Enabling Technologies - Diesel through hybrid

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Evolution of Diesel Technology

- 1990: 500 ppm S
- 2000: 15 ppm S
- 2010: Diesel Particulate Filter, Aftercooling
- 2020: Selective Catalytic Reduction, Electronic Fuel Systems, Total Cost of Ownership
Technology Introduction - Recent Tiers

Tier 3 (Stage 3A) Emissions

Tier 4i (Stage 3B) Emissions

Tier 4F (Stage IV) Emissions

Stage V Emissions (2019/20 CMI Products)

TBD Emissions Standards
- NA Tier5 potential remains gray.
- Likely to see an increase in the availability of new technologies such as hybrid, start/stop, electrification, etc.
System Integration

Cummins design, build & integrate the complete Tier 4 system from air-intake to exhaust
The Right Technology Matters

- Fit technology to market application

<table>
<thead>
<tr>
<th>Application</th>
<th>First Date</th>
<th>In-Cylinder Only</th>
<th>Cooled EGR/VGT</th>
<th>NOx Adsorber</th>
<th>SCR</th>
<th>PM Aftertreatment</th>
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</thead>
<tbody>
<tr>
<td>Tier 3 / EU Stage IIIA</td>
<td>2005</td>
<td></td>
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<td>EPA Tier 2 &gt; 751 hp</td>
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<td>Euro 4 On-Highway</td>
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<td>EPA 07 On-Highway</td>
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<td>EPA 07/10 Pickup Truck</td>
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<td>Euro 5 On-Highway</td>
<td>2009</td>
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<td>EPA 10 On-Highway</td>
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<td>Tier 4 Final / Stage IV</td>
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<td>Stage V</td>
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<td>Tier 4 Final</td>
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<td>2020</td>
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Carbon Monoxide Emissions

Tier 3 | Tier 4i | Tier 4f
---|---|---
3.5 | 0.5 | 0

CO, g/kw-hr

Tier 4f
99+% Reduction in CO
Brake Specific Cycle Composite BSNOx and BSNO2 Emissions
Tier 3, Tier 4i and Tier 4f Engines

- Composite BSNOx g/bhp-hr
- Composite BSNO2 g/bhp-hr

Tier 4f
99+% Reduction in NO₂
**Characteristics of New vs. Old Diesel PM**

HEI ACES Results Compared to earlier Testing:

_**Dramatic Reductions**_

- 98% reduction in mass
- 90% - 99% reduction in Ultrafine Particles
- Substantial reduction in carbon particles

(Courtesy of HEI Report, 2015)
Meeting ‘Near-Zero’ Emissions

Emissions from 25 Tier 4 Final machines equivalent to just one Tier 1 machine!
Operating TCO Comparison: 6.7L

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<tr>
<th></th>
<th>T3</th>
<th>T4F</th>
<th>MY 2019</th>
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<tr>
<td><strong>Total Cost</strong></td>
<td>1</td>
<td>0.93</td>
<td>0.91</td>
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<td><strong>Maint Cost</strong></td>
<td>1</td>
<td>1.08</td>
<td>.78</td>
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*TCO savings realized with newer products is highly duty cycle dependent.
*Regional diesel & DEF pricing have direct affects on the above.
Reducing \( \text{CO}_2 \)

- Idle Reduction
- Low Carbon Fuels
- Hybrid
- Low Temp Aftertreatment
- High Efficiency Clean Combustion
- Waste Heat Recovery

\( \text{CO}_2 \) → Fuel Efficiency
POWERTRAIN OF CHOICE

IC Engine

Hybrid (Range Extended) 2020

Battery Electric 2019

Fuel Cell Electric
Super Power Solution

Alternate Energy
- electrification
- natural gas
- gasoline
- others

Intelligent Data Systems
- connected systems
- controls
- intelligent transportation

Powertrain Integration
- transmission
- axles
- brakes

Super Engine System
Cummins is committed to being a diverse powertrain supplier across our regions and markets.

We are in a period of transformative change within the industry. With change comes opportunity.

The future includes:

- Internal combustion powertrain fueled by conventional and non-conventional fuels.
- Electric powertrain as pure EV, range extended EV and hybrid.
- Connected solutions to drive the demands of digital business.

energy diversity is KEY
Q+A