Appendix E

Emissions Inventory Methodology and Results

A. Background

In this appendix, ARB staff provides background on the in-use off-road diesel vehicles inventory that would be subject to the proposed regulation and a general overview of the methodologies used to estimate the emissions from these off-road equipment.

The off-road diesel vehicles that would be subject to the regulation, are mobile (self-propelled) and contain engines at or greater than 25 horsepower. They can be found in 4 categories within ARB's off-road diesel inventory: Airport Ground Support Equipment (GSE), Construction & Mining, Industrial and Oil Drilling. Table 1 shows the equipment types in each off-road category, and their statewide population in 2000 and 2005.

Table 1: Categories and Equipment Types Included in the Emissions Inventory

Category	Equipment	2000 Pop	2005 Pop
Airport Ground Support	A/C Tug Narrow Body	238	267
	A/C Tug Wide Body	59	66
	Baggage Tug	479	538
	Belt Loader	231	260
	Bobtail	17	19
	Cargo Loader	282	317
	Cargo Tractor	44	49
	Forklift	39	44
	Lift	52	58
	Other GSE	93	105
Airport Ground Support Total		1,534	1,724
Construction and Mining	Bore/Drill Rigs	1,133	1,244
	Cranes	2,208	2,425
	Crawler Tractors	14,698	16,137
	Excavators	17,630	19,356
	Graders	6,178	6,783
	Off-Highway Tractors	2,935	3,223
	Off-Highway Trucks	2,145	2,357
	Other Construction Equip	879	965
	Pavers	2,695	2,959
	Paving Equipment	530	582
	Rollers	7,121	7,818
	Rough Terrain Forklifts	6,171	6,775
	Rubber Tired Dozers	774	850
	Rubber Tired Loaders	17,839	19,586
	Scrapers	1,859	2041
	Skid Steer Loaders	26,540	29,138
	Surfacing Equipment	113	124

	Tractors/Loaders/Backhoes	27,932	30,668
	Trenchers	7,625	8,371
Construction and Mining Total		147,005	161,403
Industrial	Aerial Lifts	5,057	5,341
	Forklifts	4,868	5,142
	Other General Industrial Equip	4,538	4,793
	Other Material Handling Equip	227	240
Industrial Total		14,690	15,516
Oil Drilling	Drill Rig (Mobile)	20	20
	Workover Rig (Mobile)	1,001	1,001
Oil Drilling Total		1,021	1,021
Grand Total		164,250	179,663

Mobile off-road diesel vehicles in use today are a significant source of diesel particulate matter (PM) emissions and oxides of nitrogen (NOx) emissions in California. ARB staff is undertaking this proposed rule-making effort to require reductions in emissions from diesel equipment in these four categories. To support that rule-making and to assist in understanding the impacts from any proposed rule, it is necessary to have a detailed emissions inventory for the specific types of off-road diesel equipment used statewide.

B. EMISSION CALCULATION METHODOLOGY

In this section, ARB staff provides a discussion of the methodology used to obtain the mobile in-use off-road diesel vehicle emissions inventory.

The annual emissions inventory for each equipment type is estimated using ARB's OFFROAD2007 model. Based on data incorporated from the MacKay & Company Construction Equipment Universe Study (2003), ARB's Off-Road Diesel Equipment Survey (2005), TIAX Public Fleet Survey (2003), ARB's Off-Road Mini-Survey (2006), Yengst & Associates Equipment Analysis Reports (2003-2005), U.S Environmental Protection Agency's NONROAD model, and additional input gathered from stakeholders (2004-2006), ARB staff have updated a number of assumptions in the OFFROAD2007 model for this proposed regulatory effort.

Below, we provide a more detailed discussion of the methodology used to estimate the off-road diesel equipment emission inventory, including the assumptions and data inputs used.

1. Methodology for Estimating Emissions

The emissions inventory is calculated by Equation 1:

Equation 1: Emissions in tons/day = EF * Pop * AvgHp * Load * Activity

Where: AvgHp = Maximum rated average horsepower
Load = Load factor

Activity = Annual activity in hours per year (hr/yr)
EF = Emission factor in grams per horsepower-hour (g/hp-hr)
Pop = Population

Emission factors are composed of zero-hour emissions and deterioration rates. The emission factors can be expressed by the following equations.

For CHrs <= 12,000 hours:

Equation 2: EF = Zh + dr * CHrs

For CHrs > 12,000 hours:

Equation 3: EF = Zh + dr * 12,000

Where: EF = emission factor, in grams per horsepower-hour (g/hp-hr)
Zh =zero-hour emission rate or when the vehicle is new (g/hp-hr)
dr = deterioration rate or the increase in zero-hour emissions as the vehicle is used (g/hp-hr^2)
CHrs = cumulative hours or total number of hours accumulated on the vehicle; maximum value is equal to 12,000 hours

2. Emissions Inventory Inputs

a) Population

In the OFFROAD2007 model, year 2000 is the base year for the population. The model both forecasts and backcasts from the base year to obtain inventory estimates from 1940 to 2040.

(1) Airport Ground Support (GSE)

For the Airport Ground Support (GSE) category, the statewide population of equipment was originally based on data from the "1997 GSE Survey" sponsored by the Air Transport Association (ATA). ARB staff has updated the populations based on a more data provided by the ATA (2004). As a result, the total mobile GSE population increased by approximately 10%.

Since the 2004 ATA data did not clearly distinguish between narrow- and wide-body aircraft tugs, many airlines reported all of their aircraft tugs as narrow-body. As a result, the updated GSE population of narrow- and wide-body A/C tugs was revised maintaining the previous percentage split.

Table 2 shows the updated equipment populations for GSE equipment subject to the proposed regulation.[1]

[1] The GSE category contains 6 equipment types (Catering Truck, Fuel Truck, Hydrant Truck, Lav Truck, Service Truck and Sweeper) that are not subject to the proposed regulation because they are on-road

Table 2: Mobile Off-Road Diesel GSE Equipment (>25hp) Statewide Population (2000)

Equipment	OFFROAD Population	
	Old	New
A/C Tug Narrow Body	226	238
A/C Tug Wide Body	56	59
Baggage Tug	479	479
Belt Loader	231	231
Bobtail	17	17
Cargo Loader	282	282
Cargo Tractor	5	44
Forklift	26	39
Lift	19	52
Other GSE	48	93
TOTAL	1,389	1,534

(2) Construction and Mining

For the Construction and Mining category, the statewide population of equipment was originally based on data from the MacKay & Company's 1999 Construction Equipment Universe Study and nationwide sales data from Power Systems Research (1996). The nationwide data was aggregated to California based on the dollar value of construction, which was approximately 11% of the national total. ARB staff has updated these equipment populations based on data from the most recent MacKay & Company's Construction Equipment Universe Study (2003), ARB's Off-Road Diesel Equipment Survey (2005), and Power Systems Research (2000) via U.S Environmental Protection Agency's NONROAD model. As a result, the total mobile construction and mining population decreased by approximately 8%. Table 3 shows the updated equipment populations for Construction and Mining equipment subject to the proposed regulation.

vehicles; these equipment types are included in the OFFROAD2007 model, but were removed from the inventory in support of this rule.

