Eaton considerations on MD/HD GHG Phase 3

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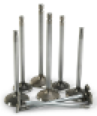
OIRA-Eaton meeting March 23rd 2023

Some pages contain Confidential Business Information

Traditional Vehicle Group Product Portfolio

Serving multiple customers & markets globally

Light Duty Technologies



Valves

Variable Valve Actuation (VVL/CDA)

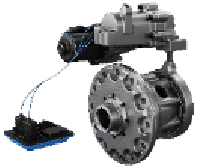
eVaptive

TVS Supercharger

Fuel Emission Controls

Gears & shafts

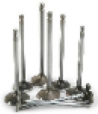
Light Duty Transmissions



Differentials

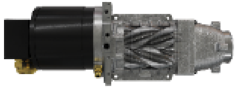
Commercial Vehicle Technologies

Engine Brake



Engin
e
Valves

Cylinder Deactivation (CDA)



TVS Fuel Cell

Clutches

Aftermarket

Automated Transmissions

EATON Cummins AUTOMATED TRANSMISSION™ TECHNOLOGIES

Gearing Systems

eMobilty

- Power Electronics
- Distribution, safety
- Charging, Hydrogen

HV power electronics

On-board charging

Power distribution and protection

Connectors and busbars

Fuel Cell systems

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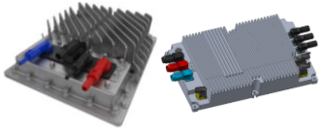
Eaton **solutions** to address emerging needs

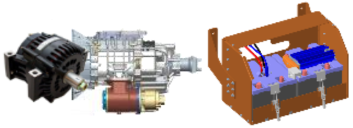
Focus on new technologies around low emissions and powertrain/ vehicle efficiency

48V Adoption

- Power creation
- 48V accessories
- System integration



Power electronics



48V architecture / power management

Engine de- accessorizing

Engine Optimization

- Efficiency, low CO2
- Low NO_x
- Natural Gas

Advanced valvetrain / Cylinder Deactivation

EGR control

Exhaust thermal management

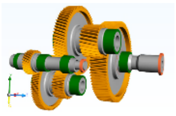
Drivetrain Efficiency

- Efficiency
- Performance
- Hybridization

Endurant (HD/XD)

Advanced clutch – down-speeding

MD & HD EV transmissions



EV high speed gear reduction

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Key ideas

- **Eaton <u>supports the EPA</u> upcoming rule**
  - Clear targets to industry
  - Builds on the track record of Phase I and II
  - <u>Creates certainty in technology investments</u> that ultimately leads to <u>US technology leadership and jobs opportunities</u>.
- The segments with **high VMT/ CO2 emissions are hardest to de-carbonize**:
  - High number of HD ICE during Phase III, and CO2 emissions accumulating through 2040-2050
- Phase III should both
  - **<u>Drive ZEV adoption</u>** wherever possible
  - Incentivizes **the <u>lowest possible emissions of remaining ICE-based vehicles</u>**, paired with low NOx emissions a recent EPA rule

2027 NOx technologies: reductions in CO2 for ICE-based vehicles, starting in 2027, within the Phase I and II framework and methodology.

- Diesel engine CO2 <u>set 3% lower than the corresponding Phase II 2027</u> limits
- Mild hybrid tractors: an additional <u>2-5% CO2 reduction at the vehicle level</u>
- Strong Hybrids improve CO2 emissions by <u>15-25% in vocational cycles</u> while improving vehicle performance and productivity.

Phase III fleet-average standards, beyond accounting for ZEV, could:

- Revisit engine standards in 2027, beyond Phase II 2027
- Vehicle CO2 reductions for the balance of the fleet, beyond <u>Phase II 2027</u>.

