Oregon Nonroad Diesel Equipment Survey and Emissions Inventory

FINAL REPORT

Submitted to:

Oregon Department of Environmental Quality 700 NE Multnomah Street
Portland, OR 97232

Submitted by:

Eastern Research Group, Inc.
3508 Far West Blvd. Suite 210
Austin, TX 78731

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Eastern Research Group, Inc.
3508 Far West Blvd, Suite 210
Austin, TX 78731

Good Company LLC
65 Centennial Loop, Suite B
Eugene, OR 97401

Oak Leaf Environmental, Inc.
8141 Mast Road
Dexter, MI 48130

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Acronyms

AGC	Associated General Contractors
BLM	Bureau of Land Management
BNSF	Burlington Northern Santa Fe
BSFC	Brake-specific fuel consumption
CAP	Criteria air pollutants
CARB	California Air Resources Board
CBP	County Business Patterns
CO	Carbon monoxide
COBA	Central Oregon Builders Association
CY	Cubic yards
DEQ	Department of Environmental Quality
DFW	Dallas/Fort Worth
DOC	Diesel oxidation catalyst
DOGAMI	Department of Geology and Mineral Industries
DOORS	Diesel Off-road Online Registration System
DPF	Diesel particulate filter
EPA	Environmental Protection Agency
EIA	Energy Information Administration
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FOKS	Fuel Oil and Kerosene Sales survey
GHG	Greenhouse gases
GSE	Ground support equipment
HP	Horsepower
HP-HR	Horsepower-hour
LF	Linear feet
LTO	Landing-and-takeoff
MBF	Thousand board-feet
MOVES	MOtor Vehicle Emission Simulator
NAICS	North American Industry Classification System
NCHRP	National Cooperative Highway Research Program
NO_x	Nitrogen oxides
NWCOA	Northwest Crane Owners Association
NWUCA	Northwest Utility Contractors Association
OCAPA	Oregon Concrete and Aggregate Producers Association
ODF	Oregon Department of Forestry
ODOT	Oregon Department of Transportation
OFB	Oregon Farm Bureau
OLE	Oak Leaf Environmental, Inc.
OSMB	Oregon State Marine Board
OWRD	Oregon Water Resources Department
PADD	Petroleum Administration for Defense District
PERP	Portable Equipment Registration Program
$PM_{2.5}$	Particulate matter < 2.5 microns in diameter

PSR	Power Systems Research
PTO	Power take-off
QA	Quality assurance
RTC	Rough terrain crane
SCR	Selective catalytic reduction
SDAO	Special Districts Association of Oregon
SF	Square feet
SIC	Standard Industrial Code
SME	Subject matter expert
SY	Square yards
TCEQ	Texas Commission on Environmental Quality
TPY	Tons per year
TRU	Transportation refrigeration unit
UP	Union Pacific
VOCs	Volatile organic compounds
WWD	Water well drilling

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Eastern Research Group would like to thank the following organizations for their support over the course of the study.

- Associated General Contractors, Oregon-Columbia Chapter
- Associated Oregon Hazelnut Industries
- Association of Oregon Counties
- Central Oregon Builders Association
- League of Oregon Cities
- Northwest Crane Owners Association
- Northwest Utility Contractors Association
- Oregon Business and Industry
- Oregon Concrete and Aggregate Producers Association
- Oregon Dairy Farmers Association
- Oregon Farm Bureau
- Oregon Hay and Forage Association
- Oregonians for Food and Shelter
- Pacific Northwest Christmas Tree Association
- Special Districts Association of Oregon

These organizations were instrumental to the success of the effort, encouraging their members to participate in surveys, recommending analysis methods, and reviewing findings to ensure the results accurately reflect operating conditions in Oregon.

We also thank the following public agencies for responding to numerous data requests and providing input on equipment activity patterns across the state.

- Oregon Department of Agriculture
- Oregon Department of Geology and Mineral Industries
- Oregon Department of Transportation
- Oregon State Marine Board
- Oregon Parks and Recreation Department
- Oregon Water Resources Department
- Port of Portland

Finally, we thank the hundreds of public and private sector respondents that voluntarily provided accurate, detailed information regarding their nonroad equipment characteristics and use.

Executive Summary

The Oregon Department of Environmental Quality (DEQ) develops periodic inventories of air emissions for the various sources of pollutants operating in the state. These emission inventories are used to assess current conditions and trends in air pollution. DEQ uses the U.S. Environmental Protection Agency's (EPA's) latest version of the MOVES-Nonroad emission model to develop inventories for nonroad diesel-powered vehicles and equipment.[1] DEQ currently relies on many of the MOVES model's default assumptions for equipment population, model year, horsepower (hp), and usage inputs. Obtaining Oregon-specific inputs for these parameters will allow DEQ to characterize equipment use and emissions more accurately for the state.

House Bill 5006 (passed during the 2017 Oregon legislative session) included funding for DEQ to oversee a statewide, multi-sector study of the nonroad diesel engines currently operated by private and public fleets across the state. This report presents the results of that study, conducted by Eastern Research Group, Inc. (ERG) and its partners Good Company LLC and Oak Leaf Environmental, Inc. (OLE), between August 2018 and April 2020. The findings of the study will be used to update DEQ's existing emission inventory and to inform and refine associated air quality models.

The study provides a comprehensive assessment of activity profiles and emission estimates for nonroad diesel equipment greater than 25 hp operating in Oregon during the 2017 calendar year for the following categories:

- Agricultural
- Airport ground support
- Commercial
- Construction/mining
- Industrial
- Lawn and garden
- Logging
- Oilfield
- Railway maintenance
- Recreational marine
- Recreational vehicles

To ensure the results were representative of Oregon operations, the study used a variety of data collection methods including detailed surveys of equipment operators, extensive input from industry experts and public agencies, and published literature. The resulting emission

[1] EPA's MOtor Vehicle Emission Simulator (MOVES) is a state-of-the-science emission modeling system that estimates emissions for on-road and non-road mobile sources. The current version of the model (MOVES2014b) and associated documentation are available at EPA's website: https://www.epa.gov/moves.

inventory is reported at the county level for both annual and summer weekday estimates. Results and assumptions were verified using reliable independent data sources such as industry fuel consumption estimates and equipment productivity metrics. Oregon is just the third state to develop such a bottom-up, statewide profile of these equipment, and the findings represent a substantial improvement to the activity and emission estimates the state previously used, which were based on the EPA's MOVES-Nonroad model.

The study found nonroad diesel equipment operating in Oregon had notably lower activity than assumed by the MOVES model, with total fuel consumption estimated to be about 61 percent of the value predicted using MOVES defaults. However, the Oregon equipment fleet is generally older, with higher emission rates than those assumed by MOVES. As a result, the study's estimates for criteria pollutant emissions[2] are close to the MOVES default estimates, although substantial differences are seen for individual equipment categories.

Table ES-1 summarizes the study's fuel consumption and emission estimates for selected pollutants by equipment category. Table ES-2 presents the study estimates expressed as a percentage of the corresponding MOVES values.

Table ES-1. Annual Fuel Consumption and Emissions by Equipment Category[3]
2017 Nonroad Diesel Equipment Study

Equipment Category	Gallons	CO (Tons)	NO_x (Tons)	$PM_{2.5}$ (Tons)	VOCs (Tons)
Airport ground support	496,923	27.9	41.6	4.5	4.7
Agriculture	32,092,379	1,870.2	3,308.8	244.1	325.5
Commercial	6,121,430	306.5	525.7	44.2	64.6
Construction/mining	39,834,517	1,878.4	3,403.4	261.1	346.9
Industrial	8,056,664	157.2	493.5	22.1	31.4
Lawn and garden	667,972	21.7	54.4	3.5	5.6
Logging	24,474,458	848.2	1,725.8	109.8	138.1
Oilfield	19,676	0.3	1.4	0.0	0.1
Railway maintenance	506,196	30.4	44.9	5.0	7.4
Recreational marine	1,410,572	29.7	157.3	3.1	7.9
Recreational vehicles	158,336	12.5	13.8	1.8	3.3
Total	**113,839,122**	**5,183.1**	**9,770.6**	**699.3**	**935.5**

[2] Including carbon monoxide (CO), nitrogen oxides (NO_x), particulate matter less than 2.5 microns in diameter ($PM_{2.5}$), and volatile organic compounds (VOCs).

[3] Nonroad equipment types are grouped here to be consistent with MOVES' categories for comparison purposes. Many equipment types are used across a range of applications and industries. For example, construction/mining equipment includes backhoes which are used not only in the construction sector but also in the agriculture and public fleet sectors as well.

Table ES-2. Annual Fuel Consumption and Emissions Percentage by Equipment Category (Study Estimate/MOVES Defaults)

2017 Nonroad Diesel Equipment Study

Equipment Category	Fuel	CO	NO_x	$PM_{2.5}$	VOCs
Airport ground support	61.2%	173.7%	116.5%	172.5%	197.9%
Agriculture	86.1%	164.2%	131.6%	118.2%	161.1%
Commercial	45.7%	62.8%	53.7%	59.2%	64.5%
Construction/mining	42.0%	80.6%	72.6%	70.9%	80.7%
Industrial	39.3%	49.9%	54.3%	45.2%	57.2%
Lawn and garden	20.1%	21.8%	19.9%	20.5%	24.1%
Logging	221.1%	763.5%	600.7%	554.2%	865.2%
Oilfield[4]	100.0%	100.0%	100.0%	100.0%	100.0%
Railway maintenance	247.5%	247.5%	247.5%	247.8%	247.5%
Recreational marine	42.6%	41.1%	42.8%	43.0%	41.0%
Recreational vehicles	100.0%	104.5%	100.3%	104.3%	106.7%
All Categories	**61.6%**	**112.8%**	**96.9%**	**93.3%**	**109.5%**

The study also provides detailed breakouts of fuel consumption and emissions across industry sectors and counties. As an example, Figure ES-1 presents the statewide $PM_{2.5}$ emission estimates by industry sector, with agricultural operations contributing 45.8 percent of all emissions, followed by logging at 18.6 percent and construction at 18.2 percent. The remaining sectors combined are responsible for 17.3 percent of these emissions. Other criteria pollutants (e.g., NO_x, CO, and VOCs) have similar industry contribution percentages.

[4] Minimal activity is estimated for oilfield equipment. MOVES defaults assumed.

Figure ES-1. 2017 Statewide Annual $PM_{2.5}$ Emissions by Industry Sector[5]
2017 Nonroad Diesel Equipment Study

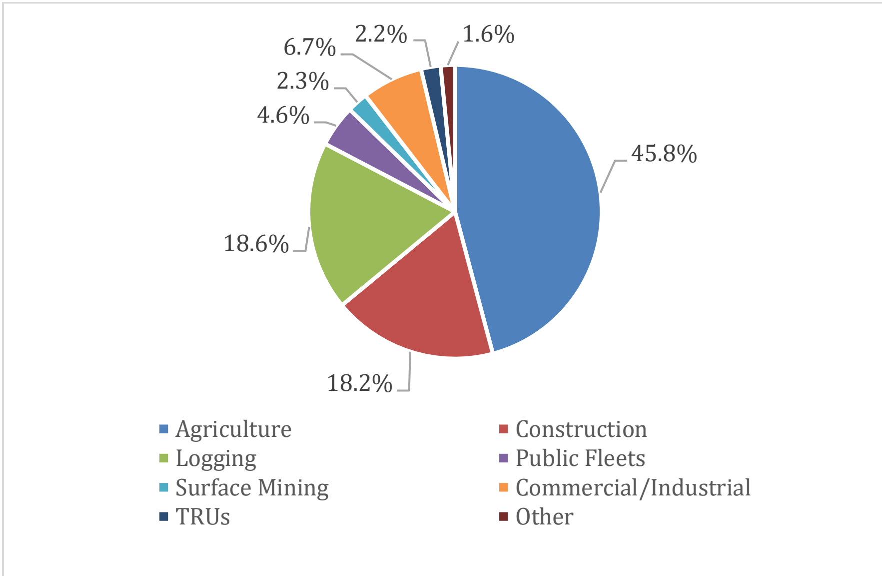
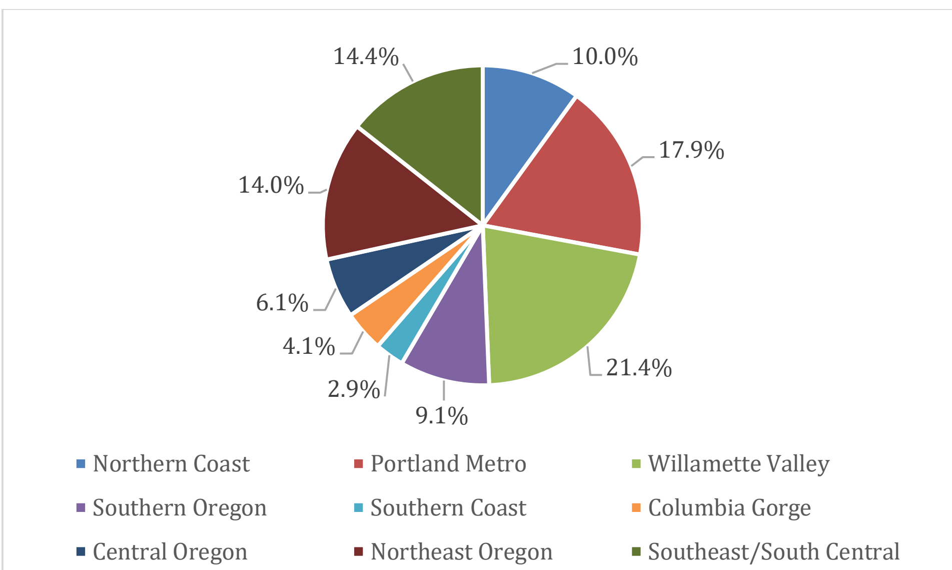


Figure ES-2 shows the distribution of statewide $PM_{2.5}$ emissions by region, with percentages ranging from 2.9 percent for the Southern Coast[6] to 21.4 percent for the Willamette Valley.[7]

Figure ES-2. 2017 Statewide Annual $PM_{2.5}$ Emissions by Region
2017 Nonroad Diesel Equipment Study



[5] TRUs – transportation refrigeration units, used to cool freight during delivery.

[6] Including Coos and Curry Counties.

[7] Including Benton, Lane, Linn, Marion and Polk Counties.

Given the broad range of data sources and challenges with data collection and calculation methodologies, the results of the study are subject to some unavoidable uncertainties. Nevertheless, extensive validation using independent data sources confirms the general accuracy and representativeness of the study findings.

While the study provides a broad assessment for nonroad diesel equipment, the results only offer a “snapshot” of activity and emissions for the 2017 calendar year. Accurate and precise growth factor determination is required to project future year emissions for air quality analysis and planning purposes. Developing accurate growth factors consistent with the current study is particularly important for sectors that are undergoing rapid equipment use changes.

1.0 Introduction

The Oregon Department of Environmental Quality (DEQ) develops periodic inventories of air emissions for the various sources of pollutants operating in the state. These emission inventories are used to assess current conditions and trends in air pollution. DEQ uses the U.S. EPA's latest version of the MOVES-Nonroad emission model to develop inventories for nonroad diesel-powered vehicles and equipment.[8] DEQ currently relies on many of the MOVES model's default assumptions for equipment population, model year, horsepower (hp), and usage inputs. Obtaining Oregon-specific inputs for these parameters would allow DEQ to characterize equipment use and emissions more accurately for the state.

House Bill 5006 (passed during the 2017 Oregon legislative session) included funding for DEQ to oversee a statewide, multi-sector study of the nonroad diesel engines currently operated by private and public fleets across the state. This report presents the results of that study, conducted by Eastern Research Group, Inc. (ERG) and its partners Good Company LLC and Oak Leaf Environmental, Inc. (OLE), between August 2018 and April 2020. The findings of the study will be used to update DEQ's existing emission inventory and to inform and refine associated air quality models.

1.1 Inventory Year

The study developed activity profiles and emission estimates for nonroad diesel equipment operating in Oregon during the 2017 calendar year.

1.2 Geographic Domain

The geographic domain of the study is the entire state of Oregon. For each piece of equipment surveyed, the ERG team collected information regarding the county and job site of primary use where available. ERG adjusted the results for equipment that spent part of the year in neighboring states, excluding activity outside Oregon from the final inventory.

1.3 Emission Sources

The emission inventory includes nonroad mobile diesel equipment with greater than 25 hp. "Nonroad" engines are internal combustion engines that are not registered for on-road use, such as agricultural tractors, excavators, and portable generators. "Mobile" sources—as defined by EPA—are vehicles or equipment that are propelled by an onboard engine or other means, or that operate at a given location for no more than 12 consecutive months.[9] Locomotives and commercial marine engines are excluded from the assessment. (Although

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[8] EPA's MOtor Vehicle Emission Simulator (MOVES) is a state-of-the-science emission modeling system that estimates emissions for on-road and non-road mobile sources. The current version of the model (MOVES2014b) and associated documentation are available at EPA's website: https://www.epa.gov/moves.

[9] 40 CFR Section 1068.30 defines nonroad engines as internal combustion engines that a) are used to propel equipment as well as to provide power for another function (e.g., lawn and garden tractors, bulldozers), b) are used to power equipment that is propelled by other means (e.g., lawn mowers), or c) are used to power portable equipment such as air compressors and generator sets.

they are nonroad sources, their emissions are not estimated by the MOVES-Nonroad model and are quantified by DEQ using other means.)

The emission sources characterized by the study include the following nonroad equipment categories, consistent with MOVES model classifications.

- Agricultural
- Airport ground support
- Commercial
- Construction and mining
- Industrial
- Lawn and garden[10]
- Logging
- Oilfield
- Railway maintenance
- Recreational marine
- Recreational vehicles

The complete list of the nonroad diesel equipment types with units greater than 25 hp is provided in Table 1-1. The equipment naming conventions shown in the table are those used in the MOVES model and are used throughout the study for comparability.

Table 1-1. Nonroad Diesel Equipment Types > 25 HP

Classification	Equipment Type
Agricultural	Agricultural tractors
Agricultural	Combines
Agricultural	Balers
Agricultural	Agricultural mowers
Agricultural	Sprayers
Agricultural	Swathers
Agricultural	Other agricultural equipment
Agricultural	Irrigation sets
Airport ground support	Airport ground support equipment (GSE)
Commercial	Generator sets
Commercial	Pumps
Commercial	Air compressors
Commercial	Welders
Commercial	Pressure washers
Commercial	Hydro power units

[10] Diesel lawn and garden equipment use is restricted to commercial operations. Residential lawn and garden equipment is gasoline-powered.

Classification	Equipment Type
Construction and mining	Pavers
Construction and mining	Rollers
Construction and mining	Scrapers
Construction and mining	Paving equipment
Construction and mining	Surfacing equipment
Construction and mining	Signal boards/light plants
Construction and mining	Trenchers
Construction and mining	Bore/drill rigs
Construction and mining	Excavators
Construction and mining	Concrete/industrial saws
Construction and mining	Cement and mortar mixers
Construction and mining	Cranes
Construction and mining	Graders
Construction and mining	Off-highway trucks
Construction and mining	Crushing/processing equipment
Construction and mining	Rough terrain forklifts
Construction and mining	Rubber tire loaders
Construction and mining	Tractors/loaders/backhoes
Construction and mining	Crawler tractor/dozers
Construction and mining	Skid steer loaders
Construction and mining	Off-highway tractors
Construction and mining	Dumpers/tenders
Construction and mining	Other construction equipment
Industrial	Aerial lifts
Industrial	Forklifts
Industrial	Sweepers/scrubbers
Industrial	Other general industrial equipment
Industrial	Other material handling equipment
Industrial	Transportation refrigeration equipment
Industrial	Terminal tractors
Lawn and garden	Commercial mowers
Lawn and garden	Lawn and garden tractors
Lawn and garden	Chippers/stump grinders
Lawn and garden	Commercial turf equipment
Lawn and garden	Other lawn and garden equipment
Logging	Forest equip—feller/bunch/skidder
Oilfield	Other oilfield equipment
Railway maintenance	Railway maintenance
Recreational marine	Inboard/sterndrive
Recreational marine	Outboards
Recreational vehicles	Specialty vehicles/carts

1.4 Emission Estimation Overview

DEQ currently uses EPA's MOVES-Nonroad model to prepare emission estimates for nonroad mobile sources. The model uses the following equation to calculate exhaust emissions for criteria pollutants, greenhouse gases (GHGs), and toxic emissions by equipment type:

$$Emissions_p = Pop \times HP_{avg} \times Activity \times LF \times EF_p \qquad \text{Equation 1-1}$$

Where:

$Emissions_p$	=	Annual emissions for pollutant *p* (grams/yr)
Pop	=	Equipment population
HP_{avg}	=	Average rated horsepower
Activity	=	Annual activity (hours/yr)
LF	=	Average engine operating load relative to rated power
EFp	=	Emission factor for pollutant *p* (grams/hp/hr)

While the populations estimated by MOVES for a given equipment type vary by state and county, MOVES relies on national-average values for many of the other modeling parameters including hp, activity,[11] engine load factor, and emission factors. Emission factors in turn depend on a variety of parameters including engine age distribution (specifically the emission standard tier level and technology type), assumed median life for the equipment type, duty cycle, and deterioration rates for the pollutant of interest, all of which are assumed to be constant across the United States.[12]

MOVES also assumes the relative *mix* of equipment types within a given equipment classification is uniform throughout the United States (e.g., the ratio of excavators to pavers is constant in every state).[13] Moreover, the factors used to allocate statewide equipment populations to the county level are also applied at the classification level, meaning that the equipment type mix within each classification is uniform down to the county level. For example, the national ratio of excavators to pavers is applied to every Oregon county.[14] In addition, while

[11] Regional variations in annual activity are of concern for certain equipment types. For example, MOVES' national-average values require that the hours per year for lawn mowers are the same in Fairbanks, Alaska, and Miami, Florida.

[12] Equipment age distributions are particularly important to the estimation of pollutant emissions: certain emission factors vary dramatically with age, reflecting the phase-in of successively more stringent emission standards over time.

[13] The uniform equipment mix assumption effectively assumes that the proportion of mining and construction operations is nationally uniform, since MOVES treats construction and mining as a single classification. This is not reflective of the local situation—aside from sand/gravel and aggregate production, Oregon does not have large-scale mining operations (e.g. for coal, metals, or other minerals).

[14] MOVES makes an exception for three equipment types (golf carts, snowmobiles and snowblowers); these three specific applications are allocated individually to the state and county level.

the model assigns a nationally uniform number of hours of use per equipment per year, the allocation of annual activity to the monthly and daily level is made using regional assumptions.[15] Finally, the diesel equipment profiles used in the current model were developed for a 2000 base year and rely on projection factors to estimate activity and emissions for subsequent years. Since the potential for error grows with each year, projecting equipment population and use profiles a full 17 years, from 2000 to the study's 2017 evaluation year, introduces substantial uncertainty into the model's emission estimates.

The above factors add substantial uncertainty to the default emission estimates currently used for Oregon. Therefore, an updated, reliable, bottom-up accounting of nonroad diesel equipment populations and activity was developed for this study. To ensure the study results are representative, data were collected using a mix of sampling techniques, including but not limited to whole fleet inventories (census-style counts), representative sampling of fleets by fleet size, and industry surveying. The resulting emission inventory is reported at the county level for both annual and summer weekday estimates. Results and assumptions were verified using reliable independent data sources such as industry fuel consumption estimates and equipment productivity metrics.

1.5 Report Organization

The following sections summarize the key steps undertaken to develop the state- and county-level activity and emission estimates for nonroad diesel equipment operating in Oregon in 2017.

- Section 2: Data Collection Methodology
- Section 3: Equipment Surveys and Findings
- Section 4: Industry-Specific Sector Profiles
- Section 5: Alternative Characterization Methods
- Section 6: Emission Modeling and Inventory Development
- Section 7: Validation and Comparative Analyses
- Section 8: Conclusions and Recommendations

[15] MOVES includes Oregon (along with Washington, Idaho, and Montana) in a four-state "northwest" region for apportioning annual activity by month and day of week.

2.0 Data Collection Methodology

A high-quality nonroad diesel emission inventory for Oregon must draw on reliable, state-specific data on equipment characteristics and activity. ERG took a three-pronged approach to collect data for the study, using public fleet surveys, random sample surveys, and development of industry-specific sector profiles. Each part of this approach focused on a different portion of the Oregon nonroad diesel equipment population. This was more precise than top-down methods used to estimate equipment populations and activity, such as approximating total state equipment from equipment manufacturer sales volume data and allocating equipment activity to the different counties and industry sectors.[16]

The subsections below provide an overview of the approaches adopted for the survey targets and the industry profile categories.[17]

2.1 Sector Surveys

ERG conducted targeted surveys of public fleet operations as well as random sample surveys for selected industry establishments.[18]

2.1.1 Public Fleet Surveys

The ERG team surveyed facilities and agencies expected to operate fleets with a significant amount of nonroad diesel equipment greater than 25 hp. Specific fleets were identified based on ERG team members' experience working with public agencies across the state, with additional input from DEQ and industry trade associations. Many of these fleets operate only in specific places—for example, fleets of ground support equipment (GSE) at airports, or of construction equipment at permitted facilities such as municipal solid waste landfills and material transfer and recycling locations. Other fleets are controlled by public agencies such as the Oregon Department of Transportation (ODOT), as well as counties and municipalities.

The final targeted list contained eight public fleet categories:

- Cities (all incorporated municipalities)
- Counties (all 36 counties)
- Special Service Districts (all district types)
- Other public agencies (ODOT, Bureau of Land Management, U.S. Forest Service, Army and Air National Guard, Oregon Department of Administrative Services, Oregon Department of Forestry, Oregon Department of Corrections, Oregon Parks and Recreation Department, and Oregon Metro)

[16] Bottom-up inventory methods may inadvertently exclude specialized and/or low use equipment. Please refer to Section 5 for details on how emissions and activity were estimated for equipment not fully characterized by the three data collection methods.

[17] Detailed discussions are provided for each method in Sections 3 and 4.

[18] An additional survey was conducted for a particularly large construction project, as discussed in Section 3.6.

- Commercial airports (Portland International, Hillsboro, Eugene, Medford, Redmond)
- Commercial marine ports (Astoria, Bandon, Brookings Harbor, Cascade Locks, Coos Bay, Garibaldi, Gold Beach, Hood River, Morrow, Newport, Orford, Portland, Siuslaw, St. Helens, Tillamook, Toledo, Umatilla)
- Permitted material handling and disposal facilities (solid waste landfills, transfer stations, material recovery facilities, compost facilities, other miscellaneous facilities)
- Education facilities (K–12, colleges,[19] universities)

Managers for many of these fleets are often easy to identify and contact, resulting in high response rates for several fleet categories. In fact, ERG's goal was to obtain a complete equipment inventory for public fleets with a limited number of locations, such as marine and airports. For other fleets, ERG selectively targeted the largest operators—such as the 10 most populous cities and counties—in order to capture the largest, most representative portion of targeted equipment as efficiently as possible.

2.1.2 Random Sample Surveys

Many nonroad equipment categories and operators cannot be fully surveyed or readily characterized by industry experts for various reasons. First, operators may simply be too numerous to contact in their entirety given available resources. For instance, the most recent Agricultural Census identified 37,616 farms operating in Oregon in 2017,[20] the vast majority of which are likely to use some type of nonroad diesel equipment. In addition, it may be difficult to create "typical" use profiles for certain equipment given the diversity of applications and operators. For example, cranes of different types and sizes are used for a variety of tasks by general construction contractors and subcontractors as well as by specialized rigging companies servicing multiple industries.

For these reasons, the ERG team conducted random sample[21] surveys for the following nonroad equipment operator categories:

- Agricultural establishments
- Logging operations
- Surface mining operations
- Crane operators

Contact information was compiled from comprehensive, reliable data sources to ensure representativeness of the potential respondent pool. Contact information for agricultural and

[19] Includes community colleges.

[20] U.S. Department of Agriculture. (2017) *2017 Agricultural Census* (Table 1, State and Summary Highlights). Retrieved from https://www.nass.usda.gov/Publications/AgCensus/2017/Full_Report/Volume_1,_Chapter_2_US_State_Level/.

[21] These surveys were not "random" in the strict sense, as trade associations encouraged their members to participate in the data collection effort.

logging sector operations was obtained from Dynata,[22] a commercial marketing vendor. Contact lists for surface mining operations and crane operators were developed with input from Oregon trade associations.

2.1.3 Survey Parameters

The public fleet and random sample surveys requested data to fill the fields listed below. The surveys were designed to differentiate between key fields required for a survey to be considered complete (e.g., equipment type and hp), and non-key fields that are helpful for quality assurance (QA) and other purposes, but are not required for estimating emissions (e.g., equipment make/model). Asterisks mark the key fields in the list.

- Population data
  - Equipment type*
  - Engine model year*
  - Maximum rated horsepower (hp)*
  - Equipment make/model
- Activity data
  - Annual hours of use (preferably based on engine clock hours)*
  - Weekday/weekend and seasonal distributions
  - Activity scaling factors as appropriate (e.g., volume produced for logging, number of acres harvested for agricultural farms)*
  - Fuel consumption estimates, where available[23]
- Location data
  - County/counties of use*
- Retirement rates
  - Anticipated year of retirement

2.1.4 Questionnaire Development

ERG developed questionnaires for each random sample and public fleet survey, prescribing the data to be collected therein. Questionnaire introductions explained the purpose of the survey, described any support received from trade associations, and clearly explained procedures used to maintain respondent confidentiality. The introductory text and survey questions were worded to promote participation, minimize non-response, and ensure reporting accuracy and precision. For example, careful wording of questions helped avoid certain reporting imprecisions commonly found in equipment use surveys. A rounding bias is often observed in activity estimates, with a large peak in responses seen at “40 hours per week.” Therefore, ERG

[22] Dynata LLC. https://www.dynata.com/company/about-us/.

[23] Few operators kept fuel consumption records at the equipment level. Records were generally provided at the fleet level.

explicitly requested estimates of “engine-on” time rather than “hours of use” to minimize the incidence of such shorthand estimation errors, resulting in more accurate, continuous parameter distributions.

2.1.5 Survey Procedures

ERG developed standard survey administration procedures to promote participation and ensure data quality. ERG first provided its survey staff with background on the purpose of the study and familiarized them with the industry and equipment terminology, allowing surveyors to engage equipment owners in a personal, familiar tone. ERG also emphasized the need to avoid certain hot-button topics such as potential regulatory development, and instead focus on trade association support and the potential for grant/subsidy program development. ERG has found this type of hands-on, respondent-focused surveyor training to be critical in obtaining effective response rates from nonroad equipment operators.

Since the available hours for respondents vary, surveys were administered from as early as 7:00 a.m. to as late as 8:00 p.m. Contacts were called, emailed, and/or faxed up to three times in an attempt to establish phone contact.[24] After three unsuccessful attempts, phone numbers were removed from the call list.

Before initiating contact with a potential respondent, the ERG team reviewed company websites to determine hours of operation, corporate structure, and (where available) fleet manager name and types of equipment used. After each initial contact, ERG set up a schedule to coordinate further emails and phone calls—one that used changing contact intervals so that emails were more likely to be opened.

Once a respondent was successfully contacted, ERG first determined whether they were eligible to participate in the survey (i.e., whether they owned/operated/used at least one target piece of nonroad diesel equipment type greater than 25 hp in Oregon during 2017) before continuing. Eligible respondents were then given the option to provide information via phone, electronically using a link provided by the surveyor, by mail/fax, or in selected cases by providing information directly from their company database reporting systems. Emails were sent immediately after phone calls to increase credibility and to provide context for follow-up contacts as necessary.

Data provided verbally were entered electronically during phone interviews, with the surveyor entering a unique ID for each respondent. To ensure that activity, hp, and model year data collected in the phone surveys were reasonable, these fields had pre-defined range checks associated with them. This allowed the surveyor to ask for qualifying information if a response was not realistic or consistent—for example, if the reported commercial engine-on time was greater than a predefined amount such as 2,000 hours/yr.

[24] Hard copy survey mailers were also sent out in advance to agricultural sector targets to improve low initial response rates.

Notes were kept on each call and any respondent concerns or objections were noted and responded to with scripted answers. After the first week of surveys (and at regular intervals thereafter), ERG reviewed and audited the results for data completeness and to determine if survey scripts or contact procedures needed to be adjusted to improve response rates or adequately collect data. Once complete, all survey responses were stored electronically using a secure data management system.

2.1.6 Processing Survey Data

After completion, ERG cleaned survey responses of all identifying participant information to maintain confidentiality, compiled and stored the data in a standardized format, and subjected them to comprehensive range checks and QA measures to ensure accuracy. Evaluations focused on assuring accurate assignment of equipment to appropriate categories, identifying missing hp and model year values, and identifying and treating suspected outliers (e.g., annual activity greater than *x* hours per year, with specific values determined after a distributional analysis of the raw data). ERG attempted to gap-fill missing key information by contacting the respondent by email or phone, then drew on other resources as needed (e.g., equipment manufacturer websites or other publicly available web resources to obtain hp estimates and/or model years).

The final, quality-assured, gap-filled data set was stored in Excel format with data files linked via a unique sample identifier assigned to each respondent. Individual records were kept for each piece of equipment surveyed. ERG used detailed comment fields when processing spreadsheets to document data sources, calculation methods, and assumptions.

2.2 Industry-Specific Sector Profiles

The industry-specific sector profiles are designed to take advantage of comprehensive, project-specific quantity information available for certain Oregon industries. For example, Dodge Analytics maintains an extensive, up-to-date database of commercial building and utility project work being bid throughout the country, containing physical quantity information on each project such as the LF of pipe installation required and square footage of building construction by county.[25] Coupling such information with equipment use profiles developed by subject matter experts (SMEs) intimately familiar with Oregon's operating conditions provides a highly representative basis for quantifying equipment activity and emissions.

ERG had previously developed equipment use profiles for the Texas Commission on Environmental Quality (TCEQ) that specified equipment mixes and hours of use for multiple construction sector tasks.[26] For this study, ERG worked closely with local industry and trade SMEs to adjust these base profiles for Oregon-specific operating conditions (e.g., accounting for differences in land clearing requirements, equipment use preference, etc.). ERG also

[25] Dodge Data and Analytics. Research and Analytics Summary, provided to ERG March 2020.

[26] ERG developed these profiles based on input from professional construction project estimators, trade association experts, civil engineering academics, and detailed project equipment operator records.

coordinated with additional SMEs to develop profiles for sectors not included in the original TCEQ study. ERG then combined the individual SME inputs into composite profiles with project-specific, physical surrogates (e.g., square footage of commercial building installations in 2017) to estimate precise equipment use levels for Oregon activities.

The following industry-specific sector profiles were developed for the study:

- Single-family housing construction
- Commercial and institutional building construction
- Highway/road construction and maintenance, including:
    - ODOT Construction Program projects
    - ODOT Maintenance Program projects
    - Projects contracted by cities, counties, and other agencies
- Utility work (i.e., sewer, water, and power line installation and repair)
- Well drilling (water, monitoring, and geotechnical)
- Agricultural services (lime application, fertilizing, spraying, haying)

2.2.1 Required Profile Parameters

Each equipment use profile is associated with a set of precise physical quantities, such as the square feet (SF) of new commercial building installation or LF of well drilling. Combining project-specific quantities for a given location and time with the corresponding equipment use profile provides hours of use estimates for different equipment types. The following summarizes the general information required for the profiles.

- Standardized task list
- Frequency of tasks (e.g., structure demolition for 10 percent of projects)
- Preferred quantity metric by task (e.g., square yards (SY) for paving tasks, LF for utility line installation)
- Equipment assignments for each task including
    - Equipment type
    - Typical hp
    - Equipment productivity estimates (e.g., hours of equipment use per 1,000 SY of paving)
- Geographic adjustment factors if appropriate (e.g., land clearing tasks require 50 percent longer in Counties X, Y, and Z)

2.2.2 SME Solicitation Process

ERG worked with Oregon trade associations to identify SMEs to assist with equipment use profile development. The SME solicitation process involved the following steps:

1. ERG presented the base profiles and reviewed the procedures used in the past to develop composite task profiles.
2. ERG requested initial input on the base profile tasks and discussed the process needed for updates.[27] Specific requests included:
    a. Review and revise the task list included in the base profiles.
    b. Provide generic equipment assignments and productivity estimates for all tasks.
    c. Review past projects to compile company-average equipment and productivity assignments for more variable tasks. For example, excavation requirements can vary dramatically, and characterizing this task could require averaging across many projects.
    d. Help estimate the frequency of "intermittent" tasks. For example, pavement demolition tasks are only required for some projects.
    e. Help identify when/where task profiles should be broken into distinct subsets. For instance, productivity adjustment factors were developed to reflect the change in equipment hours due to variable soil conditions in different regions of the state.
3. ERG worked with each SME to clarify questions and assumptions as needed and collected initial input on required profile parameters.
4. ERG prepared draft composite equipment profiles for review and comment, highlighting differences in SME opinion.
5. ERG oversaw iterative review and comment cycles to reconcile inconsistencies between SME opinions, then prepared final composite equipment use profiles.

Once complete, most profiles[28] were combined with project-specific physical quantity data to estimate total equipment use requirements for the state.

[27] ERG emphasized maintaining data confidentiality throughout the process, and the final "composite" profiles are not attributable to any one company or person.

[28] The agricultural services profile relied on county-level farm production data from the 2017 Agricultural Census rather than on project-specific quantity information.

3.0 Equipment Surveys and Findings

ERG developed and administered surveys for public fleets as well as for selected industry categories. The surveys were tailored to for each equipment operator category as described below.

3.1 Public and Other Centralized Fleets

The ERG team identified and administered surveys to selected public agencies and other facilities expected to operate a significant amount of nonroad diesel equipment. Certain fleets are controlled by public agencies such as ODOT, as well as counties and municipalities. Other fleets have their operations restricted to specific locations such as cargo handling equipment at marine ports, GSE at airports,[29] and construction equipment at permitted facilities such as municipal solid waste landfills and scrap/recycling locations.

3.1.1 Data Collection Methodology

The types of fleets targeted for survey were based on the ERG team's familiarity with agency equipment use in other states, general industry knowledge, and additional input obtained from DEQ and the Associated General Contractors (AGC). The surveys requested information on each piece of nonroad diesel equipment operated in the state during 2017, including primary location of use, engine model year, hp, and annual hours of operation, among others. In some cases, the ERG team also provided contacts with an Excel spreadsheet template for completion using information from their database management systems.

While the ERG team attempted to survey as many large, centrally operated fleets as possible, resource constraints limited the number of agencies and facilities contacted directly during the data collection effort. Therefore, the ERG team targeted the largest fleets, developed equipment use profiles for specific fleet categories based on the findings, and extrapolated the equipment population and activity estimates to non-surveyed fleets using scaling factors assumed to correlate with equipment use. (For example, hours of municipal equipment use are assumed to be roughly proportional to a municipality's population).

ERG's teaming partner, Good Company, led the data collection effort for these fleets. After making initial contact with a targeted agency or organization, Good Company helped respondents understand and complete the surveys, fielding questions by phone and email. When respondents could not respond in a timely manner, Good Company also offered to come to facilities and inventory the equipment in person (although none agreed to on-site visits).

Good Company initially reached out to 314 organizations in Oregon and received 77 responses. DEQ assisted by following up with public agencies that did not return calls or were slow to respond after an initial agreement to participate. DEQ reached out to additional organizations to help increase response rates for fleet categories with low numbers of respondents.

[29] Certain equipment types were captured in their entirety in these surveys, such as GSE.

Once a final version of the survey was received, the ERG Team reviewed it to identify gaps, ensure accurate and complete responses, and document apparent inconsistencies or unresolved questions. The following summarizes the survey findings and the associated state-level equipment use profiles for each fleet category.

3.1.2 Municipalities

The ERG Team contacted fleet managers and other officials at the 20 municipalities with the largest census population in the state. Of these, the nine municipalities responded to the survey. As seen in Table 3-1, the responding cities represent 46.8 percent of the state's total incorporated population.

Table 3-1. Municipal Respondent Equipment Units and Population[30]
2017 Nonroad Diesel Equipment Study

Municipality	# Units	Population	Percent of Incorporated Population
Bend	80	89,505	3.1%
Corvallis	36	59,280	2.1%
Eugene	89	169,695	5.9%
Gresham	36	110,505	3.8%
Hillsboro	30	101,920	3.5%
Medford	37	80,375	2.8%
Portland	235	648,740	22.5%
Springfield	19	60,865	2.1%
Tualatin	7	27,055	0.9%
Total - Survey	**569**	**1,347,940**	**46.8%**

After compiling the survey responses ERG removed records for non-diesel equipment, engines less than 25 hp, attachments using power take off (PTO), and units with zero reported hours for 2017. The filtered equipment list contained records for 569 units.[31] Gap filling was required for 32 records with missing model year, 63 records with missing hp, and 167 records with missing annual hours.

The City of Eugene appeared to estimate equipment use based solely on staff work hours, reporting over 2,000 hours per year for all units. ERG was not able to obtain revised activity estimates from the city but replaced the values with the average hour per year values estimated for other cities, by equipment type.

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[30] As of January 1, 2018. Portland State University, College of Urban and Public Affairs: Population Research Center. *Population Estimates and Reports*. Retrieved from https://www.pdx.edu/prc/population-reports-estimates.

[31] Equipment type assignments, quality assurance and gap-filling were performed following the procedures described in Section 2.

ERG scaled the survey results to account for municipalities that did not provide responses in order to estimate statewide equipment populations.[32] Table 3-2 presents the statewide equipment use profile for municipal fleets, noting the number of units, averages for hp, hours per year, and model year, and estimated annual fuel consumption by equipment type. The majority of fleet activity is associated with construction equipment such as backhoes, loaders, and surfacing equipment, with significant contributions from agricultural tractors, lawn and garden equipment (e.g. commercial mowers and chippers/stump grinders), and industrial equipment (e.g. generator sets).

Table 3-2. Statewide Municipal Fleet Profile
2017 Nonroad Diesel Equipment Study

Equipment Type	# Units	Avg HP	Avg Hrs/Yr	Avg Model Yr	Gal/Yr[33]
Agricultural tractors	143	64	194	2007	54,214
Combines	2	473	150	2007	3,543
Air compressors	36	56	72	2001	2,531
Generator sets	191	228	44	2004	29,137
Hydro-power units	2	75	3	2006	14
Pumps	39	94	22	1998	1,823
Cement and mortar mixers	11	40	275	1994	2,951
Concrete/industrial saws	2	48	580	2011	2,070
Crawler tractors/dozers	9	198	709	2001	26,476
Crushing/processing equipment	2	88	80	1995	376
Excavators	81	67	342	2011	41,041
Graders	21	160	88	2005	6,660
Other construction equipment	2	250	606	2009	7,221
Pavers	39	97	286	2010	24,081
Rollers	49	47	166	2007	7,953
Rough terrain forklifts	13	81	104	2005	2,553
Rubber tire loaders	73	133	361	2006	82,302
Rubber tire tractors/dozers	4	85	504	2005	2,063
Skid steer loaders	45	70	84	2007	6,295
Surfacing equipment	21	314	280	2010	46,030
Tractors/loaders/backhoes	167	94	297	2008	113,786
Trenchers	2	115	593	2009	3,869
Aerial lifts	2	75	384	2014	1,314
Other industrial equipment	19	105	218	2006	11,304
Other material handling equipment	4	100	421	2001	2,347

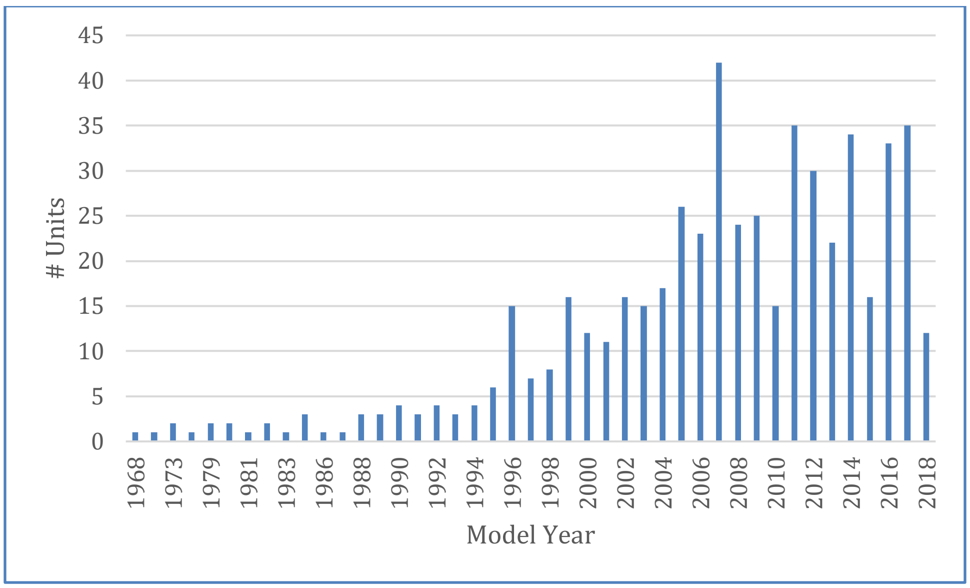
[32] Survey equipment counts were divided by 0.468 to scale to the state level, as responding municipalities accounted for 46.8% of the incorporated state population.

[33] Calculated using EPA MOVES-Nonroad model (2014b). See Section 6.2 for additional details.

Equipment Type	# Units	Avg HP	Avg Hrs/Yr	Avg Model Yr	Gal/Yr[33]
Sweepers/scrubbers	13	102	167	2007	9,889
Chippers/stump grinders	26	150	132	2007	14,641
Leafblowers/vacuums	15	74	145	2004	4,154
Commercial mowers	173	50	243	2010	58,319
Total	**1,218**	**109**	**204**	**2007**	**569,065**

Figure 3-1 through Figure 3-3 present the municipal equipment fleet distributions for model year, annual hours per unit, and hp based on the survey responses.[34] Most of the municipal fleet is less than 20 years of age (average model year = 2007), has relatively low activity (average = 196 hours/yr), and relatively low power engines (average = 105 hp).

Figure 3-1. Municipal Fleet Model Year Distribution (N=537)
2017 Nonroad Diesel Equipment Study



[34] The number of observations (N) reported for the survey parameter distributions may be less than the total number of units in the fleet due to missing responses.

Figure 3-2. Municipal Fleet Hours/Year Distribution (N=314)
2017 Nonroad Diesel Equipment Study

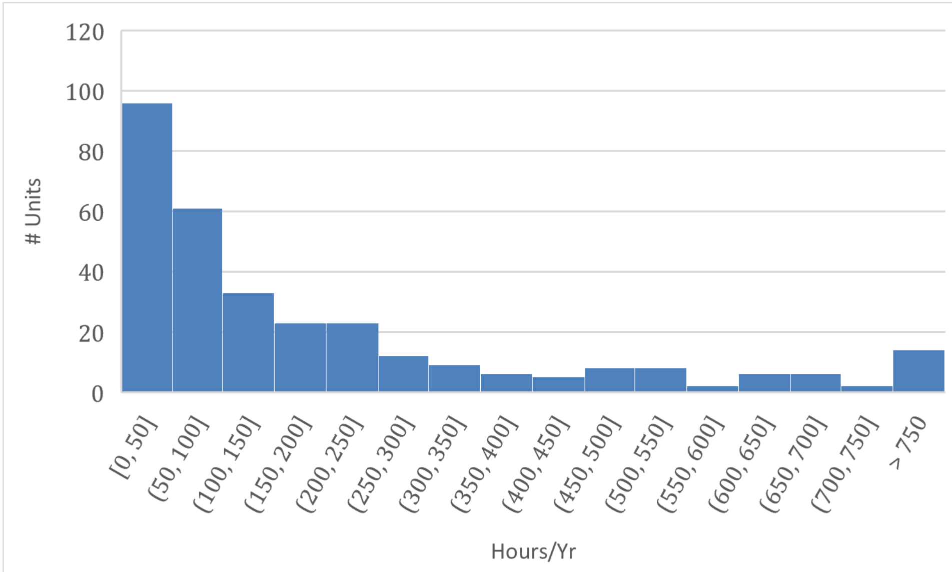
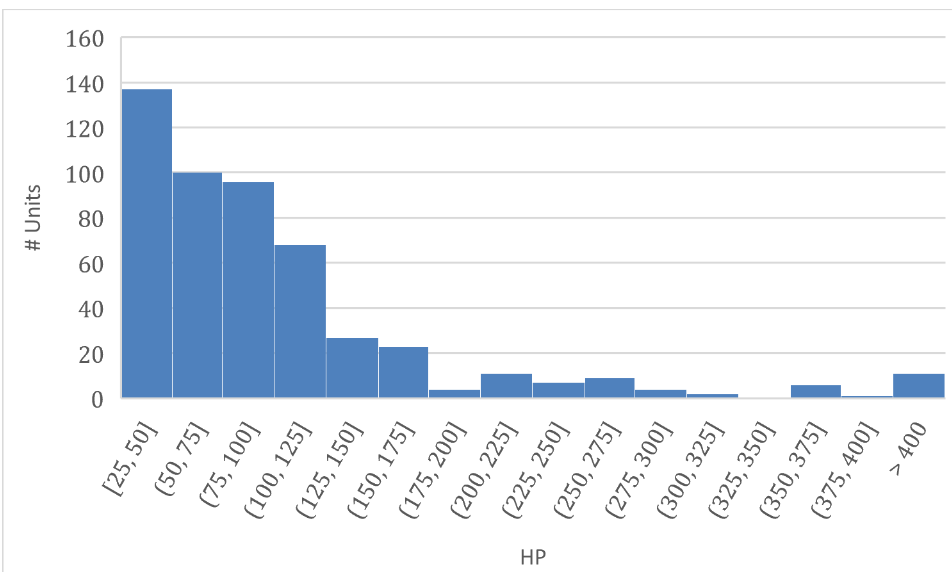


Figure 3-3. Municipal Fleet HP Distribution (N=506)
2017 Nonroad Diesel Equipment Study



[35]

[35] Some new product offerings are available in the prior calendar year, explaining why 2018 model years were in operation in 2017.

County-level municipal fleet activity was allocated from the statewide totals based on the proportion of incorporated population in each county for 2017, shown in Table 3-3.[36, 37]

Table 3-3. County-Level Municipal Fleet Activity Allocation
2017 Nonroad Diesel Equipment Study

County	Percent of Activity	County	Percent of Activity
Baker	0.40%	Lake	0.09%
Benton	2.55%	Lane	9.63%
Clackamas	7.55%	Lincoln	0.97%
Clatsop	0.87%	Linn	2.98%
Columbia	0.99%	Malheur	0.60%
Coos	1.34%	Marion	8.51%
Crook	0.35%	Morrow	0.26%
Curry	0.35%	Multnomah	27.21%
Deschutes	4.30%	Polk	2.20%
Douglas	1.87%	Sherman	0.04%
Gilliam	0.05%	Tillamook	0.34%
Grant	0.16%	Umatilla	1.97%
Harney	0.15%	Union	0.69%
Hood River	0.33%	Wallowa	0.14%
Jackson	5.10%	Wasco	0.57%
Jefferson	0.30%	Washington	12.06%
Josephine	1.37%	Wheeler	0.03%
Klamath	0.86%	Yamhill	2.80%

The municipal fleet surveys did not include responses regarding how activity was split between weekdays and weekends and across seasons. Accordingly, the fleet's temporal allocation profile was assumed to be the same as the county fleet's profile, with 100 percent of activity occurring during weekdays and 24 percent of activity during the summer months.

3.1.3 Counties

The ERG Team contacted fleet managers and other officials at the 20 counties with the largest unincorporated census population in the state. ERG focused on unincorporated population

[36] Portland State University, College of Urban and Public Affairs: Population Research Center. *Population Estimates and Reports*. Retrieved from https://www.pdx.edu/prc/population-reports-estimates.

[37] For modeling purposes, the activity and emissions associated with survey respondent fleets were estimated separately from non-respondent fleets, with statewide non-respondent activity allocated to the county level based on a renormalized population distribution (netting out respondent populations).

since the incorporated portion of a county will be serviced primarily by municipally owned equipment.

Eight of the 20 counties contacted responded to the survey, as well as Wallowa County.[38] As seen in Table 3-4, the responding counties accounted for 58.1 percent of the state's total unincorporated population.

Table 3-4. County Respondent Equipment Units and Population[39]
2017 Nonroad Diesel Equipment Study

County	# Units	Population	Percent of Unincorporated Population
Clackamas	46	202,975	15.3%
Douglas	58	58,250	4.4%
Josephine	33	47,170	3.5%
Linn	60	40,220	3.0%
Marion	45	100,095	7.5%
Multnomah	21	33,659	2.5%
Wallowa	20	3.050	0.2%
Washington	22	260,661	19.6%
Yamhill	21	27,310	2.1%
Total - Survey	**326**	**1,347,940**	**58.1%**

After compiling the survey responses and removing extraneous equipment, the remaining list contained records for 326 units. Equipment type assignments, QA and gap filling were performed following the standard procedure. Gap filling was required for 2 records with missing model year, 13 records with missing hp, and 66 records with missing annual hours.

ERG scaled the survey results to account for counties that did not provide responses in order to estimate statewide equipment populations.[40] Table 3-5 presents the statewide equipment use profile for county fleets by equipment type. The majority of fleet activity is associated with construction equipment such as graders, loaders and excavators, with significant contributions from agricultural tractors, lawn and garden equipment (e.g. commercial mowers and chippers/stump grinders), and industrial equipment (e.g. sweepers/scrubbers).

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[38] Wallowa County officials were contacted to obtain information under a different task and offered to provide their equipment data as well.

[39] As of January 1, 2018. Portland State University, College of Urban and Public Affairs: Population Research Center. *Population Estimates and Reports*. Retrieved from https://www.pdx.edu/prc/population-reports-estimates.

[40] Survey equipment counts were divided by 0.581 to scale to the state level, as responding counties contained 58.1% of the incorporated state population.

Table 3-5. Statewide County Fleet Profile
2017 Nonroad Diesel Equipment Study

Equipment Type	# Units	Avg HP	Avg Hrs/Yr	Avg Model Yr	Gal/Yr[41]
Agricultural tractors	21	100	395	2007	20,495
Air compressors	5	47	171	2000	755
Generator sets	2	134	43	2015	161
Welders	3	26	643	2006	830
Cranes	3	184	990	1996	9,513
Crawler tractors/dozers	17	176	138	1990	9,009
Excavators	50	134	329	2007	47,608
Graders	83	214	442	2006	176,721
Other construction equip.	12	256	132	2006	9,357
Pavers	12	79	224	2002	4,446
Rollers	77	86	109	2002	15,128
Rough terrain forklifts	22	58	562	1994	16,506
Rubber tire loaders	100	131	187	1999	56,848
Scrapers	3	330	914	1982	26,392
Skid steer loaders	7	66	210	2013	2,424
Surfacing equipment	22	174	150	2010	7,725
Tractors/loaders/backhoes	29	96	208	2003	15,120
Aerial lifts	2	238	60	1988	470
Forklifts	3	88	114	2007	400
Sweepers/scrubbers	29	98	287	2010	21,361
Chippers/stump grinders	19	114	363	2009	17,685
Commercial mowers	26	107	276	2008	17,634
Lawn and garden tractors	3	25	105	2015	226
Other lawn and garden equip	2	45	2	2011	4
Rear engine riding mowers	2	25	3	2015	3
Specialty vehicles/carts	2	33	14	2009	22
Total	**561**	**130**	**271**	**2004**	**476,442**

Figure 3-4 through Figure 3-6 present the county equipment fleet distributions for model year, annual hours per unit, and hp based on the survey responses. The county equipment is somewhat older than the municipal fleet (average model year = 2004) and has somewhat higher activity (244 hours per year). The county equipment is also relatively low power (average = 132 hp).

[41] Calculated using EPA MOVES-Nonroad model (2014b). See Section 6.2 for additional details.

Figure 3-4. County Fleet Model Year Distribution (N=326)
2017 Nonroad Diesel Equipment Study

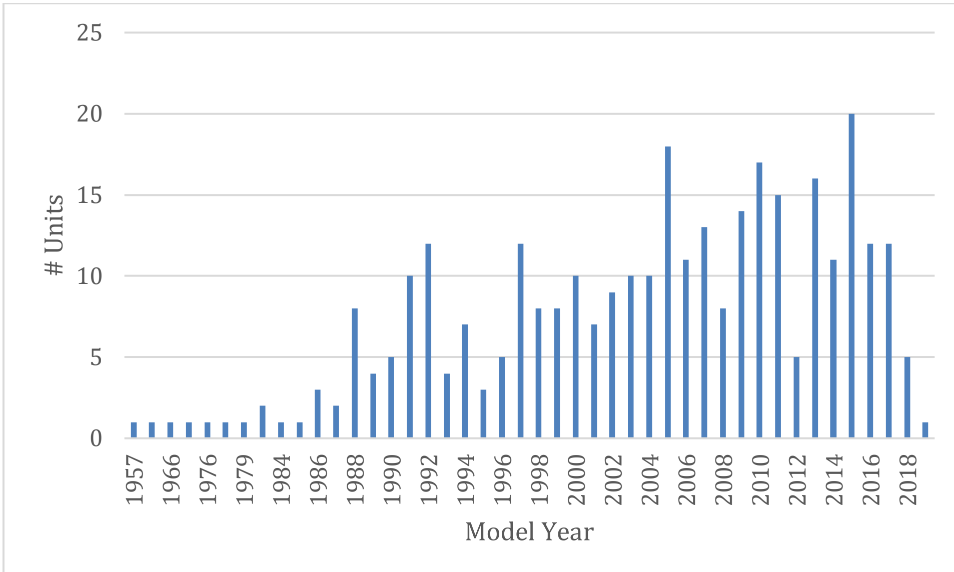


Figure 3-5. County Fleet Hours/Year Distribution (N=260)
2017 Nonroad Diesel Equipment Study

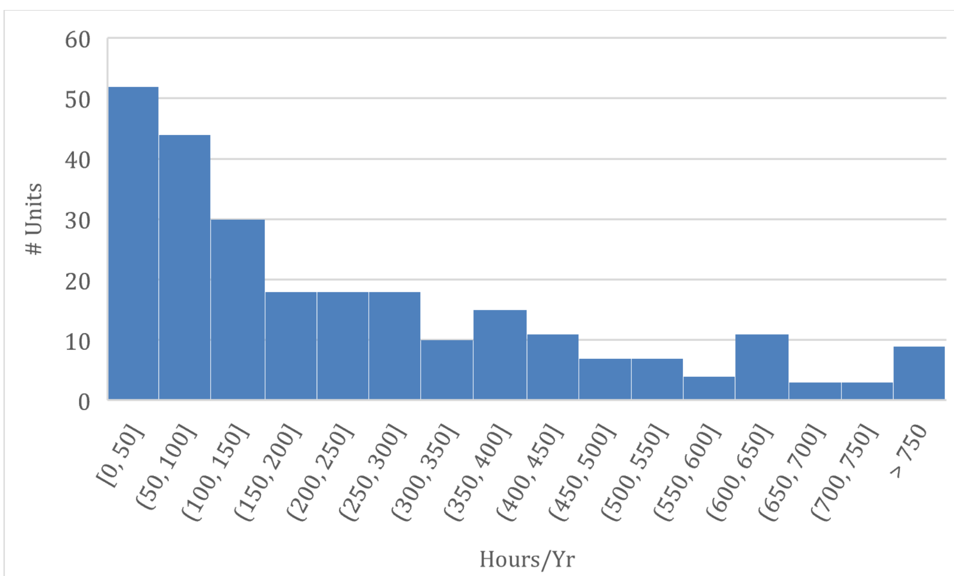
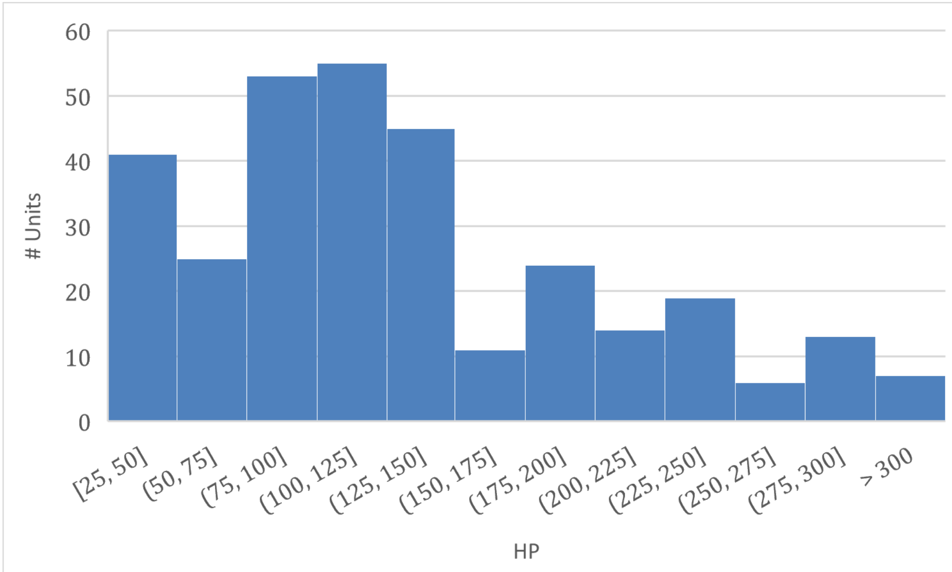


Figure 3-6. County Fleet HP Distribution (N=313)
2017 Nonroad Diesel Equipment Study



County-level county fleet activity was allocated from the statewide totals based on the proportion of unincorporated population in each county for 2017, shown in Table 3-6.[42]

Table 3-6. Count-Level County Fleet Activity Allocation
2017 Nonroad Diesel Equipment Study

County	Percent of Activity	County	Percent of Activity
Baker	0.40%	Lake	0.42%
Benton	1.53%	Lane	7.45%
Clackamas	15.26%	Lincoln	1.53%
Clatsop	1.08%	Linn	3.02%
Columbia	1.78%	Malheur	1.12%
Coos	1.86%	Marion	7.53%
Crook	0.95%	Morrow	0.32%
Curry	0.97%	Multnomah	2.53%
Deschutes	4.94%	Polk	1.42%
Douglas	4.38%	Sherman	0.04%
Gilliam	0.05%	Tillamook	1.25%
Grant	0.21%	Umatilla	1.82%
Harney	0.22%	Union	0.53%
Hood River	1.20%	Wallowa	0.23%

[42] Portland State University, College of Urban and Public Affairs: Population Research Center. *Population Estimates and Reports*. Retrieved from https://www.pdx.edu/prc/population-reports-estimates.

County	Percent of Activity
Jackson	5.50%
Jefferson	1.13%
Josephine	3.55%
Klamath	3.25%

County	Percent of Activity
Wasco	0.82%
Washington	19.60%
Wheeler	0.05%
Yamhill	2.05%

The county fleet surveys included estimates regarding how activity was split between weekdays and weekends and across seasons for 54 pieces of equipment. The fleet's temporal allocation profile estimates that 100 percent of activity occurs during weekdays and 24 percent of activity occurs during the summer months.

3.1.4 Special Districts[43]

The Special Districts Association of Oregon (SDAO) provided a complete inventory of equipment owned and operated by each district as of 2018.[44] The data contained a brief description for each unit, such as equipment type (e.g. skid steer), make, model, and/or model year.

The equipment inventory data did not include annual activity estimates. To help obtain this information, the SDAO reached out to 219 special districts known to operate target equipment on behalf of the ERG team, requesting their participation in the survey. 28 districts (listed in Table 3-7) provided information on 189 pieces of equipment.

Table 3-7. Special District Survey Respondents
2017 Nonroad Diesel Equipment Study

Special District	# Units
Bend Metro Park & Recreation District	21
Clackamas Soil & Water Conservation District	1
Columbia Improvement District	1
Columbia River Public Utility District	1
Crook County Parks and Recreation District	5
Emerald Public Utility District	13
Hermiston Cemetery District	1
Hermiston Irrigation District	7
Klamath County Extension Service District	1
La Grande Cemetery Maintenance District	2
Lane Fire Authority	3
Mid-Columbia Fire and Rescue	1
North Wasco Parks and Recreation District	3

[43] Excludes marine port districts, presented separately in Section 3.1.6.

[44] The equipment inventory list is maintained by the SDAO for insurance purposes. Provided electronically by Mark Landauer, Special Districts Association of Oregon, 10-8-2018.

Special District	# Units
Odell Sanitary District	2
Raleigh Water District	1
Rockwood Water Public Utility District	7
Rogue Valley Sewer Services	16
Rural Road Assessment District #3	8
Rural Road Assessment District #4	4
Springfield Utility Board	28
Stanfield Irrigation District	5
Sunriver Service District	1
Talent Irrigation District	14
The Dalles Irrigation District	1
Tualatin Valley Water District	26
Tumalo Water District	4
West Slope Water District	1
Willamalane Parks and Recreation District	11
Total	**189**

ERG combined the survey results with the equipment inventory information in order to develop the statewide profile for special district fleets. First ERG removed all equipment operated by the survey respondents, as well as those operated by marine ports, from the inventory list to avoid double-counting.[45] Next, ERG reviewed the equipment type descriptions in the inventory list to eliminate extraneous equipment (e.g. non-motorized attachments). After filtering, 445 units without survey responses remained on the list, 188 of which were missing model year, and 346 were missing hp. None of these records contained equipment activity information.

In order to gap-fill the missing model years ERG estimated the proportion of engines across those units by emission standard grouping, and assigned the average year for each group proportionally across the 188 units with missing data (see Table 3-8).

Table 3-8. Engine Model Year Distribution – All Districts and Equipment Types[46]
2017 Nonroad Diesel Equipment Study

Model Year Range	Emission Standard[47]	Percent of Population	Avg Model Yr
1952 – 1995	Pre-Tier 1	34.9%	1984
1996 – 2000	Tier 1	16.3%	1998
2001 – 2005	Tier 2	22.5%	2003

[45] The Marine Port fleet is discussed in Section 3.1.6.

[46] Excludes survey records with gap-filled model years.

[47] Approximate standard - varies with phase-in period and horsepower.

Model Year Range	Emission Standard[47]	Percent of Population	Avg Model Yr
2006 – 2009	Tier 3	13.3%	2007
2010 – 2014	Transitional Tier 4	8.0%	2012
2015 - 2018	Tier 4	4.8%	2016

ERG then gap-filled the inventory's missing hp and hour per year data using averages from the survey for each equipment type.[48] The fully gap-filled equipment inventory dataset was then combined with the survey data from the 29 responding districts, for a total of 634 unique equipment records.

Since the final list accounts for all the nonroad diesel equipment owned and operated by the special districts across the state, it was not necessary to identify and apply scaling factors for non-respondent fleets. Table 3-9 presents the statewide equipment use profile for the special districts by equipment type. The majority of fleet activity is associated with construction equipment such as excavators, backhoes, graders, and loaders, with significant contributions from agricultural tractors and generator sets.

Table 3-9. Statewide Special Districts Fleet Profile
2017 Nonroad Diesel Equipment Study

Equipment Type	# of Units	Avg HP	Avg Hrs/Yr	Avg Model Yr	Gal/Yr[49]
Agricultural mowers	1	76	363	1984	958
Agricultural tractors	89	71	150	1997	26,119
Other agricultural equipment	5	140	120	1992	3,231
Air compressors	8	70	38	2002	439
Generator sets	109	366	18	1998	11,513
Pumps	7	80	20	2000	281
Welders	1	46	643	1984	427
Bore/drill rigs	1	50	10	2000	15
Concrete/industrial saws	1	99	12	2010	41
Crawler tractors/dozers	22	88	53	1990	2,342
Excavators	78	75	305	2002	40,398
Graders	26	164	240	1983	22,167
Off-highway trucks	1	413	855	2005	7,112
Other construction equipment	18	77	54	1999	1,669
Rollers	5	71	84	2002	536
Rough terrain forklifts	41	83	51	1996	4,504
Rubber tire loaders	27	129	230	1992	15,976

[48] The data set did not contain enough observations to develop robust hp and activity distributions for each equipment category.

[49] Calculated using EPA MOVES-Nonroad model (2014b). See Section 6.2 for additional details.

Equipment Type	# of Units	Avg HP	Avg Hrs/Yr	Avg Model Yr	Gal/Yr[49]
Skid steer loaders	13	67	79	2002	1,821
Tractors/loaders/backhoes	93	79	163	1998	30,395
Aerial lifts	6	60	384	1999	2,945
Forklifts	3	93	73	2002	237
Other industrial equipment	18	423	20	2000	3,013
Sweepers/scrubbers	1	63	300	2014	503
Chippers/stump grinders	13	104	144	2009	4,812
Commercial mowers	6	48	327	2005	3,513
Commercial turf equipment	10	62	183	2009	3,193
Lawn and garden tractors	8	37	544	1998	3,830
Other lawn and garden equipment	2	51	433	1993	1,107
Rear engine riding mowers	5	38	254	2008	1,192
Commercial turf equipment	2	62	278	2008	843
Specialty vehicles/carts	14	28	435	2003	4,921
Total	**634**				**197,779**

Figure 3-7 through Figure 3-9 present the Special District equipment fleet distributions for model year, annual hours per unit, and hp based on the survey responses. The Special District equipment is older than the municipal and county fleets (average model year = 2002) but has lower activity level (average = 130 hours per year). The equipment is relatively low power (average = 153 hp).

Figure 3-7. Special Districts Fleet Model Year Distribution (N=178)
2017 Nonroad Diesel Equipment Study

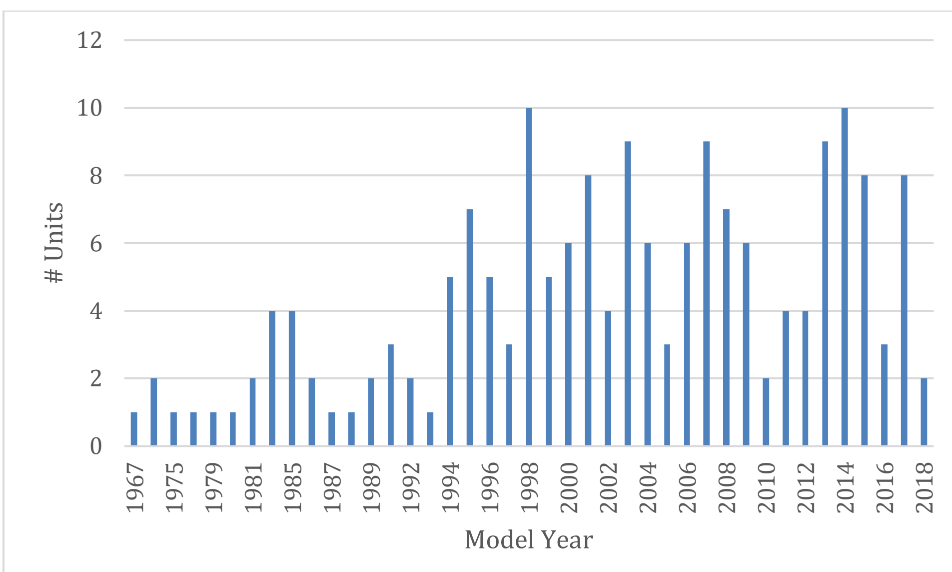


Figure 3-8. Special Districts Fleet Hours/Year Distribution (N=188)
2017 Nonroad Diesel Equipment Study

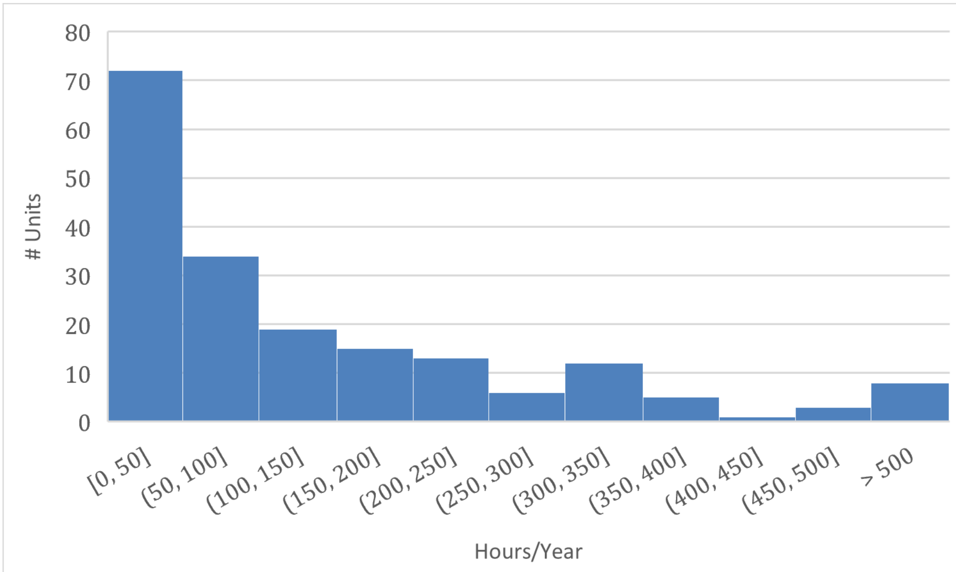
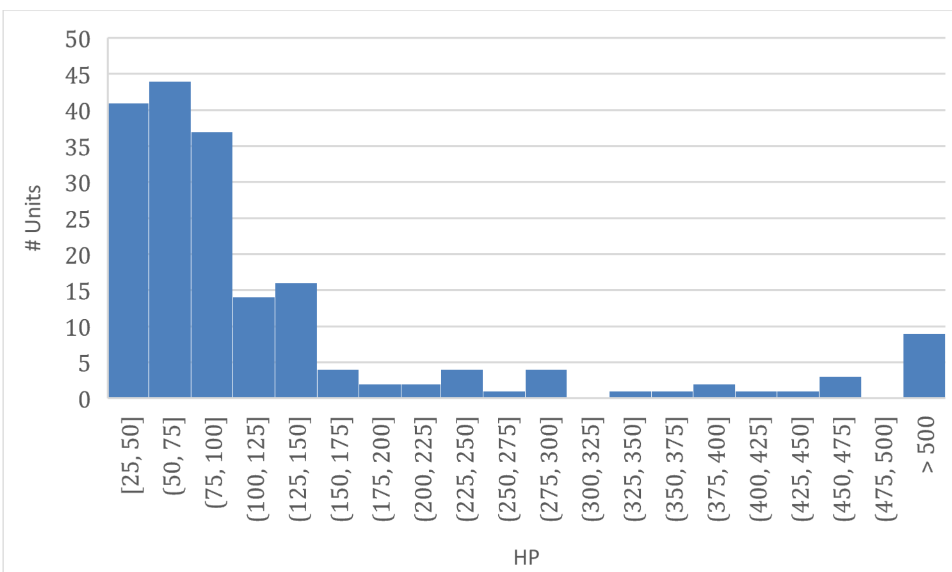


Figure 3-9. Special Districts Fleet HP Distribution (N=187)
2017 Nonroad Diesel Equipment Study



Special District equipment was assumed to operate exclusively in the county of each district's headquarters. The county-level activity distribution for the Special District fleets are shown in Table 3-10.

Table 3-10. County-Level Special District Fleet Activity Allocation 2017 Nonroad Diesel Equipment Study

County	Percent of Activity
Baker	1.55%
Benton	0.07%
Clackamas	6.36%
Clatsop	0.43%
Columbia	1.30%
Coos	1.15%
Crook	3.69%
Curry	0.21%
Deschutes	13.81%
Douglas	1.87%
Gilliam	0.14%
Grant	0.19%
Harney	0.00%
Hood River	1.77%
Jackson	4.76%
Jefferson	1.85%
Josephine	0.52%
Klamath	9.53%

County	Percent of Activity
Lake	0.57%
Lane	9.77%
Lincoln	1.48%
Linn	0.65%
Malheur	14.96%
Marion	1.04%
Morrow	0.83%
Multnomah	2.72%
Polk	0.85%
Sherman	0.07%
Tillamook	1.28%
Umatilla	6.81%
Union	1.04%
Wallowa	0.00%
Wasco	1.51%
Washington	6.25%
Wheeler	0.00%
Yamhill	0.98%

The Special District fleet surveys included estimates regarding how activity was split between weekdays and weekends and across seasons for 68 pieces of equipment. The fleet's temporal allocation profile estimates that 99 percent of activity occurs during weekdays and 24 percent of activity occurs during the summer months.

3.1.5 Other Agencies

The ERG Team conferred with DEQ and AGC staff to identify other government agencies expected to own and operate significant numbers of nonroad diesel equipment. Ultimately fleet managers and other officials were contacted at 12 state and federal agencies across the state, all of which responded to the survey.[50] Table 3-11 lists the responding agencies along with the number of units operated.

[50] ERG also contacted the U.S. Army Corps of Engineers whose representatives reported approximately 15,000 gallons of nonroad diesel fuel use in 2017 but indicated the vast majority of this fuel was consumed by generator sets, many or most of which are likely stationary and therefore excluded from the survey. Personal communication with Arthur Leskowich, US ACOE, 8-12-2019.

Table 3-11. Other Government Agency Survey Respondents 2017 Nonroad Diesel Equipment Study

Agency	# Units
Air Force National Guard - Kingsley Field	18
Air Force National Guard - Portland	50
Army National Guard - Federal	38
Army National Guard - State	59
Bureau of Land Management	120
OR Dept of Administrative Services	21
OR Dept of Corrections	44
OR Dept of Forestry	21
OR Dept of Transportation	411
OR Parks and Recreation Dept	100
Portland Metro	24
US Forest Service	54
Total	**960**

Of the 960 units included in the survey responses, only 29 lacked hp, 28 lacked model year, and 66 lacked hours per year. The Forest Service survey accounted for 54 of the 66 missing hour per year estimates, which were gap-filled using average hours for the same equipment types from the Bureau of Land Management (BLM). Equipment type distributions are similar across these agencies (see Table 3-12), and ERG assumed equipment utilization rates would be similar as well.

Table 3-12. Equipment Type Distribution – Forest Service vs BLM 2017 Nonroad Diesel Equipment Study

Equipment Type	Forest Service	BLM	Avg Hrs/Yr (BLM)
Agricultural tractors	29%	26%	280
Crawler tractors/dozers	4%	7%	729
Excavators	7%	7%	688
Graders	11%	18%	143
Other construction equipment		1%	340
Paving equipment		1%	67
Rollers		4%	197
Rough terrain forklifts	5%	1%	308
Rubber tire loaders	7%	10%	179
Skid steer loaders	14%	7%	179
Tractors/loaders/backhoes	14%	17%	225
Sweepers/scrubbers		3%	160

The remainder of the missing data were gap-filled using standard procedures.

This analysis assumes the 12 responding agencies cover all significant nonroad diesel equipment use for other government agencies in Oregon. As such, no scaling factors were used to expand the survey results to other agencies, and the filtered, quality assured equipment records are assumed to represent the statewide profile for this fleet (see Table 3-13). The majority of fleet activity is associated with generator sets, agricultural tractors and construction equipment such as rough terrain forklifts, graders, loaders and backhoes, among others.

Table 3-13. Statewide Other Agency Fleet Profile
2017 Nonroad Diesel Equipment Study

Equipment Types	# Units	Avg HP	Avg Hrs/Yr	Avg Model Yr	Gal/Yr[51]
Agricultural tractors	132	106	234	2005	90,685
Other agricultural equipment	2	128	5	2005	38
Airport ground support equipment	1	210	61	2006	265
Air compressors	2	70	64	1987	179
Generator sets	104	428	216	2001	129,682
Other industrial equipment	1	320	52	1995	297
Pumps	4	124	9	2002	122
Crawler tractors/dozers	31	152	408	2005	40,825
Excavators	31	124	482	2009	37,918
Graders	91	168	247	2007	76,994
Other construction equipment	2	135	221	1998	1,374
Paving equipment	1	131	67	2002	167
Rollers	5	124	197	2005	2,469
Rough terrain forklifts	118	123	261	1999	82,913
Rubber tire loaders	90	127	290	2005	64,812
Skid steer loaders	69	88	142	2009	20,307
Tractors/loaders/backhoes	78	126	198	2007	44,298
Aerial lifts	6	55	126	2004	1,011
Sweepers/scrubbers	45	145	180	2007	27,614
Terminal tractors	12	239	136	2003	12,786
Chippers/stump grinders	28	96	130	2009	10,476
Commercial turf equipment	2	37	1,068	2016	1,981
Commercial mowers	55	35	167	2009	7,748
Lawn and garden tractors	32	55	98	2005	4,438
Leafblowers/vacuums	1	26	11	2014	7
Other lawn and garden equipment	2	72	20	1999	87
Logging equipment	7	120	34	2006	692
Specialty vehicles/carts	4	51	39	2005	239
Total	**956**				**660,424**

[51] Calculated using EPA MOVES-Nonroad model (2014b). See Section 6.2 for additional details.

Figure 3-10 through Figure 3-12 present the Other Agency equipment fleet distributions for model year, annual hours per unit, and hp based on the survey responses. The average model year for the fleet was 2005, with a notable spike in equipment purchases in 2002 attributable to ODOT. Average activity was 225 hours per year, and the average equipment power was 144 hp.

Figure 3-10. Other Agency Fleet Model Year Distribution (N=928)
2017 Nonroad Diesel Equipment Study

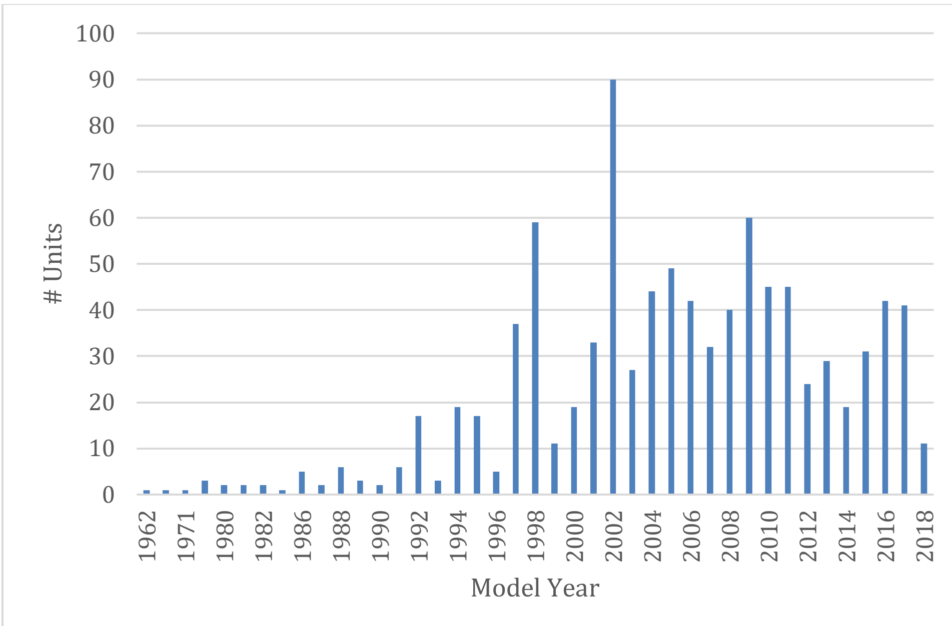


Figure 3-11. Other Agency Fleet Hours/Year Distribution (N=944)
2017 Nonroad Diesel Equipment Study

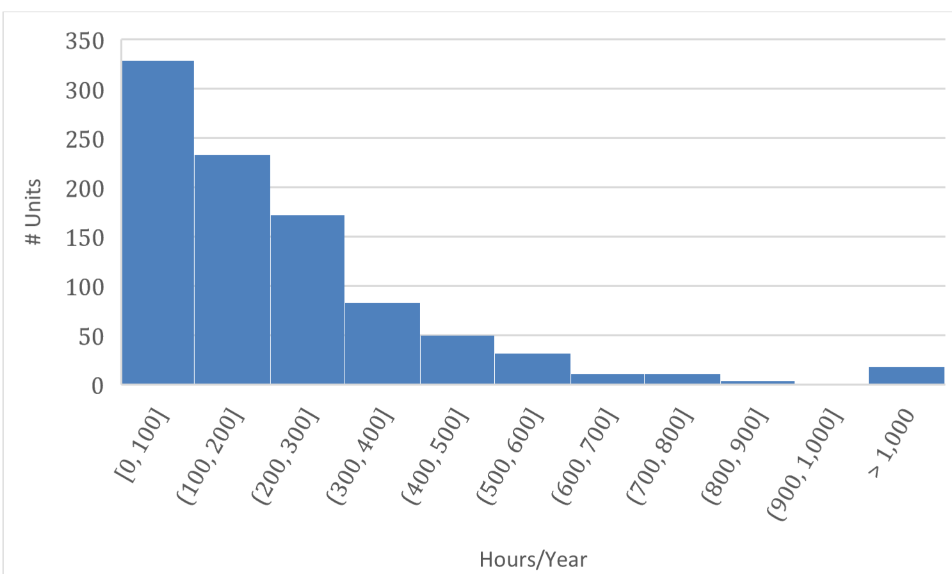
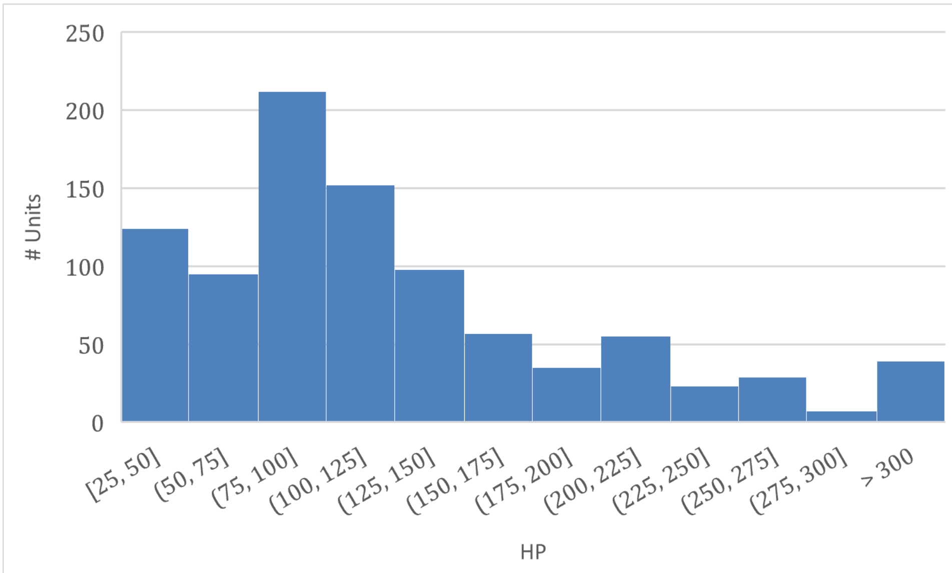


Figure 3-12. Other Agency Fleet HP Distribution (N=926)
2017 Nonroad Diesel Equipment Study



The county-level activity distribution for the Other Agency fleets were reported comprehensively in the survey responses and are shown in Table 3-14.

