Default Inputs for Diesel Engines in the NONROAD model

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Diesel Engines:
Variables modified for NONROAD2002

- Zero-hour Steady-state Emission Factors (EF)
- Transient Adjustment Factors (TAFs)
- Deterioration Factors (DFs)
- Load Factors (LF)
- Base-Year Populations
- Median Life

Diesel Exhaust Emission Inputs:
Emission Factors

Three key components*:*

EF = ZHL x TAF x DF

ZHL = "zero hour" levels -- *from new engine test data*

TAF = transient adjustment factor -- *adjusts the ZHLs that are derived from steady-state lab testing, to account for how engine speed and load variations in the field affect emissions.*

DF = deterioration factor -- *adjusts for age-related deterioration and malmaintenance*

The model also makes a PM EF adjustment for differences between test fuel sulfur levels and in-use fuel levels

Diesel Exhaust Emission Inputs
"Zero-Hour" Emission Factors

Pre-Controlled Engines*:*

- retain existing emission factors

Tier 1 Engines and 300-600hp Tier 2 Engines *:*

- update per latest certification data, and
- also correct for in-use sulfur

Other Tier 2 Engines and Tier 3 Engines*:*

- five options considered for each combination of pollutant/hp/tier/EF:
  - Examine likely impact of expected technology changes
  - Assign an emission factor from another hp category
  - Continue to use Tier 1 or Tier 2 EFs
  - Reduce the standard by a compliance margin derived from highway engines
  - Apply a default compliance margin of 10%

Diesel Exhaust Emission Inputs:
Comparison of HC ZHLs

	HC ZMLs, g/hp-hr								
	Tier 1			Tier 2			Tier 3		
Max HP	Tier 1	HD07 T1	ratio:HD07	Tier 2	HD07 T2	ratio:HD07	Tier 3	HD07 T3	ratio:HD07
11	0.7628	0.30	**2.5**	0.5508	0.30	**1.8**	na	na	na
16	0.4380	0.20	**2.2**	0.4380	0.20	**2.2**	na	na	na
25	0.4380	0.20	**2.2**	0.4380	0.20	**2.2**	na	na	na
50	0.2789	0.13	**2.1**	0.2789	0.13	**2.1**	na	na	na
100	0.5213	0.56	**0.9**	0.3672	0.36	**1.0**	0.1836	0.18	**1.0**
175	0.3384	0.40	**0.8**	0.3384	0.36	**0.9**	0.1836	0.18	**1.0**
300	0.3085	0.35	**0.9**	0.3085	0.35	**0.9**	0.1836	0.18	**1.0**
600	0.2025	0.22	**0.9**	0.1669	0.22	**0.8**	0.1669	0.18	**0.9**
750	0.1473	0.20	**0.7**	0.1669	0.20	**0.8**	0.1669	0.18	**0.9**
>750	0.2861	0.20	**1.4**	0.1669	0.20	**0.8**	na	na	na

Diesel Exhaust Emission Inputs:
Comparison of CO ZHLs

	CO ZMLs, g/hp-hr								
	Tier 1			Tier 2			Tier 3		
Max HP	Tier 1	HD07 T1	ratio:HD07	Tier 2	HD07 T2	ratio:HD07	Tier 3	HD07 T3	ratio:HD07
11	4.1127	4.1	**1.0**	4.1127	4.1	**1.0**	na	na	na
16	2.1610	1.3	**1.7**	2.1610	1.3	**1.7**	na	na	na
25	2.1610	1.3	**1.7**	2.1610	1.3	**1.7**	na	na	na
50	1.5323	1.8	**0.9**	1.5323	1.8	**0.9**	na	na	na
100	2.3655	2.0	**1.2**	2.3655	2.0	**1.2**	2.3655	2.0	**1.2**
175	0.8667	1.1	**0.8**	0.8667	1.1	**0.8**	0.8667	1.1	**0.8**
300	0.7475	0.8	**0.9**	0.7475	0.8	**0.9**	0.7475	0.8	**0.9**
600	1.3060	0.8	**1.6**	1.3060	0.8	**1.6**	1.3060	0.8	**1.6**
750	1.3272	1.2	**1.1**	1.3272	1.2	**1.1**	1.3272	1.2	**1.1**
>750	0.7642	1.1	**0.7**	0.7642	1.1	**0.7**	na	na	na