ZEV trucks and buses are <u>wasting ~25% of their grid charge</u> but all ZEV trucks are the same, regardless of efficiency

- Inefficiency: barrier to deployment, but <u>cheap energy means weak market forces</u>
- ZEV powertrain losses can be quantified in GEM (done in Europe)
- SmartWay-like program using GEM-based efficiency could drive efficiency without explicitly addressing upstream emissions and infrastructure costs

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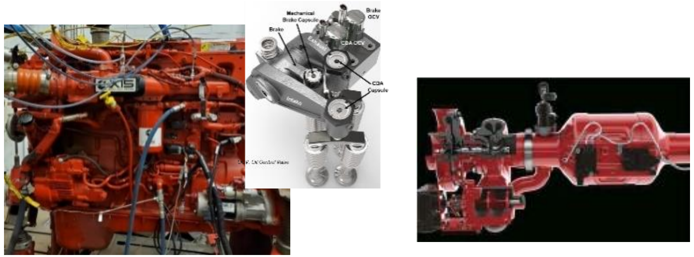
2027 NOx engine packages also lower CO2

Low NOx packages achieve 1.5% CO2 reduction beyond Phase II



2018 engine + Cylinder Deactivation + Light-Off Catalyst

NOx Technology				Engine & Aftertreatment	NOx for 2027 0.035 g/hp-hr	CO_2 Base: 513 g/hp-hr
CDA	LO-SCR	eHeater	Burner			
X				CDA Engine	*0.056*	495 *(-3.6%)*
	X			Production Engine	0.040 to 0.060	512 *(neutral)*
		X 10 kW		Production Engine	0.023	526 *(+2.4%)*
			X 50 kW	Production Engine	0.023	510 *(-0.7%)*
	X	X 7 kW		Production Engine	0.018	521 to 524 *(+1.4 to 2.1%)*
X			X 50/20 kW	CDA Engine	0.020	521 *(+1.5%)*
X	X			CDA Engine	0.018	506 *(-1.5%)*
X	X	X 2.4 kW		CDA Engine	0.012	505 *(-1.5%)*
X	X		X 50/20 kW	CDA Engine	0.012	518 *(+0.9%)*

Aftertreatment Aged to 430k+ miles

0.050 0.035 0.020 0.005

3% Cost Neutral

- Low NOx packages show lower CO2 by 1.5% (not in Phase II)
- Multiple pathways based on mature, cost-effective components that were not included in the Phase II assessments
- CO2 backstop needed: some NOx technologies do increase CO2

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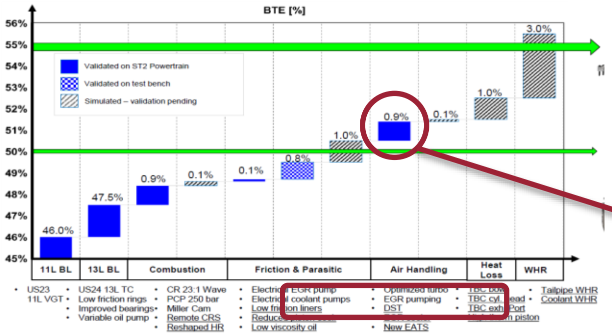
Engine focus on additional CO_2 reductions

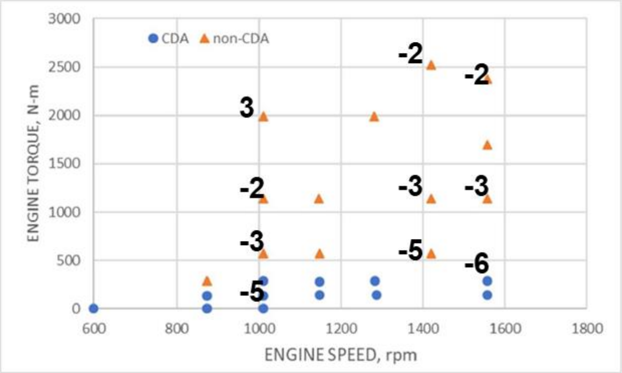
Diesel can achieve 3% CO_2 reduction beyond Phase II assessment



Volvo SuperTruck: EGR pump: re-optimized High Efficiency Turbo; Pumping work; better A/F ratio control

~**3% lower CO_2**

Ref: Volvo 2022 VTO AMR report



Cummins X15 2018 engine at SwRI shows >**3% lower CO_2**

Ref: SAE 2021-01-1154

>3% CO_2 reduction by EGR pumping demonstrated on multiple engine platforms without impact on NOx