Table 3-14. County-Level Other Agency Fleet Activity Allocation
2017 Nonroad Diesel Equipment Study

County	Percent of Activity	County	Percent of Activity
Baker	0.90%	Lake	2.51%
Benton	0.54%	Lane	3.68%
Clackamas	4.06%	Lincoln	0.94%
Clatsop	3.88%	Linn	1.07%
Columbia	0.31%	Malheur	4.90%
Coos	3.13%	Marion	24.06%
Crook	3.37%	Morrow	0.59%
Curry	0.76%	Multnomah	5.52%
Deschutes	5.48%	Polk	0.56%
Douglas	4.65%	Sherman	0.65%
Gilliam	0.39%	Tillamook	2.32%
Grant	1.20%	Umatilla	5.03%
Harney	2.21%	Union	1.05%
Hood River	1.35%	Wallowa	1.03%
Jackson	5.49%	Wasco	2.18%
Jefferson	0.08%	Washington	1.31%

County	Percent of Activity
Josephine	1.04%
Klamath	2.37%

County	Percent of Activity
Wheeler	0.12%
Yamhill	1.25%

The Other Agency fleet surveys included estimates regarding how activity was split between weekdays and weekends and across seasons for 58 pieces of equipment. The fleet's temporal allocation profile estimates that 99 percent of activity occurs during weekdays and 24 percent of activity occurs during the summer months.

3.1.6 Marine Ports

The ERG Team contacted fleet managers and other officials at nine marine ports across the state, eight of which responded to the survey. Table 3-15 lists the responding ports along with the number of pieces of nonroad diesel equipment reported for each. Each of the ports listed in the table are Special Districts, with the exception of the Port of Portland.

Table 3-15. Marine Port Survey Respondents
2017 Nonroad Diesel Equipment Study

Port	# Units
Port of Coos Bay	4
Port of Garibaldi	4
Port of Hood River	3
Port of Morrow	25
Port of Portland	24
Port of St. Helens	2
Port of Tillamook	10
Port of Umpqua	0
Total	**72**

Of the 72 units included in the survey results, there were no missing hp or model year values. Four records with missing hour per year values were gap-filled using EPA defaults for the relevant equipment categories. The survey data were then combined with the Special District equipment inventory data obtained from the SDAO (see Table 3-16) to create a complete equipment listing for marine port operations.[52]

Table 3-16. Special District Equipment Inventory – Non-Surveyed Ports
2017 Nonroad Diesel Equipment Study

Other Special District Ports	# Units
Port of Astoria	16
Port of Bandon	1

[52] Provided electronically by Mark Landauer, Special Districts Association of Oregon, 10-8-2018.

Other Special District Ports	# Units
Port of Brookings Harbor	1
Port of Cascade Locks	2
Port of Gold Beach	4
Port of Newport	3
Port of Port Orford	3
Port of Siuslaw	2
Port of Toledo	5
Port of Umatilla	1
Total	**38**

This analysis assumes the ports listed in Table 3-15 and Table 3-16 account for all significant nonroad diesel equipment use for marine ports in Oregon. As such, no scaling factors were used to expand the survey results to the state level. The statewide profile for marine ports is presented in Table 3-17. Marine port equipment activity is dominated by construction equipment including bulldozers and excavators, with additional activity attributable to agricultural tractors and other industrial equipment.[53]

Table 3-17. Statewide Marine Port Fleet Profile
2017 Nonroad Diesel Equipment Study

Equipment Types	# Units	Avg HP	Avg Hrs/Yr	Avg Model Yr	Gal/Yr[54]
Agricultural tractors	8	79	308	2003	6,381
Generator sets	4	71	971	2001	2,631
Cranes	12	300	64	2008	3,503
Crawler tractors/dozers	5	237	931	2006	31,529
Excavators	9	172	313	2005	11,985
Graders	3	149	474	2001	5,330
Other construction equip.	3	124	63	2002	548
Rollers	2	83	233	1999	863
Rough terrain forklifts	30	251	123	2006	7,975
Rubber tire loaders	6	176	237	2003	5,666
Scrapers	3	326	398	1986	9,487
Skid steer loaders	3	73	163	2008	851
Tractors/loaders/backhoes	8	84	331	2002	5,681
Aerial lifts	4	45	384	2009	1,472

[53] There were no significant container imports/exports in Oregon in 2017, which explains the lack of standard cargo handling equipment (e.g. gantry cranes, top and side picks) in the surveys. U.S. Army Corps of Engineers, IWR Planning Assistance Library, Foreign Cargo Inbound and Outbound Calendar Year 2017. Retrieved from https://publibrary.planusace.us/#/series/Waterborne%20Foreign%20Cargo.

[54] Calculated using EPA MOVES-Nonroad model (2014b). See Section 6.2 for additional details.

Equipment Types	# Units	Avg HP	Avg Hrs/Yr	Avg Model Yr	Gal/Yr[54]
Other industrial equip.	4	148	409	2017	4,316
Sweepers/scrubbers	1	134	1220	1996	3,943
Commercial turf equip.	4	174	23	1998	359
Specialty vehicles/carts	1	26	400	2014	300
Total	**110**				**102,821**

Figure 3-13 through Figure 3-15 present the Marine Port equipment fleet distributions for model year, annual hours per unit, and hp based on the survey responses. The average model year for the fleet was 2006, the average activity was 265 hours per year, and the average equipment power was 186 HP.

Figure 3-13. Marine Port Fleet Model Year Distribution (N=94)
2017 Nonroad Diesel Equipment Study

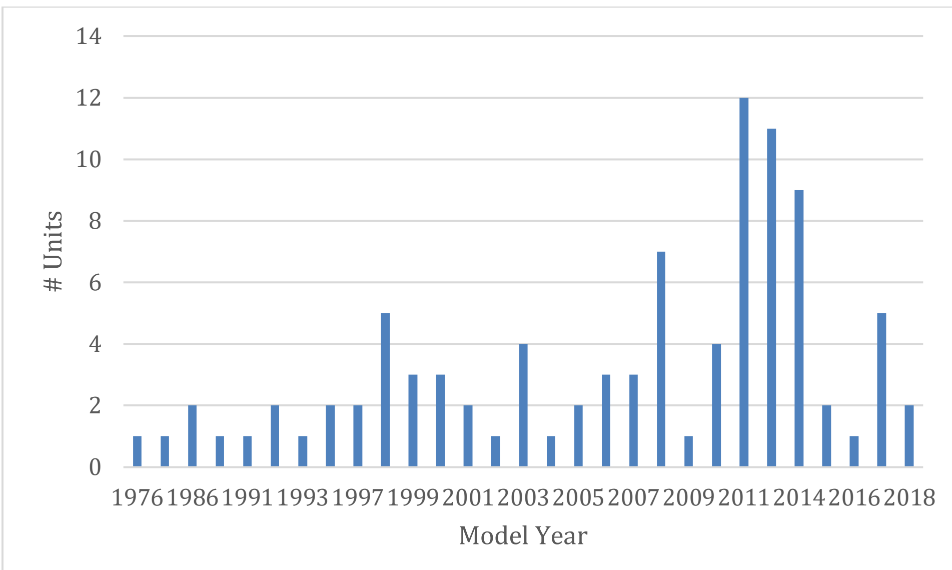


Figure 3-14. Marine Port Fleet Hour/Year Distribution (N=106)
2017 Nonroad Diesel Equipment Study

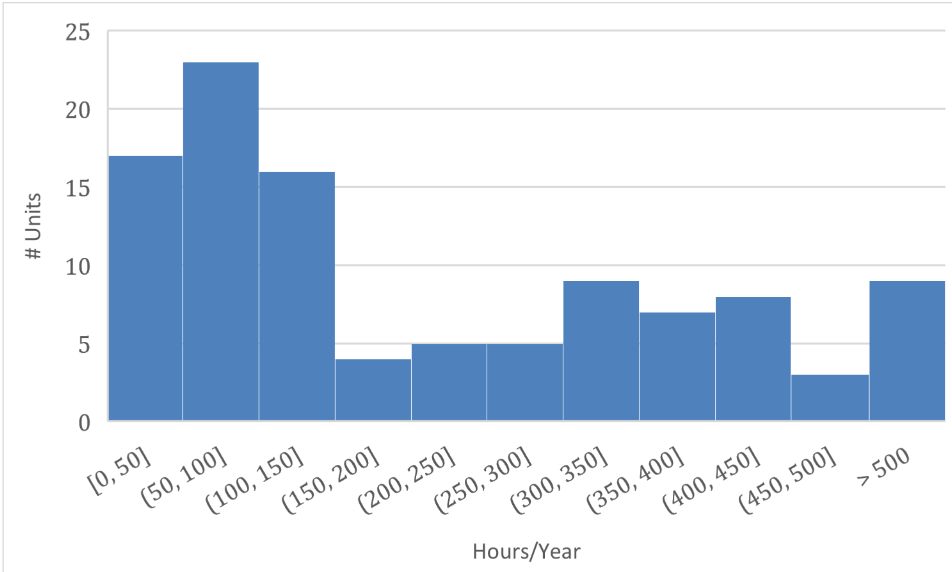
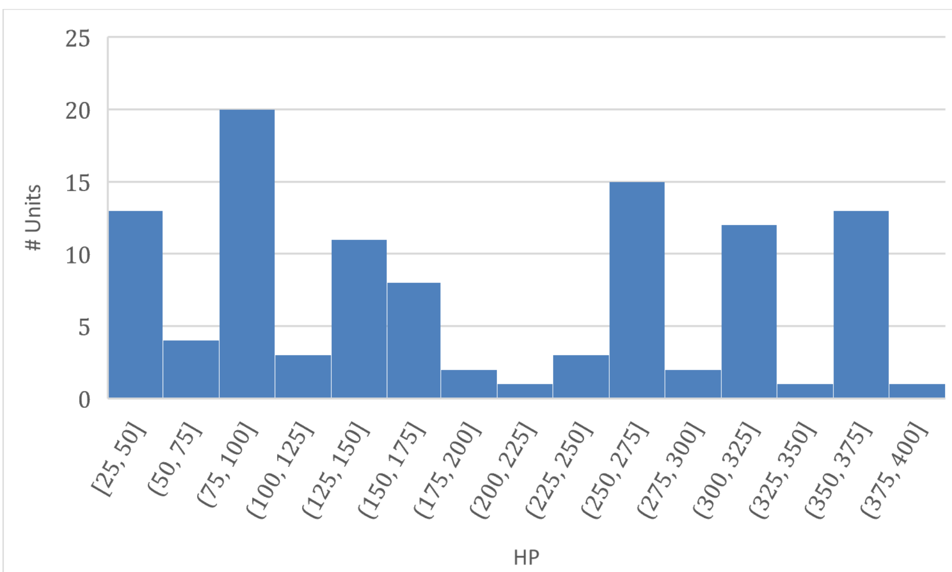


Figure 3-15. Marine Port Fleet HP Distribution (N=109)
2017 Nonroad Diesel Equipment Study



The county-level activity distribution for Marine Port fleets was reported comprehensively in the survey responses and are shown in Table 3-18.[55]

[55] The county distribution was also compared to the distribution of tonnage reported in the US Army Corps of Engineers Entrances and Clearances data for Oregon in 2017 and found to be generally consistent. U.S. Army Corps

Table 3-18. County-Level Marine Port Fleet Activity Allocation 2017 Nonroad Diesel Equipment Study

County	Percent of Activity
Baker	0.00%
Benton	0.00%
Clackamas	0.00%
Clatsop	14.00%
Columbia	0.14%
Coos	7.29%
Crook	0.00%
Curry	3.93%
Deschutes	0.00%
Douglas	0.00%
Gilliam	0.00%
Grant	0.00%
Harney	0.00%
Hood River	4.95%
Jackson	0.00%
Jefferson	0.00%
Josephine	0.00%
Klamath	0.00%

County	Percent of Activity
Lake	0.00%
Lane	1.16%
Lincoln	3.77%
Linn	0.00%
Malheur	0.00%
Marion	0.00%
Morrow	25.19%
Multnomah	31.95%
Polk	0.00%
Sherman	0.00%
Tillamook	7.36%
Umatilla	0.27%
Union	0.00%
Wallowa	0.00%
Wasco	0.00%
Washington	0.00%
Wheeler	0.00%
Yamhill	0.00%

The Marine Port fleet surveys included estimates regarding how activity was split between weekdays and weekends and across seasons for only 11 pieces of equipment. The fleet's temporal allocation profile estimates that 88 percent of activity occurs during weekdays and 26 percent of activity occurs during the summer months.

3.1.7 Airports

The ERG team reached out to the top four commercial airports in the state (Portland, Eugene, Medford and Redmond), as ranked by annual landing and takeoff (LTO) counts),[56] as well as to the Hillsboro general aviation airport, to request participation in the survey. Equipment at these locations are operated by a combination of public and private fleets. Nine survey responses were obtained, as shown in Table 3-19. The identities of the private equipment operators, many of which serve multiple airports, have been shielded to protect confidentiality.

of Engineers, IWR Planning Assistance Library, Foreign Cargo Inbound and Outbound Calendar Year 2017. Retrieved from https://publibrary.planusace.us/#/series/Waterborne%20Foreign%20Cargo.

[56] U.S. Department of Transportation, Bureau of Transportation Statistics *Transtats*. Retrieved from https://www.transtats.bts.gov/databases.asp?Mode_ID=1&Mode_Desc=Aviation&Subject_ID2=0.

Table 3-19. Airport Fleet Survey Respondents
2017 Nonroad Diesel Equipment Study

Respondent	# Units
Private Operator 1	4
Private Operator 2	17
Private Operator 3	54
Private Operator 4	9
Eugene Airport – Public	12
Private Operator 5	4
Portland Airport – Private[57]	204
Portland Airport – Public	57
Private Operator 6	1
Total	**362**

The EPA MOVES-Nonroad model does not differentiate among the types of airport GSE. For this reason, ERG followed California Air Resources Board (CARB) equipment naming conventions in order to evaluate the survey findings more precisely. The GSE categories used by CARB include:

- A/C Tug
- Baggage Tug
- Belt Loader
- Cargo Loader
- Lift
- Terminal tractors
- Ground Power Units
- Other GSE

Survey responses referencing air start units, de-icers, stairs, and fuel trucks were assigned to the "Other GSE" category for analysis. Ground power units were re-assigned to the commercial generator category, as they are functionally similar.

The survey results included records for 362 diesel powered units greater than 25 hp with non-zero operating hours in 2017. Model year information was complete for all units. Gap-filling was required for 219 units without hp values, relying on CARB averages for GSE and EPA defaults for other equipment types. Gap-filling was also required for 103 units without annual hour estimates, and scaling was based on the average reported hours of use per LTO by equipment type.

[57] Multiple private operator responses were bundled and provided to the ERG team by the Port of Portland. Personal communication with David Breen, Air Quality Program Manager, Port of Portland, 10-20-2018.

LTO data for the Portland, Eugene, Medford and Redmond airports was compiled for 2017.[58] Table 3-20 provides the LTO counts by airport, excluding those for general aviation.[59]

Table 3-20. 2017 Commercial LTOs by Airport
2017 Nonroad Diesel Equipment Study

	Portland	Eugene	Medford	Redmond
# LTOs	106,257	10,861	8,526	7,873
Percent of Total	79.6%	8.1%	6.4%	5.9%

The survey responses for the Portland and Redmond airports were determined to be complete. ERG used LTO data as a scaling factor for missing responses from Medford (no information received), and Eugene (one non-responsive private operator[60]).

Although classified as a general aviation facility, the Hillsboro airport is unusual in terms of volume, being the second busiest airport in the state.[61] Survey responses for Hillsboro were determined to be complete and included in the state profile, but were excluded from the LTO scaling process used to gap-fill missing information for commercial aviation facilities.

Table 3-21 presents the statewide profile for airport equipment fleets. Activity for these fleets are dominated by the various types of GSE and generators, with relatively small contributions from agricultural tractors and industrial equipment, among others.

Table 3-21. Statewide Airport Fleet Profile
2017 Nonroad Diesel Equipment Study

Equipment Type	# Units	Avg HP	Avg Hrs/Yr	Avg Model Yr	Gal/Yr[62]
Agricultural tractors	20	90	149	1999	5,689
Air compressors	2	37	13	1997	18
Generator sets	43	156	1,190	2005	114,597
Pavers	1	91	9	2003	20
Cranes	1	300	64	2011	292
Crawler tractors/dozers	2	98	49	1997	228
Excavators	2	50	130	2012	291
Graders	1	172	35	1980	130

[58] U.S. Department of Transportation, Bureau of Transportation Statistics *Transtats.* Retrieved from https://www.transtats.bts.gov/databases.asp?Mode_ID=1&Mode_Desc=Aviation&Subject_ID2=0.

[59] With the exception of Hillsboro airport, general aviation aircraft (i.e. private/recreational aircraft) are excluded from the LTO count at commercial airports as they require minimal diesel equipment support compared to commercial passenger and cargo aircraft.

[60] The BTS data included LTO breakouts by airport and operator. The percent of LTOs attributable the non-respondent Eugene equipment operator was 46.9% of the airport total.

[61] Port of Portland, Hillsboro Airport. https://www.portofportland.com/HIO.

[62] Calculated using EPA MOVES-Nonroad model (2014b). See Section 6.2 for additional details.

Equipment Type	# Units	Avg HP	Avg Hrs/Yr	Avg Model Yr	Gal/Yr[62]
Other construction equipment	5	137	30	2013	402
Rollers	3	99	23	2006	151
Rough terrain forklifts	5	91	10	2005	55
Rubber tire loaders	7	132	116	2003	1,902
Skid steer loaders	1	77	43	2001	84
Tractors/loaders/backhoes	2	80	7	2005	26
A/C tug (GSE)	9	173	2,920	2015	127,304
Baggage tug (GSE)	76	71	1,453	2000	160,796
Belt loader (GSE)	52	69	370	2007	24,911
Cargo loader (GSE)	10	121	379	2002	8,168
Lift (GSE)	19	91	866	2002	27,725
Other GSE	66	163	376	2002	75,922
Terminal tractors (GSE)	55	121	533	1996	71,832
Other industrial equipment	2	350	314	2013	3,923
Sweepers/scrubbers	13	141	226	2007	9,283
Transportation refrigeration equipment	5	170	1,097	2000	21,007
Other material handling equipment	4	300	72	2009	705
Commercial mowers	6	36	28	2010	182
Specialty vehicles/carts	3	74	53	2005	419
Total	**415**				**656,064**

GSE use is restricted to airport operations. As such, it is possible to compare the statewide profile results for GSE shown in Table 3-21 with the default GSE estimates in EPA's MOVES-NONROAD model.[63] Table 3-22 compares the state profile results for GSE to EPA defaults. In general, the surveyed GSE fleet is greater in number but used less (as measured by fuel consumption), is older, and lower-powered than assumed by MOVES.

Table 3-22. Statewide GSE Profile – Survey Findings vs EPA Defaults, 2017
2017 Nonroad Diesel Equipment Study

	Survey	EPA Default
# Units	239	178
Avg Hrs/Yr	819	732
Avg hp	106	197
Avg Model Yr	2001	2011
Gal/Yr	595,619	800,000

[63] Other equipment such as rubber tire loaders are used across a wide range of applications and fleets. The MOVES-Nonroad model does not specify the types of fleets in which equipment is used. Therefore, with the exception of GSE, we cannot compare estimates for the equipment used at airports directly to MOVES defaults.

Figure 3-16 through Figure 3-18 present the Airport equipment fleet distributions for model year, annual hours per unit, and hp based on the survey responses. The average model year for the fleet was 2002, with a notable spike in purchases in 2016 largely attributable to the Portland airport. The average activity was much higher than most public fleets, at 759 hours per year. The average equipment power was relatively low at 121 hp.

Figure 3-16. Airport Fleet Model Year Distribution (N=362)
2017 Nonroad Diesel Equipment Study

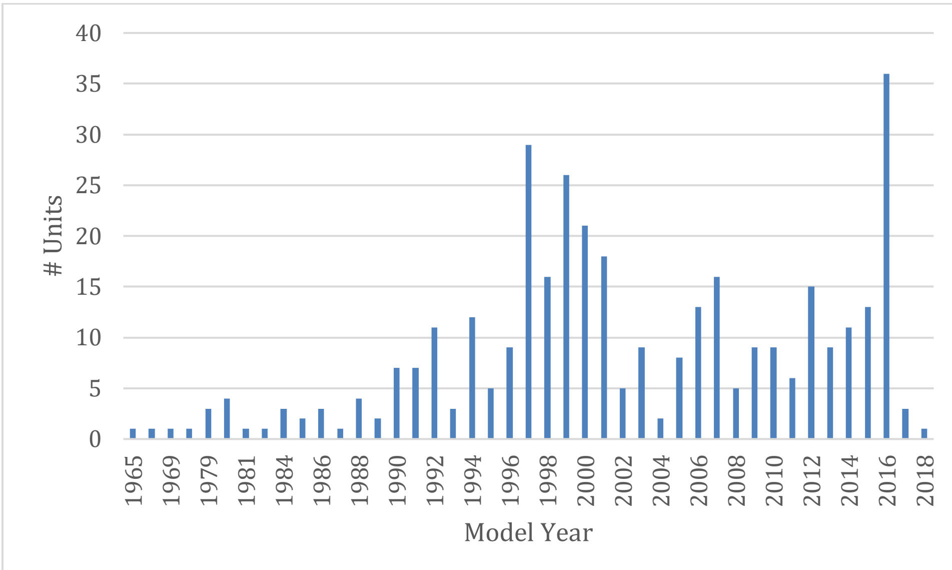


Figure 3-17. Airport Fleet Hour/Year Distribution (N=260)
2017 Nonroad Diesel Equipment Study

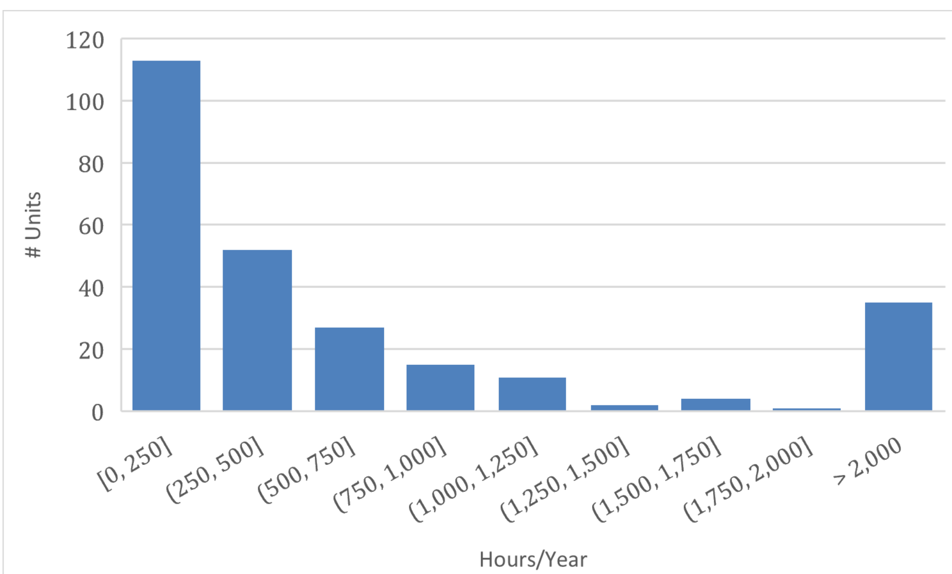
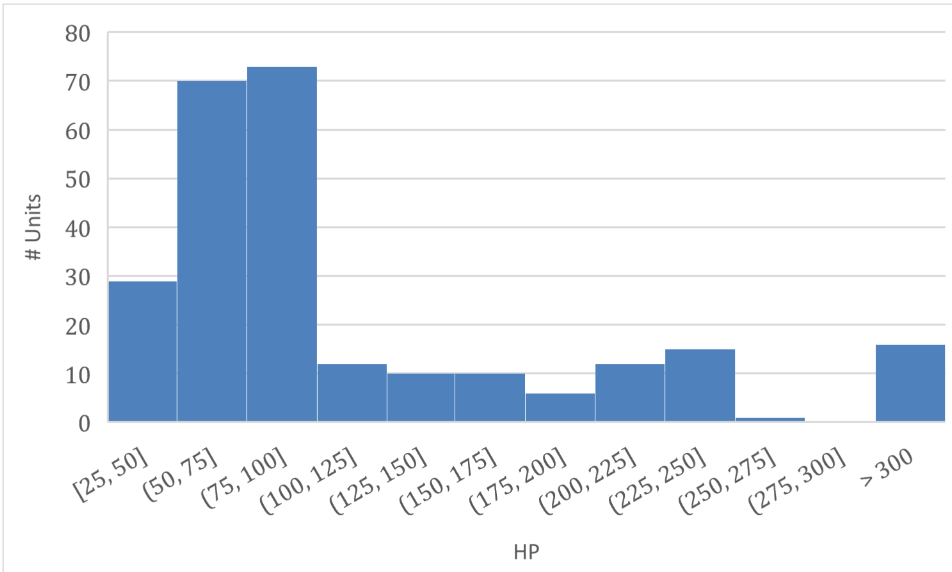


Figure 3-18. Airport Fleet HP Distribution (N=254)
2017 Nonroad Diesel Equipment Study



The county-level activity distribution for Airport fleets was reported in the survey responses and adjusted to account for non-response using LTO information from the Federal Aviation Administration (FAA). The resulting county activity allocation is provided in Table 3-23. The county distribution was also compared to the distribution of LTOs reported by the FAA for Oregon in 2017 and found to be generally consistent.[64]

Table 3-23. County-Level Airport Fleet Activity Allocation
2017 Nonroad Diesel Equipment Study

County	Percent of Activity	County	Percent of Activity
Baker	0.00%	Lake	0.00%
Benton	0.00%	Lane	7.15%
Clackamas	0.00%	Lincoln	0.00%
Clatsop	0.00%	Linn	0.00%
Columbia	0.00%	Malheur	0.00%
Coos	0.00%	Marion	0.00%
Crook	0.00%	Morrow	0.00%
Curry	0.00%	Multnomah	69.46%
Deschutes	3.10%	Polk	0.00%
Douglas	0.00%	Sherman	0.00%

[64] U.S. Department of Transportation, Bureau of Transportation Statistics *Transtats.* Retrieved from https://www.transtats.bts.gov/databases.asp?Mode_ID=1&Mode_Desc=Aviation&Subject_ID2=0.

County	Percent of Activity
Gilliam	0.00%
Grant	0.00%
Harney	0.00%
Hood River	0.00%
Jackson	4.99%
Jefferson	0.00%
Josephine	0.00%
Klamath	0.00%

County	Percent of Activity
Tillamook	0.00%
Umatilla	0.00%
Union	0.00%
Wallowa	0.00%
Wasco	0.00%
Washington	15.29%
Wheeler	0.00%
Yamhill	0.00%

The Airport fleet surveys only included estimates regarding how activity was split between weekdays and weekends and across seasons for five pieces of equipment, which was deemed inadequate for the analysis. For this reason, the fleet's temporal allocation profile was based on MOVES defaults which assume airport operations occur evenly across all days of the week and seasons of the year.

3.1.8 Schools, Colleges, and Universities

The ERG Team contacted fleet managers and other officials at 11 public school districts and 11 universities and colleges across the state, selected based on student body size. After additional outreach assistance from the DEQ, 10 schools ultimately responded to the survey (see Table 3-24).

Table 3-24. School and University Survey Respondents 2017 Nonroad Diesel Equipment Study

School District/College/University	# Units
Bend LaPine SD 1	18
Eugene SD 4J	39
Medford SD 549C	2
North Clackamas SD 12	2
Portland Community College	16
Portland Public SD 1J	10
Portland State University	2
Salem-Keizer SD 24J	7
University of Oregon	14
University of Portland	7
Total	**117**

After compiling the survey responses and removing extraneous records, the remaining list contained records for 117 units. Gap filling was required for 31 records with missing model year, 6 records with missing hp, and 10 records with missing annual hours.

Of the 117 units surveyed, 58 were either small agricultural tractors (average 50 hp) or lawn and garden equipment. Equipment use for these types of units is expected to correlate strongly with open space acreage. However, the ERG team could not identify readily available data sources for acreage and facility footprints for all schools in the state. As an alternative, ERG used student population as the scaling factor to expand the survey results to the state level. Scaling factors were compiled separately for public schools (K-12), universities, and community colleges, due to the large variation in equipment utilization per student across these categories.[65] The 2016 – 2017 student enrollment for the responding schools and universities is presented in Table 3-25, along with the percentage of total enrollment by school category.

Table 3-25. Student Enrollment and Percent Coverage for Survey Respondents 2017 Nonroad Diesel Equipment Study

School/University	Enrolment (2016-2017)	Survey Coverage
Public Schools (K-12)		
Bend-LaPine SD 1	18,325	3.2%
Eugene SD 4J	17,351	3.0%
Medford SD 549C	14,271	2.5%
North Clackamas SD 12	17,177	3.0%
Portland SD 1J	48,650	8.4%
Salem-Keizer SD 24J	41,918	7.2%
Total	**157,692**	**27.3%**
Universities and Colleges		
Portland State University	19,057	19.5%
University of Portland	3,762	3.8%
University of Oregon	19,775	20.2%
Total	**42,594**	**43.6%**
Community Colleges		
Portland Community College	26,034	32.1%
Total	**26,034**	**32.1%**

ERG expanded the survey findings for each of the school categories, scaling by the factors shown in Table 3-25. Table 3-26 presents the resulting statewide equipment use profile for these fleets.

Table 3-26. Statewide School/College/University Fleet Profile 2017 Nonroad Diesel Equipment Study

Equipment Type	# Units	Avg HP	Avg Hr/Yr	Avg Model Yr	Gal/Yr[66]
Agricultural tractors	39	50	78	1999	4,345
Air compressors	4	68	170	1980	770

[65] For example, community colleges often have a large part-time student population, while the majority of university and K-12 students are full-time.

[66] Calculated using EPA MOVES-Nonroad model (2014b). See Section 6.2 for additional details.

Equipment Type	# Units	Avg HP	Avg Hr/Yr	Avg Model Yr	Gal/Yr[66]
Generator sets	128	369	24	2007	14,019
Chippers/stump grinders	2	49	75	2011	214
Excavators	7	32	130	2011	635
Rubber tire loaders	4	75	84	1989	490
Skid steer loaders	38	50	140	1999	7,329
Tractors/loaders/backhoes	9	63	201	2002	2,333
Rough terrain forklifts	2	74	126	2017	510
Aerial lifts	2	67	246	2002	816
Commercial turf equipment	59	60	208	2006	20,725
Lawn and garden tractors	7	35	150	2015	1,073
Commercial mowers	93	41	234	2006	22,305
Total/Avg	**395**				**75,564**

Figure 3-19 through Figure 3-21 present the School/College/University equipment fleet distributions for model year, annual hours per unit, and hp based on the survey responses. The average model year for the fleet was 2004, the average activity was a relatively low 126 hours per year, and the average equipment power was 153 hp.

Figure 3-19. School/College/University Fleet Model Year Distribution (N=86)
2017 Nonroad Diesel Equipment Study

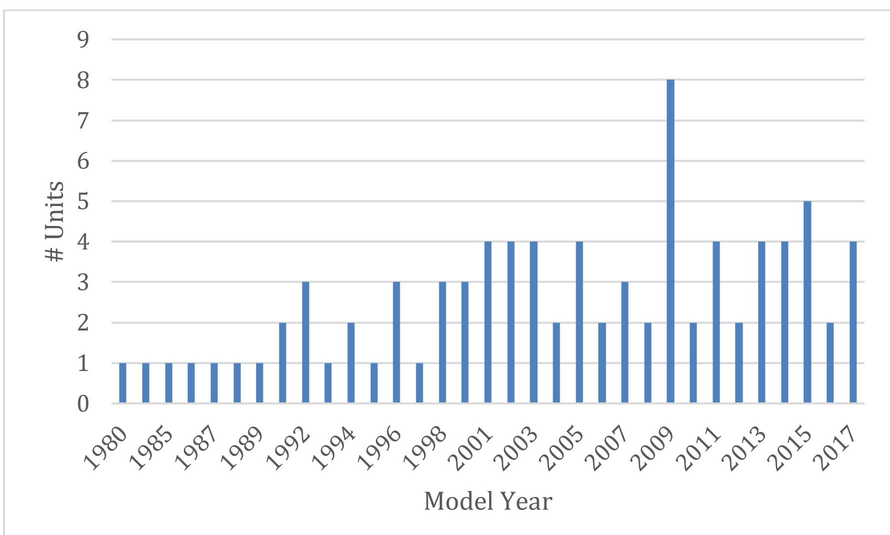


Figure 3-20. School/College/University Fleet Hour/Year Distribution (N=107) 2017 Nonroad Diesel Equipment Study

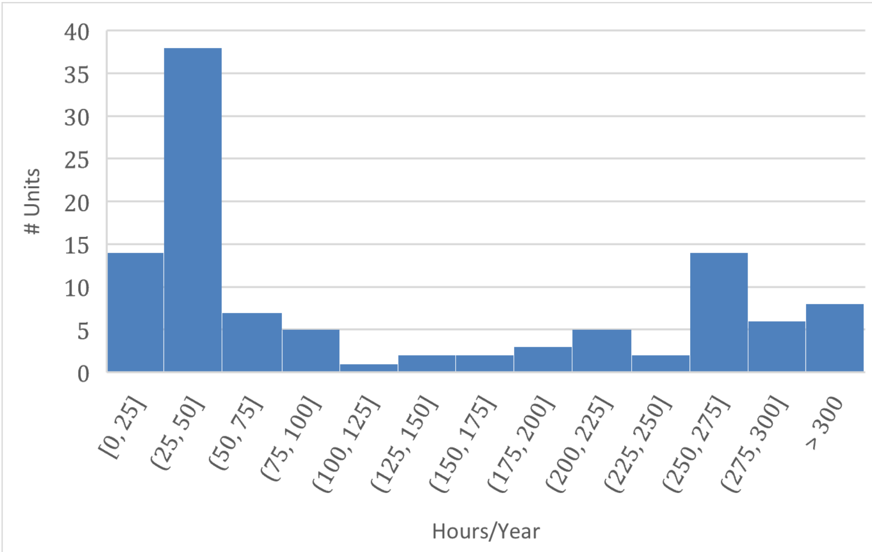
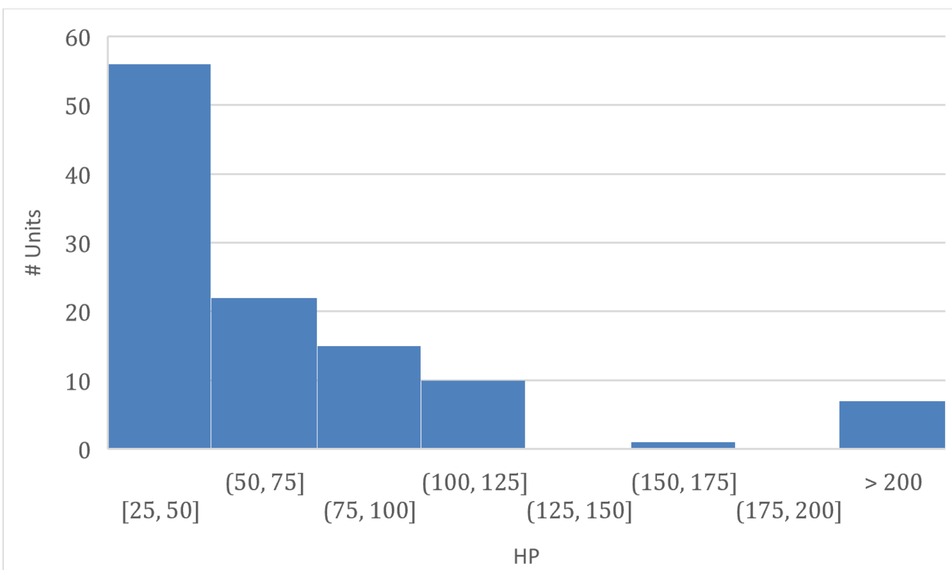


Figure 3-21. School/College/University Fleet HP Distribution (N=111) 2017 Nonroad Diesel Equipment Study



The county-level activity distribution for School/College/University fleets was based on 2017 student enrollment for each of the three survey strata, as shown in Table 3-27.

Table 3-27. County-Level School/College/University Fleet Activity Allocation 2017 Nonroad Diesel Equipment Study

County	K-12	University/College	Community Colleges
Baker	0.63%	0.00%	0.00%
Benton	1.57%	24.90%	0.00%
Clackamas	10.28%	0.00%	7.59%
Clatsop	0.89%	0.00%	0.79%
Columbia	1.31%	0.00%	0.00%
Coos	1.73%	0.00%	1.90%
Crook	0.51%	0.00%	0.00%
Curry	0.40%	0.00%	0.00%
Deschutes	4.63%	0.00%	6.35%
Douglas	2.46%	0.00%	1.41%
Gilliam	0.05%	0.00%	0.00%
Grant	0.15%	0.00%	0.00%
Harney	0.23%	0.00%	0.00%
Hood River	0.70%	0.00%	0.00%
Jackson	5.22%	4.49%	0.00%
Jefferson	0.64%	0.00%	0.00%
Josephine	1.89%	0.00%	5.05%
Klamath	1.67%	3.69%	1.48%
Lake	0.21%	0.00%	0.00%
Lane	7.93%	20.80%	10.08%
Lincoln	0.95%	0.00%	0.43%
Linn	3.92%	0.00%	7.06%
Malheur	0.87%	0.00%	2.08%
Marion	10.77%	2.91%	11.14%
Morrow	0.42%	0.00%	0.00%
Multnomah	16.19%	29.24%	41.73%
Polk	1.20%	4.92%	0.00%
Sherman	0.04%	0.00%	0.00%
Tillamook	0.59%	0.00%	0.31%
Umatilla	2.39%	0.00%	1.68%
Union	0.68%	2.78%	0.00%
Wallowa	0.14%	0.00%	0.00%
Wasco	0.62%	0.00%	0.93%
Washington	15.11%	1.89%	0.00%
Wheeler	0.17%	0.00%	0.00%
Yamhill	2.86%	4.38%	0.00%

The School/University/College fleet surveys included estimates regarding how activity was split between weekdays and weekends and across seasons for only 14 pieces of equipment. The fleet's temporal allocation profile estimates that 99 percent of activity occurs during weekdays and 27 percent of activity occurs during the summer months.

3.1.9 Permitted Facilities

The ERG Team obtained a list of 200 active, permitted solid waste, material handling and recycling facilities along with their reported 2017 tonnage estimates from the Oregon DEQ.[67] Contacts were identified for representative landfills, transfer stations, material recovery, compost and other miscellaneous facilities using recent studies conducted by DEQ and private organizations.[68, 69] Facility types were checked against Google Earth images and then cross-referenced with the reported DEQ facility tonnage before finalizing the contact list.

Many of the permitted facilities are operated by private companies under contract to one or more municipalities, counties or other public agencies. Of the 14 companies and agencies contacted, six provided survey responses covering operations at 15 facilities. Table 3-28 lists the number of respondents and the fraction of total annual tonnage represented, by facility category.[70] Respondent names are not shown to protect confidentiality.

Table 3-28. Permitted Facility Survey Respondents and Tonnage Fractions 2017 Nonroad Diesel Equipment Study

Facility Type	# Respondents	Percent of Tonnage (by facility category)
Solid Waste Landfill (> 100K TPY)	2	15.3%
Solid Waste Landfill (100 - 100K TPY)[71]	1	3.1%
Transfer Facility	5	39.8%
Material Recovery Facility	4	19.2%
Compost Facility	2	11.3%
Other Miscellaneous Facility	1	100.0%
Total	**15**	

[67] Provided electronically by Peter Spendelow, Materials Management Program, Oregon DEQ. 9-20-2020.

[68] Oregon DEQ, *2016/2017 Oregon Waste Composition Study*. https://www.oregon.gov/deq/mm/Pages/Waste-Composition-Study.aspx.

[69] Oregon DEQ, Materials Management Program. *2017 Oregon Material Recovery and Waste Generation Rates Report.* December 2018, revised March 2019. https://www.oregon.gov/deq/FilterDocs/2017mrwgrates.pdf.

[70] Certain permitted facilities were assigned to one of the six facility types shown in Table 3-28 based on the ERG Team's familiarity with local operation requirements. One demolition site was assigned to the landfill category while another was assigned to material recovery. "Wood" and "Pulp/Paper" facilities were assigned to the compost group.

[71] ERG excluded solid waste facilities reporting less 100 tons per year from the analysis. These facilities were responsible for less than 0.1% of the total annual tonnage from permitted facilities in 2017.

Survey results for the 15 facilities included records for 92 pieces of equipment, all of which included values for model year and hours per year. Gap-filling was required for 12 units lacking hp estimates. 27 units were reported to operate more than 3,000 hours per year, substantially greater than standard annual working hours (40 hours per week for 52 weeks). The ERG team confirmed the associated facilities operate at least two shifts (16 hours per day) on a regular basis in order to validate these estimates.

Table 3-29 present the survey results broken out by facility type and equipment type. Although the number of responses is small, clear differences are seen in equipment types and hours per year across the facility types. Statewide population estimates are also shown, scaled from the number of surveyed units using the tonnage percentages shown in Table 3-29.

Table 3-29. Survey Response by Facility and Equipment Type
2017 Nonroad Diesel Equipment Study

Equipment Type	# Units - Survey	Avg HP	Avg Hrs/Yr	Avg Model Yr	# Units - State
Compost Facilities					
Crawler tractors/dozers	1	240	763	2011	12
Crushing/processing equip.	3	285	328	2006	35
Excavators	1	210	620	2004	12
Rubber tire loaders	3	215	903	2006	35
Tractors/loaders/backhoes	1	42	57	2003	12
Total/Avg	**9**	**221**	**571**	**2006**	**104**
Energy Recovery Facilities					
Off-highway trucks	2	400	1,779	1986	3
Rubber tire loaders	2	229	1,375	2012	3
Total/Avg	**4**	**314**	**1,577**	**1999**	**5**
Material Recovery Facility Facilities					
Crushing/processing equip.	1	765	467	1998	5
Excavators	7	109	878	2007	37
Rough terrain forklifts	1	91	2924	2016	5
Rubber tire loaders	7	197	2115	2010	37
Skid steer loaders	3	72	1228	2013	16
Tractors/loaders/backhoes	1	101	823	2010	5
Terminal tractors	2	220	79	2003	10
Total/Avg	**25**	**168**	**1,360**	**2008**	**115**
Transfer Station Facilities					
Crawler tractors/dozers	2	226	4,622	2008	5
Excavators	2	97	1,385	2006	5
Rough terrain forklifts	4	91	1,179	2005	10
Rubber tire loaders	12	152	3,404	2010	30
Skid steer loaders	4	82	1,394	2008	10
Tractors/loaders/backhoes	2	93	1,034	2003	5
Total/Avg	**26**	**129**	**2,509**	**2008**	**55**

Equipment Type	# Units - Survey	Avg HP	Avg Hrs/Yr	Avg Model Yr	# Units - State
Large Landfills (> 100K tons per year)					
Crawler tractors/dozers	4	309	4,189	2006	26
Excavators	3	190	2,895	2010	20
Graders	1	150	406	1992	7
Off-highway trucks	4	407	3,364	2009	26
Rough terrain forklifts	1	91	113	1990	7
Rubber tire loaders	6	205	3,879	2006	39
Skid steer loaders	1	74	5,154	2014	7
Tractors/loaders/backhoes	2	100	1,002	2006	13
Other industrial equip.	2	75	5,592	2012	13
Total/Avg	**24**	**222**	**3,376**	**2006**	**157**
Medium/Small Landfills (100 - 100,000 tons per year)					
Crawler tractors/dozers	1	185	85	2006	33
Excavators	1	207	12	2007	33
Rubber tire loaders	2	232	777	2010	65
Skid steer loaders	1	71	100	2012	33
Tractors/loaders/backhoes	2	101	779	2011	65
Total/Avg	**7**	**161**	**472**	**2009**	**228**

Table 3-30 presents the statewide equipment use profile for permitted facilities aggregated across facility types. Construction equipment is responsible for most of the fleet activity, including loaders, bulldozers, off-highway trucks and excavators.

Table 3-30. Statewide Permitted Facility Equipment Profile
2017 Nonroad Diesel Equipment Study

Equipment Type	# Units	Avg HP	Avg Hrs/Yr	Avg Model Yr	Gal/Yr[72]
Crawler tractors/dozers	73	240	2,415	2008	942,295
Crushing/processing equipment	32	525	398	2002	106,795
Excavators	103	163	1,158	2007	337,872
Graders	7	150	406	1992	8,651
Off-highway trucks	28	404	2,572	1997	762,900
Rough terrain forklifts	22	91	1,405	2004	57,431
Rubber tire loaders	199	205	2,075	2009	1,571,698
Skid steer loaders	65	75	1,969	2012	136,246
Tractors/loaders/backhoes	97	87	739	2006	179,084
Other industrial equipment	13	75	5,592	2012	108,663
Terminal tractors	10	220	79	2003	5,673
Total	**673**				**4,217,306**

[72] Calculated using EPA MOVES-Nonroad model (2014b). See Section 6.2 for additional details.

Figure 3-22 through Figure 3-24 present the Permitted Facility equipment fleet distributions for model year, annual hours per unit, and hp based on the survey responses. The average model year for the fleet was 2007. Activity levels were the highest among the public fleet categories, with an average activity of 2,065 hours per year. The average equipment power was 194 hp.

Figure 3-22. Permitted Facility Model Year Distribution (N=92)
2017 Nonroad Diesel Equipment Study

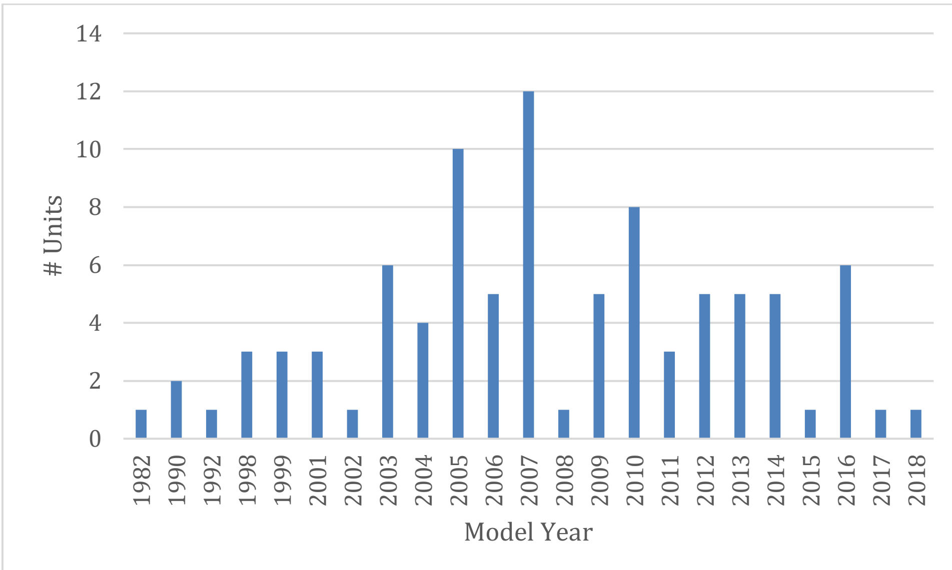


Figure 3-23. Permitted Facility Hour/Year Distribution (N=92)
2017 Nonroad Diesel Equipment Study

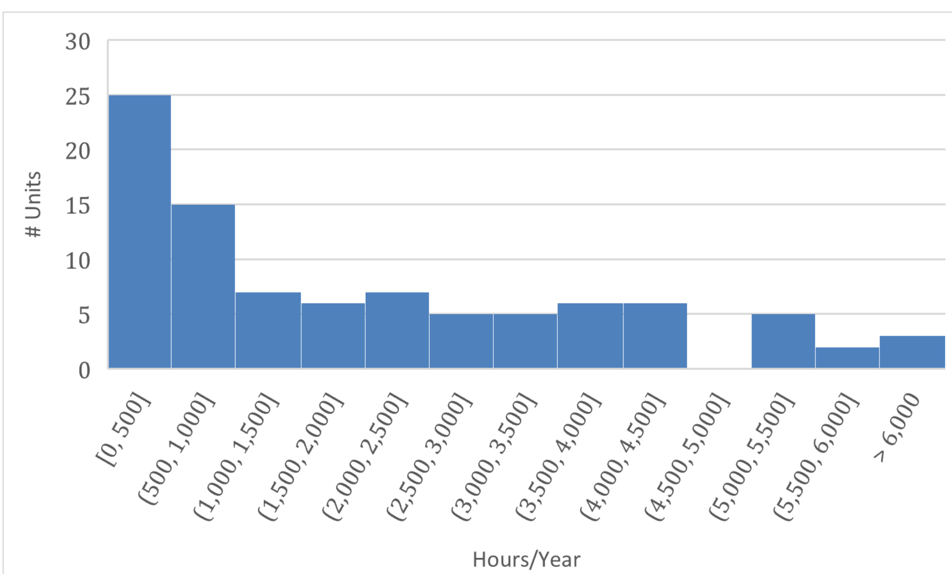
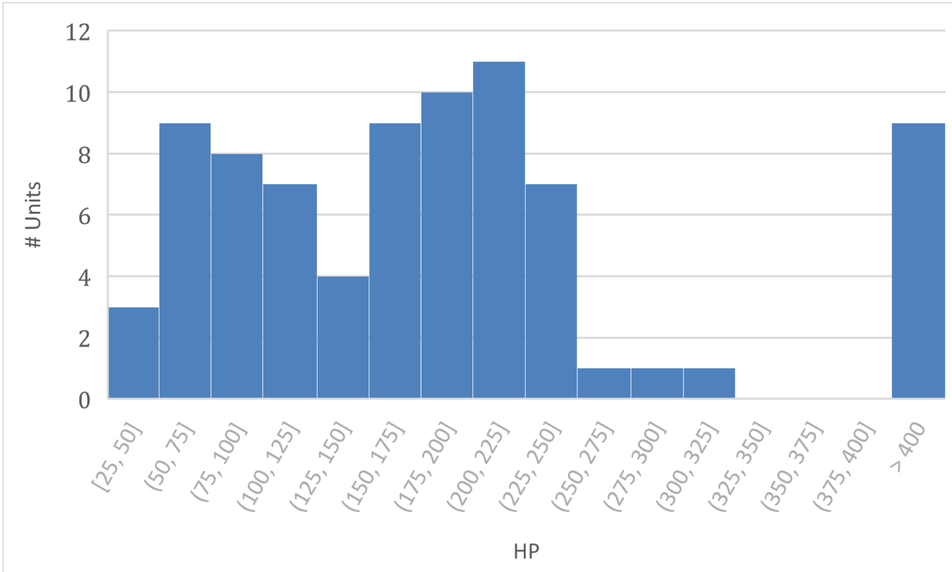


Figure 3-24. Permitted Facility Fleet HP Distribution (N=80)
2017 Nonroad Diesel Equipment Study



The county-level activity distribution for Permitted Facility fleets was based on 2017 tonnage throughput for each of the six survey strata, as shown in Table 3-31.

Table 3-31. County-Level Permitted Facility Fleet Activity Allocation
2017 Nonroad Diesel Equipment Study

County	Large Landfills	Small/Med Landfills	Transfer Stations	Material Recovery	Compost	Other Facility
Baker	0.00%	10.99%	0.03%	0.00%	0.00%	0.00%
Benton	15.30%	0.00%	0.00%	0.00%	0.59%	0.00%
Clackamas	0.00%	8.21%	19.89%	0.86%	0.59%	0.00%
Clatsop	0.00%	0.00%	3.99%	0.52%	4.31%	0.00%
Columbia	0.00%	0.00%	2.12%	0.00%	10.82%	0.00%
Coos	0.00%	0.00%	4.33%	0.00%	0.00%	0.00%
Crook	0.00%	16.30%	0.00%	0.00%	0.00%	0.00%
Curry	0.00%	1.22%	0.00%	0.00%	0.00%	0.00%
Deschutes	2.73%	0.00%	4.57%	0.00%	4.09%	0.00%
Douglas	0.00%	27.53%	2.08%	0.00%	0.00%	0.00%
Gilliam	39.31%	0.00%	0.03%	0.00%	0.00%	0.00%
Grant	0.00%	0.00%	0.01%	0.00%	0.00%	0.00%
Harney	0.00%	0.95%	0.00%	0.00%	0.00%	0.00%
Hood River	0.00%	0.00%	0.00%	0.00%	0.12%	0.00%
Jackson	7.66%	0.00%	8.10%	0.71%	4.97%	0.00%
Jefferson	0.00%	0.00%	0.81%	0.00%	0.00%	0.00%

County	Large Landfills	Small/Med Landfills	Transfer Stations	Material Recovery	Compost	Other Facility
Josephine	0.00%	0.00%	2.29%	0.00%	0.00%	0.00%
Klamath	0.00%	0.59%	2.61%	1.99%	0.12%	0.00%
Lake	0.00%	1.62%	0.00%	0.00%	0.00%	0.00%
Lane	3.92%	0.00%	6.59%	9.32%	27.39%	0.00%
Lincoln	0.00%	17.96%	3.33%	0.00%	0.00%	0.00%
Linn	0.00%	0.00%	1.46%	0.68%	0.25%	0.00%
Malheur	0.00%	1.85%	1.41%	0.00%	0.00%	0.00%
Marion	0.00%	3.07%	4.95%	14.46%	2.23%	100.00%
Morrow	10.20%	0.00%	0.00%	0.00%	0.00%	0.00%
Multnomah	0.00%	1.17%	18.01%	29.44%	0.00%	0.00%
Polk	0.00%	0.00%	0.00%	0.00%	0.85%	0.00%
Sherman	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Tillamook	0.00%	0.00%	0.02%	2.90%	0.00%	0.00%
Umatilla	0.00%	3.11%	1.53%	0.00%	0.25%	0.00%
Union	0.00%	0.00%	0.00%	0.00%	18.62%	0.00%
Wallowa	0.00%	1.10%	0.00%	0.00%	0.00%	0.00%
Wasco	10.87%	0.00%	0.00%	0.00%	0.00%	0.00%
Washington	6.12%	0.00%	9.11%	38.94%	23.67%	0.00%
Wheeler	0.00%	0.00%	0.01%	0.00%	0.00%	0.00%
Yamhill	3.90%	4.32%	2.71%	0.18%	1.13%	0.00%

The Permitted Facility fleet surveys included estimates regarding how activity was split between weekdays and weekends and across seasons for only 18 pieces of equipment. The fleet's temporal allocation profile estimates that 87 percent of activity occurs during weekdays and 30 percent of activity occurs during the summer months.

3.1.10 Sector Summary

Table 3-32 summarizes selected parameters for the different Public Fleets.

Table 3-32. Selected Public Fleet Profile Parameters
2017 Nonroad Diesel Equipment Study

Fleet	Avg Model Year	Avg HP	Avg Hours/Yr	Gal/Yr[73]
Municipal	2007	105	196	596,065
County	2004	132	244	476,442
Special Districts	2002	153	130	197,779
Other agencies	2005	144	225	660,424
Marine ports	2006	186	265	102,821

[73] Calculated using EPA MOVES-Nonroad model (2014b). See Section 6.2 for additional details.

Fleet	Avg Model Year	Avg HP	Avg Hours/Yr	Gal/Yr[73]
Airports	2002	121	759	656,064
Schools/Colleges/Universities	2004	153	126	75,563
Permitted facilities	2007	194	2,065	4,217,306

Key observations regarding the Public Fleet surveys and activity profiles include the following:

- The survey effort obtained a robust response from all but the Permitted Facility and School/College/University fleets. The high activity and hp of the Permitted Facility fleet, and the landfill strata in particular, may merit further investigation to reduce the uncertainty associated with that profile.
- In general, the fleets operate at relatively low activity levels, with the exception of Airports and Permitted Facilities.
- In general, the fleets contain relatively low hp equipment, although units greater than 300 hp are not uncommon, especially in the Permitted Facilities and Other Agencies fleets.
- Equipment is relatively old across the board, with 20-year-old units not uncommon.
- Although survey responses were limited regarding temporal activity allocation, the profiles are largely consistent across most fleets, with most activity occurring during weekdays, and summertime activity near or slightly above 25 percent of the annual total.

3.2 Agricultural Sector

ERG conducted a stratified random sample survey to collect information on nonroad diesel equipment population and activity for establishments primarily engaged in agricultural crop and animal production across the state. Small entities not engaged in commercial production were excluded from the analysis.

3.2.1 Equipment Types

Key equipment types employed in this sector include:

- Agricultural tractors
- Combines
- Irrigation sets
- Sprayers
- Swathers[74]

[74] Also known as windrowers, swathers cut hay and small grain crops, leaving the material on the ground to dry before harvesting.

The vast majority of the above equipment types are owned and operated exclusively within the agricultural sector. Other equipment types commonly used for agricultural purposes include assorted construction equipment (e.g. bulldozers, loaders, and backhoes), air compressors, pumps, and specialty vehicles/carts.

3.2.2 Survey Development and Data Collection

ERG obtained contact information for establishments operating under North American Industry Classification System (NAICS) code 111 (Crop Production), 112 (Animal Production and Aquaculture), 1151 (Support Activities for Crop Production), and 1152 (Support Activities for Animal Production) in Oregon from Dynata.[75] Survey strata were selected to be consistent with the data available from the 2017 Agricultural Census,[76] to facilitate scaling factor application and validation of results. An SME from the Oregon Farm Bureau (OFB)[77] helped refine the strata to reflect unique equipment use requirements for the state's major agricultural producer categories. The final survey strata included:

- Beef Cattle
- Dairy Cattle
- Fruit Tree/Nut
- Greenhouse/Nursery/Floriculture
- Oilseed and Grain
- Other Crops (e.g. hay production)
- Other Animals (horses, pigs, goats, sheep)
- Vegetables and Melons
- Wineries

Scaling factors are readily available data that are closely associated with equipment use and are used to expand the limited set of survey responses to the state level. After consultation with the OFB ERG selected acreage in production for crops, and number of head for animal production as the scaling factors for the sector. This data is available from the 2017 Agricultural Census for each survey stratum.

The agricultural sector survey was developed with input from the OFB to collect all information required to develop and validate equipment use profiles at the county level for the 2017 target year. Appendix A presents the questionnaire developed for the survey.

Based on prior efforts to contact establishments in the Logging sector, ERG anticipated a significant number of contacts in the agricultural sector sample frame would not be valid (e.g.

[75] Dynata LLC. https://www.dynata.com/company/about-us/.

[76] U.S. Department of Agriculture. (2017) *2017 Agricultural Census*. Retrieved from https://www.nass.usda.gov/Publications/AgCensus/2017/Full_Report/Volume_1,_Chapter_2_US_State_Level/.

[77] Jonathon Sandau, Oregon Farm Bureau Government Affairs team.

phone number out of order, establishment not involved in agricultural production) Therefore, before initiating the survey ERG pre-validated the contact information by using a paid online resource to verify the accuracy of the data and provide detailed information on phone numbers, contacts, email addresses and relationships.[78] Pre-validation was conducted for all agricultural operation categories with the exception of Nursery, Christmas Tree, and Industrial Hemp operations. Data for those groups was provided by the State of Oregon as part of the registration/licensing process, was of high quality, and generally included a valid postal address and a high percentage of valid email addresses.

The data collection process consisted of mailing the questionnaire to each contact and following up with a phone call, voice mail or email asking if they had received the survey. Respondents were informed that all responses would be kept confidential and offered a variety of modes for completing the survey including online, Excel forms exchanged by email, fax, and self-addressed prepaid mailers. The OFB also provided a formal letter supporting the survey and encouraging participation, which was included in all electronic and postal mailings.

In order to encourage additional survey participation, relevant trade associations were contacted and asked if they would offer the survey to their members through their websites and newsletters. Participating associations included the Associated Oregon Hazelnut Industries, Oregon Dairy Farmers, Oregon Hay and Forage Association, and the Pacific Northwest Christmas Tree Association.

In total, 1,145 surveys were mailed via the U.S. Postal Service. After the original deadline for the survey passed a gap-analysis on the remaining categories was conducted and an extra mailer of 172 surveys was sent out to capture a larger percentage of people that had already been contacted in categories that were lacking in responses.

The final outcome of the attempted contacts is summarized in Table 3-33.

[78] See for example Spokeo search utilities - https://www.spokeo.com/reverse-address-search.

Table 3-33. Outcome of Agricultural Sector Survey Contacts
2017 Nonroad Diesel Equipment Study

Outcome	# of Establishments
Ineligible[79]	176
Refusal	65
Complete[80]	175
No final response	1,101
No target equipment use[81]	54
Total Attempted Contacts	**1,571**

The final survey completion rate was approximately 16 percent.[82, 83]

3.2.3 Data Processing and Analysis

ERG compiled the completed survey responses and cleaned/processed the data using the standard procedures discussed in Section 2.1.6. Additional steps were taken to gap-fill missing hours per year based on reported fleet-level fuel consumption:

- Use annual hours and brake-specific fuel consumption (BSFC) values (lbs. fuel/hp-hr) for each equipment type, from MOVES defaults;
- Use CARB engine load factors for each equipment type where available, otherwise use MOVES default factors;
- Use reported hp (or average of reported values if missing) for each equipment type;
- Apply load factor, hours per year and BSFC to obtain gallons per year per unit; and,
- Sum gallons across all units, then scale the MOVES default hours per year by the ratio of reported-to-calculated gallons for unit reported in the survey.

An example calculation for one respondent illustrates how activity was estimated based on reported fuel use for two pieces of equipment:

1. A 134 hp tractor and a 138 hp excavator were reported to consume a combined total of 500 gallons of diesel per year.
2. The BSFC value for both of these units is 0.371 lbs./bhp-hr.

[79] Includes phone numbers not in service, and establishments no longer of not ever involved in agricultural production.

[80] 40 surveys completed online using general link, 13 using online using personalized link.

[81] Establishments (typically small farms < 10 acres) confirmed they were involved in agricultural production but did not utilize nonroad diesel equipment greater than 25 hp.

[82] (Completes + No equipment use) / (Total Attempted Contacts – Ineligibles)

[83] The completion rate is somewhat uncertain however, since 40 respondents submitted their information through the generalized survey link distributed by the trade associations. ERG cannot determine if these respondents were included in the Dynata contact list.

3. The CARB engine load factor is 0.40 for tractors and 0.38 for excavators.
4. The MOVES default hour per year value for tractors is 936, and 1,092 for excavators.
5. Calculate the hp-hrs per year for each unit assuming MOVES default activity:
   a. 134 hp x 936 hrs/yr x 0.40 (load factor) = 50,170 hp-hrs for the tractor
   b. 138 hp x 1,092 hrs/yr x 0.38 (load factor) = 57,246 hp-hrs for the excavator
6. Calculate the gallons per year for each unit assuming MOVES default activity:
   a. 50,170 hp-hrs x 0.371 lbs./hp-hr / 7.0 lbs./gallon = 2,659 gallons for the tractor
   b. 57,246 hp-hrs x 0.371 lbs./hp-hr / 7.0 lbs./gallon = 3,035 gallons for the excavator
7. Sum the fuel consumption estimate across units (2,659 + 3,035 = 5,694 gallons/yr)
8. Scale the gallons per year estimates for each unit by the total reported fuel consumption.
   a. 936 hrs/yr x 500 gallons/yr / 5,694 gallons/yr = 82 hrs/yr for the tractor
   b. 1,092 hrs/yr x 500 gallons/yr / 5,694 gallons/yr = 96 hrs/yr for the tractor

Since multiple crops and/or animal types were reported by 40 respondents,[84] ERG temporarily assigned these establishments to a "Mixed" category. The Agricultural Census defines Mixed operations as those that do not have a single commodity responsible for more than 50 percent of their production value. The agricultural sector survey did not request sales information by crop and animal type, only the acreage in production and number of head. Therefore, ERG estimated the dollar value for each reported crop and animal type using estimated commodity values (see Table 3-34).

Table 3-34. Estimated $/Acre by Commodity Type
2017 Nonroad Diesel Equipment Study

Commodity	Stratum	Acres or Head	$ Value	$/acre or head	Source[85]
Alfalfa seed	Other	4,490	$11,654,000	$2,596	1, 2
Apples	Fruit Tree/Nut	5,000	$38,674,000	$7,735	1, 2
Barley	Oilseed/Grain	38,000	$6,479,000	$171	1, 2
Beans - snap	Vegetables/Melons	7,500	$13,940,000	$1,859	1, 2

[84] ERG initially flagged establishments as "Mixed" if the acreage for two or more crop/animal types was greater than 10% of the total acreage in production. For example, a farm producing wheat on 100 acres that also included five acres for horses would be assigned to the Oilseed and Grain stratum. Similarly, animal production operations that reported land used for forage were retained in the appropriate animal production stratum.

[85] Sources: 1) Oregon Department of Agriculture. *Oregon Agriculture, Facts and Figures.* August 2018; 2) Oregon Department of Agriculture. *Value of Oregon Agriculture Crop Production, 2017*; 3) 2017 Agricultural Census - Table 2 - Market Value of Agricultural Products Sold; 4) 2917 Agricultural Census - Table 39 - Floriculture/Nursery Crops; 5) 2017 Agricultural Census - Table 40 - Woodland Crop Sales; 6) 2017Agricultural Census - Table 30 - Poultry Inventory and Numbers Sold; 7) 2017 Agricultural Census - Table 32 - Other Animals Inventory.

Commodity	Stratum	Acres or Head	$ Value	$/acre or head	Source[85]
Beef cattle	Beef Cattle	536,000	$695,260,000	$1,297	1, 2
Bentgrass seed	Other	6,089	$11,902,000	$1,955	1, 2
Blackberries	Fruit Tree/Nut	6,300	$31,115,000	$4,939	1, 2
Blueberries	Fruit Tree/Nut	11,700	$147,665,000	$12,621	1, 2
Bluegrass seed	Other	21,730	$27,900,000	$1,284	1, 2
Boysenberries	Fruit Tree/Nut	270	$1,393,000	$5,159	1, 2
Cherries	Fruit Tree/Nut	13,000	$70,210,000	$5,401	1, 2
Christmas trees	GNF*	45,283	$120,680,000	$2,665	5
Corn - grain	Oilseed/Grain	44,000	$35,913,000	$816	1, 2
Corn - sweet	Vegetables/Melons	23,300	$35,372,000	$1,518	1, 2
Cranberries	Fruit Tree/Nut	2,800	$12,777,000	$4,563	1, 2
Dairy cattle	Dairy Cattle	124,000	$507,116,000	$4,090	1, 2, 3
Equine	Other Animals	67,957	$14,807,000	$218	1, 2
Fescue seed	Other	134,370	$169,861,000	$1,264	1, 2
Floriculture	GNF*	2,987	$154,307,357	$51,660	4
Grapes - wine	Wineries	24,000	$171,710,000	$7,155	1, 2
Hay - alfalfa	Other	420,000	$353,976,000	$843	1, 2
Hay - other	Other	680,000	$231,200,000	$340	1, 2
Hazelnuts	Fruit Tree/Nut	37,000	$73,600,000	$1,989	1, 2
Hogs	Other Animals	9,000	$3,431,000	$381	1, 2, 3
Hops	Other	7,900	$59,566,000	$7,540	1, 2
Nursery	GNF*	26,676	$645,985,071	$24,216	4
Oats	Oilseed/Grain	10,000	$1,909,000	$191	1, 2
Onions	Vegetables/Melons	19,700	$111,002,000	$5,635	1, 2
Pears - Bartlett	Fruit Tree/Nut	3,500	$40,896,000	$11,685	1, 2
Pears - other	Fruit Tree/Nut	10,900	$135,641,000	$12,444	1, 2
Peas - green	Vegetables/Melons	12,000	$5,477,000	$456	1, 2
Peppermint	Other	21,000	$38,703,000	$1,843	1, 2
Potatoes	Vegetables/Melons	38,900	$176,937,000	$4,549	1, 2
Poultry	Other Animals	18,763,406	$126,466,000	$7	3, 6
Raspberries - black	Fruit Tree/Nut	950	$2,507,000	$2,639	1, 2
Raspberries - red	Fruit Tree/Nut	750	$3,549,000	$4,732	1, 2
Ryegrass seed - annual	Other	120,250	$86,902,000	$723	1, 2
Ryegrass seed - perennial	Other	83,450	$97,334,000	$1,166	1, 2
Sheep and Goats	Other Animals	301,000	$28,300,000	$94	1, 2, 7
Strawberries	Fruit Tree/Nut	1,200	$12,028,000	$10,023	1, 2
Sugar beets	Vegetables/Melons	9,100	$18,490,000	$2,032	1, 2
Wheat	Oilseed/Grain	763,000	$238,654,000	$313	1, 2

* Greenhous/Nursery/Floriculture

Commodity values were estimated by multiplying the reported acreage or number of head by the associated dollars per acre or head from Table 3-34. When a specific crop type was not clear from the survey description, ERG used the average $/acre value across a broader category (e.g. average of different grass seeds), or else used the average $/acre for the stratum as a whole. Since no establishment had a single commodity responsible for more than 50 percent of their total production value, ERG re-assigned all responses originally designated as “Mixed” to the stratum with the highest commodity value.

ERG performed Quality Assurance (QA) on the gap-filled data set to identify potential outliers. ERG reviewed all equipment records with reported activity greater than or equal to 2,000 hours per year, roughly corresponding to continual use 8 hours per day 5 days a week for an entire year. ERG determined several of these respondents had reported cumulative rather than annual engine hours. ERG adjusted the annual hour values for 17 respondents by dividing the reported hours by equipment age.

ERG reviewed reported hp values based on our familiarity with equipment type offerings and MOVES hp distributions. ERG confirmed all hp entries to be acceptable.

The final gap-filled, quality assured data set included 175 respondents operating 1,582 pieces of equipment. The distribution of responses across strata is summarized in Table 3-35.

Table 3-35. Agricultural Survey Responses by Stratum
2017 Nonroad Diesel Equipment Study

Stratum	# of Respondents
Beef Cattle	32
Dairy Cattle	7
Fruit Tree/Nut	30
Greenhouse/Nursery/Floriculture	26
Oilseed/Grain	12
Other Crops	40
Other Animals	10
Vegetables/Melons	7
Wineries	11
Total	**175**

Table 3-36 presents the equipment use information for the survey respondents. Corresponding tables are presented for each stratum in Appendix B.

Table 3-36. Agricultural Sector Equipment Use Summary
2017 Nonroad Diesel Equipment Study

Equipment Type	# Units	Average HP	Average Hrs/Yr	Average Model Year
Agricultural tractors	936	117	328	1996
Balers	5	70	80	1996
Combines	109	255	151	1999
Irrigation wets	23	79	645	2009
Other agricultural equipment	49	152	256	2003
Sprayers	40	171	134	2000
Swathers	75	117	130	2005
Air compressors	8	91	357	2001
Generator sets	2	33	78	1996
Pressure washers	1	31	33	1996
Pumps	9	89	161	1995
Welders	2	46	148	1996
Concrete/industrial saws	1	33	134	1996
Crawler tractors/dozers	49	125	231	1987
Excavators	57	80	300	2003
Graders	23	206	274	1986
Off-highway trucks	3	244	378	1996
Other construction equipment	6	234	140	1996
Rollers	3	85	197	1996
Rough terrain forklifts	52	76	246	2001
Rubber tire loaders	58	103	581	1995
Skid steer loaders	30	61	301	2007
Tractors/loaders/backhoes	17	74	256	1993
Trenchers	1	61	137	1996
Other industrial equipment	5	130	202	1996
Terminal tractors	2	200	398	1996
Chippers/stump grinders	1	50	67	2000
Lawn and garden tractors	3	39	217	2016
Fellers/bunchers/skidders	3	138	122	1977
Specialty vehicles/carts	9	28	132	1999
Total	**1,582**	**124**	**299**	**1998**

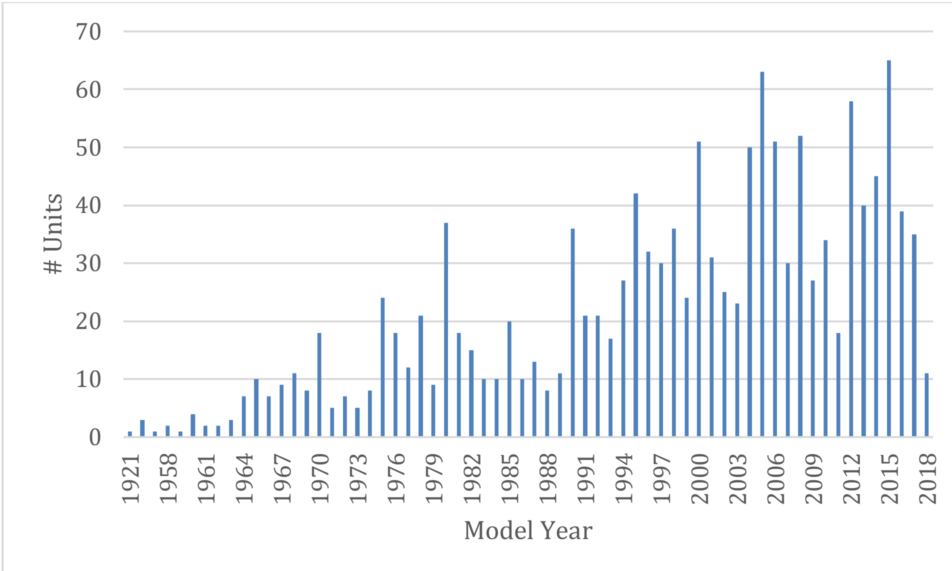


Figure 3-26 through Figure 3-27 present the Agricultural survey distributions aggregated across equipment types for model year, annual hours per unit, and hp based on the survey responses. The average model year for the surveyed equipment was 1998, with a substantial number of units greater than 30 years old. Average activity equaled 279 hours per year. The average equipment power was 122 hp.

Figure 3-25. Agricultural Survey Equipment Model Year Distribution (N=1,384) 2017 Nonroad Diesel Equipment Study

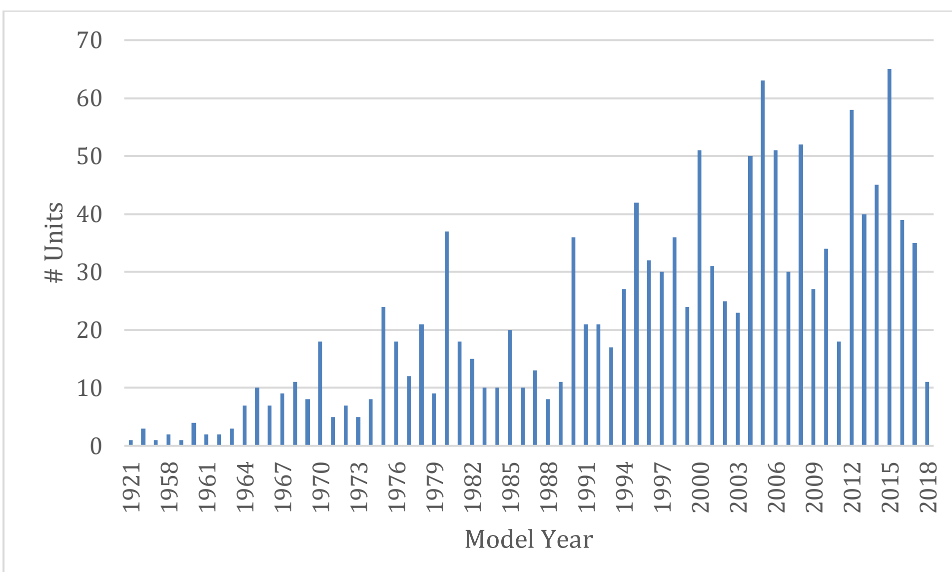


**Figure 3-26. Agricultural Survey Equipment Activity Distribution (N=1,146)
2017 Nonroad Diesel Equipment Study**

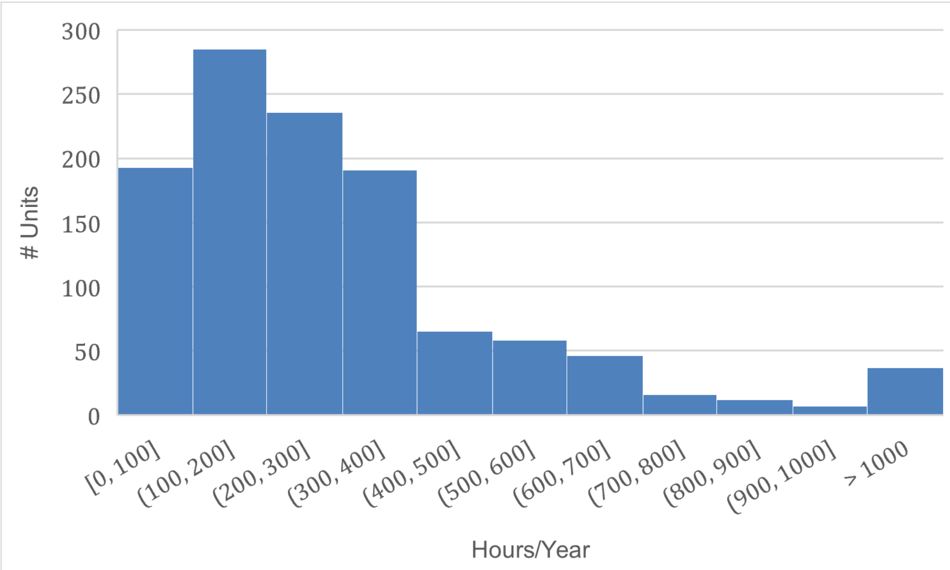


**Figure 3-27. Agricultural Survey HP Distribution (N=1,346)
2017 Nonroad Diesel Equipment Study**

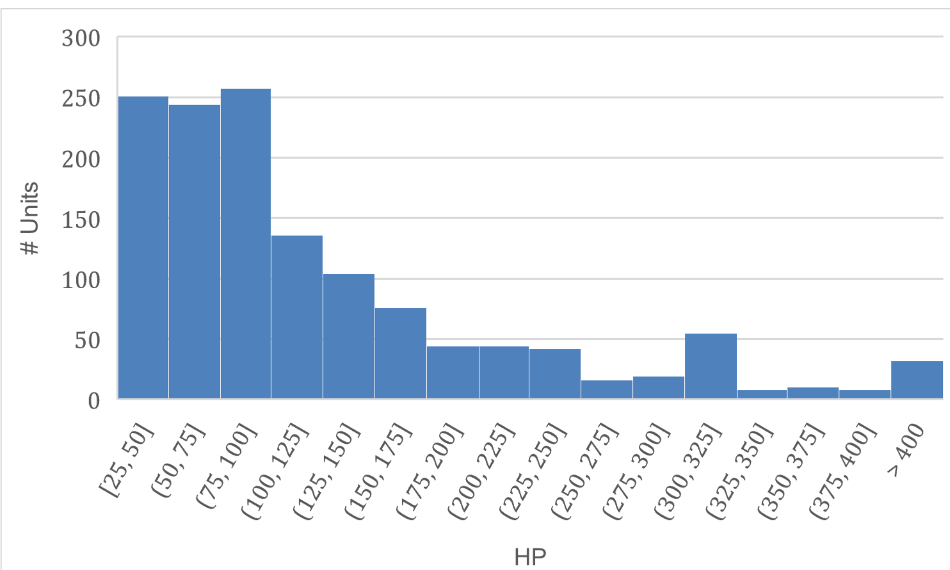


Table 3-37 presents an additional breakout of the engine tier level distributions for agricultural equipment reported by industry survey respondents, broken out by hp group. Table 3-38 presents the corresponding MOVES model default distributions for the state. Figure 3-28 directly compares the survey and MOVES distributions, aggregated across all hp groups.

Table 3-37. Agricultural Equipment Survey Tier Level[86]
2017 Nonroad Diesel Equipment Study

HP Range	Tier 0	Tier 1	Tier 2	Tier 3	Tier 4	Total #
25 - 40	0.0%	0.0%	0.0%	0.0%	100.0%	**149**
40 - 50	71.5%	3.4%	12.0%	0.0%	13.1%	**47**
50 - 75	61.1%	16.2%	10.3%	0.0%	12.3%	**157**
75 - 100	42.5%	16.3%	8.8%	14.8%	17.6%	**221**
100 - 175	37.8%	15.6%	8.3%	16.5%	21.7%	**278**
175 - 300	29.5%	24.6%	9.3%	21.2%	15.3%	**149**
300 - 600	19.4%	15.2%	11.2%	28.5%	25.6%	**108**
600 - 750	0.0%	0.0%	0.0%	9.9%	90.1%	**2**
Total	**35.4%**	**14.4%**	**8.1%**	**12.7%**	**29.4%**	**1,111**

Table 3-38. MOVES Default Agricultural Equipment Tier Level
2017 Nonroad Diesel Equipment Study

HP Range	Tier 0	Tier 1	Tier 2	Tier 3	Tier 4	Total #
25 - 40	0.3%	1.2%	11.2%	0.0%	87.2%	**2,480**
40 - 50	0.3%	1.3%	11.2%	0.0%	87.2%	**1,416**
50 - 75	5.9%	17.8%	9.9%	0.0%	66.4%	**2,424**
75 - 100	8.2%	18.6%	4.6%	36.8%	31.9%	**2,855**
100 - 175	8.3%	18.8%	1.3%	39.4%	32.1%	**5,084**
175 - 300	8.1%	20.1%	0.0%	40.4%	31.4%	**4,772**
300 - 600	14.6%	16.9%	6.1%	36.5%	25.9%	**1,626**
600 – 750	0.0%	0.0%	0.0%	0.0%	0.0%	**0**
Total	**7.5%**	**15.4%**	**15.2%**	**16.3%**	**45.5%**	**20,658**

[86] Single units may be allocated across multiple tier levels to reflect engine sales distributions during emission standard phase-in years, resulting in fractional unit numbers.

Figure 3-28. Agricultural Equipment Tier Level Distribution Comparison (N=1,384)
2017 Nonroad Diesel Equipment Study

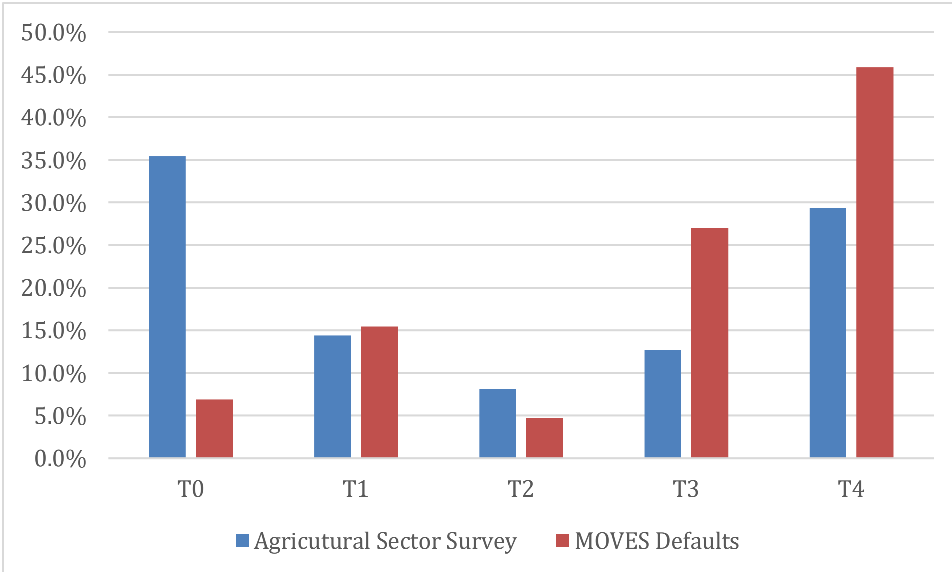


Figure 3-28 indicates similar values for the Tier 1 and 2 engine percentages. However, the tail ends of the distributions are substantially different, with 35.4 percent of surveyed equipment in the Tier 0 category vs. 7.5 percent for MOVES. Conversely, 42.1 percent of surveyed equipment fell in the Tier 3 and 4 category, compared to 61.8 percent for MOVES. These differences are due in part to MOVES assuming higher equipment activity and therefore more frequent scrappage and equipment replacement rates than are indicated by the survey results.

The findings also indicate a similar hp distribution between the survey results and that assumed by MOVES, as shown in Table 3-39. This similarity adds confidence that the survey results are reflective of actual fleet characteristics in the Oregon agricultural sector.

Table 3-39. Agricultural Equipment HP Distribution Comparison - Survey vs. MOVES
2017 Nonroad Diesel Equipment Study

HP Range	Survey	MOVES
25 - 40	13.4%	12.0%
40 - 50	4.2%	6.9%
50 - 75	14.1%	11.7%
75 - 100	19.9%	13.8%
100 - 175	25.0%	24.6%
175 - 300	13.4%	23.1%
300 - 600	9.7%	7.9%
600 - 750	0.2%	0.0%

3.2.4 Scaling Factor Application

The data used to expand the survey findings to the state level, as well as the associated scaling factors (Agricultural Census value / survey value), are presented in Table 3-40 for each stratum. The inverse of the scaling factor value indicates the portion of each stratum covered by the survey responses.

