The Next ICE Age

Michael Ruth
Director – Advanced Systems Engineering
Cummins Inc.
The more things change, the more they stay the same.

1913
- Detroit Electric
  - $2,600
  - 60 miles

1/3 range

4X cost

1913
- Model T
  - $650
  - 180 miles

2012
- Nissan Leaf
  - $36,500
  - 73 miles
  - $600/yr
  - 230 g/mi CO₂

1/4 range

3X purchase cost

31% Lower CO₂/mile

2012
- Nissan Versa
  - $12,500
  - 345 miles
  - $1750-$2050/yr
  - 335 g/mi CO₂

Nissan data based on FeulEconomy.gov information
Cummins Inc.

Diversified Global Power Leader – Four Complementary Businesses

- Engines
- Power Generation
- Components
- Distribution

- World’s largest independent diesel engine manufacturer
- Will produce over 1M diesel and natural gas engines in 2012
- Over 60% of sales outside the U.S.
- Approximately 44,000 employees worldwide
Broad Product Range

- A major expansion of the range since the late 1990s, with twice the number of engine platforms covering 49 to 4200 horsepower.
Cummins Chassis Certified Products
Light Duty Emissions Efforts at Cummins

- **1998 Mule Demo**: 21.8 mpg, 5000 lb
- **2003 LDA V6 Demo**: 20.4 mpg, 5000 lb
- **2007 Production Ram 2500**: 14 mpg, 8500 lb

Target for 2014 Demo on ATLAS program
Current Development Focus on Cost and CO₂

- Aftercooling
- Diesel Particulate Filter
- Diesel Particulate Filter
- Selective Catalytic Reduction
- Electronic Fuel Systems
- Cooled Exhaust Gas Recirculation
- Drive down TCO
Sustained Progress Indeed ...

Aggregate Emissions – 6 NAAQS Pollutants

-59%

Total Energy & CO₂ Trending Downward

8%

24%

15%

40%

65%

Economic Activity Indicators

Source “Our Nation’s Air – Status and Trends through 2010”
EPA-454/R-12-001 - February 2012
Focus Areas for All Engine Applications

- High Efficiency Clean Combustion
- Idle and Parasitic Reduction
- Hybridization
- Aftertreatment
- Waste Heat Recovery
- Low Carbon Fuels

Reduced CO2 = Fuel Efficiency
Chassis Certified Engine Technology Levers

- Parasitic Reduction
- Fuel System
- Variable Valve Actuation
- EGR Loop
- Turbo Technology
- Aftertreatment
- Fuel
- Controls
- Materials
Chassis Certified Engine Technology Levers

- Parasitic Reduction
- Fuel System
- Variable Valve Actuation
- EGR Loop
- Turbo Technology
- Aftertreatment
- Fuel
- Controls
- Materials
Air Handling Optimization

Reduce emissions while maintaining the fuel economy advantage of diesel
Lube Oil

- Engine design changes to take advantage of low viscosity lube oil
  - Bearing materials and journal sizing to maintain high durability at high film pressures

- 5500 lb full sized pick-up truck

<table>
<thead>
<tr>
<th></th>
<th>Base 15W40</th>
<th>10W30</th>
<th>5W30</th>
<th>5W30 Low V</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel Economy LA-4</td>
<td>24.6</td>
<td>24.6</td>
<td>25.0</td>
<td>25.9</td>
</tr>
<tr>
<td>Fuel Economy HWFET</td>
<td>29.6</td>
<td>30.0</td>
<td>30.0</td>
<td>30.4</td>
</tr>
</tbody>
</table>

LA-4 Fuel Economy: 24.6 24.6 25.0 25.9 MPG
HWFET Fuel Economy: 29.6 30.0 30.0 30.4 MPG
Base Engine Design Technology

**Structural Efficiency**
(Firing Load * # cylinders / mass)

**Packaging Efficiency**
(Displacement / mass)

Materials

- Al / Mg
- Aluminium
- CGI
Direct $\text{NH}_3$ Delivery and Storage Catalysts

- Urea dosing available
- NOx Storage
- $\text{NH}_3$ dosing available
- Reductant Req’d

Diagram showing Cumulative NOx [g] vs. Time [s] and Temperature [°C].
Heavy Duty Engine Technology Levers

- Parasitic Reduction
- Fuel System
- Fuel
- Controls
- Materials
- EGR Loop
- Variable Valve Actuation
- Turbo Technology
- Aftertreatment
- Waste Heat Recovery

U.S. DEPARTMENT OF ENERGY

Cummins
Heavy Duty Engine Technology Levers

- Parasitic Reduction
- Fuel System
- Fuel
- Controls
- Materials
- EGR Loop
- Variable Valve Actuation
- Turbo Technology
- Aftertreatment
- Waste Heat Recovery
SuperTruck – WHR System

- WHR Exhaust
- Heat Exchanger
- WHR Expander
- Drive Module
- EGR Heat Exchanger
- Recuperator
- Condensor
- WHR Exhaust Heat Exchanger
- Exhaust Aftertreatment
- WHR Expander Drive Module
Energy Prices Drive the Market

U.S. Fuel Prices - $/Gallon Diesel Equivalent Energy

Data on a Trailing 1 Year Rolling Average Basis

All Data from DOE Energy Information Administration
http://www.eia.gov/dnav/ng/ng_pri_sum_dcu_nus_m.htm

Fuel

- Gasoline
- Diesel Basis
- Residential Delivered Natural Gas
- Industrial Utility WellHead
Summary

- The Internal Combustion Engine has a future for personal and commercial transportation.
  - Energy costs and operational cost will drive technology choices
  - Light duty diesel has an opportunity to compete as CAFE/GHG regulations will drive the need for more technology on today’s engines
  - Diesel will be capable of matching gasoline emission rates
  - New design techniques will put LD diesels on equal weight measures as gasoline
  - Low Carbon Fuels are important to the future ICE