Agenda: Funded Projects / Commercial Products

- ISB6.7 G Update
- ISX12 G Update
- CWI Lower Emissions Pathway
Agenda: Funded Projects / Commercial Products

- ISB6.7 G Update
- ISX12 G Update
- CWI Lower Emissions Pathway
ISB6.7 G Project Introduction

- Cummins Westport (CWI) and Gas Technology Institute (GTI) were awarded $1M from the California Energy Commission Public Interest Energy Research (PIER) program.

- Grant funding supports Alpha design, development, demonstration, and Beta design of a new, 6.7 liter natural gas engine.

- Grant agreement term: Aug/13 thru Dec/14.
ISB6.7 G Project Goal

- Demonstrate the performance and emissions capability:
  - U.S. EPA / CARB 2013 emission standards (g/bhp-hr):
    - U.S. EPA 2017 GHG emission standards
    - Peak rating of 260 hp and 660 lb-ft torque.
    - 5 to 10% improved fuel economy over CWI’s 5.9l LBSI NG engine (last sold in the North American market through 2009)
Pre-Alpha Design

- Goals
  - Define and verify engine architecture.
  - Demonstrate target performance levels

- Analysis tools used prior to engine build and test were:
  - DFMEA (Design Failure Mode Effects Analysis)
  - CAD layout (Pro Engineer by Parametric Technologies)
  - Engine performance model (“GT Power” by Gamma Technologies)
  - Combustion modeling (“KIVA” by Los Alamos National Lab)
  - FEA (Finite Element Analysis)
  - CFD (Computational Fluid Dynamics)
Pre-Alpha Engine Testing

- Demonstrated Engine Performance
- Learnings for Alpha Design
  - Multiple piston designs tested, narrowed choice for Alpha
  - Confirmed use of existing ISL G three way catalyst

<table>
<thead>
<tr>
<th>VOC DELIVERABLE</th>
<th>STATUS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emissions (NOx, PM, CO, etc)</td>
<td>✔</td>
</tr>
<tr>
<td>Green House Gas</td>
<td>✔</td>
</tr>
<tr>
<td>Noise</td>
<td>✔</td>
</tr>
<tr>
<td>Peak Power</td>
<td>✔</td>
</tr>
<tr>
<td>Peak Torque</td>
<td>✔</td>
</tr>
<tr>
<td>Responsiveness</td>
<td>✔</td>
</tr>
<tr>
<td>Heat Rejection</td>
<td>✔</td>
</tr>
<tr>
<td>Fuel Economy</td>
<td>✔</td>
</tr>
<tr>
<td>Transmission Compatibility</td>
<td>✔</td>
</tr>
</tbody>
</table>

NGVTF Oct 21, 2015 – CWI Update
System Architecture

- Same architecture as ISL G & ISX12 G, sized to ISB6.7 platform
  - Stoichiometric, cooled EGR spark ignition
  - Coil-on-plug ignition
  - 4 valve head

Common Emissions Architecture
- Stoichiometric Combustion, Cooled EGR & Three Way Catalyst
- Control System

Common Base Engine Architecture
- Base Engine
- Cooled EGR
Alpha Design

- Goals:
  - apply the learning gained from the concept engine operation
  - begin optimizing the engine and engine component designs
  - further assess the design capability to meet targets

- Differences Concept / Alpha design:
  - Concept design uses existing components wherever possible
  - Alpha design strives for “production-intent” design components.
  - Alpha focuses on creating component and sub-system designs that will enable high-volume manufacturing.
Alpha Design

- Alpha design focused on the following components & subsystems
  - Power cylinder
  - Control system
  - Ignition system
  - Cylinder head
  - Air handling (i.e. turbocharger)
  - Fuel supply module
  - Aftertreatment

- Alpha testing
  - Engine Dynamometer
  - Vehicle testing
Alpha Engine Validation Testing

- Test cell & vehicle testing of performance, durability and customer acceptance
- Learnings fed into Beta engine design
- CEC funded project successfully completed
- **Thank you** to CEC’s PIER program management and staff for supporting this project.

<table>
<thead>
<tr>
<th>Project Target</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>EPA 13 criteria emissions standards</td>
<td>All successfully demonstrated – NOx target lowered target to 0.01 g (meet optional Low NOx Standard)</td>
</tr>
<tr>
<td>EPA 2017 GHG emissions standards (CO₂, CH₄, &amp; N₂O)</td>
<td>Successfully demonstrated</td>
</tr>
<tr>
<td>Peak Rating: 260 hp / 660 lb-ft</td>
<td>Successfully demonstrated</td>
</tr>
<tr>
<td>5 to 10% improved FE over 2009 5.9l engine</td>
<td>Successfully demonstrated. Also VMS simulations comparing ISB6.7 G to ISB6.7 diesel shows much less than 15% FE penalty</td>
</tr>
</tbody>
</table>
Post Funded Project