Table 3: Diesel Construction/Mining Equipment (>25hp) Statewide Population (2000)

Equipment	OFFROAD Population	
	Old	New
Bore/Drill Rigs	1,099	1,133
Cranes	2,406	2,208
Crawler Tractors	25,486	14,698
Excavators	13,593	17,630
Graders	6,510	6,178
Off-Highway Tractors	2,936	2,935
Off-Highway Trucks	2,147	2,145
Other Construction Equip	880	879
Pavers	2,601	2,695
Paving Equipment	3,676	530
Rollers	7,121	7,121
Rough Terrain Forklifts	5,779	6,171
Rubber Tired Dozers	775	774
Rubber Tired Loaders	17,653	17,839
Scrapers	1,859	1,859
Skid Steer Loaders	24,257	26,540
Surfacing Equipment	114	113
Tractors/Loaders/Backhoes	33,805	27,932
Trenchers	7,092	7,625
TOTAL	159,789	147,005

(3) Industrial

For the Industrial category, the statewide population of equipment was originally based on data from nationwide sales data from Power Systems Research (1996). ARB staff has updated these equipment populations based on more recent sales data from Power Systems Research (2000) via U.S. EPA NONROAD model. As a result, the total mobile industrial population increased by approximately 90%. Table 4 shows the updated equipment populations for the mobile off-road diesel Industrial category subject to the proposed regulation.[2]

[2] Sweepers/Scrubbers are not subject to the proposed regulation because they are on-road vehicles; these equipment types are included in the OFFROAD2007 model, but were removed from the inventory in support of this rule.

Table 4: Diesel Industrial Equipment (>25hp) Statewide Population (2000)

Equipment	OFFROAD Population	
	Old	New
Aerial Lifts	1,127	5,056
Forklifts	5,006	4,869
Other Material Handling Equip	267	227
Other General Industrial Equip	1,337	4,538
TOTAL	7,738	14,690

(4) Oil Drilling

For the Oil Drilling category, the statewide population was originally based on data from ARB's Portable Equipment Registration Database (2004). This is a voluntary registration program provided by the state as an alternate method of obtaining an operational permit for off-road portable engines. All equipment in this category was considered to be portable equipment; thus not subject to the proposed regulation. However, as a result of ARB's Off-Road Diesel Equipment Survey (2005) in combination with input from stakeholders and industry (Nabors Drilling), staff added two new equipment types to the Oil Drilling category: Mobile Drill Rig and Mobile Workover Rig. These two equipment types have a combined 2000 population of 1,021. Table 5 shows the updated equipment populations for the mobile off-road diesel Oil Drilling category subject to the proposed regulation.[3]

Table 5: Diesel Oil Drilling Equipment (>25hp) Statewide Population (2000)

Equipment	OFFROAD Population	
	Old	New
Drill Rig (Mobile)	0	20
Workover Rig (Mobile)	0	1,001
TOTAL	0	1,021

b) Average Horsepower

For the Construction and Mining, Industrial and Oil Drilling categories, the maximum fleet average horsepower utilized by OFFROAD2007 model are based on data from the Power Systems Research (1996) database. For the GSE category, the maximum fleet

[3] The Oil Drilling category contains several equipment types (Compressors, Generator, Lift, Other Workover Equipment, Pressure Washers, Pumps, Snubbing and Swivel) that are not subject to the proposed regulation because they are considered to be portable equipment; these equipment types are included in the OFFROAD2007 model, but were removed from the inventory in support of this rule.

average horsepower are based on data provided by ATA from their “1997 GSE Survey”. The average horsepower was assumed to be constant by calendar year based on the assumption that the power demand for a particular piece of equipment does not change over time.

Table 6 contains the various input factors, including average horsepower, from the OFFROAD2007 model used to estimate emissions.

Table 6: OFFROAD2007 Model Input Factors

Category	Equipment	Max HP[4]	Year 2000 Pop	Useful Life (years)	AvgHP	Load Factor	Activity at Average Age (hrs/yr)
Airport Ground Support	A/C Tug Narrow Body	250	238	30	178	0.80	625
	A/C Tug Wide Body	500	59	30	332	0.80	759
	Baggage Tug	120	479	25	71	0.55	1,392
	Belt Loader	120	231	22	54	0.50	974
	Bobtail	120	17	22	113	0.55	683
	Cargo Loader	120	282	18	101	0.50	906
	Cargo Tractor	120	44	17	88	0.54	1,309
	Forklift	175	39	16	156	0.30	743
	Lift	120	52	16	115	0.50	791
	Other GSE	175	93	22	140	0.50	922
Airport Ground Support Total			1,534				
Construction and Mining	Bore/Drill Rigs	50	131	10	33	0.75	811
		120	402	10	82	0.75	811
		175	93	10	150	0.75	811
		250	80	10	200	0.75	811
		500	178	10	331	0.75	811
		750	93	10	654	0.75	811
		1000	156	10	987	0.75	811
	Cranes	50	34	19	43	0.43	1,252
		120	373	19	93	0.43	1,252
		175	373	19	149	0.43	1,252
		250	723	19	208	0.43	1,252
		500	265	19	334	0.43	1,252
		750	195	19	562	0.43	1,252
		9999	245	19	1,800	0.43	1,252
	Crawler Tractors	50	14	29	31	0.64	1,013
		120	7,943	29	82	0.64	1,013
		175	2,688	29	151	0.64	1,013
		250	2,310	29	207	0.64	1,013

[4] The maximum horsepower is the top end of the horsepower group shown. For example, 50 means 26-50 hp; 120 means 51-120 hp; 175 means 121-175 hp, etc.

Category	Equipment	Max HP[4]	Year 2000 Pop	Useful Life (years)	AvgHP	Load Factor	Activity at Average Age (hrs/yr)
		500	1,583	29	323	0.64	1,013
		750	80	29	579	0.64	1,013
		1000	80	29	820	0.64	1,013
	Excavators	50	1,393	17	35	0.57	1,396
		120	3,783	17	103	0.57	1,396
		175	7,298	17	157	0.57	1,396
		250	2,968	17	222	0.57	1,396
		500	2,141	17	327	0.57	1,396
		750	47	17	542	0.57	1,396
	Graders	50	14	23	36	0.61	929
		120	934	23	98	0.61	929
		175	3,191	23	162	0.61	929
		250	1,980	23	225	0.61	929
		500	56	23	300	0.61	929
		750	3	23	635	0.61	929
	Off-Highway Tractors	120	1	31	115	0.65	1,091
		175	1,223	31	160	0.65	1,091
		250	1,156	31	160	0.65	1,091
		750	502	31	697	0.65	1,091
		1000	53	31	999	0.65	1,091
	Off-Highway Trucks	175	65	17	175	0.57	1,958
		250	480	17	233	0.57	1,958
		500	676	17	381	0.57	1,958
		750	629	17	618	0.57	1,958
		1000	295	17	874	0.57	1,958
	Other Construction Equipment	50	86	16	36	0.62	690
		120	142	16	104	0.62	690
		175	196	16	137	0.62	690
		250	0	16	206	0.62	690
		500	455	16	327	0.62	690
		750	0	16	624	0.62	690
		9999	0	16	1,197	0.62	690
	Pavers	50	872	26	36	0.62	821
		120	1,028	26	89	0.62	821
		175	639	26	165	0.62	821
		250	77	26	250	0.62	821
		500	79	26	300	0.62	821
	Paving Equipment	50	22	24	36	0.53	829
		120	317	24	82	0.53	829
		175	149	24	152	0.53	829
		250	42	24	184	0.53	829