Table 3-40. Agricultural Sector Scaling Factors by Stratum
2017 Nonroad Diesel Equipment Study

Stratum	Units	Agricultural Census	Survey	Scaling Factor	Survey Coverage
Beef Cattle*	Head	538,702	5,824	92.5	1.1%
Dairy Cattle*	Head	128,284	12,460	10.3	9.7%
Fruit Tree/Nut	Acres	135,877	10,155	13.4	7.5%
Greenhouse/Nursery/Floriculture	Acres	100,873	12,894	7.8	12.8%
Oilseed/Grain	Acres	771,096	51,385	15.0	6.7%
Other Crops	Acres	1,121,595	49,303	22.7	4.4%
Other Animals[87]	Head	298,266	828	287.8	0.3%
Vegetables/Melons	Acres	239,284	8,130	29.4	3.4%
Wineries	Acres	24,964	150	167.0	0.6%

* Excluding calves

Note that no survey responses were obtained from poultry operations, which included 736 establishments in 2017 according to the Agricultural Census. After consultation with OFB, ERG assigned one tractor with survey-average values for hours per year, hp and age for each Poultry operation.

ERG multiplied the survey equipment counts and annual hours of use by the scaling factors in Table 3-41 to obtain the statewide equipment use profile for this sector. Table 3-41 through Table 3-44 presents the statewide estimates for equipment counts, average hp, average hours per year, and average model year by stratum for all reported equipment types. The accompanying charts (Figure 3-29 through Figure 3-32) present the unit counts and parameter distributions aggregated across equipment types.

Table 3-41. Agricultural Sector Profile – Number of Units by Equipment Type and Stratum
2017 Nonroad Diesel Equipment Study

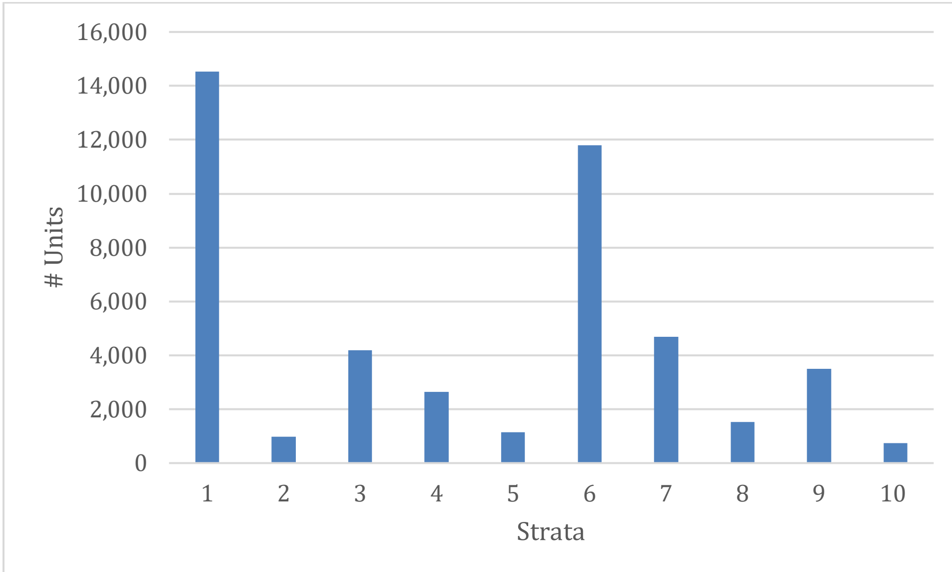
Equipment Type	Survey Stratum										
	1	2	3	4	5	6	7	8	9	10	Total
Agricultural tractors	7,585	494	2,529	1,619	690	6,552	3,962	1,324	3,340	736	28,832
Balers	370					23					393

87 Excludes aquaculture and apiculture due to expected lack of heavy equipment use – confirmed by OFB.

Equipment Type	Survey Stratum										
	1	2	3	4	5	6	7	8	9	10	Total
Combines	185		94	70	270	1,615		59			2,293
Irrigation sets		41	107	16	15	182					361
Other agricultural equipment	92	41	268	70		273		88			833
Sprayers	185		147	70	15	387					804
Swathers	647	21	40	23	60	1,206	360	59			2,416
Air compressors	92					159					252
Generator sets			27								27
Pressure washers			13								13
Pumps	277	10	54		15						356
Welders			27								27
Concrete/industrial saws			13								13
Crawler tractors/dozers	1,850	10	40	110	45	182					2,237
Excavators	555	21	107	274		136					1,093
Graders	1,387		13	31	30	23					1,485
Off-highway trucks			40								40
Other construction equipment			80								80
Rollers			27			23					50
Rough terrain forklifts	92	10	241	70		523					937
Rubber tire loaders	370	237	13	196		114					929
Skid steer loaders	277	72	54	63		159	360				985
Tractors/loaders/backhoes	462		54	23		114					653
Trenchers			13								13
Other industrial equipment			67								67
Terminal tractors						45					45
Chippers/stump grinders			13								13
Lawn and garden tractors		10	13			23					46
Fellers/bunchers/skidders	92					45					138
Specialty vehicles/carts			94			23			167		283
Total	**14,522**	**968**	**4,188**	**2,636**	**1,140**	**11,807**	**4,683**	**1,530**	**3,507**	**736**	**45,718**

Key: 1 = Beef Cattle, 2 = Dairy Cattle, 3 = Fruit Tree/Nut, 4 = Greenhouse/Nursery/Floriculture, 5 = Oilseed/Grain, 6 = Other Crops, 7 = Other Animals, 8 = Vegetables/Melons, 9 = Wineries, 10 = Poultry

Figure 3-29. Agricultural Sector Number of Units by Stratum
2017 Nonroad Diesel Equipment Study



Key: 1 = Beef Cattle, 2 = Dairy Cattle, 3 = Fruit Tree/Nut, 4 = Greenhouse/Nursery/Floriculture, 5 = Oilseed/Grain, 6 = Other Crops, 7 = Other Animals, 8 = Vegetables/Melons, 9 = Wineries, 10 = Poultry

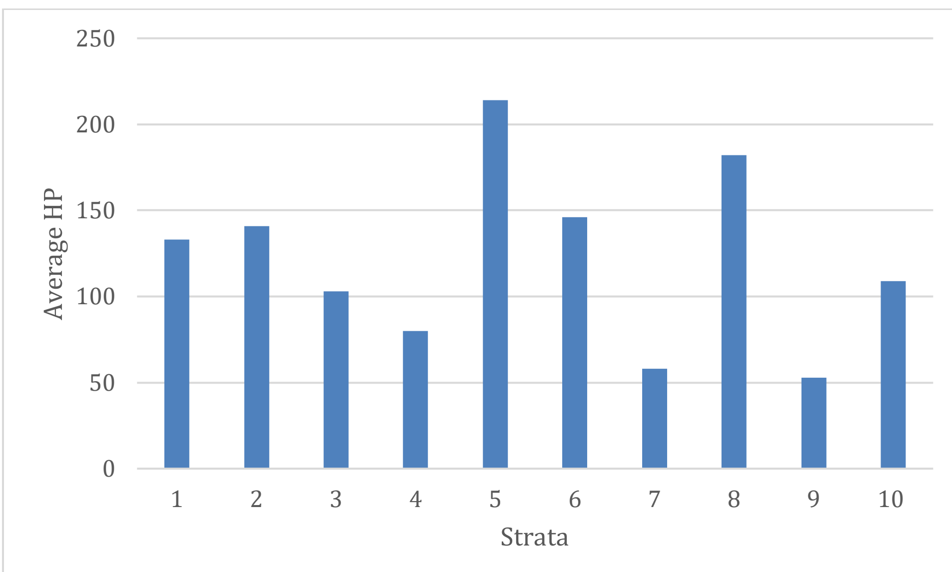
Table 3-42. Agricultural Sector Profile – Average HP by Equipment Type and Stratum 2017 Nonroad Diesel Equipment Study

	Survey Stratum										
Equipment Type	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Total**
Agricultural tractors	117	142	96	72	223	138	59	181	54	108	**108**
Balers	71					62					**71**
Combines	487		228	221	254	256		275			**273**
Irrigation sets		125	59	86	25	81					**77**
Other agricultural equipment	295	493	108	109		128		162			**160**
Sprayers	284		206	103	175	171					**197**
Swathers	89	188	145	123	103	117	60	148			**103**
Air compressors	65					95					**84**
Generator sets			33								**33**
Pressure washers			31								**31**
Pumps	86	125	86		70						**86**
Welders			46								**46**
Concrete/industrial saws			33								**33**
Crawler tractors/dozers	147	100	111	100	142	113					**141**
Excavators	111	135	103	61		113					**98**
Graders	222		230	177	170	125					**219**
Off-highway trucks			244								**244**
Other construction equipment			234								**234**
Rollers			85			85					**85**

Equipment Type	Survey Stratum										Total
	1	2	3	4	5	6	7	8	9	10	
Rough terrain forklifts	86	90	75	57		83					**79**
Rubber tire loaders	130	111	232	81		131					**117**
Skid steer loaders	52	64	51	72		57	45				**52**
Tractors/loaders/backhoes	66		78	89		69					**69**
Trenchers			61								**61**
Other industrial equipment			130								**130**
Terminal tractors						200					**200**
Chippers/stump grinders			50								**50**
Lawn and garden tractors		25	45			46					**41**
Fellers/bunchers/skidders	128					143					**133**
Specialty vehicles/carts			28			28			25		**26**
Total	**133**	**141**	**103**	**80**	**214**	**146**	**58**	**182**	**53**	**108**	**122**

Key: 1 = Beef Cattle, 2 = Dairy Cattle, 3 = Fruit Tree/Nut, 4 = Greenhouse/Nursery/Floriculture, 5 = Oilseed/Grain, 6 = Other Crops, 7 = Other Animals, 8 = Vegetables/Melons, 9 = Wineries, 10 = Poultry

Figure 3-30. Agricultural Sector Average Equipment HP by Stratum
2017 Nonroad Diesel Equipment Study



Key: 1 = Beef Cattle, 2 = Dairy Cattle, 3 = Fruit Tree/Nut, 4 = Greenhouse/Nursery/Floriculture, 5 = Oilseed/Grain, 6 = Other Crops, 7 = Other Animals, 8 = Vegetables/Melons, 9 = Wineries, 10 = Poultry

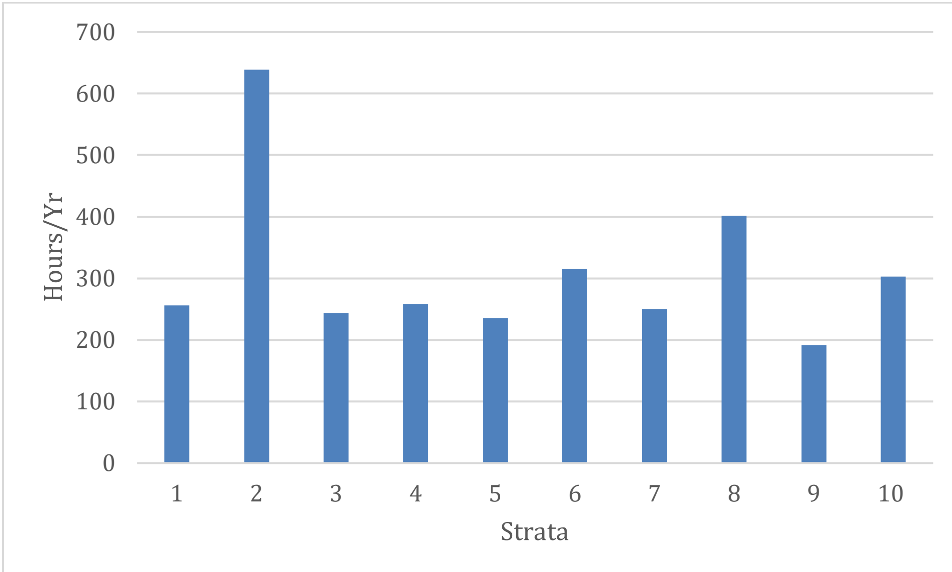
Table 3-43. Agricultural Sector Profile – Average Hours/Year by Equipment Type and Stratum

2017 Nonroad Diesel Equipment Study

	Survey Stratum										
Equipment Type	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Total**
Agricultural tractors	290	507	266	254	282	408	200	437	197	300	**300**
Balers	94					25					**90**
Combines	59		135	196	164	145		200			**143**
Irrigation sets		700	808	749	800	409					**591**
Other agricultural equipment	149	425	225	278		254		223			**240**
Sprayers	28		91	219	188	125					**106**
Swathers	50	550	98	142	81	133	50	85			**99**
Air compressors	190					381					**311**
Generator sets			78								**78**
Pressure washers			33								**33**
Pumps	158	300	93		300						**158**
Welders			148								**148**
Concrete/industrial saws			134								**134**
Crawler tractors/dozers	235	200	177	244	67	281					**235**
Excavators	261	550	232	284		439					**292**
Graders	340		222	194	50	100					**326**
Off-highway trucks			378								**378**
Other construction equipment			140								**140**
Rollers			175			241					**205**
Rough terrain forklifts	259	300	204	251		274					**253**
Rubber tire loaders	208	1,097	5	249		283					**449**
Skid steer loaders	72	361	158	341		276	100				**158**
Tractors/loaders/backhoes	353		151	275		233					**313**
Trenchers			137								**137**
Other industrial equipment			202								**202**
Terminal tractors						398					**398**
Chippers/stump grinders			67								**67**
Lawn and garden tractors		500	50			100					**174**
Fellers/bunchers/skidders	300					33					**212**
Specialty vehicles/carts			100			400			83		**114**
Total	**256**	**639**	**244**	**258**	**235**	**315**	**250**	**402**	**192**	**300**	**279**

Key: 1 = Beef Cattle, 2 = Dairy Cattle, 3 = Fruit Tree/Nut, 4 = Greenhouse/Nursery/Floriculture, 5 = Oilseed/Grain, 6 = Other Crops, 7 = Other Animals, 8 = Vegetables/Melons, 9 = Wineries, 10 = Poultry

Figure 3-31. Agricultural Sector Average Equipment Activity by Stratum
2017 Nonroad Diesel Equipment Study



Key: 1 = Beef Cattle, 2 = Dairy Cattle, 3 = Fruit Tree/Nut, 4 = Greenhouse/Nursery/Floriculture, 5 = Oilseed/Grain, 6 = Other Crops, 7 = Other Animals, 8 = Vegetables/Melons, 9 = Wineries, 10 = Poultry

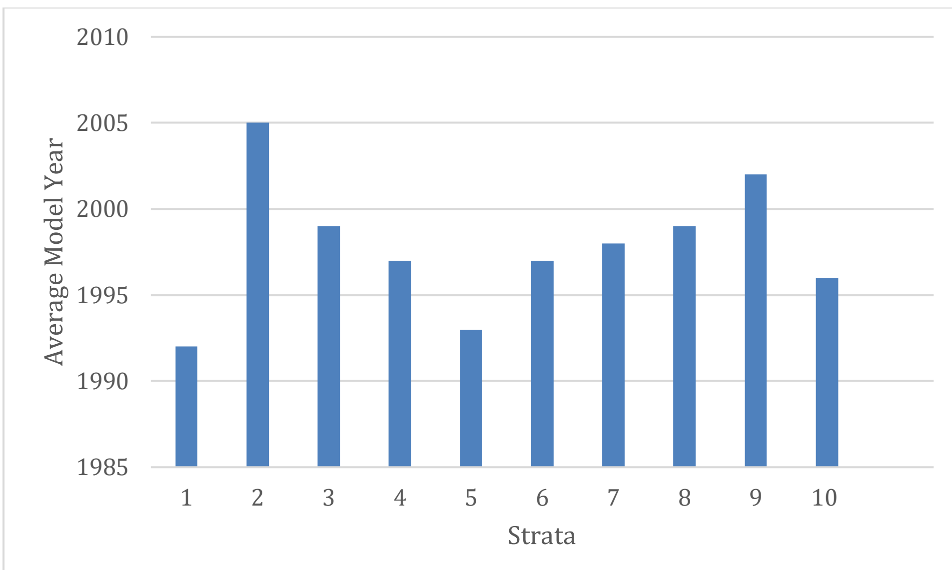
Table 3-44. Agricultural Sector Profile - Average Model Year by Equipment Type and Stratum
2017 Nonroad Diesel Equipment Study

Equipment Type	Survey Stratum										
	1	2	3	4	5	6	7	8	9	10	Total
Agricultural tractors	1993	2002	2000	1996	1993	1994	1997	2000	2002	1996	**1996**
Balers	1994					2005					**1995**
Combines	2016		1998	2001	2001	1998		2002			**2000**
Irrigation sets		2015	2008	1995	1992	2013					**2010**
Other agricultural equipment	1994	2009	2003	2007		2002		1987			**2001**
Sprayers	2005		1999	1995	2002	2002					**2002**
Swathers	1998	2009	2008	2007	1999	2006	2004	1998			**2003**
Air compressors	2004					2000					**2002**
Generator sets			1996								**1996**
Pressure washers			1996								**1996**
Pumps	1996	2017	1996		1965						**1995**
Welders			1996								**1996**
Concrete/industrial saws			1996								**1996**
Crawler tractors/dozers	1983	2004	1983	1996	1971	1987					**1983**
Excavators	1989	2009	2001	2007		1997					**1996**
Graders	1993		1996	1967	1964	1976					**1992**
Off-highway trucks			1996								**1996**
Other construction equipment			1996								**1996**
Rollers			1996			1996					**1996**
Rough terrain forklifts	1994	1997	1998	2001		2004					**2001**

	Survey Stratum										
Equipment Type	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Total**
Rubber tire loaders	1983	2007	1975	1988		1990					**1991**
Skid steer loaders	2008	2006	2000	2011		2006	2001				**2005**
Tractors/loaders/backhoes	1991		1995	1994		1993					**1992**
Trenchers			1996								**1996**
Other industrial equipment			1996								**1996**
Terminal tractors						1996					**1996**
Chippers/stump grinders			2000								**2000**
Lawn and garden tractors		2016	2017			2015					**2016**
Fellers/bunchers/skidders	1976					1978					**1977**
Specialty vehicles/carts			1996			2005			2012		**2006**
Total	**1992**	**2005**	**1999**	**1997**	**1993**	**1997**	**1998**	**1999**	**2002**	**1996**	**1998**

Key: 1 = Beef Cattle, 2 = Dairy Cattle, 3 = Fruit Tree/Nut, 4 = Greenhouse/Nursery/Floriculture, 5 = Oilseed/Grain, 6 = Other Crops, 7 = Other Animals, 8 = Vegetables/Melons, 9 = Wineries, 10 = Poultry

Figure 3-32. Agricultural Sector Average Model Year by Stratum
2017 Nonroad Diesel Equipment Study



Key: 1 = Beef Cattle, 2 = Dairy Cattle, 3 = Fruit Tree/Nut, 4 = Greenhouse/Nursery/Floriculture, 5 = Oilseed/Grain, 6 = Other Crops, 7 = Other Animals, 8 = Vegetables/Melons, 9 = Wineries, 10 = Poultry

Table 3-45 presents the equipment use profile aggregated across all strata, as well as the estimated fuel consumption for each equipment type for the state. Agricultural tractors are responsible for approximately two thirds of total fuel consumption, with significant contributions from a mix of construction and other agricultural equipment.

Table 3-45. Agricultural Sector Statewide Equipment Use Profile 2017 Nonroad Diesel Equipment Study

Equipment Type	# Units	Avg HP	Avg Hr/Yr	Avg Model Yr	Gal/Yr[88]
Agricultural tractors	28,832	108	300	1996	26,523,561
Balers	393	71	90	1995	83,027
Combines	2,293	273	143	2000	2,014,397
Irrigation sets	361	77	591	2010	393,643
Other agricultural equipment	833	160	240	2001	956,516
Sprayers	804	197	106	2002	315,157
Swathers	2,416	103	99	2003	687,914
Air compressors	252	84	311	2002	131,577
Generator sets	27	33	78	1996	1,243
Pressure washers	13	31	33	1996	347
Pumps	356	86	158	1995	121,796
Welders	27	46	148	1996	2,633
Concrete/industrial saws	13	33	134	1996	2,050
Crawler tractors/dozers	2,237	141	235	1983	1,851,143
Excavators	1,093	98	292	1996	694,027
Graders	1,485	219	326	1992	2,361,354
Off-highway trucks	40	244	378	1996	74,614
Other construction equipment	80	234	140	1996	58,413
Rollers	50	85	205	1996	19,321
Rough terrain forklifts	937	79	253	2001	421,984
Rubber tire loaders	929	117	449	1991	946,088
Skid steer loaders	985	52	158	2005	230,418
Tractors/loaders/backhoes	653	69	313	1992	391,476
Trenchers	13	61	137	1996	3,283
Other industrial equipment	67	130	202	1996	31,376
Terminal tractors	45	200	398	1996	113,272
Chippers/stump grinders	13	50	67	2000	1,128
Lawn and garden tractors	46	41	174	2016	6,603
Fellers/bunchers/skidders	138	133	212	1977	91,779
Specialty vehicles/carts	283	26	114	2006	24,982
Total	**45,714**	**120**	**271**	**1996**	**38,555,124**

3.2.5 County/Temporal Allocation

The county-level activity distribution for the Agricultural Sector fleets were based on the scaling factors from the 2017 Agricultural Census for each of the survey stratum, as shown in Table 3-46.

[88] Calculated using EPA MOVES-Nonroad model (2014b). See Section 6.2 for additional details.

Table 3-46. County-Level Agricultural Sector Fleet Activity Allocation, by Stratum
2017 Nonroad Diesel Equipment Study

County	Survey Stratum								
	1	2	3	4	5	6	7	8	9
Baker	8.75%	0.02%	0.02%	0.00%	1.40%	4.21%	1.98%	4.23%	0.00%
Benton	0.56%	1.43%	1.76%	5.39%	0.29%	2.88%	1.48%	1.92%	1.83%
Clackamas	1.29%	0.95%	8.01%	26.79%	0.08%	1.75%	6.75%	1.99%	1.49%
Clatsop	0.27%	1.12%	0.06%	0.09%	0.00%	0.17%	0.58%	0.01%	0.00%
Columbia	0.47%	0.02%	0.07%	0.30%	0.02%	0.48%	1.10%	0.02%	0.02%
Coos	1.44%	3.02%	0.08%	0.04%	0.00%	0.66%	2.68%	0.01%	0.04%
Crook	5.18%	0.04%	0.00%	0.12%	0.05%	2.37%	1.44%	0.00%	0.02%
Curry	0.67%	0.00%	1.37%	0.05%	0.00%	0.09%	5.67%	0.01%	0.00%
Deschutes	1.04%	0.00%	0.00%	0.61%	0.11%	1.57%	2.72%	0.06%	0.00%
Douglas	5.05%	0.13%	0.64%	0.46%	0.01%	2.24%	11.04%	0.21%	7.73%
Gilliam	1.22%	0.00%	0.00%	0.00%	8.22%	0.36%	0.05%	0.01%	0.00%
Grant	3.95%	0.02%	0.00%	0.01%	0.01%	2.52%	0.41%	0.00%	0.00%
Harney	12.91%	0.06%	0.00%	0.00%	0.00%	11.88%	0.93%	0.00%	0.00%
Hood River	0.05%	0.00%	14.75%	0.16%	0.00%	0.10%	0.32%	0.04%	0.87%
Jackson	2.34%	0.17%	3.81%	0.28%	0.03%	1.40%	3.33%	0.26%	10.66%
Jefferson	1.27%	0.00%	0.00%	5.43%	0.49%	2.40%	1.79%	0.61%	0.00%
Josephine	0.34%	0.02%	0.11%	0.11%	0.00%	0.30%	1.33%	0.06%	3.38%
Klamath	5.33%	5.54%	0.00%	0.00%	3.27%	5.25%	2.82%	7.99%	0.00%
Lake	8.94%	0.02%	0.00%	0.00%	0.12%	9.55%	0.93%	0.00%	0.00%
Lane	1.63%	3.46%	3.50%	3.35%	0.22%	1.82%	7.69%	0.95%	5.40%
Lincoln	0.32%	0.00%	0.05%	0.17%	0.00%	0.17%	0.88%	0.01%	0.01%
Linn	1.46%	3.20%	5.96%	6.61%	0.36%	10.45%	17.98%	3.09%	0.31%
Malheur	14.16%	2.90%	0.04%	1.38%	4.64%	6.70%	2.51%	8.64%	0.00%
Marion	0.72%	9.31%	17.51%	25.43%	1.01%	6.76%	4.23%	11.73%	13.26%

County	Survey Stratum								
	1	2	3	4	5	6	7	8	9
Morrow	2.65%	35.73%	0.00%	0.26%	19.66%	2.81%	1.44%	24.02%	0.00%
Multnomah	0.16%	0.01%	1.11%	2.94%	0.05%	0.26%	0.64%	1.30%	0.00%
Polk	0.44%	4.11%	7.99%	7.40%	1.23%	3.23%	3.04%	0.47%	17.61%
Sherman	0.44%	0.00%	0.02%	0.00%	14.26%	0.07%	0.08%	0.00%	0.00%
Tillamook	0.19%	20.05%	0.00%	0.01%	0.00%	0.59%	0.35%	0.02%	0.00%
Umatilla	4.37%	0.65%	4.00%	0.56%	31.45%	3.39%	3.80%	28.79%	0.00%
Union	3.09%	0.02%	0.14%	0.00%	2.70%	3.59%	1.39%	0.50%	0.00%
Wallowa	4.00%	0.02%	0.00%	0.00%	1.34%	2.36%	1.88%	0.00%	0.00%
Wasco	2.59%	0.01%	9.59%	0.00%	7.88%	0.61%	1.93%	0.00%	0.90%
Washington	0.32%	0.94%	9.12%	6.28%	0.79%	2.33%	2.05%	1.26%	8.63%
Wheeler	1.81%	0.00%	0.00%	0.00%	0.00%	0.55%	0.09%	0.00%	0.00%
Yamhill	0.55%	7.02%	10.29%	5.74%	0.28%	4.18%	2.64%	1.78%	27.83%

Key: 1 = Beef Cattle, 2 = Dairy Cattle, 3 = Fruit Tree/Nut, 4 = Greenhouse/Nursery/Floriculture, 5 = Oilseed/Grain, 6 = Other Crops, 7 = Other Animals, 8 = Vegetables/Melons, 9 = Wineries

The Agricultural sector surveys included estimates regarding how activity was split between weekdays and weekends and across seasons for 174 establishments. The fleet's temporal allocation profile estimates that 82 percent of activity occurs during weekdays and 42 percent of activity occurs during the summer months.

3.2.6 Profile Validation

ERG validated the survey data set for both external and internal representativeness and consistency. A high-level check of geographic coverage found 31 of the 36 Oregon counties were represented in the responses, with no responses for Baker, Clatsop, Crook, Jefferson and Wheeler Counties. According to the Agricultural Census, these five counties contained only 5.6 percent of the operating agricultural establishments in the state in 2017. The OFB representative was not aware of any unique operations in these counties that would be of concern when extrapolating the survey results to the state level.[89]

ERG also compared the survey results with data from the 2017 Agricultural Census for the state as a whole. The comparisons focused on equipment and operator characteristics that have a significant impact on emissions. ERG first compared the estimated statewide equipment populations for tractors and combines, as shown in Table 3-47.[90] While the profile's combine estimate (2,293) units corresponds closely with the Census value (2,478), the profile's estimate for tractors greater than 25 hp (28,832) differs substantially from the estimated Census value (43,623). However, there is reason to believe the Census tractor counts are substantially over-estimated, as discussed later in this section.

Table 3-47. Tractor and Combine Population Count Comparison
2017 Nonroad Diesel Equipment Study

Equipment Type	Survey	Agricultural Census
Tractors (> 25 hp)	28,832	43,623
Combines	2,293	2,478

Next, the equipment age distributions from the survey and the Agricultural Census were compared for both tractors and combines and found to be consistent, as shown in Table 3-48.[91]

[89] Personal communication with Jonathon Sandau, Oregon Farm Bureau Government Affairs team. July 2019.

[90] The baler population values provided in the Agricultural Census did not differentiate between self-propelled and pull-behind units, and therefore could not be compared directly with the survey results. Other equipment categories could not be compared directly due to nomenclature differences.

[91] The Agricultural Census does not break out age distributions for other surveyed equipment categories.

Table 3-48. Tractor and Combine Age Distribution Comparison 2017 Nonroad Diesel Equipment Study

Equipment Type	Survey	Agricultural Census
Tractors < 5 yrs old	13%	13%
Combines < 5 yrs old	12%[92]	9%

The Agricultural Census also provided hp distributions for tractors, which are compared against the survey findings in Table 3-49. While the percentage of units between 25 and 39 hp are similar, the survey data have a notably higher percentage of units greater than 100 hp.[93]

Table 3-49. Tractor HP Distribution Comparison 2017 Nonroad Diesel Equipment Study

HP Distribution	Survey	Agricultural Census
Tractors > 100 hp	46%	27%
Tractors 40-99 hp	39%	57%
Tractors 25-39 hp[94]	15%	16%

ERG also compared the farm size of the survey respondents to the Agricultural Census data, as shown in Table 3-50. The survey generally over-represents smaller establishments and under-represents the very largest establishments.

Table 3-50. Survey Respondent Farm Size vs Agricultural Census 2017 Nonroad Diesel Equipment Study

	Percent of Total Acres in Production	
Area Operated (Acres)	Survey	Agricultural Census
1.0 to 9.9	0.02%	0.63%
10.0 to 49.9	20.00%	3.00%
50.0 to 69.9	4.00%	0.94%
70.0 to 99.9	4.57%	1.61%
100 to 139	3.43%	1.63%
140 to 179	4.57%	1.69%
180 to 219	4.57%	1.30%
220 to 259	4.57%	1.24%
260 to 499	10.29%	6.43%
500 to 999	10.29%	10.62%
1,000 to 1,999	6.29%	13.29%

[92] Only seven combines in the survey data were less than five years old, so this estimate is particularly uncertain.

[93] Given that ERG corrected a substantial number of self-reported equipment hp values (based on make, model and model year information), the survey profile may prove more accurate than the Agricultural Census in this regard.

[94] The Agricultural Census reports tractor hp values in three groups - > 100, 40 – 100, and < 40. ERG used the default tractor hp distribution in EPA's MOVES model to estimate the fraction of units between 25 and 40 hp.

Area Operated (Acres)	Percent of Total Acres in Production	
	Survey	Agricultural Census
2,000 OR MORE	17.71%	57.60%

ERG also evaluated the hours of use, hp, and fuel consumption reported in the surveys for consistency. Ideally, the annual nonroad diesel consumption reported by a respondent would equal the fuel consumption calculated using Equation 3-1:

$$\text{Gallons/yr} = \sum [(\text{HRs} \times \text{HP} \times \text{LF} \times \text{BSFC}) / 7.0] \qquad \text{Equation 3-1}$$

Where, for each Equipment Type/HP combination:

HRs = annual hours

HP = rated hp

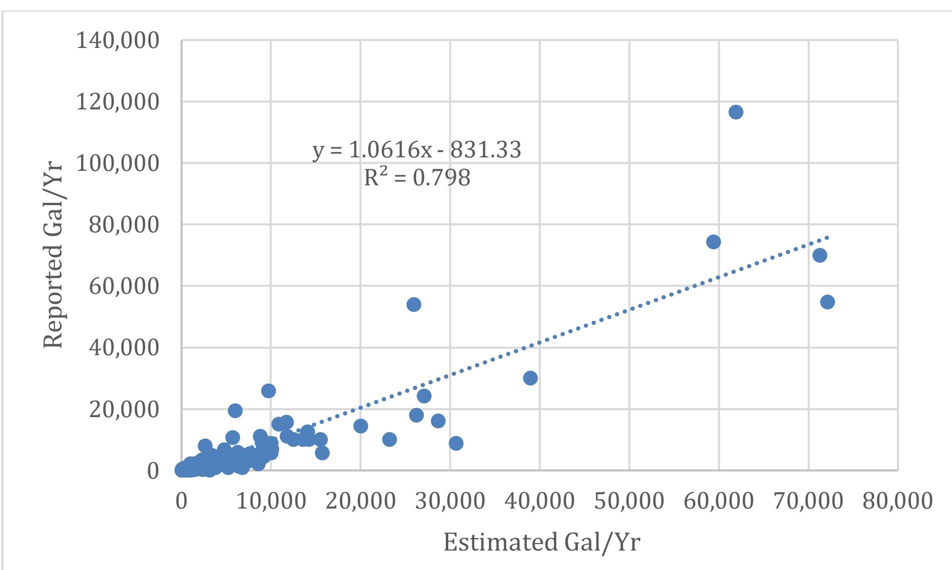
LF = Engine load factor (CARB basis where available)

BSFC = Brake-specific fuel consumption (lbs. of fuel per hp-hr)

Diesel fuel density = 7.0 (lbs./gallon)

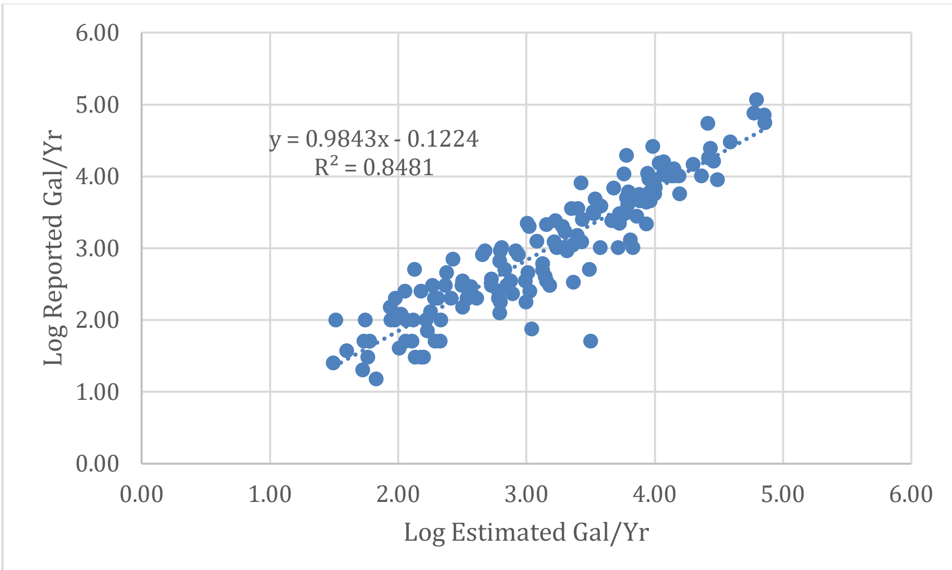
In actuality, the relationship between reported and calculated fuel consumption can differ for a variety of reasons, including the amount of nonroad diesel fuel used by engines less than 25 hp, limited use of on-road fuel in nonroad applications, and general reporting inaccuracies, in addition to equipment-specific variations in duty cycle. ERG investigated the variation between reported and calculated fuel consumption for each of the 150 respondents providing both fuel consumption and hours of equipment use. Figure 3-33 displays the relationship, along with the predictive equation derived using simple linear regression.

Figure 3-33. Reported vs Calculated Gallons per Year, by Survey Respondent (N=150) 2017 Nonroad Diesel Equipment Study



A small number of high activity operations (toward the far right of the figure) likely have a disproportionally large influence on the predictive equation and the associated R^2 value. Accordingly, ERG took the log of both variables to minimize possible outlier influence on the results, as shown in Figure 3-34.

Figure 3-34. Reported vs Calculated Gallons per Year, Log-Log Transform (N=150) 2017 Nonroad Diesel Equipment Study



While the variation between reported and calculated fuel consumption can be substantial for a given respondent, the resulting R^2 value indicates a very strong correlation for the data set as a whole. In addition, the corresponding linear equation shows no clear over-or under-prediction of fuel consumption.[95] This finding adds substantial confidence regarding the overall accuracy of the reported equipment hour and hp values.

ERG also compared the nonroad diesel fuel consumption estimates for the sector to two additional data sources: The Energy Information Administration's Fuel Oil and Kerosene Survey (FOKS),[96] and the fuel expenditure estimates included in the Agricultural Census. Table 3-51 shows the gallons per year estimates for each source.[97]

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[95] Perfect 1 to 1 correspondence between reported and predicted values would be represented by the equation y = 1.0 * x + 0.

[96] U.S. Energy Information Administration. *Fuel Oil and Kerosene Sales 2017.* Retrieved from https://www.eia.gov/petroleum/fueloilkerosene/archive/2017/foks_2017.php.

[97] Additional detail regarding the FOKS fuel sales and Agricultural Census fuel expenditures data are provide in Section 7.2.

Table 3-51. Agricultural Sector Fuel Consumption Validation
2017 Nonroad Diesel Equipment Study

Data Source	Gal/Yr	Percent of Survey Total
Survey Basis	38,555,124	
FOKS	31,440,000	81.5%
Agricultural Census	33,125,021	85.9%

The reasonably close correspondence across these three estimates, plus the combine population estimates (survey-based value 92.5 percent of the Agricultural Census total) lend credence to the suspicion that the tractor counts in the Agricultural Census are systematically over-estimated.[98] While the detailed Agricultural Census instructions clearly state "Do not report obsolete or abandoned equipment", the wording on the actual Census form only states "… report the number on this operation on December 31, 2017. Include machinery, equipment, and implements used for the farm or ranch business in 2016 or 2017, and usually kept on the operation."[99] The lack of clear direction on the Census form to exclude inoperable equipment, of which there may be many on a given farm or ranch,[100] may result in the over-reporting of functioning tractors.

3.2.7 Sector Summary

Key observations regarding the Agriculture sector surveys and activity profiles include the following:

- The survey obtained a reasonable overall response rate of 16 percent, although low return rates for certain stratum such as dairy cattle and vegetables/melons add uncertainty for these profiles.
- According to the 2017 Agricultural Census, the survey over-represented smaller establishments and under-represented of larger establishments. Additional assessment may be warranted to determine if equipment characteristics and use vary with operation size in ways that could impact total emission estimates. For example, a preliminary evaluation found a small difference in average tractor model year by farm acreage – 1993 for operations less than 100 acres, and 1998 for operations greater

[98] If the survey activity estimate is scaled to the state level using tractor counts as the scaling factor rather than acreage/number of head, the resulting fuel consumption estimate for the sector would differ from the other estimates by roughly 40%.

[99] U.S. Department of Agriculture. *2017 Census of Agriculture Sample Report Form.* https://www.nass.usda.gov/AgCensus/Report_Form_and_Instructions/2017_Report_Form/17a100_121316_general_final.pdf.

[100] While no formal studies were identified regarding the number of idled units on farms and ranches, an informal survey conducted at a recent trade show found that the majority of farmers said they had half a dozen or more pieces of equipment on their property that had not been used in the last two years. See http://bigironbuzz.com/cost-unused-equip/.

than or equal to 100 acres. Other factors such as hours of equipment operation per acre may also vary with establishment size in important ways.

- Tractors are responsible for over two thirds of the sector's total activity (as measured by fuel consumption). These units also have a notably skewed model year distribution with an average age of almost 25 years.
- Sector equipment has a low average power rating (122 hp) and a low average utilization (279 hours/yr), except for Dairy operations which operate more than 600 hours per year on average.
- There is also a substantial amount of construction equipment use across the sector, with this equipment responsible for 24 percent of total fuel consumption.
- Beef Cattle and Other Crop Production[101] establishments are the dominant strata at the state level.
- Agricultural sector activity is widely spread across state, with substantial variation across regions and strata.
- There is notable uncertainty associated with county-level activity allocation, as there were not enough responses to develop county-specific profiles. The Agricultural Census data may be used in the future to improve the geographic precision of the survey results in a number of ways. For example, Census data indicate that the portion of tractors less than five years old in Tillamook County was 19 percent in 2017, compared to only 10 percent in Harney County. Such differences can lead to substantive variation in average equipment emission rates across the state.
- State level activity validation found broad consistency between the study's fuel consumption estimates for the sector and independent data sources such as FOKS and the Agricultural Census.

3.3 Logging Sector

ERG conducted a survey of commercial firms that performed timber harvesting in Oregon in 2017. The types of activity surveyed included harvesting as well as operations such as logging roadway development and roadway/drainage maintenance. Activities related to aggregate mining (i.e., sand and gravel pits) on private lands used to support logging roadways were also surveyed.[102]

3.3.1 Equipment Types

There are two diesel equipment types defined in EPA's MOVES model to represent diesel-powered applications in the logging sector:

[101] The other crop category consists predominately of hay and forage production.

[102] These aggregate mining activities typically fall outside state permitting requirements, with reporting thresholds set at 2 million tons per year in the Willamette Valley, and 0.5 million tons elsewhere. See https://secure.sos.state.or.us/oard/viewSingleRule.action?ruleVrsnRsn=249040.

- Shredders > 6 hp[103]
- All Other Forest Equipment (Feller Bunchers, Skidders, etc.)

However, EPA estimates zero population for diesel shredders over 6 hp in the MOVES model. Therefore, all diesel-powered applications used in logging are assigned to the "All Other Forest Equipment" category for this assessment.

Survey respondents were asked to provide data for a more detailed list of harvesting equipment types to allow for a more precise evaluation of equipment use parameters. Harvesting equipment types listed in the survey included:[104]

- Feller Bunchers
- Forwarders
- Log Loaders/Picks (Self-Propelled)
- Log Loaders/Picks (Stationary/Trailer Mount)
- Shredders
- Skidders
- Tree Harvesters
- Yarders
- Other Forestry Equipment (Self-Propelled)
- Other Forestry Equipment (Stationary/Trailer Mount)

In addition to harvesting equipment, respondents were also asked to supply information on various earthmoving equipment types used in roadway, drainage and aggregate production activities.

3.3.2 Survey Development and Data Collection

The logging sector survey requested information on nonroad diesel equipment characteristics, usage, fuel consumption and throughput data. Requested parameters included engine counts, annual hours used, engine power rating, engine model year, and information on repowers and retrofits among others. Equipment make and model information were also requested to validate and check respondent supplied information.

The logging sector questionnaire is provided in Appendix C. The project team collaborated with local trade associations who participated in the survey development, wrote letters to the membership to support participation in this project and reviewed preliminary results.

Stratification of the logging sector surveys was initially considered, but ultimately rejected as infeasible due to insufficient data. The stratification options considered included differentiating

[103] Shredders are commonly known as mulchers.

[104] This list of logging equipment types represents those products currently tracked by Power Systems Research (PSR). PSR databases were used by EPA to develop the default modeling parameters in MOVES.

by land type (public versus private) and geographic subregion within the state. Contacts with industry representatives indicated that there are some usage characteristics that are potentially distinct for these subpopulations.

A list of Oregon establishments and associated contact information was obtained from Dynata.[105] The Dynata data also included information on company NAICS, number of employees and annual sales in dollars. 1,450 establishments were identified as operating under NAICS codes 1131 (Timber Tract Operations), 1132 (Forest Nurseries and Gathering of Forest Products), 1133 (Logging), and 1153 (Support Activities for Forestry) for this assessment. These represent a broad range of logging-related businesses, of which only a subset was expected to operate diesel-powered nonroad equipment. Notably, a preponderance of the 1,450 establishments were small with 80 percent classified as having 2 or fewer employees.

The data collection process consisted of phoning contacts and following up with repeated, subsequent phone calls, voicemails and/or emails asking if they had received the survey or needed assistance in its completion. Potential participants were informed that all responses would be kept confidential and offered a variety of modes for completing the survey including online, Excel forms exchanged by email, fax, and self-addressed prepaid mailers. A second round of targeted contacts was initiated in the August 2019 timeframe in order to improve participation. Completed surveys were accepted through September 2019.

ERG attempted to contact all 1,450 establishments via telephone, as well as by email where available. Direct contact was made with 762 establishments (53 percent) and 688 were fully nonresponsive (47 percent). For each completed survey, respondents were contacted a second time to confirm throughput values and validate the units of throughput. The outcome of the 762 establishment contacts is summarized in Table 3-52.

Table 3-52. Outcome of Logging Sector Survey Contacts
2017 Nonroad Diesel Equipment Study

Outcome	# of Establishments
Ineligible[106]	283
Refusals	24
Complete	14
No final response	361
No target equipment use[107]	81
Total Attempted Contacts	**763**

[105] Dynata LLC. https://www.dynata.com/company/about-us/.

[106] Includes phone numbers not in service, and establishments no longer or not ever involved in logging production.

[107] Establishments confirmed they were involved in logging production but did not utilize nonroad diesel equipment greater than 25 hp.

Ultimately, 14 completed surveys were submitted for commercial logging operations in Oregon in 2017, for a final survey completion rate of approximately 3 percent.[108]. Based on the reported throughput, these establishments represent approximately 5 percent of the 2017 Oregon timber harvest, and an estimated 25 percent of the 2017 Oregon aggregate production on private lands. The establishments also reported operation in 15 counties, with these counties responsible for 83 percent of the 2017 Oregon timber harvest total.[109]

3.3.3 Data Processing and Analysis

Survey responses were reviewed and compiled. Data cleaning and gap-filling included the following:

- There were 3 instances of "offroad trucks" in the survey compilation where the make and model information suggested that these were on-road vehicles. These vehicles were removed from the survey compilation.
- Gap-filling missing hp values was completed through web searches when make/model information was provided, otherwise the default average values for the most common hp bin from MOVES were used.
- Information on engine repowers was requested but only provided in a few instances.
    - There were 11 instances of repowering reported in the survey responses where the repower model year was 2017 or earlier.
    - There were 3 instances of repowers where the repower year was listed as either 2018 or 2019. In these cases, the emission rates were based on the reported model year for the equipment, presuming that the repower was not in effect for 2017.
- There were 4 instances of missing model year information in the survey compilation.
    - For 2 units, the midpoint of the range of production model years was selected for the specific equipment/make/model reported.
    - For 2 units simply listed as "old" in the Model Year field, the most recent "uncontrolled" model year (as assumed in MOVES emission rate assignments) of 1987 was substituted and used.

The equipment compilation for all 14 respondents summarizing the findings for 226 units is presented in Table 3-53. Subtotals by equipment type are also presented.[110]

[108] Completes / (Total Attempted Contacts – Ineligibles)

[109] County-level coverage provides a qualitative indication of geographic representativeness. The county-level activity and equipment distributions reported by the respondents were not directly used in the study.

[110] Of the logging equipment types listed in the survey, respondents did not explicitly indicate the use of "forwarders" or "shredders".

Table 3-53. Logging Sector Equipment Use Summary
2017 Nonroad Diesel Equipment Study

Equipment Type	# Units	Avg HP	Avg Hrs/Yr	Avg Model Year
Feller Bunchers	10	305	1,393	2010
Log Loaders/Picks (Self-Propelled)	59	223	1,499	2008
Log Loaders/Picks (Stationary)	3	182	1,433	2014
Other Forestry Equip (Self-Propelled)	8	205	1,364	2009
Other Forestry Equip (Stationary)	10	118	603	2007
Skidders	18	137	328	1990
Tree Harvesters	8	269	1,242	2013
Yarder	16	391	1,268	2002
Subtotal Logging	***132***	***230***	***1,210***	***2005***
Concrete/industrial saws[111]	1	35	500	2004
Crawler Tractors / Dozers	34	174	473	1985
Crushing/processing equipment	5	246	1,310	2009
Excavators	24	163	417	2001
Graders	8	175	438	1997
Rollers	3	123	442	1999
Rubber tire loaders	12	144	1,084	2009
Off-highway trucks	5	268	816	1997
Subtotal Construction / Mining	***92***	***173***	***598***	***1996***
Stump Grinders	1	60	250	2014
Wood Splitters	1	50	525	2016
Subtotal Commercial Lawn & Garden	***2***	***55***	***388***	***2015***

Figure 3-35 through Figure 3-37 present the logging equipment fleet distributions for all equipment types for model year, annual hours per unit, and hp based on the survey responses.[112] Large fractions of the fleet consist of legacy equipment greater than 20 years in age, with an average model year of 2002. Equipment activity levels are relatively high, averaging 1,004 hours/yr. Engine hp values ranged from approximately 30 hp to 650 hp, with an average value of 211 hp.

[111] The piece of equipment classified here was a "portable sawmill". This product falls under the Concrete/Industrial Saw equipment type.

[112] The number of observations (N) may be less than the total number of units in the fleet due to missing parameter responses.

**Figure 3-35. Logging Sector Equipment Model Year Distribution (N=222)
2017 Nonroad Diesel Equipment Study**

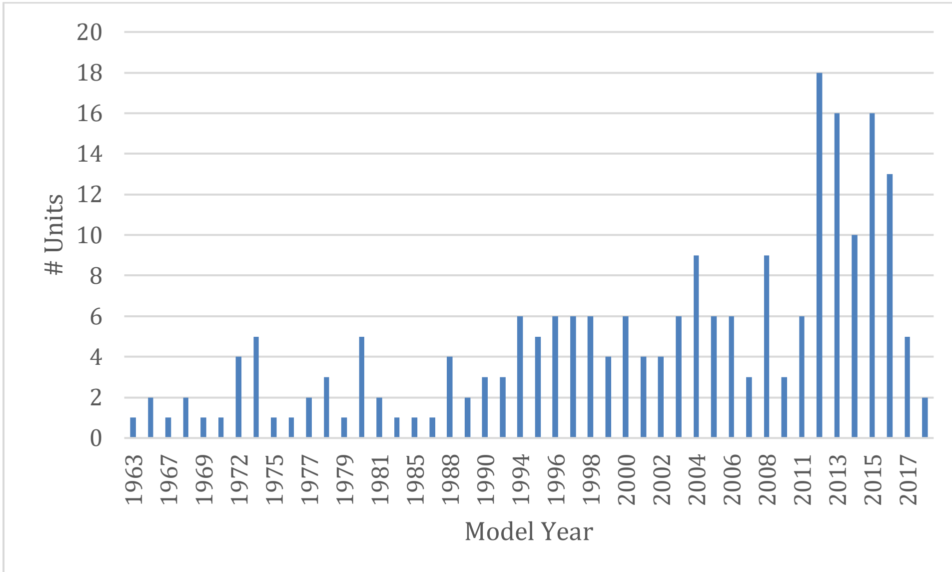


**Figure 3-36. Logging Sector Equipment Activity Distribution (N=226)
2017 Nonroad Diesel Equipment Study**

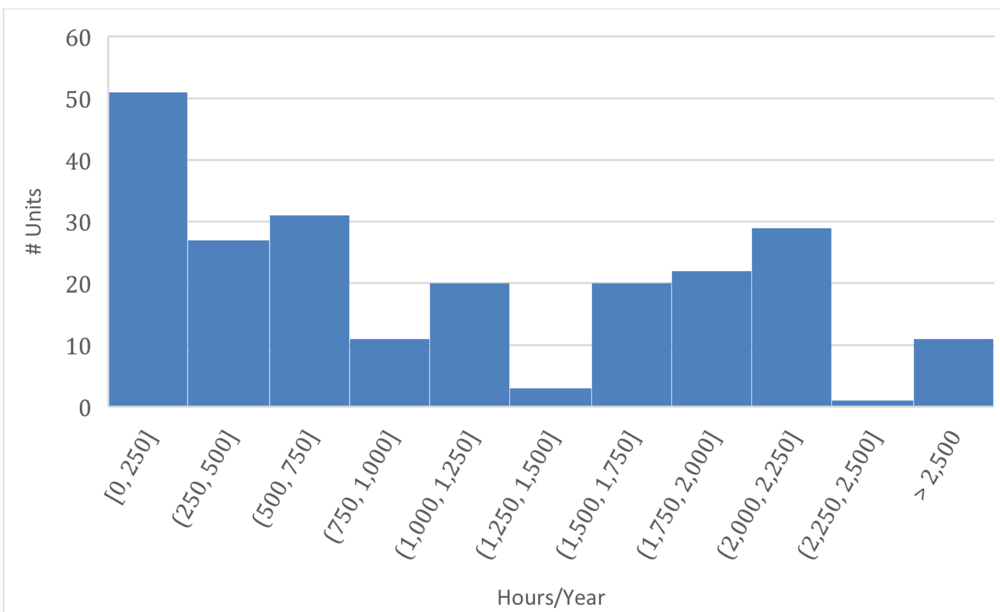


Figure 3-37. Logging Sector Equipment HP Distribution (N=226)
2017 Nonroad Diesel Equipment Study

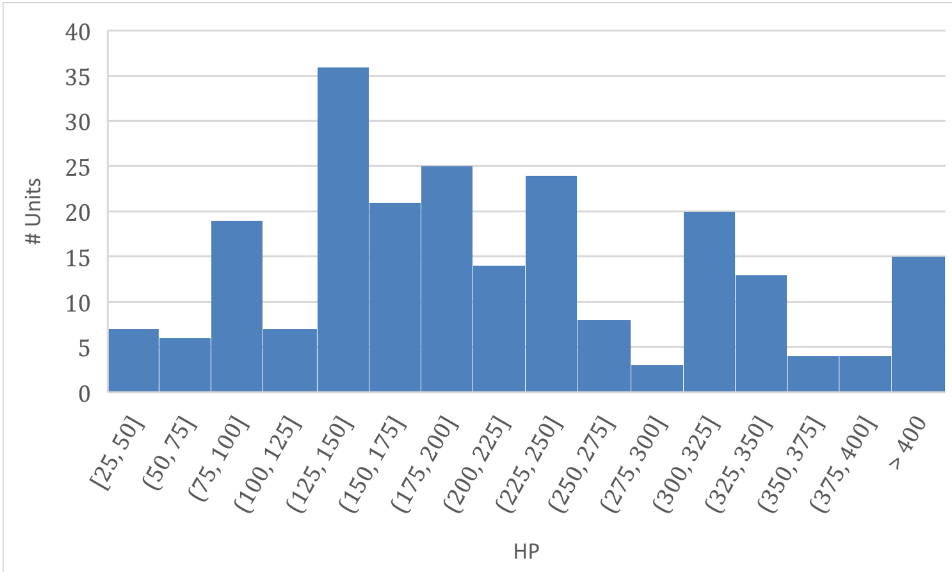


Table 3-54 presents an additional breakout of the engine tier level distributions for logging equipment reported by industry survey respondents, broken out by hp group. Table 3-55 presents the corresponding MOVES model default distributions for the state. Figure 3-38 directly compares the survey and MOVES distributions, aggregated across all hp groups.

Table 3-54. Logging Equipment Survey Tier Level[113]
2017 Nonroad Diesel Equipment Study

HP Range	Tier 0	Tier 1	Tier 2	Tier 3	Tier 4	Total #
25 - 40	0.0%	0.0%	0.0%	0.0%	0.0%	**0**
40 - 50	0.0%	0.0%	0.0%	0.0%	0.0%	**0**
50 - 75	0.0%	0.0%	4.8%	0.0%	95.2%	**1**
75 - 100	80.0%	4.0%	16.0%	0.0%	0.0%	**5**
100 - 175	26.8%	14.6%	12.7%	17.1%	28.8%	**41**
175 - 300	6.2%	6.2%	5.2%	23.9%	58.4%	**48**
300 - 600	32.4%	23.2%	9.2%	10.2%	24.9%	**37**
600 - 750	0.0%	100.0%	0.0%	0.0%	0.0%	**1**
750+	0.0%	0.0%	0.0%	0.0%	0.0%	**0**
Total	**22.6%**	**14.1%**	**9.0%**	**16.7%**	**37.6%**	**133**

[113] Single units may be allocated across multiple tier levels to reflect engine sales distributions during emission standard phase-in years, resulting in fractional unit counts.

Table 3-55. MOVES Default Logging Equipment Tier Level
2017 Nonroad Diesel Equipment Study

HP Range	Tier 0	Tier 1	Tier 2	Tier 3	Tier 4	Total #
25 - 40	0.0%	0.0%	11.4%	0.0%	88.6%	**1**
40 - 50	0.0%	0.0%	11.4%	0.0%	88.6%	**1**
50 - 75	0.0%	0.4%	8.5%	0.0%	91.1%	**2**
75 - 100	0.0%	0.4%	0.0%	29.6%	69.9%	**71**
100 - 175	0.0%	0.1%	0.0%	29.0%	70.9%	**493**
175 - 300	0.0%	0.1%	0.0%	26.0%	73.9%	**707**
300 - 600	0.0%	1.0%	5.8%	31.9%	61.3%	**61**
600 – 750	0.0%	1.5%	5.3%	31.9%	61.3%	**25**
750+	0.1%	6.7%	37.7%	0.0%	55.5%	**1**
Total	**0.0%**	**0.2%**	**0.4%**	**27.6%**	**71.8%**	**1,361**

Figure 3-38. Logging Equipment Tier Level Distribution Comparison (N=222)
2017 Nonroad Diesel Equipment Study

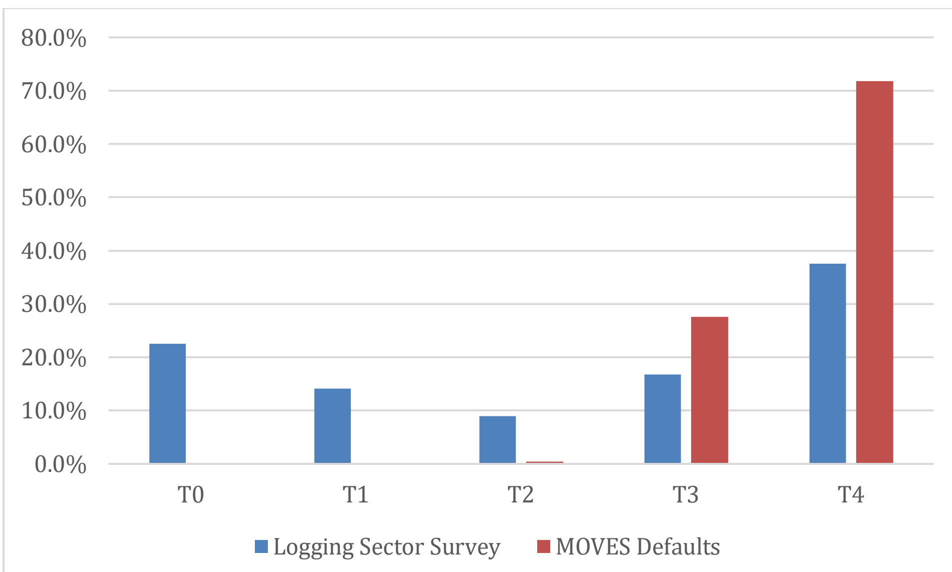


Figure 3-38 indicates the surveyed logging equipment has a substantially different engine tier distribution than that assumed by the MOVES model. Notably, over 45 percent of the surveyed equipment units are pre-tier 3, compared to less than 1 percent for MOVES. These differences are largely due to MOVES assuming a high level of average equipment activity (1,276 hours per year) which results in high equipment scrappage and turnover rates within the model.

The findings also indicate a reasonably similar hp distribution between the survey results and that assumed by MOVES, although the survey identified a substantially larger fraction of units in the 300 – 600 hp range, as shown in Table 3-56. This similarity adds confidence that the survey results are reflective of actual fleet characteristics in the Oregon logging sector.

Table 3-56. Logging Equipment HP Distribution Comparison - Survey vs. MOVES 2017 Nonroad Diesel Equipment Study

HP Range	Survey	MOVES
25 - 40	0.0%	0.1%
40 - 50	0.0%	0.1%
50 - 75	0.8%	0.1%
75 - 100	3.8%	5.2%
100 - 175	30.8%	36.2%
175 - 300	36.1%	51.9%
300 - 600	27.8%	4.5%
600 - 750	0.8%	1.8%
750+	0.0%	0.0%

Of the 14 surveys completed, 13 provided total nonroad diesel fuel consumption estimates. The diesel consumption data were used to review the equipment hour per year estimates and assess the associated engine load factor.

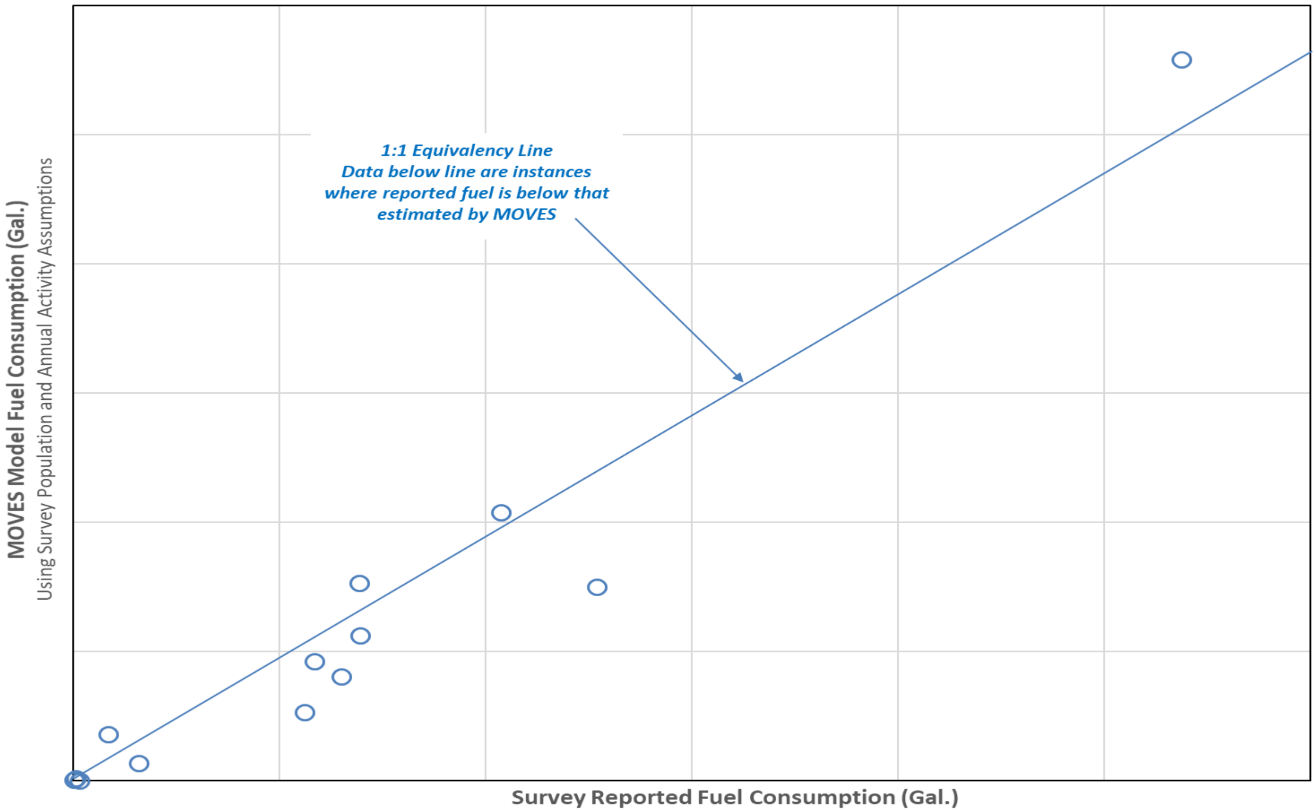
The fuel consumption data allow for review of the underlying engine load factor assumptions given the proportional relationship between fuel consumption and load in the MOVES model.[114] The survey data for population, activity and average hp were used along with the MOVES default load factor to estimate fuel consumption. The modeled results were then compared to the fuel consumption values reported in the survey, as shown in Figure 3-39. When summed over all respondents, the reported fuel consumption was 16 percent lower than the MOVES-based prediction. Using the updated load factors from CARB for the relevant construction equipment,[115] the sum of the reported consumption remains 8 percent below that predicted by MOVES. Finally, assuming a load factor of 0.52 for all log harvesting equipment, and the CARB load factors for other applications, results in the modeled and predicted fuel consumption reaching equivalency. For this reason, the study adopted the load factor of 0.52 to replace the existing MOVES default value of 0.59 for timber harvesting equipment.[116]

[114] The load factor is an input in the MOVES diesel consumption equation of Gal/yr = ∑ [(Activity x hp x LF x BSFC) / 7.0, where 7.0 is the diesel density assumption of MOVES; brake-specific fuel consumption (BSFC) is an engine fuel efficiency value used by the MOVES model. Both density and BSFC are relatively stable, known variables, and activity and engine hp are variables defined in the survey data collection. As such, if fuel consumption, activity and hp are all known quantities from the survey, then the load assumption can be evaluated independently.

[115] CARB's updated load factors do not include estimates for timber harvesting equipment.

[116] In MOVES, both emissions and fuel consumption are proportional to load; the revised load factor also yields reduced emissions estimates for this equipment.

Figure 3-39. Survey Reported Fuel Consumption Versus MOVES Model (N=13)[117]
2017 Nonroad Diesel Equipment Study



The completed surveys included both low- and high-production operations. Table 3-57 categorizes the respondents into four production ranges.

Table 3-57. Logging Sector Respondents by Production Range
2017 Nonroad Diesel Equipment Study

# Respondents	2017 Timber Production Range
4	0 to 1,000 MBF
2	1,001 to 10,000 MBF
4	10,001 to 20,000 MBF
4	20,001 to 40,000 MBF

Plots of fuel consumption versus timber harvest were used to confirm the results were similar for the low- and high-level producers. Figure 3-40 shows estimated diesel consumption versus

[117] Axes intentionally exclude a numeric scale to avoid disclosing confidential information, given the small sample size.

2017 timber production, for all equipment except those used in aggregate mining.[118] Generally, the data fall evenly across the linear trend line at all levels of production. The assumption that fuel consumption per unit of production is relatively uniform is foundational to the validation exercises summarized in Section 3.3.7, which compares the survey's diesel consumption rates per unit of harvest with the rates reported in the literature.

Figure 3-40. Timber Throughput Versus Diesel Consumption (N=14)[119]
2017 Nonroad Diesel Equipment Study

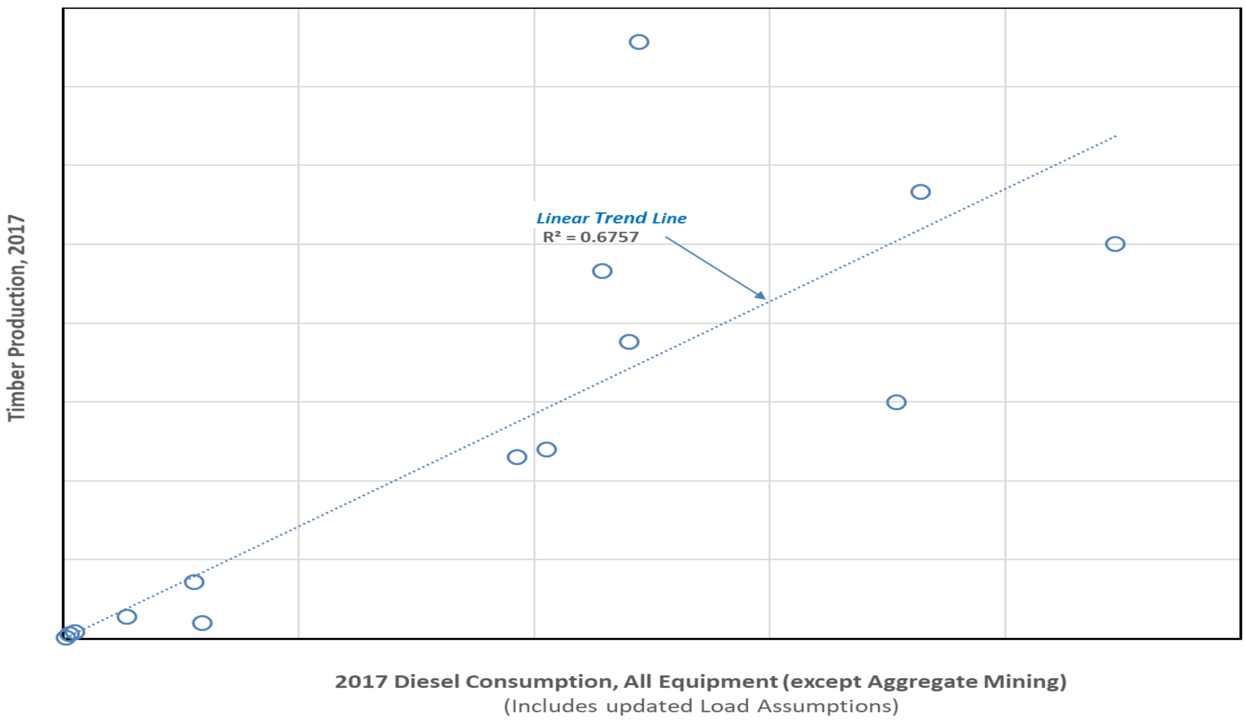


Table 3-58 presents additional survey statistics by the timber production range. There were 22 engines reported by the 4 respondents with throughput of 1,000 MBF or less. When extrapolated to the state-level, these engines make up 11 percent of the state engine equipment counts (all application types including aggregate mining), and only 2 percent of the state diesel fuel consumption (all application types including aggregate mining).

[118] Aggregate mining is excluded from the validation exercise as it was not reported in all surveys.

[119] Axes intentionally exclude a numeric scale to avoid disclosing confidential information, given the small sample size.

Table 3-58. Engine Count and Diesel Consumption by Production Range 2017 Nonroad Diesel Equipment Study

# Respondents	2017 Timber Production Range	# Engines Captured by Survey	Average # Engines per Respondent	Percent of Engine Inventory	Percent of Fuel Consumption
4	0 to 1,000 MBF	22	5.5	11%	2%
2	1,001 to 10,000 MBF	16	8.0	8%	3%
4	10,001 to 20,000 MBF	101	25.3	38%	50%
4	20,001 to 40,000 MBF	87	21.8	43%	45%

While similar diesel fuel consumption rates per throughput are seen across the range of respondents (as shown in Figure 3-40), there is an observable difference in the results reported. The equipment assigned to the two lower production ranges have a lower diesel consumption contribution relative to their equipment count. This is due to the smaller sized engines in these units and lower annual hours of use. While there are some differences in the underlying equipment characteristics for large and small producers, there is not enough information to determine if the survey proportions by production range are representative of the sector as a whole.

3.3.4 Scaling Factor Application

Total product throughput was selected as the scaling factor for extrapolating logging survey results to the state level. Throughput is believed to be the best available factor as diesel equipment use in the logging sector is commonly expressed on a per unit of production basis in the associated literature. Timber harvesting and log processing throughput was defined in terms of thousands of board feet (MBF), while aggregate production used for logging road construction and maintenance was defined in terms of tons.

The Oregon Department of Forestry (ODF) annually publishes timber harvest data by county and land ownership type and were used as the scaling factors for the timber production. The Oregon state timber harvest for 2017 equaled 3.9 million MBF. In addition, seventy-eight percent of the 2017 harvest occurred on private lands.[120] Because the timber harvest data are reported by county, this data also provides the best factor for allocating state-level logging sector activity to the county level.

There is no regularly reported value for aggregate production on private lands in Oregon. Two references were identified in the literature, and the more recent value of the two was used for this study. This reference provided a 2002-2003 state level production estimate of 1.63 million

[120] State of Oregon. "Timber Harvest Data 1962-2017", Updated October 30, 2018. Retrieved from https://data.oregon.gov/Natural-Resources/Timber-Harvest-Data-1962-2017/7ie7-wbyr.

tons on private lands.[121] Because the 2017 timber harvest on private lands has decreased by 3.9 percent relative to 2003,[122] it was assumed aggregate production in 2017 would also be 3.9 percent lower than that reported in 2002-2003. As such, this study estimated 2017 aggregate production on private lands equaled 1.57 million tons.

Scaling multipliers of 21.568 and 3.927 were applied to the surveyed equipment counts associated with timber harvest and aggregate production, respectively. These values are the inverse of the survey coverage rates for timber and aggregate production, respectively (i.e. 1/0.0464 and 1/0.2546).

The state level equipment use profile and corresponding diesel fuel consumption estimates for the logging sector are summarized in Table 3-59. There were an estimated 4,363 pieces of equipment used by the logging sector in 2017, 2,847 of which were timber harvesting equipment (65 percent of the total). Diesel fuel consumption for the logging sector in 2017 was approximately 28.3 million gallons, 24.4 million gallons of which were estimated to be consumed by timber harvesting equipment (86 percent of the total).[123]

Table 3-59. Logging Sector State Equipment Use Profile 2017 Nonroad Diesel Equipment Study

Equipment Type	# Units	Avg HP	Hrs/Yr	Avg Model Year	Gal/Yr [124]
Feller Bunchers	216	305	1,393	2010	2,610,749
Log Loaders/Picks (Self-Propelled)	1,273	223	1,499	2008	12,431,392
Log Loaders/Picks (Stationary)	65	182	1,433	2014	478,982
Other Forestry Equip. (Self-Propelled)	173	205	1,364	2009	1,479,412
Other Forestry Equip. (Stationary)	216	118	603	2007	474,446
Skidders	388	137	328	1990	498,668
Tree Harvesters	173	269	1,242	2013	1,624,298
Yarder	345	391	1,268	2002	4,784,026
Subtotal Logging	***2,847***	***231***	***1,211***	***2007***	***24,381,986***
Concrete/industrial saws	22	35	500	2004	10,919
Crawler tractors/dozers	733	174	473	1985	1,879,103
Crushing/processing equip.	20	246	1,310	2009	244,307
Excavators	341	163	417	2001	734,551
Graders	173	175	438	1997	370,389

[121] Achterman, G. et. al. "Preliminary Summary of Aggregate Mining in Oregon with emphasis in the Willamette River Basin." August 1, 2005. https://inr.oregonstate.edu/biblio/preliminary-summary-aggregate-mining-oregon-emphasis-willamette-river-basin.

[122] State of Oregon. "Timber Harvest Data 1962-2017", Updated October 30, 2018. Retrieved from https://data.oregon.gov/Natural-Resources/Timber-Harvest-Data-1962-2017/7ie7-wbyr.

[123] As shown in Table 3-59, 3.9 million gallons are estimated to be consumed by construction equipment, which represents 13.7% of the sector total diesel consumption.

[124] Calculated using EPA MOVES-Nonroad model (2014b). See Section 6.2 for additional details.

Equipment Type	# Units	Avg HP	Hrs/Yr	Avg Model Year	Gal/Yr [124]
Rollers	65	123	442	1999	106,224
Rubber tire loaders	82	103	767	2010	287,929
Off-highway trucks	37	268	816	1997	306,075
Subtotal Construction / Mining	***1,473***	***167***	***491***	***1993***	***3,939,498***
Stump Grinders	22	60	250	2014	8,098
Wood Splitters	22	50	525	2016	17,138
Subtotal Lawn and Garden	***43***	***55***	***388***	***2015***	***25,235***
Total	**4,363**	**197**	**841**	**1999**	**28,347,050**

The timber harvesting equipment results shown in Table 3-60 represent an increase over current MOVES default estimates for Oregon. MOVES only explicitly defines logging applications and these results represent an approximate doubling of the current MOVES estimate for logging equipment. The survey-based profile has an estimated logging equipment population of 2,847 units, which is 109 percent higher than the MOVES default population of 1,361 units. The survey-based profile results in an estimated 24,381,986 gallons of diesel, which is 120 percent higher than the MOVES estimated diesel consumption of 11,071,639 gallons.

Table 3-60. Harvesting Equipment State Profile vs. MOVES
2017 Nonroad Diesel Equipment Study

Basis	# Units	Avg HP	Hrs/Yr	Avg Age (Yrs)	Engine Load	Gal/Yr
MOVES Default	1,361	203	1,275	5	0.59	11,071,639
Survey-Based Profile	2,847	230	1,210	13 [125]	0.52	24,381,986
Percent Change of Survey vs. MOVES	+109%	+13%	-5%	+160%	-12%	+120%

MOVES assumes a national-average logging equipment distribution and annual hours of use throughout the US. However, there is significant regionalization in logging equipment use as key harvest characteristics differ regionally including the size and type of wood harvested, the wood product industries supported, topography, meteorology and site management practices. For these reasons it was expected that the MOVES default estimates for logging equipment activity would be biased low due to the intensity of Oregon logging operations.[126]

While annual hours per year and average engine size agree well with MOVES assumptions, the survey's average equipment age of 13 years differs notably from the MOVES estimated average age of 5 years. The MOVES age estimate is based on an equipment turnover algorithm that is

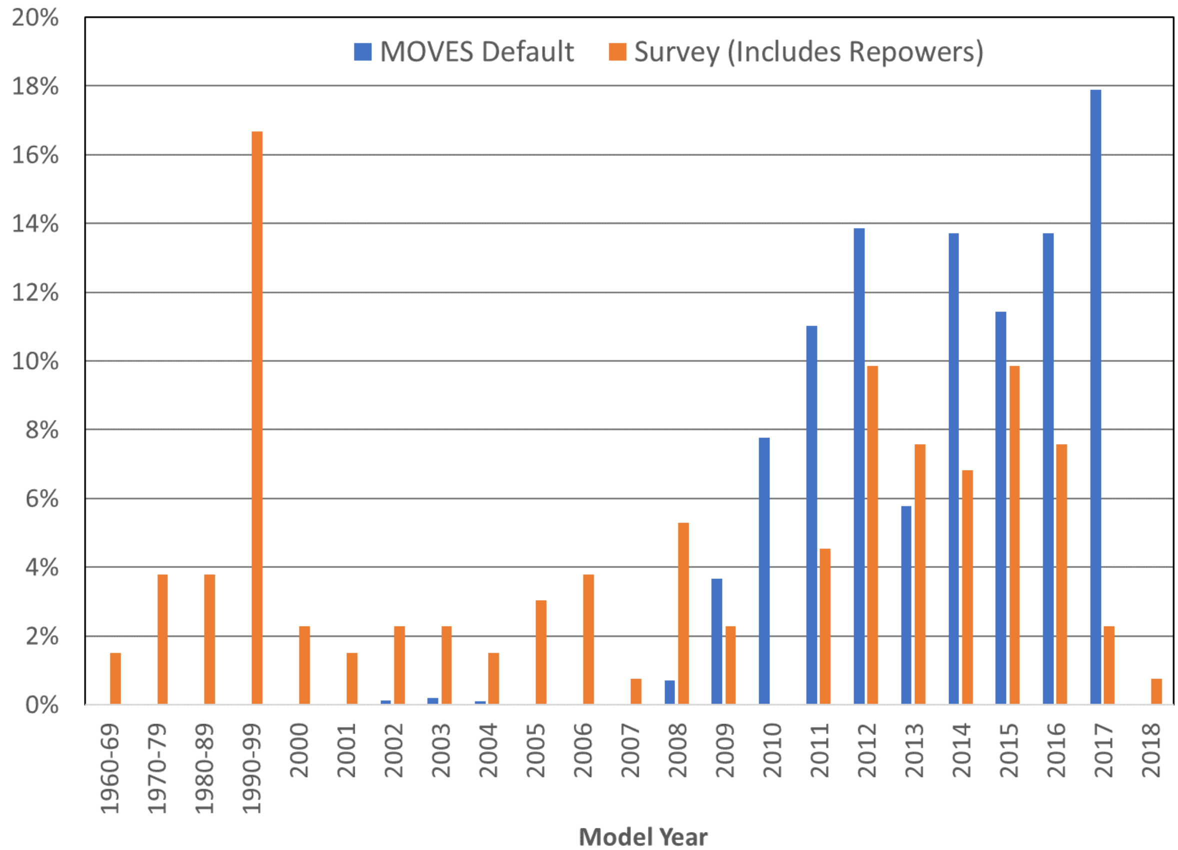
[125] The survey average equipment age includes the model year of repowers when reported.

[126] It is also important to note that the MOVES default national logging equipment profile was defined 20 years ago and has not been updated. Moreover, the default population values are not directly estimated – rather, MOVES equipment populations are calculated from PSR sales data, usage rates and anticipated useful life, while the survey results are directly estimated from state equipment counts and activity.

not specific to the logging sector, and in this instance appears to be biased low. The survey's average age of 13 years is not unexpected and is generally consistent with other studies.[127]

Figure 3-41 presents the distribution of the harvest equipment population (N=132) by model year for both MOVES and the survey results – illustrating the distinct differences between the two.

Figure 3-41. Distribution of Harvest Equipment Population by Model Year 2017 Nonroad Diesel Equipment Study



3.3.5 County/Temporal Allocation

Statewide activity for the logging sector was allocated to the county level based on timber harvest volumes compiled by ODF for 2017.[128] Table 3-61 presents the corresponding percentages used for county activity allocation.

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[127] Baker, S. et. al. "Regional Cost Analysis and Indices for Conventional Timber Harvesting Operations," Final Report to the Wood Supply Research Institute. May 5, 2013.

[128] State of Oregon. "Timber Harvest Data 1962-2017", Updated October 30, 2018. Retrieved from https://data.oregon.gov/Natural-Resources/Timber-Harvest-Data-1962-2017/7ie7-wbyr.

**Table 3-61. County-Level Logging Sector Fleet Activity Allocation
2017 Nonroad Diesel Equipment Study**

County	Percent	County	Percent
Baker	0.34%	Lake	1.00%
Benton	3.32%	Lane	14.42%
Clackamas	4.22%	Lincoln	4.80%
Clatsop	7.57%	Linn	7.94%
Columbia	4.60%	Malheur	0.03%
Coos	5.74%	Marion	1.64%
Crook	0.27%	Morrow	0.02%
Curry	3.08%	Multnomah	0.41%
Deschutes	0.77%	Polk	3.39%
Douglas	15.29%	Sherman	0.00%
Gilliam	0.00%	Tillamook	4.98%
Grant	0.72%	Umatilla	0.33%
Harney	0.08%	Union	1.23%
Hood River	0.77%	Wallowa	1.11%
Jackson	2.70%	Wasco	0.22%
Jefferson	0.01%	Washington	3.17%
Josephine	0.83%	Wheeler	0.17%
Klamath	2.21%	Yamhill	2.64%

The Logging sector surveys included estimates regarding how activity was split between weekdays and weekends and across seasons for 13 of the 14 responding establishments. The fleet's temporal allocation profile estimates that 97 percent of activity occurs during weekdays and 44 percent of activity occurs during the summer months.

3.3.6 Profile Validation

Three validation exercises were completed for the logging sector state activity profile.

1. Comparison of diesel consumption per unit of throughput as reported in the literature;
2. Comparison of state-level diesel consumption with that reported by EIA's FOKS estimates; and,
3. Scaling equipment population based on counts per unit of throughput available for other geographic areas.

The first validation took advantage of the fact that diesel fuel consumption per unit of harvest is a well-studied parameter and that per harvest consumption rates are generally similar for similar types of harvest conditions. This is the most robust validation metric of the three exercises completed, with a strong correlation between fuel use, equipment activity, and production volume.[129] In this instance, the fuel consumption per unit of harvest calculated from the survey results was compared to five selected references found in the literature.

The statewide average fuel consumption per unit of harvest estimated by the study for 2017 is presented in Table 3-62. Values are presented in liters per cubic meter, which is the most common reporting basis found in the literature.[130] Fuel consumption rates are provided as a simple average and as a harvest-weighted average which weights the data by each respondent's production volume. The fact that these two results (3.51 and 3.41 L/m^3) are similar indicates the diesel usage per unit of harvest is relatively uniform over the range of production levels surveyed. Table 3-62 also presents the diesel fuel consumption per unit of harvest for all surveyed equipment, estimated to be 3.87 L/m^3. The harvesting equipment represent 86 percent of the total diesel consumption; the other equipment (primarily heavy construction equipment) represent 14 percent of total diesel consumption. Overall, the weighed-average results, accounting for the volume harvested, are the preferable metric. The standard deviation estimated is ± 10 percent for the harvesting equipment (3.41 L/m^3) and is ± 21 percent across all equipment (3.87 L/m^3).[131]

Table 3-62. Logging Sector Gallons per Unit Harvest (L/m^3)
2017 Nonroad Diesel Equipment Study

	Mean	Standard Deviation
Harvesting Equipment, Simple Average	3.51	2.52 - 4.50
Harvesting Equipment, Harvest-Weighted Average	3.41	3.06 - 3.77*
Total Equipment, Harvest-Weighted Average	3.87	3.05 - 4.14*

*Determined by linear regression (i.e., standard error of the slope of consumption versus harvest).

A summary of the results from five literature-based surveys are presented in Table 3-63. These were assembled for comparison to the study results shown in Table 3-63. Three references

[129] ERG team member Oak Leaf Environmental has completed similar comparisons using business confidential information to validate national logging sector equipment populations for Environment and Climate Change Canada. Unpublished results.

[130] Conversions between BF and volume of timber are not standardized and are specific to local timber characteristics. ODF assumptions on the conversion of MBF to volume of lumber harvested were used, which vary by land-use type. The 2017 Oregon timber harvest equaled 3,851,038 MBF or 26,431,708 m^3.

[131] Given a throughput-based scaling factor, the standard deviation provides a measure of the uncertainty in the state-level fuel consumption estimates shown in Table 3-59 for harvest equipment, (24.4 million gallons ± 10 percent) and for total equipment (28.4 million gallons ± 21 percent).

cover harvesting operations within the US. [132] [133] [134] The New Zealand study was selected because their steep slope pine forests feature similar conditions to those in Oregon, and it was the most recent assessment identified.[135] The Alberta study was selected because it was the only survey that included a separate accounting of off-road equipment used in harvesting versus equipment used in logging roadway development and maintenance.[136]

[132] Baker, S. et. al. "Regional Cost Analysis and Indices for Conventional Timber Harvesting Operations." Final Report to the Wood Supply Research Institute. May 5, 2013.

[133] Greene, W. Biang, E. and Baker, S. "Fuel Consumption Rates of Southern Timber Harvesting Equipment." 37th Council on Forest Engineering Annual Meeting. 2014. http://docplayer.net/40103850-Fuel-consumption-rates-of-southern-timber-harvesting-equipment.html.

[134] Kenney J.T., "Factors that Affect Fuel Consumption and Harvesting Cost." Graduate thesis, School of Forestry and Wildlife Sciences, Auburn University, May 10, 2015. https://etd.auburn.edu/bitstream/handle/10415/4652/Factors%20that%20Affect%20Fuel%20Consumption%20and%20Harvesting%20Cost.pdf?sequence=2&isAllowed=y.

[135] Oyier, P.O., "Fuel consumption of timber harvesting systems in New Zealand." Gradate thesis, School of Forestry, University of Canterbury, November 2015. https://ir.canterbury.ac.nz/bitstream/handle/10092/14515/Oyier_Visser_2016_EJFE2016_2-2.pdf?sequence=2&isAllowed=y.

[136] Canadian Forest Service, Northern Forestry Centre. "The Alberta Logging Cost Survey Data 1996–1998." 2002. https://cfs.nrcan.gc.ca/pubwarehouse/pdfs/21258.pdf.