Diesel Exhaust Emission Inputs:
Comparison of NOx ZHLs

	NOx ZMLs, g/hp-hr								
	Tier 1			Tier 2			Tier 3		
Max HP	Tier 1	HD07 T1	ratio:HD07	Tier 2	HD07 T2	ratio:HD07	Tier 3	HD07 T3	ratio:HD07
11	5.2298	5.6	**0.9**	4.3	4.3	**1.0**	na	na	na
16	4.4399	4.0	**1.1**	4.4399	4.0	**1.1**	na	na	na
25	4.4399	4.0	**1.1**	4.4399	4.0	**1.1**	na	na	na
50	4.7279	4.8	**1.0**	4.7279	4.3	**1.1**	na	na	na
100	5.5988	5.3	**1.1**	4.7	4.7	**1.0**	3.0	3.0	**1.0**
175	5.6523	5.9	**1.0**	4.1	4.1	**1.0**	2.5	2.5	**1.0**
300	5.5772	5.8	**1.0**	4.0	4.0	**1.0**	2.5	2.5	**1.0**
600	6.0153	5.8	**1.0**	4.3351	4.1	**1.1**	2.5	2.5	**1.0**
750	5.8215	5.8	**1.0**	4.1	4.1	**1.0**	2.5	2.5	**1.0**
>750	6.1525	5.8	**1.1**	4.1	4.1	**1.0**	na	na	na

Diesel Exhaust Emission Inputs:
Comparison of PM ZHLs

	PM ZMLs, g/hp-hr								
	Tier 1			Tier 2			Tier 3		
Max HP	Tier 1	HD07 T1	ratio:HD07	Tier 2	HD07 T2	ratio:HD07	Tier 3	HD07 T3	ratio:HD07
11	0.4474	0.52	**0.9**	0.50	0.44	**1.1**	na	na	na
16	0.2665	0.52	**0.5**	0.2665	0.36	**0.7**	na	na	na
25	0.2665	0.36	**0.7**	0.2665	0.36	**0.7**	na	na	na
50	0.3389	0.38	**0.9**	0.3389	0.32	**1.1**	na	na	na
100	0.4730	0.37	**1.3**	0.24	0.24	**1.0**	0.30	0.24	**1.3**
175	0.2799	0.22	**1.3**	0.18	0.18	**1.0**	0.22	0.18	**1.2**
300	0.2521	0.19	**1.3**	0.1316	0.12	**1.1**	0.15	0.12	**1.3**
600	0.2008	0.12	**1.7**	0.1316	0.12	**1.1**	0.15	0.12	**1.3**
750	0.2201	0.14	**1.6**	0.1316	0.12	**1.1**	0.15	0.12	**1.3**
>750	0.1934	0.13	**1.5**	0.1316	0.12	**1.1**	na	na	na

- No changes to BSFCs

Diesel Exhaust Emission Inputs:
Transient Adjustment Factors

- Still based on cycle test data, BUT
  - Added data for excavator cycle (7 cycles in all)
  - Combined Tier 0 and Tier 1 data (not statistically different based on Student's *t*-test)
  - Average of ratios used vs ratio of averages
  - Binned cycle data by load factor category
- TAF assignments to equipment no longer vary by tier

Diesel Exhaust Emission Inputs:
Transient Adjustment Factors

Cycle	Load Factor	Assignment	HC		CO		NOx	
			Cycle TAFs	Average	Cycle TAFs	Average	Cycle TAFs	Average
Agricultural Tractor	0.78	**High**	0.83	**1.05**	0.50	**1.53**	0.98	**0.95**
Crawler Dozer	0.58		0.88		1.50		0.98	
Rubber-Tire Loader	0.48		1.07		3.68		0.96	
Excavator	0.53		1.40		0.44		0.87	
Backhoe Loader	0.21	**Low**	2.23	**2.29**	2.66	**2.57**	1.05	**1.10**
Skid-Steer Loader	0.23		1.49		1.83		0.95	
Arc Welder	0.19		3.16		3.22		1.31	