Category	Equipment	Max HP[4]	Year 2000 Pop	Useful Life (years)	AvgHP	Load Factor	Activity at Average Age (hrs/yr)
	Rollers	50	787	20	37	0.56	695
		120	4,225	20	84	0.56	695
		175	1,699	20	154	0.56	695
		250	241	20	218	0.56	695
		500	169	20	312	0.56	695
	Rough Terrain Forklifts	50	111	16	45	0.60	1,123
		120	5,316	16	83	0.60	1,123
		175	681	16	166	0.60	1,123
		250	38	16	227	0.60	1,123
		500	25	16	341	0.60	1,123
	Rubber Tired Dozers	175	10	32	175	0.59	1,589
		250	245	32	248	0.59	1,589
		500	377	32	358	0.59	1,589
		750	133	32	539	0.59	1,589
		1000	9	32	800	0.59	1,589
	Rubber Tired Loaders	50	272	21	46	0.54	957
		120	7,395	21	87	0.54	957
		175	4,168	21	157	0.54	957
		250	4,145	21	220	0.54	957
		500	1,725	21	350	0.54	957
		750	121	21	717	0.54	957
		1000	13	21	877	0.54	957
	Scrapers	120	39	26	104	0.72	1,092
		175	357	26	164	0.72	1,092
		250	348	26	232	0.72	1,092
		500	958	26	356	0.72	1,092
		750	157	26	615	0.72	1,092
	Skid Steer Loaders	50	17,415	13	37	0.55	834
		120	9,125	13	62	0.55	834
	Surfacing Equipment	50	20	22	25	0.45	446
		120	4	22	113	0.45	446
		175	3	22	152	0.45	446
		250	6	22	239	0.45	446
		500	50	22	392	0.45	446
		750	30	22	615	0.45	446
	Tractors/Loaders/Backhoes	50	1,685	18	44	0.55	942
		120	22,538	18	75	0.55	942
		175	1,682	18	147	0.55	942
		250	544	18	249	0.55	942
		500	878	18	500	0.55	942
		750	605	18	750	0.55	942

Category	Equipment	Max HP[4]	Year 2000 Pop	Useful Life (years)	AvgHP	Load Factor	Activity at Average Age (hrs/yr)
	Trenchers	50	3,007	28	35	0.75	618
		120	4,075	28	69	0.75	618
		175	446	28	153	0.75	618
		250	40	28	237	0.75	618
		500	51	28	331	0.75	618
		750	6	28	624	0.75	618
Construction and Mining Total			147,005				
Industrial	Aerial Lifts	50	2,517	16	34	0.46	384
		120	2,231	16	66	0.46	384
		500	286	16	369	0.46	384
		750	23	16	667	0.46	384
	Forklifts	50	763	12	39	0.30	1,800
		120	1,197	12	83	0.30	1,800
		175	1,203	12	149	0.30	1,800
		250	1,194	12	205	0.30	1,800
		500	511	12	295	0.30	1,800
	Other General Industrial Equipment	50	244	16	34	0.51	1,425
		120	976	16	97	0.51	1,425
		175	979	16	150	0.51	1,425
		250	975	16	212	0.51	1,425
		500	973	16	415	0.51	1,425
		750	243	16	684	0.51	1,425
		1000	148	16	875	0.51	1,425
	Other Material Handling Equipment	50	7	16	41	0.59	1,318
		120	42	16	82	0.59	1,318
		175	45	16	165	0.59	1,318
		250	107	16	196	0.59	1,318
		500	20	16	259	0.59	1,318
		9999	6	16	1,002	0.59	1,318
Industrial Total			14,690				
Oil Drilling	Drill Rig (Mobile)	50	2	38	33	0.75	3,000
		120	7	38	82	0.75	3,000
		175	2	38	150	0.75	3,000
		250	1	38	200	0.75	3,000
		500	3	38	331	0.75	3,000
		750	2	38	654	0.75	3,000
		1000	3	38	987	0.75	3,000
	Workover Rig (Mobile)	50	116	38	33	0.75	3,000
		120	355	38	82	0.75	3,000
		175	82	38	150	0.75	3,000
		250	71	38	200	0.75	3,000

Category	Equipment	Max HP[4]	Year 2000 Pop	Useful Life (years)	AvgHP	Load Factor	Activity at Average Age (hrs/yr)
		500	157	38	331	0.75	3,000
		750	82	38	654	0.75	3,000
		1000	138	38	987	0.75	3,000
Oil Drilling Total			1,020				

c) Engine Load Factor

The load factor is the average operational level in a given application as a percent of the engine manufacturer's maximum horsepower rating. Each engine in a specific application is assumed to operate for the average annual number of hours at the average load factor. The load factor in the OFFROAD2007 model is used to adjust the maximum rated horsepower to normal operative horsepower levels. These load factors were obtained from the Power Systems Research (1996) database.

Table 6 contains the various input factors, including engine load factor, from the OFFROAD2007 model used to estimate emissions.

d) Activity

The activity or annual use is measured in annual average use hours and varies by category and equipment type. Table 6 contains the various input factors, including activity, from the OFFROAD2007 model used to estimate emissions.

(1) Construction and Mining

For the Construction and Mining category, the activity was originally based on data from the MacKay & Company's 1999 Construction Equipment Universe Study and nationwide sales data from Power Systems Research (1996). The activity in the OFFROAD2007 model was updated using recent data from the MacKay & Company's Construction Equipment Universe Study (2003), TIAX Survey of Public Fleets (2003) and ARB's Off-Road Diesel Equipment Survey (2005). Table 7 shows the activity by equipment and the data source used.

Table 7: Diesel Construction and Mining Annual Activity

Equipment	Activity (hrs/yr)	Source[5]
Bore/Drill Rigs	811	MacKay
Cranes	1,252	MacKay
Crawler Tractors	1,013	Surveys
Excavators	1,396	Surveys
Graders	929	MacKay
Off-Highway Tractors	1,091	Surveys
Off-Highway Trucks	1,958	MacKay
Other Construction Equipment	690	Surveys
Pavers	821	MacKay
Paving Equipment	829	MacKay
Rollers	695	MacKay
Rough Terrain Forklifts	1,123	MacKay
Rubber Tired Dozers	1,589	Surveys
Rubber Tired Loaders	957	Surveys
Scrapers	1,092	Surveys
Skid Steer Loaders	834	MacKay
Surfacing Equipment	446	Surveys
Tractors/Loaders/Backhoes	942	Surveys
Trenchers	618	MacKay

Originally, the activity for Construction & Mining equipment in the OFFROAD model was assumed to be constant throughout the life of the equipment. However, results from the MacKay & Company's Construction Equipment Universe Study (2003) in addition to anecdotal information from stakeholders and industry indicated that equipment is used less as it ages. ARB staff has updated the OFFROAD2007 model for construction and mining equipment to reflect this trend. For each equipment type, the percent decline in annual use starting from brand new to its median useful life, shown in Table 8, was obtained from the MacKay & Company's Construction Equipment Universe Study (2003). The annual use at the average age (one half the useful life) was set as the average annual use, and then the MacKay & Company's derived percent decline was used to determine the slope of a line passing through this average annual use for the period from age 0 to median useful life. After the median useful life, the annual use is assumed to remain constant. The annual use trend is illustrated in Figure 1.

