Cummins Next Generation Tier 2, Bin 2 Light Truck Diesel Engine

Michael Ruth
Principal Investigator
5 October 2011
Program
Timeline
Technical approach
Progress

ATLAS
Changing the Climate on Climate Change
Program Goals

- ½ Ton Pick-up Truck application

- 40% Better miles per gallon
  - Compared to V8 gasoline powered equivalent

- US Tier 2, Bin 2 emissions levels

- Commercially Viable Solutions
  - High quality, Great Performance, Low Total Cost of Ownership
Scope

- Weight reduction in comparison to current diesel
- Aftertreatment effectiveness improvement
- Reduction in emission control fuel economy penalty
- Low impact vehicle integration for OEM application
Partners

- Johnson-Matthey
  - Catalyst technology

- Nissan Motors
  - Vehicle targets and integration support

- U.S. Department of Energy
Power & Torque for U.S. Light Truck Market

Approximate limit in light duty drive train torque capacity

ATLAS Target
210 Hp
500 N-m

Bubble size represents relative market size
Baseline

- 5.6L all aluminum V-8
- 317HP @ 5,200rpm
- 385ft-lb @ 3,400rpm
- 5 spd automatic transmission
- 5078lb curb / 8299lb GVWR / 15,100lb GCWR
- Tier2Bin5 (FED) / LEVII LEV (CA)

2010 Nissan Titan
## Fuel Economy

### 5500 lb ETW

<table>
<thead>
<tr>
<th></th>
<th>Baseline vehicle data+</th>
<th>DoE Program at Target</th>
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</thead>
<tbody>
<tr>
<td><strong>FTP – 75</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>“city”</td>
<td>15.6 mpg</td>
<td>21.8 mpg</td>
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<tr>
<td></td>
<td>570 CO2 g/mi</td>
<td>467 CO2 g/mi</td>
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<tr>
<td>HFET</td>
<td></td>
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<tr>
<td>“hi-way”</td>
<td>24.5 mpg</td>
<td>34.3 mpg</td>
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<tr>
<td></td>
<td>363 CO2 g/mi</td>
<td>297 CO2 g/mi</td>
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<tr>
<td><strong>CAFE</strong></td>
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<td></td>
</tr>
<tr>
<td></td>
<td>18.6 mpg</td>
<td>26.1* mpg</td>
</tr>
<tr>
<td></td>
<td>476 CO2 g/mi</td>
<td>390 CO2 g/mi</td>
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</table>

*DoE Performance Metric
+ Data from EPA 2010 Certification database
Program

**Timeline**

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**ATLAS**

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Program Timeline

4 year program
October 2010 Kickoff

- T2B5 Vehicle Demo
  December 2013
- T2B2 Vehicle Demo
  August 2014
- T2B5 Eng Dyno Demo
  June 2013
- Engine Out at Target
  July 2012
- New Engine Available
  December 2012
- New Engine Available
  December 2012
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Design Vision; Highly Integrated

- Engine package that will include close coupled aftertreatment and doser for fast light off and reduced burden on OEM assembly stations
- Weight neutral to baseline gasoline powertrain
- Elimination of “generic adaptation”
- Down sized, high power density, and minimized NVH
Technical Approach – F.E. & Emissions

Down sized engine

- Increased loads
- Higher exhaust gas temperature
- Improved A/T performance

![Graph showing emission reduction and temperature increase with load increase for Small and Large Displacement engines.](image-url)

- SCR
- NAC

- FTP-75 Cycle Requirement

Technical Approach – F.E. & Emissions

Low pressure EGR to reduce pumping work

Steady speed and load, Fixed A/F ratio, EGR sweep

Increased Gas Cooling

Reducing Intake Manifold O2 Concentration

LP Loop

HP Loop

Exhaust

Fresh air

Engine

Increasing Pumping Work to Drive EGR
Technical Approach – F.E. & Emissions

Design features for fast warm up

- Fabricated exhaust manifold instead of cast iron
- Close coupled aftertreatment
  - DOC/DPF assembled onto engine
  - Dual wall exhaust pipe work underbody
- Minimized exhaust port “wetted” area

![Graph showing exhaust stack temperature over time]

Reducing Manifold Weight

![Diagram showing insulated exhaust port and air gap]
LT NOx Slip Control Strategies

- **SCR development focus**
  - Low temperature conversion
  - Reductant delivery

- **Major focus areas**
  - Control engine out NOx in cold start
  - Limit NOx slip
  - Improve A/T warm up performance
Program
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Progress

- **Mule Engine**
  - Low viscosity engine oil evaluation
  - Variable swirl system testing
  - Generation 3 Piezo FIE applied to baseline engine
  - Design and procurement of HP/LP EGR system
    - Testing started 9/15

- **Mule Vehicle**
  - Build complete, first fire in April 2011
  - Development of shift strategy, acc load management, etc.
Low Viscosity Oil Testing (Engine Dyno Cycle)

- Engine dyno cycles were used to approximate vehicle cycle operation.

<table>
<thead>
<tr>
<th></th>
<th>Base 15W40</th>
<th>10W30</th>
<th>5W30</th>
<th>5W30 Low V</th>
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<td>Fuel Economy FTP-75</td>
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<td>Fuel Economy HWFET</td>
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<td>30.0</td>
<td>30.4</td>
</tr>
</tbody>
</table>

- Low V 5W30 is a 2.9 cp HTHS rating, all others are 3.4 cp HTHS rating or greater.
Mule Vehicle Test Results

Engine Torque [ft-lbf] vs. Engine Speed [rpm]

- 5500 lb Mule Test FE (mpg)
  - US06: 22.4
  - HFET: 34.1
  - LA-4: 25.1
Technical Accomplishments – New Engine

- **Base engine design work**
  - Analysis of crankshaft to design included low viscosity oil properties
  - Power cylinder designed for short compression height and high cylinder pressure requirements

- **Control system**
  - Coupled control system logic to GT simulation

- **Aftertreatment modeling**
  - New A/T technology first order model (PNA)
  - Full model for A/T options (SCR vs NAC)
  - Detailed model for target development of 0-180 sec

- **Vehicle model**
  - Integrated system model under development
Thank You!

- **Partners**
  - Johnson-Matthey Inc. Catalyst systems
  - Nissan Motors Light Truck – Vehicle development

- **Contributors**
  - Rose-Hulman Institute of Technology – Advanced control system analysis

- **U.S. Department of Energy**

- **Cummins management and team members**