Equipment	19,478	2,552	163
Trenchers	30,890	49,306	1,889
Bore/Drill Rigs	102,790	38,008	1,358
Excavators	0	112,601	0
Cement & Mortar Mixers	243,961	22,083	0
Cranes	1,040	28,591	646
Graders	0	37,230	0
Off-highway Trucks	0	15,243	0
Rough Terrain Forklifts	977	104,735	1,003
Rubber Tire Loaders	1,558	155,915	1,655
Tractors/Loaders/Backhoes	8,087	337,076	187
Crawler Tractor/Dozers	0	108,719	0
Skid Steer Loaders	9,940	457,815	3,874
Off-Highway Tractors	0	2,234	0
Dumpers/Tenders	28,697	2,150	0
Total	858,138	1,618,431	12,774

Source: Derived from EPA (2002b), NONROAD2002 model.

4.4 PERSONAL AND RECREATIONAL

Over half of all transportation-related off-highway personal and recreational vehicles are residential lawn mowers (Table 19). Nearly all of the vehicles in this category use gasoline.

Table 19. Transportation-related off-highway personal and recreational vehicles, 2001 (number of vehicles)

	Gasoline	Diesel	LPG & CNG
Lawn Mowers	35,982,199	0	0
Rear Engine Riding Mowers	1,919,996	0	0
Rotary Tillers < 6 HP	3,675,866	0	0
Lawn & Garden Tractors	13,120,656	0	0
Other Lawn & Garden Equipment	646,273	0	0
Motorcycles: Off-Road	1,211,471	0	0
Snowmobiles	1,580,514	0	0
All-Terrain Vehicles	4,861,414	0	0
Golf Carts	177,808	0	0
Specialty Vehicles/Carts	456,645	34,700	4,535
Total	63,632,842	34,700	4,535

Source: Derived from EPA (2002b), NONROAD2002 model.

4.5 OTHER OFF-HIGHWAY VEHICLES

The “other” category in the NONROAD model consists of airport ground equipment. For 2001, the EPA model gives an estimate of 1,841 gasoline vehicles; 13,923 diesel vehicles; and 505 alternative fuel vehicles used for airport ground equipment.

4.6 OFF-HIGHWAY TRUCKS

The 1997 VIUS was also used as a data source in the fuel use calculations. In that survey, truck owners were asked “What approximate percent of this vehicle’s 1997 mileage was accounted for by trips off-the-road?” By using these data, ORNL was able to derive the number of off-highway truck equivalents (i.e., one truck having 20% of trips off-the-road and another truck having 80% of trips off-the-road would equal one off-highway truck equivalent). The off-highway truck equivalents are shown by sector and fuel type in Table 20.

**Table 20. Off-highway trucks, 1997
(number of truck equivalents)^a**

Sector ^b	Gas	Diesel	Other
Agriculture	541,485	76,143	6,161
Industrial/Comm	492,438	100,268	2,206
Construction	169,333	62,659	461
Personal	2,353,810	59,793	12,917
Total	3,557,066	298,863	21,745

Source: Derived from the Bureau of the Census (2000).

^aTruck equivalents calculated using the share of trips off-the-road (i.e., one truck having 20% of trips off-the-road and another truck having 80% of trips off-the-road would equal one off-highway truck equivalent).

^bContents of each sector are given in Table 9.

5. SUMMARY AND CONCLUSIONS

The total fuel used off-highway for vehicles and transportation-related equipment in 2001 is estimated at almost 18.7 billion gallons, consisting of 10.6 billion gallons of diesel, 5.9 billion gallons of gasoline/gasohol, and 2.1 billion gallons of other fuels. This total off-highway fuel use in 2001 is over a tenth as large as the amount of fuel used on-highway.

The primary fuel used off-highway is diesel, representing over half of the total off-highway fuel use in 2001. The sector with the greatest fuel usage in 2001 is that of industrial and commercial, representing about a third of all fuel use.

Off-highway fuel use is growing. The off-highway fuel use in 2005 is projected to be almost 20.5 billion gallons.