Table 3-63. Other Survey-Based Logging Sector Fuel Consumption Rates per Unit Harvest (L/m3) 2017 Nonroad Diesel Equipment Study

Reference	Mean Diesel Rate (L/m³)	Location	Survey Sample Size[137]	Survey Period	Activity Included: Harvesting & Processing	Activity Included: Roadway Development	Activity Included: Post-Harvest Clean Up	Harvesting System	Cut Type	Notes
(1) Regional Cost Analysis and Indices for Conventional Timber Harvesting Operations	4.09	Western US	8	2011	X	X	X	Mixed	Thinning & clearcut	Examination of total business costs of logging operations; implicitly assumed roadway development and maintenance are included; impact of subcontracting on estimated fuel use unknown.
	2.50	Southeast US	23							
	6.26	Northeast US	7							
	2.88	Great Lakes US	9							
(2) Fuel consumption of timber harvesting systems in New Zealand	3.18	New Zealand	28	2014 - 2015	X		X	Cable Yarding	Primarily clearcut	Primarily steep-slope pine forests
	3.04		17					Ground Based		
(3) The Alberta Logging Cost Survey	2.52	Alberta, Canada	29	1996 - 1998	X		X	Mixed	n/d	Equipment used in roadway development & maintenance consumed 15 percent of off-road diesel. Diesel estimates determined by mean machine usage rates (hours per year) and mean consumption rates (L/hr) divided by study total harvest (m³).
	2.95				X	X	X			

[137] Survey sample size represents the number of harvesting contractors; for References 1, 2 and 3 results represent the sum over all contractor operations; for References 4 and 5, results represent the long-term monitoring of a single project crew per contractor.

Reference	Mean Diesel Rate (L/m³)	Location	Survey Sample Size[137]	Survey Period	Activity Included: Harvesting & Processing	Activity Included: Roadway Development	Activity Included: Post-Harvest Clean Up	Harvesting System	Cut Type	Notes
(4) Fuel Consumption Rates of Southern Timber Harvesting Equipment	1.59	Georgia, US	7	2012 - 2014	**X**			Ground Based	Thinning & clearcut	Only harvesting equipment surveyed.
(5) Factors that Affect Fuel Consumption and Harvesting Cost	2.79[138]	Southeast US	9	2012 - 2015	**X**	**?**	**X**	Ground Based	Thinning & clearcut	Bulldozers included in some respondents could be used as forwarders or in roadway development & maintenance (unclear); smaller sample size covers respondents supplying weekly data.
	2.11‡[139]		6							

[138] Standard deviation of ± 32 percent.

[139] Standard deviation of ± 11 percent.

The estimated 2017 Oregon logging diesel consumption rates of 3.42 and 3.87 L/m^3 for harvesting and all equipment, respectively, compares reasonably well with the range reported in the literature. Key factors impacting logging diesel consumption are terrain, size of timber, type of wood, harvesting mechanism, cut type and local requirements for road, drainage and cleanup management. A wide range of diesel consumption rates are seen with a distinct regional difference in the US, with timber harvesting in the Southeast US being the least fuel-intensive. The Oregon diesel consumption was expected to be above the US average based on terrain, timber size and rigorous forest and water management requirements.

Key observations from this validation exercise include the following:

- Given the clear regional differences observed in the US, the expectation that Oregon logging equipment usage per unit of harvest is higher than the national average appears to be confirmed by the region-specific data.
- The only "western" US diesel consumption rate found in the literature was 4.09 L/m3, which is similar to the rate estimated from the Oregon equipment survey (3.87 L/m3). This result affirms the reasonableness of the project's survey-estimated diesel fuel consumption given the size of the state's harvest in 2017.
- The Alberta results estimated 0.43 L/m^3 for roadway and heavy construction equipment; this compares well with the 0.46 L/m^3 for heavy construction equipment estimated for Oregon, which includes both roadway development and aggregate production.

The second validation exercise compared the study's statewide nonroad diesel fuel consumption estimates to the corresponding fuel sales estimates from the EIA's FOKS survey.[140] FOKS includes nonroad diesel consumption for the logging sector within a broad "Other Off-Highway" category.[141] Therefore ERG adjusted the FOKS sales estimates to subtract out well drilling, trucking TRUs and other sources of fuel consumption also included in the Other Off-Highway category. Due to uncertainties in isolating logging sector fuel sales, the estimates for the logging component are presented as a range, between 8 and 24 million gallons per year. This range is less than the fuel consumption estimated by the study (28M gallons), as is shown in Table 3-64. The table also presents the MOVES default estimate (11M gallons) for comparison.[142]

[140] U.S. Energy Information Administration. "Adjusted Distillate Fuel Oil and Kerosene Sales by End Use." Retrieved from https://www.eia.gov/dnav/pet/pet_cons_821usea_dcu_SOR_a.htm.

[141] The FOKS other off-highway category includes equipment used in logging, geothermal drilling, water well drilling, scrap/junk yards, truck TRUs, and privately-owned ports and loading docks.

[142] Section 7.4 of this report provides a detailed discussion of how the 8 to 24-million-gallon sales range was derived.

**Table 3-64. 2017 Oregon Logging Sector Diesel Consumption Estimates (Gallons)
2017 Nonroad Diesel Equipment Study**

Equipment Application	Logging Sector Diesel Sales (FOKS) (All Diesel Engines)[143]	MOVES Default (All Diesel Engines)[144]	Study Estimate (Diesel > 25 HP)
Timber Harvesting	8,000,000 – 24,000,000	11,071,639	24,381,986
Construction Equipment used in Logging		*N/D (Equipment are assigned to other sectors and not identifiable)*	3,939,498
Other Applications used in Logging[145]			25,565
Total	**8,000,000 – 24,000,000**	**11,071,639**	**28,347,050**

The third validation exercise involved scaling equipment populations based on throughput. This exercise assumes that equipment counts per unit of throughput can be applied as scalable metric (i.e., that the number of equipment used per unit harvest is reasonably constant). Given that production can vary substantially from year to year, but equipment stocks are relatively constant, scaling population based on a single year's production is the least certain of the three validation exercises.

Table 3-65 presents estimated Oregon equipment populations scaled based on relative throughput. The calculation was completed for the US, California and Canada resulting in population estimates for Oregon ranging from 1,315 to 4,769.[146] The throughput-scaled equipment populations are roughly consistent with the 2,847 pieces of equipment estimated for Oregon. Notably, all three base year population estimates are nonroad equipment populations developed by Power Systems Research (PSR) and are not based on surveys.[147] Moreover, both the California and US populations were estimated at a period when timber harvesting operations were undergoing a significant contraction, so the link to a single base year's throughput is more uncertain for these two locations. The Canadian timber harvest has been steady for several years and the assessment is the most recent, making the Canadian result the preferred point of comparison for this exercise. The Oregon result of 2,242 units, as

[143] FOKS Other Off-Highway sector value minus study estimate for truck/trailer based TRUs and well drilling.

[144] All diesel engines assigned to the logging sector in MOVES are over 25 hp. There are a nominal number of diesel engines below 25 hp used in equipment harvesting such as cable yarding carriages which can be powered by diesel engines, both above and below 25 hp.

[145] Covers applications classified as Commercial Lawn and Garden and Industrial categories in MOVES.

[146] For example, the Oregon population estimate scaled from Canada equals the Canada population divided by Canada throughput multiplied by Oregon throughput (2,242 = 12,239/144,273,611 × 26,431,708).

[147] PSR derives nonroad equipment populations from sales data, annual usage rates and useful life assumptions.

scaled from Canada in 2015, is reasonably similar, 21 percent lower than this study's survey-based population of 2,847 units.

Table 3-65. 2017 Scaled Harvesting Equipment Populations
2017 Nonroad Diesel Equipment Study

Parameter	Location		
	US National	California	Canada
Base Year	2000	2000	2015
Equipment Population (Base Year)	22,818	2,786	12,239
Throughput (Location, Base Year)	458,789,548	2,249,700	144,273,611
Throughput (Oregon, 2017)	26,431,708	3,851,038	26,431,708
Throughput Units	Cubic Meters	Thousand BF	Cubic Meters
Estimated Oregon Equipment Population (2017) as Scaled from Alternate Location	***1,315***	***4,769***	***2,242***

3.3.7 Sector Summary

Key observations regarding the Logging sector surveys and activity profile include the following:

- The participation rate for the logging sector survey (with 14 surveys completed) was low at approximately 3 percent. Within the results though, good consistency was observed in the amount of diesel consumed per unit harvest across individual surveys. This suggests a relatively stable data set, usable for extrapolation to a state-level profile. The estimated amount of diesel consumed per unit harvest from the surveys also matched the literature values well. For these reasons the equipment use profile developed by the study is a sounder basis for estimating emissions for the Oregon logging sector than the 18-year-old default national MOVES assumptions.
- The age profile for the logging sector equipment fleet is skewed toward older model years, with a substantial number of legacy units in operation for 30 years or more.
- Equipment activity levels in the logging sector are high relative to many other sectors, averaging over 1,000 hours per year across all equipment types.

3.4 Surface Mining Sector

This sector includes equipment used in surface mining operations, which includes strip mining, open pit mining, and mountain top removal. The vast majority of surface mining activity in Oregon is associated with open pit mining used to produce construction sand, gravel and aggregate. [148, 149] According to DEQ Air Quality Permit reports obtained from the TRAACS

[148] "Aggregate" refers to medium and coarse-grained crushed stone.

[149] While nonroad diesel equipment is also used in underground mining operations, no such operations were identified for Oregon in 2017.

database,[150] sand/gravel and aggregate was responsible for 89.3 percent of total state production in 2017.[151] The remaining 10.7 percent of production is associated with non-metallic mineral mining, clay and ceramic and refractory mineral mining, kaolin and ball clay mining, and other chemical and fertilizer mining.

3.4.1 Equipment Types

Key nonroad diesel equipment types used in Oregon surface mining activities include:

- Wheeled loaders
- Excavators
- Dozers
- Off-highway trucks
- Generators (used to power rock crushers)
- Other crushing/processing equipment (featuring their own engines)

These six equipment types are generally high hp and are estimated to consume over 95 percent of the total nonroad diesel fuel used in the sector. The remaining fuel is consumed by a small number of assorted construction and industrial equipment including pavers, rollers, graders, rough terrain forklifts, skid steer loaders, aerial lifts and sweepers, among others. Product delivery involving on-road trucks are excluded from the analysis.

3.4.2 Survey Development and Data Collection

The ERG team combined information on surface mining establishments and points of contact obtained from the Oregon Department of Geology and Mineral Industries (DOGAMI) with additional information provided by the Oregon Concrete and Aggregate Producers Association (OCAPA) for a final list of 118 survey targets for the sector. Each survey target operated one or more surface mining locations in Oregon in 2017.

The surface mining sector survey requested information on nonroad diesel equipment characteristics, usage, fuel consumption and scaling factor data. The requested parameters included engine counts, annual hours used, engine power rating, engine model year, and information on repowers / retrofits. Equipment make and model information were used to validate and check respondent supplied information. The sector questionnaire is provided in Appendix D. The project team collaborated with OCAPA who provided input regarding the survey questions, conducted outreach to their membership to support participation in the survey, and reviewed preliminary results.

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[150] Tracking, Reporting and Administration of Air Contaminated Sources. Provided to ERG electronically by DEQ.

[151] DEQ Air Quality permits are associated with crushing and processing equipment use, which account for approximately 75 percent of the total surface mining production reported by DOGAMI, discussed in Section 3.4.4 below. The remaining 25 percent of production does not involve crushing/processing (e.g. material is simply collected and piled).

Total production data provided by DOGAMI (expressed in tons and available by county and year) was selected as the scaling factor to extrapolate survey results to the state level, given that diesel equipment use is directly correlated with tons of production. That said, there is significant variation in production efficiency depending on product type, site geology, and equipment power options, among other factors. The tonnage data from DOGAMI did not differentiate by product type (e.g. sand/gravel vs. aggregate) or site type (e.g. sites using electric line power vs. diesel powered for crushing/processing). For this reason, the sector's survey results were not stratified into subgroups, which in turn increases the uncertainty associated with the activity and emissions estimates for the sector, especially at the county level.

The data collection process consisted of phoning contacts and following up with repeated, subsequent phone calls, voicemails and/or emails asking if they had received the survey or needed assistance in its completion. Potential participants were informed that all responses would be kept confidential and offered a variety of modes for completing the survey including online, Excel forms exchanged by email, fax, and self-addressed prepaid mailers. Outreach was initiated in October of 2018 and completed surveys were accepted through May of 2019.

ERG attempted to contact all 118 establishments via telephone, as well as by email where available. The outcome of the 118 establishment contacts is summarized in Table 3-66.

Table 3-66. Outcome of Surface Mining Sector Survey Contacts
2017 Nonroad Diesel Equipment Study

Outcome	# Establishments
Ineligible*	56
Refusals	9
Complete	7
No Response	46
Total Attempted Contacts	**118**

* Includes disconnected phones and establishments no longer associated with surface mining.

Ultimately, 7 surveys were completed for surface operations in Oregon in 2017 for a response rate of 5.9 percent. These 7 establishments provided information on 348 pieces of equipment operating at 55 sites in 18 counties and represented approximately 40 percent of total sector activity (based on fuel consumption estimates). However, respondents did not provide information on the production levels associated with their equipment activity, possibly due to the difficulty in apportioning production associated with portable crushers used at multiple locations throughout the year. The lack of site-specific production data necessitated an alternative approach to scaling survey findings to the state level, as discussed in Section 3.4.3.

3.4.3 Data Processing and Analysis

Survey responses were reviewed and compiled. Data cleaning and gap-filling details related to the surface mining sector surveys included the following.

- Gap-filling for 3 missing model years was completed using the average model year by equipment type.
- 2 propane units were dropped from the data set.
- 9 units with zero reported hours were dropped from the data set.

The resulting compilation for all respondents (N=7) is summarized in Table 3-67, by equipment type, along with estimated fuel consumption.

Table 3-67. Surface Mining Sector Equipment Use Summary
2017 Nonroad Diesel Equipment Study

Equipment Type	# Units	Avg HP	Avg Hrs/Yr	Avg Model Year	Gal/Yr[152]
Aerial lifts	19	53	211	2009	4,560
Agricultural tractors	1	25	1,000	2004	636
Cranes	3	149	112	1986	883
Crawler tractors/dozers	22	262	950	2007	141,624
Crushing/processing equipment	12	247	643	2001	60,452
Excavators	33	331	1,028	2012	244,506
Generator sets	25	628	1,173	2002	358,835
Graders	5	168	215	1985	3,933
Off-highway trucks	28	447	1,292	2012	330,933
Other construction equipment	1	75	122	1995	226
Pavers	2	200	1,309	2013	11,525
Paving equipment	1	184	32	2008	112
Pumps	1	75	160	2004	301
Rollers	6	83	908	2011	7,772
Rough terrain forklifts	27	122	294	2010	20,335
Rubber tire loaders	101	335	1,477	2008	1,044,574
Skid steer loaders	30	75	373	2016	20,527
Sweepers/scrubbers	1	85	899	2005	1,843
Tractors/loaders/backhoes	6	55	332	2001	2,105
Total	**324**	**280**	**969**	**2008**	**2,255,683**

Of the 324 units reported, only 2 were flagged as having been retrofit (with diesel oxidation catalysts - DOCs), and 3 were flagged as having been repowered (although repower year was not provided). None of the respondents reported using alternative fuels such as B20. As such, all units were assumed to use B5 fuel.

[152] Calculated using EPA MOVES-Nonroad model (2014b). See Section 6.2 for additional details.

Figure 3-42 through Figure 3-44 present the model year, hour per year, and equipment hp distributions for the survey respondents, respectively. Figure 3-42 clearly indicates an uptick in new equipment purchases in the 2000s prior to the recession in 2008, and a much larger influx of new equipment starting in 2016. The resulting average model year for the sector is 2008. Figure 3-43 indicates a large portion of equipment units are operated at high utilization rates, with a sector-average activity level of 969 hours per year. Finally, Figure 3-44 indicates the large fraction of high hp equipment operating in the sector, with an average power rating of 324 hp.

Figure 3-42. Surface Mining Sector Equipment Model Year Distribution (N=324)
2017 Nonroad Diesel Equipment Study

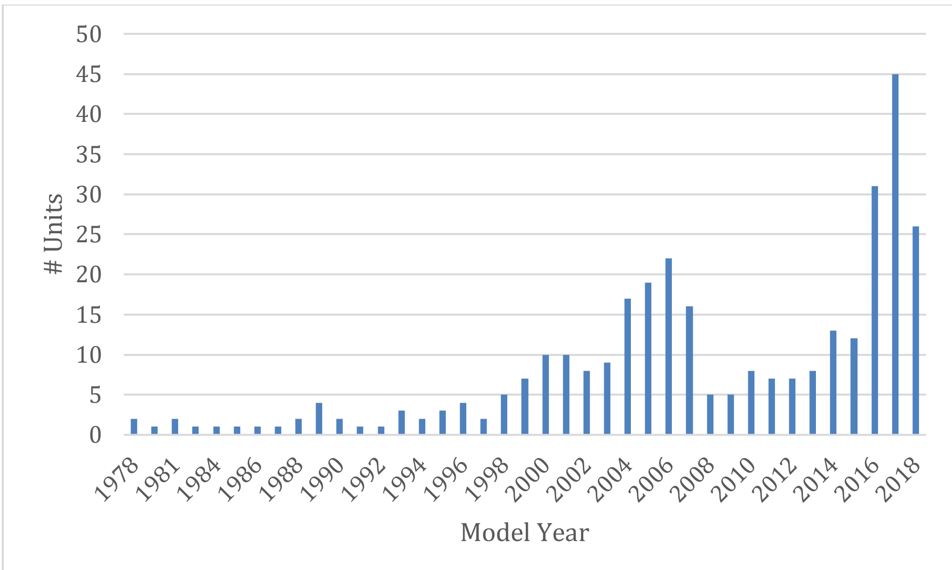

Figure 3-43. Surface Mining Sector Equipment Use Hour/Year Distribution (N=324) 2017 Nonroad Diesel Equipment Study

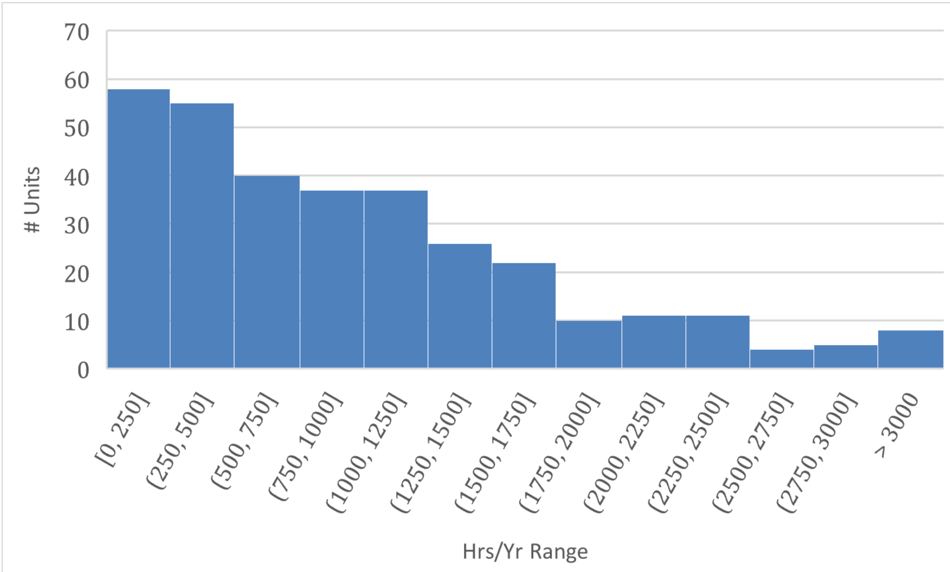

Figure 3-44. Surface Mining Sector Equipment HP Distribution (N=324) 2017 Nonroad Diesel Equipment Study

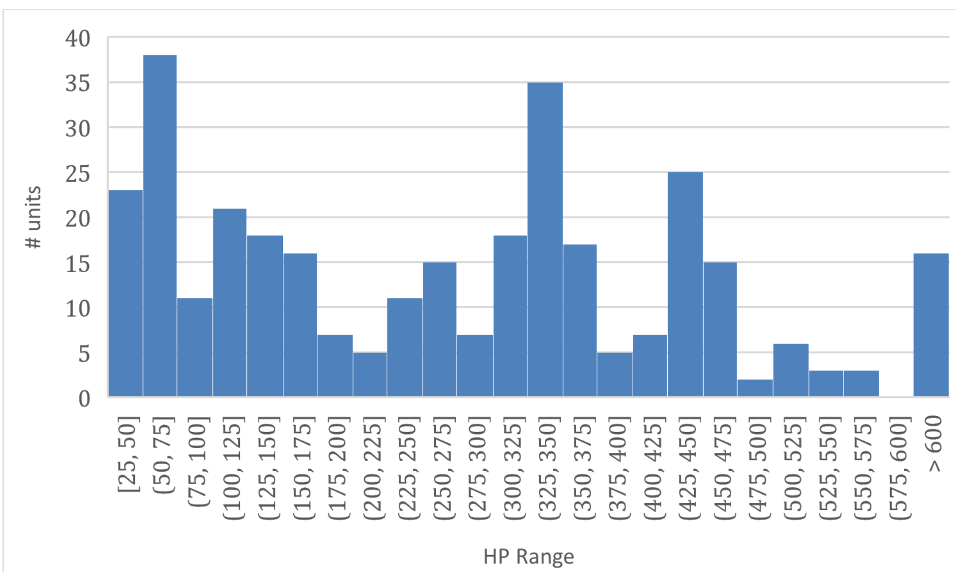

Table 3-68 presents an additional breakout of the engine tier level distributions for construction/mining equipment reported by surface mining survey respondents, broken out by hp group. Table 3-69 presents the corresponding MOVES model default distributions for the state. Figure 3-45 directly compares the survey and MOVES distributions, aggregated across all hp groups.

Table 3-68. Construction/Mining Equipment Tier Level Distribution – Surface Mining Sector[153]
2017 Nonroad Diesel Equipment Study

HP Range	Tier 0	Tier 1	Tier 2	Tier 3	Tier 4	Total #
25 - 40	0.0%	0.0%	0.0%	0.0%	100.0%	**3**
40 - 50	32.5%	42.5%	6.1%	0.0%	19.0%	**4**
50 - 75	0.0%	7.6%	15.9%	0.0%	76.6%	**37**
75 - 100	33.3%	50.0%	0.0%	8.0%	8.6%	**6**
100 - 175	18.2%	17.6%	15.1%	8.7%	40.4%	**55**
175 - 300	15.9%	15.9%	11.6%	27.2%	29.4%	**44**
300 - 600	4.4%	7.9%	15.4%	26.6%	45.7%	**135**
600 - 750	16.7%	68.3%	15.0%	0.0%	0.0%	**6**
750+	0.0%	0.0%	0.0%	0.0%	100.0%	**9**
Total	**22.6%**	**14.1%**	**9.0%**	**16.7%**	**37.6%**	**299**

Table 3-69. Construction/Mining Equipment Tier Level – MOVES Defaults
2017 Nonroad Diesel Equipment Study

HP Range	Tier 0	Tier 1	Tier 2	Tier 3	Tier 4	Total #
25 - 40	4.1%	10.8%	20.2%	0.0%	64.8%	**2,707**
40 - 50	3.1%	8.2%	18.6%	0.0%	70.1%	**1,385**
50 - 75	11.1%	36.1%	17.2%	0.0%	35.6%	**5,693**
75 - 100	7.4%	31.5%	12.9%	11.5%	36.7%	**8,197**
100 - 175	2.6%	17.2%	11.7%	19.2%	49.3%	**6,076**
175 - 300	0.5%	5.7%	3.8%	28.1%	61.8%	**3,029**
300 - 600	2.3%	10.1%	21.9%	21.1%	44.6%	**1,678**
600 – 750	1.7%	10.7%	14.2%	23.2%	50.2%	**348**
750+	2.6%	19.5%	30.0%	0.0%	47.9%	**239**
Total	**5.5%**	**22.2%**	**14.1%**	**11.6%**	**46.6%**	**29,352**

[153] Single units may be allocated across multiple tier levels to reflect engine sales distributions during emission standard phase-in years, resulting in fractional unit counts.

Figure 3-45. Surface Mining Equipment Tier Level Distribution Comparison (N=324)
2017 Nonroad Diesel Equipment Study

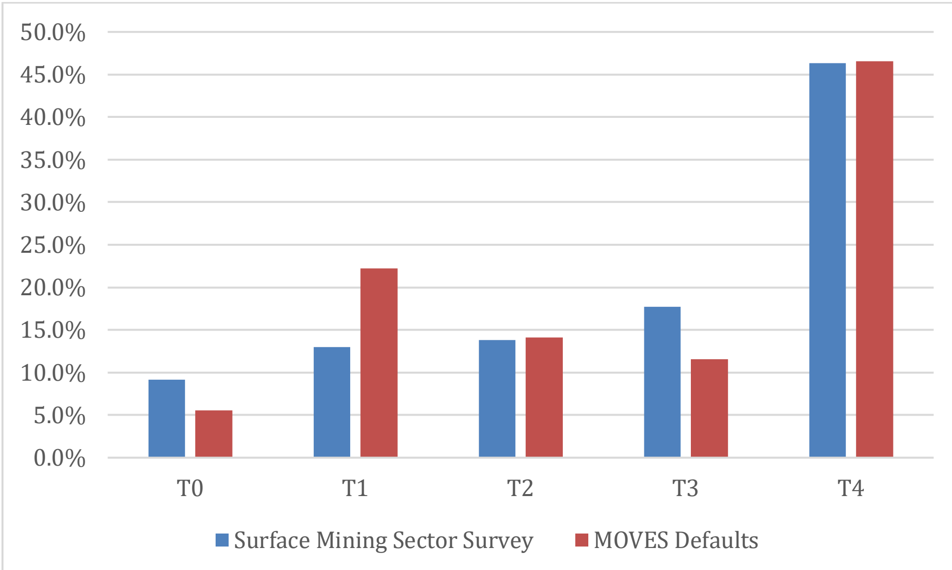

Figure 3-46 indicates the surveyed surface mining equipment has a very similar engine tier distribution compared to MOVES, reflecting relatively rapid engine scrappage and replacement within this sector. The findings also indicate a reasonably similar hp distribution between the survey results and that assumed by MOVES, although the survey identified a substantially larger fraction of units in the 300 – 600 hp range, and correspondingly smaller fraction in the 75 – 100 hp range, as shown in Table 3-70. This similarity adds confidence that the survey results are reflective of actual fleet characteristics in the Oregon surface mining sector.

Table 3-70. Surface Mining Equipment HP Distribution Comparison - Survey vs. MOVES
2017 Nonroad Diesel Equipment Study

HP Range	Survey	MOVES
25 - 40	1.0%	9.2%
40 - 50	1.3%	4.7%
50 - 75	12.4%	19.4%
75 - 100	2.0%	27.9%
100 - 175	18.4%	20.7%
175 - 300	14.7%	10.3%
300 - 600	45.2%	5.7%
600 - 750	2.0%	1.2%
750+	3.0%	0.8%

3.4.4 Scaling Factor Application

Given the lack of productivity estimates provided in the surveys, ERG obtained information on production efficiency from an industry SME. The efficiency data, expressed in tons of production per gallon of diesel consumed by nonroad equipment, varied substantially by county, ranging from 0.91 to 26.37 tons per gallon, with an average value of 7.06 across all locations. The geographic regions represented included sites with and without line power (for rock crushers and dredges) and covered a wide range of production conditions and counties. As such, the efficiency data sample represents a statistically significant level of production in Oregon, allowing for extrapolation to the state level.

As a first step, total production tonnage for the state in 2017 (40,407,081 tons) was divided by the 7.06 ton/gallon efficiency factor to estimate total fuel consumption for the sector's nonroad diesel equipment, yielding an estimate of 5,723,383 gallons per year. This figure was then divided by the estimated fuel consumption for the surveyed portion of the fleet (2,255,683 gallons per year) to obtain a scaling factor of 2.537. ERG then scaled the activity profile of the surveyed equipment by a factor of 2.537 to obtain estimates for the state. Table 3-71 presents the state level activity profile by equipment type. Almost half of all fuel consumption is attributable to loaders, with substantial contributions from other large construction equipment as well as generators.

Table 3-71. State Level Surface Mining Sector Activity Profile by Equipment Type, 2017 2017 Nonroad Diesel Equipment Study

Equipment Type	# Units	Hours/Yr	HP-HRs/Yr	Gal/Yr[154]
Aerial lifts	48	10,154	168,381	11,570
Agricultural tractors	3	2,537	30,448	1,792
Cranes	8	853	42,747	2,241
Crawler tractors/dozers	56	53,025	6,780,096	359,341
Crushing/processing equipment	30	19,583	2,925,617	153,981
Excavators	84	86,106	11,705,462	620,634
Generator sets	63	74,381	15,620,964	820,128
Graders	13	2,733	188,284	9,979
Off-highway trucks	71	91,818	15,843,046	839,672
Other Equipment	3	310	9,751	574
Pavers	5	6,643	551,754	29,243
Paving equipment	3	81	5,378	285
Pumps	3	406	13,093	763
Rollers	15	13,823	372,070	20,499
Rough terrain forklifts	69	20,129	973,510	51,811
Rubber tire loaders	259	379,192	50,093,609	2,655,570

[154] Calculated using EPA MOVES-Nonroad model (2014b). See Section 6.2 for additional details.

Equipment Type	# Units	Hours/Yr	HP-HRs/Yr	Gal/Yr[154]
Skid steer loaders	74	27,687	669,808	46,025
Sweepers/scrubbers	3	2,281	89,189	5,198
Tractors/loaders/backhoes	15	5,054	100,794	6,926
Total	**822**	**796,796**	**106,184,000**	**5,636,231**

3.4.5 County/Temporal Allocation

County level activity for the surface mining sector was allocated from the statewide total using the percent of total production for each county, as shown in Table 3-72.

Table 3-72. County Level Surface Mining Activity Allocation[155]
2017 Nonroad Diesel Equipment Study

County	Percent of Production
Baker	6.13%
Benton	4.40%
Clackamas	5.77%
Clatsop	1.17%
Columbia	8.96%
Coos	1.28%
Crook	4.58%
Curry	0.47%
Deschutes	2.07%
Douglas	3.01%
Gilliam	0.09%
Grant	0.19%
Harney	0.05%
Hood River	0.10%
Jackson	8.18%
Jefferson	0.60%
Josephine	0.76%
Klamath	2.82%

County	Percent of Production
Lake	1.15%
Lane	9.03%
Lincoln	1.21%
Linn	2.87%
Malheur	0.76%
Marion	8.56%
Morrow	1.01%
Multnomah	3.28%
Polk	4.31%
Sherman	0.09%
Tillamook	0.94%
Umatilla	2.65%
Union	0.46%
Wallowa	0.30%
Wasco	0.58%
Washington	8.57%
Wheeler	0.07%
Yamhill	3.51%

The Surface Mining sector surveys included estimates regarding how activity was split between weekdays and weekends and across seasons for 104 pieces of equipment operating at 9

[155] State of Oregon Department of Geology and Mineral Industries. Surface Mining Permit and Production Information, 2017. Retrieved from https://www.oregongeology.org/mlrr/surfacemining-report.htm.

locations. The fleet's temporal allocation profile estimates that 88 percent of activity occurs during weekdays and 27 percent of activity occurs during the summer months.

3.4.6 Profile Validation

The ERG team only identified one potential data source to help validate the state level fuel consumption and activity estimates for this sector. The 2002 Economic Census for Mining, Quarrying and Oil and Gas Extraction provided fuel consumption and production estimates for a sample of surface mining operations across the U.S.[156] The resulting ratio of 0.969 tons per gallon[157] includes both on-road and nonroad diesel fuel consumption. OCAPA polled selected members and estimated that roughly 40 percent of the surface mining sector's current diesel consumption is associated with nonroad fuel. Assuming the split between on-road and nonroad fuel consumption has held relatively constant over time, adjusting the productivity ratio to eliminate on-road fuel leads to an estimated average efficiency factor of 2.42 tons per gallon of nonroad diesel.

Although based on 18-year-old national level data and rough estimates for fuel type splits, the figure implies that the industry has undergone substantial efficiency improvements over the last two decades, possibly due to increased electrification,[158] improved operations and advances in engine/equipment efficiency. Discussions with industry experts tend to corroborate these conclusions, with SMEs emphasizing the rapid trend toward electrification of sites in particular.

3.4.7 Sector Summary

Although the number of establishments responding to the surface mining survey was low (N=7), the portion of activity covered by their operations was substantial at almost 40 percent of the sector total (as measured by nonroad diesel equipment fuel consumption). The survey responses were also broadly geographically representative, with information reported for 55 sites located in 18 counties.

The resulting equipment activity profile developed from the survey responses is characterized by relatively new, high-hp construction equipment and generators with high utilization rates.

The annual production estimates published by DOGAMI provide excellent surrogates for estimating statewide equipment activity and allocating it to the county level. However, survey respondents were frequently unable or unwilling to provide site-specific production estimates, making it difficult to develop the scaling factors needed to account for unsurveyed operations. Accordingly, ERG worked with industry SMEs to develop a state average "efficiency factor", expressed in tons of production per gallon of nonroad diesel equipment fuel use. This industry

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[156] U.S. Census Bureau. *Mining (NAICS Sector 21) General Subject Series.* 2002. Retrieved from https://www.census.gov/data/tables/2002/econ/census/mining-reports.html.

[157] 43.9M tons / 45.3M gallons.

[158] The DEQ Annual Air Quality reports indicate that over 44 percent of permitted crushers used electric line power in 2017.

average efficiency factor was then combined with fuel consumption estimates for surveyed operations to develop the scaling factor required for statewide activity estimation.

The site-specific variation in observed efficiency factors is substantial, ranging by up to two orders of magnitude depending on a variety of factors. As such, activity and emissions estimates for the sector include substantial uncertainty, especially at the county level. In the future simple surveys could be conducted to obtain nonroad diesel fuel consumption estimates from operators at the county level, which could then be combined with the DOGAMI production totals to develop county-specific efficiency factors, allowing for more precise, geographically resolved estimates of activity and emissions. Electrification trends in the industry could be tracked using information from the DEQ Annual Reports and used to forecast adjustments for future year efficiency factors.

3.5 Crane and Rigging Services

This section characterizes mobile cranes equipped with nonroad diesel engines, including crawler and rough terrain cranes (RTCs). Larger cranes may feature a separate upper engine dedicated to lifting, and a lower engine for locomotion. Truck cranes, which utilize a PTO configuration drawing power from an on-road engine, are excluded from the analysis.

The following assessment differentiates between larger cranes such as lattice boom and crawler units that are operated almost exclusively by specialized rigging service companies, and smaller RTCs operated more broadly across the construction industry. Non-RTC crane ownership is largely restricted to rigging companies for a number of reasons, including the substantial investment required to purchase and maintain these units, the limited amount of time required for their use at many job sites, and notable insurance and operator licensing requirements. According to industry experts only a small number of such cranes are expected to be owned and operated outside the rigging industry, most likely by very large general contractors with significant amounts of bridge construction work.[159] However, RTCs are typically lower in cost, are generally easier to operate, and are relatively common across the construction sector.

Given the limited number of equipment operators in this sector, a targeted assessment was conducted for these units rather than a broad, random sample survey like those conducted for agriculture and logging. To this end, ERG contacted the Northwest Crane Owners Association (NWCOA) which facilitated a survey of two of its larger members to obtain information on the number of cranes by type, engine hp and model year, and hours per year of operation. The non-RTC portion of their inventory included 31 engines with an average model year of 2001 and average hp of 345 operating an average of 1,376 hours per year. The two respondents were responsible for approximately 65 percent of the Oregon rigging services market, based on

[159] Personal communication, Mike Vlaming, NWCOA, 9-27-19. NWCOA also confirmed the absence of significant ownership among structural steel and similar companies.

operator hour records.[160] Scaling to account for the remaining 35 percent of the market increases the non-RTC unit count to 48 for the state.

ERG also identified an additional 17 non-RTC cranes through a broad survey of 20 construction companies operating almost 1,400 pieces of nonroad diesel equipment (discussed in Section 3.7). The small fraction of large cranes included in this data set (0.05 percent) is consistent with the assumption that most large crane operation is provided by specialized rigging services. These 17 units were added to the estimated number of rigging company cranes without further scaling, resulting in a statewide total of 65 units for non-RTC cranes.

ERG also requested information on RTC crane use from AGC members. Information on 10 RTCs was obtained from two AGC members responsible for an unknown share of the construction sector crane ownership total. When combined with data on the 17 additional units operated by construction companies, the 27 RTCs had an average hp of 248,[161] and average model year of 2004, and an average hours per year of 1,201.

Since the number of RTCs owned and operated outside of the rigging services industry is unknown, ERG developed a state population estimate for these units using the estimated number of non-RTC cranes (65) and historical crane sales records for Oregon.[162] The available data indicated that 68.7 percent of all non-truck crane sales in the state over the last 20 years were for RTCs, with 31.3 percent for non-RTCs. Under these assumptions the state total for RTCs is estimated to be 142 units.

Table 3-73 summarizes the statewide profile for nonroad cranes along with the default estimates assumed by EPA's MOVES-Nonroad model.

Table 3-73. Statewide Crane Equipment Profile with MOVES Comparison 2017 Nonroad Diesel Equipment Study

Source	# Units	Avg HP	Avg Hrs/Yr	Avg Model Year	Gal/Yr
Study	207	276	1,248	2002	1,177,112[163]
EPA MOVES Model	602	231	990	2011	3,070,986

Note that a substantial portion of the difference between the gallons per year estimates in Table 3-74 is due to different assumptions regarding crane engine load factors; the load factor assumed for this study (0.29) was developed by CARB while the factor used by the MOVES model is substantially higher (0.43). Lowering the factor from 0.43 to 0.29 reduces the gallon consumption differential roughly from a factor of three to two.

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[160] Ibid.

[161] This power rating corresponds very closely to the average estimated for over 300 Oregon RTC sales records (245 hp) from Equipment Data Associates.

[162] Equipment Data Associates. See https://www.randallreilly.com/construction-marketing/.

[163] Calculated using EPA MOVES-Nonroad model (2014b). See Section 6.2 for additional details.

The county-level activity distribution for cranes was based on MOVES defaults for the Oregon construction sector, with the allocation percentages shown in Table 3-74.

Table 3-74. County-Level Crane Activity Allocation
2017 Nonroad Diesel Equipment Study

County	Percent Activity
Baker	0.14%
Benton	2.57%
Clackamas	10.87%
Clatsop	0.86%
Columbia	0.93%
Coos	0.67%
Crook	0.61%
Curry	0.58%
Deschutes	9.69%
Douglas	1.73%
Gilliam	0.03%
Grant	0.05%
Harney	0.04%
Hood River	0.54%
Jackson	6.58%
Jefferson	0.40%
Josephine	1.14%
Klamath	1.08%

County	Percent Activity
Lake	0.05%
Lane	6.78%
Lincoln	0.71%
Linn	2.08%
Malheur	0.27%
Marion	6.37%
Morrow	0.05%
Multnomah	21.49%
Polk	0.97%
Sherman	0.15%
Tillamook	0.71%
Umatilla	1.47%
Union	0.30%
Wallowa	0.05%
Wasco	0.22%
Washington	17.38%
Wheeler	0.02%
Yamhill	2.40%

ERG also assumed MOVES default values for the northwest region of the U.S. for temporal allocation, with 30.6 percent of total crane activity occurring during the summer, and 83.3 percent of activity during weekdays.

While representatives from NWCOA confirmed the reasonableness of the study’s estimates, independent data sources were not identified to help validate the crane activity profile, and notable uncertainties remain regarding crane ownership and operation outside of specialty rigging service companies.

3.6 Special Projects

The standard industry profile methodology employed by the study (and presented in Section 4) may not adequately characterize certain construction project activity. For example, the development of a large civic center or major flood control project may require substantial amounts of diesel construction equipment, used in ways that do not scale accurately with the study’s surrogates. Accordingly, ERG coordinated with local trade associations and government agencies to identify any unusually large construction projects (e.g. buildings greater than 100,000 SF) that occurred during the 2017 calendar year.

One such project was identified and equipment use information was requested from the general contractor managing the work.[164] Only one piece of information was missing from the survey response, the hp for a mobile crushing plant which was gap-filled based on the average of three jaw crushers identified for sale online, all of which were close to 300 hp. Table 3-75 presents the equipment use profile for special project activity during 2017.[165]

Table 3-75. Special Project Activity Profile by Equipment Type, 2017
2017 Nonroad Diesel Equipment Study

Equipment Type	# Units	Avg HP	Avg Hrs/Yr	Avg Model Year	Gallons[166]
Crawler tractors/dozers	2	285	2,000	2016	24,125
Crushing/processing equipment	1	300	2,000	2015	13,526
Excavators	4	155	1,750	2012	21,852
Graders	1	224	2,000	2013	9,735
Off-highway trucks	3	329	2,000	2014	39,756
Rubber tire loaders	2	206	2,000	2015	15,684
Tractors/loaders/backhoes	2	66	2,000	2016	6,712
Total	**15**	**216**	**1,933**	**2014**	**131,390**

This single project was responsible for almost one percent of the total construction industry nonroad diesel fuel consumption for 2017 (14.6M gallons).[167] Accordingly, the sheer size of the project merits a more detailed assessment of equipment characteristics and activity than would have occurred using the standardized equipment use profiles developed for the Commercial and Institutional Building sector (presented in Section 4.4).

3.7 Supplemental Construction Equipment Survey

The activity profiles developed for the construction sector rely on input from industry experts and readily available information on project requirements and equipment productivity. The resultant profiles characterize equipment needs and hp-hour requirements in great detail but lack the information on engine age distributions necessary to estimate emission levels.

ERG coordinated with Oregon construction industry trade associations (AGC, NWUCA, and OCAPA) to obtain engine age information through surveys of their membership. The surveys

[164] Project description and location are omitted from the report to protect respondent confidentiality.

[165] This project was identified in the Dodge Analytics listing and removed from the Commercial/Institutional building profile presented in Section 4.4 to avoid double-counting.

[166] Calculated using EPA MOVES-Nonroad model (2014b). See Section 6.2 for additional details.

[167] Section 6.3.2 provides a detailed fuel consumption breakdown for the different construction industry components.

requested unit-specific details on nonroad diesel engines greater than 25 hp including equipment type, make, model, model year and/or tier level,[168] and hp. Twenty companies responded with information on over 1,400 units, providing a snapshot of their equipment fleets as of mid-2019.[169] Based on MOVES default values for construction and mining equipment, and accounting for the estimated decrease in total construction sector fuel consumption relative to MOVES,[170] ERG estimates the survey sampled approximately 11 percent of the state's construction and mining equipment population.

Records missing both model year and engine tier level were dropped from the data set, leaving 1,381 units for analysis. The effective fleet sizes for the respondents ranged from 1 to 566 units, as summarized in Table 3-76.

Table 3-76. Construction/Mining Sector Engine Age Survey – Respondent Fleet Size 2017 Nonroad Diesel Equipment Study

Respondent ID	# Units
1	154
2	28
3	14
4	70
5	17
6	566
7	34
8	30
9	14
10	34
11	41

Respondent ID	# Units
12	21
13	26
14	216
15	1
16	54
17	4
18	10
19	2
20	45
Total	**1,381**

The model years reported ranged from 1958 to 2019, and hp estimates ranged from 25 to 1,800. Some respondents provided a model year range for their equipment rather than a precise year. In these cases, ERG assumed the midpoint value of the range for the analysis. Missing hp estimates were gap-filled using equipment make and model information when provided. In the absence of other information, the average hp for the most common MOVES hp bin was used for the given equipment type.

A specific model year value does not necessarily determine the engine tier level for a given unit since new emission standards may be phased into the fleet over multiple years. For equipment without a specified tier level, ERG randomly assigned units to a specific tier level based on the

[168] One respondent provided engine tier level information instead of model years.

[169] Up to four percent of the total hp reported for the survey may have been purchased after the 2017 calendar year, introducing a slight error in the resulting tier distribution estimates.

[170] Section 6.3.3 provides further details comparing MOVES defaults and the study's activity and emissions estimates by equipment category.

proportion of sales assumed by the MOVES model for the appropriate model year/hp grouping. For example, approximately 17 percent of 300 hp engines purchased in 2012 were assigned to the Tier 3 category, and 83 percent to Tier 4.

The processed data set contained information on 29 different types of nonroad diesel equipment, with 87 percent of all equipment falling in the MOVES Construction/Mining category (1,201 of 1,381 units). Table 3-77 presents the final equipment count by tier level.

Table 3-77. Construction Industry Equipment Profile by Equipment Type 2017 Nonroad Diesel Equipment Study

Equipment Type	# Tier 0	# Tier 1	# Tier 2	# Tier 3	# Tier 4	Total
Excavators	13	19	47	42	128	**249**
Rubber tire loaders	38	31	41	44	68	**222**
Rollers	34	18	12	21	45	**130**
Crawler tractors/dozers	45	12	12	19	22	**110**
Off-highway trucks	29	2	6	15	39	**91**
Scrapers	81	4	1	1	0	**87**
Rough terrain forklifts	14	20	17	7	18	**77**
Generator sets	22	12	9	4	16	**64**
Skid steer loaders	1	6	6	4	44	**60**
Sweepers/scrubbers	8	12	7	5	0	**32**
Tractors/loaders/backhoes	4	9	4	3	10	**30**
Aerial lifts	2	6	10	0	8	**26**
Pavers	4	4	3	5	10	**26**
Graders	10	3	2	7	3	**25**
Cold Planers	4	5	2	6	7	**24**
Agricultural tractors	4	2	7	5	5	**23**
Cranes	15	3	1	0	2	**21**
Crushing/processing equipment	2	3	3	3	2	**13**
Air compressors	0	1	3	2	6	**12**
Pumps	0	0	1	1	9	**11**
Paving equipment	5	3	1	2	0	**11**
Concrete/industrial saws	2	2	3	0	2	**10**
Bore/drill rigs	4	4	0	0	0	**8**
Other construction equipment	3	2	0	0	0	**5**
Specialty vehicles/carts	0	0	0	2	2	**4**
Other material handling equipment	0	0	1	3	0	**4**
Fellers/bunchers/skidders	1	1	1	0	0	**3**
Trenchers	1	1	0	0	0	**2**
Chippers/stump grinders	1	0	0	0	0	**1**
Total	**348**	**187**	**199**	**201**	**446**	**1,381**

Table 3-78 presents the engine tier level distributions just for the construction/mining equipment reported by industry survey respondents, broken out by hp group. Table 3-79 presents the corresponding MOVES model default distributions for the state. Figure 3-46 directly compares the survey and MOVES distributions, aggregated across all hp groups.

Table 3-78. 2017 Construction/Mining Equipment Survey Tier Level[171]
2017 Nonroad Diesel Equipment Study

HP Range	Tier 0	Tier 1	Tier 2	Tier 3	Tier 4	Total #
25 - 40	25.8%	0.0%	0.0%	0.0%	74.2%	**31**
40 - 50	15.0%	6.5%	17.6%	0.0%	60.8%	**52**
50 - 75	5.8%	14.9%	17.6%	1.0%	60.8%	**104**
75 - 100	30.4%	27.9%	17.7%	7.0%	16.9%	**92**
100 - 175	16.4%	15.0%	11.4%	20.0%	37.2%	**311**
175 - 300	29.8%	15.4%	10.8%	19.8%	24.2%	**201**
300 - 600	35.6%	7.0%	12.8%	17.8%	26.8%	**362**
600 - 750	43.3%	7.0%	26.3%	9.2%	14.1%	**30**
750+	38.9%	16.7%	27.8%	11.1%	5.6%	**18**
Total	**25.8%**	**12.7%**	**13.3%**	**14.9%**	**33.3%**	**1,201**

Table 3-79. 2017 MOVES Default Construction/Mining Tier Level
2017 Nonroad Diesel Equipment Study

HP Range	Tier 0	Tier 1	Tier 2	Tier 3	Tier 4	Total #
25 - 40	4.1%	10.8%	20.2%	0.0%	64.8%	**2,707**
40 - 50	3.1%	8.2%	18.6%	0.0%	70.1%	**1,385**
50 - 75	11.1%	36.1%	17.2%	0.0%	35.6%	**5,693**
75 - 100	7.4%	31.5%	12.9%	11.5%	36.7%	**8,197**
100 - 175	2.6%	17.2%	11.7%	19.2%	49.3%	**6,076**
175 - 300	0.5%	5.7%	3.8%	28.1%	61.8%	**3,029**
300 - 600	2.3%	10.1%	21.9%	21.1%	44.6%	**1,678**
600 – 750	1.7%	10.7%	14.2%	23.2%	50.2%	**348**
750+	2.6%	19.5%	30.0%	0.0%	47.9%	**239**
Total	**5.5%**	**22.2%**	**14.1%**	**11.6%**	**46.6%**	**29,352**

[171] Single units may be allocated across multiple tier levels to reflect engine sales distributions during emission standard phase-in years, resulting in fractional unit counts.

Figure 3-46. Construction/Mining Equipment Tier Level Distribution Comparison 2017 Nonroad Diesel Equipment Study

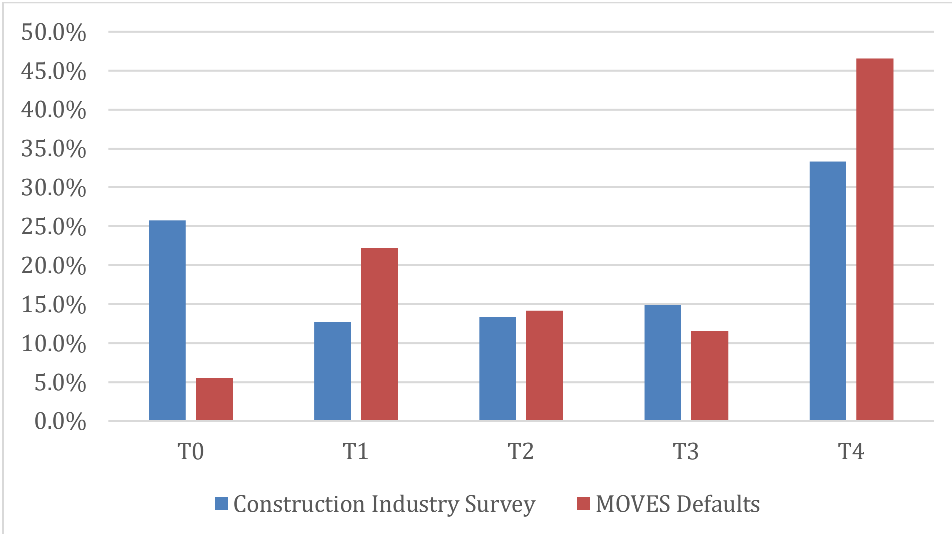

Figure 3-46 indicates similar values, especially for the Tier 2 – 3 engine percentages. However, the tail ends of the distributions are substantially different, with 25.8 percent of surveyed equipment in the Tier 0 category vs. 5.5 for MOVES. Conversely, 33.3 percent of surveyed equipment fell in the Tier 4 category, compared to 46.6 percent for MOVES. These differences are due in part to MOVES assuming higher equipment activity and therefore more frequent scrappage and equipment replacement rates than are indicated by the survey results.

The survey results also indicate a different hp distribution than assumed by MOVES, with relatively more high-hp units appearing in the survey as shown in Table 3-80. It is unknown if this difference is a result of sampling bias or is reflective of actual fleet characteristics in the Oregon construction industry.

Table 3-80. Construction/Mining Equipment HP Distribution - Survey vs. MOVES Defaults 2017 Nonroad Diesel Equipment Study

HP Range	Survey	MOVES
25 - 40	2.6%	9.2%
40 - 50	4.3%	4.7%
50 - 75	8.7%	19.4%
75 - 100	7.7%	27.9%
100 - 175	25.9%	20.7%
175 - 300	16.7%	10.3%
300 - 600	30.1%	5.7%
600 - 750	2.5%	1.2%
750+	1.5%	0.8%

4.0 Industry-Specific Sector Profiles

Unlike the public fleet and random sample surveys discussed in Section 3.0, which collect information on equipment counts and annual activity levels, the industry-specific sector profiles described in this section are designed to take advantage of comprehensive, project-specific quantity information available for certain Oregon industries. For example, Dodge Analytics maintains an extensive, up-to-date database of commercial building and utility project work being bid throughout the country, containing physical quantity information on each project such as the LF of pipe installation required and square footage of building construction by county. Coupling such information with equipment use profiles developed by SMEs intimately familiar with Oregon's operating conditions provides a highly representative basis for quantifying equipment activity and emissions.

4.1 Methodology and Assumptions

Industry surveys were conducted by coordinating with SMEs from selected industries to refine established diesel equipment use profiles. The SMEs were identified through outreach to Oregon industry trade associations and other organizations including the following:

- Associated General Contractors (AGC) Oregon-Columbia Chapter, for input on commercial building and highway profiles;
- Northwest Utility Contractors Association (NWUCA), for input regarding utility projects;
- Central Oregon Builders Association (COBA) – for input regarding single-family housing construction;
- Oregon Farm Bureau (OFB) – for input regarding third party agricultural services; and,
- Oregon Water Resources Department (OWRD) – for input regarding well drilling services.

All SMEs had direct industry experience. The AGC, NWUCA, and COBA contacts had specific experience managing construction projects for general and earthwork contractors in their respective sectors and were very familiar with equipment use requirements for all work phases.

ERG previously developed equipment use profiles for the TCEQ which specified distinct equipment mixes and hours of use for multiple construction activities including utility, commercial and institutional building, and single-family housing construction projects.[172] ERG worked closely with the local industry and trade association SMEs in Oregon to adjust the TCEQ base profiles for Oregon-specific operating conditions (e.g., accounting for differences in soil type and ground cover). ERG then combined the modified profiles with project-specific, physical surrogates (e.g. square footage of commercial building installations in 2017) to estimate precise equipment use levels for these specific construction activities.

[172] Eastern Research Group. *Statewide Diesel Construction Equipment Inventory.* Prepared for the Texas Commission on Environmental Quality. August 31, 2005.

The input provided by the SMEs often included confidential business information regarding operating practices and efficiencies. As such, ERG agreed to ensure SME anonymity throughout the data collection and reporting process.

4.2 Single-Family Housing Sector

The Single-Family Housing sector includes the construction and demolition of single-family homes and duplexes. Multi-family construction (i.e. apartment complexes) is included under the Commercial and Institutional Building sector profile. The Single-Family Housing sector also includes utility contract work associated with service extensions up to the property line. Off-property utility service extensions, for both residential and commercial developments, are included in the Utility sector profile.

This sector features a large number of contractors and subcontractors performing similar tasks for different developers. ERG previously developed a profile for this sector as part of a prior study for the TCEQ based on a typical or "Model" subdivision for the state.[173] Key assumptions for the base case subdivision development are provided in Table 4-1.

Table 4-1. Single-Family Housing Sector – Model Subdivision Characteristics 2017 Nonroad Diesel Equipment Study

1. 100 lot subdivision
2. Lots between 50’ and 80' x 120'
3. Total area -- 20 - 30 acres
4. Forested lots assumed -- clearing required for lots and street/utility right of ways.
5. Felled trees assumed logged off site rather than pit burned -- on-highway trucks used
6. Finishing activities do not include landscaping
7. Utility work beyond property lines not included – estimated separately
8. 8 hours engine operation per day, 5 days per week assumed
9. Slipform/screed paving rather than form paving assumed -- more equipment-intensive
10. Assume backfilling on-site with cut dirt rather than hauling off-site

4.2.1 Equipment Productivity Profile

ERG worked with representatives from COBA to identify two SMEs to review the Texas model subdivision assumptions and revise the base equipment productivity profile for Oregon conditions. One SME agreed that the model subdivision characteristics were generally consistent with their own development work, while the other SME noted their developments tended to be about one third the size, but otherwise agreed with the base case assumptions.

The SMEs then provided extensive adjustments to the Texas equipment productivity profile based on their development experience in Central Oregon, specifically for Deschutes, Jefferson

[173] Eastern Research Group. *Statewide Diesel Construction Equipment Inventory.* Prepared for the Texas Commission on Environmental Quality. August 31, 2005.

and Crook Counties. The equipment use requirements provided by the second SME were multiplied by three in order to scale up to the 100 unit subdivision model.

The SMEs frequently reported using different equipment/hp combinations to accomplish the same task, reflecting different equipment ownership patterns and preferences for performing work. In these instances, ERG assumed 50 percent of the task duration for a given subdivision would be accomplished by the first SME's equipment/hp mix, and 50 percent by the second SME's mix. The resulting composite equipment productivity profile for Central Oregon is presented in Table 4-2. One row is presented for each equipment/hp combination.

Table 4-2. Single-Family Housing Sector Equipment Productivity/Subdivision – Central Oregon
2017 Nonroad Diesel Equipment Study

Task	Duration - days	# Units	Equipment Type	Typical HP
1. Land Clearing	8.3	1	Excavator	250
	6.7	1	Articulated Truck - off road	325
	25.0	1	Rock Drill	440
	7.5	1	Excavator	300
	7.5	1	Off Highway Water Truck	280
	7.5	1	Crawler Dozer	410
2. Street Cutting / Mass Grading	33.3	1	Excavator	250
	33.3	1	Excavator	165
	33.3	1	Crawler Dozer	133
	33.3	2	Articulated Truck - off road	325
	16.7	1	Wheel Loader	270
	33.3	1	Crusher	200
	20.0	2	Excavator	300
	20.0	5	Articulated Truck - off road	325
	20.0	1	Crawler Dozer	410
	20.0	1	Crusher	780
	20.0	2	Wheel Loader	270
	20.0	2	Excavator w/hammer	300
	20.0	1	Off Highway Water Truck	280
	20.0	1	Grader	185
	20.0	1	Pneumatic Roller	125
3. Utility Work - Sewer, Water, Storm, Power, Phone/Cable	58.3	1	Excavator	250
	58.3	1	Articulated Truck - off road	325
	58.3	1	Rubber tire loader	230
	58.3	1	Backhoe w/ Vibratory Compactor	95
	25.0	2	Excavator	300
	25.0	5	Articulated Truck - off road	325
	25.0	3	Excavator w/hammer	300
	25.0	1	Crusher	780

Task	Duration - days	# Units	Equipment Type	Typical HP
	25.0	2	Rubber tire loader	270
	25.0	1	Off Highway Water Truck	280
	25.0	3	Backhoe w/ Vibratory Compactor	100
	25.0	3	Rock Drills	180
4. Road Grading / Paving	6.7	1	Grader	140
	3.3	1	Pavers (slipform/screeds)	230
	0.8	1	Backhoe	100
	3.3	1	Double Drum Roller	130
	6.7	1	Vibratory Compactor	150
	7.5	1	Grader	185
	7.5	1	Off Highway Water Truck	280
	7.5	1	Pneumatic Roller	125
	7.5	1	Backhoe	100
	2.5	2	Asphalt Paver	175
	2.5	3	Double Drum Roller	100
5. Finishing Work	8.3	1	Crawler Dozer	133
	3.3	1	Curbing Machine	150
	8.3	1	Rubber tire loader	230
	3.3	1	Vibratory Compactor	150
	4.0	1	Curbing Machine	100
	10.0	3	Backhoe	100
	30.0	1	Skid Steer	65

The most significant difference from the Texas base case productivity estimates reflects the intensive equipment use required for rock drilling and blasting in these counties, which greatly increases the hp-hour and fuel use requirements for the earthwork tasks (tasks 2 and 3). Both SMEs clearly noted that the earthwork task profiles are only applicable to the three Central Oregon counties: Deschutes, Jefferson and Crook. One SME stated that the Texas earthwork task profiles were reasonable for the remainder of Oregon, while the other SME did not provide input regarding equipment requirements for other regions.

ERG assumed the land clearing requirements in the base profile, which were developed for forested land in the eastern portion of Texas, were reasonable for western Oregon counties. The land clearing requirements estimated for the Central Oregon profile were assumed to be applicable to the eastern Oregon counties.[174] The modified equipment profile used for other areas of the state is provided in Table 4-3. The task categories are slightly different from the Central Oregon profile, reflecting the original organization of the base profile.

[174] Includes Baker, Harney, Klamath, Lake, Malheur, Morrow, Umatilla, Union and Wallowa Counties.

Table 4-3. Single-Family Housing Sector Equipment Productivity/Subdivision – Other Regions[175]
2017 Nonroad Diesel Equipment Study

Task	Duration - days	# Units	Equipment Type	Typical HP
1. Land Clearing	43	2	Crawler Dozer	140
	43	1	Excavator	220
	43	1	Rubber tire loader	130
2. Utility Work	43	2	Excavator	300
	43	1	Crawler Dozer	155
	43	1	Rubber tire loader	130
	43	1	Vibratory Compactor	100
3. Street Cutting/Dirt Moving	12	1	Excavator	220
	12	2	Crawler Dozer	155
	12	1	Grader	140
4. Compaction	9	1	Soil Stabilizer	300
	9	2	Grader	165
	9	1	Pneumatic Roller	100
	9	1	Crawler Dozer	80
4. Paving	14	1	Grader	140
	14	2	Pavers (slipform/screeds)	230
	14	2	Crawler Dozer	80
	14	1	9 Wheel Roller	100
5. Finishing Work	3	1	Crawler Tractor	90
	2	1	Curbing Machine	149
	7	1	Rubber tire loader	130
	7	1	Rubber Tire Roller	100

The Single-Family Housing Sector profile also accounts for demolition of pre-existing structures. Table 4-4 presents the base profile for demolishing a 2,500 SF house.

Table 4-4. Single-Family Housing Sector Equipment Productivity – Structure Demolition
2017 Nonroad Diesel Equipment Study

Task #	Task Description	Equipment Type	Quantity	Avg HP	Quantity/Hr	Days/House
1	Building Demolition	Dozer	SF	250	191	1.7
2	Slab Demolition	Dozer	SF	250	179	1.8
3	Load Debris	Loader	CY*	250	38	0.2

* Cubic Yards

[175] Excludes Deschutes, Jefferson and Crook Counties.

4.2.2 Equipment Activity Estimation

The estimated equipment activity for a 100-unit subdivision was scaled up to the state level using the number of new housing starts reported at the county level.[176] The number of new permits issued for single units and duplexes in 2017 were as follows:

- Oregon state total – 10,966
- Central Oregon total (Deschutes, Jefferson and Crook Counties) – 2,046
- Eastern counties (Baker, Harney, Klamath, Lake, Malheur, Morrow, Umatilla, Union and Wallowa Counties) – 561[177]

Separate surrogates were used to estimate statewide demolition activity. ERG worked with DEQ staff to compile demolition permit information from various cities and counties, for both residential and commercial structures. Table 4-5 summarizes the findings for residential demolition permits.

Table 4-5. Single-Family Housing Structure Demolition Rates 2017 Nonroad Diesel Equipment Study

City/County	New Permits	Demolition Permits	Percent of New Permits	Source[178]
West Linn	37	7	18.9%	1
Cornelius	2	1	50.0%	1
Deschutes County[179]	451	11	2.4%	1
Forest Grove	90	7	7.8%	1
Happy Valley	156	10	6.4%	1
Hood River County	74	5	6.8%	1
Klamath County	91	13	14.3%	1
Milwaukie	9	4	44.4%	2
Newport	6	2	33.3%	1
Springfield	144	6	4.2%	1
Washington County	833	53	6.4%	3
Portland	5,945	324	5.4%	4
Salem	548	36	6.6%	5
Total	**8,386**	**479**	**5.7%**	

[176] U.S. Census Bureau. Buildings Permit Surveys. Retrieved 2017 Oregon data from https://www2.census.gov/econ/bps/.

[177] Only differentiated for land clearing adjustments.

[178] Sources: 1) Oregon e-permitting system, retrieved by DEQ from https://aca-oregon.accela.com/oregon/; 2) Data provided electronically by City of Milwaukie, Harmony Drake, Permit Technician., 10-17-19; 3) Washington County Permit Data - transmitted to DEQ electronically; 4) Portland Maps. Retrieved from https://www.portlandmaps.com/advanced/?action=permits#advanced; 5) City of Salem Permit Search. Retrieved from https://splash.cityofsalem.net/AMANDA5/eNtraprise/Salem/public/public_query_permit.jsp.

[179] Includes City of Bend.

Based on the information in Table 4-5, ERG assumed that 5.7 percent of new construction permits would be associated with a structure demolition (for a statewide total of 627 units) and applied the demolition equipment profile for this fraction.

The resulting statewide equipment use profile for this sector is presented in Table 4-6. When combined with equipment model year distributions for the Oregon construction industry, this information provides the basis for estimating state-level emissions for the sector.

Table 4-6. Statewide Single-Family Housing Sector Equipment Use Profile 2017 Nonroad Diesel Equipment Study

Equipment Type	Avg HP	Total Hours	Total HP-HRs	Total Gal/Yr[180]
Crawler tractors/dozers	211	2,125	138,725	538,201
Crushing/processing equipment	687	627	143,677	154,119
Excavators	278	3,895	401,736	852,580
Graders	164	625	41,430	124,256
Off-highway trucks	319	3,333	403,459	441,354
Other construction equipment	297	800	82,320	100,254
Pavers	224	291	27,154	108,622
Paving equipment	133	75	3,450	7,020
Rollers	114	915	38,671	126,141
Rubber tire loaders	227	2,187	164,053	312,614
Skid steer loaders	65	240	5,772	8,029
Surfacing equipment	300	72	6,480	30,737
Tractors/loaders/backhoes	98	1,374	49,950	70,224
Total		16,559	1,506,878	2,874,152

4.2.3 County/Temporal Allocation

Equipment activity for the single-family housing sector were estimated at the county level in three steps. First, the housing permit data for 2017 were grouped by county region (Central, Eastern, and Other Counties) as discussed in Section 4.2.2, with the percentage of permits determined by group. For example, the number of permits issued for single-unit homes and duplexes in the Central Oregon counties in 2017 was 1,806 for Deschutes, 128 for Crook, and 112 for Jefferson. This translates to a regional percentage distribution of 88.2 percent for Deschutes, 6.3 percent for Crook, and 5.5 percent for Jefferson.

Next, total fuel consumption for each region was estimated by multiplying the fuel consumption required for a 100-unit subdivision by the equivalent number of new subdivisions permitted. For the Central Oregon counties, a total of 2,046 new units were permitted in 2017,

[180] Calculated using EPA MOVES-Nonroad model (2014b). See Section 6.2 for additional details.

equivalent to 20.46 new subdivisions. Multiplying by the 63,140 gallons modeled for each Central Oregon subdivision[181] yields an estimated 1,310,300 gallons for the region.[182]

Finally, the total fuel consumption estimate for each region is then multiplied by the region-specific permit fractions (for the Central Oregon counties, 88.2, 6.3, and 5.5 percent) to obtain county-specific fuel consumption estimates. The county-level consumption estimates were then combined in a single list and re-normalized to determine the final statewide county activity distribution, as shown in Table 4-7.

Table 4-7. Statewide Single-Family Housing Sector County Activity Distribution 2017 Nonroad Diesel Equipment Study

County	Percent of Activity
Baker	0.17%
Benton	0.74%
Clackamas	7.74%
Clatsop	0.82%
Columbia	1.03%
Coos	0.20%
Crook	2.85%
Curry	0.27%
Deschutes	40.21%
Douglas	1.51%
Gilliam	0.00%
Grant	0.00%
Harney	0.10%
Hood River	0.59%
Jackson	4.59%
Jefferson	2.49%
Josephine	1.50%
Klamath	0.78%

County	Percent of Activity
Lake	0.10%
Lane	5.18%
Lincoln	1.03%
Linn	3.01%
Malheur	0.18%
Marion	3.94%
Morrow	0.17%
Multnomah	5.64%
Polk	1.18%
Sherman	0.00%
Tillamook	0.76%
Umatilla	1.00%
Union	0.28%
Wallowa	0.39%
Wasco	0.00%
Washington	9.50%
Wheeler	0.00%
Yamhill	2.05%

Information on the temporal distribution of single-family housing construction was not determined for the study. For emissions modeling purposes ERG assumed MOVES defaults for summer (30.6 percent of annual activity) and weekday (16.7 percent of total week activity) allocations.

[181] Details regarding region-specific fuel consumption rates were provided to DEQ in electronic format.

[182] Excludes minor adjustments for infrequent structure demolition.

4.2.4 Validation

Independent validation sources were not identified for most of the single-family housing sector task profiles. However, the productivity estimates for the demolition task correspond closely to those provided in the RSMeans construction cost estimating guide – a national average value of 2 days for demolishing a 3,200 SF home.[183] Assuming equipment requirements scale directly with square footage, the RSMeans rate translates to 1.6 days for a 2,500 SF house. In addition, the average house size assumed (2,500 SF) is almost identical to the average size of structures with demolition permits identified in the Portland Online Permit system (2,602 SF).[184]

Sector-wide estimates were also generated for North Texas to provide additional points of comparison for certain components of the Oregon construction sector. ERG used the Texas Commission on Environmental Quality's TexN2.0 utility[185] to estimate fuel consumption for the single-family housing, commercial building, and highway/utility subsectors operating in the Dallas-Fort Worth (DFW) region for 2017.[186, 187] Table 4-8 compares the relative fuel consumption percentages across these subsectors for DFW and for Oregon as a whole.

Table 4-8. Relative Fuel Consumption Comparison for Selected Construction Subsectors 2017 Nonroad Diesel Equipment Study

Sector	Oregon	DFW
Single Family Housing	31%	29%
Commercial/Institutional Buildings	36%	35%
Highway + Utility[188]	33%	36%
Total	**100%**	**100%**

While the specific construction project operating conditions and requirements vary between the two regions, the relative fuel consumption estimates are clearly similar for all three subsectors.

4.2.5 Sector Summary

Key observations regarding the Single-Family Housing Sector profile include the following:

[183] RSMeans 2017 Heavy Construction Cost Book, profile 02 41 16.13.

[184] Portland Maps. *Residential and Commercial Building Demolition Permits.* Retrieved from https://www.portlandmaps.com/advanced/?action=permits#advanced.

[185] Eastern Research Group. "TexN2.0 User Guide," prepared for the Texas Commission on Environmental Quality, May 9, 2019.

[186] The TexN2.0 model defines single-family housing, commercial, and highway/utility construction in a way similar to that used for this study. However, the TexN model accounts for specific equipment activity (e.g. from backhoes and trenchers) in a manner inconsistent with the study's approach. As such, this equipment is excluded from the comparison in Table 4.8.

[187] The DFW region was chosen as it includes a range of urban and suburban construction project settings.

[188] The highway and utility subsectors are broken out differently by the TexN2.0 model and are combined here to allow for consistent comparison with the Oregon study totals.

- The sector requires a substantial amount of heavy construction equipment use with excavators, dozers, and off-highway trucks having the highest fuel consumption levels. At 2.87M gallons of fuel consumption per year statewide, the sector is a significant contributor to the construction industry's overall total of 14.64M gallons (or 19.6 percent of the industry total).[189]
- Notable differences in equipment use requirements are seen across different parts of the state. The three Central Oregon counties of Deschutes, Crook and Jefferson feature particularly equipment-intensive profiles, consisting of approximately 20 percent of the state's new housing but consuming approximately 50 percent of the sectors' total fuel consumption.
- The points of reference available for validation of the sector profile are limited, but the data sources identified are in reasonable concurrence with the profile's activity estimates.
- The study relied on input regarding equipment use requirements and productivity from two SMEs, whose recommendations differed substantively for certain tasks. Additional uncertainty is caused by site-specific variations in task requirements. For example, differences in lot sizes, vegetation and terrain impact all impact land clearing requirements. These uncertainties could be reduced in the future through input from additional SMEs, preferably with extensive operations the Portland Metro and/or Willamette Valley regions.

4.3 Utility Sector

This sector characterizes nonroad diesel equipment use associated with the installation, maintenance and repair of the following:

- Storm Sewers
- Sanitary Sewers
- Water Lines
- Electrical/Communication Lines
- Utility Tunnels

Contracts for this sector are predominately conducted for municipalities and counties, as well as work for other government agencies and private clients.[190]

[189] Section 6.3.2 provides a detailed fuel consumption breakdown for the different construction industry components.

[190] A substantial amount of utility work is also included in the ODOT Highway Sector profile and is excluded here to avoid double-counting. Utility work performed on commercial and residential subdivision properties is characterized in those sector profiles and is also excluded here.

4.3.1 Equipment Productivity Profile

ERG worked with two SMEs identified through NWUCA in order to update the base Utility Sector profile originally developed for Texas. The SMEs were in general agreement regarding equipment productivity estimates, and when different values were provided ERG selected the lower productivity value (corresponding to higher activity) to be conservative. The resulting composite equipment productivity profile for the sector is presented in Table 4-9, broken out by task. Tasks 6 - 10 and 16a - 16d were assumed for all projects. Project specific details were used to determine if site work likely required land clearing (Task 1), pavement demolition, removal, and replacement (Tasks 2 -5 and 11 – 14),[191] or horizontal boring (Task 15).[192]

Table 4-9. Utility Sector Equipment Productivity Profile
2017 Nonroad Diesel Equipment Study

Task #	Task Description	Quantity	Units	Equipment Type	HP
1	Clear and Grub	0.25	Acres/hr	Excavator	138
2	Remove site pavement	17	CY/hr	Excavator	138
3	Remove concrete curbs	100	LF/hr	Excavator	238
4	Load from pile	38	CY/hr	Rubber tire loader	250
5	Haul Material	140	CY/hr	Off-highway Truck	450
6	Excavate trench	17	CY/hr	Excavator	238
7	Pipe bedding	17	CY/hr	Rubber tire loader	250
8	Backfill/compact trench	17	CY/hr	Excavator	138
9	Compact subgrade	250	CY/hr	Roller	163
10	Finish grading	500	SY/hr	Grader	225
11	Place aggregate base	150	Tons/hr	Grader	225
12	Compact base	150	Tons/hr	Roller	138
13	Place asphalt	200	Tons/hr	Paver	250
14	Compact asphalt	200	Tons/hr	Roller	138
15	Horizontal boring	65	LF/hr	Bore/Drill Rig	200
16a	Daily Clean up	0.5	Hrs/day	Skid steer loader	58
16b	Daily Clean up	0.5	Hrs/day	Tractors/Loaders/Backhoe	87
16c	Daily Clean up	0.5	Hrs/day	Sweepers/scrubber	134
16d	Daily Clean up	0.25	Hrs/day	Off-highway Truck	280

[191] Initial site conditions could not be identified for 121 projects. These projects were randomly assigned to either the land-clearing or pavement removal/replacement tasks, with a 50 percent probability.

[192] Horizontal boring projects were assumed to be self-contained, with no other task requirements.

4.3.2 Equipment Activity Estimation

ERG combined the composite equipment productivity profile with utility project data obtained from Dodge Analytics.[193] Dodge provided ERG with a comprehensive list of utility projects conducted in Oregon during 2017,[194] including the following information:

- General Description - Project Title, Structure Group and Structure Code
- Location – City and County
- Target Start and Completion Dates (where available)
- Project Owner (e.g. city/county agency)
- Project Valuation ($)
- Project Details – non-standardized project descriptions, with some records including key quantities and dimensions (LF of pipe, pipe diameters, and/or trench depth)

ERG filtered the Dodge project list to retain records for Storm Sewers/Flood Control, Sanitary Sewers, Water Lines, Communication Lines, and Utility Tunnels. ERG excluded records with ODOT as the Project Owner to avoid double-counting. Finally, ERG excluded records with Project Details referencing work known to use minimal or no heavy diesel equipment – specifically trenchless excavation projects utilizing pipe bursting and cured in place pipe rehabilitation.[195]

The final filtered project list includes 222 projects. Of these, 194 primarily involved linear trench work and boring projects, which could be matched with the equipment productivity profile shown in Table 4-8. The remaining 28 "Miscellaneous" projects included various drainage structures and systems (e.g. manholes, vaults, laterals, culvert replacement, among others). These projects have highly variable equipment use requirements and could not be characterized using a general equipment use profile.

The key parameters needed to estimate equipment use requirements for utility projects are trench length, width and depth. The utility sector SMEs both agreed that standardized trench depths could be assumed depending upon project type: 6 feet for sanitary sewers; 5 feet for storm sewers; and 4 feet for water and communication lines. However, trench length and width (or pipe diameter[196]) requirements vary by project. Of the 194 projects for which the equipment productivity profile could be applied, 110 included linear feet information, and 103 included information on pipe diameters. ERG estimated the linear feet for the remaining 84 projects

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[193] Dodge Data and Analytics. *Lead Center.* See http://dodgeprojects.construction.com/Select-Project-Oregon_stcVVcatId546098VVviewcat.htm for example project listings.

[194] The Dodge data contained complete listings for project start date. However, project end dates were almost entirely lacking. ERG assumed all projects with a start date on or before 2017 would be completed entirely within the analysis year, to be conservative.

[195] Minimal equipment use confirmed by both SMEs.

[196] Trench widths have a fairly uniform relation with pipe diameters – see http://www.hancor.com/daids/dh63_trench.asp for the values used in the Utility sector profile.

using the average contract dollar value per linear foot calculated for the other 110 projects as shown in Table 4-10 for each project type.

Table 4-10. Average Dollar per Linear Foot, by Utility Project Type
2017 Nonroad Diesel Equipment Study

Project Type	Linear Feet	Project Value	Dollars/Foot	# Projects
Sanitary Sewers	142,297	$20,674,800	$145	31
Storm Sewers	27,925	$8,198,700	$294	18
Water Lines	100,631	$24,642,400	$245	40
Combination[197]	89,078	$18,800,200	$211	21
Total	**359,931**	**$72,316,100**	**$201**	**110**

Communications projects had no reported values for linear feet. For these projects ERG used the lowest $/LF value (for Sanitary Sewers) to reflect the shallower trenches used for electrical and communication conduit (4 ft).

Next, ERG gap-filled missing pipe diameters using average values by Project Type, shown in Table 4-11.

Table 4-11. Average Pipe Diameters (inches), by Utility Project Type[198]
2017 Nonroad Diesel Equipment Study

Project Type	Avg Diameter	# Projects
Sanitary Sewers	10	28
Storm Sewers	22	16
Water Lines	11	42
Combination	11	17

Once values for trench length, width and depth were assigned for project types other than Miscellaneous, these parameters were linked with the equipment productivity profile to estimate total equipment use requirements for each project. In order to tie the available project dimensions to the productivity profile, additional assumptions were made in consultation with the SMEs:

1. Assume 25 feet of access is required on either side of the trench, requiring either clearing and grubbing or pavement/curb demolition. (Tasks 1-5, 9-14, and 16)
2. If surface clearance requirements cannot be determined directly from the Project Detail field, assume 50 percent of projects require demolition and 50 percent require

[197] Projects involving work from two or more other project categories – e.g. Sanitary and Storm Sewers.

[198] Communications and electrical conduit assumed to be 4-inch diameter.

land clearing – task type is then assigned randomly to specific projects. (Tasks 1-5, 9-14, and 16)

3. For pavement demolition, assume a 6-inch-deep strip for the entire pipe length, 50 feet wide (25 feet wide on both sides of trench). (Tasks 2-5, 9-14, and 16)
4. Assume curb demolition for the entire pipe length. (Tasks 2-5, 9-14, and 16)
5. For the Load from Pile task, assume a 33 percent "swell factor" to convert from CY of pavement removed.[199] (Task 4)
6. Pipe bedding is assumed 6 inches deep for entire trench. (Task 7)
7. The required backfill volume equals the trench volume less the pipe and bedding volumes. (Task 8)
8. Assume a 12-inch depth for compacting subgrade. (Task 9)
9. Assume a 6-inch-thick aggregate base, with a density of 1.25 CY/ton.[200] (Tasks 11-12)
10. Assume 150 lbs./CF and a 4-inch course for placing and compacting asphalt.[201] (Tasks 13-14)
11. Clean up tasks are applicable for projects including pavement demolition and replacement, assuming each piece of equipment is utilized half an hour a day[202]. Hour per day units are linked to LF of line installation per day using NCHRP's productivity estimates for sewer line crews (80 feet per day for trenches greater than 4 feet deep).[203]
12. Assume a 2-foot-deep, 14-inch-wide trench for one underdrain project included in the Dodge data.[204]

After gap-filling and applying the above assumptions, physical quantities were summed across all non-Miscellaneous projects to assess statewide project requirements for 2017:

- 977,828 LF of pipe installation/repair/replacement
- 5,715,560 SY of land clearing or pavement demolition

[199] Eastern Research Group. *Statewide Diesel Construction Equipment Inventory.* Prepared for the Texas Commission on Environmental Quality. August 31, 2005.

[200] Input from highway construction SMEs.

[201] National Asphalt Pavement Association. *How to Determine Quantities.* http://www.asphaltpavement.org/index.php?option=com_content&view=article&id=144&Itemid=227.

[202] 50% of water trucks are assumed to be licensed on-road vehicles and are excluded from the analysis, as per multiple SMEs.

[203] Skolnik, J., Brooks, M. and Oman, J. *Fuel Usage Factors in Highway and Bridge Construction*. NCHRP Report 744. 2013.

[204] Purdue University. *Underdrain Construction: Guidelines for Inspectors and Contractors.* https://www.in.gov/dot/div/contracts/tutorial/UnderdrainConstruction.pdf.

- 534,485 cubic yards of trench excavation and backfilling

ERG assumed the remaining Miscellaneous project categories would have similar equipment utilization per dollar,[205] and scaled total activity upward to account for these additional projects. The contract dollar value for the Miscellaneous projects was 10.2 percent of the total for all project types, resulting in a scaling factor of 1.102. The complete Utility Sector equipment use profile for all 222 projects is provided in Table 4-12.

Table 4-12. Statewide Utility Sector Equipment Use Profile
2017 Nonroad Diesel Equipment Study

Equipment Type	HP	Hours/Yr	HP-HRs/Yr	Gal/Yr[206]
Excavators	189	110,175	7,341,622	389,102
Rubber tire loaders	250	27,765	2,498,830	132,437
Off-highway trucks	409	9,968	1,486,985	78,809
Graders	225	12,017	1,108,544	58,752
Rollers	149	13,923	780,178	41,349
Pavers	250	4,680	491,357	26,042
Bore/drill rigs	200	72	7,212	378
Skid steer loaders	58	6,734	144,501	9,853
Tractors/loaders/backhoes	87	6,734	216,751	14,912
Sweepers/scrubbers	134	6,734	415,053	21,760
	Total	**198,800**	**14,491,034**	**773,393**

When combined with equipment model year distributions for the Oregon construction industry, this information provides the basis for estimating state-level emissions for the sector.

4.3.3 County/Temporal Allocation

The Dodge Analytics data used for this analysis included county information for each project listing. ERG summed the estimated equipment hp-hours associated with each project by county to determine the county level allocation factors for the Utility sector, shown in Table 4-13.

Table 4-13. Statewide Utility Sector County Activity Distribution
2017 Nonroad Diesel Equipment Study

County	Percent Activity
Baker	0.00%
Benton	0.26%
Clackamas	8.93%
Clatsop	0.91%

County	Percent Activity
Columbia	0.95%
Coos	0.73%
Crook	0.10%
Curry	0.54%

[205] Equipment use requirements for the miscellaneous projects will most likely be lower than other categories since demolition, trenching and paving requirements will likely be less per contract dollar.

[206] Calculated using EPA MOVES-Nonroad model (2014b). See Section 6.2 for additional details.

County	Percent Activity
Deschutes	16.78%
Douglas	0.98%
Gilliam	0.00%
Grant	0.00%
Harney	0.00%
Hood River	0.44%
Jackson	0.69%
Jefferson	0.26%
Josephine	1.46%
Klamath	2.45%
Lake	0.06%
Lane	3.89%
Lincoln	0.61%
Linn	1.18%

County	Percent Activity
Malheur	2.33%
Marion	2.78%
Morrow	9.10%
Multnomah	32.55%
Polk	0.16%
Sherman	0.40%
Tillamook	1.14%
Umatilla	0.57%
Union	1.96%
Wallowa	0.20%
Wasco	2.40%
Washington	4.73%
Wheeler	0.00%
Yamhill	0.44%

Information on the temporal distribution of utility project work was not determined for the study. For emissions modeling purposes ERG assumed MOVES defaults for summer (30.6 percent of annual activity) and weekday (16.7 percent of total week activity) allocations.

4.3.4 Validation

ERG identified independent equipment productivity estimates for some of the utility project tasks for validation purposes.

- The profile's productivity estimate of 0.25 acres per day for clear and grub operations corresponds closely to the value from a National Cooperative Highway Research Program (NCHRP) study of 0.225 for "light clearing" activities.[207]
- The productivity estimate for removing site pavement of 17 cubic yards (CY) per hour is substantially lower than the value referenced by NCHRP for asphalt pavement demolition of 50 CY/hr.[208]
- The estimate for removing concrete curbs of 100 LF per hour was substantially higher than the RSMeans value of 45 LF/hr.[209] However, both SMEs independently verified the higher value as reasonable for utility work.
- RSMeans estimates slightly higher productivity for trench excavation than the SMEs (25 CY/hr[210] vs. 17 CY/hr).

[207] Skolnik, J., Brooks, M. and Oman, J. *Fuel Usage Factors in Highway and Bridge Construction*. NCHRP Report 744. 2013.

[208] Ibid.

[209] RSMeans Heavy Construction Cost Book, 2017. 31st edition.

[210] RSMeans profile for 4-6-foot-deep trench using a ½ cubic yard excavator working in common earth.

- The SME estimate for backfilling/compacting the trench (17 CY/hr) is within the broad range provided by RSMeans (12.5 – 75 CY/hr).[211]
- The SME estimate for finish grading of 500 SY per hour is comparable to the RSMeans value of 438.[212]
- The SME estimates for placing and compacting aggregate road base (150 tons/hour) is slightly lower than the NCHRP value of 217 tons/hr.[213]
- The SME and RSMeans values for placing and compacting asphalt were identical at 200 tons/hr.

For most tasks the equipment productivity estimates developed for the Utility sector profile were either comparable to or lower (i.e. requiring more hours of use) than independent estimates provided by RSMeans and NCRHP.