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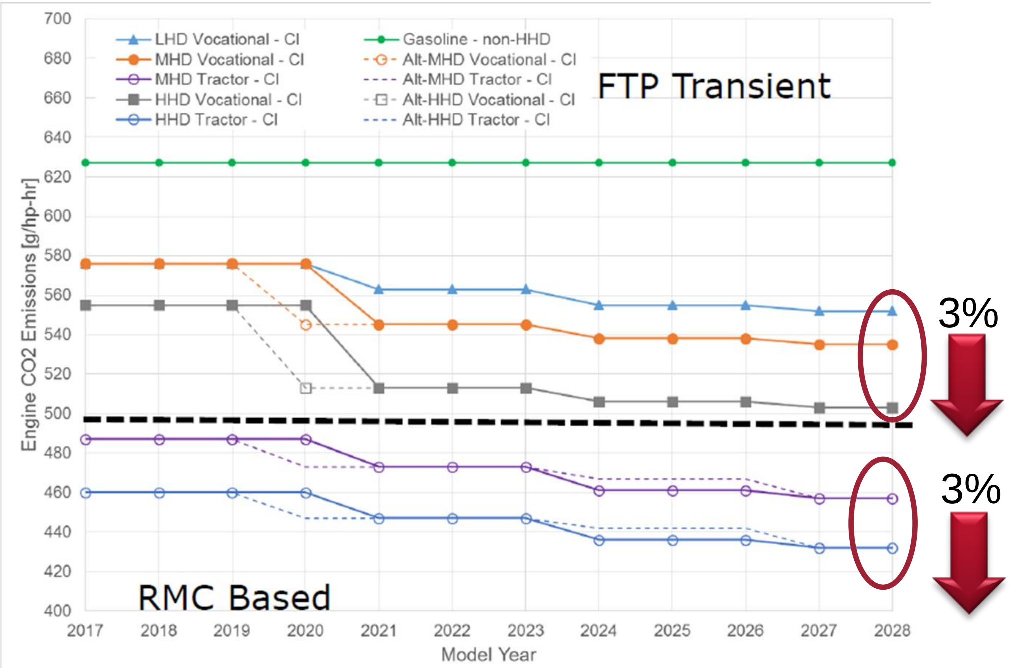
1. Additional CO2 reductions for engines

Diesel Powertrains can achieve 4.5% CO2 reduction today



Phase II Engine standards

- Engine CO2 engine emissions improve by up to 3% vs Phase II GHG 2027 limits
- **Achievable with technologies…**
  - …anyhow needed for 2027 NOx final standard
  - …not accounted for in the Phase II rule, but developed since 2017
  - …cost-effective* at \$200 - \$700, generating economic value
  - … with 50% compliance margin (technology entitlement is 4.5%)

**vs 2027 NOx compliance costs*

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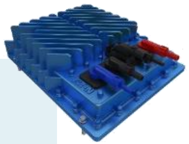
ICE vehicles – beyond Phase II packages

2. Vehicle

5% less CO_2 from 48V mild hybrids: an extensions of e-heater NOx

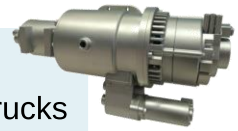
Active Heating for NOx

- All on-road OEMs are implementing minimal architectures
- Can deliver up to 1.5% CO_2 reduction
- Cost: $800 - $2,000

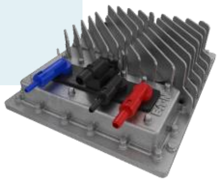


Increment

48V mild hybrids



- Development since 2017: mild-hybrid HD trucks
- Functions: heater power, electrical accessories, electrical air conditioning, power steering
- Cost increment: $1,700 to $4,000
- CO_2 reduction: 2% – 6% (incremental)



48V mild hybrid technology can realize 5% CO_2 reduction with 2-year payback based on saved fuel in the largest GHG emissions segment, incremental to low NOx technology

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**Source: DoE AMR 2022, Volvo, PACCAR, Cummins, Daimler*

ICE vehicles – beyond Phase II packages

HD Hybrids reuse investments in MD BEV for 16% CO2 reduction

HD Hybrid = [Downsized] powertrain + MD BEV e-drive + [smaller] MD BEV battery

Modified Endurant: market-leading efficiency long haul freight transmission

Medium duty motor, inverter, battery (BorgWarner, Akasol)