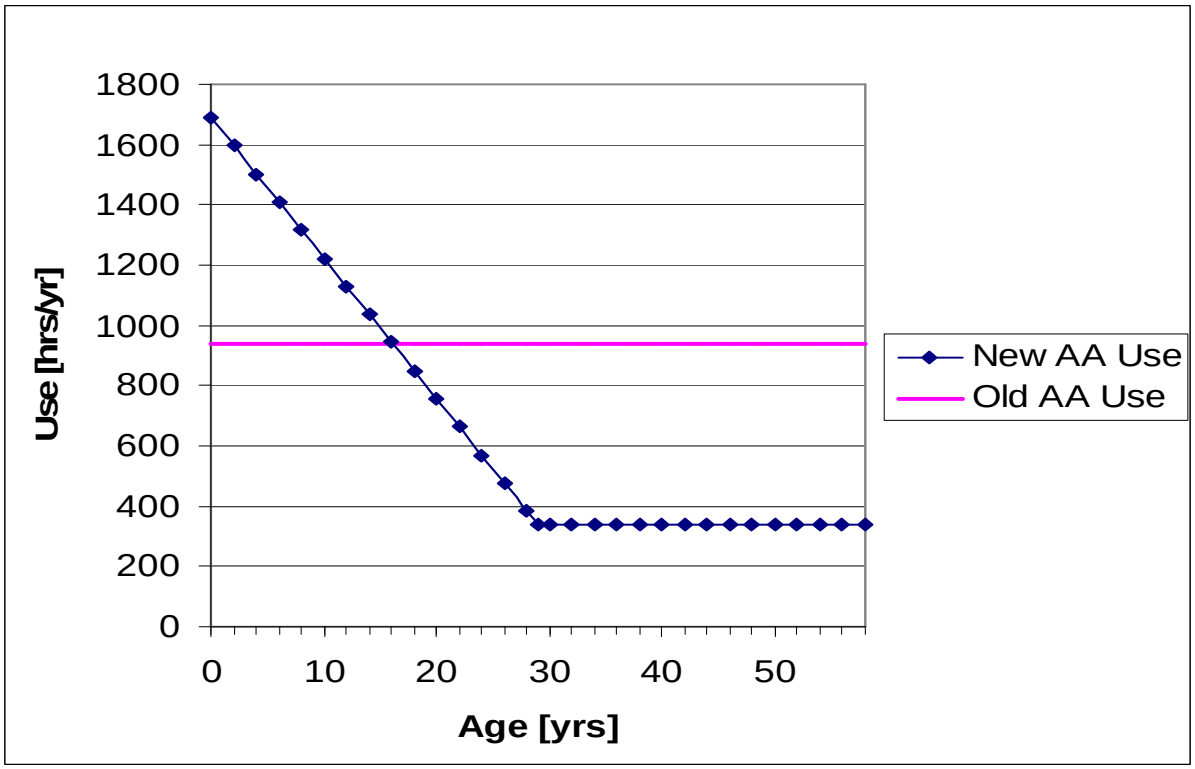
[5] "MacKay" means average annual use is average annual hours of operation reported in the MacKay & Company's Construction Equipment Universe Study (2003); "Surveys" means average annual use from combined data from the TIAX Survey of Public Fleets (2003) and ARB's Off-Road Diesel Equipment Survey (2005).

Table 8: Construction and Mining Equipment Percent of Decline in Usage

Equipment Type	% Decline[6]
Bore/Drill Rig	86%
Crane	30%
Crawler Tractor	80%
Excavator	65%
Grader	79%
Off-Hwy Tractor	59%
Off-Hwy Truck	57%
Other Const Equip	59%
Paver	53%
Paving Equip	38%
Roller	41%
Rough Terrain Forklift	34%
Rubber Tired Dozer	59%
Rubber Tired Loader	69%
Scraper	61%
Skid Steer Loader	67%
Surfacing Equip	59%
Tractor/Loader/Backhoe	81%
Trencher	61%

[6] Percent Decline in Usage are from MacKay & Company's Construction Equipment Universe Study (2003). Since not all equipment are included in the MacKay (2003) Study, the average usage percent decline was used for the following equipment types: Off-Hwy Tractor, Other Construction Equipment, Rubber Tired Dozer and Surfacing Equipment.

Figure 1: Construction and Mining Equipment Average Annual Usage Trend (Example for Equipment with Useful Life = 29 years)



(2) Airport Ground Support (GSE)

For the GSE category, the activity was originally based on nationwide sales data from Power Systems Research (1996). The activity in the OFFROAD2007 model the data sources used to update the activity were ARB's Off-Road Diesel Equipment Survey (2005) and data provided by the ATA (2004). Since no data was reported for A/C Tug Wide Body, the activity remained the same for that equipment type. Table 9 shows the updated activity by equipment type.

Table 9: Airport Ground Support (GSE) Annual Activity (hrs/yr)

Equipment	Activity (hrs/yr)
A/C Tug Narrow Body	625
A/C Tug Wide Body	759
Baggage Tug	1,392
Belt Loader	974
Bobtail	683
Cargo Loader	906
Cargo Tractor	1,309
Forklift	743
Lift	791
Other GSE	922

(3) Industrial

For the Industrial category, the activity was originally based on nationwide sales data from Power Systems Research (1996). The ARB's Off-Road Diesel Equipment Survey (2005) was used to update the activity in the OFFROAD2007 model. The activity for Aerial Lifts and Forklifts remained unchanged due to an insufficient response rate[7] in the survey for those two equipment types. Table 10 shows the updated activity by equipment type and source.

Table 10: Industrial Equipment Annual Activity (hrs/yr)

Equipment	Activity (hrs/yr)	Source
Aerial Lifts	384	PSR
Forklifts	1,800	PSR
Other General Industrial Equip	1,425	Survey
Other Material Handling Equip	1,318	Survey

(4) Oil Drilling

For the Oil Drilling category, the activity was based on input from stakeholders and industry along with data from ARB's Off-Road Diesel Equipment Survey (2005). Table 11 shows the activity by equipment type.

[7] Insufficient response from the survey is deemed when the data represents less than 10% of the total population for a particular equipment type.

Table 11: Oil Drilling Annual Activity (hrs/yr)

Equipment	Activity (hrs/yr)
Drill Rig (Mobile)	3,000
Workover Rig (Mobile)	3,000

e) Useful Life

The useful life is the age at which the survival curve shows a point of inflection equivalent to when half of the units of a certain model year will have been scrapped. At the age equal to twice the useful life, all equipment will have been scrapped. In this inventory, the useful life is defined as the life of the engine, which is assumed to be the same as the life of the equipment. Engine rebuilds are accounted for in the deterioration rate cap at 12,000 hours, however this inventory assumes that there are no re-powers. The original useful life was based on nationwide sales data from Power Systems Research (1996) and had a maximum value of 16 years, such that the equipment would live at most to twice that value or 32 years. Based on discussions with stakeholders and industry, the useful life in the OFFROAD2007 model was updated to more accurately reflect the age of equipment presently in use today. The updated useful life has a maximum value of 38 years, such that the longest equipment would ever live would be to twice that value (i.e.,76 years).