Cycle	Load Factor	Assignment	PM		BSFC	
			Cycle TAFs	Average	Cycle TAFs	Average
Agricultural Tractor	0.78	**High**	0.71	**1.23**	0.98	**1.01**
Crawler Dozer	0.58		1.29		0.99	
Rubber-Tire Loader	0.48		2.02		1.04	
Excavator	0.53		0.89		1.03	
Backhoe Loader	0.21	**Low**	2.07	**1.97**	1.16	**1.18**
Skid-Steer Loader	0.23		1.74		1.09	
Arc Welder	0.19		2.11		1.29	

Diesel Exhaust Emission Inputs:
Comparison of TAFs

Cycle	Model Version	Tier	TAFs				
			HC	**CO**	**NOx**	**PM**	**BSFC**
Agricultural Tractor	HD07	Tier 0	0.88	0.42	1.00	0.61	0.98
		Tier 1+	0.91	0.65	0.94	0.82	0.99
	2002	All*	1.05	1.53	0.95	1.23	1.01
Backhoe Loader	HD07	Tier 0	2.19	2.32	1.02	1.96	1.18
		Tier 1+	1.81	2.26	1.13	1.87	1.13
	2002	All*	2.29	2.57	1.10	1.97	1.18
Crawler Dozer	HD07	Tier 0	0.92	1.27	0.99	1.17	0.98
		Tier 1+	0.87	1.52	0.96	1.30	1.00
	2002	All*	1.05	1.53	0.95	1.23	1.01
Rubber-Tire Loader	HD07	Tier 1+	0.94	3.73	0.96	2.03	1.04
	2002	All*	1.05	1.53	0.95	1.23	1.01
Skid-Steer Loader	HD07	Tier 1+	1.29	1.85	0.95	1.75	1.09
	2002	All*	2.29	2.57	1.10	1.97	1.18
Arc Welder	HD07	Tier 1+	2.76	3.22	1.31	2.12	1.29
	2002	All*	2.29	2.57	1.10	1.97	1.18
Excavator	2002	All*	1.05	1.53	0.95	1.23	1.01

* Except Tier 3 for NOx and PM

Transient Adjustment Factors:
Key Issue for Tier 3 Engines

Lacking a transient test, Tier 3 engines using EGR are likely to be designed with higher transient emissions

PM for Tier 3 Engines***:*** TAF change: ↑20%

- **old approach:** assume same as Tier 1 (based on Tier 1 engine test data)
- **new approach:** assume EGR increases transient PM (due to the time lag for clearance of the intake system)

NOx for Tier 3 Engines***:*** TAF change: ↑10%

- **old approach:** assume same as Tier 1 (based on Tier 1 engine test data)
- **new approach:** assume EGR increases transient NOx (due to EGR being turned off during transients)

Diesel Exhaust Emission Inputs:
Deterioration Factors

The HDD 2007 version uses very low DFs for all pollutants based on highway engine data in MOBILE6

HC, CO, and NOx (all tiers):

- no clear trend from new (highway-only) data
- so stick with existing DFs, BUT
- now using simple unweighted averages of DFs by hp category

PM (all tiers):

- **new approach**: use ARB OFFROAD DF: 47% over the median life (DF=1.47)

All DF's still capped at one median life

Diesel Exhaust Emission Inputs:
Comparison of DFs

Pollutant	Model Version	Deterioration Factor (% increase/ % useful life)* Tier 0	Tier 1	Tier 2	Tier 3
HC	HD07	0.059	0.014	0.013	0.007
	2002	0.047	0.036	0.034	0.027
	ratio:HD07	**0.8**	**2.6**	**2.6**	**3.9**
CO	HD07	0.190	0.144	0.144	0.175
	2002	0.185	0.101	0.101	0.151
	ratio:HD07	**1.0**	**0.7**	**0.7**	**0.9**
NOx	HD07	0.026	0.026	0.012	0.007
	2002	0.024	0.024	0.009	0.008
	ratio:HD07	**0.9**	**0.9**	**0.8**	**1.1**
PM	HD07	0.058	0.058	0.032	0.035
	2002	0.473	0.473	0.473	0.473
	ratio:HD07	**8.2**	**8.2**	**14.8**	**13.5**