On-highway HD hybrid, up to 50 mile EV range, ultra-low NOx

High performance vocational / off-road capable trucks

	2021 X15-based powertrain			Improvement in GHG value		
	P2/P3	AT	Endurant HD	AMT vs TCA	P2/P3 vs AMT	P2/P3 vs TCA
HHD - Regional	226.0	259.7	248.2	4.4%	8.9%	13.0%
HHD-MM	255.0	303.3	285.8	5.8%	10.8%	15.9%
HHD-Urban	289.0	356.5	332.4	6.7%	13.1%	18.9%
Sleeper Cab Linehaul	85.8	97.0	93.5	3.6%	8.2%	11.5%
Day Cab Linehaul	89.6	102.9	98.5	4.3%	9.0%	12.9%

13-19% CO2 reduction in vocational trucks, 8-9% in tractors

Transmission	Time* to Reach [Sec.]			
Target speed	10 mph	30 mph	45 mph	65 mph
P2/P3	13.0	15.7	29.6	60.3
Allison 4000	12.0	15.1	36.7	84.9
Endurant AMT	15.5	22.6	46.5	98.9

Vocational space value proposition: both fuel reduction and increased productivity

Hybrid technology re-applies MD BEV investments to realize 8% CO2 reduction in regional and 16% in vocational while increasing truck capability and further reducing NOx

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2. Additional CO2 reductions for ICE vehicles

2. Vehicle

Diesel trucks set to achieve 5 - 18% CO2 reduction beyond Phase II

Hypothetical category: Phase II HHD mixed

- Diesel only standard = **230 g/ton-mile**
- 3 3-year roll-out (similar to Phase III)
- Non-Bev technologies:
  - 100% ICE with 48V in 2027
  - Increased deployment HD hybrid 2027 through 2033

	Phase II baseline	BEV penetration	CO2 BEV correction	ICE increment	ICE tech penetration	CO2 ICE correction	Phase III limits
2027	230	10%	**207**	18%	33%	216.3	**194.7**
2030	230	20%	**184**	18%	67%	202.3	**161.8**
2033	230	30%	**161**	18%	100%	188.6	**132.0**

Eaton assumption on NPRM:
Adjust Phase II by BEV penetration

ICE-based vehicle adjustment
for new CO2 technology

- Vehicle emissions improve by 5% - 18% additional CO2 reductions vs Phase II GHG final limits for non-BEV trucks
- **Achievable with technologies…**
  - …that improve engine emissions by 3% (applicable across non-ZEV vehicles)
  - …not accounted for in the Phase II rule, but developed since 2017
  - Increase penetration from 2027 through life of Phase III rule, achieving 100% in final year

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3. HD EV efficiency needs incentives

BEV technology can reduce grid load by 24%, but needs regulatory pull

	Charger	Battery	Inverter	Motor	Gearbox	Wheel	Overalll
Low Tech	95%	96%	94%	93%	98%	**78.1%**	**90.5%**
						12.3%*	
High Tech.	98%	98%	99%	98%	98%	**90.4%**	**119.2%**
						28.9%*	

	Energy at wheels [year]	Effective plug-to-wheels eff.	Load on grid	Wasted energy	Cost of technology	Saved energy cost
Low Tech	24 MWh**	90.5%	26.5MWh			
Hi Tech	24 MWh**	119.2%	20.1Mwh	**-24.1%**	**+ $5,000**	**-$640/yr**

Electrical bill savings does not justify efficiency…

- *6.4 MWh / year = $640 cost of electricity*
- *Hi-Tech package ~ $4,000 - $6,000*

… but 24% reduction in load is critical for at-scale deployment

- A program like SmartWay can incentivize lower electrical energy usage and inform end-customers to enable choice
- **ZEV efficiency can be quantified precisely**
  - GEM framework allows the quantification of efficiency, and Europe is already doing this in VECTO
  - SmartWay and/or Energy Efficiency labels are proven EPA methods to guide end-customers

*35% of wheel energy is regenerated; 50% limited by motor in single speed powertrains, 5% limit with multi-speed gearbox

** 1.2 kW/mile x 80 miles /day x 250 miles /year = 24 MWh / year at wheels

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