- Completed Beta design
- Field Trials well underway
- Remaining commercialization activities progressing
- **Q2 2016 production date**
- Initial launch in School Bus:
  - Thomas Built Bus C2 CNG
- Working with other bus OEMs and speciality vehicle OEMs on both EPA13 and Euro V ratings for launch later in 2016
Design Architecture

- 4 Valve Cylinder Head
- Ignition Control Module
- Engine Control Module
- Fuel Module
- Wastegate Turbo
- EGR Valve
- Coil on Plug Ignition
### ISB6.7 G

<table>
<thead>
<tr>
<th>Model</th>
<th>Power @ 2400 RPM</th>
<th>Torque @ 1600 RPM</th>
</tr>
</thead>
<tbody>
<tr>
<td>ISB6.7 G 200</td>
<td>200 hp</td>
<td>520 lb ft</td>
</tr>
<tr>
<td>ISB6.7 G 220</td>
<td>220 hp</td>
<td>520 lb ft</td>
</tr>
<tr>
<td>ISB6.7 G 240</td>
<td>240 hp</td>
<td>560 lb ft</td>
</tr>
<tr>
<td>ISB6.7 G 260</td>
<td>260 hp</td>
<td>660 lb ft</td>
</tr>
</tbody>
</table>

NGVTF Oct 21, 2015 – CWI Update
Agenda: Funded Projects / Commercial Products

- ISB6.7 G Update
- ISX12 G Update
- CWI Lower Emissions Pathway
NREL 11.9 Natural Gas Engine Project

- Funding partners:
  - NREL (with funding from DOE, CEC’s PIER program, and AQMD)
  - CEC AB118 program (in conjunction with Gas Technology Institute)

- Dovetails into prior CEC PIER project, conducted in conjunction with Gas Technology Institute

- Project Objectives
  - Continue the 11.9 liter heavy duty natural gas engine development, building on the success of the CEC PIER-sponsored preliminary development work
  - Demonstrate a number of engines in a variety of on-road operating conditions to identify and resolve engine issues prior to commercial launch
  - Allow key customers to demonstrate the engine
  - Obtain emission certification at or below EPA / CARB emission standards
  - Prepare for high-volume commercial launch with OEM availability in a range of industry-leading Class 8 truck & tractor models by 2013
ISX12 G - Field Demonstration

- CWI deployed 25 field test trucks, plus additional “market seed” units, powered by pre-production Alpha & Beta engines

- ~2.5 million miles of vehicle operation from the field test fleet
- Test engines have been removed new, emission-certified, production-built ISX12 G engines installed

<table>
<thead>
<tr>
<th>State</th>
<th># Field Test Trucks</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>California</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Utah</td>
<td>5</td>
<td>Base for trucks operating interstate</td>
</tr>
<tr>
<td>Indiana</td>
<td>4</td>
<td>Includes CWI-operated Engineering trucks</td>
</tr>
<tr>
<td>Arkansas</td>
<td>2</td>
<td>De-commissioned and re-powered to diesel during field test due to oilfield contractor losing their contract and re-locating entire fleet to a different state, without CNG access.</td>
</tr>
<tr>
<td>Nebraska</td>
<td>2</td>
<td>Base for trucks operating interstate</td>
</tr>
<tr>
<td>Texas</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Arizona</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Wisconsin</td>
<td>1</td>
<td>Base for trucks operating interstate</td>
</tr>
<tr>
<td>New Jersey</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Oklahoma</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Various</td>
<td>1</td>
<td>OEM demo truck; operated in multiple states</td>
</tr>
</tbody>
</table>
Project Summary

- ISX12 G engine launched in 2013
  - Limited Production Apr-Jul (350 hp max rating)
  - Full Production with full range of ratings (320 to 400 hp) August

- CWI / NREL Subcontract expired Dec 31, 2013

- ISX12 G development program has been a huge success.

- Thank you to CEC, DOE, AQMD & NREL program management and staff for supporting this project.
Natural Gas Engine Introduction

- **Target Markets**
  - Regional haul truck / tractor
  - Vocational
  - Refuse

- **Platform & Technology**
  - Cummins 11.9 litre ISX12 diesel is base engine
  - Utilizing spark-ignition with cooled EGR & three way catalyst (TWC)
    - Same combustion technology as ISL G
# Differences