(1) Construction and Mining

Based on discussions with stakeholders and industry, staff concluded that the useful life of equipment in the Construction and Mining category was underestimated, that is, that equipment actually lasted longer than was reflected in the old OFFROAD model. Using data from the MacKay & Company Construction Equipment Universe Study (2003), ARB's Off-Road Diesel Equipment Survey (2005), TIAX Public Fleet Survey (2003), and ARB's Off-Road Mini-Survey (2006)[8], the useful life was updated to more accurately reflect the age of equipment presently in use today. There is a set relationship between the average age of equipment and its useful life based on the normal distribution of ages of equipment in the inventory. Equipment with a long useful life has a high average age; equipment with a short useful life turns over quickly and thus has a low average age. The average age of equipment is equal to approximately one half of the useful life. Based on this relationship, the useful life was updated in the OFFROAD2007 model to equal twice the average age of equipment present in the field, as shown in Table 12.

[8] ARB's Off-Road Mini-Survey (2006) gathered data on the average age of equipment, by equipment type, of 13 fleets. In combination with age data from the TIAX Public Fleet Survey (2003), over 5,000 pieces of equipment were represented.

Table 12: Construction and Mining Useful Life (years)

Equipment	Useful Life[9] (Years)	Source[10]
Bore/Drill Rigs	10	MacKay
Skid Steer Loaders	13	MacKay
Rough Terrain Forklifts	16	MacKay
Other Construction Equip	16	Survey
Excavators	17	MacKay
Off-Highway Trucks	17	MacKay
Tractors/Loaders/Backhoes	18	MacKay
Cranes	19	MacKay
Rollers	20	MacKay
Rubber Tired Loaders	21	MacKay
Surfacing Equipment	22	Survey
Graders	23	MacKay
Paving Equipment	24	Survey
Pavers	26	Survey
Scrapers	26	MacKay
Trenchers	28	Survey
Crawler Tractors	29	Survey
Off-Highway Tractors	31	Survey
Rubber Tired Dozers	32	Survey

(2) Airport Ground Support (GSE)

For the GSE category, the useful life was originally based on nationwide sales data from Power Systems Research (1996). Based on ARB's Off-Road Diesel Equipment Survey (2005) and data provided by the ATA Survey (2004), the useful life was updated to equal twice the average age reported[11]. Table 13 shows the updated useful by equipment type.

[9] The useful life shown is the median useful life, the age at which 50% of vehicles have died. In the model, at most, vehicles live to twice the median useful life.

[10] "MacKay" means twice the average age as reported in the MacKay & Company's Construction Equipment Universe Study (2003) was used as the equipment useful life; "Survey" means twice the average age from the TIAX Survey of Public Fleets (2003) and ARB's Off-Road Mini-Survey (2006) was used as the equipment useful life.

[11] GSE useful life was updated using ATA Survey (2004) if the survey represented at least 25% of the equipment population statewide. If response for a particular equipment type was inadequate in both the ATA Survey (2004) and ARB's Off-Road Diesel Equipment Survey (2005), the useful life was not changed.

Table 13: Airport Ground Support (GSE) Useful Life (years)

Equipment	Useful Life (Years)	Source
A/C Tug Narrow Body	30	ATA Survey
A/C Tug Wide Body	30	ATA Survey
Baggage Tug	25	ATA Survey
Belt Loader	22	ATA Survey
Bobtail	22	ATA Survey
Cargo Loader	18	ATA Survey
Cargo Tractor	17	ATA Survey
Forklift	16	No Change
Lift	16	ATA Survey
Other	22	ATA Survey

(3) Industrial

For the Industrial category, the useful life was originally based on nationwide sales data from Power Systems Research (1996). Upon review of the data obtained from ARB's Off-Road Diesel Equipment Survey (2005), staff determined that the reported average age data by equipment type matched well with the current useful life. As a result, the useful life for equipment types in the Industrial category remained unchanged, and are shown in Table 14.

Table 14: Industrial Equipment Useful Life (years)

Equipment	Useful Life (Years)
Aerial Lifts	16
Forklifts	12
Other General Industrial Equip	16
Other Material Handling Equip	16

(4) Oil Drilling

For the Oil Drilling category, the useful life was based on input from stakeholders and industry along with data from ARB's Off-Road Diesel Equipment Survey (2005). Table 15 shows the useful life for the Oil Drilling category by equipment type.

Table 15: Oil Drilling Useful Life (years)

Equipment	Useful Life (Years)
Drill Rig (Mobile)	38
Workover Rig (Mobile)	38

f) Emission Factors

Emission factors are composed of zero-hour emission rates[12] and deterioration rates. The emission factors can be expressed by the following equations.

For cumulative hours (CHrs) <= 12,000 hours:

Equation 4: EF = Zh + dr * CHrs

For cumulative hours (CHrs) > 12,000 hours:

Equation 5: EF = Zh + dr * 12,000

Where: EF = emission factor, in grams per horsepower-hour (g/bhp-hr)
Zh = zero-hour emission rate or when the equipment is new (g/bhp-hr)
dr = deterioration rate or the increase in zero-hour emissions as the equipment is used (g/bhp-hr^2)
CHrs = cumulative hours or total number of hours accumulated on the equipment; maximum value is equal to 12,000 hours

The diesel emission factors in the OFFROAD2007 model are in grams per brake horsepower-hour and vary by fuel type, horsepower group and model year as shown in Table 16.

[12] Section I-G of ARB's Mail-Out#: MSC 99-32 contains a more detailed discussion of how each emission rate is derived for Tier 0 or uncontrolled, through Tier 3. The Tier 4 emission rates were adopted December 7, 2005, as detailed in "Amendments to the California Exhaust Emission Standards and Test Procedures for New 2008 and Later Tier 4 Off-Road Compression-Ignition Engines and Equipment, Part 1-C" **(http://www.arb.ca.gov/regact/offrdcie/offrdcie.htm)**

Table 16: OFFROAD2007 Model Diesel Emission Factors (g/bhp-hr)

HP	Year	HC ZH (g/bhp-hr)	HC DR (g/bhp-hr^2)	CO ZH (g/bhp-hr)	CO DR (g/bhp-hr^2)	NOX ZH (g/bhp-hr)	NOX DR (g/bhp-hr^2)	PM ZH (g/bhp-hr)	PM DR (g/bhp-hr^2)
50	1987	1.84	2.35E-04	5.00	5.13E-04	7.00	1.05E-04	0.76	5.89E-05
50	1998	1.80	2.30E-04	5.00	5.13E-04	6.90	1.04E-04	0.76	5.89E-05
50	2003	1.45	1.85E-04	4.10	4.20E-04	5.55	1.03E-04	0.60	4.65E-05
50	2004	0.64	9.80E-05	3.27	3.34E-04	5.10	9.33E-05	0.43	3.36E-05
50	2005	0.37	6.90E-05	3.00	3.05E-04	4.95	9.67E-05	0.38	2.93E-05
50	2007	0.24	5.45E-05	2.86	2.90E-04	4.88	9.83E-05	0.35	2.72E-05
50	2012	0.10	4.00E-05	2.72	2.76E-04	4.80	1.00E-04	0.16	1.22E-05
50	2040	0.10	4.00E-05	2.72	2.76E-04	2.90	6.04E-05	0.01	1.11E-06
120	1987	1.44	6.66E-05	4.80	1.27E-04	13.00	3.01E-04	0.84	6.11E-05
120	1997	0.99	4.58E-05	3.49	9.23E-05	8.75	2.02E-04	0.69	5.02E-05
120	2003	0.99	4.58E-05	3.49	9.23E-05	6.90	1.60E-04	0.69	5.02E-05
120	2004	0.46	3.33E-05	3.23	8.55E-05	5.64	1.03E-04	0.39	2.85E-05
120	2005	0.28	2.92E-05	3.14	8.33E-05	5.22	8.40E-05	0.29	2.12E-05
120	2007	0.19	2.71E-05	3.09	8.21E-05	5.01	7.45E-05	0.24	1.76E-05
120	2011	0.10	2.50E-05	3.05	8.10E-05	2.89	3.80E-05	0.20	1.45E-05
120	2012	0.09	2.31E-05	3.05	8.10E-05	2.53	3.33E-05	0.07	4.69E-06
120	2014	0.09	2.31E-05	3.05	8.10E-05	2.53	3.33E-05	0.01	9.33E-07
120	2040	0.07	1.74E-05	3.05	8.10E-05	1.40	1.84E-05	0.01	9.33E-07
175	1969	1.32	6.11E-05	4.40	1.16E-04	14.00	3.24E-04	0.77	5.60E-05
175	1971	1.10	5.09E-05	4.40	1.16E-04	13.00	3.01E-04	0.66	4.80E-05
175	1979	1.00	4.63E-	4.40	1.16E-	12.00	2.78E-	0.55	4.00E-