4.3.5 Sector Summary

Key observations regarding the Utility Sector profile include the following:

- The sector utilizes a mix of heavy construction equipment with the largest fuel consumption attributable to excavators and loaders. At approximately 770 thousand gallons of fuel consumption per year statewide, the sector is responsible for 5.3 percent the construction industry's overall total of 14.64M gallons.[214]
- As expected, Utility sector work is focused in counties with substantial populations and/or new development, with Multnomah, Clackamas, and Deschutes responsible for 58 percent of sector activity. However, rural county activity can be significant as well. For example, a single, very large sanitary sewer project in Morrow County was largely responsible for bringing the county's contribution to 9 percent of the state total.
- The profile's equipment productivity estimates were generally consistent with, or lower than, the independent data sources identified.
- The study relied on input regarding equipment use requirements and productivity from two SMEs, whose recommendations were largely consistent for most tasks. However, some uncertainty is caused by site-specific variations in task requirements, such as the percent of projects requiring pavement demolition and land clearing.
- Applying the standardized equipment use profile to the "Miscellaneous" project category (scaled by relative project value) adds an additional degree of uncertainty to the sector's activity estimates. Under the scaling assumption, the equipment usage intensity per dollar expended for the 28 Miscellaneous projects is assumed to equal

[211] See RSMeans profile 31 23 16.13.

[212] See RSMeans Profile 31 2 16.10.

[213] Skolnik, J., Brooks, M. and Oman, J. *Fuel Usage Factors in Highway and Bridge Construction*. NCHRP Report 744. 2013.

[214] Section 6.3.2 provides a detailed fuel consumption breakdown for the different construction industry components.

that of the 194 standardized projects, although the equipment mix and utilization levels are likely substantially different. Nevertheless, any bias introduced through this equivalency assumption is less of a concern as only about 10 percent of total sector project value is subject to the error.

4.4 Commercial and Institutional Building Sector

The Commercial and Institutional Building sector characterizes nonroad diesel equipment use associated with the construction, expansion, and alteration of commercial and institutional buildings and structures. The building and structure categories covered include:

- Apartments
- Commercial offices and banks
- Dormitories
- Government service buildings
- Hospitals and other health care facilities
- Hotels and motels
- Manufacturing, warehouse, and lab facilities
- Parking garages and automotive services
- Power, gas, and communication utility buildings
- Religious buildings
- Schools, libraries and research labs
- Stores and restaurants
- Storage units and other warehouses
- Social and recreational amusement facilities
- Other non-building structures (e.g. parks, public pools)

Work for this sector is conducted for private clients, municipalities, counties, and other government agencies.

4.4.1 Equipment Productivity Profile

ERG worked with an SME identified through AGC in order to update the equipment productivity profile originally developed for the state of Texas. The resulting profile is presented in Table 4-14, broken out by task. The "Percent of Tasks" column indicates how common it is for a piece of equipment to be used for a given task, based on SME input.

Table 4-14. Commercial Sector Equipment Productivity Profile
2017 Nonroad Diesel Equipment Study

Task #	Task Description	Quantity	Units	Equipment Type	HP	Percent of Tasks
1a	Building Demolition	191	SF/hr	Crawler tractors/dozers	250	20%
1b	Building Demolition	300	SF/hr	Excavators	300	80%
1c	Building Demolition	1,624	SF/hr	Rubber tire loaders	250	20%
2	Pavement Demolition	350	SF/hr	Excavators	138	100%
3a	Clear and Grub	0.32	Acres/hr	Crawler tractors/dozers	250	20%
3b	Clear and Grub	0.25	Acres/hr	Excavators	138	80%
4	Strip/Stockpile Topsoil	0.037	Acres/hr	Excavators	250	100%
5a	Cut and Fill	0.008	Acres/hr	Excavators	300	80%
5b	Cut and Fill	0.018	Acres/hr	Crawler tractors/dozers	250	20%
5c	Cut and Fill	0.040	Acres/hr	Rollers	125	100%
6	Excavate Utility Trench	20	CY/hr	Excavators	238	100%
7a	Backfill Trench	8	CY/hr	Excavators	138	80%
7b	Backfill Trench	8	CY/hr	Skid steer loaders	58	20%
8a	Rough Grade	4,000	SF/hr	Crawler tractors/dozers	238	30%
8b	Rough Grade	1,000	SF/hr	Excavators	300	100%
9a	Spread Crushed Stone	8,640	SF/hr	Crawler tractors/dozers	238	50%
9b	Spread Crushed Stone	3,780	SF/hr	Excavators	138	100%
10	Finish Grade	4,500[215]	SF/hr	Graders	238	100%
11	Spread Asphalt	8,000[216]	SF/hr	Pavers	138	100%
12	Compact Asphalt	10,800	SF/hr	Rollers	138	100%
13	Misc. Material Handling	3	Hrs/day	Rough terrain forklifts	86	100%
14	Subsurface Excavation	165	CY/hr	Excavators	350	100%

The following summarizes the key assumptions made regarding the above tasks.

- Demolition activities (Tasks 1 and 2) are relatively infrequent, occurring for just 4.5 percent of projects based on a review of municipal and county commercial demolition permits.[217] Demolition tasks were assigned to projects randomly with a frequency of 4.5 percent.

[215] The SME estimate for this task was a factor of 2.8 higher than that provided by the SMEs for the Utility profile for the same task and were set equal to the lower value to be conservative.

[216] The SME estimate for this task was a factor of 2.2 higher than that provided by the SMEs for the Utility profile for the same task and were set equal to the lower value to be conservative.

[217] Commercial demolition permit counts were obtained for 2017 for four counties (Deschutes, Hood River, Klamath and Washington), and nine cities (Cornelius, Forest Grove, Happy Valley, Milwaukie, Newport, Portland, Salem, Springfield, and West Linn).

- Clearing and grubbing, (land clearing - Task 3), stripping/stockpiling topsoil (Task 4), and cut and fill (leveling uneven terrain - Task 5) are assumed for the entire lot, but only for buildings designated as "New" in the Dodge data.
- Utility work (Tasks 6 and 7) is assumed for all new buildings, including covered parking lots. Separate trenches are assumed for sewer lines (6-foot depth), water lines (4-foot depth), and power/communication lines (2-foot depth). The required length of the lines is determined assuming square lots and building footprints,[218] with buildings placed at the back of the lot.
- Rough grading (Task 8) is assumed for the entire lot, including building footprint.
- Paving (Tasks 9-12) is assumed for a portion of the lot (excluding footprint) and varying with building type. Apartments are assumed to require one parking space requiring 288 SF[219] for each apartment unit. Commercial buildings are assumed to require four spaces per 1,000 SF of building, as per SME input.
- Miscellaneous material handling and cleanup activities (Task 13) are assumed to occur throughout the duration of the project.
- Subsurface excavation is assumed for structures with stories below ground.

4.4.2 Equipment Activity Estimation

ERG combined the modified equipment productivity profile with commercial project data obtained from Dodge Analytics.[220] Dodge provided ERG with a comprehensive list of commercial and institutional construction projects conducted in Oregon during 2017,[221] including the following information:

- General Description - Project Title, Structure Group and Structure Code
- Location – City and County
- Target Start and Completion Dates (partial list)
- Project Owner (e.g. city/county agency)
- Project Valuation ($)
- Number of buildings
- Number of stories (above and below ground)
- Building square footage

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[218] Building footprints were estimated by dividing total building square footage by the total number of stories (above and below ground).

[219] Angie Schmitt, StreetsBlog USA. "Parking Takes Up More Space Than You Think." July 5, 2016. https://usa.streetsblog.org/2016/07/05/parking-takes-up-more-space-than-you-think/.

[220] Dodge Data and Analytics. *Lead Center.* See http://dodgeprojects.construction.com/Select-Project-Oregon_stcVVcatId546098VVviewcat.htm for example project listings.

[221] The Dodge data contained complete listings for project start date. However, project end dates were almost entirely lacking. ERG assumed all projects with a start date on or before 2017 would be completed entirely within the analysis year, to be conservative.

- Other Project Details – non-standardized project descriptions, with some records including key information (e.g. number of apartment units, alteration details such as tenant improvements, etc.)

ERG excluded Dodge records with Project Details referencing work known to use minimal or no heavy diesel equipment, such as tenant improvements, buildouts and other alterations (i.e. interior remodeling). Information on one "Special Project" profiled separately was also removed to avoid double-counting.[222]

The final filtered list included 1,074 projects. Of these, 771 projects could be matched with the equipment productivity profile shown in Table 4-14. The remaining 303 records, categorized as "Miscellaneous", covered a wide range of project types including stadiums, dams and reservoirs, transmission towers and water tanks. These projects have very different equipment use requirements and could not be characterized using the general equipment profile.

Of the 771 building-related projects, 218 lacked information on building square footage, and 31 were missing information on the number of stories. ERG gap-filled missing information on the number of stories using the average number reported for each structure type (e.g. apartments, offices, etc.). ERG then investigated the relationships between square footage and project value reported in the Dodge data, finding a reasonably strong correlation within similar structure types (e.g. for manufacturing plants and warehouses, apartments and hotels, hospitals and offices, etc.).[223] Given these relationships, ERG gap-filled the missing square footage values by multiplying the average dollar per SF by the value for each project type (new, alterations, additions, etc.). Table 4-15 summarizes the average dollar per SF values for various new building categories. Table 4-16 presents the same information for the remaining project categories.

Table 4-15. Average Value per Square Foot – New Project Categories
2017 Nonroad Diesel Equipment Study

Building Type	# Projects	Avg $/SF	Structure Group #	Group Avg
Warehouses (excl. manufacturer owned)	51	$73	1	**$77**
Manufacturing Plants, Warehouses, Labs	6	$81	1	
Miscellaneous Non-residential Buildings	8	$99	1	
Parking Garages and Automotive Services	12	$135	2	**$137**
Stores and Restaurants	77	$137	2	
Apartments	137	$152	3	**$154**
Religious Buildings	1	$154	3	

[222] Refer to Section3.6 for Special Project details.

[223] Regression analyses evaluating the relationship between project value and square footage by structure type have been provided to DEQ electronically.

Building Type	# Projects	Avg $/SF	Structure Group #	Group Avg
Hotels and Motels	20	$161	3	
Dormitories	3	$166	3	
Office and Bank Buildings	51	$184	4	**$195**
Hospitals and Other Health Treatment	29	$215	4	
Amusement/Social/Recreational Buildings	10	$240	5	**$240**
Schools, Libraries, and Labs	36	$331	6	**$331**
Government Service Buildings	9	$332	6	

Table 4-16. Average Value per Square Foot – Miscellaneous Project Categories 2017 Nonroad Diesel Equipment Study

Project Category	# Projects	Average $/SF
Additions	33	$201
Alterations/Renovations, Interior Completions	83	$287
Alterations/Renovations, Additions	104	$557
New, Add, Alt or New, Add, Interior Completions	25	$361

Lot size was needed in order to apply the equipment use profile to each project, but in most cases this information was not included in the Dodge data set. Accordingly, ERG investigated the relationship between lot size and building footprint with the goal of using available footprint estimates for gap-filling.[224] Tax appraisal district and other websites were used to identify lot sizes for new projects with street addresses, and 126 properties were identified with lot size acreage in Jackson, Marion, Multnomah, and Washington counties. The ratio of building footprint to lot size varied markedly for apartments versus other building types as shown in Table 4-17. These factors were used to gap-fill missing lot sizes by dividing available project value by the appropriate factor.

Table 4-17. Average Value per Square Foot by Project Category 2017 Nonroad Diesel Equipment Study

Structure Category	# Projects	1,000 SF/Acre
Nonresidential	69	12.68
Apartments	57	24.03

[224] Regression analyses evaluating the relationship between lot size and building footprint by structure category have been provided to DEQ electronically.

Finally, 42 records were missing information on the number of apartment units.[225] A reasonably strong relationship was found between project value and the number of units,[226] and project values were divided by the average value of $149,908 per unit to gap-fill the missing data.

After gap-filling and applying the above assumptions, physical quantities were summed across all non-Miscellaneous project categories to assess statewide physical quantity requirements for the sector in 2017:

- 37.0M SF of building installation
- 17.8M SF of paving
- 108,370 cubic yards of trench excavation and backfilling

Once missing parameters were gap-filled, ERG randomly selected 4.5 percent of the projects for demolition tasks, then combined the project-specific information on lot size, building footprint, and required paving area with the equipment productivity profile in Table 4-14 to estimate total equipment use requirements for the 771 projects matched with the standardized equipment profile.[227] ERG then scaled the estimated equipment hours of use for the 771 projects upward to account for the 303 "Miscellaneous" projects that could not be linked with the standardized profile. Scaling was based on the project value ratio for the two project groups: $674,355,500 for "Miscellaneous" projects, divided by $6,224,386,000 for the remaining 771 projects, for a scaling factor of 10.8 percent.

The resulting state level equipment use profile for the Commercial and Institutional Building sector is presented in Table 4-18.

Table 4-18. Statewide Equipment Use Profile – Commercial and Institutional Building Sector
2017 Nonroad Diesel Equipment Study

Equipment Type	HP	Hours	HP-HRs/Yr	Gal/Yr[228]
Crawler tractors/dozers	246	35,569	3,872,619	205,246
Excavators	291	389,892	45,378,722	2,405,046
Graders	238	23,451	2,530,956	134,139
Pavers	137	2,219	142,000	7,526
Rollers	181	72,496	5,146,844	131,115
Rough terrain forklifts	86	173,017	6,565,937	386,448

[225] The number of units is needed to estimate parking requirements for apartment complexes.

[226] Regression analyses evaluating the relationship between apartment project value and the number of apartment units have been provided to DEQ electronically.

[227] Three solar farm projects were included in the list, assuming only clear and grub, rough and finish grading tasks.

[228] Calculated using EPA MOVES-Nonroad model (2014b). See Section 6.2 for additional details.

Equipment Type	HP	Hours	HP-HRs/Yr	Gal/Yr[228]
Rubber tire loaders	250	72	7,172	380
Skid steer loaders	58	2,709	64,439	4,394
Total		**673,756**	**61,035,735**	**3,274,294**

When combined with equipment model year distributions for the Oregon construction industry, this information provides the basis for estimating state-level emissions for the sector.

4.4.3 County/Temporal Allocation

The Dodge Analytics data used for this analysis included county information for each project listing. ERG summed the estimated equipment hp-hours associated with each project by county to determine the county level allocation factors for the Commercial and Institutional Building sector, shown in Table 4-19.

Table 4-19. Statewide Commercial and Institutional Building Sector County Activity Distribution
2017 Nonroad Diesel Equipment Study

County	Percent Activity
Baker	0.01%
Benton	0.53%
Clackamas	2.86%
Clatsop	0.81%
Columbia	1.30%
Coos	0.55%
Crook	4.81%
Curry	0.00%
Deschutes	8.06%
Douglas	0.62%
Gilliam	0.02%
Grant	0.00%
Harney	0.01%
Hood River	0.22%
Jackson	6.70%
Jefferson	0.07%
Josephine	0.19%
Klamath	0.62%

County	Percent Activity
Lake	0.00%
Lane	3.76%
Lincoln	0.39%
Linn	0.86%
Malheur	0.31%
Marion	7.23%
Morrow	0.43%
Multnomah	41.65%
Polk	0.17%
Sherman	0.03%
Tillamook	0.12%
Umatilla	1.56%
Union	0.04%
Wallowa	0.02%
Wasco	0.14%
Washington	15.18%
Wheeler	0.00%
Yamhill	0.73%

Information on the temporal distribution of commercial and institutional building projects was not determined for the study. For emissions modeling purposes ERG assumed MOVES defaults for summer (30.6 percent of annual activity) and weekday (16.7 percent of total week activity) allocations.

4.4.4 Validation

ERG identified independent equipment productivity estimates for some of the commercial and institutional sector tasks for validation purposes.

- The profile's productivity estimate of 0.25 acres per day for clear and grub operations corresponds closely to the value from an NCHRP study of 0.225 for "light clearing" activities.[229]
- The productivity estimate for removing site pavement of 39 square yards (SY) per hour (or 6.5 cubic yards (CY) per hour assuming 6-inch pavement) is much lower than the value referenced by NCHRP for asphalt pavement demolition of 50 CY/hr.[230]
- RSMeans estimates slightly higher productivity for trench excavation than the SMEs (25 CY/hr[231] vs. 20 CY/hr).
- The SME estimate for backfilling/compacting the trench (8 CY/hr) is slightly outside the range provided by RSMeans (12.5 – 75 CY/hr).[232]
- The SME estimate for finish grading of 12,600 SF per hour was much higher than the to the RSMeans value of 3,942 SF per hour,[233] and the Utility profile value of 4,500 SF per hour. (Value was reset to 4,500 SF per hour to be consistent with Utility profile.)
- The SME estimate for spreading asphalt of 18,000 SF per hour was much higher than the to the RSMeans and Utility profile value of 8,000 SF per hour. (Value was reset to 8,000 SF per hour to consistent with Utility profile.)

For most tasks the equipment productivity estimates developed for the commercial sector profile were either comparable to or lower (i.e. requiring more hours of use) than independent estimates provided by RSMeans and NCRHP.

Sector-wide estimates were also generated for North Texas to provide additional points of comparison for certain components of the Oregon construction sector. ERG used the Texas Commission on Environmental Quality's TexN2.0 utility[234] to estimate fuel consumption for the single-family housing, commercial building, and highway/utility subsectors operating in the

[229] Skolnik, J., Brooks, M. and Oman, J. *Fuel Usage Factors in Highway and Bridge Construction*. NCHRP Report 744. 2013.

[230] Ibid.

[231] RSMeans profile for 4-6-foot-deep trench using a ½ cubic yard excavator working in common earth.

[232] See RSMeans profile 31 23 16.13.

[233] See RSMeans Profile 31 2 16.10.

[234] Eastern Research Group. "TexN2.0 User Guide," prepared for the Texas Commission on Environmental Quality, May 9, 2019.

DFW region for 2017.[235,236] Table 4-20 compares the relative fuel consumption percentages across these subsectors for DFW and for Oregon as a whole.

Table 4-20. Relative Fuel Consumption Comparison for Selected Construction Subsectors 2017 Nonroad Diesel Equipment Study

Sector	Oregon	DFW
Single Family Housing	31%	29%
Commercial/Institutional Buildings	36%	35%
Highway + Utility[237]	33%	36%
Total	**100%**	**100%**

While the specific construction project operating conditions and requirements vary between the two regions, the relative fuel consumption estimates are clearly similar for all three subsectors.

4.4.5 Sector Summary

Key observations regarding the Commercial and Institutional Building Sector profile include the following:

- The sector utilizes a mix of heavy construction equipment excavators responsible for over half of all fuel consumption. At approximately 3.3M gallons of fuel consumption per year statewide, the sector is responsible for 22.4 percent the construction industry's overall total of 14.64M gallons.[238]
- As expected, Commercial and Institutional sector work is highly focused in counties with substantial populations and/or new development, with Multnomah and Washington County alone responsible for half of sector activity.
- The profile's equipment productivity estimates were generally consistent with, or lower than, the independent data sources identified.
- The study relied on input regarding equipment use requirements and productivity from a single SME, although many of their recommendations were consistent with the base profile. Additional uncertainty is caused by site-specific variations in task requirements. For example, differences in lot sizes, vegetation and terrain impact all

[235] The TexN2.0 model defines single-family housing, commercial, and highway/utility construction in a way similar to that used for this study. However, the TexN model accounts for specific equipment activity (e.g. from backhoes and trenchers) in a manner inconsistent with the study's approach. As such, this equipment is excluded from the comparison in Table 4-20.

[236] The DFW region was chosen as it includes a range of urban and suburban construction project settings.

[237] The highway and utility subsectors are broken out differently by the TexN2.0 model and are combined here to allow for consistent comparison with the Oregon study totals.

[238] Section 6.3.2 provides a detailed fuel consumption breakdown for the different construction industry components.

impact land clearing requirements. These uncertainties could be reduced in the future through input from additional SMEs.

Applying the standardized equipment use profile to the "Miscellaneous" project category (scaled by relative project value) adds an additional degree of uncertainty to the sector's activity estimates. Under the scaling assumption, the equipment usage intensity per dollar expended for the 303 Miscellaneous projects is assumed to equal that of the 771 standardized projects, although the equipment mix and utilization levels are likely substantially different. Nevertheless, any bias introduced through this equivalency assumption is less of a concern as only about 11 percent of total sector project value is subject to the error.

4.5 Highway and Road Sector – ODOT Construction Program Profile

The highway and road sector includes construction and maintenance activities performed on public highways and roads across the state. Equipment needs vary greatly depending on the type of project (e.g. new construction, bridgework, reconstruction). Projects covered in this section are contracted out; highway and road projects conducted in-house using public agency fleets are included in the Public Fleet profiles presented in Section 3.1.

The single largest contracting entity in the highway sector is the ODOT's Highway Division. City and county agencies are responsible for significant contracting as well, with a smaller number of contracts administered by other federal, state and local agencies. The information available for characterizing equipment use in this sector varies by contracting entity, as described below.

ODOT maintains a repository of highly detailed information on projects within their Construction and Maintenance and Operations Programs. Each bid item includes the following information:

- Contract Number
- Project Title
- ODOT Region
- County/Counties
- Completion Date
- Prime Contractor
- Bid item Number
- Standard Item Code
- Bid Item Description
- Quantity
- Quantity Units (e.g. tons, square yards, etc.)
- Amount ($)

Multiple bid items are listed for each construction project specifying a precise task and quantity (e.g. 100 LF of trenching), allowing contractors to estimate equipment use requirements and overall costs. ERG requested and obtained a complete listing of Construction Program bid item records for the 2017 calendar year from ODOT's Highway Division. The bid item list obtained from ODOT provides an opportunity to estimate equipment use requirements at an extremely granular level, far beyond that possible through standard project surveys. The raw data included 25,369 records, 24,417 of which represented activity occurring during 2017.

ERG evaluated all 24,417 bid items to identify and exclude activities that required little or no nonroad diesel equipment greater than 25 hp. For example, a large number of bid items were associated exclusively with project planning and preparation (e.g. mobilization), field labor (e.g. flaggers), licensed vehicles using PTO (e.g. striping activities), handheld and/or gasoline powered equipment (e.g. walk behind shot blasters), or accounting adjustments (e.g. escalations, payment adjustments, and overtime). ERG also removed bid items with quantities and/or dollar values less than zero, as these would translate to negative equipment activity levels.[239]

ERG consulted with SMEs contacted through AGC, other industry experts, and a variety of reference sources to identify additional bid items for exclusion. Bid items utilizing only cranes, air compressors, aerial lifts, chippers/stump grinders, geotechnical boring/drilling units and/or welders were also excluded from the highway construction profile, as their profiles were developed and presented separately. After review, a total of 15,151 bid items were excluded, leaving 9,264 items for further analysis. The list of excluded bid item categories is provided in Appendix E.

4.5.1 Equipment Productivity Profile and Activity Estimation

The remaining 9,264 bid item records were assumed to require heavy nonroad diesel equipment use.

ERG primarily relied upon three references to link equipment use requirements with bid items– ODOT's 2018 Standard Specifications for Construction, RSMeans' Heavy Construction Costs reference guide for 2018, and "Fuel Usage Factors in Highway and Bridge Construction" developed for the NCHRP in 2013.[240, 241, 242] ODOT's Standard Specification guide simply listed the equipment required to execute a given bid item. The RSMeans and NCHRP references identified equipment needs as well as average productivity values.

ERG consulted online references as well as SMEs to determine which RSMeans and NCHRP equipment use profiles were most appropriate for the different bid items. Ultimately 7,906 (85 percent) of the bid items (referred to as "assigned bid items") were assigned to 1 of 39 equipment use profiles developed for the study. Each profile features a unique set of equipment requirements and productivity assumptions. The following lists the steps required to

[239] Negative quantities and/or dollars are assumed represent ODOT accounting adjustments.

[240] Oregon Department of Transportation. *Oregon Standard Specifications for Construction.* 2018. https://www.oregon.gov/odot/Business/Pages/Standard_Specifications.aspx.

[241] RSMeans Heavy Construction Cost Book, 2017. 31st edition.

[242] National Asphalt Pavement Association. *How to Determine Quantities.* http://www.asphaltpavement.org/index.php?option=com_content&view=article&id=144&Itemid=227.

estimate equipment activity along with an example calculation for the "Excavation" profile, based on the NCHRP profile for "general grading" work.[243]

1. Identify required equipment as per the reference profile;
2. Look up the associated hp values for all equipment based on SME input, manufacturer websites and/or other references;
3. Look up the estimated engine load factor for each piece of equipment;
4. Identify the task productivity estimate from the reference profile;
5. Determine quantity for the specific bid item from ODOT records; and,
6. Calculate the work required for each piece of equipment in hp-hours.

Example calculation (Excavation work):

- Required equipment from NCHRP "general grading" profile
  - One Caterpillar D-7G Dozer
  - One Caterpillar 345 GC Excavator
  - One Caterpillar 12G Grader, and
  - One Caterpillar 815 Roller.
- Representative hp values from manufacturer websites
  - Dozer = 200 hp
  - Excavator = 345 hp
  - Grader = 135 hp
  - Roller = 170 hp.
- Engine load factors from CARB construction equipment analyses
  - Dozer = 0.40
  - Excavator = 0.38
  - Grader = 0.41
  - Roller = 0.38
- Task productivity from NCHRP "general grading" profile
  - 233 cubic yards per hour
- Specific bid item quantity from ODOT Construction Program Bid Item
  - 1,000 cubic yards (CY)
- Equipment activity in hp-hours

[243] The hp-hr values for each equipment type/hp combination are combined with emission factors from EPA's MOVES model to estimate total emissions for each project and the sector as a whole.

- Dozer: (1,000 CY / 233 CY/hr) x 200 hp x 0.40 = 343 hp-hours
- Excavator: (1,000 CY / 233 CY/hr) x 345 hp x 0.38 = 563 hp-hours
- Grader: (1,000 CY / 233 CY/hr) x 135 hp x 0.41 = 238 hp-hours
- Roller: (1,000 CY / 233 CY/hr) x 170 hp x 0.38 = 277 hp-hours

In many instances the units provided in the ODOT bid item data for physical quantities did not match the units specified in the reference profiles. For example, 22 of the general excavation items expressed quantities in tons rather than cubic yards (used in the NCHRP profiles). In this case ERG converted the tons to cubic yards using an average value of 1.25 CY/ton, as per SME guidance.

In cases where quantities were reported as lump sums ERG estimated an average dollar value and converted units by dividing the reported lump sum amount by the conversion value. (For instance, if a bid item for riprap was priced as a $1,000 lump sum, and other riprap bids reported in terms of tons averaged of $25/ton, ERG assumed $1,000/25 = 40 tons of riprap for the lump sum item). Such unit conversion factors were based on averages for other ODOT records if 10 or more records were available. Otherwise ERG referred to average cost data provided for selected ODOT bid items.[244, 245]

Table 4-21 summarizes the quantities and equipment activity estimated for each of the 39 equipment use profiles developed for the study.

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[244] Oregon Department of Transportation. *Weighted Average Price Item Report*. 2017. https://www.oregon.gov/ODOT/Business/Documents/Weighted_Average_Prices_2017.pdf.

[245] Oregon Department of Transportation. *Bridge Cost Data Report.* ftp://ftp.odot.state.or.us/Bridge/CostData/CostDataBook2017/.

**Table 4-21. ODOT Construction Program - Equipment Use Profile Categories
2017 Nonroad Diesel Equipment Study**

Profile Category	# Bid Items	Project Value ($)	Quantity	Units	Hours	HP-HRs
Asphalt Concrete Pavement - Repair	25	$340,040	349	Square Yards	349	25,837
Asphalt Concrete Pavement	1,412	$57,490,968	940,133	Tons	4,690	773,513
Backfill/Compaction	124	$1,000,488	19,038	Cubic Yards	288	12,948
Base Stone	1,282	$10,289,896	483,130	Tons	2,226	373,501
Blast Hole Drilling	17	$502,382	52,559	Feet	1,752	337,255
Clear and Grub	123	$745,559	257	Acres	1,711	497,211
Cold Planing	557	$7,407,251	4,121,617	Square Yards	7,338	4,569,109
Concrete Barrier Install/Removal	184	$4,596,135	201,371	Feet	4,738	507,738
Concrete Grooving	14	$103,968	26,437	Square Yards	53	32,922
Concrete Manhole, Inlet, Catch Basin	333	$2,169,540	828	Each	3,311	94,335
Concrete Repair	52	$1,080,048	1,101	Square Yards	105	6,415
Demo Pavement/Curbs	96	$281,903	45,289	Square Yards	1,380	72,845
Drilled Shaft Supports	68	$2,671,336	2,911	Feet	438	65,753
Excavation	595	$17,921,387	2,047,034	Cubic Yards	8,786	2,908,458
Fence Installation	97	$873,881	61,659	Feet	2,466	52,928
Guardrail Installation	412	$8,225,272	403,377	Feet	2,892	206,492
Guardrail Removal	25	$122,173	14,722	Feet	196	3,486
Hydrodemolition	2	$45,807	3,054	Square Yards	366	20,448
Large Drainpipe Installation	9	$100,440	421	Feet	53	15,548
Medium Drainpipe Installation	73	$579,387	7,599	Feet	475	95,462
Pavement Marking with Grooving	16	$485,868	388	Mile	129	11,486
Remove Fence	15	$22,870	11,824	Feet	236	4,200
Remove Pipes	35	$75,289	6,311	Feet	263	39,791
Remove Traffic Lines	103	$188,445	577,679	Feet	92	4,464
Retaining Walls	159	$7,479,444	118,256	Square Feet	3,153	67,674

Profile Category	# Bid Items	Project Value ($)	Quantity	Units	Hours	HP-HRs
Rigid Concrete Paving	103	$11,594,371	155,401	Square Yards	568	85,940
Riprap and Rock Lining	100	$793,928	33,632	Tons	448	35,874
Rumble Strips	38	$385,846	335	Mile	112	9,927
Saw Cut Control Joints	61	$130,420	72,237	Feet	722	28,555
Sewer Line Installation	468	$3,966,071	47,827	Feet	7,395	1,486,390
Sidewalks/Curbs/Islands/Driveways	607	$7,359,595	385,401	Feet	2,471	194,213
Sign Supports/Footings/Foundations	80	$719,595	555	Cubic Yards	33	3,287
Small Drainpipe Installation	96	$363,179	12,964	Feet	540	108,571
Subgrade Stabilization	136	$2,861,866	114,676	Square Yards	1,597	910,163
Topsoil Placement and Grading	68	$468,161	14,892	Cubic Yards	596	15,654
Trenching	36	$188,405	8,329	Cubic Yards	490	114,096
Utility Connections	10	$70,507	14	Each	112	1,989
Water Distribution Valves	32	$198,564	42	Each	57	1,004
Water Line/Communication Installation	243	$3,625,736	311,980	Feet	16,266	3,269,438
Total	**7,906**	**$157,526,022**			**78,896**	**17,064,921**

A detailed listing of each of the equipment use profiles was provided to DEQ in electronic format, noting representative bid item descriptions, estimated productivity, assigned equipment types, hp, and key assumptions.

Projects involving paving and pavement demolition tasks were assumed to utilize additional equipment for cleanup and miscellaneous maintenance tasks, including skid steers, backhoes, sweepers, and off-highway water trucks. The SMEs estimated clean up and maintenance activities require roughly 1 hour per day on average. Table 4-22 summarizes the activity associated with clean up and maintenance tasks based on the 1 hr/day activity assumption for the four equipment categories.

Table 4-22. Cleanup and Maintenance Equipment Hours/Year
2017 Nonroad Diesel Equipment Study

Profile Category	Skid Steers	Backhoes	Sweepers	Water Trucks[246]	Total Hours
Asphalt Concrete Paving	586	586	586	293	4,690
Small Drainpipe Installation	68	68	68	34	540
Medium Drainpipe Installation	59	59	59	30	475
Large Drainpipe Installation	7	7	7	3	53
Sewer Line Installation	924	924	924	462	7,395
Water Line Installation	2,033	2,033	2,033	1,017	16,266
Asphalt Concrete Pavement Repair	44	44	44	22	349
Total Hours	**3,721**	**3,721**	**3,721**	**1,860**	**29,768**
Avg HP	58	87	134	280	
Load Factor	0.37	0.37	0.46	0.38	
HP-HRs	79,852	119,777	229,359	197,955	**626,943**

Approximately 15 percent of bid items associated with heavy diesel equipment use (1,358) were not included in the final equipment profile assignments. These “unassigned bid items” cover a wide variety of activities that could not be characterized adequately for inclusion in the equipment use profiles. For example, numerous bid items specified work on “water quality swales” and “bioretention ponds”, with quantities expressed as a lump sum (as opposed to cubic yards, tons, or some other discrete physical measure of scale). These activities require earthwork of some type, but the bid item descriptions are not specific enough to determine the equipment types and/or hours of use. Appendix F provides a detailed list of the unassigned bid items and their corresponding dollar values.

[246] Multiple SMEs also estimated that 50 percent of the water trucks were certified for on-road use and excluded from the analysis. This reduction accounts for the lower total hours relative to other maintenance equipment.

Unassigned bid item categories were responsible for 19.3 percent of the total dollar value associated with ODOT Construction Program projects using nonroad equipment. ERG assumed the unassigned bid categories for this sector would have equipment use requirements similar to the assigned categories, proportional to bid item dollar value. Accordingly, ERG scaled the activity and fuel consumption estimates by an additional 19.3 percent to account for the unassigned bid item categories. The resulting statewide equipment activity profile estimates are provided in Table 4-23.

Table 4-23. ODOT Construction Program – Statewide Equipment Use Profile 2017 Nonroad Diesel Equipment Study

Equipment Type	HP	Hours/Yr	HP-HRs/Yr	Gal/Yr[247]
Bore/drill rigs	328	1,859	228,700	11,990
Concrete/industrial saws	67	1,010	39,944	2,332
Crawler tractors/dozers	158	49,103	2,144,721	118,912
Excavators	316	50,499	6,011,973	318,631
Graders	161	16,291	1,035,840	54,899
Off-highway trucks	287	1,556	86,593	4,589
Other construction equipment	169	3,644	257,589	13,652
Pavers	186	6,501	502,147	26,614
Rollers	147	26,891	1,444,732	76,570
Rubber tire loaders	151	42,132	2,206,705	118,960
Skid steer loaders	58	12,912	243,694	14,331
Surfacing equipment	681	14,775	5,610,505	297,353
Tractors/loaders/backhoes	73	8,313	214,940	14,688
Paving equipment	153	2,809	151,595	8,034
Sweepers/scrubbers	134	12,137	652,215	34,194
Total		**250,434**	**20,831,894**	**1,115,749**

When combined with equipment model year distributions for the Oregon construction industry, this information provides the basis for estimating state-level emissions for the sector.

4.5.2 County/Temporal Allocation

ERG summed the estimated equipment hp-hours associated with each project by county to determine the county level activity distribution for the ODOT Construction Program sector, shown in Table 4-24.

[247] Calculated using EPA MOVES-Nonroad model (2014b). See Section 6.2 for additional details.

Table 4-24. Statewide ODOT Construction Program Sector County Activity Distribution 2017 Nonroad Diesel Equipment Study

County	Percent Activity	County	Percent Activity
Baker	1.79%	Lake	1.88%
Benton	0.41%	Lane	5.67%
Clackamas	6.78%	Lincoln	3.65%
Clatsop	2.57%	Linn	3.56%
Columbia	0.83%	Malheur	0.07%
Coos	1.22%	Marion	1.44%
Crook	0.02%	Morrow	0.07%
Curry	0.80%	Multnomah	9.65%
Deschutes	4.39%	Polk	1.30%
Douglas	7.10%	Sherman	0.01%
Gilliam	0.11%	Tillamook	7.64%
Grant	0.07%	Umatilla	1.09%
Harney	0.07%	Union	0.59%
Hood River	1.73%	Wallowa	0.07%
Jackson	11.15%	Wasco	2.74%
Jefferson	0.93%	Washington	10.25%
Josephine	0.82%	Wheeler	0.01%
Klamath	2.74%	Yamhill	6.79%

Information on the temporal distribution of ODOT project work was not determined for the study. For emissions modeling purposes ERG assumed MOVES defaults for summer (30.6 percent of annual activity) and weekday (16.7 percent of total week activity) allocations.

4.5.3 Validation

ERG received comprehensive equipment use, fuel consumption and project dollar value information for nine highway and road construction projects conducted by three general contractors operating in Oregon in 2017. These projects covered a wide range of activities, including new highway construction, maintenance, and bridgework. ERG used this information to estimate the gallons of fuel consumed per million dollars of contract value for each project. ERG then applied that ratio to the total contract value for the ODOT Construction Program in 2017 to develop an independent fuel consumption estimate, as shown in Table 4-25.

Table 4-25. ODOT Construction Program – Survey-Based Fuel Consumption Validation 2017 Nonroad Diesel Equipment Study

Survey #	Contract Value	Total Gal	Gal/M$
1	$10,712,398	27,000	2,520
2	$5,568,526	60,000	10,775
3	$8,767,233	70,000	7,984
4	$2,476,032	10,000	4,039
5	$26,000,000	55,960	2,152
6	$4,700,000	14,527	3,091
7	$10,000,000	58,825	5,883
8	$23,000,000	75,013	3,261
9	$9,000,000	30,096	3,344
Total	**$100,224,189**	**401,421**	**4,005**
ODOT 2017 Contract $ - all projects	**$336,854,556**		
Estimated Gallons - Survey Basis	**1,349,180**		
Estimated Gallons - Profile Basis	**1,150,847**		
Percent Difference	**17%**		

To the extent that the mix of surveyed projects is representative of ODOT Construction Program projects in 2017, the estimated fuel consumption shown in Table 4-25 should be similar. At a 17 percent difference this may be the case, although the relatively small number of projects included in the survey reduces the confidence level.

ERG was also able to compare the ODOT bid item data directly with five project surveys that were completed entirely within the 2017 calendar year. The total gallons estimated for these five projects (182,819) was 82 percent of the reported gallons from the surveys (222,960). The difference (18 percent) is very close to the 17 percent value noted in Table 4-25, further increasing the confidence in the study's fuel consumption estimate for the sector.

4.5.4 Sector Summary

Key observations regarding the ODOT Construction Program Sector profile include the following:

- The sector utilizes a variety of heavy construction equipment with excavators, loaders, dozers, and cold planers responsible for over three quarters of the sector's fuel consumption. At approximately 1.1M gallons of fuel consumption per year statewide, the sector is responsible for 7.6 percent the construction industry's overall total of 14.64M gallons.[248]

[248] Section 6.3.2 provides a detailed fuel consumption breakdown for the different construction industry components.

- While sector work is somewhat more prevalent in counties with substantial population and/or new development, rural project work is clearly evident, with all 36 counties having some amount of ODOT project activity.
- Identifying required equipment types and estimating hours of use for associated bid quantities proved challenging, not only due to the sheer number of records, but also because many of the bid items are not fully standardized. For example, excavation items may be billed by the cubic yard or as a lump sum, drilled shafts may or may not specify shaft diameter, "backfill" may be abbreviated in different ways, etc.
- The study relied on input regarding equipment use requirements and productivity from multiple SMEs, and many of their recommendations were consistent with equipment productivity values reported in industry reference guides and the literature. However, as with all generalized equipment use profiles, some uncertainty is unavoidable due to project-specific variations in site conditions. For example, differences in site access, soil conditions and weather, among many other factors, impact equipment use requirements.
- The independent, survey-based fuel consumption estimates were generally consistent with the profile's estimates.
- Scaling the profiled equipment activity upward to account for unassigned bid items adds a further element of uncertainty to the sector's activity estimates. Under the scaling assumption, the equipment usage intensity per dollar expended for the unassigned bid items is assumed to equal that of the assigned bid item list, although the equipment mix and utilization levels may be substantially different. Nevertheless, any bias introduced through this equivalency assumption is less of a concern as only about 10 percent of total sector project value is subject to the error.

4.6 Highway and Road Sector – ODOT Maintenance and Operations Program Profile

This sector includes project activities performed under ODOT's Maintenance and Operations program across the state. Projects covered under this sector are contracted out; highway and road projects conducted in-house using public agency fleets are included in the Public Fleet profiles presented in Section 3.1.

ERG obtained bid item data for projects conducted during 2017 for ODOT's Maintenance and Operations Program. This data set was significantly smaller than the Construction Program data, containing 1,742 records. The data was processed in the same manner as the Construction Program data, excluding a total 1,207 records assumed to have minimal-to-no heavy nonroad diesel equipment use. Bid items utilizing only cranes, air compressors, aerial lifts, chippers/stump grinders, geotechnical boring/drilling units and/or welders were also excluded from the profile, as their activity is characterized and presented separately. Bid item exclusions were based on SME input, ODOT's Standard Specifications, and various web resources. The majority of the exclusions were similar to those made for the Construction

Program dataset, with additional exclusions for material purchases, price agreements for on-call services,[249] and building construction (e.g. rest areas).[250]

4.6.1 Equipment Productivity Profile and Activity Estimation

The equipment assignment process and profile categories used for the remaining 535 records are the same as those used for the Construction Program. Table 4-26 presents the equipment use profile categories for the ODOT Maintenance and Operations Program.

Table 4-26. ODOT Maintenance and Operations Program - Equipment Use Profile Categories
2017 Nonroad Diesel Equipment Study

Profile Category	# Bid Items	Project Value	Quantity	Units	Hours	HP-HRs
Asphalt Concrete Pavement Repair	2	$45,140	3,200	Square Yards	13	976
Base Stone	36	$1,570,934	42,795	Tons	197	33,084
Asphalt Concrete Paving	96	$18,164,297	248,368	Tons	1,242	204,705
Asphalt Pavement Patches	5	$130,815	3,841	Square Feet	34	636
Backfill/Compaction	6	$104,296	3,020	Cubic Yards	38	1,885
Clear and Grub	10	$76,133	10	Acres	39	11,426
Cold Planing	103	$2,997,505	777,076	Square Yards	1,791	1,115,404
Concrete Barrier Install/Removal	1	$750	63	Feet	1	158
Concrete Manhole, Inlet, Catch Basin	7	$43,773	9	Each	36	1,026
Concrete Paving	3	$39,220	1,891	Square Feet	5	764
Concrete Repair	2	$189,000	172	Square Yards	15	942
Demo Pavement/Curbs	2	$6,220	1,178	Square Yards	37	2,719
Excavation	42	$2,606,704	113,823	Cubic Yards	489	161,721
Fence Installation	13	$179,148	92,485	Feet	3,699	79,389
Guardrail installation, including terminals	22	$254,427	8,440	Feet	28	2,009
Large drainpipe installation	2	$39,120	95	Feet	12	3,506
Medium drainpipe installation	1	$27,060	165	Feet	10	2,073
Remove Guardrail	4	$18,248	2,127	Feet	28	504
Retaining Wall	2	$826,250	14,678	Square Feet	391	8,400
Riprap and Rock Lining	10	$155,677	2,199	Tons	29	2,346
Rumble Strips	3	$20,052	18	Mile	6	538

[249] The data set contained separate records for actual service payments, so on-call contract records were removed to avoid double-counting.

[250] Institutional building construction is included in the Commercial/Institutional Building profile, presented in Section 4.4.

Profile Category	# Bid Items	Project Value	Quantity	Units	Hours	HP-HRs
Saw cut control joints	8	$29,137	7,324	Feet	73	2,895
Sewer Lines	6	$303,588	1,207	Feet	227	45,647
Sidewalks/curbs	17	$194,091	5,874	Feet	38	2,992
Small drainpipe installation	11	$592,200	17,483	Feet	728	146,420
Subgrade Stabilization	4	$270,750	8,425	Square Yards	70	40,016
Supports/Footings/Foundations	20	$104,057	3,923	Cubic Yards	232	23,249
Topsoil Placement and Grading	3	$28,805	375	Cubic Yards	15	395
Water Lines	11	$405,759	69,818	Feet	3,505	704,575
Total	**452**	**$29,423,155**			**13,033**	**2,600,397**

Equipment were also assigned for miscellaneous cleanup and site maintenance activities, assuming one hour of use per day for skid steers, backhoes, sweepers, and water trucks,[251] as per SME input (see Table 4-27).

Table 4-27. Cleanup and Maintenance Equipment Activity Hours/Year (Maintenance and Operations Program)
2017 Nonroad Diesel Equipment Study

Category	Skid Steers	Backhoes	Sweepers	Water Trucks	Total Hrs
Asphalt Concrete Paving	155	155	155	78	1,242
Small Drain Pipe Installation	91	91	91	46	728
Medium Drainpipe Installation	1	1	1	1	10
Large Drainpipe Installation	1	1	1	1	12
Sewer Line Installation	28	28	28	14	227
Water Line Installation	438	438	438	219	3,505
ACP Repair	2	2	2	1	13
Total	**717**	**717**	**717**	**359**	**5,738**
Avg HP	58	87	134	280	
Load Factor	0.37	0.37	0.46	0.38	
HP-HRs	15,392	23,089	44,212	38,158	**120,852**

Approximately 16 percent of the bid items assumed to have significant heavy nonroad diesel equipment use could not be included in the final equipment profile assignments. These unassigned bid items are responsible for 10.7 percent of the total value of contracts with nonroad equipment use. As with the Construction Program Profile, ERG assumed the unassigned bid categories would have equipment use requirements similar to the assigned

[251] 50% of water trucks were assumed to be on-road licensed vehicles which are excluded, resulting in the lower total hours of use compared to other cleanup and maintenance equipment.

categories, proportional to bid item dollar value. Accordingly, ERG scaled the activity and fuel consumption estimates presented in Table 4-26 and Table 4-27 by an additional 10.7 percent to account for unassigned bid item categories. The resulting statewide equipment activity profile estimates are provided in Table 4-28.

Table 4-28. ODOT Maintenance and Operations Program – Statewide Equipment Use 2017 Nonroad Diesel Equipment Study

Equipment Type	HP	Hours	HP-HRs	Gallons[252]
Bore/drill rigs	200	257	25,736	1,343
Concrete/industrial saws	67	98	3,881	227
Crawler tractors/dozers	107	5,882	186,787	10,622
Excavators	317	5,555	668,756	35,444
Graders	158	845	53,116	2,815
Off-highway trucks	282	112	11,952	633
Other construction equipment	170	31	2,224	118
Pavers	188	1,386	109,291	5,792
Rollers	129	3,648	171,419	9,088
Rubber tire loaders	146	7,007	356,648	19,323
Skid steer loaders	58	5,029	103,150	7,029
Surfacing equipment	736	2,145	1,075,452	56,998
Tractors/loaders/backhoes	80	340	9,698	664
Paving equipment	149	39	2,041	108
Sweepers/scrubbers	134	2,428	135,936	7,127
Total		**34,802**	**2,916,087**	**157,331**

When combined with equipment model year distributions for the Oregon construction industry, this information provides the basis for estimating state-level emissions for the sector.

4.6.2 County/Temporal Allocation

ERG summed the estimated equipment hp-hours associated with each project by county to determine the county level activity distribution for the ODOT Maintenance and Operations Program sector, shown in Table 4-29.

252 Calculated using EPA MOVES-Nonroad model (2014b). See Section 6.2 for additional details.

Table 4-29. Statewide ODOT Maintenance and Operations Program Sector County Activity Distribution
2017 Nonroad Diesel Equipment Study

County	Percent Activity	County	Percent Activity
Baker	1.80%	Lake	0.07%
Benton	0.90%	Lane	4.88%
Clackamas	5.23%	Lincoln	1.81%
Clatsop	0.11%	Linn	3.31%
Columbia	1.17%	Malheur	26.52%
Coos	9.14%	Marion	1.10%
Crook	0.19%	Morrow	0.00%
Curry	0.04%	Multnomah	5.12%
Deschutes	0.00%	Polk	0.32%
Douglas	6.00%	Sherman	0.00%
Gilliam	11.93%	Tillamook	0.86%
Grant	0.00%	Umatilla	9.81%
Harney	0.00%	Union	0.56%
Hood River	0.15%	Wallowa	0.00%
Jackson	3.73%	Wasco	1.70%
Jefferson	0.00%	Washington	2.61%
Josephine	0.02%	Wheeler	0.02%
Klamath	0.13%	Yamhill	0.77%

Information on the temporal distribution of ODOT project work was not determined for the study. For emissions modeling purposes ERG assumed MOVES defaults for summer (30.6 percent of annual activity) and weekday (16.7 percent of total week activity) allocations.

4.6.3 Validation

No independent data sources were identified to validate the ODOT Maintenance and Operations program sector profile. However, the bid item categories, equipment assignment and productivity assumptions for this sector are identical to the ODOT Construction program sector.[253]

4.6.4 Sector Summary

Key observations regarding the ODOT Maintenance and Operations Program Sector profile include the following:

[253] See Section 4.5.3 for information on the validation exercise for the ODOT Construction Program profile.

- The sector utilizes a variety of heavy construction equipment with excavators, loaders, dozers, and cold planers responsible for over three quarters of the sector's fuel consumption. At 157,331 gallons of fuel consumption per year statewide, the sector is responsible for 1.1 percent the construction industry's overall total of 14.64M gallons.[254]
- Sector work is relatively common in rural counties, with a limited number of projects in Coos, Gilliam and Malheur counties responsible for almost 50 percent of total sector activity.
- Identifying required equipment types and estimating hours of use for associated bid quantities proved challenging, not only due to the sheer number of records, but also because many of the bid items are not fully standardized.
- The study relied on input regarding equipment use requirements and productivity from multiple SMEs, and many of their recommendations were consistent with equipment productivity values reported in industry reference guides and the literature. However, as with all generalized equipment use profiles, some uncertainty is unavoidable due to project-specific variations in site conditions. For example, differences in site access, soil conditions and weather, among many other factors, impact equipment use requirements.
- Scaling the profiled equipment activity upward to account for unassigned bid items adds a further element of uncertainty to the sector's activity estimates. Under the scaling assumption, the equipment usage intensity per dollar expended for the unassigned bid items is assumed to equal that of the assigned bid item list, although the equipment mix and utilization levels may be substantially different. Nevertheless, any bias introduced through this equivalency assumption is less of a concern as only about 11 percent of total sector project value is subject to the error.

4.7 Highway and Road Sector – City, County and Other Agencies Profile

This profile includes highway and roadwork contracted by cities, counties, and other public agencies, excluding ODOT. Project types were similar to those managed by ODOT, with an emphasis on repair and maintenance work.

4.7.1 Equipment Productivity Profile and Activity Estimation

ERG worked with the League of Oregon Cities and the Association of Oregon Counties to obtain information regarding projects conducted across Oregon during 2017. Responses were obtained from 11 counties and 26 municipalities. The information provided included the following:

- City/County
- Project Name

[254] Section 6.3.2 provides a detailed fuel consumption breakdown for the different construction industry components.

- Brief Project Description
- Start and End Dates
- Contract Value

ERG used project names and descriptions to exclude non-roadway work (e.g. institutional building construction) and utility projects to avoid double-counting with other sectors. The resulting list included 94 municipal projects totaling $46.8M, and 71 county projects totaling $77.1M. The cities responding to the survey constituted 43.2 percent of the incorporated state total population, while responding counties covered 62.2 percent of the unincorporated population.

Bid item level information was not available for these projects. Therefore, equipment activity for this sector was assumed to scale directly with contract value given the lack of information on physical quantities (e.g. cubic yards of excavation). The total contract value for each responding city and county are shown in Table 4-30 and Table 4-31 respectively. Cities reporting no activity for 2017 are indicated by the zero-dollar value entries.

Table 4-30. Highway and Road Project Contract Value - City Survey Respondents 2017 Nonroad Diesel Equipment Study

City	2017 Contract Value	City	2017 Contract Value
Astoria	$71,953	Medford	$7,609,894
Cannon Beach	$132,511	Monmouth	$18,937
Carlton	$0	Pendleton	$83,832
Corvallis	$1,137,000	Portland	$23,663,208
Cottage Grove	$437,851	Reedsport	$137,156
Estacada	$359,153	Salem	$3,512,483
Florence	$594,498	Seaside	$108,500
Halfway	$0	Silverton	$0
Hillsboro	$4,671,805	Stayton	$20,394
Keizer	$869,489	Unity	$0
King City	$250,000	West Linn	$0
Lafayette	$0	Willamina	$45,000
Lebanon	$2,965,065	Winston	$0
Madras	$95,714	**Total**	**$46,784,443**

Table 4-31. Highway and Road Project Contract Value - County Survey Respondents 2017 Nonroad Diesel Equipment Study

County	2017 Contract Value
Clackamas	$5,128,671
Douglas	$3,869,456
Hood River	$2,005,187
Jackson	$45,074
Josephine	$273,682
Lake	$0
Marion	$6,982,525
Multnomah	$21,379,094
Wallowa	$0
Washington	$34,277,220
Yamhill	$3,094,348
Total	**$77,055,257**

Oregon's highway and road construction and maintenance funding is distributed across ODOT, counties and cities in an approximate 50/30/20 ratio, respectively.[255] Assuming these funding ratios for 2017, ERG followed these steps to scale the reported city and county contract totals to account for non-responding agencies.

Step 1 – Estimate the state-level contract value for cities and counties based on the total value for ODOT projects. The total value of the bid item data provided for the ODOT Construction Program for 2017 was $366,598,963. This figure was multiplied by 0.6 (30 percent/50 percent) to estimate the total county agency project value for 2017 ($201,959,378), and by 0.4 (20 percent/50 percent) to estimate the corresponding value for city agencies ($134,639,585).

Step 2 – Adjust the state-level city and county contract values to net out utility project work. The ODOT sector profiles included utility work (e.g. installation and maintenance of stormwater sewer lines), which was excluded from the Utility sector profile.[256] However, the Utility profile does include work performed under city and county contracts. Accordingly, the contract value associated with utility work must by netted out of the total city and county contract estimates to avoid double-counting. To this end ERG estimated the percent of the total contract value reported in the city and county agency surveys associated with utility work (based on project description) - 41.1 percent for cities, and only 0.4 percent for counties. ERG then applied these percentages to the state-level contract estimates calculated in Step 1 to net out the Utility

[255] State of Oregon, Legislative and Policy Research Office. *Funding Transportation Background Brief.* September 2016. https://www.oregonlegislature.gov/lpro/Publications/BB2016FundingTransportation.pdf.

[256] See section 4.3 for further details regarding the Utility sector profile.

sector component, yielding $201,161,483 for county agencies, and $79,257,557 for city agencies.

Contract value was also estimated for highway and road work contracted out by other public agencies, including the Federal Highway Administration (FHWA), the BLM, and the Forest Service, among others. ERG used data from Dodge Analytics to identify 30 projects contracted out by these agencies in Oregon in the 2017 timeframe.[257] All projects were assumed to require heavy nonroad diesel equipment use. Table 4-32 presents the associated contract values, aggregated by county.

Table 4-32. Other Agency Highway and Road Contract Value by County
2017 Nonroad Diesel Equipment Study

County	2017 Contract Value
Clackamas	$1,873,900
Coos	$1,321,400
Crook	$50,000
Deschutes	$1,920,800
Douglas	$700,000
Hood River	$16,375,100
Josephine	$2,627,100
Lane	$379,400
Lincoln	$397,200
Marion	$857,000
Multnomah	$1,055,200
Polk	$150,000
Umatilla	$148,000
Union	$5,250,700
Washington	$50,000
Total	**$33,155,800**

ERG assumed the project listing for other agency contracts in the Dodge data was complete and did not apply an adjustment factor to the $33M total.

The ODOT Construction Program equipment use profile shown in Table 4-32 was assumed to be representative of the equipment requirements for city, county, and other agency projects. Given this assumption the adjusted state-level contract values estimated under Step 2 above were divided by the total ODOT Construction Program contract value, yielding final scaling factors of 0.598 for county agencies and 0.235 for city agencies. Similarly, the contract total for

[257] The Dodge data contained complete listings for project start date. However, project end dates were almost entirely lacking. ERG assumed all projects with a start date on or before 2017 would be completed entirely within the analysis year, to be conservative.

other agencies was divided by the ODOT Construction Program total yielding a scaling factor of 0.099. Applying these factors to the hp-hours estimates in the ODOT Construction Program profile and summing across agency types produces the corresponding profile for this sector shown in Table 4-33.

Table 4-33. City, County, and Other Agency Highway and Road Activity Profile – Statewide Equipment Use
2017 Nonroad Diesel Equipment Study

Equipment Type	HP	Hours/Yr	HP-HRs/Yr	Gal/Yr[258]
Bore/drill rigs	328	1,732	213,057	11,170
Concrete/industrial saws	67	941	37,212	2,172
Crawler tractors/dozers	158	45,744	1,998,017	110,778
Excavators	316	47,045	5,600,741	296,836
Graders	161	15,177	964,987	51,144
Off-highway trucks	287	1,450	80,670	4,275
Other construction equipment	169	3,395	239,969	12,718
Pavers	186	6,057	467,799	24,793
Rollers	147	25,052	1,345,909	71,332
Rubber tire loaders	151	39,251	2,055,761	110,823
Skid steer loaders	58	12,029	227,024	15,471
Surfacing equipment	681	13,764	5,226,734	277,014
Tractors/loaders/backhoes	73	7,744	200,238	13,683
Paving equipment	153	2,617	141,226	7,485
Sweepers/scrubbers	134	9,857	607,602	31,855
Total		**231,854**	**19,406,946**	**1,041,549**

When combined with equipment model year distributions for the Oregon construction industry, this information provides the basis for estimating state-level emissions for the sector.

4.7.2 County/Temporal Allocation

County-level city agency highway and road contracting equipment activity was allocated from the statewide totals based on the proportion of incorporated population in each county for 2017, shown in Table 4-34.[259, 260]

[258] Calculated using EPA MOVES-Nonroad model (2014b). See Section 6.2 for additional details.

[259] Portland State University, College of Urban and Public Affairs: Population Research Center. *Population Estimates and Reports*. Retrieved from https://www.pdx.edu/prc/population-reports-estimates.

[260] For modeling purposes, the activity and emissions associated with survey respondents was estimated separately from non-respondents, with statewide non-respondent activity allocated to the county level based on a renormalized population distribution (netting out respondent populations).

Table 4-34. Statewide City Agency Highway/Road Contracting Equipment Activity – County Distribution
2017 Nonroad Diesel Equipment Study

County	Percent Activity
Baker	0.65%
Benton	2.50%
Clackamas	2.66%
Clatsop	1.76%
Columbia	2.91%
Coos	3.04%
Crook	1.56%
Curry	1.58%
Deschutes	8.07%
Douglas	1.92%
Gilliam	0.08%
Grant	0.34%
Harney	0.37%
Hood River	0.99%
Jackson	0.02%
Jefferson	1.84%
Josephine	0.14%
Klamath	5.31%

County	Percent Activity
Lake	0.00%
Lane	12.18%
Lincoln	2.50%
Linn	4.94%
Malheur	1.82%
Marion	3.49%
Morrow	0.53%
Multnomah	10.59%
Polk	2.33%
Sherman	0.07%
Tillamook	2.04%
Umatilla	2.98%
Union	0.87%
Wallowa	0.00%
Wasco	1.34%
Washington	16.97%
Wheeler	0.08%
Yamhill	1.53%

County-level county agency highway and road contracting equipment activity was allocated from the statewide totals based on the proportion of unincorporated population in each county for 2017, shown in Table 4-35.[261]

Table 4-35. Statewide County Agency Highway/Road Contracting Equipment Activity – County Distribution
2017 Nonroad Diesel Equipment Study

County	Percent Activity
Baker	0.28%
Benton	1.20%
Clackamas	4.98%
Clatsop	0.40%
Columbia	0.71%

County	Percent Activity
Coos	0.97%
Crook	0.25%
Curry	0.25%
Deschutes	3.11%
Douglas	1.21%

[261] Portland State University, College of Urban and Public Affairs: Population Research Center. *Population Estimates and Reports*. Retrieved from https://www.pdx.edu/prc/population-reports-estimates.

County	Percent Activity
Gilliam	0.03%
Grant	0.12%
Harney	0.11%
Hood River	0.24%
Jackson	8.21%
Jefferson	0.13%
Josephine	0.99%
Klamath	0.62%
Lake	0.06%
Lane	8.13%
Lincoln	0.70%
Linn	3.93%
Malheur	0.43%

County	Percent Activity
Marion	4.15%
Morrow	0.19%
Multnomah	43.24%
Polk	1.36%
Sherman	0.03%
Tillamook	0.25%
Umatilla	1.16%
Union	0.50%
Wallowa	0.10%
Wasco	0.41%
Washington	9.70%
Wheeler	0.02%
Yamhill	1.84%

The Dodge Analytics data used for the analysis of other agency highway and road work contracting included county information for each project listing. ERG summed the estimated equipment hp-hours associated with each project by county to determine the county level allocation factors for other agency contracting, shown in Table 4-36.

Table 4-36. Statewide Other Agency Highway/Road Contracting Equipment Activity – County Distribution
2017 Nonroad Diesel Equipment Study

County	Percent Activity
Baker	0.00%
Benton	0.00%
Clackamas	5.65%
Clatsop	0.00%
Columbia	0.00%
Coos	3.99%
Crook	0.15%
Curry	0.00%
Deschutes	5.79%
Douglas	2.11%
Gilliam	0.00%
Grant	0.00%
Harney	0.00%
Hood River	49.39%

County	Percent Activity
Jackson	0.00%
Jefferson	0.00%
Josephine	7.92%
Klamath	0.00%
Lake	0.00%
Lane	1.14%
Lincoln	1.20%
Linn	0.00%
Malheur	0.00%
Marion	2.58%
Morrow	0.00%
Multnomah	3.18%
Polk	0.45%
Sherman	0.00%

County	Percent Activity
Tillamook	0.00%
Umatilla	0.45%
Union	15.84%
Wallowa	0.00%

County	Percent Activity
Wasco	0.00%
Washington	0.15%
Wheeler	0.00%
Yamhill	0.00%

Information on the temporal distribution for city, county, and other agency project work was not determined for the study. For emissions modeling purposes ERG assumed MOVES defaults for summer (30.6 percent of annual activity) and weekday (16.7 percent of total week activity) allocations.

4.7.3 Validation

No independent data sources were identified to validate the City, County and Other Agency Highway and Road Contracting sector profile. However, the bid item categories, equipment assignment and productivity assumptions for this sector are identical to the ODOT Construction program sector.[262]

4.7.4 Sector Summary

Key observations regarding the City, County and Other Agency Highway and Road Contracting sector profile include the following:

- The sector utilizes a variety of heavy construction equipment with excavators, loaders, dozers, and cold planers responsible for over three quarters of the sector's fuel consumption. At 1,041,549 gallons of fuel consumption per year statewide, the sector is responsible for 7.1 percent the construction industry's overall total of 14.64M gallons.[263]
- The sector activity is primarily located in urban and developing counties, although over half of Other Agency activity is located in Hood River and Union counties.
- The response to the request for project information was robust, with the cities responding to the survey constituting 43.2 percent of the incorporated state total population, and responding counties constituting 62.2 percent of the unincorporated population.
- Certain descriptions provided by the city and county agencies contained unclear information regarding the nature of their project work, some of which may be excluded from the highway and road work category. As such, the degree to which the

[262] See Section 4.5.3 for information on the validation exercise for the ODOT Construction Program profile.

[263] Section 6.3.2 provides a detailed fuel consumption breakdown for the different construction industry components.

ODOT Construction Program profile is representative of highway and road project work contracted by city, county, and other agencies is also uncertain.

4.8 Well Drilling Sector

This sector characterizes truck-mounted portable drilling rigs used to drill wells throughout the Oregon. These units often feature high-hp engines (e.g. > 400 hp) and consume significant amounts of diesel fuel per unit. Certain rigs draw power directly from the on-road truck engine (referred to as a power-take-off configuration, or PTO), and are excluded from the following analysis.

4.8.1 Equipment Productivity Profile and Activity Estimation

Attempts to identify and recruit drilling rig operators to survey equipment use through a state trade association were unsuccessful. As an alternative, ERG consulted with OWRD staff to develop a generalized equipment use profile for well drilling activities.[264] This profile was then combined with information from OWRD's statewide water supply well database to estimate total hp-hour and fuel consumption estimates by county for 2017. The following information is included in the database for each permitted well:

- County
- Well type – water, monitoring, and geotechnical[265]
- Depth drilled (feet)
- Well bore diameter (inches)
- Drilling project type – new, abandonment, deepening, alteration
- Start/end dates

Since all well drilling activity in the state must be permitted by law,[266] the OWRD data set was assumed to be complete and no additional activity scaling factors were applied.

ERG dropped 19 records from the OWRD data set reporting 0 feet drilled, and 454 records with missing drill depths, leaving 10,302 records for evaluation. Of these, bore diameter was missing from 1,311 records. ERG gap-filled missing diameters using average values by well type. Table 4-37 summarizes the number of wells, average depth and average diameter by well type.

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[264] Personal communication with Joel Jefferey, OWRD Well Construction Program Coordinator, September 2019.

[265] Monitoring wells collect data on groundwater levels and water quality. Geotechnical wells are used to gather information on site foundations conditions prior to construction.

[266] 2017 ORS 520.025, *Permit for drilling well or using well.* https://www.oregonlaws.org/ors/520.025.

Table 4-37. Oregon Well Drilling Activity Summary
2017 Nonroad Diesel Equipment Study

Well Type	# Wells	Average Depth (ft)	Average Diameter (in)
Water	3,031	228	12.2
Monitoring	884	32	6.0
Geotechnical	6,387	24	3.5

ERG obtained and reviewed water well drilling rig purchase records for Oregon for the prior 20 years, finding 53 of 121 units (44 percent) featured PTO.[267] The 68 units with independent deck-mounted nonroad engines had an average hp of 530. This hp value was assumed for both water and monitoring well drilling activity.

Two industry experts provided approximate estimates for water well drilling rates for a 12-inch bore (in feet per day):[268]

- 100 feet per day minimum[269]
- 67 – 100 feet per day[270]

ERG assumed 100 feet per 8 work hour day (or 12.5 feet/hr) in order to estimate activity for water and monitoring well drilling.

Geotechnical drill rigs generally create shallow, narrow bore holes requiring significantly lower hp. ERG identified four common geotechnical rig models offered by Geoprobe,[271] two of which featured nonroad diesel engines. ERG selected the higher hp rig (99 hp) to estimate average power requirements for these units and assumed all such rigs utilized nonroad engines to be conservative. The corresponding drill rate of 33 ft/hr was taken from the RSMeans profile for geotechnical wells with cased borings.[272]

The following assumptions were made to estimate the equipment activity for each well and drilling project type:

- The same drill rates and power requirements were assumed for water and monitoring wells;

[267] Equipment Data Associates. https://www.randallreilly.com/construction-marketing/.

[268] Both experts emphasized that drilling rates can vary dramatically depending site-specific conditions (e.g. soil conditions and geological formations), the amount of caving and casing requirements, and efficiency variations between rigs and companies.

[269] Personal communication, Skyles Well Drilling Manager, 7-18-2019.

[270] Personal communication with Joel Jefferey, OWRD Well Construction Program Coordinator, September 2019.

[271] Geoprobe product offerings. See https://geoprobe.com/geoprobe-machines.

[272] RSMeans Heavy Construction Cost Book, 2017. 31st edition.

- Well alterations were treated like new drilling projects, requiring full bore to full depth;
- Well deepening projects were assumed to require full bore to the new depth;
- Water well abandonment projects were assumed to require boring to full depth; and,
- 30 percent of monitoring well abandonments were assumed to not require significant equipment use.[273]

Before estimating required hp-hours of engine activity, ERG randomly excluded 44 percent of the well drilling records to exclude PTO unit use, and 30 percent of monitoring well abandonments to account for de minimus equipment use, as per industry expert estimates. ERG then adjusted the foot per hour estimates for each permit record assuming the average drilling rate varied directly with the cross-sectional area of the bore. For example, the 12.5 foot/hr rate assumed for a 12-inch bore corresponds to a cross-sectional area of 113 square inches. Therefore, the drill rate for an 8-inch bore (cross-section = 50) would equal 12.5 x 113/50, or 28.25 ft/hr.

Total hours for each project were then determined by multiplying the adjusted drill rate by total drill depth. Next the engine load factor for all drill rigs was assumed to be 50 percent.[274] Finally, ERG calculated required hp-hours and fuel consumption for each permit. The resulting statewide activity totals are summarized in Table 4-38.

Table 4-38. 2017 Well Drilling Equipment Activity Profile
2017 Nonroad Diesel Equipment Study

Equipment Type	Average HP	Hours/Yr	HP-HRs/Yr	Gal/Yr[275]
Bore/drill rigs	412	37,211	10,175,658	548,639

When combined with equipment model year distributions for the Oregon construction industry, this information provides the basis for estimating state-level emissions for the sector.

4.8.2 County/Temporal Allocation

County-level activity for the well drilling sector was determined by summing the estimated hp-hours for each permit. The hp-hour distribution by county is presented in Table 4-39.

Table 4-39. Statewide Well Drilling Equipment Activity – County Distribution
2017 Nonroad Diesel Equipment Study

[273] Personal communication with Joel Jefferey, OWRD Well Construction Program Coordinator, September 2019.

[274] California Air Resources Board. *In-Use Off-Road Diesel-Fueled Fleets and LSI: Appendix D – OSM and Summary of Off-Road Emissions Inventory Update*. https://ww3.arb.ca.gov/regact/2010/offroadlsi10/offroadappd.pdf.

[275] Calculated using EPA MOVES-Nonroad model (2014b). See Section 6.2 for additional details.

County	Percent Activity
Baker	0.99%
Benton	1.62%
Clackamas	7.90%
Clatsop	0.97%
Columbia	1.25%
Coos	1.34%
Crook	4.77%
Curry	0.74%
Deschutes	7.72%
Douglas	2.60%
Gilliam	0.51%
Grant	0.60%
Harney	0.60%
Hood River	0.29%
Jackson	5.35%
Jefferson	1.31%
Josephine	6.08%
Klamath	2.92%

County	Percent Activity
Lake	0.82%
Lane	5.92%
Lincoln	0.87%
Linn	4.59%
Malheur	0.88%
Marion	4.09%
Morrow	0.40%
Multnomah	13.09%
Polk	0.98%
Sherman	0.01%
Tillamook	1.47%
Umatilla	4.38%
Union	0.16%
Wallowa	1.40%
Wasco	1.27%
Washington	8.29%
Wheeler	0.20%
Yamhill	3.60%

ERG used well-start date information from the OWRD permit data to estimate the temporal allocation profile for this sector, with 97 percent of activity occurring during weekdays and 33 percent of activity occurring during the summer months.

4.8.3 Validation

The RSMeans construction cost estimation guide provided independent points of reference regarding assumed well drilling productivity rates. The assumed value of 100 feet per 8 work hour day (or 12.5 feet/hr) for water and monitoring well drilling, corresponds reasonably well with a national average estimate of 95 feet per day for an 8-inch bore provided by RSMeans for water supply wells.[276]

4.8.4 Sector Summary

Key observations regarding the well drilling sector profile include the following:

- The sector utilizes a single type of heavy construction equipment – bore/drill rigs, consuming an estimated 548,630 gallons of diesel fuel per year statewide.
- The sector activity is primarily located in urban and developing counties, although some amount of drilling activity was reported for all 36 counties.

[276] RSMeans Heavy Construction Cost Book, 2017. 31st edition.

Well drilling efficiency is expected to vary widely depending on site-specific conditions. As such, the estimated hp-hours, fuel consumption and emissions associated with this sector feature substantial uncertainty.

4.9 Agricultural Services Sector

The agricultural activity profile presented in Section 3.2 covered establishments that operate their own equipment on their own property. Equipment operated by third party contractors, also known as custom operators, is described in this section. Custom operators typically provide one or more specialized services (e.g. lime application, haying) for a portion of the agricultural establishments operating across the state.

4.9.1 Equipment Productivity Profile and Activity Estimation

The agricultural establishment survey discussed in Section 3.2 requested information on third party services utilized in 2017. Eighty one of the 175 respondents listed at least one service. Of these, ERG disregarded six references to aerial spraying since aircraft do not utilize diesel fuel. In addition, two references to custom farming for vineyards/orchards and one reference to fence and working cattle contractors were assumed to involve labor only and were also excluded from the analysis.

The remaining custom services reported fell into one of five categories, as shown in Table 4-40 by survey stratum. Table 4-41 presents the number of surveyed acres utilizing custom services, and Table 4-42 shows the corresponding percent of surveyed acreage utilizing such services.

Table 4-40. Number of Survey Respondents Utilizing Custom Services
2017 Nonroad Diesel Equipment Study

Survey Stratum	Lime Application	Fertilizing	Spraying	Haying	Harvesting	Total
Beef Cattle	1	5	10	3	1	20
Dairy Cattle	1	1	1	0	2	5
Fruit Tree/Nut	6	3	6	1	2	18
Greenhouse/Nursery/Floriculture	5	0	5	0	2	12
Oilseed/Grain	1	1	1	0	2	5
Other Animals	0	0	0	1	1	2
Other Crops	14	4	14	3	0	35
Vegetables/Melons	3	2	3	0	0	8
Wineries	1	0	1	0	1	3
All Strata	**32**	**16**	**41**	**8**	**11**	**108**

Table 4-41. Surveyed Acres Utilizing Custom Services 2017 Nonroad Diesel Equipment Study

Survey Stratum	Lime Application	Fertilizing	Spraying	Haying	Harvesting	Total
Beef Cattle	40	5,180	129,159	9,360	50	143,789
Dairy Cattle	300	20	1,080	0	460	1,861
Fruit Tree/Nut	3,901	593	733	37	388	5,652
Greenhouse/Nursery/Floriculture	8,988	0	5,508	0	4,368	18,864
Oilseed/Grain	105	2,800	6,750	0	6,950	16,605
Other Animals	0	0	0	18	300	318
Other Crops	20,517	1,778	15,249	6,392	0	43,936
Vegetables/Melons	7,731	7,086	4,677	0	0	19,494
Wineries	20	0	0	0	8	28
All Strata	**41,602**	**17,457**	**163,156**	**15,807**	**12,524**	**250,547**

Table 4-42. Percent of Surveyed Acres Utilizing Custom Services 2017 Nonroad Diesel Equipment Study

Survey Stratum	Lime Application	Fertilizing	Spraying	Haying	Harvesting
Beef Cattle	0.0%	1.3%	32.5%	2.4%	0.0%
Dairy Cattle	8.0%	0.5%	28.9%	0.0%	12.3%
Fruit Tree/Nut	38.4%	5.8%	7.2%	0.4%	3.8%
Greenhouse/Nursery/Floriculture	69.7%	0.0%	42.7%	0.0%	33.9%
Oilseed/Grain	0.2%	5.4%	13.1%	0.0%	13.5%
Other Animals	0.0%	0.0%	0.0%	2.1%	34.6%
Other Crops	41.6%	3.6%	30.9%	13.0%	0.0%
Vegetables/Melons	95.1%	87.2%	57.5%	0.0%	0.0%
Wineries	13.4%	0.0%	0.0%	0.0%	5.4%
All Strata	**7.8%**	**3.3%**	**30.6%**	**3.0%**	**2.3%**

ERG then estimated the number of acres utilizing custom work at the state level by multiplying the total acreage for each survey stratum (shown in Table 4-43) by the percent of the surveyed acreage utilizing custom work (from Table 4-42). Table 4-44 shows the resulting estimated number of acres serviced by custom operators for each service category.

Table 4-43. Statewide Acreage by Agricultural Sector Stratum 2017 Nonroad Diesel Equipment Study

Survey Stratum	Statewide Acres
Beef Cattle	8,323,042
Dairy Cattle	90,757
Fruit Tree/Nut	135,877
Greenhouse/Nursery/Floriculture	100,873
Oilseed/Grain	771,096
Other Animals	1,605,703
Other Crops	1,121,595
Vegetables/Melons	239,284
Wineries	24,964
All Strata	**12,413,191**

Table 4-44. Estimated Number of Acres Utilizing Custom Work – Statewide 2017 Nonroad Diesel Equipment Study

Survey Stratum	Lime Application	Fertilizing	Spraying	Haying	Harvesting
Beef Cattle	838	108,553	2,706,687	196,150	1,048
Dairy Cattle	7,280	491	26,214	0	11,163
Fruit Tree/Nut	52,198	7,935	9,808	495	5,192
Greenhouse/Nursery/Floriculture	70,315	0	43,090	0	34,172
Oilseed/Grain	1,576	42,017	101,292	0	104,293
Other Animals	0	0	0	33,336	555,607
Other Crops	466,742	40,448	346,900	145,412	0
Vegetables/Melons	227,541	208,557	137,655	0	0
Wineries	3,340	0	0	0	1,336
All Strata	**829,828**	**408,001**	**3,371,645**	**375,394**	**712,810**

In order to characterize equipment use requirements for the different types of custom work, ERG attempted to contact 87 companies described as providing “farm management”, “soil preparation, planting and cultivating”, or “crop harvesting” services in Oregon. None of the companies provided a response to the survey requests after multiple contact attempts. As an alternative, ERG developed generalized equipment use profiles by service type based on average productivity estimates. For example, fertilizer may be applied at an average rate of “X acres per hour” using a 100 hp agricultural tractor. These rates can them be multiplied by the total acreage values shown in Table 4-44 to estimate total hours of custom operator equipment use.

Productivity estimates were developed for each service category from a variety of sources, with input from two SMEs identified through the OFB.

Lime Application

ERG obtained contact information for a custom operator specializing in lime application from the OFB. The operator estimated a "typical" lime application rate for their services based on lime delivery of a 35-ton trailer which could cover 17.5 acres in one and a half hours using dedicated buggies pulled by agricultural tractors, yielding and average rate of 11.7 acres per hour. The operator acknowledged significant variation in application rates depending on location.

Fertilizer Application

ERG identified an average fertilizer application rate of 80 acres per hour, based on an agricultural tractor pulling a spreader with an 80-foot spread at 12 miles per hour.[277]

Ground Spraying

ERG identified an average application rate of 87.3 acres per hour for self-propelled, 100-foot sprayers operating at 12 miles per hour. The application rate is at the upper end of the source's estimated productivity values, assumed to be applicable for dedicated specialty service equipment.[278]

Haying

ERG identified an average swather cut rate of five acres per hour,[279] and an average baling rate of 8.9 acres per hour. The baling rate was based on a productivity estimate of 40 tons of hay per hour using a pull-type forage harvester,[280] and an average of 4.5 tons of hay per acre (40/4.5 = 8.9). The tons per acre estimate is based on the average of the low and high-end hay production rates reported for Oregon (2-7 tons per acre, depending on location).[281]

Harvesting

After discussion with OFB representatives ERG concluded that the equipment use requirements for "harvesting" services are too variable across the range of crops, farm locations and sizes to develop a single, generalized activity profile. Therefore, equipment use associated with custom harvesting work has not been estimated for this study. However, as shown in Table 4-42, less than three percent of the surveyed acres were custom harvested, possibly indicating a relatively small amount of equipment use for this activity.

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[277] Mark Hanah, Iowa State University Extension and Outreach. *Estimating the Field Capacity of Farm Machines*. May 2016. https://www.extension.iastate.edu/agdm/crops/pdf/a3-24.pdf.

[278] Ibid.

[279] Hay Talk - How many acres of alfalfa can I cut with two swathers in a day? https://www.haytalk.com/forums/topic/20197-how-many-acres-of-alfalfa-can-i-cut-with-two-swathers-a-day/.

[280] Mark Hanah, Iowa State University Extension and Outreach, Estimating the Field Capacity of Farm Machines, May 2016.

[281] Oregon State University Extension Service, Hey, How Much Hay? https://extension.oregonstate.edu/crop-production/pastures-forages/hey-how-much-hay.

ERG combined the statewide acreage with the equipment productivity estimates described above to estimate total equipment hours per year for custom work, as shown in Table 4-45.

Table 4-45. Total Equipment Hours per Year for Custom Operators – Statewide 2017 Nonroad Diesel Equipment Study

Survey Stratum	Tractors - Lime App	Tractors - Fertilizing	Sprayers	Tractors - Haying	Swathers - Haying
Beef Cattle	72	1,357	31,004	22,067	39,230
Dairy Cattle	624	6	300	0	0
Fruit Tree/Nut	4,474	99	112	56	99
Greenhouse/Nursery /Floriculture	6,027	0	494	0	0
Oilseed/Grain	135	525	1,160	0	0
Other Animals	0	0	0	3,750	6,667
Other Crops	40,006	506	3,974	16,359	29,082
Vegetables/Melons	19,503	2,607	1,577	0	0
Wineries	286	0	0	0	0
All Strata	**71,128**	**5,100**	**38,621**	**42,232**	**75,079**

Lacking information from the custom operators themselves, ERG assumed average hp values from the agricultural sector survey (discussed in Section 3.2) to estimate the statewide equipment activity levels for custom operators, excluding those providing harvesting services (see Table 4-46).[282]

Table 4-46. Custom Operator Equipment Activity Profile – Statewide 2017 Nonroad Diesel Equipment Study

Equipment Type	HP	Hours/Yr	HP-HRs/Y	Gal/Yr[283]
Tractors	109	118,460	6,197,823	328,481
Sprayers	197	38,621	3,652,036	193,556
Swathers	104	75,079	7,099,444	376,267
Total		**232,160**	**16,949,304**	**898,303**

When combined with equipment model year distributions for the Oregon construction industry, this information provides the basis for estimating state-level emissions for the sector.

4.9.2 County/Temporal Allocation

County-level equipment activity for custom operators is based on total acres harvested in each county in 2017 as reported by the Agricultural Census. Percentages are presented in Table 4-47.

[282] 109 hp for tractors, 197 hp for sprayers, and 104 hp for swathers.

[283] Calculated using EPA MOVES-Nonroad model (2014b). See Section 6.2 for additional details.

Table 4-47. Statewide Custom Operator Equipment Activity – County Distribution 2017 Nonroad Diesel Equipment Study

County	Percent Activity
Baker	2.70%
Benton	2.05%
Clackamas	2.27%
Clatsop	0.09%
Columbia	0.30%
Coos	0.38%
Crook	1.21%
Curry	0.10%
Deschutes	0.86%
Douglas	1.24%
Gilliam	2.90%
Grant	1.25%
Harney	5.85%
Hood River	0.60%
Jackson	1.00%
Jefferson	1.62%
Josephine	0.20%
Klamath	3.95%

County	Percent Activity
Lake	4.73%
Lane	2.80%
Lincoln	0.10%
Linn	6.27%
Malheur	6.04%
Marion	6.65%
Morrow	9.30%
Multnomah	0.40%
Polk	2.94%
Sherman	4.63%
Tillamook	0.34%
Umatilla	13.69%
Union	2.93%
Wallowa	1.69%
Wasco	3.21%
Washington	2.14%
Wheeler	0.32%
Yamhill	3.28%

The temporal allocation profile for this sector assumed to mirror the Agricultural sector, with 82 percent of activity occurring during weekdays and 42 percent of activity during the summer months.

4.9.3 Validation

Independent sources of validation information were not identified for the custom operator sector equipment use profile.

4.9.4 Sector Summary

Key observations regarding the custom operator sector profile include the following:

- The sector utilizes agricultural tractors, sprayers and swathers. At 898,303 gallons of diesel fuel per year statewide, the sector consumes 2.3 percent of the agricultural establishment total of 38.55M gallons.[284]

[284] Section 3.2.2 provides a detailed fuel consumption breakdown for the different agricultural establishment stratum.

- Sector activity is primarily located in rural counties, although some amount of activity is estimated for all 36 counties.
- Although suspected to comprise a relatively small portion of sector activity, equipment use for custom harvesting services has not been quantified for this study.
- Some of the equipment productivity estimates used in the sector profile are based on data compiled outside the state and may not accurately reflect Oregon operations.

5.0 Alternative Characterization Methods

The equipment operator surveys and industry sector profiles developed for the study provide a thorough assessment for many nonroad diesel categories, including large construction, agricultural, and logging equipment. However, the activity for some equipment types, listed in Table 5-1, is not adequately characterized through surveys or industry profiles for several reasons.

Table 5-1. Equipment Categories with Alternative Characterization Methods 2017 Nonroad Diesel Equipment Study

Equipment Type
Aerial lifts
Chippers/stump grinders
Commercial mowers
Commercial turf equipment
Compressors
Dumpers/tenders
Generator sets
Hydropower units
Inboard/sterndrive engines (marine)
Lawn and garden tractors
Other lawn and garden equipment

Equipment Type
Outboard engines (marine)
Pressure washers
Pumps
Railway maintenance equipment
Recreational marine engines
Signal boards/light towers
Skid steer loaders
Tractors/loaders/backhoes
Transportation refrigeration units (TRUs)
Trenchers
Welders

- *Difficulty identifying and contacting operators – common equipment:* Generators, compressors, welders, and other hand-held/portable equipment units are manufactured in large numbers and used in a wide range of industries. However, the actual *percentage* of industrial and commercial establishments that operate one or more diesel powered units greater than 25 hp is generally quite low. The combination of a large number of potential operators and low ownership frequency renders surveys impractical for these equipment types.[285]
- *Difficulty identifying and contacting operators – uncommon equipment:* Other equipment including diesel powered recreational marine engines and lawn and garden equipment, are relatively rare in Oregon and inherently difficult to survey and characterize.
- *Incomplete information on certain construction equipment:* Some equipment such as signal boards/light towers are not clearly associated with specific construction tasks (e.g. trenching and paving) but are likely used in ancillary support. As such they are

[285] ERG attempted to survey commercial and industrial establishments regarding their compressor, generator, and other portable diesel equipment use in coordination with Oregon Business and Industry, but response rates were minimal.

likely under-represented in the standardized construction activity profiles. In addition, skid steers, trenchers and backhoes are frequently used outside the construction sector altogether (e.g. in landscaping activities).

- *Challenges associated with transient equipment:* A substantial fraction of some equipment types such as TRUs and railway maintenance equipment units are highly mobile, frequently entering and leaving the state. Identifying and contacting equipment operators, as well as determining populations and estimating the fraction of operating time within the state is particularly challenging for these units.[286]
- *Limited registration information:* The Oregon Marine Board (OSMB) maintains accurate boater registration information including recreational marine engine drive configuration (inboard, stern drive, and outboard) and fuel type. However, surveys were not attempted to determine engine characteristics such as hp, model year, and hours per year due to restricted access to owner contact information.