**ISX12 diesel and ISX12 G natural gas**

<table>
<thead>
<tr>
<th></th>
<th>ISX12</th>
<th>ISX12 G</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Horsepower</strong></td>
<td>310-425 HP</td>
<td>320-400 HP</td>
</tr>
<tr>
<td></td>
<td>231-317 kW</td>
<td>239-298 kW</td>
</tr>
<tr>
<td><strong>Peak Torque</strong></td>
<td>1150-1650 lb-ft</td>
<td>1150-1450 lb-ft</td>
</tr>
<tr>
<td></td>
<td>1559-2237 N-m</td>
<td>1559-1966 N-m</td>
</tr>
<tr>
<td><strong>Torque at Idle</strong></td>
<td>800 lb-ft</td>
<td>700 lb-ft</td>
</tr>
<tr>
<td></td>
<td>1085 N-m</td>
<td>949 N-m</td>
</tr>
<tr>
<td><strong>Aftertreatment</strong></td>
<td>DPF + SCR</td>
<td>Three Way Catalyst</td>
</tr>
<tr>
<td><strong>Engine Brake</strong></td>
<td>Optional 380 HP @ 2100 RPM</td>
<td>Optional 240 HP @ 2100 RPM</td>
</tr>
<tr>
<td><strong>Performance</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Customer Feedback

John Erwin
Director of Operations Support

- ISX12 G does everything we need it to do..from city delivery to 80,000 lb class 8 highway transport.
- Our commitment to natural gas has brought new business our way

Carl Suhr
Kwik Trip

- Fuel economy is currently running 12-13% per DGE below our diesels in like application. That being said, our average cost differential between diesel and CNG is running at a 48% advantage for CNG. Due to this differential our fuel CPM is dramatically improved with the CNG equipment.

Mark Storemann
Director of Operations

Our 42 - ISX12 G Kenworth T660 Ruan trucks at Fair Oaks farm have accumulated about 72,000 miles/truck, and the fuel economy has been 5.8 - 6.0 mpg., which is 12% better than our ISL G fleet."
Design Architecture

- Wastegate Turbo
- 4 Valve Cylinder Head
- Coils on Plug Ignition
- EGR Valve
- Fuel Module
- Ignition Control Module
- Engine Control Module
# ISX12 G Availability

<table>
<thead>
<tr>
<th>OEM</th>
<th>Freightliner</th>
<th>Peterbilt</th>
<th>Kenworth</th>
<th>Volvo</th>
<th>Mack</th>
<th>Autocar</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>Cascadia Day Cab, Sleeper 114SD**</td>
<td>320</td>
<td>W900S T660 T800 SH T680</td>
<td>VNL</td>
<td>Pinnacle</td>
<td>Xpeditor</td>
</tr>
<tr>
<td>Engine</td>
<td>ISX12 G</td>
<td>ISX12 G</td>
<td>ISX12 G</td>
<td>ISX12 G</td>
<td>ISX12 G</td>
<td>ISX12 G</td>
</tr>
<tr>
<td>Application</td>
<td>Tractor</td>
<td>Refuse Tractor Vocational</td>
<td>Tractor Vocational</td>
<td>Tractor Vocational</td>
<td>Tractor Vocational</td>
<td>Refuse</td>
</tr>
</tbody>
</table>

** New chassis for 2015

NGVTF Oct 15, 2014 – CWI Update
# Fuel Economy Feature Comparison

<table>
<thead>
<tr>
<th>Feature</th>
<th>ISX12 G</th>
<th>ISX12/15</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adaptive Cruise Control</td>
<td>Yes*</td>
<td>Yes</td>
</tr>
<tr>
<td>Ambient Idle Shutdown</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Cruise Control</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Driver Reward</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Engine Brake Controls</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Gear Down Protection</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Idle Shutdown</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Load Based Speed Control</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Powertrain Protection</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Road Speed Governor</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Vehicle Acceleration Management</td>
<td>No</td>
<td>Yes</td>
</tr>
</tbody>
</table>

*Requires Additional Hardware from OEMs
ISX12 G with UltraShift PLUS

- Eaton approved package
- For Linehaul Active Shifting (LAS) and Multipurpose High Performance (MHP) transmission models
- Linehaul and Regional Haul only
Agenda: Funded Projects / Commercial Products

- ISB6.7 G Update
- ISX12 G Update
- CWI Lower Emissions Pathway
California (ARB) Has Plans to Lower NOx

- CARB/EPA current standards for engine manufacturers have achieved 96.7% NOx reduction since 1990!
- Moving forward ARB has established three optional low NOx emissions standards
  - 0.02 g/bhp-hr is called “Near Zero” NOx emissions,
  - This is a 90% reduction in NOx from current EPA standards!