HP	Year	HC ZH (g/bhp-hr)	HC DR (g/bhp-hr^2)	CO ZH (g/bhp-hr)	CO DR (g/bhp-hr^2)	NOX ZH (g/bhp-hr)	NOX DR (g/bhp-hr^2)	PM ZH (g/bhp-hr)	PM DR (g/bhp-hr^2)
			05		04		04		05
175	1984	0.94	4.35E-05	4.30	1.14E-04	11.00	2.54E-04	0.55	4.00E-05
175	1987	0.88	4.07E-05	4.20	1.11E-04	11.00	2.54E-04	0.55	4.00E-05
175	1996	0.68	3.15E-05	2.70	7.14E-05	8.17	1.89E-04	0.38	2.76E-05
175	2002	0.68	3.15E-05	2.70	7.14E-05	6.90	1.60E-04	0.38	2.76E-05
175	2003	0.33	2.79E-05	2.70	7.14E-05	5.26	9.64E-05	0.24	1.70E-05
175	2004	0.22	2.63E-05	2.70	7.14E-05	4.72	7.52E-05	0.19	1.35E-05
175	2006	0.16	2.57E-05	2.70	7.14E-05	4.44	6.46E-05	0.16	1.18E-05
175	2011	0.10	2.50E-05	2.70	7.14E-05	2.45	3.20E-05	0.14	1.00E-05
175	2014	0.09	2.17E-05	2.70	7.14E-05	2.27	2.96E-05	0.01	4.67E-07
175	2040	0.05	1.17E-05	2.70	7.14E-05	0.27	3.56E-06	0.01	4.67E-07
250	1969	1.32	6.11E-05	4.40	1.16E-04	14.00	3.24E-04	0.77	5.60E-05
250	1971	1.10	5.09E-05	4.40	1.16E-04	13.00	3.01E-04	0.66	4.80E-05
250	1979	1.00	4.63E-05	4.40	1.16E-04	12.00	2.78E-04	0.55	4.00E-05
250	1984	0.94	4.35E-05	4.30	1.14E-04	11.00	2.54E-04	0.55	4.00E-05
250	1987	0.88	4.07E-05	4.20	1.11E-04	11.00	2.54E-04	0.55	4.00E-05
250	1995	0.68	3.15E-05	2.70	7.14E-05	8.17	1.89E-04	0.38	2.76E-05
250	2002	0.32	1.48E-05	0.92	2.43E-05	6.25	1.45E-04	0.15	7.96E-06
250	2003	0.19	2.09E-05	0.92	2.43E-05	5.00	9.05E-05	0.12	6.51E-06
250	2004	0.14	2.30E-05	0.92	2.43E-05	4.58	7.23E-05	0.11	6.03E-06
250	2006	0.12	2.40E-05	0.92	2.43E-05	4.38	6.33E-05	0.11	5.79E-06
250	2010	0.10	2.50E-05	0.92	2.43E-05	2.45	3.18E-05	0.11	5.59E-06
250	2013	0.07	1.83E-	0.92	2.43E-	1.36	1.77E-	0.01	4.55E-

HP	Year	HC ZH (g/bhp-hr)	HC DR (g/bhp-hr^2)	CO ZH (g/bhp-hr)	CO DR (g/bhp-hr^2)	NOX ZH (g/bhp-hr)	NOX DR (g/bhp-hr^2)	PM ZH (g/bhp-hr)	PM DR (g/bhp-hr^2)
			05		05		05		07
250	2040	0.05	1.17E-05	0.92	2.43E-05	0.27	3.56E-06	0.01	4.55E-07
500	1969	1.26	4.39E-05	4.20	8.32E-04	14.00	2.33E-04	0.74	3.93E-05
500	1971	1.05	3.66E-05	4.20	8.32E-04	13.00	2.16E-04	0.63	3.34E-05
500	1979	0.95	3.31E-05	4.20	8.32E-04	12.00	2.00E-04	0.53	2.81E-05
500	1984	0.90	3.14E-05	4.20	8.32E-04	11.00	1.83E-04	0.53	2.81E-05
500	1987	0.84	2.93E-05	4.10	8.12E-04	11.00	1.83E-04	0.53	2.81E-05
500	1995	0.68	2.37E-05	2.70	5.35E-05	8.17	1.36E-04	0.38	2.02E-05
500	2000	0.32	1.12E-05	0.92	1.82E-05	6.25	1.04E-04	0.15	7.96E-06
500	2001	0.19	1.95E-05	0.92	1.82E-05	4.95	7.34E-05	0.12	6.51E-06
500	2002	0.14	2.22E-05	0.92	1.82E-05	4.51	6.32E-05	0.11	6.03E-06
500	2004	0.12	2.36E-05	0.92	1.82E-05	4.29	5.81E-05	0.11	5.79E-06
500	2005	0.10	2.50E-05	0.92	1.82E-05	4.00	5.30E-05	0.11	5.55E-06
500	2010	0.10	2.50E-05	0.92	1.82E-05	2.45	3.18E-05	0.11	5.55E-06
500	2013	0.07	1.83E-05	0.92	1.82E-05	1.36	1.77E-05	0.01	4.55E-07
500	2040	0.05	1.17E-05	0.92	1.82E-05	0.27	3.56E-06	0.01	4.55E-07
750	1969	1.26	4.39E-05	4.20	8.32E-04	14.00	2.33E-04	0.74	3.93E-05
750	1971	1.05	3.66E-05	4.20	8.32E-04	13.00	2.16E-04	0.63	3.34E-05
750	1979	0.95	3.31E-05	4.20	8.32E-04	12.00	2.00E-04	0.53	2.81E-05
750	1984	0.90	3.14E-05	4.20	8.32E-04	11.00	1.83E-04	0.53	2.81E-05
750	1987	0.84	2.93E-05	4.10	8.12E-04	11.00	1.83E-04	0.53	2.81E-05
750	1995	0.68	2.37E-05	2.70	5.35E-05	8.17	1.36E-04	0.38	2.02E-05
750	2001	0.32	1.12E-	0.92	1.82E-	6.25	1.04E-	0.15	7.96E-