* These are values for A in the equation: DF = 1 + A*(fraction of useful life expended)

Diesel Exhaust Emission Inputs
Sulfur Adjustment to PM EF

- Basic equation unchanged, although errors relating to the equation in the HDD 2007 version of the core model have been corrected
- Revised certification fuel sulfur levels by regulatory tier

Diesel Exhaust Emission Inputs: *Load Factor*

- In NONROAD HDD 2007
  - Load Factors from 1998 PSR *Partslink*
  - assigned individual LF to specific applications
- In NONROAD2002
  - load factors developed from transient-cycle development project
  - Seven cycles developed, designed to mimic equipment operation

Agricultural Tractor	Rubber-Tire Loader	Arc Welder
Backhoe loader	Skid-steer loader	
Crawler Dozer	Excavator	

Diesel Exhaust Emission Inputs:
Transient-cycle Load Factors

Cycle	Load Factor	Assignment
Agricultural Tractor	0.78	high
Crawler Dozer	0.58	high
Excavator	0.53	high
Rubber-tire Loader	0.48	high
Skid-steer Loader	0.23	low
Backhoe-Loader	0.21	low
Arc Welder	0.19	low
None (steady-state)	---	average 7-cycle

Diesel Exhaust Emission Inputs:
Load Factor Assignments

We assigned averages for each group:

Group	Load factor
high	0.59
low	0.21
7-cycle	0.43

Examples:

Application	HDD 2007	NR 2002	
		Assignment	LF
Agricultural tractors	0.70	high	0.59
Crawler dozers	0.64	high	0.59
Excavators	0.70	high	0.59
Skid-steer loaders	0.55	low	0.21
Welders	0.60	low	0.21
Crushing equipment	0.74	none	0.43
Generator sets	0.78	none	0.43

Diesel Engine Scrappage:
Median Life

Median life estimates are used to calculate engine age distributions and turnover rates. At one median life, for a given engine size, half of the machines have been retired, and half are still in use.

- NONROAD had an **internal inconsistency**, obscured by the fact that the PSR *Partslink* model internally uses median life values to determine populations.
- **PSR data were not** well-documented
- **Best alternative** source: **EEA** (already used elsewhere in NONROAD)
  - EEA median life values were developed for ARB OFFROAD
  - based mainly on **highway experience,** carried-over
  - EEA has provided credible documentation of how they derived estimates
  - Now using **EEA with some modifications**

Diesel Engine Scrappage: *Median Life*

We adjusted the median life for <16 hp engines to match that for 16-50 hp engines, to avoid median lives shorter than the regulatory useful lives; 2500 hrs at full load equates to 5000 hrs at a 50% typical average load factor (the regulatory useful life for these engines is 3000 hr).

Power Category	Source: PSR	Source: EEA	Modified EEA
<16 hp	13,000 hrs	1,250 hrs	2,500 hrs
16-50 hp	10,000 hrs	2,500 hrs	2,500 hrs
50-300 hp	11,500 hrs	4,000 hrs	4,667 hrs
300-1000 hp	9,000 hrs	6,000 hrs	7,000 hrs
>1000 hp	7,500 hrs	6,000 hrs	7,000 hrs

We removed EEA's "rugged life" adjustment:
EEA shortened the highway-derived median lives by 15% to account for the more severe operating conditions of nonroad engines. However, nonroad engine designs typically already account for this (mainly by use of de-rated bigger engines); so we removed the 15% adjustment.

Diesel Base-Year Populations:
Sales Data

- Historical sales data is key component in calculating equipment populations in base year
- PSR still has most comprehensive sales data including all NONROAD applications
  - PSR has done an extensive upgrade of 1990-98 diesel sales estimates
  - Expanded capture of imports/exports

Inputs: Equipment Population

- Population = f(sales, activity, load factor, median life)
- For diesel equipment, we now use PSR sales data to calculate populations, rather than using PSR populations directly.
  - Allows consistent median life and LFs
  - Decreased diesel Pops by ~25%