The number of off-highway vehicles and equipment is obtained from the same sources as the fuel use estimates. Population data from EPA's model show that diesel agricultural tractors are a large share of the agricultural off-highway population; commercial lawn and garden equipment make up the largest share of the industrial and commercial off-highway population; the construction sector has the most vehicle types which can run on alternative fuels; and the personal and recreational sector vehicles are nearly all gasoline vehicles. Estimates of off-highway trucks from VIUS indicate that most off-highway trucks are personal vehicles which run on gasoline.

The transport of fuel to large off-highway vehicles and other equipment is via tanker vehicles where it may be pumped directly into the equipment or into a storage tank, either above-ground or under-ground. Transport to small off-highway equipment is by portable equipment (e.g., a "gas can").

Knowing the population of vehicles and the amounts and types of fuel used in off-highway applications is important for making decisions on new technologies for small engines. Before introducing additional alternative fuels into the off-highway marketplace or making investments in technologies to improve fuel efficiency of off-highway vehicles, data and information are needed about the off-highway sector to show where improvements can make the most impact. Unfortunately, there is no one data source that currently has information on all the off-highway vehicles. ORNL, however, was able to make estimations based on currently available data sources.

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APPENDIX

SOURCE CATEGORY CODES (SCCs) USED IN ANALYSIS OF NONROAD2002 MODEL

**APPENDIX
SOURCE CATEGORY CODES (SCCs)
USED IN ANALYSIS OF NONROAD2002 MODEL**

TRANSPORTATION-RELATED EQUIPMENT USED TO DETERMINE OFF-HIGHWAY FUEL USE			
Classification	Fuel Type	Equipment	SCC
Recreational Equipment	Gasoline	Motorcycles: Off-Road	2260001010
Recreational Equipment	Gasoline	Motorcycles: Off-Road	2265001010
Recreational Equipment	Gasoline	Snowmobiles	2260001020
Recreational Equipment	Gasoline	ATVs	2260001030
Recreational Equipment	Gasoline	ATVs	2265001030
Recreational Equipment	Gasoline	Golf Carts	2265001050
Recreational Equipment	Diesel	Speciality Vehicle Carts	2270001060
Recreational Equipment	Gasoline	Specialty Vehicles/Carts	2260001060
Recreational Equipment	Gasoline	Specialty Vehicles/Carts	2265001060
Recreational Equipment	LPG	Specialty Vehicle Carts	2267001060
Construction and Mining Equipment	Diesel	Pavers	2270002003
Construction and Mining Equipment	Gasoline	Pavers	2265002003
Construction and Mining Equipment	LPG	Pavers	2267002003
Construction and Mining Equipment	Diesel	Tampers/Rammers	2270002006
Construction and Mining Equipment	Gasoline	Tampers/Rammers	2260002006
Construction and Mining Equipment	Gasoline	Tampers/Rammers	2265002006
Construction and Mining Equipment	Diesel	Plate Compactors	2270002009
Construction and Mining Equipment	Gasoline	Plate Compactors	2260002009
Construction and Mining Equipment	Gasoline	Plate Compactors	2265002009
Construction and Mining Equipment	Diesel	Rollers	2270002015
Construction and Mining Equipment	Gasoline	Rollers	2265002015
Construction and Mining Equipment	LPG	Rollers	2267002015
Construction and Mining Equipment	Diesel	Scrapers	2270002018
Construction and Mining Equipment	Diesel	Paving Equipment	2270002021
Construction and Mining Equipment	Gasoline	Paving Equipment	2260002021
Construction and Mining Equipment	Gasoline	Paving Equipment	2265002021
Construction and Mining Equipment	LPG	Paving Equipment	2267002021
Construction and Mining Equipment	Diesel	Surfacing Equipment	2270002024
Construction and Mining Equipment	Gasoline	Surfacing Equipment	2265002024
Construction and Mining Equipment	LPG	Surfacing Equipment	2267002024
Construction and Mining Equipment	Diesel	Trenchers	2270002030
Construction and Mining Equipment	Gasoline	Trenchers	2265002030
Construction and Mining Equipment	LPG	Trenchers	2267002030
Construction and Mining Equipment	Diesel	Bore/Drill Rigs	2270002033
Construction and Mining Equipment	Gasoline	Bore/Drill Rigs	2265002033
Construction and Mining Equipment	LPG	Bore/Drill Rigs	2267002033
Construction and Mining Equipment	Diesel	Excavators	2270002036
Construction and Mining Equipment	Diesel	Cement & Mortar Mixers	2270002042
Construction and Mining Equipment	Gasoline	Cement & Mortar Mixers	2265002042
Construction and Mining Equipment	Diesel	Cranes	2270002045
Construction and Mining Equipment	Gasoline	Cranes	2265002045
Construction and Mining Equipment	LPG	Cranes	2267002045
Construction and Mining Equipment	Diesel	Graders	2270002048