HP	Year	HC ZH (g/bhp-hr)	HC DR (g/bhp-hr^2)	CO ZH (g/bhp-hr)	CO DR (g/bhp-hr^2)	NOX ZH (g/bhp-hr)	NOX DR (g/bhp-hr^2)	PM ZH (g/bhp-hr)	PM DR (g/bhp-hr^2)
			05		05		04		06
750	2002	0.19	1.95E-05	0.92	1.82E-05	4.95	7.34E-05	0.12	6.51E-06
750	2003	0.14	2.22E-05	0.92	1.82E-05	4.51	6.32E-05	0.11	6.03E-06
750	2005	0.12	2.36E-05	0.92	1.82E-05	4.29	5.81E-05	0.11	5.79E-06
750	2010	0.10	2.50E-05	0.92	1.82E-05	2.45	3.18E-05	0.11	5.55E-06
750	2013	0.07	1.83E-05	0.92	1.82E-05	1.36	1.77E-05	0.01	4.55E-07
750	2040	0.05	1.17E-05	0.92	1.82E-05	0.27	3.56E-06	0.01	4.55E-07
1000	1969	1.26	4.39E-05	4.20	8.32E-04	14.00	2.33E-04	0.74	3.93E-05
1000	1971	1.05	3.66E-05	4.20	8.32E-04	13.00	2.16E-04	0.63	3.34E-05
1000	1979	0.95	3.31E-05	4.20	8.32E-04	12.00	2.00E-04	0.53	2.81E-05
1000	1984	0.90	3.14E-05	4.20	8.32E-04	11.00	1.83E-04	0.53	2.81E-05
1000	1987	0.84	2.93E-05	4.10	8.12E-04	11.00	1.83E-04	0.53	2.81E-05
1000	1999	0.68	1.12E-05	2.70	5.35E-05	8.17	1.36E-04	0.38	2.02E-06
1000	2005	0.32	1.12E-05	0.92	1.82E-05	6.25	1.04E-04	0.15	7.96E-06
1000	2006	0.19	1.95E-05	0.92	1.82E-05	4.95	7.34E-05	0.12	6.51E-06
1000	2007	0.14	2.22E-05	0.92	1.82E-05	4.51	6.32E-05	0.11	6.03E-06
1000	2009	0.12	2.36E-05	0.92	1.82E-05	4.29	5.81E-05	0.11	5.79E-06
1000	2010	0.10	2.50E-05	0.92	1.82E-05	4.08	5.30E-05	0.11	5.55E-06
1000	2014	0.07	1.83E-05	0.92	1.82E-05	2.36	3.06E-05	0.06	2.78E-06
1000	2040	0.05	1.17E-05	0.92	1.82E-05	2.36	3.06E-05	0.02	1.11E-06
9999	1969	1.26	4.39E-05	4.20	8.32E-04	14.00	2.33E-04	0.74	3.93E-05
9999	1971	1.05	3.66E-05	4.20	8.32E-04	13.00	2.16E-04	0.63	3.34E-05
9999	1979	0.95	3.31E-	4.20	8.32E-	12.00	2.00E-	0.53	2.81E-

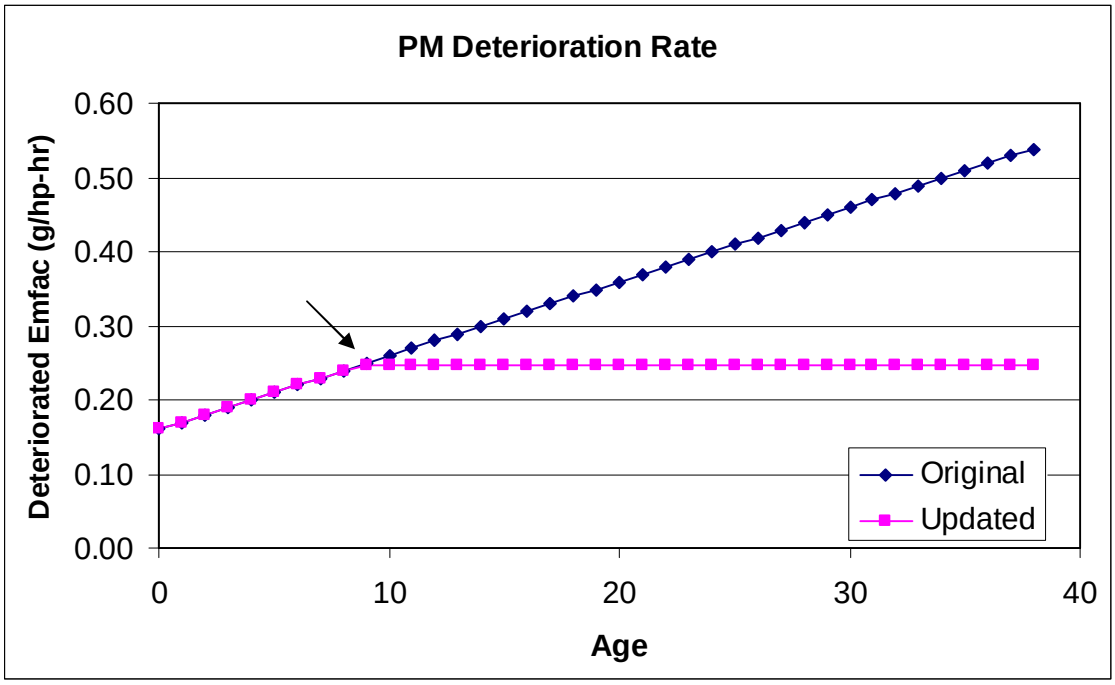
HP	Year	HC ZH (g/bhp-hr)	HC DR (g/bhp-hr^2)	CO ZH (g/bhp-hr)	CO DR (g/bhp-hr^2)	NOX ZH (g/bhp-hr)	NOX DR (g/bhp-hr^2)	PM ZH (g/bhp-hr)	PM DR (g/bhp-hr^2)
			05		04		04		05
9999	1984	0.90	3.14E-05	4.20	8.32E-04	11.00	1.83E-04	0.53	2.81E-05
9999	1987	0.84	2.93E-05	4.10	8.12E-04	11.00	1.83E-04	0.53	2.81E-05
9999	1999	0.68	1.12E-05	2.70	5.35E-05	8.17	1.36E-04	0.38	2.02E-06
9999	2005	0.32	1.12E-05	0.92	1.82E-05	6.25	1.04E-04	0.15	7.96E-06
9999	2006	0.19	1.95E-05	0.92	1.82E-05	4.95	7.34E-05	0.12	6.51E-06
9999	2007	0.14	2.22E-05	0.92	1.82E-05	4.51	6.32E-05	0.11	6.03E-06
9999	2009	0.12	2.36E-05	0.92	1.82E-05	4.29	5.81E-05	0.11	5.79E-06
9999	2010	0.10	2.50E-05	0.92	1.82E-05	4.08	5.30E-05	0.11	5.55E-06
9999	2014	0.10	2.50E-05	0.92	1.82E-05	2.36	3.06E-05	0.06	2.78E-06
9999	2040	0.05	1.17E-05	0.92	1.82E-05	2.36	3.06E-05	0.02	1.11E-06

g) Emission Factor Deterioration

Deterioration rates[13] are in units of grams per brake horsepower-hour2 and are defined as the change in emissions as a function of usage. These are based on the deterioration rates of on-highway diesel-powered engines with similar horsepower ratings. The rate of emissions changes over time as a result of wear on various parts of an engine due to use. Originally, the deterioration rate continued to increase throughout the entire useful life of the equipment. Based on discussions with stakeholders and industry, staff concluded that the deterioration for off-road diesel equipment was over-estimated because diesel engines are rebuilt after approximately 12,000 hours of use. It is assumed that an engine would be rebuilt back to the standard of that particular emissions tier (varies by model year of the engine). Taking engine rebuilds into account, staff has updated the diesel emission factor deterioration in the OFFROAD2007 model to cap at 12,000 hours. As a result, once an engine's cumulative hours equals 12,000 hours, the deteriorated emission factor is assumed to be constant at that rate for the rest of the life of the equipment, as illustrated in Figure 2.