In the absence of other sources of information average hp, hours per year per unit, and model year distributions were set equal to the corresponding MOVES defaults for most of these equipment categories.[287, 288] However, ERG identified other sources of information that could be used to adjust the MOVES default population estimates for the equipment categories listed in Table 5-1, as discussed below.

5.1 Recreational Marine Engines

The recreational marine equipment category includes inboard, sterndrive and outboard engines used primarily on inland lakes and waterways, with limited coastal use as well. Most of these engines are gasoline powered, with a small fraction of diesel units. Commercial marine vessel engines are excluded from the category.[289]

5.1.1 Population and Activity Estimates

The OSMB provided ERG with the state's boater registration dataset in order to obtain boat population counts and other details.[290] Relevant data fields included fuel type, vessel and propulsion type, engine drive type, primary operation, and county of registration. Table 5-2

[286] ERG was unsuccessful in its attempt to obtain historical information on TRU fleet operations in Oregon (including engine on-time, fuel use and load factors) from a telematics data provider.

[287] The public fleet surveys contained information on a substantial number for lawn and garden equipment units, and the survey's average hour per year values were used for these units.

[288] Prior detailed evaluation of construction equipment use in Texas found the activity estimates for backhoes (582 hours/yr) was approximately 50 percent less than the MOVES default (1,135). The Texas value was adopted for use in the study. Eastern Research Group. 2008. *Update of Diesel Construction Equipment Emission Estimates for the State of Texas.* Prepared for the Texas Commission on Environmental Quality.

[289] Commercial marine engines are generally used to propel ocean-going vessels and harbor craft.

[290] 168,137 total registration records were provided by the Oregon State Marine Board, current as of March 27, 2019. Data provided electronically by Janess Eilers, Titling and Registration Operations Manager, Oregon State Marine Board, March 29, 2019.

summarizes total registrations and diesel engine counts by drive type, along with the default diesel engine counts from EPA's MOVES model for the state.

Table 5-2. Recreational Marine Diesel Engine Population - Registrations vs. MOVES 2017 Nonroad Diesel Equipment Study

Data Source/Engine Type	# Engines (> 25 hp)[291]	Percent of Total
OSMB Inboard/sterndrive[292]	1,412	97.51%
OSMB Outboard engines	36	2.49%
OSMB Total engines	**1,448**	
MOVES Inboard/sterndrive engines	3,311	96.47%
MOVES Outboard engines	121	3.53%
MOVES Total engines	**3,432**	

As shown in Table 5-2, the relative number of inboard/sterndrive engines and outboard engines is quite similar between the registration data and MOVES defaults, although the total number of registered diesel units is significantly lower (42 percent of the MOVES value).

In the absence of other data ERG assumed MOVES default values for annual activity for inboard/sterndrive engines (200 hours/yr) and outboard engines (150 hours/yr). These relatively low utilization rates may be justified given the small amount of activity implied in the registration data set. For example, 609 of the 1,448 registered diesel engines were designated as auxiliary (and therefore intermittent) use. These include Propulsion = "Sail", and Vessel Type = "Sail Only" and "Auxiliary Sail". In addition, 756 of the remaining 839 engines were designated as "Pleasure" for their primary operation type. These units are expected to be used significantly less frequently than vessels operated for commercial purposes (e.g. typically on weekends, holidays, etc.).

ERG estimated fuel consumption for these engines using MOVES default activity estimates for all 1,448 diesel units, regardless of primary operation and propulsion type. Table 5-3 summarizes the inputs used to calculate annual fuel consumption for these units.

Table 5-3. Statewide Recreational Marine Engine Activity Profile 2017 Nonroad Diesel Equipment Study

Engine Type	# Units	Avg HP	Avg Hrs/Yr	Gal/Yr[293]
Inboard/sterndrive	1,412	271	200	1,407,019
Outboard	36	32	150	3,553
All Engines	**1,448**			**1,410,572**

[291] All units assumed to be greater than 25 hp.

[292] Includes seven engine types listed as "Other" in the OSMB registration data.

[293] Calculated using EPA MOVES-Nonroad model (2014b). See Section 6.2 for additional details.

When combined with MOVES default equipment model year distributions, this information provides the basis for estimating state-level emissions for recreational marine engines.

5.1.2 County/Temporal Allocation

The engine population and activity levels presented in Table 5-2 and Table 5-3 represent state totals. In order to estimate activity and emissions at the county level, ERG distributed the statewide values considering both county of registration and the relative water surface area of lakes, rivers, and coastal boating zones. Based on consultations with DEQ, county of registration was weighted more heavily than water surface area (by a ratio of 1.5:1) for in-state registrations to reflect an assumed preference for boating at nearby locations. Out-of-state registrations (19.3 percent of the diesel engine total) were allocated to counties based solely on water surface area. Table 5-4 presents the distribution of registrations and water surface area across counties, as well as the final weighted average county allocation percentages.[294]

Table 5-4. Recreational Marine Engine County Activity Distribution
2017 Nonroad Diesel Equipment Study

County	Diesel Registrations	Water Surface Area[295]	Weighted Allocation
Baker	0.30%	1.16%	0.68%
Benton	1.48%	0.15%	0.89%
Clackamas	12.41%	0.61%	7.18%
Clatsop	4.28%	9.49%	6.59%
Columbia	7.53%	1.81%	5.00%
Coos	3.55%	7.09%	5.11%
Crook	0.15%	0.46%	0.29%
Curry	1.18%	9.92%	5.05%
Deschutes	3.40%	2.07%	2.81%
Douglas	2.36%	4.06%	3.11%
Gilliam	0.00%	1.07%	0.47%
Grant	0.30%	0.04%	0.18%
Harney	0.00%	5.21%	2.31%
Hood River	0.44%	0.63%	0.53%
Jackson	1.92%	0.94%	1.49%
Jefferson	0.59%	0.59%	0.59%
Josephine	0.59%	0.11%	0.38%
Klamath	0.74%	10.82%	5.20%
Lake	0.00%	12.58%	5.58%

[294] OSMB staff also provided input on marine engine activity use, noting that diesel engines in particular are likely to be used largely on the lower Columbia River and along the coast. Personal communication from Rachel Graham, OSMB Business Services Manager, February 2020.

[295] U.S EPA. *Geographic Allocation of Nonroad Engine Population Data to the State and County Level*. NR-014d. December 2005. https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P1004LDX.pdf.

County	Diesel Registrations	Water Surface Area[295]	Weighted Allocation
Lane	4.73%	6.91%	5.70%
Lincoln	4.58%	6.78%	5.56%
Linn	1.62%	1.00%	1.35%
Malheur	0.00%	2.42%	1.07%
Marion	3.55%	0.57%	2.23%
Morrow	0.00%	0.89%	0.40%
Multnomah	28.06%	1.72%	16.40%
Polk	1.48%	0.17%	0.90%
Sherman	0.00%	0.46%	0.20%
Tillamook	1.77%	7.79%	4.44%
Umatilla	0.30%	0.89%	0.56%
Union	0.59%	0.09%	0.37%
Wallowa	0.00%	0.35%	0.15%
Wasco	0.44%	0.81%	0.60%
Washington	9.75%	0.15%	5.50%
Wheeler	0.00%	0.02%	0.01%
Yamhill	1.92%	0.15%	1.14%

The temporal allocation profile for these engines were based on MOVES defaults, with 30 percent of activity occurring during weekdays and 57 percent of activity during the summer months.

5.1.3 Validation

The OSMB's 2017 Oregon Motorboat Fuel Use Survey provides an independent estimate for recreational marine engine fuel consumption.[296] Table 5-5 presents diesel fuel consumption estimates from the OSMB survey by vessel category. The relatively small difference between the study's fuel consumption estimate and that developed by OSMB (12.8 percent) lends confidence to the reasonableness of the assumed engine activity estimates.

[296] Oregon State University. *2017 Oregon Motorboat Fuel Use Survey.* September 2018.

Table 5-5. Diesel Fuel Consumption Estimates – MOVES Basis 2017 Nonroad Diesel Equipment Study

Vessel Category	Gal/Yr
Charter Boats	45,052
Dealers	18,456
Fleet Boats	890,454
AIS Pleasure Boats	622
Registered Pleasure Boats	255,200
Total Gal/Yr	**1,209,784**
Gal/Yr (study)	**1,410,572**
Percent Difference	**14.2%**

5.1.4 Sector Summary

Key observations regarding the recreational marine engine profile include the following:

- Most of the activity and fuel use are attributable to inboard/sterndrive engines.
- The estimated fuel consumption of approximately 1.4M gallons per year is generally consistent with the OSMB's Motorboat Fuel Use survey for 2017, at 1.2M gallons per year.
- The approach for geographic allocation yields a relatively large amount of activity in the most populous counties, with the Portland Metro region responsible for almost 30 percent of the state total. However, as per input from OSMB staff, diesel engine activity may be almost entirely restricted to coastal regions and the lower Columbia River.
- This activity allocation approach does not account for waterbody accessibility or amenity value and could be improved through surveys or other means.

5.2 Railway Maintenance Equipment

Railway maintenance equipment includes ballast handlers, rail/tie handlers, and other units used to repair and maintain rail lines. This equipment is used by the Class I railroads operating in Oregon - Union Pacific (UP), and Burlington Northern Santa Fe (BNSF) – as well as the smaller Class II and III railroads throughout the state.

5.2.1 Population and Activity Estimates

Railway maintenance activity data is not readily available at the county or state level. However, national level fuel consumption estimates are available for Class I railroad work trains. Work trains transport labor and equipment to rail line work sites, and work train fuel consumption data, available at the national level from Surface Transportation Board (STB) R-1 forms for UP and BNSF,[297, 298] include diesel fuel consumed by railway maintenance equipment.

County-level railway maintenance equipment activity for UP and BNSF was estimated based upon the ratio of county-to-national track miles,[299] using Equation 5-1:

$$A_{c,r} = \left(\frac{T_{c,r}}{T_{US,r}}\right) \times F_r \times CF \qquad \text{Equation 5-1}$$

Where:

$A_{c,r}$	=	Railroad maintenance activity in county *c* for rail company *r* (hp-hr)
$T_{c,r}$	=	Track length in county *c* for rail company *r* (miles)
$T_{US,r}$	=	National track length for rail company *r* (miles)
F_r	=	National work train fuel use for rail company *r* (gallons)
CF	=	Conversion factor (15.08 bhp-hr/gallon)[300]

Summing activity across counties yields statewide equipment activity total of 7,893,973 hp-hrs for Class I railroads operating in Oregon in 2017.

Subtracting the county-level rail track mileage for UP and BNSF from the overall track mileage for Oregon yields the mileage for the Class II and III railroads, equaling 1,555 miles, or 47.1 percent of all track miles in the state. However, estimates for Class II and III railway maintenance activity are not available at any level of geographic aggregation. In order to estimate maintenance equipment activity on this portion of the state's rail lines, ERG assumed repair and maintenance requirements are proportional to total rail line fuel consumption per track mile. Given this assumption, the following steps were followed to estimate the percentage of amount of Class II and III rail line fuel consumption in Oregon in 2017.

[297] Union Pacific Railroad. *Class I Railroad Annual Report R-1.* 2017. Retrieved from https://www.stb.gov/econdata.nsf/f039526076cc0f8e8525660b006870c9/1543778168f2a6608525826300475827?OpenDocument.

[298] Burlington Northern Santa Fe Railroad. *Class I Railroad Annual Report R-1.* 2017. Retrieved from https://www.stb.gov/econdata.nsf/f039526076cc0f8e8525660b006870c9/b3b4fc26db4fb98e85258263004722e5?OpenDocument.

[299] U.S. Department of Transportation, Bureau of Transportation Statistics, North American Rail Lines. Retrieved from http://osav-usdot.opendata.arcgis.com/datasets?keyword=Rail.

[300] Population weighted average BSFC from MOVES-Nonroad.

Step 1 – Obtain fuel consumption for all activities by railroad class. National level fuel consumption was available by railroad class for 2017 – 3,526,477,592 gallons for Class I railroads and 162,329,147 gallons for Class II/II railroads.[301]

Step 2 – Determine fuel consumption per track mile by railroad class. The national level fuel consumption estimates obtained under Step 1 were divided by the national level track miles maintained by each railroad class,[302] yielding 37,018 gallons per track mile for Class I railroads, and 3,752 gallons per track mile for Class II and III railroads.

Step 3 – Estimate total railroad fuel consumption by railroad class in Oregon. The gallon per track mile values calculated under Step 2 were multiplied by the track miles for each Oregon railroad operator class, yielding 64,708,276 gallons for Class I railroads and 5,833,956 gallons for Class II and III railroads (or 9.0 percent of the Class I value).

Step 4 – Scale the Class I railroad activity estimate for Class II and III railroads. The statewide railway maintenance equipment activity level calculated for Class I railroads (7,893,973 hp-hrs) using Equation 5-1 was multiplied by 9 percent (the ratio of Class II/III to Class I fuel consumption estimated for Oregon under Step 3) to obtain the statewide hp-hr estimate for the Class II and III railroads (711,659 hp-hrs).

The railway maintenance equipment use profile combines the hp-hr estimates for call railroad classes with default MOVES hp and engine load factor values to estimate total fuel consumption, as shown in Table 5-6.

Table 5-6. Statewide Railway Maintenance Equipment Activity Profile
2017 Nonroad Diesel Equipment Study

Engine Type	# Units	Avg HP	Avg Hrs/Yr	Gal/Yr[303]
Railway Maintenance Equipment	275	158	943	506,196

When combined with MOVES default equipment model year distributions, this information provides the basis for estimating state-level emissions for this equipment category.

5.2.2 County/Temporal Allocation

The statewide Class II and III railway maintenance equipment hp-hour estimates were allocated to the county level based on the track miles operated by these railroads and combined with the county-level hp-hour values calculated using Equation 5-1. Table 5-7 presents county level activity distribution reflecting the combine hp-hour values.

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[301] Eastern Region Technical Advisory Committee, 2017 National Fuel Use Estimates. Retrieved from https://gaftp.epa.gov/AIR/nei/2017/doc/supporting_data/point/2017Rail_main_21aug2019.pdf.

[302] U.S. Department of Transportation, Bureau of Transportation Statistics. *Miles of Freight Railroad Operated by Class of Railroad.* Retrieved from https://www.bts.gov/content/miles-freight-railroad-operated-class-railroad.

[303] Calculated using EPA MOVES-Nonroad model (2014b). See Section 6.2 for additional details.

Table 5-7. Railway Maintenance Equipment County Activity Distribution 2017 Nonroad Diesel Equipment Study

County	Percent Activity	County	Percent Activity
Baker	4.80%	Lane	0.23%
Benton	0.43%	Lincoln	13.66%
Clackamas	1.78%	Linn	0.09%
Clatsop	0.17%	Malheur	9.71%
Columbia	0.37%	Marion	0.20%
Coos	0.22%	Morrow	3.61%
Crook	0.10%	Multnomah	2.08%
Deschutes	0.00%	Polk	3.49%
Douglas	4.96%	Sherman	2.75%
Gilliam	0.92%	Tillamook	16.83%
Hood River	2.16%	Umatilla	0.24%
Jackson	0.00%	Union	1.04%
Jefferson	0.00%	Wallowa	0.32%
Josephine	1.67%	Wasco	10.94%
Klamath	0.51%	Washington	3.47%
Lake	3.22%	Yamhill	0.26%

The temporal allocation profile for railway maintenance equipment were based on MOVES defaults, with 90 percent of activity occurring during weekdays and 25 percent of activity during the summer months.

5.2.3 Validation

No independent data sources were identified to validate the railway maintenance equipment activity profile.

5.2.4 Sector Summary

Key observations regarding the railway maintenance equipment profile include the following:

- The estimated fuel consumption for this equipment is relatively low compared to other industry sectors, at approximately 500,000 gallons per year.
- The geographic allocation of activity is largely determined by the location of the Class I rail lines, with substantial activity in Klamath, Multnomah, and Umatilla Counties, among others. Four counties have no rail lines and no activity (Curry, Grant, Harney and Wheeler).

- The total activity value for this equipment is most likely over-estimated, since the work train fuel consumption used to calculate railway maintenance fuel consumption also includes fuel used by locomotives to transport labor and non-self-propelled equipment to the work sites.
- The lack of county and state-level railroad activity data increase the uncertainty associated with the equipment use profile.

5.3 Scaling Equipment Populations

The equipment operator surveys and industry profiles developed for the study provide a thorough assessment for many nonroad diesel categories, including large construction, agricultural, and logging equipment. However, the activity for some equipment types, listed in Table 5-8, is not adequately characterized through surveys or industry profiles for several reasons.

Table 5-8. Equipment Categories with Scaled Populations 2017 Nonroad Diesel Equipment Study

Equipment Type	Equipment Type
Aerial lifts	Other lawn and garden equipment
Chippers/stump grinders	Outboard engines (marine)
Commercial mowers	Pressure washers
Commercial turf equipment	Pumps
Compressors	Signal boards/light towers
Dumpers/tenders	Skid steer loaders
Generator sets	Tractors/loaders/backhoes
Hydro Power Units	TRUs
Inboard/sterndrive engines (marine)	Trenchers
Lawn and garden tractors	Welders

- *Difficulty identifying and contacting operators – common equipment:* Generators, compressors, welders, and other hand-held/portable equipment units are manufactured in large numbers and used in a wide range of industries. However, the actual *percentage* of industrial and commercial establishments that operate one or more diesel powered units greater than 25 hp is generally quite low. The combination of a large number of potential operators and low ownership frequency renders surveys impractical for these equipment types.[304]

[304] ERG attempted to survey commercial and industrial establishments regarding their compressor, generator, and other portable diesel equipment use in coordination with Oregon Business and Industry, but response rates were minimal.

- *Difficulty identifying and contacting operators – uncommon equipment:* Other equipment including diesel powered lawn and garden equipment, are relatively rare in Oregon and inherently difficult to survey and characterize.
- *Incomplete information on certain construction equipment:* Some equipment such as signal boards/light towers are not clearly associated with specific construction tasks (e.g. trenching and paving) but are likely used in ancillary support. As such they are likely under-represented in the standardized construction activity profiles. In addition, skid steers, trenchers and backhoes are frequently used outside the construction sector altogether (e.g. in landscaping activities).
- *Challenges associated with transient equipment:* A substantial fraction of TRUs are highly mobile, frequently entering and leaving the state. Identifying and contacting equipment operators, as well as determining populations and estimating the fraction of operating time within the state is particularly challenging for these units.[305]
- *Limited registration information:* The OSMB maintains accurate boater registration information including recreational marine engine drive configuration (inboard, stern drive, and outboard) and fuel type. However, surveys were not attempted to determine engine characteristics such as hp, model year, and hours per year due to restricted access to owner contact information.

In the absence of other sources of information, average hp, hours per year, and model year distributions were set equal to the corresponding MOVES defaults for most of these equipment categories.[306, 307] However, ERG identified other sources of information that could be used to scale MOVES default population estimates for Oregon for each of the equipment categories listed in Table 5-8.

5.3.1 Scaling Based on California Populations

CARB maintains the most comprehensive set of nonroad equipment inventory information in the country. The Diesel Off-Road Online Registration System (DOORS) covers all self-propelled nonroad diesel equipment greater than 25 hp operating in the state, and requires registrants update their information within 30 days of adding equipment to their fleets.[308] CARB also compiles information on non-self-propelled diesel equipment through the Portable Equipment

[305] ERG was unsuccessful in its attempt to obtain historical information on TRU fleet operations in Oregon (including engine on-time, fuel use and load factors) from a telematics data provider.

[306] The public fleet surveys contained information on a substantial number of lawn and garden equipment units, and the survey's average hour per year values were used for this category.

[307] Prior detailed evaluation of construction equipment use in Texas found the activity estimates for backhoes (582 hours/yr) was approximately 50 percent less than the MOVES default (1,135). The Texas value was adopted for use in this study. See Eastern Research Group, *Update of Diesel Construction Equipment Emission Estimates for the State of Texas.* Prepared for the Texas Commission on Environmental Quality. August 31, 2008.

[308] California Air Resources Board, In-Use Off-Road Diesel-Fueled Fleets Regulation. https://ww2.arb.ca.gov/our-work/programs/use-road-diesel-fueled-fleets-regulation.

Registration Program (PERP).[309] Finally, CARB requires registration of TRUs through its ARBER program.[310] Equipment population estimates from these programs are updated regularly and made available through CARB's ORION database.[311]

Given the comprehensiveness of the CARB information, the mandatory reporting requirements, frequency of updates, and the geographic proximity of the nonroad fleet, California equipment population data were selected as the preferred basis for scaling equipment counts for Oregon. ERG compiled population estimates for nonroad diesel units greater than 25 hp operating in California in 2017 for the following equipment types:

- Aerial lifts
- Air compressors
- Generator sets
- Pumps
- Skid steer loaders
- Tractor/loader/backhoes
- Trenchers
- TRUs

The following steps were taken to scale the California population estimates for Oregon.

Step 1 – ERG obtained sales records for nonroad equipment purchases in Oregon between 1998 and 2018 from Equipment Data Associates (EDA). The EDA records contained data on equipment and fuel type as well as purchaser information including Standard Industrial Code (SIC). ERG compiled the SIC distribution for Oregon establishments purchasing six of the seven equipment types listed above, over the 21-year time frame.[312] The total California equipment population for each equipment type was then allocated across the corresponding Oregon SIC distribution.

[309] California Air Resources Board, Portable Equipment Registration Program. https://ww2.arb.ca.gov/our-work/programs/portable-equipment-registration-program-perp?utm_medium=email&utm_source=govdelivery.

[310] California Air Resources Board, Air Resources Board Equipment Registration. https://ww3.arb.ca.gov/arber/arber.htm.

[311] California Air Resources Board, OFFROAD2017 – ORION. Retrieved from https://www.arb.ca.gov/orion/?bay.

[312] The methodology for scaling TRU populations is discussed later in this section.

Step 2 – ERG obtained employment estimates for each SIC group for California and Oregon from the 2016 County Business Patterns (CBP) database.[313, 314] The ratios of state employment totals were then determined for each SIC group (Oregon totals / California totals).

Step 3 – The allocated California equipment population was then multiplied by the SIC group employment ratio to adjust for relative differences in the California and Oregon industry sectors.

Step 4 – ERG then replaced the equipment population estimates for the Agriculture/Forestry, Mining, and Government SIC groupings with the survey and profile-based estimates.[315] Summing across the resulting SIC-specific populations yields the final Oregon statewide estimates.

Table 5-9 presents an example population estimate for aerial lifts.

Table 5-9. Equipment Population Scaling Example – Aerial lifts
2017 Nonroad Diesel Equipment Study

Step 1 - Distribute Sales by SIC Group			*Step 2 – Ratio # Employees*			*Step 3 - # OR Units*
SIC Group	Percent of OR Sales	CA Unit Allocation	CA	OR	Ratio	Scaled Population
Agriculture, Forestry, & Fishing	3.1%	245	108,893	21,586	0.198	**49**
Mining	0.2%	18	20,933	1,399	0.067	**1**
Construction	19.4%	1,537	723,574	86,202	0.119	**183**
Manufacturing	5.8%	458	2,043,200	294,267	0.144	**66**
Transportation & Utilities	1.9%	149	684,079	73,479	0.107	**16**
Wholesale Trade	49.4%	3,919	843,285	83,938	0.100	**390**
Retail Trade	0.7%	54	2,220,310	279,505	0.126	**7**
Finance, Insurance, Real Estate	0.4%	32	904,046	89,498	0.099	**3**
Services/Other	19.2%	1,523	7,934,994	801,891	0.101	**154**
	Total	**7,935***			**Total**	**869^**

* 2017 aerial lift population for California

^ 2017 aerial lift population estimate for Oregon

313 2016 was the most recent year available from CBP at the time of the analysis. See U.S. Census Bureau, County Business Patterns 2017. Retrieved from https://www.census.gov/data/datasets/2017/econ/cbp/2017-cbp.html.

314 CBP employment data is characterized by NAICS rather than SIC category. A NAICS-to-SIC crosswalk was obtained from NAICS Crosswalk, SIC to NAICS Crosswalk Search Results. Retrieved from https://www.naics.com/sic-naics-crosswalk-search-results.

315 The equipment population estimates from the Agriculture, Logging, Surface Mining, and Public Fleet surveys cover these SIC groupings in their entirety and are more likely to represent Oregon estimates than estimates scaled from California populations.

Table 5-10 presents the equipment population estimates for these equipment categories, excluding TRUs (evaluated separately).

Table 5-10. Scaled Equipment Population Estimates – California Basis (2017)
2017 Nonroad Diesel Equipment Study

Equipment Type	California Population	Scaled Oregon Population	Oregon Population - MOVES Default
Aerial lifts	7,935	**869**	1,103
Air compressors	5,058	**621**	2,491
Generator sets	12,617	**1,523**	8,997
Pumps[316]	7,312	**774**	1,619
Skid steer loaders	11,676	**2,100**	8,368
Tractors/loaders/backhoes	35,216	**3,564**	6,128
Trenchers	2,116	**202**	1,052

The population estimates shown in Table 5-10 for Oregon range from 9.5 to 18.0 percent of the corresponding California values, similar to the census population ratio for the two states in 2017 (10.6 percent).[317] *These adjustments lead to substantial decreases in equipment counts compared to the MOVES defaults, with reductions ranging from 21 percent for aerial lifts to 83 percent for generator sets.*

Estimating TRU Populations

Unlike the equipment types listed in Table 5-10, TRUs are operated exclusively by establishments in the Transportation and Utilities SIC grouping. As such, TRU population estimates do not need to be adjusted for relative differences in industry prevalence between California and Oregon.

ERG used diesel TRU population, hour per year, and engine load factor estimates from CARB[318] to develop a population scaling factor for units operating in Oregon in 2017. ERG used the CARB TRU parameters to estimate total hp-hours by TRU type as shown in Table 5-11.

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[316] Equipment sales data were not available for diesel pumps. Pump equipment populations were scaled directly from California estimates without adjustment for SIC distribution differences.

[317] 2017 Oregon population (4.2 million) divided by California population (39.6 million). U.S. Census Bureau. *State Population Totals and Components of Change: 2010-2019.* Retrieved from https://www.census.gov/data/tables/time-series/demo/popest/2010s-state-total.html.

[318] California Air Resources Board, Initial Statement of Reasons for Proposed Rulemaking: 2011 Amendments for the Airborne Toxic Control Measure for In-Use Diesel-Fueled Transportation Refrigeration Units (TRUs) and TRU Generator Sets, and Facilities where TRUs Operate. August 2011. https://ww2.arb.ca.gov/our-work/programs/transport-refrigeration-unit.

Table 5-11. California TRU Population Profile (2017)
2017 Nonroad Diesel Equipment Study

TRU Type	Population	Avg HP	Hrs/Yr*	Load Factor	HP-HRs/Yr
In-State Genset	5,824	31.5	781	0.33	47,283,725
In-State Trailer	26,799	34.0	1,325	0.46	555,350,069
Out-of-State Genset	23,173	31.5	781	0.33	188,132,062
Out-of-State Trailer	102,875	34.0	210	0.46	337,883,026
Railcar	6,930	34.0	322	0.46	34,899,285
All Units	**165,601**	**33.5**	**861**	**0.43**	**1,163,548,168**

* In-state operation only

ERG scaled the total hp-hour value for California TRUs by the census population ratio for Oregon and California to estimate the corresponding population for Oregon: 1,163,548,168 x 0.106 = 123,237,281 hp-hours/yr.[319] This value was allocated across hp bin categories using the default activity proportions from the MOVES model, which were then used to estimate the total number of units operating in Oregon as shown in Table 5-12.

Table 5-12. Oregon TRU Population Estimate (2017)
2017 Nonroad Diesel Equipment Study

HP Bin	HP-HRs/Yr	Avg HP*	Hrs/Yr*	Load Factor	Population
25-40	1,994,580	31.8	1,341	0.43	109
40-50	20,612,254	44.9	1,341	0.43	796
50-75	100,630,446	57.0	1,341	0.43	3,062
All Units	**123,237,281**	**54.6**	**1,341**	**0.43**	**3,966**

* MOVES default values

This analysis estimates the number of diesel TRUs greater than 25 hp operating in Oregon in 2017 (3,966) is slightly higher than that estimated by the MOVES model (3,664).

5.3.2 Scaling Based on Canadian Populations

CARB aggregates certain equipment types into "Other" categories for California's nonroad emission inventory. For example, pressure washers are included under "Other Portable Equipment", while signal boards/light plants and dumpers/tenders are placed in the "Other construction equipment" category.[320] In addition, CARB assumes there are no diesel-powered units in the lawn and garden equipment category. Accordingly, ERG sought alternative sources of information in order to scale equipment populations for the following 11 categories:

[319] This approach is consistent with the MOVES model which allocates TRU populations to the state and county levels based on human population.

[320] "Vintage" estimates for these categories are available from CARB's prior OFFROAD emission model, but these values have been superseded by the new, aggregated data.

- Cement/mortar mixers
- Chippers/stump grinders
- Commercial mowers
- Commercial turf equipment
- Dumpers/tenders
- Hydro power units
- Lawn and garden tractors
- Other lawn and garden equipment
- Pressure washers
- Signal boards/light plants
- Welders

Detailed nonroad equipment population data were obtained for Canada for the 2017 calendar year.[321] The Canadian data should provide a reasonable basis for scaling population estimates for Oregon for a few reasons:

- The Canadian nonroad engine regulations are generally harmonized with those of the US federal government, creating a single North American regulatory framework for manufacturers selling equipment in both countries.
- There are few domestic nonroad equipment manufacturers in Canada, with production mostly limited to marine engines and snowmobiles. As such, the nonroad product lines available in Canada largely mirror those in the US.
- In many instances nonroad equipment populations largely track with human population for both countries.[322]
- Canada and Oregon have comparable rural/urban population splits, approximately 19 percent for both.[323] It is expected that the market penetration of industrial and lawn and garden equipment in particular will differ for rural and urban areas, and it is desirable to have similar urban/rural splits when scaling across jurisdictions.
- The Canadian equipment estimates are based on 2015 base year populations developed by PSR and extrapolated to 2017. The MOVES default population estimates are also based on PSR data (for base year 2000) and are generally consistent with the

[321] Data provided via Oak Leaf Environmental (OLE).

[322] Personal communication from OLE. OLE has worked on Canadian mobile source model development for the Canadian federal government since 2001. Those models were based on the US equivalents for MOBILE, NONROAD and MOVES. OLE also worked on Canadian regulatory impact analyses for criteria pollutants from portable/handheld as well as other large spark ignition engines, and heavy-duty on-road fuel efficiency. Part of OLE's QA/QC process (for both model and RIA development) involves directly comparing equipment activity estimates between countries and identifying when certain sectors function similarly between countries.

[323] The 2010 US census estimated a 19 percent rural population split in Oregon; the 2011 Canadian census estimated a 19 percent rural population split nationally.

equipment categorization scheme used for Canada. However, the 2015 base year for Canada reflects recent changes in market share for various products and applications more accurately than the MOVES defaults. For example, comparing the older MOVES estimates with the more recent Canadian data, it appears that diesel-powered product offerings have become substantially more common for welders, and less common for pressure washers.

Populations for the 11 equipment categories were assumed to vary directly with human population. Scaling the Canadian national equipment populations by the ratio of human population for the two regions (4.19M / 36.54M = 0.115) yields the estimates shown in Table 5-13.

Table 5-13. Scaled Equipment Population Estimates – Canadian Basis (2017)
2017 Nonroad Diesel Equipment Study

Equipment Type	Canadian Population	Oregon Population - MOVES Default	Scaled Oregon Population
Cement/mortar mixers	0	60	**0**
Chippers/stump grinders	2,900	1,334	**333**
Commercial mowers	10,380	1,884	**1,190**
Commercial turf equipment	392	139	**45**
Dumpers/tenders	2,442	29	**280**
Hydro power units	175	124	**20**
Lawn and garden tractors	5,477	44	**628**
Other lawn and garden equipment	11	6	**1**
Pressure washers	106	538	**12**
Signal boards/light plants	2,888	259	**331**
Welders	49,045	3,628	**5,642**

The scaled Oregon population values for these equipment categories are highly variable relative to the MOVES defaults, ranging from 100 percent decrease for cement/mortar mixers,[324] to a 14-fold increase associated with diesel lawn and garden tractors. These variations likely reflect substantive changes in fuel type and hp offerings over the 2000 – 2015 time period.

5.3.3 Scaled Activity Profiles

Many of the equipment types listed in Table 5-13 were included in the survey responses as well. The units reported as part of the surveys were subtracted from the scaled activity estimates in

[324] No diesel cement/mortar mixers > 25 hp appeared in the PSR 2015 base year data set prepared for Canada.

order to avoid double-counting. The statewide activity profiles adjusted for equipment included in the survey profiles are provided in Table 5-14.

Table 5-14. Scaled, Adjusted Population Equipment Profiles, Statewide (2017)
2017 Nonroad Diesel Equipment Study

Equipment Type	# Units	Avg HP*	Avg Hrs/Yr^	Avg Model Year*	Gal/Yr[325]
Aerial lifts	826	56	384	2005	376,477
Chippers/stump grinders	238	144	178	2005	142,689
Commercial mowers	738	41	238	2008	179,294
Commercial turf equipment**	0	-	-	-	0
Compressors	506	84	815	2010	611,690
Dumpers/tenders	280	60	566	2004	133,315
Generator sets	1,460	77	338	2006	662,114
Hydropower units	20	72	790	2010	27,701
Inboard/sterndrive (marine)	1,412	271	200	2006	1,407,019
Lawn and garden tractors	550	50	166	2009	113,979
Other lawn and garden equip.**	0	-	-	-	0
Outboard engines (marine)	36	32	150	2004	3,553
Pressure washers	11	94	145	2005	3,489
Pumps	627	87	403	2006	532,022
Signal boards/light towers	331	39	535	2011	171,142
Skid steer loaders	1,379	60	818	2005	2,111,997
Tractors/loaders/backhoes	2,212	93	582	2006	3,831,492
TRUs	3,954	54	1,341	2013	7,161,123
Trenchers	196	76	593	2012	252,197
Total	**17,903**				**17,721,293**

* Values from MOVES defaults

^ Values from MOVES defaults, with the exception of lawn and garden equipment

** More fuel consumed by surveyed units than estimated through population scaling. Activity set to 0.

5.4 MOVES Default Profiles

ERG did not identify alternative sources of information for agricultural mowers, off-highway tractors, other oilfield equipment, and specialty vehicles/carts, and MOVES defaults were used to estimate population and activity for these units without adjustment. Table 5-15 presents the statewide equipment use profiles for these equipment types.

[325] Calculated using EPA MOVES-Nonroad model (2014b), with adjustments for surveyed equipment.

Table 5-15. MOVES Default Equipment Profiles, Statewide (2017)
2017 Nonroad Diesel Equipment Study

Equipment Type	# Units	Avg HP	Avg Hrs/Yr	Avg Model Yr	Gal/Yr[326]
Agricultural mowers*	3	76	363	2005	3,328
Off-highway tractors	75	722	855	2010	1,080,355
Other oilfield equipment	2	353	1,231	2010	19,676
Specialty vehicles/carts	247	87	435	2004	158,336
Total	**327**				**1,261,695**

* self-propelled

According to MOVES these equipment types are rare in Oregon. Agricultural mowers are typically used for mowing highway right-of-ways, roadsides, and difficult to reach off-road areas. Product searches indicate most units are not self-propelled, instead relying on power-take-off from tractors or other equipment.[327]

Off-highway tractors are similar to off-highway trucks, but feature hitches rather than rigid frames.[328] MOVES estimates these units have very high average hp. As such one would expect their operation to be limited to very large mining operations.

The use of nonroad mobile oilfield equipment is highly limited in Oregon due to the very low production levels in this sector. According to the Energy Information Administration, Oregon has no known crude reserves or production.[329] The very small amount of activity estimated by the MOVES model may be attributable to limited drilling exploration.

Specialty vehicles/carts are used primarily for off-road transportation. Diesel models are relatively uncommon but are found in the agricultural sector in particular.

The estimated fuel consumption for the four equipment types relying on MOVES defaults is approximately one percent of the amount consumed by all nonroad diesel equipment operating in Oregon (approximately 114M gallons in 2017). In other words, the current study updated the equipment populations, characteristics and/or activity profiles for nonroad diesel equipment responsible for approximately 99 percent total fuel consumption in the state.

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[326] Calculated using EPA MOVES-Nonroad model (2014b). See Section 6.2 for additional details.

[327] Power Systems Research, Product Definitions Guide. https://www.powersys.com/wp-content/uploads/2019/07/PSR-Product-Definition-Guide_29Jan2020.pdf.

[328] Ibid.

[329] U.S. Energy Information Administration, *Oregon State Profile and Energy Estimates: Profile Analysis.* https://www.eia.gov/state/analysis.php?sid=OR.

6.0 Emissions Modeling and Inventory Development

Emission estimates were developed for nonroad diesel equipment greater than 25 hp operating in Oregon for the 2017 calendar year. Table 6-1 presents the nonroad diesel pollutants modeled for the study.

Table 6-1. Nonroad Diesel Engine Pollutants Modeled (MOVES 2014b)[330]
2017 Nonroad Diesel Equipment Study

Criteria Pollutants and Precursors (CAPs)
Carbon monoxide (CO)
Ammonia (NH_3)
Oxides of nitrogen (NO_x)
Particulate matter (PM_{10} and $PM_{2.5}$)
Sulfur dioxide (SO_2)
Volatile organic compounds (VOCs)
Greenhouse Gases (GHGs)
Carbon dioxide (CO_2)
Nitrous oxide (N_2O)
Methane (CH_4)
Toxic Pollutants
1,3-butadiene
Acenaphthene (gaseous)
Acenaphthylene (gaseous)
Acenaphthylene (particulate)
Acetaldehyde
Acrolein
Anthracene (gaseous)
Anthracene (particulate)
Arsenic
Benz(a)anthracene (gaseous)
Benz(a)anthracene (particulate)
Benzene

Toxic Pollutants *(Continued)*
Benzo(a)pyrene (particulate)
Benzo(b)fluoranthene (particulate)
Benzo(g,h,i)perylene (gaseous)
Benzo(g,h,i)perylene (particulate)
Benzo(k)fluoranthene (particulate)
Chrysene (gaseous)
Chrysene (particulate)
Chromium 6 (Cr+6)
Dibenzo(a,h)anthracene (particulate)
Ethyl benzene
Fluoranthene (gaseous)
Fluoranthene (particulate)
Fluorene (gaseous)
Fluorene (particulate)
Formaldehyde
Indeno(1,2,3,c,d) pyrene (particulate)
Naphthalene (gaseous)
Naphthalene (particulate)
Phenanthrene (gaseous)
Phenanthrene (particulate)
Pyrene (gaseous)
Pyrene (particulate)

The following sections present emission estimates for criteria pollutants and associated precursors as well as for greenhouse gases (including estimates for CO_2-equivalents, "CO_{2e}").[331] Emissions are presented at the county and state levels, as annual totals and for typical summer weekdays. Emission sources are also aggregated and presented in various ways including by operator category (e.g., agricultural and construction sectors) and by equipment type to allow for comparison with independent emission and fuel consumption estimates.

[330] U.S. EPA, *Latest Version of MOtor Vehicle Emission Simulator (MOVES).* Retrieved from https://www.epa.gov/moves/latest-version-motor-vehicle-emission-simulator-moves.

[331] Toxic emissions have been provided to DEQ separately in electronic format.

ERG used the equipment characteristic and activity data compiled for the study along with other data sources to develop Oregon-specific parameters for modeling emissions. While the modeling methodology adopted is consistent with that used for the latest version of EPA's MOVES model version 2014b, the updated parameters replace the default MOVES values, improving the overall accuracy of the emission estimates.

Updated values were developed for the following modeling parameters, depending on the industry sector and equipment type:

- Engine load factor
- Equipment population
- hp
- Hours per year
- Model year/engine tier distribution
- County population allocation
- Seasonal activity allocation

The following sections summarize the updates made to selected emission modeling parameters, the modeling methodologies applied, and the revised emission estimates.

6.1 Engine Load Factor Adjustments

EPA encourages state and local agencies to develop area-specific estimates for nonroad equipment populations and characteristics in order to improve their emission inventories. However, certain modeling parameter inputs such as engine load factors and emission rates are particularly difficult to quantify, requiring direct engine measurements. As such, EPA assumes default values will be used for these parameters when conducting emission modeling.

The nonroad diesel engine load factor estimates used in the MOVES model were developed using a limited set of engine measurement data developed over 20 years ago, and are particularly uncertain.[332] ERG investigated the available literature and conferred with multiple industry stakeholders to identify potential sources of improved engine load factor data. It was determined that updated estimates developed by CARB offer the most comprehensive, consistent set of load factors available for use in the study.[333] CARB has undertaken many survey efforts over the past several years to collect fuel consumption, activity, and hp data for thousands of engines in order to update the load factors for the following equipment types:

- Construction/mining and Industrial equipment[334]

[332] U.S. EPA, *Median Life, Annual Activity, and Load Factor Values for Nonroad Engine Emission Modeling.* NR-005d. July 2010. https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P10081RV.pdf.

[333] The CARB factors have the added benefit of being part of an EPA-approved emission modeling system.

[334] California Air Resources Board, In-Use Off-Road Diesel-Fueled Fleets Regulation. https://ww2.arb.ca.gov/our-work/programs/use-road-diesel-fueled-fleets-regulation.

- Agricultural equipment[335]
- Cargo handling equipment[336]
- TRUs[337]
- GSE[338]
- Miscellaneous portable equipment (e.g., generators, compressors)[339]

The engine load factors developed by CARB cover the majority of the equipment categories included in the study. MOVES default factors were assumed for most of the remaining categories. Table 6-2 presents the CARB and MOVES load factors as well as the final values adopted for the study for all equipment categories.

Table 6-2. Engine Load Factor Comparison
2017 Nonroad Diesel Equipment Study

Equipment Category	Equipment Type	CARB Factor	MOVES Factor	Value Selected
Recreational vehicles	Specialty vehicles/carts	N/A	0.21	0.21
Agricultural	Agricultural mowers	N/A	0.59	0.59
Agricultural	Agricultural tractors	0.48	0.59	0.48
Agricultural	Balers	0.50	0.59	0.50
Agricultural	Combines	0.44	0.59	0.44
Agricultural	Irrigation sets	N/A	0.59	0.59
Agricultural	Other agricultural equipment	N/A	0.59	0.59
Agricultural	Sprayers	0.42	0.59	0.42
Agricultural	Swathers	0.48	0.59	0.48
Commercial	Air compressors	0.31	0.43	0.31
Commercial	Generators	0.31	0.43	0.31
Commercial	Hydro-power units	N/A	0.43	0.43
Commercial	Other commercial equipment	N/A	0.43	0.43
Commercial	Pressure washers	N/A	0.43	0.43
Commercial	Pumps	N/A	0.43	0.43

335 California Air Resources Board. *Emission Inventory for Agricultural Diesel Vehicles.* December 2018. https://ww3.arb.ca.gov/msei/ordiesel/ag2011invreport.pdf.

336 California Air Resources Board. *Emission Inventory Development for Cargo Handling Equipment.* 2011. https://ww3.arb.ca.gov/regact/2011/cargo11/cargoappb.pdf.

337 California Air Resources Board, Initial Statement of Reasons for Proposed Rulemaking: 2011 Amendments for the Airborne Toxic Control Measure for In-Use Diesel-Fueled Transportation Refrigeration Units (TRUs) and TRU Generator Sets, and Facilities where TRUs Operate. August 2011. https://ww2.arb.ca.gov/our-work/programs/transport-refrigeration-unit.

338 California Air Resources Board. *In-Use Off-Road Diesel-Fueled Fleets and LSI: Appendix D – OSM and Summary of Off-Road Emissions Inventory Update*. https://ww3.arb.ca.gov/regact/2010/offroadlsi10/offroadappd.pdf.

339 California Air Resources Board. *2017 Diesel-Fueled Portable Equipment Emission Inventory – Technical Documentation.* March 2017. https://ww3.arb.ca.gov/msei/ordiesel/perp2017report.pdf.

Equipment Category	Equipment Type	CARB Factor	MOVES Factor	Value Selected
Commercial	Welders	N/A	0.21	0.21
Construction/mining	Bore/drill rigs	0.50	0.43	0.50
Construction/mining	Cement/mortar mixers	N/A	0.43	0.43
Construction/mining	Concrete/industrial saws	N/A	0.59	0.59
Construction/mining	Cranes	0.29	0.43	0.29
Construction/mining	Crawler tractors/dozers	0.43	0.59	0.43
Construction/mining	Crushing/processing equipment	N/A	0.43	0.43
Construction/mining	Dumpers/tenders	N/A	0.21	0.21
Construction/mining	Excavators	0.38	0.59	0.38
Construction/mining	Graders	0.41	0.59	0.41
Construction/mining	Off-highway tractors	0.44	0.59	0.59[340]
Construction/mining	Off-highway trucks	0.38	0.59	0.38
Construction/mining	Other construction equipment	0.42	0.59	0.42
Construction/mining	Pavers	0.42	0.59	0.42
Construction/mining	Paving equipment	0.36	0.59	0.36
Construction/mining	Rollers	0.38	0.59	0.38
Construction/mining	Rough terrain forklifts	0.40	0.59	0.40
Construction/mining	Rubber tire loaders	0.36	0.59	0.36
Construction/mining	Scrapers	0.48	0.59	0.48
Construction/mining	Signal boards/light plants	N/A	0.43	0.43
Construction/mining	Skid steer loaders	0.37	0.21	0.37
Construction/mining	Surfacing equipment	0.30	0.59	0.30[341]
Construction/mining	Tractors/loaders/backhoes	0.37	0.21	0.37
Construction/mining	Trenchers	0.50	0.59	0.50
GSE[342]	A/C tugs	0.54	0.59	0.54
GSE	Baggage tug	0.37	0.59	0.37
GSE	Belt loader	0.34	0.59	0.34
GSE	Bobtail	0.37	0.59	0.37
GSE	Cargo loader	0.34	0.59	0.34
GSE	Cargo tractor	0.36	0.59	0.36
GSE	GSE forklift	0.20	0.59	0.20
GSE	GSE lift	0.34	0.59	0.34

[340] The average hp values reported for off-highway tractors were substantially different between the MOVES and CARB data sets (722 vs. 184, respectively), leading ERG to believe these equipment categories are not defined consistently by the two agencies. Accordingly, the MOVES factors were retained to be conservative.

[341] Cold planers (a subset of the surfacing equipment category) were assigned a separate load factor of 0.70 for emissions modeling, based on industry expert input. Refer to Section 4.5.1 for further details.

[342] Although emissions were modeled separately for the different types of GSE, the MOVES model only reports emission totals for a single aggregated GSE category.

Equipment Category	Equipment Type	CARB Factor	MOVES Factor	Value Selected
GSE	Other GSE	0.34	0.59	0.34
Industrial	Aerial lifts	0.31	0.21	0.31
Industrial	Forklifts	0.20	0.59	0.20
Industrial	Other general industrial equip.	0.34	0.43	0.34
Industrial	Other material handling equip.	0.40	0.21	0.40
Industrial	Sweepers/scrubbers	0.46	0.43	0.46
Industrial	Terminal tractors	0.39	0.59	0.39
Industrial	TRUs	0.46	0.43	0.46
Lawn and garden	Chippers/stump grinders	N/A	0.43	0.43
Lawn and garden	Commercial mowers	N/A	0.43	0.43
Lawn and garden	Commercial turf equipment	N/A	0.43	0.43
Lawn and garden	Lawn and garden tractors	N/A	0.43	0.43
Lawn and garden	Other lawn and garden equipment	N/A	0.43	0.43
Logging	Logging equipment	N/A	0.59	0.52[343]
Other	Oilfield equipment	N/A	0.43	0.43
Other	Railway maintenance equipment	N/A	0.21	0.21
Recreational marine	Inboard/sterndrive motors	N/A	0.35	0.35
Recreational marine	Outboard motors	N/A	0.35	0.35

With limited exceptions,[344] the updated values are lower than the MOVES defaults, which will tend to lower the corresponding emission estimates proportionally.

6.2 Emission Modeling Methodology

Each of the activity profile categories required one of the following emission modeling approaches:

- **Survey-based activity profiles** (e.g., developed for public fleets and agricultural equipment) employed emission factor lookup tables to estimate emissions specifically for each piece of equipment reported.
- **Task-based activity profiles** (e.g., for highway construction and well drilling) combined aggregated hp-hour estimates with average emission factors weighted by engine tier level distributions to estimate total emissions for each equipment type/hp combination.
- **MOVES-based profiles** were developed for equipment that could not be adequately characterized by first two approaches (e.g., generator sets and skid steer loaders). In

[343] Derived from logging sector survey responses. Please refer to Section 3.3.3 for further details.

[344] Bore/drill rigs, skid steer loaders, tractors/loaders/backhoes, aerial lifts, other material handling equipment, sweepers/scrubbers, transportation refrigeration units, and cold planers (included in MOVES under Surfacing equipment) are assumed to have higher load factors than the corresponding MOVES defaults.

most cases, default MOVES model emission estimates were scaled to reflect adjusted equipment counts.[345]

These approaches are described in more detail below.

6.2.1 Methodology and Assumptions for Survey-Based Activity Profiles

The ERG team surveyed 13 types of nonroad diesel equipment operators, as shown in Table 6-3. As shown in the table, four surveys resulted in a complete census, with information provided on all targeted equipment. Five surveys required simple scaling of the activity and emission estimates using a single scaling factor to account for operators that did not provide information. Finally, four surveys required more complex scaling using different surrogates for multiple survey strata (e.g., separate factors for beef and dairy cattle for the agricultural sector survey).[346]

Table 6-3. Survey-Based Emission Modeling Scenarios 2017 Nonroad Diesel Equipment Study

Modeling Category	Survey
Census	Marine ports
Census	Other government agency fleets
Census	Special districts
Census	Special project
Simple scaling	Airports
Simple scaling	City fleets
Simple scaling	County fleets
Simple scaling	Construction crane operators
Simple scaling	Surface mining
Scaling by strata	Agricultural operations
Scaling by strata	Logging operations
Scaling by strata	School/university fleets
Scaling by strata	Solid waste/material recovery

The detailed equipment characteristics and operation information provided in the surveys offered an opportunity to develop very precise emission estimates specific to each piece of equipment reported. The following steps were undertaken to develop these estimates for each survey category.

345 For example, the total population of skid steer loaders for the state was estimated at 2,100 based on CARB equipment registration data and census population ratios between Oregon and California, among other factors. (Further details are available in Section 5.3). This compares to the MOVES default estimate of 8,368 skid steer loaders for the state. Under this method the MOVES emission estimates for skid steers were scaled downward to 25.1 percent of the default value (2,100/8,368).

346 Refer to Section 3 for more details on survey response rates and scaling factors.

- **Step 1—estimate "zero-hour" emission rates.** ERG ran the most recent version of EPA's MOVES model (2014b) for calendar years 1990 and 1999–2017.[347] All MOVES runs used updated engine load factors where available, and default values for remaining inputs (e.g., hours per year, average hp). ERG then compiled the gram per hp-hour emission rates output by MOVES for the newest model year from each run. The newest model year for a given calendar year represents new equipment with no accumulated hours of use. As such, the associated gram per hp-hour values represent "zero-hour" emission rates.
- **Step 2—apply deterioration rates.** As equipment is used over time, its engine and emission control components will deteriorate, resulting in increased emissions for many pollutants. To reflect these impacts, the MOVES model applies deterioration factors to the zero-hour emission rates as shown in Equations 6-1 and 6-2.

$$EF = ZHRF \times DF \qquad \text{Equation 6-1}$$

$$\begin{aligned} DF &= 1 + A \times (\text{age factor})^{b} && \text{for age factors} \leq 1 \qquad \text{Equation 6-2} \\ DF &= 1 + A && \text{for age factors} > 1 \end{aligned}$$

Where:

EF = deteriorated emission factor (g/hp-hour)
ZHRF = zero-hour emission factor (g/hp-hour)
DF = deterioration factor (unitless)
age factor = (cumulative hours × load factor) ÷ median life at full load in hours[348]
A = relative deterioration factor (% increase ÷ % of useful life)
b = 1 for diesel engines

Table 6-4 provides the relative deterioration factors (A) used in the model by pollutant and engine tier level.

Table 6-4. Deterioration Factors (A) by Pollutant and Tier Level (MOVES 2014b) 2017 Nonroad Diesel Equipment Study

Pollutant[349]	Base/Tier 0	Tier 1	Tier 2	Tier 3+
CO	0.185	0.101	0.101	0.151
NO_x	0.024	0.024	0.009	0.008
PM	0.473	0.473	0.473	0.473
VOCs	0.047	0.036	0.034	0.027

[347] MOVES run scenarios are limited to 1990 and post-1998 calendar years.

[348] Age Factors represent the fraction of the expected life expended for a given level of cumulative hours. MOVES assumes expected engine life (expressed in terms of hours of use at full load) is fixed for a given equipment type/hp combination.

[349] Fuel consumption, CO_2, methane, N_2O, NH_3, SO_2, and CH_4 rates, as well as certain toxic emission rates are assumed to be unaffected by deterioration. Other toxic emission rates are associated with specific criteria pollutants (e.g. VOCs and PM) and utilize the corresponding factors shown in Table 6-4.

As Table 6-4 shows, deterioration rates are most significant for PM followed by CO, with relatively little change in the zero-hour rates expected for VOCs and NO_x over the equipment's useful life. Equation 6-2 also indicates that emission deterioration impacts are capped once an engine has reached its full useful life (i.e., the age factor exceeds 1).

ERG used the above equations and relative deterioration factors to estimate the in-use emission rates for each piece of equipment reported in the surveys. The age factor was calculated for each unit assuming the hours per year reported for 2017 were also accrued in each prior year of operation, dating back to the model year of manufacture.

- **Step 3—estimate weighted-average emission factors.** The emission rates output by the MOVES model vary not only by model year and age factor but also by equipment type,[350] hp, and, in the case of Tier 3 and later engines, by technology type. Model year, age factor, and hp can be identified precisely for surveyed equipment. However, multiple engine tier levels and technology types may be sold in a single year, making it difficult to determine the exact tier level and technology type based solely on model year. For this reason, ERG developed weighting factors across tier levels and technology types for each engine model year, based on the default activity values output by the MOVES model. ERG then applied these factors to estimate a single weighted average emission rate for each model year/equipment type/hp group combination.
- **Step 4—gap-fill emission rates for missing equipment type/hp/model year combinations.** In some instances, the MOVES model does not produce an emission rate for all model years of a given equipment type-hp bin combination. To address gaps in the emission rate outputs, ERG made a substitute emission rate assignment based on another equipment type of identical age, load factor, hp group, and transient adjustment factor type.[351]
- **Step 5—scale activity for the unsurveyed equipment population and estimate emissions.** ERG scaled the activity estimates for surveyed equipment to account for the unsurveyed portion of the target equipment population when necessary. Annual hours of use were then multiplied by the reported hp and the estimated engine load factor to calculate total hp-hours for each unit in 2017. ERG then multiplied hp-hours by the weighted-average emission factors for each pollutant, matching specific units and emission factors based on equipment type, hp group, and model year. Finally,

[350] Different equipment types are assumed to have different load factors as well as different transient adjustment factors, both of which affect base emission rates within MOVES. See U.S. EPA, *Median Life, Annual Activity, and Load Factor Values for Nonroad Engine Emission Modeling.* NR-005d. July 2010. https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P10081RV.pdf.

[351] Equipment with the same model year, hp group, load factor, and transient adjustment factor will have identical zero-hour emission rates in MOVES. ERG attempted to match these parameters whenever possible when gap-filling.

scaled emissions were summed across all equipment for each surveyed fleet to obtain statewide tons per year estimates for each pollutant.

- **Step 6—estimate N_2O and CO_{2e} emissions.** While MOVES outputs estimates for CO_2 and CH_4, it does not output values for N_2O, which in turn are needed to calculate CO_{2e} emissions. ERG calculated N_2O emissions based on MOVES' estimates for fuel consumption, as shown in Equation 6-3. CO_{2e} emissions are based on standard weighting factors, shown in Equation 6-4.

$$EF_{N2O} = EF \times 10^{-9} \times EC \times 1{,}000 \times BSFC \qquad \text{Equation 6-3}$$

Where:

EF_{N2O} = emissions of N_2O (tons)
EF = emission factor of 28.6 kg N_2O per TJ diesel (kg/TJ)[352]
10^{-9} = conversion factor from TJ to kJ (TJ/kJ)
EC = energy content of nonroad diesel fuel from MOVES (43.306 kJ/g)
1,000 = conversion factor from g to kg (g/kg)
$BSFC$ = brake-specific fuel consumption (tons)

$$Tons\ CO_{2e} = 1 \times tons\ CO_2 + 25 \times tons\ CH_4 + 298 \times tons\ N_2O \qquad \text{Equation 6-4}$$ [353]

- **Step 7—allocate emissions to counties.** ERG assigned the emission estimates associated with the public fleet survey responses to their associated counties, then allocated the remaining state-level activity using the allocation profiles developed for each survey group, as described in Section 3.1. ERG allocated state-level totals directly to counties for the agricultural, logging, and crane operator categories, without adjusting for the location reported in the surveys.[354]
- **Step 8—estimate tons per summer weekday emissions.** ERG applied a factor specific to each survey group to scale statewide and county-level annual emissions to summer weekday emissions. The scaling factors are specific to each survey category and are discussed in Section 4.

ERG quality-assured the outputs for each survey category, comparing the total fuel consumption estimates output from the modeling process with the estimates developed for the

[352] Intergovernmental Panel on Climate Change. *2006 IPPC Guidelines for National Greenhouse Gas Inventories*. https://www.ipcc-nggip.iges.or.jp/public/2006gl/.

[353] U.S. EPA, *How Do I get Carbon Dioxide Equivalent (CO2e) Results for Nonroad Equipment?* https://www.epa.gov/moves/how-do-i-get-carbon-dioxide-equivalent-co2e-results-nonroad-equipment.

[354] ERG did not attempt to adjust for survey respondent location for the logging and crane operator surveys due to the highly mobile nature of these fleets. Survey respondent location was not adjusted for the agricultural survey category due to the very small fraction of equipment represented at the county level.

activity profile task. In all cases, the estimates from the modeling exercise were within 10 percent of the prior values.

6.2.2 Methodology for Industry Sector Activity Profiles

ERG developed project-specific, industry sector activity profiles for eight categories of nonroad diesel equipment operators:

- Agricultural services
- Commercial and institutional building construction
- Highway/road—ODOT Construction Program
- Highway/road—ODOT Maintenance Program
- Highway/road—city, county, and other agency contracting
- Single family housing construction
- Utility work
- Well drilling

The industry sector activity profiles provided hp-hour estimates by equipment type/hp combination but did not include activity estimates for individual pieces of equipment with specific model years. This difference required modifications to the survey-based emission modeling methodology described above. While the process to obtain the initial zero-hour emission rates was the same, deterioration impacts were calculated using MOVES defaults for hours per year instead of the hours reported for a specific piece of equipment.

Since model year specific information was not available, a single weighted average emission factor was developed *across all model years* for each equipment type/hp group/pollutant combination.[355] MOVES population estimates, using updated load factors and defaults for other inputs, were broken out by model year and technology type for 2017 and used to develop the weighting factors for each tier level. ERG then applied the model year survey results for the construction industry, grouped by hp category,[356] to combine the tier-specific emission factors into a single composite value.[357] This composite value was then multiplied by the total hp-hour value for each equipment type/hp group combination and summed across all equipment to estimate total emissions for each industry sector profile. ERG followed the same gap-filling county and temporal allocation procedures as for the survey-based profiles.

[355] This approach sidesteps the need to input specific equipment population estimates into MOVES, relying instead on relative technology type distributions and total activity estimates expressed in hp-hours.

[356] Section 3.7 provides further details on the construction sector engine tier level survey.

[357] The emission calculations for agricultural services and well drilling assumed MOVES default tier level distributions.

6.2.3 Methodology for MOVES-Based Activity Profiles

ERG developed general equipment activity profiles for 25 equipment types not fully characterized by the survey and industry profile approaches, using the adjustment methods listed in Table 6-5.

Table 6-5. Emission Modeling Scenarios and Activity for MOVES-Based Profiles 2017 Nonroad Diesel Equipment Study

Adjustment	Equipment Type	Hours/Yr	Data Source
Adjust hrs/yr and population	Chippers/stump grinders	178	Public fleet survey
Adjust hrs/yr and population	Commercial mowers	238	Public fleet survey
Adjust hrs/yr and population	Commercial turf equipment	180	Public fleet Survey
Adjust hrs/yr and population	Lawn and garden tractors	166	Public fleet survey
Adjust hrs/yr and population	Other lawn and garden equipment	226	Public fleet survey
Adjust hrs/yr and population	Tractors/loaders/backhoes	582	TCEQ[358]
Adjust population	Aerial lifts	384	MOVES default
Adjust population	Compressors	815	MOVES default
Adjust population	Dumpers/tenders	566	MOVES default
Adjust population	Generator sets	338	MOVES default
Adjust population	Hydro power units	790	MOVES default
Adjust population	Inboard/sterndrive motors	200	MOVES default
Adjust population	Outboard motors	150	MOVES default
Adjust population	Pressure washers	145	MOVES default
Adjust population	Pumps	403	MOVES default
Adjust population	Railway maintenance equipment	943	MOVES default
Adjust population	Signal boards/light towers	535	MOVES default
Adjust population	Skid steer loaders	818	MOVES default
Adjust population	TRUs	1,341	MOVES default
Adjust population	Trenchers	593	MOVES default
Adjust population	Welders	643	MOVES default
None—MOVES default	Agricultural mowers	363	MOVES default
None—MOVES default	Off-highway tractors	855	MOVES default
None—MOVES default	Other oilfield equipment	1,231	MOVES default
None—MOVES default	Specialty vehicles/carts	435	MOVES default

Emissions for the equipment listed in Table 6-5 were estimated by running the MOVES model for Oregon in 2017 using the hours per year values shown above and the engine load factors shown in Table 6-2. Statewide emission estimates were then scaled up or down by the ratio of the updated equipment population estimate to the MOVES default population estimate. The

[358] Eastern Research Group, *Update of Diesel Construction Equipment Emission Estimates for the State of Texas.* Prepared for the Texas Commission on Environmental Quality. August 31, 2008.

activity and population scaling factors applied for these equipment types are discussed in detail in Section 5.3.

Activity and emissions were also included for most of the 25 equipment types in the survey and industry sector profiles described in Sections 6.2.1 and 6.2.2. To avoid double-counting, ERG calculated the total fuel consumption for the survey and industry sector profiles and reduced the equipment counts and emissions estimated for the MOVES-based profiles in direct proportion with the fuel consumption reduction. For two of the equipment categories, commercial turf equipment and other lawn and garden equipment, the fuel consumption estimated for the survey and sector profiles slightly exceeded the estimate based on population scaling (by approximately 15,000 gallons each, corresponding to about 50 units of each equipment type). For this reason, emissions were set to zero for the “Other Activity Profiles” for these two equipment categories.

The fuel consumption total associated with generator use in the survey-based profiles also exceeded that estimated for generators in the “Other Activity Profile,” in this instance by a large margin, greater than 400,000 gallons per year. The vast majority of this discrepancy is associated with generators used to power crushing/processing equipment at surface mining locations. Although relatively small in number (approximately 63 units estimated statewide), these units have a very high average power rating (over 600 hp) and very high utilization rates (over 1,100 hours per year), resulting in high fuel consumption levels. ERG concluded that these generators are not representative of typical units, which EPA estimates to have an average power rating of 77 hp and average utilization of 338 hours per year. For this reason, ERG adjusted the “Other Activity Profile” values for generators by reducing the population by 63 units, rather than adjusting by fuel consumption totals. This resulted in positive population counts and emissions for this category, which reflects how this type of equipment is being used in Oregon according to the survey results and SMEs.

6.3 Emission Inventory Results and Analysis

This section summarizes the results of the emission modeling exercise, highlighting key findings and sources of uncertainty.

6.3.1 Statewide and County-Level Emission Estimates

Emission totals were compiled across the 46 modeling scenarios described in Sections 6.2.1 through 6.2.3 to estimate county level and statewide emissions for 2017. Table 6-6 presents the county totals for CAPs and GHGs in tons per year. Appendix G presents the county-level fuel consumption and emission estimates for tons per summer weekday.

The information presented in Table 6-6 shows that more populous counties are responsible for a higher share of total emissions. In fact, many of the Portland Metro–area counties (Multnomah, Washington, and Clackamas), as well as several other counties in the Willamette Valley (e.g., Lane and Linn) all fall in the top 10 for emission totals. The table also shows that emission percentages are relatively constant across the different pollutants.

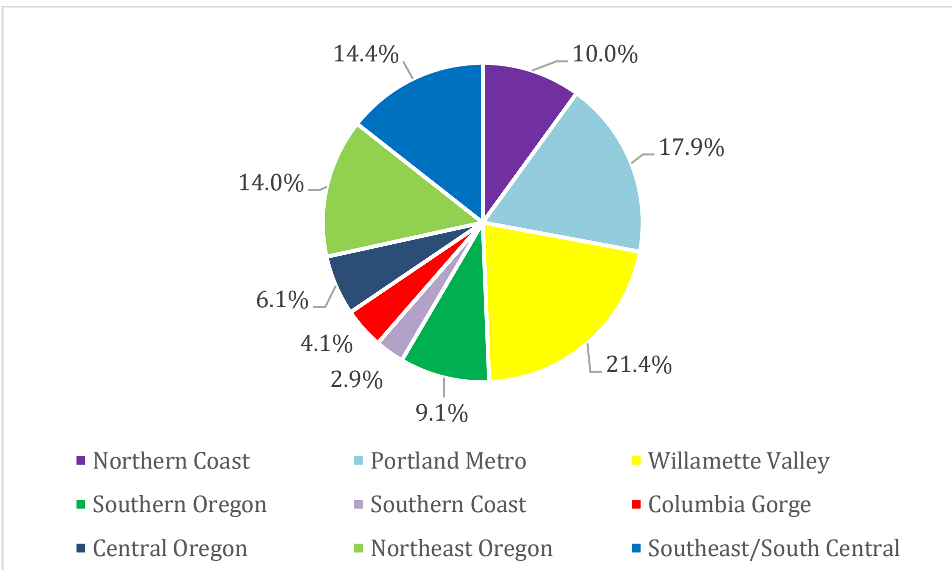
Table 6-6. County-Level Annual CAP and GHG Emissions (TPY, %)
2017 Nonroad Diesel Equipment Study

County	CO TPY	CO %	NO_x TPY	NOx %	$PM_{2.5}$ TPY	$PM_{2.5}$ %	VOCs TPY	VOCs %	CO_{2e} TPY	CO_{2e} %
Baker	131	2.54%	239	2.44%	17	2.46%	23	2.48%	30,006	2.12%
Benton	117	2.26%	228	2.33%	16	2.27%	21	2.23%	36,018	2.55%
Clackamas	259	5.00%	488	5.00%	36	5.15%	49	5.21%	75,540	5.35%
Clatsop	100	1.93%	210	2.15%	13	1.89%	17	1.85%	34,540	2.44%
Columbia	82	1.59%	177	1.81%	11	1.56%	14	1.54%	29,973	2.12%
Coos	99	1.91%	201	2.06%	13	1.86%	17	1.84%	31,610	2.24%
Crook	89	1.72%	168	1.72%	12	1.71%	16	1.71%	23,780	1.68%
Curry	55	1.05%	111	1.14%	7	1.02%	10	1.02%	17,050	1.21%
Deschutes	177	3.42%	334	3.42%	25	3.62%	34	3.59%	50,053	3.54%
Douglas	267	5.15%	527	5.39%	35	5.01%	46	4.92%	82,023	5.81%
Gilliam	48	0.93%	100	1.02%	7	0.99%	8	0.90%	17,687	1.25%
Grant	61	1.17%	109	1.11%	8	1.13%	11	1.14%	13,280	0.94%
Harney	203	3.91%	356	3.64%	26	3.76%	36	3.82%	40,215	2.85%
Hood River	46	0.89%	85	0.87%	6	0.87%	8	0.88%	11,365	0.80%
Jackson	171	3.30%	328	3.36%	24	3.40%	32	3.37%	51,753	3.66%
Jefferson	49	0.95%	89	0.91%	7	0.94%	9	0.95%	11,021	0.78%
Josephine	36	0.70%	72	0.74%	5	0.72%	7	0.72%	11,523	0.82%
Klamath	165	3.19%	306	3.14%	22	3.11%	29	3.15%	40,219	2.85%
Lake	166	3.20%	300	3.07%	22	3.08%	29	3.13%	35,561	2.52%
Lane	319	6.16%	632	6.47%	43	6.19%	57	6.11%	103,120	7.30%
Lincoln	72	1.39%	152	1.55%	10	1.36%	13	1.34%	25,040	1.77%
Linn	266	5.13%	497	5.09%	35	5.01%	47	5.00%	69,855	4.94%
Malheur	209	4.04%	369	3.77%	27	3.91%	37	3.97%	42,764	3.03%
Marion	283	5.45%	527	5.40%	38	5.48%	52	5.53%	74,117	5.25%
Morrow	179	3.46%	320	3.28%	24	3.37%	32	3.39%	38,752	2.74%
Multnomah	355	6.85%	662	6.77%	52	7.43%	69	7.42%	106,760	7.56%
Polk	127	2.46%	242	2.48%	17	2.40%	22	2.40%	34,356	2.43%
Sherman	22	0.43%	40	0.41%	3	0.42%	4	0.43%	4,804	0.34%
Tillamook	99	1.91%	196	2.01%	13	1.85%	17	1.84%	29,449	2.08%
Umatilla	202	3.91%	363	3.72%	27	3.83%	36	3.88%	44,881	3.18%

County	CO TPY	CO %	NO_x TPY	NOx %	$PM_{2.5}$ TPY	$PM_{2.5}$ %	VOCs TPY	VOCs %	CO_{2e} TPY	CO_{2e} %
Union	82	1.58%	149	1.53%	11	1.54%	14	1.55%	19,455	1.38%
Wallowa	68	1.31%	123	1.26%	9	1.27%	12	1.27%	15,496	1.10%
Wasco	72	1.38%	133	1.36%	10	1.38%	13	1.37%	17,979	1.27%
Washington	322	6.21%	600	6.14%	46	6.56%	61	6.57%	96,630	6.84%
Wheeler	21	0.40%	36	0.37%	3	0.38%	4	0.38%	4,340	0.31%
Yamhill	162	3.12%	301	3.08%	22	3.08%	29	3.08%	41,898	2.97%
Total	**5,180**		**9,767**		**699**		**935**		**1,412,917**	

Figure 6-1 presents a regional breakout for $PM_{2.5}$ emissions—a higher-level view of how emissions are distributed across the state.[359]

Figure 6-1. Regional Distribution of Annual $PM_{2.5}$ Emissions
2017 Nonroad Diesel Equipment Study



6.3.2 Emission Estimates by Sector

Statewide annual fuel consumption, CAP emission, and GHG emission estimates were broken out by study sector. Ten sectors were characterized with distinct equipment type and sector profiles. Table 6-7 summarizes the fuel consumption and emissions for each sector, and Table 6-8 presents the corresponding county-level activity distributions. Figure 6-2 and Figure 6-3

[359] For the county group listing, see https://oregoneconomicanalysis.files.wordpress.com/2012/03/region_map.jpg.

provide examples of the sector contributions for statewide fuel consumption and $PM_{2.5}$. The following observations can be drawn from the study's activity and emission modeling results.

- The agriculture sector, including farm and ranch establishments, is responsible for 33.9 percent of total nonroad diesel equipment fuel consumption in the state.[360] Agricultural tractors are responsible for the vast majority of fuel consumption within the sector, and their highly skewed age distribution (with an average model year of 1996) results in an even higher proportion of total CAP emissions (between 44 and 48 percent of the state total). Emissions are broadly distributed across the state's non-urban counties, with no single county responsible for more than 8 percent of activity.
- The logging sector includes establishments involved in timber harvesting as well as logging road construction and maintenance and associated aggregate production for roadbeds. The sector is responsible for 24.9 percent of the state's nonroad diesel equipment fuel consumption. The equipment profile for the sector features newer units than those found in the agricultural sector, with an average model year of 2005 for harvesting equipment. This leads to a proportionally lower contribution to total CAP emissions compared to the agricultural sector (between 18 and 21 percent of the state total). While all but two counties have some logging emissions (Gilliam and Sherman), activity is concentrated in Douglas, Lane, Linn, Clatsop, and Coos Counties, which are responsible for more than 50 percent of the state total.
- The construction sector encompasses a wide range of activities, including development of single-family homes, commercial and institutional buildings, highways and roads, and utility contract work. Construction activities are responsible for 15.9 percent of the state's nonroad diesel fuel consumption and GHG emissions. The construction sector's CAP emission percentages are comparable to its fuel and GHG percentages (between 15 and 18 percent of the state total). Equipment activity is concentrated in urban and suburban counties, with Multnomah, Deschutes, Washington, and Clackamas Counties responsible for 57.9 percent of the sector total.
- TRUs are used in on-highway trucks and railcars to provide temperature control for cargo. Survey information was not collected for this equipment. Rather, ERG calculated total fuel consumption and emissions by scaling MOVES default outputs by the adjusted population ratio. Since the MOVES model generally assumes a newer equipment fleet than observed for most operation categories, the CAP emission levels estimated for TRUs are proportionally lower than the activity estimate, between 2 and 4 percent of the state total. The MOVES model was also used to allocate state activity and emission totals to the county level. MOVES assumes TRU use tracks directly with census population, resulting in over 50 percent of activity attributed to Multnomah, Washington, Clackamas, and Lane Counties.

[360] The agricultural sector excludes independent agricultural service providers, which are included in the commercial/industrial sector for consistency with the validation analysis (see Section 7).

- Public fleets include a wide range of agency operations (e.g., cities, counties, Special Districts, and other agencies), in addition to “captive” private fleets working under public contracts (e.g., some port terminal, municipal solid waste, and recycling facility operators). Public fleets commonly operate low-hp equipment at low utilization rates (e.g. less than 500 hours per year). Total fuel consumption for this sector is 6.1 percent and CAP emissions are between 4 and 5 percent of the state total. Activity is distributed across both urban and rural counties, with Gilliam,[361] Multnomah, Washington, Benton, and Lane responsible for over 50 percent of the sector’s activity.
- Surface mining operations in Oregon are almost exclusively associated with the production of sand, gravel, and aggregate used in the construction industry. The sector is responsible for 5.0 percent of the state’s nonroad diesel equipment fuel consumption. Surface mining operations commonly feature high-hp, high-utilization equipment with a relatively rapid fleet turnover resulting in a newer equipment distribution than many other sectors. This results in a relatively low contribution to overall CAP emissions, ranging from approximately 2 to 3 percent of the state totals. Activity is reported for every county, with almost 50 percent of total activity attributable to Lane, Columbia, Washington, Marion, Jackson, and Baker Counties.
- Other commercial/industrial includes a range of generally low-hp equipment: specialty vehicles/carts, welders, air compressors, and generators, among others. Some units were characterized based on survey responses; others were modeled using MOVES default outputs scaled to reflect equipment population adjustments. Other commercial/industrial equipment was estimated to consume 5.8 percent of the state fuel total, with estimated CAP emissions between 5 and 7 percent of the state total. Units are geographically concentrated in urban areas, with Multnomah, Washington, Clackamas, Lane, and Marion counties responsible for over 67% of sector activity.
- The remaining four operation sectors—recreational marine, railway maintenance, lawn and garden, and other oilfield equipment—are estimated to consume 2.1 percent of nonroad equipment diesel fuel consumption, with CAP emissions ranging from 1.5 to 2.5 percent of the state total. Recreational marine activity is broadly distributed across the state. The allocation of this activity is based on the county of boater registration and the location of boatable surface waters, with county of registration given greater weight. Railway maintenance activity is assumed to correlate with track-miles (weighted by railroad operator class activity), with Multnomah, Lane, Klamath, Umatilla, Linn, Wasco, and Douglas Counties responsible for approximately half of the sector’s activity. Lawn and garden equipment use is highly concentrated in urban areas, with over three quarters of sector activity attributed to Washington, Clackamas, Multnomah, Marion, and Lane Counties. Most oilfield equipment use is assumed to occur in six counties: Benton, Clackamas, Josephine, Klamath, Wasco, and Washington.

[361] Primarily associated with solid waste landfill activity.

Table 6-7. Annual Fuel Consumption and Emissions by Operator Sector 2017 Nonroad Diesel Equipment Study

Sector	Gallons	Percent	CO		NO_x		$PM_{2.5}$		VOCs		CO_2e	
			Tons/Yr	Percent	Tons/Yr	Percent	Tons/Yr	Percent	Tons/Yr	Percent	Tons/Yr	Percent
Agriculture	38,557,494	33.88%	2,479	47.86%	4,290	43.93%	320	45.85%	436	46.61%	478,115	33.84%
Logging	28,347,050	24.91%	1,007	19.44%	2,071	21.20%	130	18.65%	167	17.84%	352,349	24.94%
Construction	18,125,468	15.93%	858	16.56%	1,481	15.16%	127	18.17%	166	17.74%	225,005	15.92%
Transportation Refrigeration Units	7,161,123	6.29%	106	2.05%	412	4.22%	15	2.17%	21	2.26%	89,015	6.30%
Public Fleets	6,955,465	6.11%	211	4.08%	453	4.64%	32	4.59%	39	4.15%	86,394	6.11%
Other Commercial/Industrial	6,683,887	5.87%	328	6.33%	499	5.11%	47	6.79%	67	7.14%	82,933	5.87%
Surface Mining	5,636,231	4.95%	117	2.25%	321	3.28%	16	2.29%	21	2.22%	70,102	4.96%
Recreational Marine	1,410,572	1.24%	30	0.57%	157	1.61%	3	0.45%	8	0.85%	17,480	1.24%
Railway Maintenance Equipment	506,196	0.44%	30	0.59%	45	0.46%	5	0.71%	7	0.79%	6,291	0.45%
Commercial Lawn & Garden	435,961	0.38%	17	0.33%	40	0.41%	3	0.40%	4	0.47%	5,400	0.38%
Other Oilfield Equipment	19,676	0.02%	0	0.01%	1	0.01%	0	0.01%	0	0.01%	244	0.02%
Total	**113,839,122**		**5,183**		**9,771**		**699**		**935**		**1,413,328**	

Figure 6-2. Statewide Annual Fuel Consumption by Sector
2017 Nonroad Diesel Equipment Study

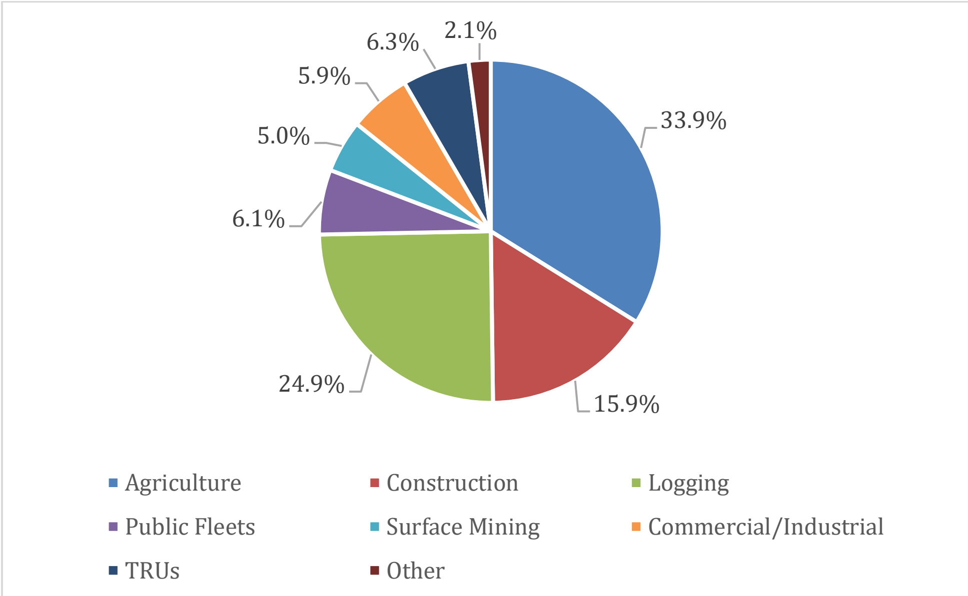


Figure 6-3. Statewide Annual $PM_{2.5}$ Emissions by Sector
2017 Nonroad Diesel Equipment Study

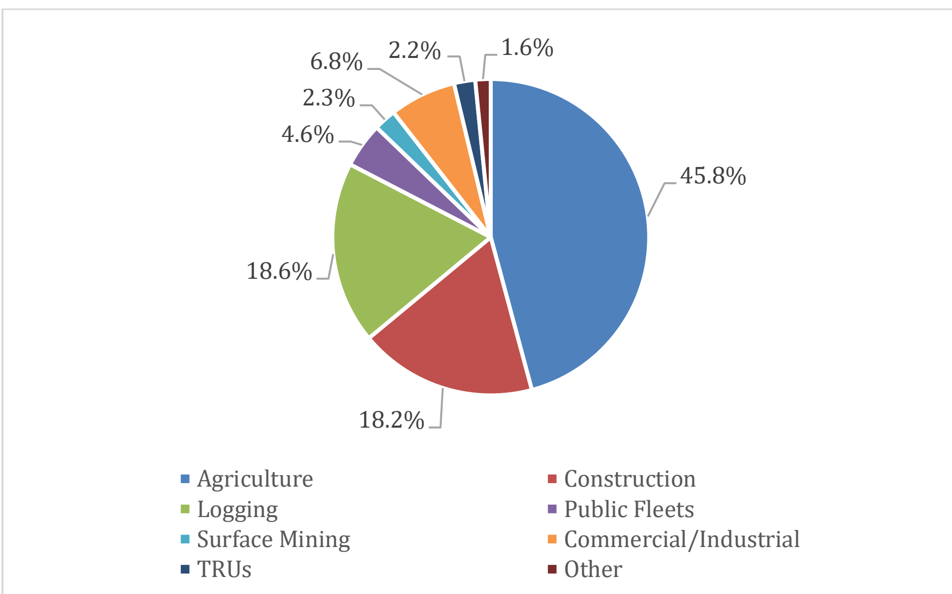


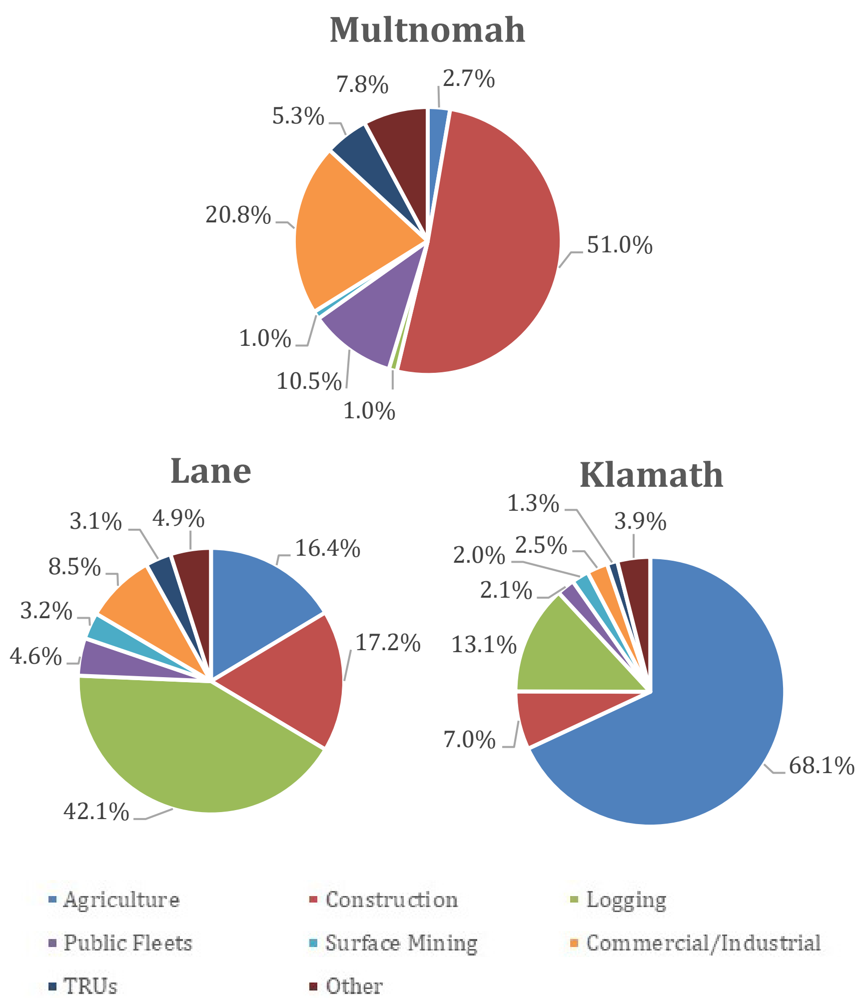
Table 6-8. County Activity and Emissions by Operator Sector
2017 Nonroad Diesel Equipment Study

County	Agriculture	Logging	Construction	TRUs	Public Fleets	Other Comm./Ind.	Surface Mining	Rec. Marine	Rail Maintenance	Lawn and Garden	Other Oilfield
Baker	4.55%	0.34%	0.26%	0.47%	0.82%	0.37%	6.13%	0.68%	2.77%	0.10%	0.00%
Benton	1.83%	3.32%	1.54%	2.24%	6.18%	1.22%	4.40%	0.89%	2.46%	2.69%	16.28%
Clackamas	3.01%	4.22%	7.84%	10.00%	4.22%	11.94%	5.77%	7.18%	1.85%	23.04%	15.12%
Clatsop	0.23%	7.57%	0.97%	1.01%	1.19%	0.80%	1.17%	6.59%	0.97%	0.92%	0.00%
Columbia	0.37%	4.60%	1.08%	1.29%	0.77%	0.57%	8.96%	5.00%	2.11%	0.46%	0.00%
Coos	0.93%	5.74%	0.80%	1.78%	0.99%	1.00%	1.28%	5.11%	1.24%	0.31%	0.00%
Crook	2.42%	0.27%	2.54%	0.57%	1.44%	0.77%	4.58%	0.29%	0.55%	0.10%	0.00%
Curry	0.58%	3.08%	0.45%	0.61%	0.30%	0.43%	0.47%	5.05%	0.00%	0.25%	0.00%
Deschutes	1.00%	0.77%	14.18%	3.56%	3.36%	4.04%	2.07%	2.81%	2.98%	2.71%	3.49%
Douglas	3.07%	15.27%	1.82%	2.87%	2.67%	1.67%	3.01%	3.11%	4.98%	1.42%	0.00%
Gilliam	0.91%	0.00%	0.14%	0.05%	14.73%	0.10%	0.09%	0.47%	1.71%	0.00%	0.00%
Grant	2.06%	0.72%	0.04%	0.21%	0.15%	0.16%	0.19%	0.18%	0.00%	0.00%	0.00%
Harney	7.94%	0.08%	0.06%	0.21%	0.29%	0.13%	0.05%	2.31%	0.00%	0.00%	0.00%
Hood River	1.07%	0.77%	0.88%	0.59%	0.37%	0.49%	0.10%	0.53%	1.56%	0.42%	0.00%
Jackson	1.93%	2.70%	5.94%	5.31%	5.58%	4.72%	8.18%	1.49%	2.92%	4.63%	4.65%
Jefferson	1.55%	0.01%	0.77%	0.56%	0.22%	0.58%	0.60%	0.59%	1.87%	0.10%	0.00%
Josephine	0.38%	0.83%	0.99%	2.21%	0.64%	1.71%	0.76%	0.38%	1.33%	1.13%	15.12%
Klamath	4.62%	2.21%	1.25%	1.83%	1.17%	1.37%	2.82%	5.20%	8.24%	0.33%	15.12%
Lake	5.97%	1.00%	0.17%	0.21%	0.38%	0.19%	1.15%	5.58%	0.49%	0.12%	0.00%
Lane	2.26%	14.42%	5.85%	9.28%	6.18%	8.52%	9.03%	5.70%	9.34%	5.29%	0.00%
Lincoln	0.21%	4.80%	0.97%	1.26%	1.63%	0.74%	1.21%	5.56%	1.11%	0.67%	0.00%
Linn	5.92%	7.94%	2.18%	2.98%	0.75%	2.77%	2.87%	1.35%	5.53%	3.23%	0.00%
Malheur	7.77%	0.03%	0.65%	0.89%	1.20%	0.73%	0.76%	1.07%	2.00%	0.13%	0.00%
Marion	6.67%	1.64%	5.36%	8.37%	5.84%	5.47%	8.56%	2.23%	4.51%	7.46%	0.00%
Morrow	6.62%	0.02%	0.58%	0.33%	4.31%	0.24%	1.01%	0.40%	2.14%	0.00%	0.00%

County	Agriculture	Logging	Construction	TRUs	Public Fleets	Other Comm./Ind.	Surface Mining	Rec. Marine	Rail Maintenance	Lawn and Garden	Other Oilfield
Multnomah	0.45%	0.41%	21.89%	19.16%	13.59%	25.69%	3.28%	16.40%	10.86%	12.04%	0.00%
Polk	2.98%	3.39%	0.88%	1.84%	0.40%	0.79%	4.31%	0.90%	1.35%	0.60%	0.00%
Sherman	0.88%	0.00%	0.10%	0.05%	0.07%	0.03%	0.09%	0.20%	0.60%	0.00%	0.00%
Tillamook	1.28%	4.98%	1.12%	0.70%	0.70%	0.56%	0.94%	4.44%	1.84%	0.12%	0.00%
Umatilla	6.95%	0.33%	1.46%	2.04%	1.25%	1.55%	2.65%	0.56%	7.29%	1.35%	0.00%
Union	2.40%	1.23%	0.47%	0.70%	0.82%	0.56%	0.46%	0.37%	3.19%	0.12%	0.00%
Wallowa	2.15%	1.11%	0.11%	0.20%	0.19%	0.24%	0.30%	0.15%	1.46%	0.04%	0.00%
Wasco	2.12%	0.22%	0.49%	0.67%	4.41%	0.72%	0.58%	0.60%	5.08%	0.15%	15.12%
Washington	2.25%	3.17%	14.04%	13.40%	10.70%	17.15%	8.57%	5.50%	4.05%	28.52%	15.12%
Wheeler	0.73%	0.17%	0.01%	0.04%	0.03%	0.05%	0.07%	0.01%	0.00%	0.00%	0.00%
Yamhill	3.93%	2.64%	2.12%	2.49%	2.48%	1.92%	3.51%	1.14%	1.63%	1.56%	0.00%

A detailed review of sector activity at the county level provides further insights. For example, Figure 6-4 presents annual $PM_{2.5}$ emissions by sector for Multnomah, Lane, and Klamath Counties. The figure clearly illustrates the substantial geographic variation in sector emissions, with construction being the largest contributor in Multnomah County, logging in Lane County, and agriculture in Klamath County.