TRANSPORTATION-RELATED EQUIPMENT USED TO DETERMINE OFF-HIGHWAY FUEL USE			
Classification	Fuel Type	Equipment	SCC
Construction and Mining Equipment	Diesel	Off-highway Trucks	2270002051
Construction and Mining Equipment	Diesel	Rough Terrain Forklifts	2270002057
Construction and Mining Equipment	Gasoline	Rough Terrain Forklifts	2265002057
Construction and Mining Equipment	LPG	Rough Terrain Forklifts	2267002057
Construction and Mining Equipment	Diesel	Rubber Tire Loaders	2270002060
Construction and Mining Equipment	Gasoline	Rubber Tire Loaders	2265002060
Construction and Mining Equipment	LPG	Rubber Tire Loaders	2267002060
Construction and Mining Equipment	Diesel	Tractors/Loaders/Backhoes	2270002066
Construction and Mining Equipment	Gasoline	Tractors/Loaders/Backhoes	2265002066
Construction and Mining Equipment	LPG	Tractors/Loaders/Backhoes	2267002066
Construction and Mining Equipment	Diesel	Crawler Tractor/Dozers	2270002069
Construction and Mining Equipment	Diesel	Skid Steer Loaders	2270002072
Construction and Mining Equipment	Gasoline	Skid Steer Loaders	2265002072
Construction and Mining Equipment	LPG	Skid Steer Loaders	2267002072
Construction and Mining Equipment	Diesel	Off-Highway Tractors	2270002075
Construction and Mining Equipment	Diesel	Dumpers/Tenders	2270002078
Construction and Mining Equipment	Gasoline	Dumpers/Tenders	2265002078
Industrial Equipment	Diesel	Aerial Lifts	2270003010
Industrial Equipment	Gasoline	Aerial Lifts	2265003010
Industrial Equipment	LPG	Aerial Lifts	2267003010
Industrial Equipment	CNG	Forklifts	2268003020
Industrial Equipment	Diesel	Forklifts	2270003020
Industrial Equipment	Gasoline	Forklifts	2265003020
Industrial Equipment	LPG	Forklifts	2267003020
Industrial Equipment	CNG	Sweepers/Scrubbers	2268003030
Industrial Equipment	Diesel	Sweepers/Scrubbers	2270003030
Industrial Equipment	Gasoline	Sweepers/Scrubbers	2260003030
Industrial Equipment	Gasoline	Sweepers/Scrubbers	2265003030
Industrial Equipment	LPG	Sweepers/Scrubbers	2267003030
Industrial Equipment	CNG	Other General Industrial Equipment	2268003040
Industrial Equipment	Diesel	Other General Industrial Eqp	2270003040
Industrial Equipment	Gasoline	Other General Industrial Eqp	2260003040
Industrial Equipment	Gasoline	Other General Industrial Eqp	2265003040
Industrial Equipment	LPG	Other General Industrial Equipm	2267003040
Industrial Equipment	CNG	AC\Refrigeration Trucks	2268003060
Industrial Equipment	Diesel	AC\Refrigeration Trucks	2270003060
Industrial Equipment	Gasoline	AC\Refrigeration Trucks	2265003060
Industrial Equipment	CNG	Terminal Tractors	2268003070
Industrial Equipment	Diesel	Terminal Tractors	2270003070
Industrial Equipment	Gasoline	Terminal Tractors	2265003070
Industrial Equipment	LPG	Terminal Tractors	2267003070
Lawn and Garden Equipment (Res)	Gasoline	Lawn mowers	2265004010
Lawn and Garden Equipment (Com)	Gasoline	Lawn mowers	2265004011
Lawn and Garden Equipment (Res)	Gasoline	Rotary Tillers < 6 HP	2260004015
Lawn and Garden Equipment (Res)	Gasoline	Rotary Tillers < 6 HP	2265004015
Lawn and Garden Equipment (Com)	Gasoline	Rotary Tillers < 6 HP	2260004016
Lawn and Garden Equipment (Com)	Gasoline	Rotary Tillers < 6 HP	2265004016
Lawn and Garden Equipment (Res)	Gasoline	Rear Engine Riding Mowers	2265004040
Lawn and Garden Equipment (Com)	Gasoline	Rear Engine Riding Mowers	2265004041