[13] Section I-I of ARB's Mail-Out#: MSC 99-32 contains a more detailed discussion of how each deterioration rate is derived for uncontrolled, and Tier 1 to Tier 3. The Tier 4 deterioration rates were derived using the ratio to the standard of Tier 3.

Figure 2: Construction and Mining Equipment Deterioration of Emission Factors as a Function of Equipment Age



C. Emissions Projections

Emissions projections, from the base year 2000 up to year 2040, reflect expected growth rates in equipment population, attrition of the fleet and the decrease in emission factors over time as new engine standards are implemented.

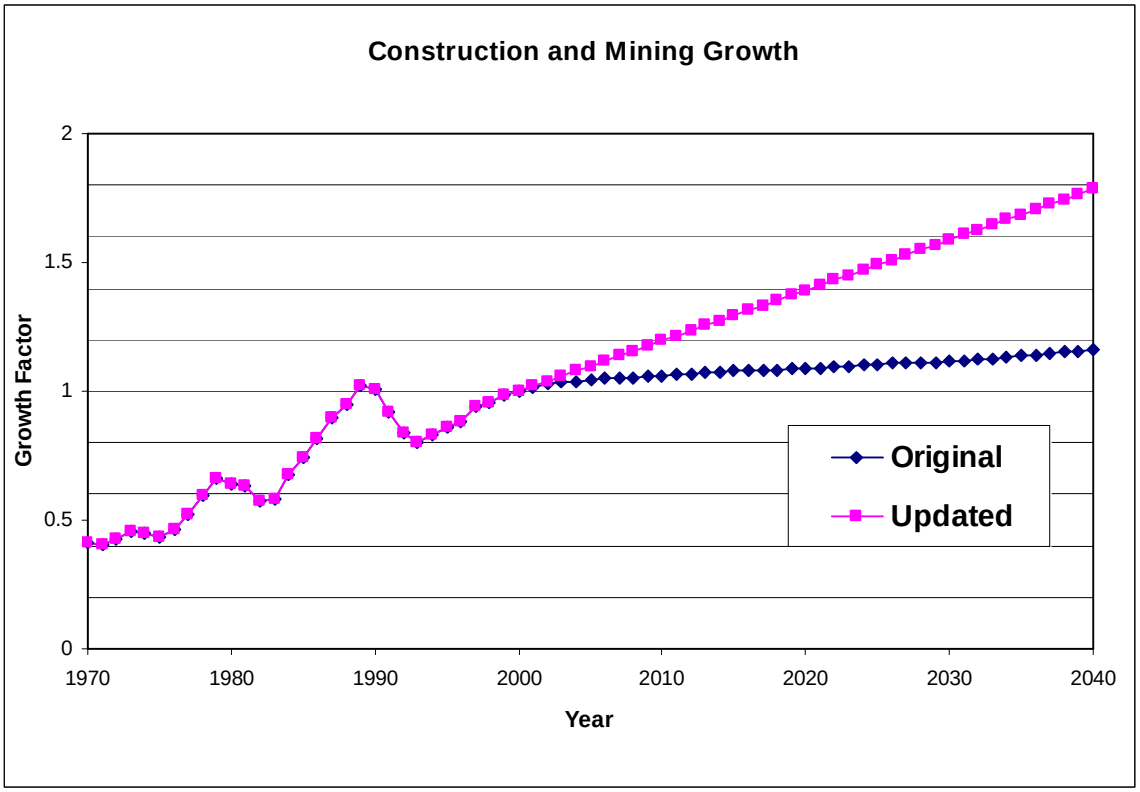
1. Growth Factors

In the inventory, growth is defined as the increase or decrease in vehicle population. The growth factors were originally derived by Energy & Environmental Analysis (EEA) in 1995, based on "A Study to Develop Projected Activity for Non-Road Mobile Categories in California, 1970-2020" (California State University, Fullerton, 1994). They were based on category-specific economic indicator data, such as employment, dollars spent, sales and fuel expenditures. The growth factors are applied to the base year 2000 population to obtain the population of past and future years (1960-2040).

a) Construction and Mining

Based on discussions with stakeholders and industry, staff concluded that the original growth factors of equipment in the Construction and Mining category (based on 1994 DRI/McGraw-Hill employment data via EEA (1995)) did not fully reflect the increasing trend as seen in this industry. Based on construction employment data obtained from the Regional Economic Models, Inc. (REMI, 2001), between the years 1970 to 2000, the updated growth rate was derived as a 1.96% increase per year starting in year 2001. Pre-2001 growth reflected actual historical data. Figure 3 illustrates the comparison between the original growth factors and the updated growth factors as reflected in the OFFROAD2007 model.

Figure 3: Construction and Mining Growth Trend



b) Industrial

For the Industrial category, the growth rate was originally based on employment data (DRI/McGraw-Hill, 1994 via EEA (1995)). Staff determined that the growth rate for this category matched well with the current industry trend. As a result, the growth rate for the Industrial category remained unchanged.

c) Airport Ground Support (GSE)

For the GSE category, the growth rate was originally based on FAA flight operations data (United States Department of Transportation, 1997). This growth rate was reviewed by the ATA and participating airlines[14] and it determined that the growth rate for this category matched well with the current industry trend. As a result, the growth rate for the GSE category remained unchanged in the OFFROAD2007 model.

d) Oil Drilling

For the Oil Drilling category, the original growth rate is constant. Based on data from ARB's Off-Road Diesel Equipment Survey (2005), in addition to discussions with stakeholders and industry, staff determined that the growth rate for this category

[14] Growth rate for GSE were reviewed by the ATA and airlines represented by Ev Ashworth of the Ashworth Leininger Group (2006)

matched well with the current industry trend. As a result, the growth rate for the Oil Drilling category remained unchanged in the OFFROAD2007 model.

2. Attrition or Scrappage

Scrappage is a function that describes the relationship between equipment age and the proportion of equipment that has been removed from service. The scrappage curve[15] utilized in the OFFROAD2007 model was developed by Power Systems Research (PSR, 1992) and represents the engine fleet retirement rate based on nationwide data. In the field, there are variations in maintenance, accidental failures, and variations of engine quality and performance. The smoothed scrappage curve estimates the effect of these factors on engine life expectancies.

3. New Engine Standards

The emission factors in the OFFROAD2007 model reflect the new Tier 4 diesel engine standards that were adopted by ARB in December, 2005. These emission factors also reflect the phase-in/flexibility portion of the emission standards as allowed by the regulations that established the new engine standards. Table 16contains the zero-hour emission rates and deterioration rates by pollutant.

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