Figure 6-4. Annual $PM_{2.5}$ Emissions by Sector—Selected Counties
2017 Nonroad Diesel Equipment Study



6.3.3 Emission Estimates by MOVES Equipment Category

Nonroad diesel engines were also grouped by equipment category in order to compare activity and emissions directly to MOVES model outputs. MOVES groups nonroad diesel equipment into 11 categories, as shown in Table 6-9. These categories are largely a way to organize data collection and processing; they do not necessarily reflect how the equipment is used or who operates it. Some categories, such as airport GSE and railway maintenance, include highly specialized equipment used in a single industry operation. Other categories, such as industrial and commercial, include equipment used in a wide range of applications and operations.

Nonroad diesel equipment is used in a wide range of industries and applications. For example, industrial and commercial equipment (e.g., generators) is common in public fleets and surface mining. Similarly, construction equipment (e.g., excavators and graders) is often employed in the agricultural and logging sectors. In this analysis, it is important to distinguish between "agricultural equipment," for instance, and the agricultural sector.

Table 6-9. MOVES-Nonroad Diesel Equipment Category Groupings (MOVES 2014b) 2017 Nonroad Diesel Equipment Study

Equipment Group	SCC
Recreational vehicles	2270001XXX
Construction	2270002XXX
Industrial	2270003XXX
Commercial lawn and garden	2270004XXX
Agricultural	2270005XXX
Commercial	2270006XXX
Logging	2270007XXX
Airport ground support	2270008XXX
Recreational marine	228202XXXX
Railway maintenance	2285002015
Other oilfield equipment	2270010010

Table 6-10 and Table 6-11 present the statewide annual fuel consumption and emission estimates for the study and MOVES defaults by nonroad diesel equipment category group, respectively.[362] Table 6-12 presents the ratio of the study's emission estimates to MOVES defaults to facilitate direct comparison. Figure 6-5 compares the study's fuel consumption estimates with the MOVES defaults, and Figure 6-6 provides the same comparison for $PM_{2.5}$ emissions to illustrate the differences by equipment category.

[362] Refer to Table 1.1 for a detailed listing of equipment types by category.

Table 6-10. Annual Fuel Consumption and Emissions by Equipment Category – Study Basis
2017 Nonroad Diesel Equipment Study

Equipment Category	Gallons	CO	NO_x	$PM_{2.5}$	VOCs	CO_{2e}
Construction/mining	39,834,517	1,878	3,403	261	347	494,477
Agriculture	32,092,379	1,870	3,309	244	326	398,098
Logging	24,474,458	848	1,726	110	138	304,261
Industrial	8,056,664	157	493	22	31	100,133
Commercial	6,121,430	307	526	44	65	75,937
Recreational marine	1,410,572	30	157	3	8	17,480
Lawn and garden	667,972	22	54	4	6	8,281
Railway maintenance	506,196	30	45	5	7	6,291
Airport ground support	496,923	28	42	5	5	6,167
Recreational vehicles	158,336	12	14	2	3	1,958
Other oilfield equipment	19,676	0	1	0	0	244
Total	**113,839,122**	**5,183**	**9,771**	**699**	**935**	**1,413,328**

Table 6-11. Annual Fuel Consumption and Emissions by Equipment Category – MOVES Basis
2017 Nonroad Diesel Equipment Study

Equipment Category	Gallons	CO	NO_x	$PM_{2.5}$	VOCs	CO_{2e}
Construction/mining	94,838,699	2,331	4,685	369	4309	1,180,712
Agriculture	37,263,257	1,139	2,514	206	202	463,842
Logging	11,071,639	111	287	20	16	137,914
Industrial	20,512,233	315	908	49	55	255,483
Commercial	13,405,973	488	980	75	100	166,849
Recreational marine	3,311,440	72	367	7	19	41,221
Lawn and garden	3,324,658	99	273	17	23	41,373
Railway maintenance	204,511	12	18	2	3	2,541
Airport ground support	811,389	16	36	3	2	10,105
Recreational vehicles	158,336	12	14	2	3	1,958
Other oilfield equipment	19,676	0	1	0	0	244
Total	**184,921,881**	**4,596**	**10,083**	**749**	**854**	**2,302,242**

Table 6-12. Annual Fuel Consumption and Emission by Equipment Category - Ratio of Study to MOVES
2017 Nonroad Diesel Equipment Study

Equipment Category	Gallons	CO	NO_x	$PM_{2.5}$	VOCs	CO_{2e}
Construction	42.0%	80.6%	72.6%	70.9%	80.7%	41.9%
Agriculture	86.1%	164.2%	131.6%	118.2%	161.1%	85.8%
Logging	221.1%	763.5%	600.7%	554.2%	865.2%	220.6%
Industrial	39.3%	49.9%	54.3%	45.2%	57.2%	39.3%
Commercial	45.7%	62.8%	53.7%	5.92%	64.5%	45.5%
Recreational marine	42.6%	41.1%	42.8%	43.0%	41.0%	42.4%
Lawn and garden	20.1%	21.8%	19.9%	20.5%	24.1%	20.0%
Railway maintenance	247.5%	247.5%	247.5%	247.8%	247.5%	247.5%
Airport ground support	61.2%	173.7%	116.5%	172.5%	197.9%	61.0%
Recreational vehicles	100.0%	104.5%	100.3%	104.3%	106.7%	100.0%
Other oilfield equipment	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Total	**61.6%**	**112.8%**	**96.9%**	**93.3%**	**109.5%**	**61.4%**

Figure 6-5. Statewide Annual Fuel Consumption (M Gallons) by Equipment Category
2017 Nonroad Diesel Equipment Study

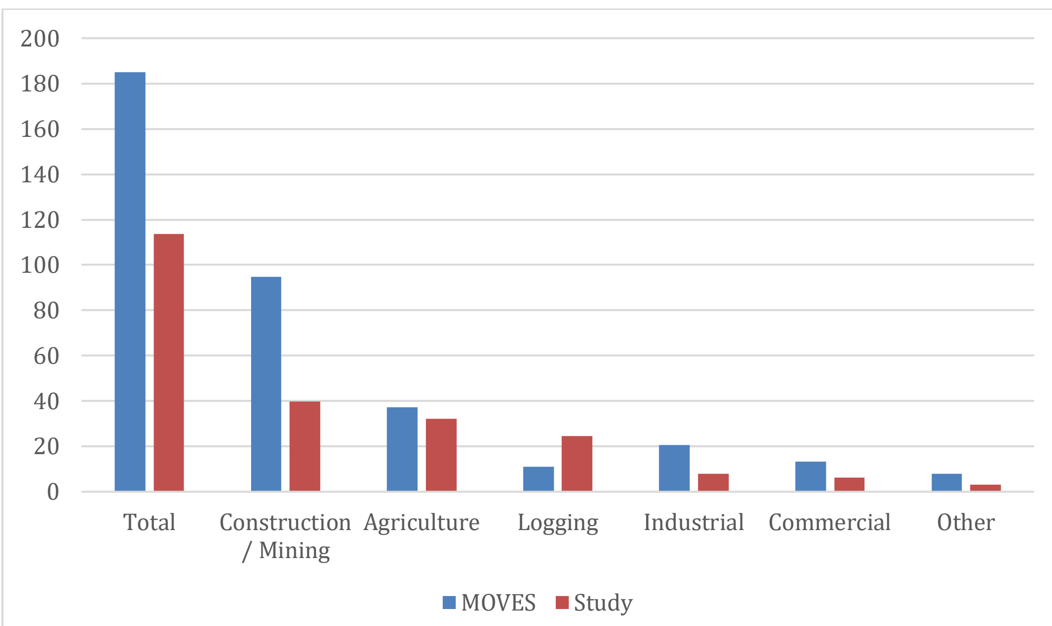
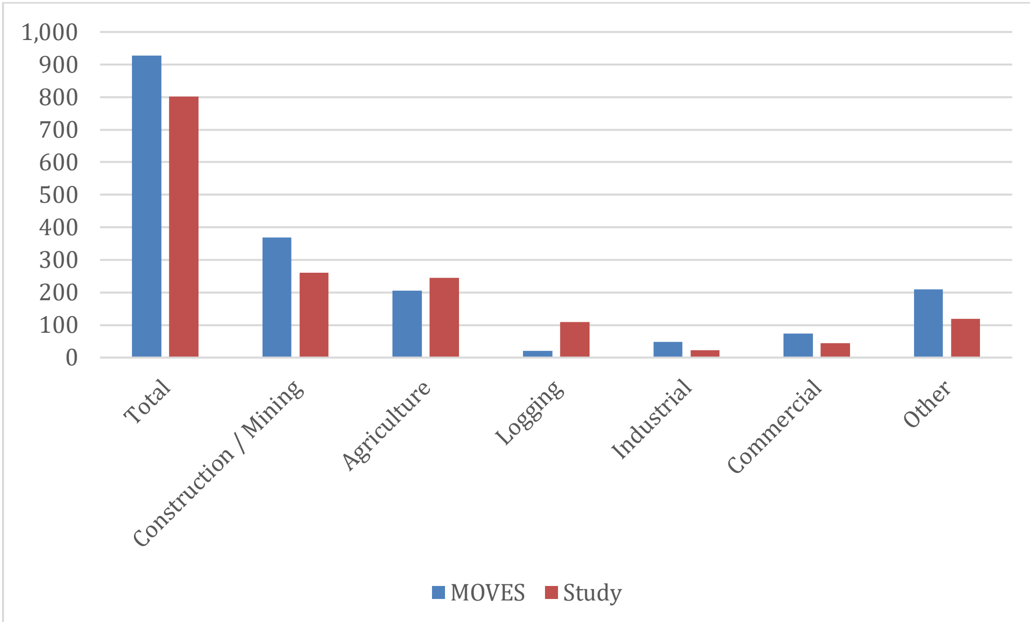


Figure 6-6. Statewide Annual $PM_{2.5}$ Emissions (Tons) by Equipment Category 2017 Nonroad Diesel Equipment Study



The fuel consumption estimates presented in Table 6-10 through Table 6-12 show the collective impact of the parameters ERG developed for equipment population, activity, engine hp, and (in some instances) engine load, for numerous industry sectors and equipment types.

The recreational diesel vehicle category as defined by the MOVES model is limited to specialty vehicles and carts. The recreational vehicle populations and fuel consumption estimated by the study are assumed to equal MOVES defaults, with emissions adjusted to reflect available model year and activity information obtained through the survey responses.

MOVES' construction category includes over 20 types of equipment such as excavators, pavers, and rubber-tired loaders. The study's estimated fuel consumption for this equipment is substantially less than the MOVES default (42.0 percent of the MOVES value). However, the model year distribution based on the construction sector equipment survey results was notably older than that assumed by MOVES, leading to proportionally higher CAP emission estimates (ranging from 70.9 percent of the MOVES value for $PM_{2.5}$ to 80.7 percent for VOCs).

The industrial category contains seven equipment types including aerial lifts, sweepers/scrubbers, and TRUs. The study's estimated fuel consumption for industrial equipment is less than the MOVES default (39.3 percent of the MOVES value), as shown in Table 6-12. CAP emission estimates for this category range from 45.2 percent of the MOVES value for $PM_{2.5}$ to 57.2 percent for VOCs.

Lawn and garden equipment include commercial mowers, lawn and garden tractors, chippers/stump grinders, commercial turf equipment, and other lawn and garden equipment.

The study's estimated fuel consumption for this equipment is low in absolute terms, estimated by MOVES to be just 1.8 percent of the state total, and by the study to be 0.6 percent of the state total. The study's activity estimate is substantially lower than the MOVES value (20.1 percent of the MOVES value), as a result of significant population and hour per year adjustments as described in Section 5.3. The study's CAP emission estimates for the sector range from 19.9 percent of the MOVES estimate for NO_x to 19.9 percent for VOCs.

Agricultural equipment includes agricultural mowers and tractors, balers, combines, irrigation equipment, sprayers, swathers, and other agricultural equipment. The study's estimated fuel consumption for this equipment is 86.1 percent of the MOVES default. The study's CAP emission estimates for the sector range from 118 percent of the MOVES estimate for $PM_{2.5}$ to 164 percent for CO, with the increases largely attributable to the age of the tractor population.

Commercial equipment includes generator sets, pumps, air compressors, welders, pressure washers, and hydraulic power units. The study's estimated fuel consumption for this equipment is 45.7 percent of the MOVES default, primarily due to large downward adjustment to the EPA population estimates based on registration data obtained from California and extrapolated to Oregon. The study's CAP emission estimates for the sector range from 53.7 percent of the MOVES estimate for NO_x to 64.5 percent for VOCs.

Logging equipment is grouped into a single category by the MOVES model. The study's estimated fuel consumption for this equipment is 221 percent of the MOVES default. The study's CAP emission estimates for the sector range from 554 percent of the MOVES estimate for $PM_{2.5}$ to 865 percent for VOCs. See Section 3.3 for a detailed discussion of the factors leading to the large differences.

Airport GSE is grouped into a single category by the MOVES model. The study's estimated fuel consumption for this equipment is 61.2 percent of the MOVES default. However, the model year distribution estimated for the sector was substantially older than that assumed by MOVES, leading to proportionally higher CAP emission estimates (from 117 percent for NO_x to 198 percent for VOCs).

Recreational marine engines include inboard/sterndrive motors and outboard motors. The study's estimated fuel consumption for this equipment is 42.6 percent of the MOVES default. ERG estimated emissions for this equipment by applying a simple scaling factor for population.

Railway maintenance equipment is grouped into a single category by the MOVES model. The study's estimated fuel consumption for this equipment is 248 percent of the MOVES default. ERG estimated emissions for this equipment by applying a simple scaling factor for population.

Other oilfield equipment emissions were assumed to be minimal in Oregon and set equal to MOVES default values.

In summary, the MOVES model's default outputs provide standard points of comparison for the population, fuel consumption, and other modeling parameters developed for the study. However, MOVES' modeling parameters are subject to substantial uncertainties themselves.[363] The following points about the MOVES defaults for Oregon should be kept in mind:

- MOVES' "base year" for nonroad diesel equipment is 2000, 17 years before the 2017 evaluation year. The base year defines the equipment use characteristics along with the Oregon share of the national nonroad equipment population.
- Key modeling parameters represent national averages including annual usage rates, equipment type distributions within a source sector, engine power distributions, and equipment lifetime/scrappage rates, and are not specific to Oregon.
- The surrogates used to project source sector population from the base year to the evaluation year are generally state-specific but have varying degrees of uncertainty.

6.3.4 Temporal Allocation

Annual emissions were adjusted to account for the fraction of activity occurring during summer months (June–August) and weekdays (Monday–Friday) in order to estimate typical summer weekday emission levels. Activity fractions for agriculture, logging, surface mining, and most public fleets were obtained from survey responses. Fractions for well drilling were derived from OWRD drilling permit data. Fractions for remaining equipment types were assumed to equal MOVES default values for the Northwest region of the United States.[364]

Figure 6-7 presents the percent of summer season activity by study sector. Figure 6-8 presents the corresponding percentages for weekdays. As the two figures show, a substantial portion of total activity occurs during the summer for several sectors including agriculture, logging and recreational marine. And, with the exception of recreational marine and lawn and garden, the sectors have most of their activity during weekdays.

[363] Refer to Appendix H for further information on the various data sources and uncertainties associated with the MOVES model.

[364] MOVES defaults for temporal allocation were used for airport fleets due to lack of survey information.

Figure 6-7. Summer Season Activity and Emission Fractions
2017 Nonroad Diesel Equipment Study

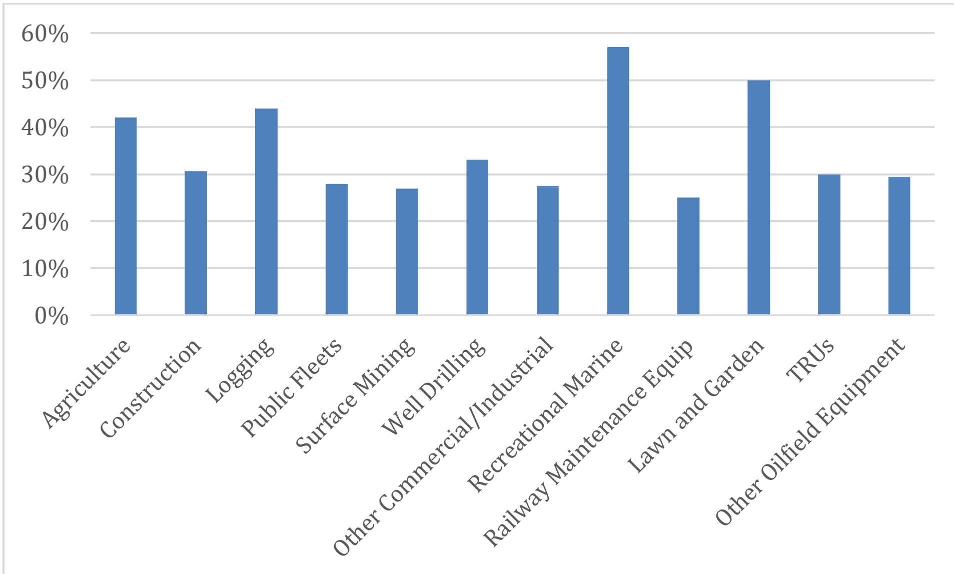
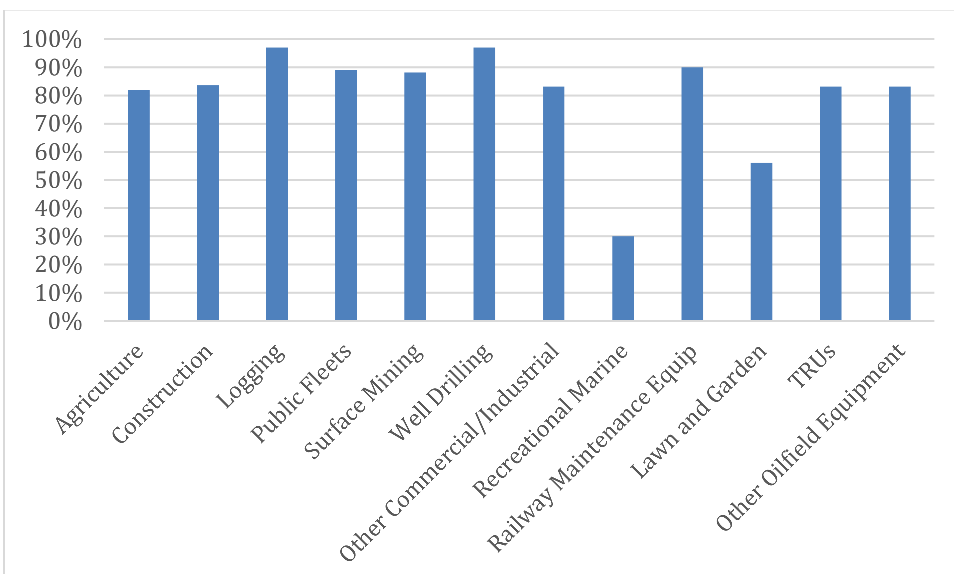


Figure 6-8. Weekday Activity and Emission Fractions
2017 Nonroad Diesel Equipment Study



6.3.5 Adjustments for Alternative Fuels, Retrofits, and Repowers

Under Oregon's renewable fuels mandate, all diesel offered for sale in the state must contain at least 5 percent biodiesel (B5).[365] ERG applied adjustment factors from the MOVES model to estimate the impact of statewide B5 use on emissions. While MOVES does not calculate biodiesel impacts for nonroad equipment emissions, it does so for on-road vehicles manufactured prior to 2007. Table 6-13 shows the emission impacts associated with B20 use in these vehicles. ERG assumed emission impacts scale linearly with blend level, decreasing the B20 impacts by 75 percent for B5 use (also shown in Table 6-13).

Table 6-13. Biodiesel Emission Impacts 2017 Nonroad Diesel Equipment Study

Pollutant	Percent Change in Emissions	
	B20[366]	B5[367]
VOCs	-14.1%	-3.5%
CO	-13.8%	-3.5
NO_x	+2.2%	+0.6%
$PM_{2.5}$	-15.6%	-4.5%

ERG applied the B5 adjustments to the emission estimates for nonroad diesel equipment with the technology types listed below.[368, 369]

- Baseline (pre-1998)
- Tier 0–Tier 3
- Tier 3B, 4A, and 4B transitional
- Tier 1M transitional–Tier 3M transitional
- Tier 4B transitional
- Interim Tier 4–no diesel particulate filter (DPF), no selective catalytic reduction (SCR)

In public fleet survey responses, 60 pieces of equipment operated by the BLM, the Oregon Parks and Recreation Department, and the Portland and Eugene airports were reported to use

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365 U.S. Department of Energy, Alternative Fuels Data Center. *Biodiesel Laws and Incentives in Oregon.* https://afdc.energy.gov/fuels/laws/BIOD?state=OR.

366 MOVES estimates for pre-2007 on-road engines using B20. See U.S. EPA, *Fuel Effects on Exhaust Emissions from On-Road Vehicles in MOVES2014*. February 2016. https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100O5W2.pdf.

367 Linear interpolation from B20 to B0.

368 Railway equipment is likely to use fuel purchased from outside the state and did not receive adjustments.

369 Personal communication with Sarah Roberts, EPA Office of Transportation and Air Quality, July 18, 2019.

B20. Applying the factors shown in Table 6-7 to the emission estimates for these units yields the following estimated impacts:[370]

- CO: 0.139 TPY reduction
- NO_x: 0.041 TPY increase
- $PM_{2.5}$: 0.024 TPY reduction
- VOCs: 0.024 TPY reduction

Survey respondents in the public fleet, logging, and agriculture sectors reported that 18 pieces of equipment had received emission control retrofits, either DOCs or DPFs. However, 16 of these were late model units meeting Tier 4 emission standards. It is very likely that the survey respondents merely reported the presence of emission control devices provided by the equipment manufacturers rather than aftermarket retrofits. Accordingly, ERG excluded these units and estimated emission impacts for the two remaining units: a sweeper receiving a DPF and an agricultural tractor receiving a DOC, both operated by the Army National Guard. Assuming a PM reduction of 25 percent for DOCs and a 90 percent reduction for DPFs[371] yields a total $PM_{2.5}$ reduction of 0.00387 TPY for these units.

In addition, survey respondents in the public fleet, surface mining, and logging sectors reported a total of 18 units being repowered. The potential emission reductions associated with these units are highly uncertain, however, as ERG could not confirm if the engines had been replaced with systems meeting the same emission standards or with systems meeting some later engine tier level. It is very likely that most of the new engine systems were of the same tier level as the replaced ones, given the configurational constraints associated with integrating new components such as SCR into existing equipment. Therefore, the estimated emission benefits associated with the reported repowers is presented as a range below:

- CO: 0–46 TPY
- NO_x: 0–108 TPY
- $PM_{2.5}$: 0–5 TPY
- VOCs: 0–7 TPY

Given the uncertainty associated with these measures, ERG did not adjust the final emission inventory estimates to account for them.

[370] Adjustments applied regardless of technology type, providing an upper bound estimate for B20 impacts.

[371] U.S. EPA, *2020 SmartWay Truck Carrier Partner Tool: Truck Tool Technical Documentation.* January 2020. https://www.epa.gov/sites/production/files/2020-01/documents/420b20002.pdf.

7.0 Validation and Comparative Analyses

The ERG team completed high-level validation exercises of the study's data collection and analysis efforts. The nonroad modeling parameters and survey expansion surrogates used in the study were processed and compared against independent, reliable data sources. These sources were not used within the study itself and provide independent points of reference for validation. The data available vary considerably by nonroad sector—e.g., construction, mining, logging—such that the validation methods are specific to each sector.

Section 7.1 summarizes the key data and methods common to the analysis of multiple sectors and equipment types. Sections 7.2 through 7.5 then provide validation and comparative exercises for the following sectors:

- Agriculture
- Construction
- Logging
- Other sectors
- Total nonroad fleet

7.1 Multi-Sector Data Sources

This section presents the relevant background, methods, and data for the sources used to support the validation exercises across multiple sectors and equipment types. It describes two resources:

- The Energy Information Administration's (EIA's) annual publication *Fuel Oil and Kerosene Sales* (FOKS)
- Agricultural and construction diesel cost data

7.1.1 Fuel Oil and Kerosene Survey (FOKS)

FOKS estimates national diesel sales and publishes state-level results.[372] Sales are categorized by customer type (i.e., source sectors). The FOKS data are an important validation element for multiple nonroad sectors evaluated in this study.

FOKS performs two levels of surveys:[373]

- A comprehensive, industry-wide census of all fuel sales is conducted periodically, with the most recent completed in 2009.
- For the years between each census, annual fuel sales surveys are completed for a targeted subset of wholesalers and distributors. The targeted subset is the same each

[372] Publication and data releases are provided at https://www.eia.gov/petroleum/fueloilkerosene/. The most recent data release (February 2020) includes sales estimates through 2018.

[373] Personal communication with Daniel Walzer, FOKS technical lead.

year. The targeted survey results are scaled up to the industry total using an algorithm that accounts for respondent market-share and other data gathered in the most recently completed comprehensive census.[374]

The published sales data are stratified by customer type and state of destination. Survey participation is mandatory, although there is no mechanism for enforcement.[375] FOKS data include diesel sales to on-highway, off-highway (i.e., nonroad) and stationary sources. The survey itself only covers off-highway and stationary sources; the on-highway sales data reported in FOKS are obtained from the FHWA.

FOKS reports the unadjusted and "adjusted" sales for each year. Unadjusted sales are reported directly from the surveys without modification. Adjusted sales are "corrected" so that the total volume of sales matches the volume of products produced, as determined by another EIA data collection effort (the *Petroleum Supply Annual*). Sales and production volumes are reconciled at the Petroleum Administration for Defense District (PADD) level.[376] Key assumptions of the adjustment process include the following.

- The sales and production reconciliation assumes no transfers of finished products between PADDs, which is a simplification. Oregon has no refining capacity and imports all of its diesel. Over 90 percent of Oregon diesel comes from within PADD 5, with some finished product (less than 10 percent) coming from PADD 4.[377]
- The reconciliation assumes the full annual production is sold in that same year. EIA supply estimates for PADD 5 in 2017 indicated that 13 percent of the annual distillate production was stored in the distribution system (i.e., in tanks and pipelines), which implies a 22-day delay, on average, from date of production to wholesale delivery.[378] Additional time lags occur for delivery to individual customers and then for actual use in nonroad equipment.[379]
- The reconciliation assumes that there is no blending of finished products prior to sale, which does occur to a limited degree.
- The reconciliation adjustment is not applied to reported on-highway diesel sales.

[374] Respondent market share for the 2017 survey is determined using the 2009 industry-wide census. Over time, changes in fuel contracts and supply vendors increase the underlying uncertainty associated with the market share estimates.

[375] The EIA cannot provide statistics on survey sample size or compliance rates for FOKS estimates at the national or state level. Other, similar EIA survey programs with published statistics show that fuel production industry compliance is generally over 90 percent.

[376] Oregon is part of PADD 5, along with Alaska, Arizona, California, Hawaii, Nevada, and Washington.

[377] Oregon Department of Energy. *2015–17 State of Oregon Biennial Energy Plan.* https://www.oregon.gov/energy/Data-and-Reports/Documents/2015-2017%20Biennial%20Energy%20Plan.pdf.

[378] EIA Weekly Supply Estimates. Retrieved from https://www.eia.gov/dnav/pet/pet_sum_sndw_dcus_r50_w.htm.

[379] Additionally, during economic downturns and a corresponding reduction in sales, production may be relatively unaffected and final products diverted, thereby increasing fuel stock volumes.

- A single reconciliation adjustment is applied to all distillate across all states in PADD 5, and across all source sectors by fuel type. In 2017, a -29.5 percent adjustment was applied to all distillate fuel sales to calculate the adjusted sales.[380] It is not known if this adjustment is reflective of Oregon or any of the individual source sectors.

The validation exercises completed for the study relied on the adjusted FOKS data, consistent with EPA's use in the development of the MOVES nonroad growth factors.[381] However, each of the assumptions noted above contributes to the uncertainty of the FOKS fuel sales estimates. The size of the final 2017 adjustment (-29.5 percent) in particular indicates that overall uncertainty of the sales estimates may be substantial.

Table 7-1 summarizes the 2017 adjusted Oregon sales data for the FOKS sectors that contain some amount of nonroad equipment.[382] It also presents the share of fuel sales estimated to be consumed by nonroad equipment. ERG developed the nonroad share estimates using methods employed by previous researchers who used FOKS data as a fuel-based validation for nonroad equipment emission inventories,[383] adjusted to reflect Oregon conditions. A nonroad equipment share was not estimated for military (including U.S. Coast Guard vessel operations, which are excluded from the study) and vessel bunkering sectors: most sales for these sectors are for commercial-sized vessels, which are not included in the study. Similarly, fuel sales in the railroad sector are predominately for locomotives, which are also excluded from this analysis.

Table 7-1. FOKS Adjusted Diesel Sales in Oregon 2017 (Selected Sectors) and Estimated Nonroad Sales Share

2017 Nonroad Diesel Equipment Study

FOKS: Sector	FOKS Fuel Type[384]	FOKS Adjusted 2017 Sales (Gallons)	Estimated Nonroad Sales Share	Estimated 2017 Nonroad Diesel Sales (Gallons)
Commercial	Diesel	11,777,000	50.6%[385]	5,959,000
Farm	Diesel	31,440,000	100.0%[†]	31,440,000
Industrial	Diesel	14,549,000	63.0%[385]	9,166,000

380 The unadjusted sales in Oregon in 2017, as directly surveyed, are 42 percent higher than the adjusted sales (i.e., the inverse of -29.5 percent). This is a relatively large reconciliation adjustment; an adjustment of this size last occurred in 2001.

381 See Appendix H for background on the data sources used by the MOVES model.

382 FOKS' residential, electric power, and on-highway sectors are not presented in Table 7-1.

383 Kean, A. Sawyer, R. and Harley, A. 2000. "A Fuel-Based Assessment of Off-Road Diesel Engine Emissions." *Journal of the Air & Waste Management Association*, 50:11, 1929–1939, DOI: 10.1080/10473289.2000.10464233. https://www.tandfonline.com/doi/pdf/10.1080/10473289.2000.10464233.

384 Diesel is a subset of distillate. Diesel is not reported separately for all sectors. FOKS documentation describes the additional fuel distinctions of the surveyed sectors.

385 Nonroad share estimated by a review of Oregon historical proportions of low- and high-sulfur diesel sales, assuming 100 percent of high sulfur diesel is nonroad and 6 percent of low sulfur is nonroad, as included in the reference method (see footnote 383).

FOKS: Sector	FOKS Fuel Type[384]	FOKS Adjusted 2017 Sales (Gallons)	Estimated Nonroad Sales Share	Estimated 2017 Nonroad Diesel Sales (Gallons)
Off-highway, construction	Diesel	14,965,000	100.0%†	14,965,000
Off-highway, other	Diesel	16,283,000	100.0%†	16,283,000
Oil company	Distillate	226,000	50.0%†	113,000
Subtotal				**77,926,000**
Military	Diesel	2,288,000	n/d‡	n/d
Railroad	Distillate	798,000[386]	n/d‡	n/d
Vessel bunkering	Distillate	30,352,000	n/d‡	n/d

† as determined in the reference method (see footnote 383).

‡ n/d = not determined; significant portion of sales not used by nonroad equipment (see discussion).

The following types of consumers are included in each FOKS sector.[387]

- **Commercial** consumers consist of service-providing facilities and nonmanufacturing businesses; federal, state, and local governments; and other private and public organizations, such as religious, social, or fraternal groups. Ski resorts and public airports, ports, and landfills are included.
- **Farm** consumers consist of establishments where the primary activity is growing crops and/or raising animals; fuel use can include residential heating.
- **Industrial** consumers consist of all facilities and equipment used for producing, processing, or assembling goods; wood products industries (including sawmills) and mining operations are included.
- **Off-highway construction** consumers cover construction, excavation, dredging, privately owned landfills, roadway repair, and roadway development.
- **Off-highway other** consumers cover logging, truck transportation refrigeration, drilling (water wells and geothermal), privately owned ports, and junk/scrap yards.

The FOKS data can exhibit substantial year-over-year changes, with some variability attributable to real-world economic factors and some due to survey sampling error. Nevertheless, the FOKS adjusted sales data provide an indispensable resource for independent validation of Oregon's statewide nonroad diesel fuel consumption, as well as for the agriculture, construction, and logging sectors. Understanding key details of the underlying FOKS survey and adjustment

[386] 2017 railroad sales estimate of 798 thousand gallons appears to be an anomaly; recent FOKS data suggest 9 to 11 million gallons of distillate are typically sold in Oregon annually.

[387] Descriptive sector summaries are included in the FOKS documentation—see https://www.eia.gov/petroleum/fueloilkerosene/pdf/foks.pdf. Detailed examples of fuel customers are included in the Line-By-Line Reference Guide for Survey Form EIA-821—see https://www.eia.gov/petroleum/fueloilkerosene/pdf/reference_guide.pdf.

methodology is important to assess the uncertainty associated with the different sectors' fuel consumption estimates.

7.1.2 Agriculture and Construction Diesel Cost

Key agriculture and construction validation data sources provided total annual expenditures for nonroad diesel consumption in Oregon. ERG converted expenditure estimates from dollars to gallons of diesel consumed by dividing by the sector-average cost per gallon. ERG then determined the average diesel cost for the different sectors as follows:

The available fuel consumption references covered the years 2012 and 2017; to estimate the retail nonroad diesel cost for a given year, ERG adjusted for tax exemptions for nonroad use and bulk sales discounts to customers.

Table 7-2 summarizes the per-gallon diesel cost calculation data. References used in the calculation include:

- EIA provided the average retail diesel cost for PADD Region 5.[388]
- FHWA's annual Highway Statistics provided the state and federal on-road diesel tax rates.[389] ERG calculated a PADD-average state tax by weighting the individual tax rates for PADD 5 states by the sales volumes for each state, as reported by FOKS. The weighted average state tax rate ($0.325/gallon) was added to the federal tax rate for on-road fuel ($0.244/gallon) to calculate the total tax rate for PADD 5 ($0.569/gallon).[390]
- A statewide Oregon fuel wholesaler and distributor provided estimates for sector-specific discounts offered for bulk fuel delivery. Agricultural deliveries are larger on average, reflected in the greater price discount.

Table 7-2. Estimated Diesel Cost ($ per Gallon) by Year - Construction and Agriculture Sectors
2017 Nonroad Diesel Equipment Study

	2012	2017	Notes
Retail diesel (Annual average, including taxes)	4.085	2.833	EIA estimate for PADD 5 (minus California)
Combined state and federal tax rate, on-road diesel	0.534	0.569	Sales-weighted average for PADD 5 (minus California)

388 EIA retail price data are reported at the PADD region level. For PADD 5, EIA reports standalone data for California and aggregated data for the remainder of the district. Retrieved from https://www.eia.gov/dnav/pet/pet_pri_gnd_a_EPD2DXL0_pte_dpgal_a.htm.

389 Federal Highway Administration, Office of Highway Policy Information. *Highway Statistics Series.* Retrieved from https://www.fhwa.dot.gov/policyinformation/statistics.cfm.

390 State-level data are from the annual Kerosene and Fuel Oil Sales (FOKS) publication. Retrieved from https://www.eia.gov/petroleum/fueloilkerosene/.

	2012	2017	Notes
Tax-exempt diesel cost, agricultural end users	3.302	2.106	Estimated nonroad sector diesel cost (tax-exempt and sector-specific savings over retail)
Tax-exempt diesel cost, Construction end users	3.409	2.173	

7.2 Agricultural Sector Validation

ERG compared the nonroad diesel fuel consumption estimates developed for the agricultural sector (38,557,494 gallons per year in 2017) to estimates based on two data sources: the EIA FOKS data and fuel expenditure estimates from the 2017 Agricultural Census. While FOKS provides explicit estimates for nonroad diesel consumption in gallons per year, the Agricultural Census only provides total fuel expenditures, aggregating across different fuel types including on-road and nonroad diesel, gasoline, propane, and natural gas, as well as engine lubricants ($188,163,000 per year in 2017).

To estimate nonroad diesel fuel consumption using fuel cost data from the Agricultural Census, ERG first estimated the fraction of expenditures associated with diesel purchases. Table 7-3 presents national average estimates for diesel and total fuel/lubricant expenditures (less electricity costs) in the agricultural sector across a range of crop and animal production categories.[391]

Table 7-3. National Average Fuel Consumption Ratios by Agricultural Commodity (2014)[392]
2017 Nonroad Diesel Equipment Study

Principal Commodity	Cost Basis	Diesel Only	Total Fuels and Lubes	Percent Diesel
Beef cattle	Per farm	$5,435	$8,696	63%
Dairy cattle	Per farm	$22,826	$31,522	72%
Poultry	Per farm	$5,072	$26,449	19%
Other livestock	Per farm	$3,261	$5,435	60%
Wheat	Per acre	$9.38	$13.13	71%
Other cash grains	Per acre	$15.95	$23.45	68%

ERG then combined the cost factors from Table 7-3 with corresponding values for acreage and number of establishments to estimate diesel and total fuel/lubricant costs for Oregon agricultural operations in 2017. For example, ERG multiplied the number of acres in production for oilseed and grain in 2017 (771,096) by the average diesel fuel cost per acre of wheat ($9.38)

391 Equivalent fuel expenditure data was not available for Oregon specifically.

392 USDA National Agricultural Statistics Service and USDA Economic Research Service. *2014 Tenure, Ownership, and Transition of Agricultural Land Survey*. Retrieved from https://www.nass.usda.gov/Publications/AgCensus/2012/Online_Resources/TOTAL/index.php.

to estimate total diesel fuel expenditures for the oilseed/grain stratum ($7,232,880). The estimates for each stratum are presented in Table 7-4.[393]

The ratio of total diesel expenditures to total fuel/lubrication expenditures (59.8 percent) was then multiplied by the total fuel and lubrication expenditures reported for Oregon in the 2017 Agricultural Census ($188,163,000) to estimate the diesel component of expenditures ($112,518,217). The $217 million figure from Table 7-4 compares reasonably well with the $188 million figure from the 2017 Agricultural Census, supporting the validity of using the national average cost factors presented in Table 7-3.

The next step in estimating nonroad diesel fuel consumption required dividing the estimated diesel fuel expenditures for the agricultural sector by the average wholesale price of nonroad diesel ($2.106 per gallon from Table 7-2), yielding an estimated 53,427,453 gallons of diesel for 2017. Finally, adjusting for the fraction of nonroad fuel use in the Oregon agricultural sector (62 percent of all diesel use)[394] yields an estimated 33,125,021 gallons of nonroad diesel consumed per year by the sector.

[393] The estimates are subject to a number of uncertainties, such as the appropriateness of the national average cost factors and the assignment of cost factors to the different study strata (e.g., using costs developed for wheat production to estimate costs for hay production).

[394] Oregon Farm Bureau. *Farm Energy Fact Sheet.* Undated.

Table 7-4. Estimated Agricultural Fuel Expenditures by Study Stratum (2017)
2017 Nonroad Diesel Equipment Study

Study Stratum	Agricultural Census Value	Units	Diesel Expenditures	Total Fuel and Lube Expenditures	Cost Factor Assignment
Fruit tree/nut	135,877	Acres	$2,167,238	$3,186,316	Other cash grains
Greenhouse/nursery/ floriculture	100,873	Acres	$1,608,924	$2,365,472	Other cash grains
Oilseed/grain	771,096	Acres	$7,232,880	$10,124,490	Assigned to wheat
Other crops	1,121,595	Acres	$10,520,561	$14,726,542	Assigned to wheat (to represent hay)
Vegetables/melons	239,284	Acres	$3,816,580	$5,611,210	Other cash grains
Wineries	24,964	Acres	$398,176	$585,406	Other cash grains
Poultry	736	# establishments	$3,732,992	$19,466,464	Assigned to poultry
Beef cattle	12,291	# establishments	$66,801,585	$106,882,536	Assigned to beef
Dairy cattle	269	# establishments	$6,140,194	$8,479,418	Assigned to dairy
Other animals	8,369	# establishments	$27,291,309	$45,485,515	Assigned to other livestock
Total			**$129,710,440**	**$216,913,369**	

Table 7-5 compares the gallon-per-year estimates for each source of agricultural fuel consumption information with those developed for the study.

Table 7-5. Agricultural Sector Fuel Consumption Validation
2017 Nonroad Diesel Equipment Study

Data Source	Gal/Yr	Percent of Survey Total
Study estimate[395]	38,557,494	
FOKS	31,440,000	81.5%
Agricultural Census basis	33,125,021	85.9%

The reasonably close correspondence across these estimates fosters confidence in the findings for the agricultural sector as a whole.

7.3 Construction Sector Validation

Table 7-6 presents the study's fuel consumption estimates for the different components of Oregon's construction sector. The subsectors and equipment types listed are those reported under the construction category in Section 6.

Table 7-6. Statewide Construction Sector Fuel Consumption (2017)
2017 Nonroad Diesel Equipment Study

Component	Gallons	Percent
Backhoes*	3,831,492	21.1%
Commercial/Institutional Buildings	3,274,294	18.1%
Single Family Housing	2,874,152	15.9%
Skid steer loaders*	2,111,997	11.7%
Construction Cranes	1,177,112	6.5%
Highway/Road - ODOT Construction Program	1,115,749	6.2%
Off Highway Tractors*	1,068,014	6.0%
Highway/Road - City/County/Other Agencies	1,041,549	5.7%
Utility - excluding ODOT projects	773,393	4.3%
Trenchers*	252,197	1.4%
Light plants/signal boards*	171,142	0.9%
Highway/Road - ODOT Maintenance Program	157,331	0.9%
Dumpers/tenders*	133,315	0.7%
Special Project	131,390	0.7%
Total	**18,125,467**	

* Equipment categories used extensively across the construction industry, with consumption attributable to individual subsectors netted out.

[395] ERG adjusted the figure derived from the agricultural sector survey to account for a small amount of estimated agricultural mower use not captured by the survey (2,370 gallons).

ERG identified two independent estimates of fuel consumption information to help validate the study's findings for the construction sector: FOKS data (shown in Table 7-1) and estimates developed for the U.S. Construction Census. The U.S. Census Bureau produces a periodic national economic census of selected sectors and industries, and the most recent census for the construction sector (defied as NAICS Sector 23) was published in 2012.[396] The Construction Census includes estimated expenditures for nonroad fuel purchases, reported at the state level. For Oregon in 2012, the estimated fuel expenditures were $37,003,000.[397] Dividing this figure by the statewide average cost of diesel in 2012 ($3.409 per gallon, from Table 7-2) yields an estimated 10,854,659 gallons of fuel consumed by the Oregon construction sector in 2012.[398]

ERG scaled the 2012 Construction Census consumption estimate by a factor of 1.331 to account for growth in industry activity through 2017.[399] This leads to an estimated 14,449,463 gallons of diesel consumed by the Oregon construction sector in 2017.

The fuel consumption estimates shown in Table 7-6 fall outside the range defined by the Construction Census and FOKS estimates by about 21 percent. Table 7-7 compares the independent fuel sales estimates for the construction sector with the estimate developed for the study.

Table 7-7. Construction Sector Fuel Consumption Estimates by Data Source (2017) 2017 Nonroad Diesel Equipment Study

Data Source	Gallons
Study[400]	18,125,467
Construction Census	14,449,463
FOKS	14,965,000

NOTE: While backhoes, skid steer loaders and other equipment types marked with an asterisk in Table 7-6 are assigned exclusively to the construction sector for reporting purposes, many of these units are actually operated by commercial and industrial establishments (e.g. in landscaping, retail nurseries, scrap yards, and miscellaneous manufacturing companies

[396] The Census Bureau is scheduled to release reports and data from the 2017 Construction Census incrementally from November 2020 through September 2021.

[397] U.S. Census Bureau, 2012 Construction: Geographic Area Series. Retrieved from https://data.census.gov/cedsci/table?q=EC1223a1&lastDisplayedRow=25&table=EC1223A1&tid=ECNBASIC2012.EC1223A1&hidePreview=true&g=0400000US41.

[398] Assumes 100% of off-highway fuel expense is for diesel.

[399] 1.331 is the ratio of Oregon construction sector GDP for 2017 vs. 2012 ($8,084M/$6,073M). See U.S. Bureau of Economic Affairs, *Real GDP by State.* Retrieved from https://apps.bea.gov/iTable/iTable.cfm?reqid=70&step=1&isuri=1&acrdn=1#reqid=70&step=1&isuri=1&acrdn=1.

[400] Excludes fuel consumption for units less than 25 hp. MOVES estimates 2.0% of all nonroad diesel fuel is consumed by engines less than 25 hp.

among others). Accordingly, the activity and emission levels estimated for the construction sector are likely over-estimated by some degree.

Estimates generated for north Texas provide additional points of comparison for certain components of the Oregon construction sector. ERG used the TCEQ's TexN2.0 utility[401] to estimate fuel consumption for the single-family housing, commercial building, and highway/utility subsectors operating in the DFW region for 2017.[402,403] Table 7-8 compares the relative fuel consumption percentages across these subsectors for DFW and for Oregon as a whole.

Table 7-8. Relative Fuel Consumption for Selected Construction Subsectors 2017 Nonroad Diesel Equipment Study

Sector	Oregon	DFW
Single family housing	31%	29%
Commercial/institutional buildings	36%	35%
Highway and utility[404]	33%	36%
Total	**100%**	**100%**

While the specific construction project operating conditions and requirements vary between the two regions, the relative fuel consumption estimates are clearly similar for all three subsectors.

7.4 Logging Sector Validation

Section 3.3.6 of this report described three distinct validation exercises conducted for the logging sector's state activity profile:

- Comparison of diesel consumption per unit of throughput as reported in the literature
- Comparison of state-level diesel consumption with that reported in EIA's FOKS estimates
- Comparison of scaled equipment populations based on the number of equipment units per unit of throughput, available for other geographic areas

This section expands on the second of these validation exercises.

[401] Eastern Research Group. (2019, May 9). *TexN2.0 User Guide* prepared for the Texas Commission on Environmental Quality.

[402] The TexN2.0 model defines single-family housing, commercial, and highway/utility construction in a way similar to that used for this study. However, the TexN model accounts for specific equipment activity (e.g. from backhoes and trenchers) in a manner inconsistent with the study's approach. As such, this equipment is excluded from the comparison in Table 7.8.

[403] The DFW region was chosen as it includes a range of urban and suburban construction project settings.

[404] The highway and utility subsectors are broken out differently by the TexN2.0 model and are combined here to allow for consistent comparison with Oregon totals.

Two main issues confound the comparison of the logging sector diesel consumption estimates with the FOKS diesel sales estimates for Oregon. First, the FOKS logging sector sales data are grouped into the "other off-highway" category, which includes consumption by other sectors. Second, the year-to-year variability of the FOKS other off-highway category is particularly high. Given these uncertainties, the FOKS estimates are best presented as a range, rather than a single value for comparison. Moreover, because of the underlying uncertainty the ERG team also examined "adjusted" and "unadjusted" versions of FOKS data,[405] and evaluated the option of using a two-year average of fuel sales values (i.e., the average of the 2016 and 2017 values).[406] The pertinent FOKS data are presented in Table 7-9.

Table 7-9. FOKS Other Off-Highway Diesel Sales, Oregon 2017 (Gallons)
2017 Nonroad Diesel Equipment Study

FOKS Estimate Type	Single Year 2017	Two-Year (2016–17) Average
Adjusted	16,283,000	20,539,000
Unadjusted	23,099,000	24,960,000

The first step in the evaluation is to estimate the portion of fuel sales within the FOKS other off-highway category attributable to the logging sector. The EIA defines this category as including the following types of establishments/equipment types:

- Logging
- Truck-based TRUs
- Water well drilling (WWD)
- Junk or scrap yard
- Geothermal drilling
- Privately owned port or dock

Notably, EIA assigns "forestry services" to the FOKS commercial category. Therefore, sales assigned to forestry services may represent an additional source of discrepancy between the FOKS estimates and this study's diesel consumption estimates for the logging sector.[407]

As part of the study, ERG quantified diesel consumption specifically for logging, TRUs, and WWD; the results are summarized in Table 7-10.[408] Two TRU estimates are presented, one for truck and railcar use and one for truck use only. The truck-only case is directly comparable to

[405] Section 7.1.1 provides a detailed discussion of the FOKS adjustment process.

[406] 2017 consumption is a combination of 2016 and 2017 diesel production, thereby a 2-year running average is a potential alternative assumption to a single point year.

[407] The logging sector survey targeted the logging industry as well as other diesel-consuming support activities.

[408] The study did not estimate fuel consumption for junk/scrap yards or geothermal drilling. These sources are not expected to be significant consumers of nonroad diesel. While recreational marine distillate consumption was estimated it was not differentiated by port/dock-ownership type.

the FOKS "other off-highway" case, as TRU fuel sales associated with rail car refrigeration is assigned to the FOKS Railroad Use category.

Table 7-10. Fuel Consumption Estimates for FOKS Other Off-Highway Sales 2017 Nonroad Diesel Equipment Study

Sector/Source	Gallons
Logging[409]	28,347,050
TRU (truck and rail)	8,260,381
TRU (truck only)	7,973,122
WWD	548,639

ERG subtracted the study's estimates for TRU (truck only) and WWD fuel consumption from the FOKS total for the other off-highway category in order to estimate the portion attributable to the logging sector.[410]

ERG expects that potentially little of the estimated truck TRU consumption for Oregon would be captured by FOKS in the other off-highway sales estimates, for two reasons:

- TRU diesel fuel is purchased largely through the on-highway diesel fuel distribution network. Truck refueling practices show that TRU fueling commonly occurs at the same facilities as on-highway fueling.[411] In addition, TRU fuel only differs from on-highway diesel by its tax-exempt status.[412] Often, TRUs' fuel purchase is a separate transaction from vehicle fueling, after which tax refunds are requested for the TRU purchase. Conversely, a limited number of facilities offer point-of-sale tax exemptions for TRU fuel through the same fuel dispensers.[413]
- There is reason to believe that fuel purchases for TRU use in Oregon are made disproportionately from out-of-state sources. Oregon differs from each of its neighboring states (Washington, California, and Idaho) in that it does not offer a state tax refund for TRU diesel sales. Therefore, TRU fuel costs are 30 cents per gallon higher than in neighboring states. This incentivizes out-of-state fueling where feasible for TRUs operating in Oregon.

[409] Including earthmoving equipment used in roadway and drainage maintenance as well as earthmoving and crushing equipment used to quarry roadway materials (stone and sand) for logging road development.

[410] Independent estimates for TRU and WWD fuel use were not identified in the literature.

[411] References to "reefer" fueling as commonly practiced at retail outlets include: https://somanymiles.wordpress.com/2014/10/20/fueling-the-truck/, https://www.ooida.com/EducationTools/Info/docs/Reefer-Refund-Rates-1st-Qt-2019.pdf, https://www.glostone.com/2017/02/09/federal-tax-credit-available-reefer-fuel-purchases/, http://truckerspermitservice.com/reefer-tax-refund/

[412] TRU diesel is exempt from the 22.4 cent per gallon federal tax; TRU diesel is not exempt from Oregon fuel taxes.

[413] TRU fuel purchased at a dedicated pump would be a dyed, tax-free fuel, tanked separately from on-highway diesel. Moreover, large, centrally fueled distribution centers might maintain infrastructure for both types of diesel.

For these reasons, the amount of Oregon's TRU consumption captured in the FOKS other off-highway category is presented as a range, assuming either 0 or 100 percent of truck TRU consumption is included. The resulting logging sector diesel sales estimates are presented in Table 7-11.

Table 7-11. Estimated FOKS Logging Sector Fuel Sales, Oregon 2017
2017 Nonroad Diesel Equipment Study

FOKS Estimate Type	Assumed Capture Rate of Truck TRU Consumption	Logging Sector Diesel Sales (Gallons)	
		Single Year 2017	Two-Year (2016–17) Average
Adjusted	0%*	15,734,361	19,990,340
Adjusted	100%†	7,761,239	12,127,189
Unadjusted	0%*	22,550,361	24,411,340
Unadjusted	100%†	14,577,239	16,548,189

* Logging sector diesel = other off-highway (Table 7-129) minus WWD (Table 7.10).

† Logging sector diesel = other off-highway (Table 7-12) minus WWD and truck-only TRU (Table 7.10).

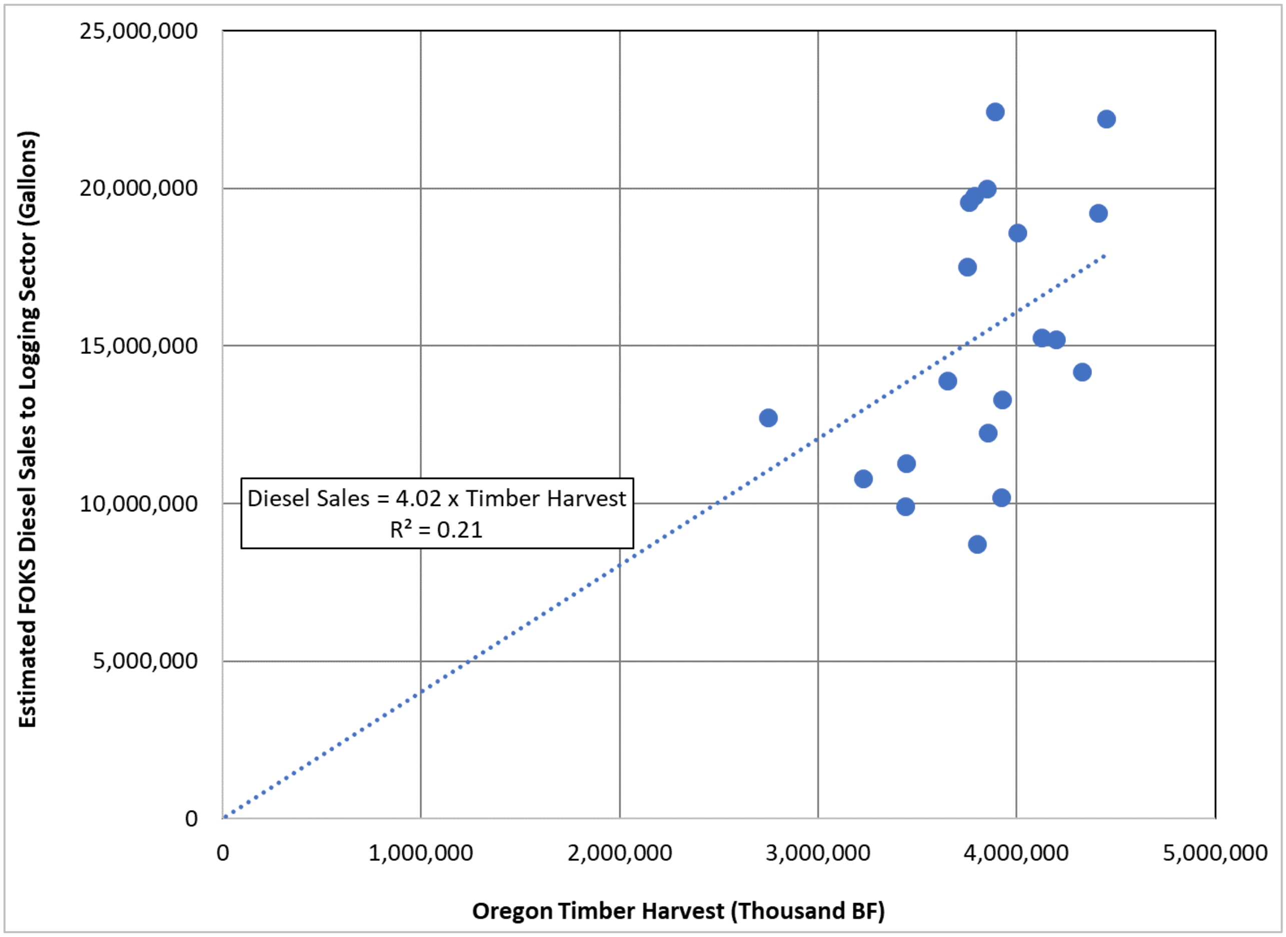
Each of the eight diesel sales estimates shown in Table 7.11 was compared against state timber harvest data over a 20-year period. Given that logging sector diesel consumption is approximately proportional to logging harvest, a linear regression of diesel sales and harvest was completed to determine which of the eight estimates provided the best sales-harvest correlation. Those results are summarized in Table 7.12. An example of the data regression is shown in Figure 7-1.

Table 7-12. Linear Regression Results for 20-Year Sales vs. Timber Harvest
2017 Nonroad Diesel Equipment Study

FOKS Data Type	Assumed Capture Rate of Truck TRU Consumption	R-Squared from the Linear Regression 20-Year Sales History vs. Timber Harvest	
		Single Year Sales	Two-Year Average Sales
Adjusted	0%	0.08	0.15
Adjusted	100%	0.05	0.08
Unadjusted	0%	0.12	0.21
Unadjusted	100%	0.05	0.09

Figure 7-1. Linear Regression of 20 Years of Historical Data (1999–2018)
2017 Nonroad Diesel Equipment Study

Case = Unadjusted FOKS Values, 0 Percent TRU Capture, Two-Year Running Average



The results shown in Table 7-12 indicate that:

- The correlations based on two-year averages performed better than the single-year values.
- Assuming the other off-highway FOKS estimates do not include TRU consumption, performance was better than assuming 100 percent capture.

Overall, the study's estimated diesel consumption of 28 million gallons is higher than the 8 to 24-million-gallon range estimated from FOKS resources, as shown in Table 7-13.

Table 7-13. 2017 Logging Sector Diesel Comparison - FOKS vs Study 2017 Nonroad Diesel Equipment Study

	Gallons
Study[414]	28,347,050
FOKS	8,000,000–24,000,000

The study's fuel consumption estimate for the logging sector falls outside of the FOKS range and is not conclusive. However, the FOKS validation was just one of several validation exercises performed for this sector. Most notably, the study's estimated fuel consumption per unit of harvest was well within the range of literature values.[415] The comparison in Table 7-13 is also confounded by the difficulty of isolating Oregon logging sector fuel sales within the FOKS other off-highway category. Because it does not explicitly break out the logging sector and because it has a second "forestry services" subcategory that is implicitly included in the commercial sector, FOKS may count an unknown amount of the diesel fuel consumption estimated by the study as commercial sales. Accordingly, an assessment of the logging sector fuel consumption estimate's accuracy should consider the complete set of validation exercises as well as the uncertainty of the validation data.

7.5 Validation and Comparison—Total Nonroad Fleet

ERG also conducted a validation of the aggregated study results for the following FOKS sectors:[416]

- Farm
- Commercial
- Industrial
- Off-highway construction
- Other off-highway

A key goal of this comparison is to assess the study's fuel consumption estimates at the highest level, without differentiating among the various industry sectors. This approach allows us to disregard any inconsistencies in the way fuel consumption sources are assigned to different sectors.

In addition to the comparison against FOKS, the analysis also included a comparison against the total nonroad consumption estimates from the MOVES model defaults. Finally, the MOVES

[414] Includes earthmoving equipment used in roadway and draining maintenance as well as earthmoving and crushing equipment used to quarry roadway materials (stone and sand) for use in logging roadway development.

[415] See Section 3.3.6 for further details.

[416] Excludes diesel consumption from recreational marine, military, railroad maintenance, rail TRUs, and oil industry categories: it was not feasible to identify their contributions in the FOKS sales data.

construction/mining sector equipment category was assessed separately, accounting for the multiple industry sectors that use this equipment.

7.5.1 FOKS Comparison

In this validation exercise, ERG included both "adjusted" and "unadjusted" sales reported by FOKS. While the adjusted FOKS values are the preferred point of comparison for the study,[417] ERG also compared the study's fuel consumption estimates to FOKS' unadjusted sales values. FOKS' adjusted sales values are derived by applying a single factor uniformly across all sectors (except on-highway) throughout the PADD 5 region. In 2017, the adjustment factor was -29.5 percent. Notably, Oregon sales only make up 9 percent of PADD 5 region sales and it could not be determined if the adjustment factor is applicable to Oregon generally, or specifically to any of its sectors. Given potential errors introduced when applying the adjustments for Oregon, it may be more appropriate to reference the range of fuel consumption estimates determined by the adjusted and unadjusted FOKS values for this assessment.[418]

Table 7-14 compares the study's fuel consumption estimates with the adjusted and unadjusted FOKS diesel sales values for 2017. The individual sector unadjusted FOKS values are 42.0 percent higher (the inverse of negative 29.5 percent) than the adjusted FOKS values. In this comparison, the total nonroad consumption is within 1 percent of the unadjusted FOKS value, and 44 percent higher than the adjusted FOKS value. Overall, the study's estimated total nonroad consumption is within the range defined by the two FOKS values.

[417] EPA also uses the adjusted FOKS data as the source for the growth factors in MOVES.

[418] The size of the adjustment (29.5 percent) is relatively large, historically speaking; 2001 was the last FOKS year featuring a similarly sized adjustment factor.

Table 7-14. 2017 Total Nonroad Diesel Comparison—FOKS vs. Study (Gallons)
2017 Nonroad Diesel Equipment Study

FOKS Sector*	Study Estimate†	FOKS (Adjusted–Unadjusted)	Study Ratio to FOKS (Unadjusted–Adjusted)	FOKS Sector Components
Farm	38,557,494	31,440,000–44,601,000	0.86–1.23	Includes all farm-based diesel consumption; excludes agricultural services (in commercial category)
Commercial	9,875,772	5,959,000–8,454,000‡	1.17–1.66	Includes non-manufacturing businesses, government fleets, airports, ports, institutions, and public landfills
Industrial	9,144,289	9,166,000–13,003,000‡	0.70–1.00	Includes manufacturing, industry, recycling, and mining; excludes oil and gas industries.
Off-highway construction	18,125,468	14,965,000–21,229,000	0.85–1.211	Includes construction, crane use, dredging, earthmoving, excavating, paving, and road building/repair
Other off-highway	36,056,811	16,283,000–23,099,000	1.56–2.21	Includes logging, geothermal drilling, privately owned ports/loading docks, scrap/junk yards, WWD, and TRUs
Total	**111,759,834**	**77,813,000–110,386,000**	**1.01–1.44**	

* Excludes recreational marine, military, railroad maintenance, rail TRUs and oil/gas industries.

† Includes diesel engines over 25 hp.

‡ Includes adjustment for nonroad fraction of total sales. Nonroad sales are broken out for the remaining FOKS sectors. See Table 7-1 for further details.

Sector-specific uncertainties and variables need to be considered in more detail to provide further context when comparing the study results with the FOKS estimates presented in Table 7-14.

- **Farm.** Fuel consumption estimates for the farm sector show generally good agreement with the FOKS values; additional validation sources also show good agreement (see Section 7.2 for more detail).
- **Commercial.** Fuel consumption estimates for the commercial sector are higher than the FOKS values. The commercial sector estimates include the findings for a number of directly surveyed entities[419] and equipment-specific approaches.[420] FOKS' commercial sector sales estimates have additional uncertainty because FOKS does not report nonroad sales separately for this sector. In fact, the "nonroad share" adjustment factor (50.6 percent of total sector diesel consumption) is substantial, as described in Section 7.1.1. Nevertheless, the ultimate cause of the discrepancy between FOKS and the study's estimate is not known.
- **Industrial.** Fuel consumption estimates for the industrial sector are lower than the FOKS values. Notably, there is significant uncertainty associated with surface mining fuel consumption estimates, which represent half of the industrial sector total. Moreover, as with the commercial sector, the industrial sector estimates have additional uncertainty because FOKS does not break out nonroad sales for this sector, requiring an adjustment factor of 60.3 percent to the total sector estimate.
- **Off-highway construction.** The construction sector consumption estimates show generally good agreement with the adjusted FOKS values; additional validation sources also show good agreement. Equipment-specific adjustments for backhoes and skid steer loaders in particular would improve the accuracy of the estimates by re-assigning some of their activity to the commercial and industrial sectors and correcting for the corresponding over-estimation of emissions and fuel consumption in the construction sector. See Section 7.3 for a further discussion of this topic.
- **Other off-highway.** The other off-highway sector consumption estimates for the study are higher than the FOKS estimates. There are three sources of uncertainty behind this discrepancy. First, while the study estimates 7 million gallons of consumption for truck TRUs, it is unclear how much of this FOKS captures. Second, FOKS' other off-highway sales estimates exhibit particularly high year-to-year variability. Third, the study's logging sector consumption is generally greater than FOKS indicates (whereas other validations for the logging sector show reasonable agreement). See Section 7.4 for further discussion of this topic.

[419] Directly surveyed entities included airports, city fleets, county fleets, Special District fleets, other non-military government, marine ports, schools/universities, public landfills, and agricultural services.

[420] Equipment type approaches include those classified as and lawn and garden.

7.5.2 FOKS and MOVES Comparison[421]

It is important to recognize that both the study's estimated fuel consumption and the FOKS estimates for Oregon in 2017 are significantly lower than the MOVES defaults for total nonroad diesel equipment. Differences in sector definitions confound direct comparisons to some extent and are noted in the "FOKS Sector Assignment" column. Overall, the study's fuel consumption estimate is 39 percent below the MOVES default (for diesel engines over 25 hp), and FOKS adjusted sales totals are 58 percent below the MOVES default (for all diesel engines), as shown in Table 7-15.

Table 7-15. 2017 Total Nonroad Diesel Consumption - MOVES Defaults (Gallons)
2017 Nonroad Diesel Equipment Study

Equipment Type*	Diesel Engines Over 25 hp	All Diesel Engines	FOKS Sector Assignment
Agriculture	37,263,256	37,587,096	Mix of farm and commercial (agricultural services only)
Airport ground support	811,389	814,096	Commercial
Commercial	13,405,974	14,568,254	Mix of construction, commercial, and industrial
Construction/mining	94,838,699	95,598,524	Mix of farm, construction, commercial, industrial, and other off-highway
Industrial	20,281,977	20,840,336	Mix of industrial and other off-highway (truck TRUs only)
Lawn and garden (commercial)	3,324,657	4,253,523	Commercial
Logging	11,071,639	11,071,639	MOVES only includes harvesting equipment (in other off-highway)
Recreational vehicles	124,690	158,191	Mix of commercial and industrial
Total	**181,122,281**	**184,891,659**	

* Excludes recreational marine, military, railroad maintenance, rail TRUs, and oil/gas industries.

Table 7-16. 2017 Total Nonroad Diesel Comparison (Gallons)
2017 Nonroad Diesel Equipment Study

	Diesel Engines Over 25 hp	All Diesel Engines
MOVES default consumption*	181,122,281	184,891,659
Study consumption*	113,839,112	—
Adjusted FOKS values	—	77,813,000
Percent change relative to MOVES	-37%	-58%

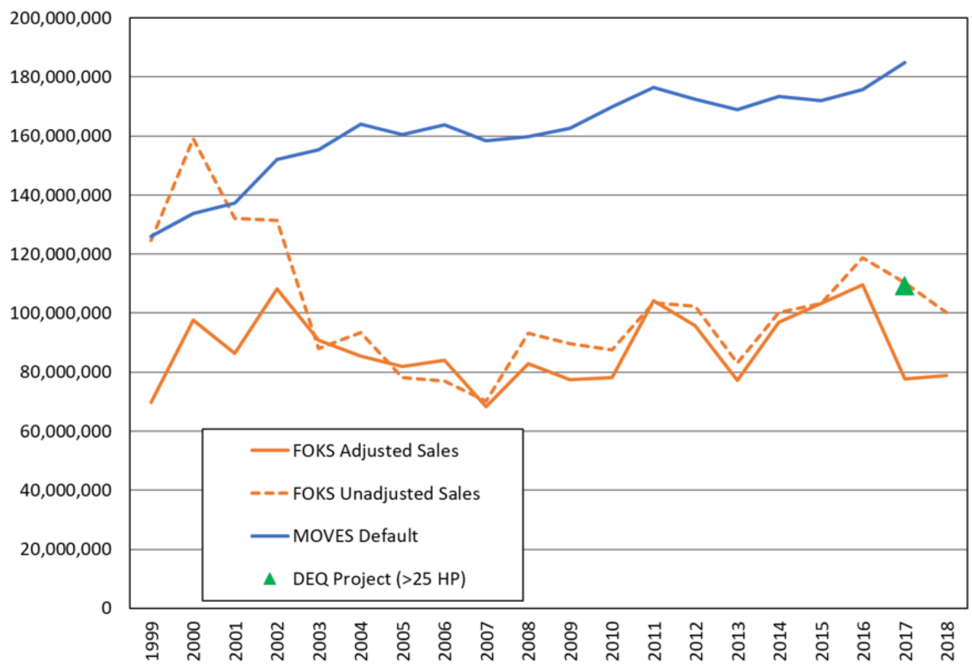
* Excludes recreational marine, military, railroad maintenance, rail TRUs, and oil/gas industries.

[421] Sections 6.2 and 6.3 compare the study results and MOVES model estimates in detail. Additional comparisons between MOVES and the study results are included here for the sum of the five FOKS sectors representing "total nonroad." These sectors represent over 90 percent of nonroad fuel consumption.

Figure 7-2 presents a 20-year timeline of the total nonroad consumption and sales in Oregon. It shows that:

- The most recent 10 years of FOKS estimates are generally in the range of 80 to 120 million gallons. The DEQ study result falls within this range.
- The MOVES model's default consumption estimates appear to be increasing at a rate higher than the FOKS trend.

Figure 7-2. Timeline of Sales and Nonroad Fuel Consumption (Gallons) *
2017 Nonroad Diesel Equipment Study



* Excludes recreational marine, military, railroad maintenance, rail TRUs and oil/gas industries

7.5.3 Cross-Sector Breakdown of Construction/Mining Equipment

Finally, it was important to examine the MOVES construction/mining equipment category in more detail. This MOVES category encompasses all earthmoving, paving, and surfacing equipment as well as cranes, rough terrain forklifts, and other assorted equipment typically found at construction project sites (e.g., signal boards, dumpers and tenders). EPA treats these equipment types as a homogenous group, under the assumption that these units are predominately associated with construction.[422] In actuality, such equipment is used in a wide variety of situations. Of particular relevance for Oregon, MOVES defaults estimate that this

[422] EPA uses the dollar value of construction to distribute the national base year equipment populations to the state and county levels. EPA also uses construction industry fuel consumption projections to project 2000 base year equipment populations to 2017.

equipment type is responsible for more than 50 percent of total nonroad diesel consumption, as shown in Table 7-16.

All equipment classified by MOVES as construction/mining was extracted and assembled, allowing for a direct comparison with the study results. The study's diesel consumption for construction/mining equipment is summarized in Table 7-17, broken out by industry sector. Fuel consumption estimates from MOVES and the study are compared in Table 7-18.

Table 7-17. Study Consumption Estimate for Construction/Mining Equipment (Gallons)
2017 Nonroad Diesel Equipment Study

Sector	Gallons	Percent of Total
Construction	18,030,531	45%
Agriculture	7,054,172	18%
Public fleets	5,464,897	14%
Surface mining	4,796,780	12%
Logging	3,939,498	10%
Commercial/Industrial	548,639	1%
Total	**39,834,517**	

Table 7-18. Fuel Consumption Comparison for Construction/Mining Equipment (Gallons)
2017 Nonroad Diesel Equipment Study

	Diesel Engines Over 25 hp
MOVES default	94,838,699
Study	39,834,517
Difference (gallons)	-55,004,181
Percent change relative to MOVES	-58%

The key observations regarding the findings in Table 7-17 and Table 7-18 include:

- The study estimated a significant decrease in diesel fuel consumption of 55 million gallons for construction/mining equipment (a 58 percent decrease relative to the MOVES default).
- The MOVES model assumes these equipment types constitute a uniform sector (nationally down to the county level), which is a significant oversimplification. This is most likely a substantial cause of the significant difference between the MOVES defaults and the study estimates for this sector.
- While the construction sector is responsible for the largest component of construction/mining equipment use (at 45 percent), the other study sectors make up the majority of overall use (55 percent), with agriculture representing the second largest share (18 percent).

7.5.4 Conclusions

Overall, the validation analysis provides three key findings:

- The study's total nonroad diesel consumption fell within the range bounded by FOKS adjusted and unadjusted sales for Oregon in 2017.
- The study's total nonroad diesel consumption is a significant (37 percent) decrease over that estimated by MOVES.
- The equipment classified as construction/mining by MOVES was identified in multiple study sectors, and the total estimated consumption for these units is a significant (58 percent) decrease over that estimated by MOVES.

8.0 Conclusions and Recommendations

This study provided a comprehensive assessment of nonroad diesel equipment activity and emissions for the state of Oregon. The results were obtained using a variety of data sources including detailed surveys of equipment operators, extensive input from industry experts and public agencies, and published literature, among many others. Oregon is just the third state to develop such a bottom-up, statewide profile of these equipment,[423] and the findings represent a substantial improvement to the activity and emission estimates the state previously used, which were based on EPA's MOVES-Nonroad model.

8.1 Final Activity and Emission Adjustments

In general, the study found nonroad diesel equipment operating in Oregon had notably lower activity than assumed by the MOVES model, with total fuel consumption estimated to be 38 percent lower than the value predicted using MOVES defaults. This substantial reduction is generally corroborated by the Energy Information Administration's adjusted FOKS fuel sales data, which are 58 percent lower than the MOVES value.

Table 8-1 summarizes the study's fuel consumption estimates, expressed as a percentage of the corresponding MOVES values, by equipment category.[424]

Table 8-1. Fuel Consumption by Equipment Category (Study Estimate/MOVES Defaults) 2017 Nonroad Diesel Equipment Study

Equipment Category	Percent
Recreational vehicles	100.0%[425]
Construction/mining	42.0%
Industrial	39.3%
Lawn and garden	20.1%
Agriculture	86.1%
Commercial	45.7%
Logging	221.1%
Airport ground support	61.2%
Recreational marine	42.6%
Railway maintenance	247.5%
Other oilfield equipment	100.0%[426]
All Categories	**61.6%**

[423] California and Texas have also conducted studies of similar breadth.

[424] Sections 6.2 and 6.3 provide further details regarding MOVES equipment category definitions and the associated activity level differences.

[425] Recreational vehicle activity was assumed to equal MOVES defaults due to lack of data for this equipment type.

[426] Oilfield equipment activity was assumed to equal MOVES defaults due to lack of data for this equipment type.

The MOVES model also assumes higher-than-actual equipment activity rates for Oregon's nonroad diesel equipment. This has two distinct implications for estimating emissions:

- MOVES overestimates those pollutants that vary in direct proportion with fuel consumption including CO_2, N_2O, NH_3, and SO_2.
- Higher-use equipment will reach the end of its useful life sooner, meaning that MOVES estimates equipment will be replaced faster than it is in Oregon. Older equipment generally emits more criteria pollutants than newer units, reflecting the adoption of tighter engine emission standards over time. By assuming faster replacement of older, higher-emitting equipment with newer, cleaner units, the MOVES model predicts lower average emission rates (though that reduction will be countered to some extent by the higher assumed activity levels).

These assumptions' net impact on emission estimates will depend on a number of factors, including the relative difference between assumed and actual hours of use and engine tier level distributions, which vary by equipment category. Overall, the increased emission rates assumed by MOVES have a greater impact on criteria emissions than the decreased activity rates, although the effect varies by pollutant. Table 8-2 presents the net difference and percentage change in Oregon's total nonroad diesel equipment emissions, between MOVES' default assumptions and this study's estimates.

Table 8-2. Changes in Emission Estimates by Pollutant, 2017 Statewide Emissions 2017 Nonroad Diesel Equipment Study

Pollutant	Difference (Tons/Yr)[427]	Percent of MOVES
CO	587	112.8%
NO_x	-313	96.9%
$PM_{2.5}$	-50	93.3%
VOCs	81	109.5%
CO_{2e}	-888,915	61.4%

The study also provides detailed breakouts of fuel consumption and emissions across industry sectors, equipment types, and counties. As an example, Figure 8-1 presents the statewide $PM_{2.5}$ emission estimates by industry sector, with agricultural operations contributing 45.8 percent of all emissions, followed by logging at 18.6 percent and construction at 18.2 percent. The remaining sectors combined are responsible for 17.3 percent of these emissions. Other criteria pollutants (e.g., NO_x, CO, and VOCs) have similar industry contribution percentages.

[427] Study estimate minus MOVES estimate.

Figure 8-1. 2017 Statewide Annual $PM_{2.5}$ Emissions by Industry Sector
2017 Nonroad Diesel Equipment Study

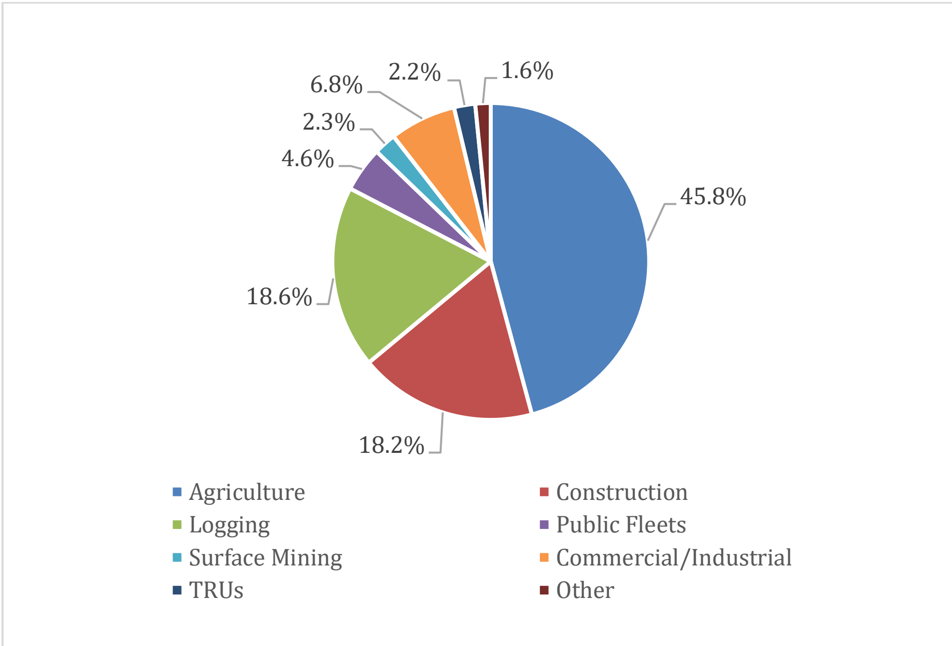


Figure 8-2 presents the $PM_{2.5}$ totals categorized by equipment type, which allows for a direct comparison with MOVES default estimates.[428] While total emissions are roughly similar, distinct differences can be seen between the study's estimates and the MOVES values for certain equipment types, most notably for construction and mining equipment (with a 29 percent reduction relative to MOVES), and logging equipment (with a fivefold increase relative to MOVES).

[428] The MOVES model does not estimate emissions by equipment operator category, just by equipment type.

Figure 8-2. 2017 Statewide Annual $PM_{2.5}$ Emissions by Equipment Type (Tons) 2017 Nonroad Diesel Equipment Study[429]

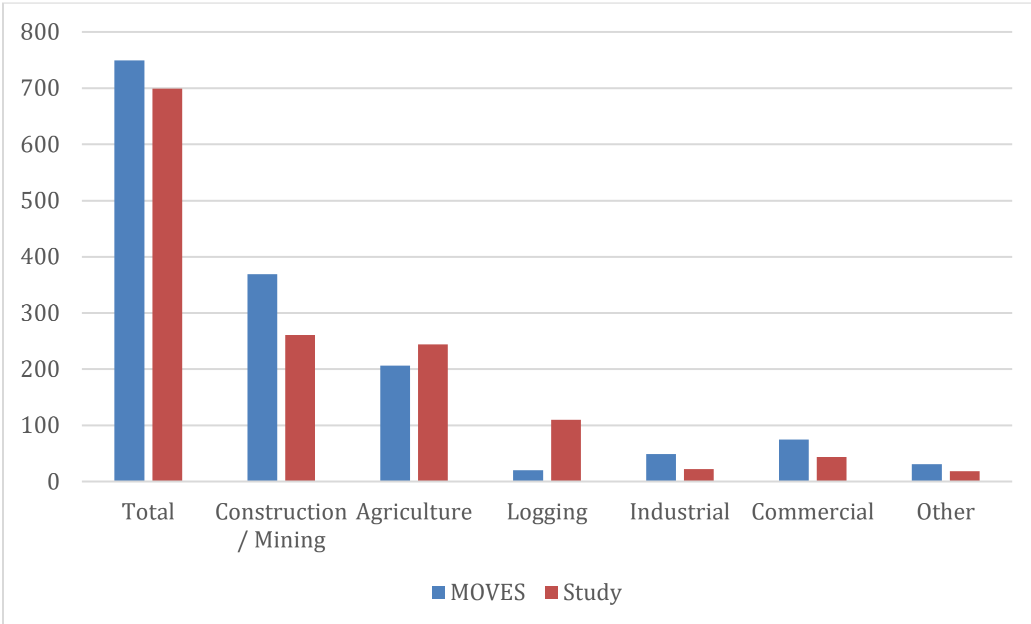


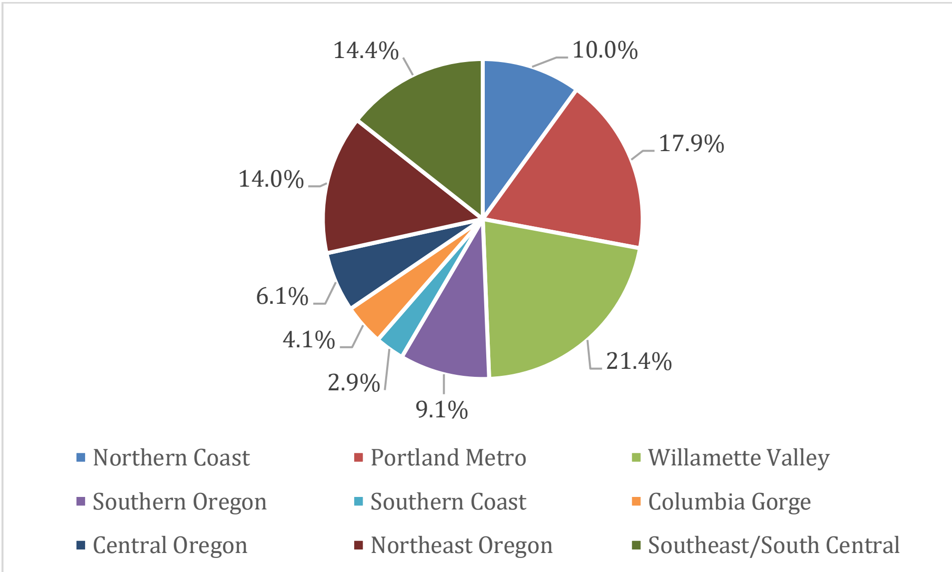
Figure 8-3 shows the distribution of statewide $PM_{2.5}$ emissions by region, with percentages ranging from 2.9 percent for the Southern Coast region[430] to 21.4 percent for the Willamette Valley.[431]

[429] As discussed in Section 6.3.3, equipment types are grouped to be consistent with MOVES' categories for comparison purposes. Many equipment types are used across a range of applications and industries. For example, construction/mining equipment includes backhoes which are used not only in the construction sector but also in the agriculture and public fleet sectors as well.