TRANSPORTATION-RELATED EQUIPMENT USED TO DETERMINE OFF-HIGHWAY FUEL USE			
Classification	Fuel Type	Equipment	SCC
Lawn and Garden Equipment (Com)	Diesel	Front Mowers	2270004046
Lawn and Garden Equipment (Com)	Gasoline	Front Mowers	2265004046
Lawn and Garden Equipment (Com)	Gasoline	Shredders < 6 HP	2265004051
Lawn and Garden Equipment (Res)	Gasoline	Lawn & Garden Tractors	2265004055
Lawn and Garden Equipment (Com)	Diesel	Lawn & Garden Tractors	2270004056
Lawn and Garden Equipment (Com)	Gasoline	Lawn & Garden Tractors	2265004056
Lawn and Garden Equipment (Com)	Diesel	Chippers/Stump Grinders	2270004066
Lawn and Garden Equipment (Com)	Gasoline	Chippers/Stump Grinders	2265004066
Lawn and Garden Equipment (Com)	LPG	Chippers/Stump Grinders	2267004066
Lawn and Garden Equipment (Com)	Diesel	Commercial Turf Equipment	2270004071
Lawn and Garden Equipment (Com)	Gasoline	Commercial Turf Equipment	2260004071
Lawn and Garden Equipment (Com)	Gasoline	Commercial Turf Equipment	2265004071
Lawn and Garden Equipment (Res)	Gasoline	Other Lawn & Garden Eqp.	2265004075
Lawn and Garden Equipment (Com)	Diesel	Other Lawn & Garden Eqp.	2270004076
Lawn and Garden Equipment (Com)	Gasoline	Other Lawn & Garden Eqp.	2265004076
Agricultural Equipment	Diesel	2-Wheel Tractors	2270005010
Agricultural Equipment	Gasoline	2-Wheel Tractors	2265005010
Agricultural Equipment	Diesel	Agricultural Tractors	2270005015
Agricultural Equipment	Gasoline	Agricultural Tractors	2265005015
Agricultural Equipment	Diesel	Combines	2270005020
Agricultural Equipment	Gasoline	Combines	2265005020
Agricultural Equipment	Diesel	Balers	2270005025
Agricultural Equipment	Gasoline	Balers	2265005025
Agricultural Equipment	Diesel	Agricultural Mowers	2270005030
Agricultural Equipment	Gasoline	Agricultural Mowers	2265005030
Agricultural Equipment	Diesel	Tillers > 6 HP	2270005040
Agricultural Equipment	Gasoline	Tillers > 6 HP	2265005040
Agricultural Equipment	Diesel	Swathers	2270005045
Agricultural Equipment	Gasoline	Swathers	2265005045
Agricultural Equipment	CNG	Other Agricultural Equipment	2268005055
Agricultural Equipment	Diesel	Other Agricultural Equipment	2270005055
Agricultural Equipment	Gasoline	Other Agricultural Equipment	2265005055
Agricultural Equipment	LPG	Other Agricultural Equipment	2267005055
Logging Equipment	Diesel	Shredders > 6 HP	2270007010
Logging Equipment	Gasoline	Shredders > 6 HP	2265007010
Logging Equipment	Diesel	Forest Eqp - Feller/Bunch/Skidder	2270007015
Logging Equipment	Gasoline	Forest Eqp - Feller/Bunch/Skidder	2265007015
Airport Equipment	Diesel	Airport Ground Support Equipment	2270008005
Airport Equipment	Gasoline	Airport Ground Support Equipment	2265008005
Airport Equipment	LPG	Airport Ground Support Equipment	2267008005