[430] Including Coos and Curry Counties.

[431] Including Benton, Lane, Linn, Marion and Polk Counties.

Figure 8-3. 2017 Statewide Annual $PM_{2.5}$ Emissions by Region
2017 Nonroad Diesel Equipment Study



8.2 Key Uncertainties

Given the broad range of data sources and calculation methodologies employed throughout the study, the results are subject to a number of uncertainties, the most notable of which are discussed qualitatively below.

- **Survey findings.** Certain surveys obtained relatively low numbers of responses and sector coverage rates. For example, response rates were low for permitted facilities including landfills, material recovery and compost locations, with the surveys representing less than 20 percent of total activity for these facility types. While the surface mining survey covered over 50 operation sites and about 40 percent of market share, the efficiency factor used to extrapolate total equipment activity to the state level was based on input from a single industry expert and is subject to significant uncertainty. In addition, the number of cranes (other than rough terrain units) operated outside rigging service companies was based on a few observations from construction company surveys. As such the total number of cranes in operation across the state remains somewhat uncertain. Finally, scrap and junk yards are expected to operate some amount of nonroad diesel equipment, such as small cranes and material handling equipment. While total activity and emission levels at these locations are expected to be small, they were not included in ERG's Data Collection Plan and may merit their own survey in the future.
- **Industry equipment use profiles.** The agricultural services profile did not include harvesting support activities due to the expected variability in equipment needs across

different crop types.[432] In addition, while the Dodge Analytics data used to quantify equipment needs for the commercial building construction and utility sectors rely on a range of data sources and are widely referenced by industry, they have not been independently verified, adding an unknown degree of uncertainty to the emission estimates for these sectors. The degree to which the ODOT Construction Program profile is representative of highway and road project work contracted by city, county, and other agencies is also uncertain. Finally, railway maintenance activity and emissions are highly uncertain in Oregon due to a lack of state-level data for Class I as well as Class II and III rail line operators.[433]

- **Spatial distributions.** While detailed project-level data were collected for several industry sectors, the study's activity profiles are aggregated and presented at the county level. Therefore, the final emission estimates do not lend themselves to project-specific analysis. That said, much of the equipment activity characterized by the study is associated with detailed, reliable spatial surrogates used for county allocation, although the operating areas for certain equipment types are uncertain. For example, public agency experts have indicated that the diesel recreational marine engine operation may be largely limited to coastal ports and portions of the Columbia and Willamette Rivers, rather than being more widely distributed as assumed by this study. There are also potential errors introduced in county activity allocation when survey data are aggregated and expanded to estimate statewide activity, then allocated back down to the county level, as was done for the logging, agricultural, and crane surveys. In these cases, unidentified survey sampling bias (where the aggregated survey results do not reflect average state-level operations) are propagated across all counties.
- **Other data source limitations.** Certain equipment and operator categories proved challenging to characterize via surveys and/or industry profiles. TRU population and activity is particularly difficult to evaluate given the large number of units continually entering and leaving the state. Use of portable equipment (e.g., generators and compressors) in the commercial and industrial/manufacturing sectors is also difficult to survey and profile due to the large number of establishments combined with low ownership frequencies. Finally, several equipment types have been assigned to a single industry sector for reporting purposes, such as backhoes and skid steers to the construction sector and welders to the commercial sector.[434] However, many of these units are operated across multiple sectors. For example, backhoes are commonly used in landscaping operations (part of the commercial sector), while welders can be used in manufacturing operations (part of the industrial sector) as well as in construction.

[432] ERG does not expect fuel consumption associated with custom harvesting to exceed the total for all other agricultural services (less than 900,000 gallons per year in 2017). As such, unaccounted-for emissions for this activity are expected to be relatively small.

[433] Refer to Section 5.2 for further details.

[434] Five other equipment types with "default" operation sector assignments include trenchers (construction), pumps, generators and compressors (commercial), and aerial lifts (industrial). Backhoes, skid steers and welders are responsible for over three fourths of the total emissions for these eight equipment types.

While such "default" equipment assignments are expected to overestimate emissions in the construction sector and underestimate emissions in the commercial and industrial sectors, and the precise equipment and emissions allocation across sectors is uncertain, the overall equipment activity and emissions estimates across sectors are well characterized.

8.3 Recommendations

The current study required substantial time and financial resources. As such, it is unlikely to be repeated for many years. Future updates to the new emission inventory should selectively focus on reducing uncertainties associated with the most significant inventory sectors. Follow-on studies might investigate selected "high-impact" areas:

- Follow-on surveys to expand the respondent pool for permitted facilities and landfills in particular;
- Targeted surveys of surface mining operations, limited to estimating gallons of nonroad diesel fuel consumption per ton of production at the county level;[435]
- Consultation with equipment manufacturers and rental companies to assess what fraction of backhoes, skid steers, welders, and other equipment should be assigned to different operation sectors based on sales and market share data;
- Investigation of using transponder data to characterize TRU equipment population and use patterns in Oregon.[436]

Finally, while the study provides a broad assessment for targeted equipment, the results only offer a "snapshot" of activity and emissions for the 2017 calendar year. Default MOVES growth factors can be used to project forward from 2017, although these factors are based on national or regional data and may not be appropriate for Oregon.[437] In addition, MOVES' growth factors often do not have the granularity required to be consistent with the new base year data (e.g., the MOVES construction factors do not differentiate highway, commercial building, and other construction subsector activity). Accurate and precise growth factor determination is particularly important for sectors such as surface mining that are undergoing rapid equipment use changes (in this case due to frequent site electrification).

Growth factors could be developed using sector-specific GDP projections available from data vendors at the state and county levels.[438] Additional sector-specific growth adjustments could be obtained through industry surveys and trade association input (e.g., highway sector growth could be adjusted to account for changes in relative materials costs over time). Limited periodic

[435] Such a survey would be substantially smaller in scope than the one just executed for the sector, excluding equipment-specific details.

[436] Transponder data have been used successfully to characterize activity for a variety of on-road mobile source inventory efforts.

[437] See Appendix H for details on MOVES growth factors and assumptions.

[438] DEQ is strongly encouraged to wait until markets stabilize after the disruptions from the coronavirus outbreak before developing state-specific growth factors.

engine age surveys could also be undertaken to adjust tier level distributions by sector. These adjustments are particularly important for industries with quick equipment turnover and/or frequent engine repowering.

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Appendix A – Agricultural Sector Questionnaire

Establishment Name: ________________________

Oregon Non-Road Diesel Equipment Emission Inventory -
Agricultural Sector

The Oregon legislature has directed the Oregon Department of Environmental Quality (DEQ) to conduct a study of non-road diesel equipment, and the DEQ has hired Eastern Research Group, Inc. (ERG) to collect information for the study. Your company is one of the types of businesses they have asked us to contact.

The survey focuses on diesel-powered nonroad equipment greater than 25 horsepower (e.g. agricultural and construction equipment) operated in Oregon in 2017. The first part of the survey asks a number of questions for each piece of equipment that you operate. The second part of the survey asks questions applicable to your overall equipment inventory.

ERG will only present aggregated survey results to DEQ. ***All identifying information collected during the survey will remain confidential and will be removed from the final survey results.***
Your participation will help the state estimate air emissions and develop grant and subsidy programs to replace older diesel engines.
Thank you for your time and assistance!

PLEASE FAX YOUR COMPLETED SURVEY TO EASTERN RESEARCH GROUP AT: 512-419-0089

How many pieces of diesel-powered off-road equipment greater than 25 horsepower (hp) did you operate in Oregon in 2017?
Number of pieces of equipment: ___________________

IMPORTANT NOTES:
The survey only includes diesel-powered engines over 25 hp (maximum engine rating). All on-road vehicles registered by the Department of Motor Vehicles for highway use (e.g. trucks used for commodity transport) are excluded.
"Non-road" covers all off-highway equipment that changed locations at least once in 2017. If the equipment was in a fixed location for the entire 12-month period, it should be excluded.
Please submit copies of PART 1 (Page 2) for each applicable, non-road piece of equipment.

Establishment Name: ________________________

PART 1 – EQUIPMENT DATA

<u>For EACH piece of equipment used in 2017, please answer the following questions:</u>

<u>Please see pages 5-6 for a list of equipment types.</u>

Equipment Type: ____

If other, please describe: ____

Make: ___________________ Model: ___________________ Model Year (XXXX): ______________

Horsepower (HP) - Exact, if known: ___________________ OR Estimated (Select from the ranges below):

25-40	40-50	50-75	75-100	100-175
175-300	300-600	600-750	750-1000	

What were the total hours of engine on-time for 2017? ___________________

What is the basis for hours of operation? Select one.

☐ Clock hours

☐ Other - Please describe (e.g. labor records, owner experience, maintenance records, etc.)

____

Do you own/rent/lease this piece of equipment? Select one.

☐ Own ☐ Rent ☐ Lease

Has the equipment received an exhaust retrofit to control emissions? Select one.

☐ Yes, diesel oxidation catalyst ☐ Yes, particulate trap ☐ No

Has the equipment been repowered?

☐ No ☐ Yes – Please specify model year: _______ (XXXX)

What is the estimated retirement year for this unit? _______ (XXXX)

PART 2 – PRODUCTION DATA

For your BUSINESS AS A WHOLE, please answer the following questions for your operations in 2017:

Please estimate your establishment's acreage in production by crop type.

- Oilseed/Grains _______
- Vegetables/Fruits _______
- Greenhouse/Nursery/Floriculture _______
- Winery _______
- Other Crops _______
- Animal Production _______

For Animal Production, please enter type of animal and number of head.

Livestock Type	Number of Head
Beef Cattle	
Dairy Cattle	
Goats	
Hogs	
Sheep	
Poultry	
Other	

What was your total farm size in acres? (circle one)

- 1-9
- 10-49
- 50-69
- 77-99
- 100-139
- 140-179
- 180-219
- 220-259
- 260-499
- 500-999
- 1,000-1,999
- 2,000+

What was the primary county/counties of operation? ________________________________

How were your equipment operations hours typically split across weekdays and weekends? Should sum to 100%.

Weekdays: _______%
Weekends: _______%

How were your equipment operation hours split across seasons? Should sum to 100%.

Summer (June-August): _______%

Winter (December-February): _______%

Fall (September-November): _______%

Spring (March-May): _______%

What was the total annual diesel fuel consumption (in gallons) for your off-road diesel equipment?
Number of gallons: __________ Number of biodiesel gallons: _________ Biodiesel blend: ______

Did you employ a third party for crop services (e.g. spraying, lime application, etc.) during 2017? Yes No
If so, please specify the type of service(s) provided:

____

____

____

____

What is the structure of your company (corporation, sole proprietorship, partnership, Limited Liability Corporation, disadvantaged business establishment, etc.)? Select one.

- ☐ Corporation
- ☐ Sole proprietorship
- ☐ Partnership
- ☐ Other, please describe: ____
- ☐ Limited liability Corporation
- ☐ Disadvantaged business

For equipment that you have purchased, what was your most common method of financing? Select one.

☐ Bank financing ☐ Line of Credit ☐ Cash

Categories and Types of Equipment

Equipment Category	Equipment Type:
Agricultural	Agricultural Tractors
	Agricultural Mowers
	Balers
	Combines
	Hydro-power Units
	Irrigation Sets
	Sprayers
	Swathers
	Tillers
	Other Agricultural Equipment
Commercial/Other	Air Compressors
	All-terrain vehicles (ATVs) / Utility carts
	Gas Compressors
	Generator Sets
	Hydro-power Units
	Pressure Washers
	Pumps
	Welders
	Other Commercial Equipment
Lawn and Garden	Chippers/Stump Grinders
	Commercial Turf Equipment
	Front Mowers
	Lawn and Garden Tractors
	Lawn Mowers
	Leafblowers/Vacuums
	Rear Engine Riding Mowers
	Snowblowers
	Trimmers/Edgers/Brush Cutters
	Turf Equipment
	Wood Splitters
	Other Commercial Lawn and Garden Equipment

Equipment Category	Equipment Type:
Industrial	AC/Refrigeration Equipment
	Aerial Lifts
	Forklifts
	Other Material Handling Equipment
	Sweepers/Scrubbers
	Terminal Tractors
	Other General Industrial Equipment
Construction and Mining	Bore/Drill Rigs
	Cement and Mortar Mixers
	Concrete Pavers
	Concrete/Industrial Saws
	Cranes
	Crawler Tractors/Dozers
	Crushing/Processing Equipment
	Dumpers/Tenders
	Excavators
	Graders
	Off-highway Tractors
	Off-highway Trucks
	Pavers
	Paving Equipment
	Plate Compactors
	Rollers
	Rough Terrain Forklifts
	Rubber Tire Loaders
	Rubber Tire Tractors/Dozers
	Scrapers
	Signal Boards/Light Plants
	Skid Steer Loaders
	Surfacing Equipment
	Tampers/Rammers
	Tractors/Loaders/Backhoes
	Trenchers
	Other Construction Equipment

Equipment Category	Equipment Type:
Logging	Chippers/Shredders
	Feller Bunchers
	Forwarders
	Log Loaders/Picks (Self-Propelled)
	Log Loaders/Picks (Stationary or Trailer Mount)
	Skidders
	Tree Harvesters
	Other Forestry Equip (Self-Propelled)
	Other Forestry Equip (Stationary or Trailer Mount)

Appendix B – Agricultural Survey Responses by Stratum

Table B-1. Equipment Use Summary – Beef Cattle Stratum (N=32) 2017 Nonroad Diesel Equipment Study

Equipment Type	# of Units	Average HP	Average Hrs/Yr	Average Model Year
Agricultural Tractors	82	117	290	1993
Balers	4	71	94	1994
Combines	2	487	59	2016
Other Agricultural Equipment	1	295	149	1994
Sprayers	2	284	28	2005
Swathers	7	89	50	1998
Air Compressors	1	65	190	2004
Pumps	3	86	158	1996
Crawler Tractors/Dozers	20	147	235	1983
Excavators	6	111	261	1989
Graders	15	222	340	1993
Forklifts	1	86	259	1994
Rubber Tire Loaders	4	130	208	1983
Skid Steer Loaders	3	52	72	2008
Tractors/Loaders/Backhoes	5	66	353	1991
Fellers/Bunchers/Skidders	1	128	300	1976
Total	**157**	**133**	**256**	**1992**

Table B-2. Equipment Use Summary – Dairy Cattle Stratum (N=7) 2017 Nonroad Diesel Equipment Study

Equipment Type	# of Units	Average HP	Average Hrs/Yr	Average Model Year
Agricultural Tractors	48	142	507	2002
Irrigation Sets	4	125	700	2015
Other Agricultural Equipment	4	493	425	2009
Swathers	2	188	550	2009
Pumps	1	125	300	2017
Crawler Tractors/Dozers	1	100	200	2004
Excavators	2	135	550	2009
Forklifts	1	90	300	1997
Rubber Tire Loaders	23	111	1097	2007
Skid Steer Loaders	7	64	361	2006
Lawn and Garden Tractors	1	25	500	2016
Total	**94**	**141**	**639**	**2005**

Table B-3. Equipment Use Summary – Greenhouse/Nursery/Floriculture Stratum (N=26) 2017 Nonroad Diesel Equipment Study

Equipment Type	# of Units	Average HP	Average Hrs/Yr	Average Model Year
Agricultural Tractors	207	72	254	1996
Combines	9	221	196	2001
Irrigation Sets	2	86	749	1995
Other Agricultural Equipment	9	109	278	2007
Sprayers	9	103	219	1995
Swathers	3	123	142	2007
Crawler Tractors/Dozers	14	100	244	1996
Excavators	35	61	284	2007
Graders	4	177	194	1967
Forklifts	9	57	251	2001
Rubber Tire Loaders	25	81	249	1988
Skid Steer Loaders	8	72	341	2011
Tractors/Loaders/Backhoes	3	89	275	1994
Total	**337**	**80**	**258**	**1997**

Table B-4. Equipment Use Summary – Oilseed/Grail Stratum (N=12) 2017 Nonroad Diesel Equipment Study

Equipment Type	# of Units	Average HP	Average Hrs/Yr	Average Model Year
Agricultural Tractors	46	223	282	1993
Combines	18	254	164	2001
Irrigation Sets	1	25	800	1992
Sprayers	1	175	188	2002
Swathers	4	103	81	1999
Pumps	1	70	300	1965
Crawler Tractors/Dozers	3	142	67	1971
Graders	2	170	50	1964
Total	**76**	**214**	**235**	**1993**

Table B-5. Equipment Use Summary – Other Crop Stratum (N=40) 2017 Nonroad Diesel Equipment Study

Equipment Type	# of Units	Average HP	Average Hrs/Yr	Average Model Year
Agricultural Tractors	288	138	408	1994
Balers	1	62	25	2005
Combines	71	256	145	1998
Irrigation Sets	8	81	409	2013
Other Agricultural Equipment	12	128	254	2002
Sprayers	17	171	125	2002
Swathers	53	117	133	2006

Equipment Type	# of Units	Average HP	Average Hrs/Yr	Average Model Year
Air Compressors	7	95	381	2000
Crawler Tractors/Dozers	8	113	281	1987
Excavators	6	113	439	1997
Graders	1	125	100	1976
Rollers	1	85	241	1996
Forklifts	23	83	274	2004
Rubber Tire Loaders	5	131	283	1990
Skid Steer Loaders	7	57	276	2006
Tractors/Loaders/Backhoes	5	69	233	1993
Terminal Tractors	2	200	398	1996
Lawn and Garden Tractors	1	46	100	2015
Fellers/Bunchers/Skidders	2	143	33	1978
Specialty Vehicles	1	28	400	2005
Total	**519**	**146**	**315**	**1997**

Table B-6. Equipment Use Summary – Fruit Tree/Nut Stratum (N=30) 2017 Nonroad Diesel Equipment Study

Equipment Type	# of Units	Average HP	Average Hrs/Yr	Average Model Year
Agricultural Tractors	189	96	266	2000
Combines	7	228	135	1998
Irrigation Sets	8	59	808	2008
Other Agricultural Equipment	20	108	225	2003
Sprayers	11	206	91	1999
Swathers	3	145	98	2008
Generator Sets	2	33	78	1996
Pressure Washers	1	31	33	1996
Pumps	4	86	93	1996
Welders	2	46	148	1996
Concrete/Industrial Saws	1	33	134	1996
Crawler Tractors/Dozers	3	111	177	1983
Excavators	8	103	232	2001
Graders	1	230	222	1996
Off-highway Trucks	3	244	378	1996
Other Construction Equipment	6	234	140	1996
Rollers	2	85	175	1996
Forklifts	18	75	204	1998
Rubber Tire Loaders	1	232	5	1975
Skid Steer Loaders	4	51	158	2000
Tractors/Loaders/Backhoes	4	78	151	1995

Equipment Type	# of Units	Average HP	Average Hrs/Yr	Average Model Year
Trenchers	1	61	137	1996
Other Industrial Equipment	5	130	202	1996
Chippers/Stump Grinders	1	50	67	2000
Lawn and Garden Tractors	1	45	50	2017
Specialty Vehicles	7	28	100	1996
Total	**313**	**103**	**244**	**1999**

Table B-7. Equipment Use Summary – Other Animals Stratum (N=10)
2017 Nonroad Diesel Equipment Study

Equipment Type	# of Units	Average HP	Average Hrs/Yr	Average Model Year
Agricultural Tractors	11	59	200	1997
Swathers	1	60	50	2004
Skid Steer Loaders	1	45	100	2001
Total	**13**	**58**	**250**	**1998**

Table B-8. Equipment Use Summary – Vegetables/Melons Stratum (N=7)
2017 Nonroad Diesel Equipment Study

Equipment Type	# of Units	Average HP	Average Hrs/Yr	Average Model Year
Agricultural Tractors	45	181	437	2000
Combines	2	275	200	2002
Other Agricultural Equipment	3	162	223	1987
Swathers	2	148	85	1998
Total	**52**	**182**	**402**	**1999**

Table B-9. Equipment Use Summary – Winery Stratum (N=11)
2017 Nonroad Diesel Equipment Study

Equipment Type	# of Units	Average HP	Average Hrs/Yr	Average Model Year
Agricultural Tractors	20	54	197	2002
Specialty Vehicles	1	25	83	2012
Total	**21**	**53**	**192**	**2002**

Appendix C – Logging Sector Questionnaire

Establishment Name: ________________________

Oregon Non-Road Diesel Equipment Emission Inventory -
Logging Sector

Eastern Research Group, Inc. (ERG) has been hired to conduct a survey of nonroad diesel equipment use for the Oregon Department of Environmental Quality (DEQ), and your establishment is one of the types of businesses they have asked us to contact.

The survey focuses on diesel-powered nonroad equipment greater than 25 horsepower (e.g. agricultural, construction and logging equipment) operated in Oregon in 2017. The logging-sector survey covers equipment usage associated with timber harvesting, log processing and aggregate production/mining (which may occur on privately-owned lands to support logging road construction and maintenance). You will be asked a brief series of questions for each piece of equipment (PART 1) and for your business as a whole (PART 2).

ERG will only present aggregated survey results to DEQ; ***All identifying information collected during the survey will remain confidential and will be removed from the final survey results.***

Your participation will help the state estimate air emissions and develop grant and subsidy programs to replace older diesel engines.

Thank you for your time and assistance!

PLEASE FAX YOUR COMPLETED SURVEY TO EASTERN RESEARCH GROUP AT: 512-419-0089

How many pieces of diesel-powered non-road equipment greater than 25 horsepower (hp) did you operate in Oregon in 2017?
Number of pieces of equipment: ___________________

IMPORTANT NOTES:
The survey only includes diesel-powered engines over 25 hp (maximum engine rating). All on-road vehicles registered by the Department of Motor Vehicles for highway use (e.g. Logging Trucks) are excluded.
"Non-road" covers all off-highway equipment that changed locations at least once in 2017. If the equipment was in a fixed location for the entire 12-month period, it should be excluded.
Please submit copies of PART 1 (Page 2) for each applicable, non-road piece of equipment.

Establishment Name: ________________________

PART 1 - EQUIPMENT

<u>For EACH piece of equipment used in 2017, please answer the following questions:</u>

<u>Please see Page 5 for a list of equipment types.</u>

Only include equipment directly used by your business (and exclude equipment used by subcontractors)

Equipment Type: ____

If other, please describe: ____

Make: ___________________ Model: ___________________ Model Year (XXXX): ______________

Horsepower (HP) - Exact, if known: ___________________ OR Estimated (Select from the ranges below):

25-40	40-50	50-75	75-100	100-175
175-300	300-600	600-750	750-1000	

What were the total hours of engine on-time for 2017? ___________________

What is the basis for hours of operation? Select one.

- ☐ Clock hours
- ☐ Other - Please describe (e.g. labor records, owner experience, maintenance records, etc.)

____

Do you own/rent/lease this piece of equipment? Select one.

☐ Own ☐ Rent ☐ Lease

Has the equipment received an exhaust retrofit to control emissions? Select one.

☐ Yes, diesel oxidation catalyst ☐ Yes, particulate trap ☐ No

Has the equipment been repowered?

☐ No ☐ Yes – Please specify model year: _______ (XXXX)

What is the estimated retirement year for this unit? ___________________ (XXXX)

PART 2 – PRODUCTION DATA

For your BUSINESS AS A WHOLE, please answer the following questions for your timber harvesting & log processing sites:

What were the number of sites worked in 2017 by type?

______ Timber Harvesting

______ Log Processing (Wood Products Industry)

_____ Log Sorting Yard

_____ Log Export Yard

_____ Aggregate Production Pit

2017 Lumber Throughput (thousand board-feet, MBF): ___________

How is Throughput distributed across Counties?

County	Throughput (%)
____________	_______________
____________	_______________
____________	_______________
____________	_______________

(Should total 100% for each column)

2017 Aggregate Production (Tons): ____________

How is aggregate production distributed across counties?

County	Aggregate Production (%)
____________	_______________
____________	_______________
____________	_______________
____________	_______________

(Should total 100% for each column)

Establishment Name: _________________________

2017 Timber Harvesting Sites, Total Land Area (Acres): ______________

How is the total Land Area distributed across counties?

County	Total Land Area (%)
_____________	________________
_____________	________________
_____________	________________
_____________	________________

(Should total 100% for each column)

What is the distribution of throughput / production by day of week (should sum to 100%)?

Weekdays: _______% Weekends: _______%

What is the distribution of throughput / production by season (should sum to 100%)

Summer (June-August): _______% Winter (December-February): _______%

Fall (September-November): _______% Spring (March-May): _______%

What was the total diesel fuel consumption (in gallons) for your non-road diesel equipment in 2017?
Number of gallons: ____________________

PART 2 (CONTINUED)

Additional Questions for Timber Harvesting Sites Only:

What were the number of harvesting sites worked as Prime Contractor in 2017? ______
As Prime Contractor, at how many sites were the following activities performed by subcontractors?

_____ Roads and Landings
_____ Timber Falling
_____ Timber Bunching
_____ Timber Bucking
_____ Skidding
_____ Yarding
_____ Other (Please Describe):

_____ Log Processing
_____ Sorting
_____ Decking
______ Loading
_____ Slash Piling
______Clean Up

What were the total number of harvesting sites worked as Subcontractor in 2017? ______
As Subcontractor, at how many sites were the following activities performed?

_____ Roads and Landings
_____ Timber Falling
_____ Timber Bunching
_____ Timber Bucking
_____ Skidding
_____ Yarding
_____ Other (Please Describe):

_____ Log Processing
_____ Sorting
_____ Decking
______ Loading
_____ Slash Piling
______Clean Up

<u>Additional Questions:</u>

How many Full Time Equivalent (FTE) employees worked for you in 2017? Include Part Time Employees together with Full Time Employees. Example: 2 employees at 20 hours per week + 1 Full Time= 2 (FTE)

Number of Full Time Equivalent Employees (FTE): ________

What is the structure of your company (corporation, sole proprietorship, partnership, Limited Liability Corporation, disadvantaged business establishment, etc.)? Select one.

☐ Corporation

☐ Limited liability Corporation

☐ Sole proprietorship

☐ Disadvantaged business establishment

☐ Partnership

☐ Other, please describe: ____

For equipment that you have purchased, what was your most common method of financing? Select one.

☐ Bank financing ☐ Line of Credit ☐ Cash

Thank you for your assistance!

ATTACHMENT
Categories and Types of Equipment

Equipment Category	Equipment Type:
Logging (equipment used in tree harvesting or log processing)	Chippers/Shredders
	Feller Bunchers
	Forwarders
	Log Loaders/Picks (Self-Propelled)
	Log Loaders/Picks (Stationary or Trailer Mount)
	Skidders
	Tree Harvesters
	Other Forestry Equip (Self-Propelled)
	Other Forestry Equip (Stationary or Trailer Mount)
Earthmoving (equipment as used in harvesting site preparation, logging road & drainage maintenance, harvesting site clean-up, or aggregate production)	Crawler Tractors/Dozers
	Crushing/Processing Equipment
	Excavators
	Graders
	Off-highway Trucks
	Rough Terrain Forklifts
	Rubber Tire Loaders
	Rubber Tire Tractors/Dozers
	Scrapers
	Tampers/Rammers
	Tractors/Loaders/Backhoes
	Trenchers
Industrial (as used generally)	AC/Refrigeration Equipment
	Aerial Lifts
	Forklifts
	Other Material Handling Equipment
	Sweepers/Scrubbers
	Terminal Tractors
Commercial Equipment (as used generally)	Air Compressors
	Gas Compressors
	Generator Sets
	Hydro-power Units
	Pressure Washers
	Pumps
	Welders
Commercial Lawn and Garden (as used generally)	Stump Grinders
	Brush Cutters

Appendix D – Surface Mining Sector Questionnaire

Oregon Non-Road Diesel Emission Inventory
(Surface Mining - including open pit mining, strip mining, quarrying)

Eastern Research Group, Inc. (ERG) has been hired to conduct a survey of nonroad diesel equipment use for the Oregon Department of Environmental Quality (DEQ), and your company is one of the types of businesses they have asked us to contact.

The survey focuses on diesel-powered nonroad equipment greater than 25 horsepower (e.g. construction and agricultural equipment) operated in Oregon in 2017. The first part of the survey asks a number of questions for each piece of equipment in your fleet. The second part of the survey asks questions applicable to your overall equipment fleet.

ERG will only present aggregated survey results to DEQ; all identifying information collected during the survey will remain confidential and will be removed from the final survey results.

Your participation will help the state estimate air emissions and develop grant and subsidy programs to replace older engines.
Thank you for your time and assistance!

PLEASE FAX YOUR COMPLETED SURVEY TO EASTERN RESEARCH GROUP AT: 512-419-0089

* **indicates required field**
* **How many pieces of diesel-powered off-road equipment greater than 25 horsepower (hp) did you operate in Oregon in 2017?**
Number of pieces of equipment: ___________________

IMPORTANT: *You will be asked a series of questions for each unit operated.*
Please submit a COPY OF PAGE 2 for each piece of diesel-powered off-road equipment greater than 25 horsepower (hp) you operated in Oregon in 2017.

<u>For EACH piece of equipment, please answer the following questions:</u>
Please see Pages 4-5 for equipment categories and types.

* Equipment Category:____
* Equipment Type: ____
* If other, please describe: ____

Make: ____________________ Model: ____________________ * Model Year (XXXX): _______________

* Horsepower (HP) - Exact, if known: ____________________ OR Estimated (Select a range below):

25-40	40-50	50-75	75-100	100-175
175-300	300-600	600-750	750-1000	

*** What were the annual hours of engine on-time in Oregon for 2017?** ____________________ hours

What is the basis for hours of operation? Select one.

☐ Clock hours

☐ Other - Please describe (e.g. labor records, manager experience, maintenance records, etc.)

____

How were those hours typically split across weekdays and weekends? Please sum to 100%.
Weekdays: _______%
Weekends: _______%

How were the hours split across seasons? Please sum to 100%.

Summer (June-August):	_______%	Winter (December-February):	_______%
Fall (September-November):	_______%	Spring (March-May):	_______%

Do you own/rent/lease this piece of equipment? Select one.

☐ Own ☐ Rent ☐ Lease

Has the equipment received an exhaust retrofit to control emissions? Select one.

☐ Yes, diesel oxidation catalyst ☐ Yes, particulate trap ☐ No

Has the equipment been repowered?

☐ No ☐ Yes – Please specify model year or tier level of repowered engine: _____ (XXXX)

What is the anticipated retirement year for this unit? ____________________ (XXXX)

ERG

What was the primary operation location for your equipment in 2017?

* County: ____________________

If known (enter answer for one):

Metro Area: __________________________

City: __________________________

Site address: __________________________

What was the total diesel fuel consumption (in gallons) for your off-road diesel equipment in 2017?

Number of gallons: _________ Number of biodiesel gallons _______ Biodiesel blend _______

How many non-administrative workers did you employ in 2017?

Number of non-administrative workers: ____________________

What is the structure of your company (corporation, sole proprietorship, partnership, limited liability corporation, disadvantaged business establishment, etc.)? Select one.

- ☐ Corporation
- ☐ Sole proprietorship
- ☐ Partnership
- ☐ Limited liability corporation
- ☐ Disadvantaged business establishment
- ☐ Other, please describe: ____

For equipment that you have purchased, what was your most common method of financing? Select one.

☐ Bank financing ☐ Line of Credit ☐ Cash

Please share any comments or recommendations about the survey in the space below.

Categories and Types of Equipment

Equipment Category	Equipment Type:
Construction and Mining	Bore/Drill Rigs
	Cement and Mortar Mixers
	Concrete Pavers
	Concrete/Industrial Saws
	Cranes
	Crawler Tractors/Dozers
	Crushing/Processing Equipment
	Dumpers/Tenders
	Excavators
	Graders
	Off-highway Tractors
	Off-highway Trucks
	Pavers
	Paving Equipment
	Plate Compactors
	Rollers
	Rough Terrain Forklifts
	Rubber Tire Loaders
	Rubber Tire Tractors/Dozers
	Scrapers
	Signal Boards/Light Plants
	Skid Steer Loaders
	Surfacing Equipment
	Tampers/Rammers
	Tractors/Loaders/Backhoes
	Trenchers
	Other Construction Equipment
Agricultural	2-Wheel Tractors
	Agricultural Mowers
	Agricultural Tractors
	Balers
	Combines
	Hydro-power Units
	Irrigation Sets
	Sprayers
	Swathers
	Tillers
	Other Agricultural Equipment
Industrial	AC/Refrigeration Equipment
	Aerial Lifts
	Forklifts
	Other Material Handling Equipment

Equipment Category	Equipment Type:
	Sweepers/Scrubbers
	Terminal Tractors
	Other General Industrial Equipment
Commercial	Air Compressors
	Gas Compressors
	Generator Sets
	Hydro-power Units
	Pressure Washers
	Pumps
	Welders
	Other Commercial Equipment
Logging	Chain Saws
	Fellers/Bunchers/Skidders
	Shredders
	Other Logging Equipment
Recreational Marine	Inboard
	Outboard
	Sailboat Auxiliary Inboard
	Sailboat Auxiliary Outboard
	Sterndrive
	Other Recreational Marine
Airport Ground Support	Terminal Tractors
	Other Airport Ground Support Equipment
Commercial Lawn and Garden	Chippers/Stump Grinders
	Commercial Turf Equipment
	Front Mowers
	Lawn and Garden Tractors
	Lawn Mowers
	Leafblowers/Vacuums
	Rear Engine Riding Mowers
	Snowblowers
	Trimmers/Edgers/Brush Cutters
	Turf Equipment
	Wood Splitters
	Other Commercial Lawn and Garden Equipment
Railroad	Railway Maintenance Equipment
Underground Mining	Underground Mining Equipment
Other	Other Equipment

Appendix E – Excluded ODOT Bid Items

Table E-1. Excluded ODOT Bid Items[439]

Bid Item
1" Water Meter Assembly
12 Inch Landscape Catch Basins
Abandon Drains and Pipe
Above Ground Enclosures
ADA Ramp Adjustments, Modifications, Repairs
Additional Liability Coverage
Adjustable Chevron Mount
Anchor Bolts
Anode Terminal Plate
Architectural Treatments
Asphalt in Fog Coat
Automatic Traffic Recorder
Barges
Benches
Bicycle Racks/Shelter
Blankets, Various
Blowoff Assembly
Bollards
Breakaway Sign Supports
Bridge Drains
Broken Weld Bolt
Bus Shelter
Cabinets (appears to be electrical)
Camera Poles and Foundations
Camera/Sensors
Capping Concrete Structures
Cathode Protection
Check Dam
CIPP Pipe Liner
Class 2 And 3 Preparation (handheld tools only, could include air compressors)
Clean/Grease/Recondition Bearings
Cleanouts
Coating Applications/Materials (assumed to be metal powder coatings)
Communications Equipment/Systems
Compost
Compression Seals
Concrete Blocks
Concrete Curb Opening
Concrete Drain Inlet Protection, Adjustment, Removal
Concrete Nosing
Concrete/Resin Buildup on Shallow Rebar
Concrete Coating
Concrete Core Drilling
Construct and Remove Detours
Construction Survey Work
Contaminated Water Handling/Removal
Continuity Checks
Crack Seal
Crosswalk Closure, Other Non-Concrete Barricades
CSL Access Tubes
Culvert Protection Barriers
Dairylands Unit Pavers
Deck Paving (No Diesel Deck Pavers > 25 hp)
Deliniators
DEQ Permit Renewal
Design Tasks
Detectable Warning Surfaces
Detector Installation (loop detectors assumed)
Diagrams/Drawings
Dollar Adjustments (e.g., for thermal segregation)
Door/Window Installation
Downspout Repair
Drain Cleaning
Drum Signs
DTI/Bolts
Ductile Iron Pipe - Bend, Coupling, Reducer (Not Pipe Installation Itself)

[439] Assumed to have minimal/no diesel equipment use > 25 hp, or sole reliance on equipment covered in other profiles.

Bid Item
Elastomeric Bearing Devices (assume minimal crane use)
End Wall Chipping
Erosion Control
Evacuate for Continuity Welds
Fastener Replacement
Fence Gate
Fertilizing
Fiber Optic Work
Fiberglass Poles
Fill Surface Void
Flagger Station Lighting
Flaggers
Flagpole Sleeve
Flashing Beacon Install
Foundation Concrete
Geo, Polymer, And Waterproofing Membranes
Geogrid
Geotechnical Drilling/Boring (Included in Well Drilling Profile)
Geotextile
GFRP Reinforcement and Generic "Reinforcement" (assume in place)
Groundwater, Soil, Balance, CSL, Fiber Optic, Guardrail Terminal, Pile Load, Pressure, Shotcrete, and Other Tests
Grout
Guardrail Anchors, Connections, Height Adjustment, Repair, Transitions
Gusset Plates
Hand Formed Curbs
Hand Holes
Handrails
Hydrants
Imaging Services
Impact Attenuators
Inspections, Various
Install Bird Deterrent Spikes
Install/Remove Monitor Wiring
Interconnect Cables, Related Items (associated with signals)

Bid Item
Irrigation Systems (excluding irrigation pipes)
ITS Installation
Joint Repair/Seal
Kiosk Frame
Lag Bolts
Landscaping
Latex Polymer
LED Signs/Lights
Lenel Card Reader
Light, Illumination
Liquidated Damages (and other items with negative 0 dollars)
Litter Receptacles
Locate Damaged Concrete and Near Surface Metal
Lumber Purchases
Luminaires, Lamps, & Ballasts
Mailbox Concrete Collars
Mailbox Supports
Manhole Slope Protector
Markers, Various Types
Masonry Luminaire Pilasters
Material Acceptance Credit
Matting
Messenger/Restrainer Cable
Metal Sheet Pile Retaining Walls (crane only according to RSMeans)
Methyl Methacrylate
Minor/Major Manhole Adjustment/Removal
Misc. Electrical, Including Communication Raceways
Misc. Labor Billed by the Hour or Day
Misc. Mechanical Work
Mobilization
Modified Urethan Sprayed
Mowing
Non-Grooved Pavement Markings
Nuclear Gauge Testing
Offsite Disposal
Ornamental Protective Screens

Bid Item
Outlet To G-2Ma Inlet
Pack Rust Removal
Paint/Separated Paint
Pajari Readings
Parking Spot Markings/Removal
Patterned Concrete (assume hand installation)
Pavement Legend
Pavement Legend, Bar (assume removed by equipment < 25 hp)
Pavement Line Removal
Pedestrian Buttons
Pedestrian Channelizing Devices
Pedestrian Counter, Crossing Signal, Railing
Pedestrian Landings
Pedestrian Poles
Pedestrian, Access, Pollution Control and Other Plans
Perforated Steel Square Tube Supports
Perimeter Controlled Blast Holes (assumes significant ripping/excavation included in other bid items)
PGE Power Changes
Pile Protection/Rehab Wrap
Pilot Cars
Pipe Anchor
Pipe Fittings
Pipe Sock
Pipe Tees
Pipe Wyes
Plastic Sheeting
Plug Drains
Plural Component (appears to be associated with pavement marking tasks)
Pole Foundations (Cranes Only)
Pollution Control Plans
Polymer Concrete Overlay (scarifyers assumed < 25 hp, polymer application assumed by hand and/or using licensed vehicles)
Portable Changeable Message Signs
Post-Tensioning
Poured Seal/Plug Seal

Bid Item
Powder Coated Steel
Precast Ornamental Concrete
Precast Prestressed Concrete Members (assume cranes only)
Pre-Cast Sound Walls (assume crane only)
Prepare/Install Anodes
Pressure Washing
Price Adjustments
Project Acceleration
Protect Monitoring Wells
Provide Work Access and Containment
Pumps
Purchase of Unused Manhole
Radar Detection/Trailer
Rail/Handrail
Ramp Closure Gate
Realkalinization
Reconnect Existing Water Services/Drains
Reconnect Loop Feeder
Reinhart Modified Bearing Plate
Relocate Water Meter Assembly
Removal of Timber Braces
Remove and Install Plug Joint
Remove and Reinstall Bridge Rail
Remove and Reinstall Existing Signs
Remove Asbestos Material
Remove Bollards/Barriers
Remove Fish Ladder
Remove Non-Essential Near-Surface Metal
Remove Riprap (Crane Only)
Remove Traffic Control Device
Repair Cable
Retrofit Sidewalk Ramps
Reuse Existing Slope Ending
Re-Wash/Remove Mow Strip
Riprap Backing
Rivet and Bolt Replacement
Rock Reinforcing Bolts
Roller Bearing Skirts

Bid Item
Roof Repair
Root Barrier/Barrier Pins
Rootwad Log
RR Advance Warning Kit
Sand Bag Ditch Protection
Sanding Material Removal
Seal Cracks
Sediment Barrier
Seeding (Hydroseeders are PTO)
Seismic Restraint System
Sequential Arrow Signs
Settlement Plates
Shoring/Cofferdams (crane only)
Shot Blast (assume equipment < 25 hp)
Shotcrete
Sidewalk Ramps (assume poured in place)
Sign and Water Quality Equipment Rental
Sign Posts
Signals, Ramp Meters
Signs in Place - Various Types
Sloped End Sections
Smart Work Zone System
Snow Removal (assume licensed vehicle)
Sod Lawn
Soil Sample Collection and Analytical TE
Spall Repair
Span Lock Bolts
Stain Inside of Undercrossing
Staking
Statistical Analysis
Statutory Interest
Steel Pipe Post Sleeves
Steel Weirs
Stone Embankment/Grouted Riprap (assume machine-placed w/ crane)
Storage Costs, Design Costs, Delay Costs, QC Costs, Savings
Storm Drain Repair
Stormwater Filters

Bid Item
Stormwater Planter, Plant Container
Straw Bales/Wattles
Structural Steel Members (crane only)
Subsurface Drainage Outlets
Surface Mounted Tubular Mark
Surface Pipe Installation
Suspensions
Synthetic Fiber Install/Reinforcing
Tack Coat (assume asphalt distributors are PTO)
TCS Shifts
Temporary Drainage Facilities
Temporary Live Load Assemblies
Temporary Plastic Drums
Temporary Protection and Direction of Traffic
Temporary Signs
Thermoplastic Paint
Traffic Signal Maintenance
Traffic Signals
Training
Tree Removal
Tree Watering Bags
Trench Resurfacing
Truncated Domes
Tug Assistance
Turbity Monitoring
Unit Pavers (assume hand installation)
Utility Hanger Softener
Utility Hole Sleeves
Vapor Blast
Vault Modification
Vegetation, Mulch
Vegetative/Water Quality Filter Strips and Planters
Ventilation Fans
Vibration Monitoring
Video Inspection
VMS Sign
Washout Facility
Watering

Bid Item
Waterproofing
Weed Control
Wet Layup System
Wetland Plugs
Wildlife Passage Substrate
Winter Shutdown
Work Zone Isolation

Appendix F – Unassigned ODOT Bid Items and Dollar Value

Table F-1. Unassigned ODOT Bid Items and Dollar Value[440]

Bid Item	Amount
10.17 FOOT PRECAST WINGWALLS	$42,953
12" C900 PIPE	$2,645
12" PIPE BORING	$15,872
17" FULL DEPTH DIGOUT	$15,176
18 INCH AC REMOVAL	$3,532
18" PIPE REPAIR AT MP 39.5	$4,032
1ST RUN VALVE COVER FEE	$312
24-INCH BURIED ACCESS MANWAY FOR	$12,000
252 INCH X 156 INCH STRUCTURAL PLATE	$68,640
3/4 INCH PLATE	$26,000
30 FOOT 4 INCH PRECAST END PANELS	$360,717
33 INCH PCAST PRESTR BOX BM	$523,001
3-TUBE CURB MOUNT RAIL	$168,750
4 FOOT PRECAST PILE CAPS	$191,232
4 INCH - 2 INCH BALLAST AGGREAGATE	$1,799
4 INCH SS LATERAL EXTRA WORK	$1,440
4" GRIND & ACP INLAY	$43,986
448 INCH X 224 INCH STRUCTURAL PLATE ARC	$241,120
48" MH & 8" DIA. X 32' PVC PIPE	$7,565
66-INCH	$1,008,321
6-INCH PERF. MSE WALL FRENCH DRAIN PIPE	$526
7/8" 7 X 7 IWRC STRUCTURAL WIRE ROPE	$5,499
78" PIPE JACKING & CASING GROUT	$94,256
ACCESS VAULT WITH MANWAY AND TEMPORARY	$31,000
ACP REMOVAL	$1,399
ADD EMERGENCY ACCESS	$18,564
ADD GUARD RAIL TRANSITION POSTS	$2,186
ADD INTERIM 180.50(H-1) 6/2/17 (MEM DAY	$550,000
ADD ITEM 6 INCH CMP CONNECT	$601
ADD ITEM BAY 17 ANGLE REPLACE	$2,818
ADD ITEM CORE EXISTING PIPE	$2,359
ADD ITEM COUNTERWEIGHT STEEL	$17,168
ADD ITEM EPOXY INJECT CAPS - OYB	$36,794

Bid Item	Amount
ADD ITEM EXTRA LACING BARS	$69,335
ADD ITEM EXTRA SPAN DRIVE WORK	$72,583
ADD ITEM NEW DRIVEWAY TRANSITION	$870
ADD ITEM OYB NODE 2/3 STEEL REPAIR	$1,881
ADD ITEM OYB NW TRUNNION PLATE	$430
ADD ITEM OYB PIER HOUSE RAIL REHAB	$4,361
ADD ITEM OYB SHARP GRINDING	$2,492
ADD OYB NODE 1-4 FLOOR BEAM GRINDING	$1,113
ADD OYB RAIL GUSSET PLATE / DRAIN HOLE	$924
ADD SINKHOLE REPAIR	$5,180
ADD SLOPE ARMORING	$23,942
ADD: OYB NODE 1 STEEL REPAIR NEAR SUMP	$2,344
ADDED ADA REMOVAL & PREP.	$17,622
ADDED BARRIER @ D185 RAMP	$2,543
ADDED DRAINAGE & SIDEWALK RAMP	$18,001
ADDED DRAINS	$1,283
ADDED GRADING ALONG S. CLA	$4,859
ADDED REBAR BENT 1 & 2	$5,052
ADDED REBAR SW 1	$12,237
ADDED REMOVAL & PREP LANE HOUSE	$9,231
ADDED REMOVAL STRUCTURES & OBSTRUCTIONS	$324
ADDED SAWCUTTING MONOLITH TATTOO	$415
ADDED WATERLINE FEATURES	$20,899
ADDED WORK IN STABILIZED AREA	$2,889
ADDITIONAL ACP REMOVAL	$4,472
ADDITIONAL BARRIER MOVES US26	$23,066
ADDITIONAL CONCRETE WORK	$702
ADDITIONAL GRADING AT PHOENIX AUTO	$1,778
ADDITIONAL SLOPE REMEDIATION COSTS	$5,565
ADDITIONAL STREAM ENHANCEMENT	$2,189
ADD'L DRAINAGE - 147TH AVE.	$1,738
ADD'L DRAINAGE - WENDY LN.	$5,018
ADD'L RMVL., STRUCTURES & OBSTRUCTIONS	$14,414
ADJUSTABLE STEEL PIPE POST CAP	$28,000

[440] Assumed to require nonroad diesel equipment > 25 hp.

Bid Item	Amount
ADJUSTING BOXES	$63,880
AGENCY FURNISHED 36 INCH CULVERT PIPE, 5	$8,520
AGGREGATE	$900
ALL-WEATHER CRUSHED SURFACING	$3,938
ATTACHMENT ON STRUCTURES, MOSIER WATER &	$26,000
BENT 1 AND 4 ADDL CONCRETE & REINFRCMT	$65,796
BENT 5 DRAIN TRAY	$812
BIORETENTION POND	$449,063
BIOSLOPE	$25,000
BIOSLOPE, D01036	$55,780
BOULDERS	$4,000
BR #39C123, ADD'L BR REMOVAL	$860
BRIDGE JACKING	$50,400
BRIDGE JOINT SYSTEM	$65,000
BRIDGE REMOVAL	$2,410,239
BRIDGE SIDEWALK RESURFACING	$37,000
BRIDGE STRUCTURE MOUNTS	$236,500
BROOK AT SOUTH POND	$954
BUMP GRIND & PAVE	$9,684
CASCADE CHUTE MATERIAL	$6,258
CEMENT TREATED HAUL ROAD	$11,921
CHIP EXISTING FOUNDATION	$2,042
CITY PARTICIPATION	$10,500
CLEANING & SWEEPING HIGHWAY	$1,005
CMP PIPE	$1,662
COBBLE INFILL	$586
COMPENSATION FOR BARRIER	$53,784
CONCRETE BUS SHELTER PADS	$2,700
CONCRETE IRRIGATION BOXES	$6,800
CONCRETE JUNCTION BOXES	$7,830
CONCRETE MOMENT SLAB, STRUCTURE NO.	$20,000
CONCRETE MONUMENT BOXES	$2,430
CONCRETE PAD	$6,016
CONCRETE PARAPET, MODIFIED	$42,500
CONCRETE STAIRS	$4,840
CONEX ROCKFALL PROTECTION	$5,100
CONNECT APARTMENT BLDG. STORM	$956

Bid Item	Amount
CONNECTION TO CENTURYLINK UTILITY	$966
CONNECTION TO EXISTING STRUCTURE	$1,389
CONNECTION TO EXISTING STRUCTURES	$10,200
CONNECTION TO EXTG STRUCTURES	$62,145
CONSTRUCT SILVERLEAF ACCESS	$4,241
CONSTRUCTION ENTRANCE, TYPE 1	$58,346
CONSTRUCTION ENTRANCE, TYPE 2	$32,300
CONTROLS AND SUPPORT	$15,679
CORRECT BR 22004 RAIL ENDS	$3,400
CPC ADDITIONAL QUANTITY OF CONCRETE	$2,906
CTB AT CPA LINE	$3,737
DEBRIS REMOVAL	$278
DECOMMISSION HEATING OIL TANKS	$40,000
DEER SB TRUSS EXTENSION	$8,178
DEFORMED BAR REINFORCEMENT 2ND ST.	$1,458
DETERIORATED CORE FILL	$216
DEWATERING	$91,000
DEWATERING 66 INCH LINE	$6,251
DRAIN PIPE ADJUST	$1,932
DRAINAGE CUT - NOT EMBANKED	$14,931
DRAINAGE PIPE ON STRUCTURE	$170,000
DRAINAGE PROFILE CORRECTION	$34,970
DRAINAGE SWALE REMEDIATION	$4,500
DRILL ADDITIONAL MISALIGNED CORBEL HOLE	$1,069
DRILLED SHAFT REINFORCEMENT	$199,000
DRIVE HP 12 X 74 STEEL PILES	$19,800
DRIVE HP 14 X 89 STEEL PILES	$31,200
DRIVE PP 16 X 0.5 STEEL PILES	$63,400
DRIVE PP 20 X 0.5 STEEL PILES	$16,020
EDGE OF DECK REPAIR	$9,159
EMBANKMENT MP45 AND MP48 LINE	$38,138
EMERGENCY ACCESS ROAD	$604
END BENT FALSEWORK	$32,582
ESC STABILIZATION / REPAIR WORK	$31,057
EX FOR TERMINAL EXP JOINT STEEL BEAM	$65,520
EXCAVATOR, 115 HP, 16-18 TON	$5,457
EXIST. FDN. REMOVAL SW1	$981
EXISTING PILE AND NEW STEEL PIPE POST TO	$4,890

Bid Item	Amount
EXTEND CULVERT AT 402+50	$5,279
EXTERNAL COUNTERWEIGHT PLATES	$1,500,000
EXTRA ACCESS	$5,961
EXTRA COST FOR REV POLE #16	$1,424
EXTRA FOR CONCRETE CURB CUTS	$18,400
EXTRA FOR PARALLEL RAMPS	$6,900
EXTRA FOR PAVEMENT REPAIR	$400
EXTRA FOR PERPENDICULAR RAMPS	$10,840
EXTRA FOR PRECAST PILE CAPS, BENTS 1 &	$9,000
EXTRA FOR SALVAGING AND STOCKPILING	$3,000
EXTRA OVERLAY REMOVAL, 08302E	$9,379
EXTRA TO ADJ. "F" 7+24 MH	$2,504
F LINE DITCHING	$3,340
FALL PROTECTION CL-4 FNCE ABV WALL	$4,813
FIBERGLASS POLE ACCESS PADS	$38,539
FILLING HOLES IN EXISTING TIMBER PILES	$2,580
FINISHING ROADBEDS	$31,400
FLOOD WATCH & DITCH REV	$17,263
FURN HP 12 X 53 STEEL PILES	$5,468
FURN HP 12 X 74 STEEL PILES	$40,440
FURN HP 14 X 117 STEEL PILES	$12,750
FURN HP 14 X 89 STEEL PILES	$42,457
FURN PILE DRIVING EQUIPMENT	$90,800
FURN PP 16 X 0.5 STEEL PILES	$101,949
FURN PP 20 X 0.5 STEEL PILES	$32,268
FURNISH DRILLING EQUIPMENT	$309,875
FURNISH DRILLING EQUIPMENT FOR PREBORED	$37,801
FURNISH FISH LOGS	$1,500
FURNISH HP 14 X 89 STEEL PILES	$91,493
FURNISH INTELLIGENT COMPACTION	$19,500
FURNISH PILE DRIVING EQUIPMENT	$44,000
FURNISH PP 16 X 0.375 STEEL PILES	$19,680
FURNISH PP 16 X 0.5 STEEL PILES	$20,518
FURNISH PREBORING EQUIPMENT	$28,000
FURNISH SHEET PILE	$33,525
FURNISH SHEET PILE INSTALLATION	$12,500
FURNISH SILICA FUME CONCRETE	$1
GABION ROCKFALL BARRIER	$23,800

Bid Item	Amount
GENERAL STR. CONCRETE CL 4000	$150,719
GENERAL STRC CONCRETE, CLASS 3300	$584,155
GENERAL STRC CONCRETE, CLASS 4000	$950,921
GENERAL STRC CONCRETE, CLASS 5000	$114,825
GENERAL STRC CONCRETE, CLASS HPC4000	$11,000
GENERAL STRUCTURAL CONCRETE, CLASS 3300	$15,000
GENERAL STRUCTURAL CONCRETE, CLASS 4000	$1,181,000
GRADE REPAIR DAMAGE AT BR 22004	$5,416
GRIND "C" LINE	$2,888
GRIND AND INLAY	$35,625
GRIND BR. #08583 END PANEL	$1,200
GRIND STUMPS	$4,170
GRINDING PLUS UPS	$3,097
HIGH EARLY STRENGTH CONCRETE	$799
HORIZONTAL DRAIN COLLECTION SYSTEM	$18,000
HORIZONTAL DRAIN DISCHARGE PIPE	$2,957
HORIZONTAL DRAINS	$265,932
HP 18 X 157 BEAM	$10,000
IMPACT PANEL REPAIR, BR 22004	$1,994
INSTALL LANDSCAPE WALL	$1,267
INSTALL MODIFIED BMC LIDS	$4,331
INSTALL MONUMENT	$5,000
INSTALL REFERENCE CELLS	$119,200
INSTALL SHEET PILE	$46,800
INTELLIGENT COMPACTION	$260,000
INTERCONNECT BOX ADJUSTMENT	$3,792
JACKING AND BLOCKING	$225,000
JLG 120 HX MANLIFT	$5,876
K&E DRILL PAD PREPARATION	$3,266
LAKESIDE PAVING COSTS	$1,198
LEAD-RUBBER BEARINGS	$96,000
LEVEL 4 RAM REDUCTION	$4,550
LOW DENSITY CELLULAR CONCRETE	$522,605
LOWER GAS LINE OS LINE	$2,551
LOWERING CONDUIT IN JT. UTIL. TRENCH	$5,136
MANOR MEMORIAL	$1,575
MISCELLANEOUS TRACKED WORK	$18,268
MOD CONTROL CAB. INSTALL SITE #7	$324

Bid Item	Amount
MOD WALL REHAB	$3,990
MODIFIED FLUSH MOUNTED COMBINATION	$142,578
MODIFIED HORIZONTAL DRAINS	$12,150
MODIFIED INSTRUMENTATION POST	$18,468
MODIFIED REINFORCED CONCRETE END PANELS	$50,382
MODIFY COUNTERWEIGHT PLATES	$18,105
MODIFY POWER CONNECTIONS	$15,867
MODIFY SEWER VAULT - NBB 138+04	$8,913
MODIFY SMITH ST. WQ SWALE	$652
MODIFY SOUND WALL REINFORCEMENT	$3,005
MODIFY STORM SEWER AT HARBOR ST.	$6,467
MODULAR BRIDGE JOINT SYSTEMS	$150,000
MODULAR COUNTERWEIGHT BLOCKS	$61,425
MOVING & HAULING BOULDERS	$12,992
NETWORK EQUIPMENT INSTALLATION	$34,084
NORTON CREEK BRIDGE EXTRA WORK	$7,958
OAK AVE. BR. REBAR & DRIP CHAMFER	$882
OR58 MP14.4 BMC INSTALLATION, COMPLETE	$8,206
PAD PREP	$996
PARTIAL REMOVAL OF TIMBER PILES	$8,280
PED. RAMP L3, 1/2" ACP PATCHING	$769
PGE ACCESS RD. STA. 2890+00	$14,678
PIPE GRADE ADJUSTMENT	$1,591
PIPE REPAIR AT MP 53.46	$3,571
PIPELINE SHIFT	$20,906
PLANTER WALL	$77,501
PLANTER WALL WITH CURB AND GUTTER	$38,721
POND #3, ORIFICE CORRECTION	$881
POND #6 SLIDE MITIGATION	$5,150
POND #6 SLIDE REPAIR	$11,229
PORTLAND CEMENT	$6
POWER CONNECTION MODIFICATION	$9,256
PRCTS	$651,000
PREBORED PILES	$153,968
PRE-CAST BENT CAPS	$353,363
PRECAST END PANEL	$134,300
PRECAST PILE CAP	$70,020
PRECAST PRESTRESSED DECK PANELS	$561,326
PRECAST SPLIT REINFORCED CONCRETE BOX CU	$317,000
PRECAST WINGWALLS	$31,827
PREP. FOR PCC DWY. CONNECITONS	$4,282
PREPARATION OF SHOULDERS	$32,902
PRESENCE OF BOULDERS	$66,333
PRIVATE WATERLINE REPLACEMENT	$1,594
PROOF TEST NAILS	$14,400
PROVIDE SPECIALTY COATINGS	$9,536
RAIL, WALL & AC REMOVAL	$1,418
RAISE J-2 BOXES US26 MEDIAN	$1,998
RC LINE DITCHING	$660
RECONSTRUCT 3 BEARING SEATS	$110,849
RE-GRADE BR 22001 SLOPE, BENT 1	$6,529
RE-GRADE FISH ROCKS	$1,630
RE-GRADE SWALE 00877	$7,500
REINF CONC BRIDGE END PANELS	$796,719
REINF CONCRETE BOX CULVERTS	$308,181
REINFORCED CONCRETE BOX CULVERTS	$88,290
REINFORCED PILE TIPS	$11,104
REINFORCEMENT FOR CONCRETE WALKS	$49,333
REMOVAL OF BUILDINGS	$83,000
REMOVAL OF BUS STATIONS	$19,000
REMOVAL OF STRUCTURES AND OBSTRUCTIONS	$427,351
REMOVAL OF VAULTS	$9,100
REMOVE & BACKFILL ANCHORS	$24,000
REMOVE & REINSTALL 18" WATERLINE	$8,237
REMOVE & REPLACE FOUNDATION 18D	$2,384
REMOVE ACCESS AT WATERFRONT RD.	$10,450
REMOVE AND REINSTALL EXISTING CONCRETE	$2,214
REMOVE EXIST. ESC MEASURES, STG. 2	$710
REMOVE REBAR / ENLARGE DISSIPATOR	$10,501
REMOVE TBB SUPPORT & FTG.	$6,150
REMOVE TEMPORARY ASPHALT NP 21+00	$2,634
REMV & REPLC SAMP CONC BY ACP	$42,660
REMV OF STR AND OBSTUCTIONS	$857,109
REPAIR CPB SLOPE FAILURE	$11,205
REPAIR DAMAGED CONCRETE RAIL	$97,250

Bid Item	Amount
REPAIR DAMAGED REINFORCING BARS	$9,615
REPAIR SINKHOLE MP 20.62	$10,178
REPAIR SINKHOLE MP 31.44	$25,762
RE-ROOF COVERED BRIDGE 39C123	$90,793
RE-ROOF COVERED BRIDGE 39C650	$171,902
RESETTING BEAM SEAT ELEVS. STG. 2	$19,588
RETAINING WALL REPAIR	$4,523
REVISED PARTLY FILLED GRID DECK	$1,956,824
RIPRAP BASINS	$25,200
RIPRAP CHANNEL	$1,900
RIPRAP DITCH REPAIRS	$24,954
RIPRAP DITCH SLOPE	$2,400
ROCK REMOVAL CMP 2831+50 LT	$1,970
ROCK SLIDE @ MP 61	$19,600
ROUND CUT SLOPES	$3,965
RRVID SIPHON REMOVAL	$10,242
S. JACK BIO. POND EARTHWORK	$2,889
S. SWANSON WING WALL BLOCKOUTS	$3,116
SHEET PILE MODIFICATIONS	$46,643
SHIN PROTECTORS	$252
SHLDR WIDENING NB MP155.75 & SB MP166.3	$1,717
SHOULDER GRADING	$2,436
SITE A BANK MODIFICATIONS	$13,218
SKIM WALL / SILANE APPL. - SPAN 9 & 11	$42,211
SOIL NAIL WALL	$120,387
SPAN 21 FLOORBEAM REPAIR	$2,321
SPAN LOCK MACHINERY REHABILITATION	$75,000
STEEL COUNTERWEIGHT PLATES	$137,442
STEEL MEMBER INCREASE - TBB	$1,216
STEEL REMOVAL	$2,700
STORAGE POND, #6	$3,800
STORAGE POND, PD3	$2,500
STORAGE POND, PD4	$4,950
STORM SEWER ELEVATION MODIFICATIONS	$11,599
STORMWATER RAIN GARDENS	$5,616
STRC PLATE CONC FOOTINGS & HEADWALLS	$173,483
STREAMBED ENHANCEMENT	$226,770
STREAMBED ENHANCEMENT, SWANSON CR NORTH	$22,200

Bid Item	Amount
STREAMBED ENHANCEMENT, SWANSON CR SOUTH	$58,000
STREAMBED ENHANCEMENT, WHETSTONE CR	$29,000
STRUCTURAL CONCRETE 3300	$5,840
STRUCTURE 22004 DECK EDGE REPAIR	$2,215
SURFACE PREPARATION	$5,620,340
SURFACE PREPARATION - FULL COATING	$181,600
TAP WATERLINE REPAIR	$5,576
TBB SIGN SUPPORT LS ADJUST	$1,042
TEMP ACCESS ROAD FOR 22009 BEAMS	$18,750
TEMP WIDENING CPA LINE	$6,226
TEMP WIDENING CPB LINE	$14,931
TEMPORARY ACCESS	$18,750
TEMPORARY ACCESS AT BAVARIAN INN	$492
TEMPORARY BRIDGE	$112,053
TEMPORARY BRIDGE CONNECTIONS	$4,000
TEMPORARY BRIDGE PROTECTION	$1
TEMPORARY COLUMN SUPPORTS	$10,923
TEMPORARY DECK REPAIRS	$66,156
TEMPORARY DETOUR BRIDGE	$49,800
TEMPORARY FALSEWORK TOWERS	$40,000
TEMPORARY SANITARY SEWER DIVERSION	$21,375
TEMPORARY SCOUR BASIN	$1,830
TEMPORARY SHOULDER WIDENING	$6,211
TEMPORARY WORK ACCESS ROADS	$45,531
TEMPORARY WORK BRIDGE - EXISTING BRIDGE	$75,000
TEMPORARY WORK BRIDGE - NEW BRIDGE	$15,000
TEMPORARY WORK BRIDGES	$196,845
TEMPORARY WORK PLATFORM	$465,867
TERMINAL TRANSITION PANELS WITH TEJ	$18,900
TITANIUM ALLOY REINFORCEMENT SYSTEM	$11,500
TRANSFORMER PAD RELOCATION	$8,316
TRENCH DRAIN	$6,406
TRENCH DRAIN ENDS	$6,700
TRENCH DRAIN, TYPE 1	$4,575
TRENCH DRAIN, TYPE 2	$17,640
TRUNNION COLLAR STRENGTHENING	$190,800
TUNNELING, BORING, & JACKING	$2,500

Bid Item	Amount
TYPE "F" CONC RAIL, MODIFIED	$59,180
TYPE "F" CONCRETE RAIL	$155,073
TYPE "F" CONCRETE RAIL, RETROFIT	$100,000
ULTRA HIGH PERFORMANCE CONCRETE	$135,000
ULTRA HIGH PERFORMANCE CONCRETE, CLASS	$530,000
US26 EAGLE BABY EXTRA DRILLING	$31,943
US26-D DEER WB SITE CHANGES	$12,230
USPS MODIFICATIONS	$89,850
UTILITY ATTACHMENT ON STR	$18,000
UTILITY ATTACHMENT ON STRUCTURES, CENTUR	$33,000
UTILITY ATTACHMENT ON STRUCTURES, CHENOW	$17,000
UTILITY CONFL. @ STR. #21633	$1,622
UTILITY DUCT BANK REPAIRS	$3,526
VERIFICATION TEST NAILS	$10,500
WALL DRAINAGE SYSTEM	$8,000
WASHINGTON AVE. BR. CONDUIT BORE	$6,898
WATER QUALITY SWALE	$580,852
WATERWAY ENHANCEMENT	$125,000
WATERWAY ENHANCEMENT REWORK	$844
WB VMS CAB. FOUNDATION CHANGES	$7,539
WEDGE REM. / PERM. WEDGE CONST.	$11,479
WINGWALL EXTENSIONS, BRIDGE #4	$56,212
WINGWALLS AND APRONS	$70,150
Total	**$34,821,098**

Appendix G – County-Level Emission Summary Tables

**Table G-1. County Level Summer Weekday CAP and GHG Emissions - Tons/Day
2017 Nonroad Diesel Equipment Study**

County	CO	NO_x	$PM_{2.5}$	VOCs	CO_{2e}
Baker	0.66	1.19	0.086	0.117	146
Benton	0.53	1.02	0.072	0.094	157
Clackamas	1.11	2.08	0.153	0.206	314
Clatsop	0.43	0.89	0.057	0.074	148
Columbia	0.35	0.74	0.047	0.061	124
Coos	0.44	0.89	0.058	0.077	138
Crook	0.43	0.80	0.057	0.076	108
Curry	0.25	0.49	0.032	0.043	75
Deschutes	0.72	1.36	0.103	0.136	201
Douglas	1.22	2.38	0.159	0.209	365
Gilliam	0.22	0.45	0.031	0.038	76
Grant	0.31	0.55	0.040	0.054	66
Harney	1.05	1.84	0.137	0.185	208
Hood River	0.22	0.40	0.029	0.039	52
Jackson	0.73	1.40	0.101	0.134	215
Jefferson	0.24	0.43	0.032	0.043	53
Josephine	0.16	0.31	0.022	0.029	49
Klamath	0.80	1.47	0.105	0.143	188
Lake	0.85	1.51	0.110	0.149	178
Lane	1.37	2.70	0.185	0.243	435
Lincoln	0.31	0.64	0.041	0.053	106
Linn	1.27	2.35	0.166	0.222	323
Malheur	1.07	1.88	0.140	0.190	216
Marion	1.32	2.43	0.177	0.239	331
Morrow	0.92	1.63	0.120	0.162	194
Multnomah	1.32	2.47	0.193	0.258	398
Polk	0.61	1.14	0.080	0.107	158
Sherman	0.11	0.20	0.015	0.020	24
Tillamook	0.45	0.88	0.059	0.078	131
Umatilla	1.01	1.81	0.134	0.181	220
Union	0.40	0.73	0.053	0.071	93
Wallowa	0.34	0.62	0.044	0.060	76

County	CO	NO_x	$PM_{2.5}$	VOCs	CO_{2e}
Wasco	0.35	0.64	0.047	0.062	84
Washington	1.31	2.44	0.185	0.247	386
Wheeler	0.11	0.19	0.014	0.018	22
Yamhill	0.77	1.42	0.102	0.137	192
Total	**23.77**	**44.35**	**3.185**	**4.259**	**6,253**

Table G-2. County Level Summer Weekday CAP and GHG Emissions – Percentage 2017 Nonroad Diesel Equipment Study

County	CO	NO_x	$PM_{2.5}$	VOCs	CO_{2e}
Baker	2.79%	2.69%	2.71%	2.75%	2.33%
Benton	2.23%	2.31%	2.25%	2.22%	2.52%
Clackamas	4.66%	4.68%	4.80%	4.84%	5.03%
Clatsop	1.82%	2.02%	1.79%	1.75%	2.36%
Columbia	1.48%	1.67%	1.46%	1.43%	1.99%
Coos	1.86%	2.00%	1.82%	1.80%	2.20%
Crook	1.81%	1.80%	1.79%	1.79%	1.73%
Curry	1.04%	1.11%	1.01%	1.01%	1.19%
Deschutes	3.04%	3.06%	3.23%	3.20%	3.22%
Douglas	5.12%	5.36%	5.00%	4.92%	5.84%
Gilliam	0.92%	1.00%	0.98%	0.90%	1.22%
Grant	1.30%	1.24%	1.26%	1.27%	1.06%
Harney	4.43%	4.15%	4.29%	4.35%	3.32%
Hood River	0.92%	0.90%	0.90%	0.91%	0.84%
Jackson	3.08%	3.15%	3.18%	3.15%	3.45%
Jefferson	1.02%	0.98%	1.01%	1.02%	0.84%
Josephine	0.66%	0.70%	0.68%	0.68%	0.78%
Klamath	3.38%	3.31%	3.31%	3.35%	3.01%
Lake	3.57%	3.41%	3.45%	3.50%	2.84%
Lane	5.76%	6.09%	5.79%	5.71%	6.96%
Lincoln	1.30%	1.44%	1.28%	1.25%	1.69%
Linn	5.33%	5.30%	5.22%	5.21%	5.17%
Malheur	4.51%	4.24%	4.38%	4.45%	3.46%
Marion	5.54%	5.48%	5.57%	5.61%	5.29%

County	CO	NO_x	$PM_{2.5}$	VOCs	CO_{2e}
Morrow	3.86%	3.67%	3.77%	3.80%	3.10%
Multnomah	5.56%	5.56%	6.06%	6.05%	6.37%
Polk	2.57%	2.58%	2.51%	2.51%	2.53%
Sherman	0.48%	0.46%	0.47%	0.48%	0.39%
Tillamook	1.90%	1.98%	1.85%	1.84%	2.09%
Umatilla	4.27%	4.08%	4.20%	4.24%	3.51%
Union	1.70%	1.65%	1.66%	1.67%	1.49%
Wallowa	1.44%	1.39%	1.40%	1.41%	1.22%
Wasco	1.47%	1.44%	1.46%	1.46%	1.35%
Washington	5.50%	5.50%	5.81%	5.81%	6.18%
Wheeler	0.44%	0.42%	0.43%	0.43%	0.35%
Yamhill	3.24%	3.20%	3.21%	3.21%	3.07%

Table G-3. County Level Annual CAP and GHG Emissions – Percentage
2017 Nonroad Diesel Equipment Study

County	CO	NO_x	$PM_{2.5}$	VOCs	CO_{2e}
Baker	2.54%	2.44%	2.46%	2.48%	2.12%
Benton	2.26%	2.33%	2.27%	2.23%	2.55%
Clackamas	5.00%	5.00%	5.15%	5.21%	5.35%
Clatsop	1.93%	2.15%	1.89%	1.85%	2.44%
Columbia	1.59%	1.81%	1.56%	1.54%	2.12%
Coos	1.91%	2.06%	1.86%	1.84%	2.24%
Crook	1.72%	1.72%	1.71%	1.71%	1.68%
Curry	1.05%	1.14%	1.02%	1.02%	1.21%
Deschutes	3.42%	3.42%	3.62%	3.59%	3.54%
Douglas	5.15%	5.39%	5.01%	4.92%	5.81%
Gilliam	0.93%	1.02%	0.99%	0.90%	1.25%
Grant	1.17%	1.11%	1.13%	1.14%	0.94%
Harney	3.91%	3.64%	3.76%	3.82%	2.85%
Hood River	0.89%	0.87%	0.87%	0.88%	0.80%
Jackson	3.30%	3.36%	3.40%	3.37%	3.66%
Jefferson	0.95%	0.91%	0.94%	0.95%	0.78%
Josephine	0.70%	0.74%	0.72%	0.72%	0.82%

County	CO	NO_x	$PM_{2.5}$	VOCs	CO_{2e}
Klamath	3.19%	3.14%	3.11%	3.15%	2.85%
Lake	3.20%	3.07%	3.08%	3.13%	2.52%
Lane	6.16%	6.47%	6.19%	6.11%	7.30%
Lincoln	1.39%	1.55%	1.36%	1.34%	1.77%
Linn	5.13%	5.09%	5.01%	5.00%	4.94%
Malheur	4.04%	3.77%	3.91%	3.97%	3.03%
Marion	5.45%	5.40%	5.48%	5.53%	5.25%
Morrow	3.46%	3.28%	3.37%	3.39%	2.74%
Multnomah	6.85%	6.77%	7.43%	7.42%	7.56%
Polk	2.46%	2.48%	2.40%	2.40%	2.43%
Sherman	0.43%	0.41%	0.42%	0.43%	0.34%
Tillamook	1.91%	2.01%	1.85%	1.84%	2.08%
Umatilla	3.91%	3.72%	3.83%	3.88%	3.18%
Union	1.58%	1.53%	1.54%	1.55%	1.38%
Wallowa	1.31%	1.26%	1.27%	1.27%	1.10%
Wasco	1.38%	1.36%	1.38%	1.37%	1.27%
Washington	6.21%	6.14%	6.56%	6.57%	6.84%
Wheeler	0.40%	0.37%	0.38%	0.38%	0.31%
Yamhill	3.12%	3.08%	3.08%	3.08%	2.97%

Appendix H – Background on MOVES Data Sources

Background on MOVES Data Sources

A primary goal of the study is to replace EPA's MOVES default data with locally-collected information to characterize the activity and emissions of Oregon's nonroad diesel equipment more accurately. Understanding the data sources, assumptions, and uncertainties associated with the MOVES default data provides critical context when comparing the study findings for each sector.

The MOVES default data for diesel-powered nonroad equipment operating in different states, counties and analysis years are processed by the model in three steps.

- Estimates for national nonroad equipment population and characteristics are used to set modeling parameters for the base year (2000);
- Equipment populations are distributed to states and counties for the base year; and,
- Growth factors are applied to the base year populations to determine the equipment profile for the evaluation year of interest (i.e., 2017 for this study).

MOVES begins the emissions modeling process with a national-level equipment assessment for calendar year 2000 for diesel-powered applications. The national assessment is largely derived from Power Systems Research (PSR) databases. PSR provided EPA with equipment populations by type, annual usage rates, engine characteristics, load factors and average useful life estimates. EPA then made modifications to the PSR-based assumptions in some instances.[441, 442] The PSR population estimates are not derived from surveys or field inventories, but are developed using proprietary algorithms based on sales figures, usage and assumed useful life.

Next, MOVES apportions the national population values for the base year to the state level by applying spatial allocation factors, usually at the nonroad sector level (e.g., each state's fraction of total harvested acreage for agriculture equipment). Other parameters for activity, engine load, relative distribution within equipment categories, engine power distribution and useful life remain fixed at the national-average level. In other words, population is the only equipment-related default parameter that is specific to Oregon within MOVES.[443]

Oregon's share of the national diesel-powered equipment population for the 2000 base year is summarized in Table H-1 by sector. The state's estimated share of the national equipment population ranges from 0 percent (for the underground mining sector) to 4.8 percent (for the logging sector) in the base year. Each share represents the proportion of the national total

[441] "Nonroad Engine Population Estimates," EPA-420-R-10-017, NR-006e, U.S. Environmental Protection Agency, July 2010.

[442] "Median Life, Annual Activity, and Load Factor Values for Nonroad Engine Emissions Modeling," EPA-420-R-10-016, NR-005d, U.S. Environmental Protection Agency, July 2010.

[443] "Geographic Allocation of Nonroad Engine Population Data to the State and County Level," EPA420-R-05-021, NR-014d, U.S. Environmental Protection Agency, December 2005.

defined by each allocation factor. Taking logging as an example, 4.8 percent of the national volume of wood harvest product (less residues) occurred in Oregon in 2000.

Table H-1. Oregon's Share of the National MOVES Equipment Population 2017 Nonroad Diesel Equipment Study

Sector	Equipment Types	Oregon Share	Spatial Allocation Factor
Agriculture	All	1.0%	Harvested acreage
Airport ground support	All	1.0%	Aircraft NO_x Emissions‡
Commercial	All	1.3%	Number of wholesale establishments
Construction/mining	All	1.3%	Construction valuation (dollars)
Industrial	All	1.3%	Employees in manufacturing sector
Lawn and garden*	Snowblowers	2.6%	Number of landscaping / horticulture employees in counties with 15" snowfall
Lawn and garden*	All others	1.2%	Number of landscaping / horticulture employees
Logging	All	4.8%	Volume of wood harvest product less residues
Oil field	All	0.06%	Number of employees in oil & gas extraction
Rail maintenance	All	0.9%	Locomotive NO_x Emissions‡
Recreational vehicles	All	1.2%	Motorcycle Industry Council data
Recreational marine	All	1.3%	Oak Ridge National Lab "non-highway gasoline use" model
Underground mining	All	n/a†	Underground coal mining tons

* All diesel-powered lawn and garden applications are assumed to be commercially owned and operated.
† No underground mining operations in Oregon.
‡ Emissions compiled in EPA's National Emission Inventory for 2002.

State-level equipment populations for the base year are then projected forward or backward in time to represent other calendar years using "growth" factors. These population adjustments are applied at the nonroad sector level. MOVES relies on two groups of growth factors – "historical" data and "future year" projections. In MOVES2014b, the period covered by historical data runs through 2014. The model relies on future year projections for model years beyond 2014.[444] The historical and future year growth factors are applied by MOVES to

[444] For modeling years other than the base year, equipment populations are adjusted. All other modeling parameters including activity, engine load, distribution by equipment type (within each sector), engine power distribution (within each equipment type) and useful life are set equal to national averages.

generate the evaluation year equipment populations of interest and are summarized in Tables H-2 and H-3, respectively.[445]

Table H-2. Growth Factors in MOVES, Years 2000 – 2014
2017 Nonroad Diesel Equipment Study

Nonroad Sector	Allocation Scale	Data Source	Allocation Factor
Agriculture	State	EIA's *Fuel Oil and Kerosene Sales*†	Fuel sales to farm consumers
Airport grounds support	State	FAA Terminal Area Forecasts	Number of commercial aviation operations
Commercial	State	Bureau of Economic Analysis	GDP from multiple economic sectors
Construction/mining	State	EIA's *Fuel Oil and Kerosene Sales*†	Fuel sales to off-highway (construction) consumers
Industrial	State	Bureau of Economic Analysis	GDP from multiple economic sectors
Lawn and garden	State	U.S. Census Bureau	Number of landscaping services establishments
Logging	State	EIA's *Fuel Oil and Kerosene Sales*†	Fuel sales to off-highway (non-construction) consumers
Oil field	State	EIA's *Fuel Oil and Kerosene Sales*†	Sales to oil company consumers
Rail maintenance	National	ORNL's *Transportation Energy Data Book*	Revenue ton miles
Recreational vehicles	State	U.S. Census Bureau	Human population
Recreational marine	State	National Marine Manufacturers Association	Boat registrations
Underground mining	State	EIA's *Fuel Oil and Kerosene Sales*†	Fuel sales to industrial consumers

† For Fuel Oil and Kerosene Sales (FOKS), EPA used a 5-year rolling average in MOVES; FOKS data are also a validation resource for this project and their application is discussed in Section 7.

[445] "Nonroad Engine Population Growth Estimates in MOVES2014b," EPA-420-R-18-010, U.S. Environmental Protection Agency, July 2018.

Table H-3. MOVES Growth Factors, Years 2014 – 2040
2017 Nonroad Diesel Equipment Study

Equipment Sector	Allocation Scale*	Data Source	Allocation Factor
Agriculture	Census region	EIA's *Annual Energy Outlook*	Energy consumption (agriculture sector)
Airport ground support	State	FAA Terminal Area Forecasts	Number of commercial aviation operations
Commercial	State	Moody's Analytics	Economy-wide GDP
Construction/mining	Census region	EIA's *Annual Energy Outlook*	Energy consumption (construction sector)
Industrial	State	Moody's Analytics	GDP from warehousing sector
Lawn and garden	State	U.S. Census Bureau	Human population
Logging	Census region	EIA's *Annual Energy Outlook*	Energy consumption (other agriculture sector)
Oil field	Census region	EIA's *Annual Energy Outlook*	Energy consumption (oil and gas mining sector)
Rail maintenance	National	EIA's *Annual Energy Outlook*	Revenue ton-miles
Recreational vehicles	State	U.S. Census Bureau	Human population
Recreational marine	National	EIA's *Annual Energy Outlook*	Fuel consumption (recreational marine)
Underground mining	Census region	EIA's *Annual Energy Outlook*	Energy consumption (sum of specific mining sectors)

* Oregon is in the Census region that also includes AK, AZ, CA, CO, HI, ID, MT, NV, NM, UT, WA and WY.

The allocation factors used for the commercial and industrial sectors are especially broad and include industries likely to have minimal equipment use such as real estate, and oil/gas production (which is minimal for Oregon). Accordingly, the growth factors for these sectors may be particularly uncertain.

Table H-4 summarizes the MOVES estimates for the Oregon diesel equipment population for the 2000 base year and the 2017 evaluation year. The growth from the base year is also presented. According to MOVES the total number of nonroad engines grew 41 percent from just under 60 thousand in 2000 to just over 84 thousand in 2017. For comparison, the human population of the state grew by 21 percent over this same period.[446] Therefore according to MOVES the nonroad engine population is estimated to increase at twice the rate of population

[446] From 3.436 to 4.141 million. July 1st populations from "Population Estimates and Reports", Portland State University, College of Urban & Public Affairs, https://www.pdx.edu/prc/population-reports-estimates, data accessed January 2020.

growth over the 17-year period. The growth rate for the Commercial sector of 7 percent per year is particularly questionable, considering the time period includes the Great Recession.

Table H-4. Oregon Diesel Equipment Population (> 25 hp) - MOVES Defaults 2017 Nonroad Diesel Equipment Study

Sector	Equipment Population		Percent Change
	2000	2017	
Agriculture	18,511	20,658	12%
Airport ground support	140	178	27%
Commercial	8,226	17,398	111%
Construction/mining	21,101	29,352	39%
Industrial	4,648	8,157	75%
Lawn and garden	1,974	3,429	74%
Logging	1,090	1,361	25%
Oil field	5	2	-56%
Rail maintenance	92	111	21%
Recreational vehicles	207	247	19%
Recreational marine	3,699	3,432	-7%
Underground mining	0	0	n/a
Nonroad Total	**59,693**	**84,325**	**41%**

The MOVES default fuel consumption estimates also provide a key point of comparison for the study. MOVES calculates diesel consumption by summing over all equipment types and engine hp bins as shown in Equation H-1.

$$Diesel\left(\frac{\text{gal}}{\text{yr}}\right) = \sum \frac{Pop \times Activity\left(\frac{\text{hrs}}{\text{yr}}\right) \times Rating(\text{hp}) \times Load \times BSFC\left(\frac{\text{lb}}{\text{hp-hr}}\right)}{7.0\left(\frac{\text{lb}}{\text{gal}}\right)} \qquad \text{Equation H-1}$$

Where:

Pop = equipment population

Activity = annual hours of use

Rating = engine rated power (hp)

Load = mean load factor (fraction of maximum hp) observed during operation

BSFC = Brake-specific fuel consumption, lbs of fuel consumed per unit work (lb/hp-hr)[447]

7.0 = density of diesel (lbs/gal)

[447] BSFC is a measure of fuel efficiency and is a MOVES model variable.

The study developed values for equipment population, activity, rated engine hp and (in some instances) the engine load parameters used in Equation H-1 for numerous industry sectors and equipment types. The fuel consumption estimates shown in Tables 6-10 through 6-12 in the report allow for an evaluation of the collective impact of these four parameters.