<table>
<thead>
<tr>
<th>NOx Standard</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.2 g/bhp-hr</td>
<td>Current EPA NOx standard</td>
</tr>
<tr>
<td>0.1 g/bhp-hr</td>
<td>ARB optional low NOx standards</td>
</tr>
<tr>
<td>0.05 g/bhp-hr</td>
<td></td>
</tr>
<tr>
<td>0.02 g/bhp-hr</td>
<td>“Near Zero”</td>
</tr>
</tbody>
</table>
Near Zero Emissions Natural Gas Engine

- NOx Emissions Target: 0.02g/bhp-hr
- Near Zero Technology developed through funding from:
  - South Coast Air Quality Management District
  - California Energy Commission
  - Southern California Gas

- In 2014 - completed laboratory-based R&D, using prototype hardware, testing the ISL G for near zero emissions while maintaining current architecture
- 2015 work to be completed:
  - Component and engine design for high volume manufacture
  - Extensive component / system validation to demonstrate performance, reliability and durability, including field testing in California
Near Zero Technology Development

- Thorough technology investigation to understand opportunities for improvement
- Technologies evaluated for performance impact
- Near Zero Architecture chosen based on:
  - Emissions performance
  - Fuel Efficiency
  - Cost
  - Development time
CARB & EPA Certification Received – Oct

Pursuant to the authority vested in the Air Resources Board by Health and Safety Code Division 26, Part 5, Chapter 2; and pursuant to the authority vested in the undersigned by Health and Safety Code Sections 39515 and 39516 and Executive Order G-14-012;

IT IS ORDERED AND RESOLVED: The engine and emission control systems produced by the manufacturer are certified as described below for use in on-road motor vehicles with a manufacturer’s GVWR over 14,000 pounds. Production engines shall be in all material respects the same as those for which certification is granted.

<table>
<thead>
<tr>
<th>MODEL YEAR</th>
<th>ENGINE FAMILY</th>
<th>ENGINE SIZES (L)</th>
<th>FUEL TYPE</th>
<th>STANDARDS &amp; TEST PROCEDURE</th>
<th>INTENDED SERVICE CLASS</th>
<th>ECS &amp; SPECIAL FEATURES</th>
<th>DIAGNOSTIC</th>
</tr>
</thead>
<tbody>
<tr>
<td>2016</td>
<td>GCEXH0540LB1</td>
<td>8.9</td>
<td>CNG/LNG</td>
<td>Diesel</td>
<td>UB</td>
<td>TBI, TC, CAC, ECM, EGR, TWC, HO2S</td>
<td>EMD+</td>
</tr>
</tbody>
</table>

**Primary Engine’s idle emissions control:** EXEMPT

**Engine Models / Codes (rated power, in hp):**
- ISL G 250 / 4836; FR95359 (258), ISL G 280 / 4836; FR95354 (280), ISL G 300 / 4836; FR95351 (300), ISL G 320 / 4836; FR95348 (320)

<table>
<thead>
<tr>
<th>In</th>
<th>g/bhp-hr</th>
<th>NMHC</th>
<th>SET</th>
<th>NOx</th>
<th>SET</th>
<th>NMHC+NOx</th>
<th>SET</th>
<th>CO</th>
<th>FTP</th>
<th>SET</th>
<th>PM</th>
<th>FTP</th>
<th>SET</th>
<th>HCHO</th>
<th>FTP</th>
<th>SET</th>
</tr>
</thead>
<tbody>
<tr>
<td>STD</td>
<td>0.14</td>
<td>0.14</td>
<td>FTP</td>
<td>0.02</td>
<td>FTP</td>
<td>0.02</td>
<td>FTP</td>
<td>15.5</td>
<td>FTP</td>
<td>15.5</td>
<td>0.01</td>
<td>0.01</td>
<td>*</td>
<td>*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CERT</td>
<td>0.01</td>
<td>0.000</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NTE</td>
<td>0.21</td>
<td>0.03</td>
<td>19.4</td>
<td>*</td>
<td>0.02</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Manufacturer:** CUMMINS INC

**Engine Family:** GCEXH0540LB1
**Certificate Number:** CEX-ONHWY-16-01
**Intended Service Class:** URBAN BUS
**Fuel Type:** NATURAL GAS
**FELs G/BHP:** NMHC +NOx: N/A
**NOx:** N/A
**PM:** N/A

**Greenhouse Gas Info.**
- Primary Intended Service Class: VOCATIONAL
- Primary Test Configuration FTP (if applicable):
  - CO₂ FCL value (g/bhp-hr): 476
  - CO₂ FEL value (g/bhp-hr): 490
  - N₂O FEL value (g/bhp-hr): 0.10
  - CH₄ FEL value (g/bhp-hr): 0.65
- Primary Test Configuration Ramped-model (if applicable):
  - CO₂ FCL value (g/bhp-hr): CO₂ FEL value (g/bhp-hr)
EPA GHG Standards

- Two compliance paths:
  1. Engine emissions < standards for each GHG pollutant, or
  2. CO$_2$-equivalent path
     \[ \text{CO}_2\text{eq} = \text{CO}_2 + \text{CH}_4 \times 25 + \text{N}_2\text{O} \times 310 \]
     - If N2O below std then don’t include in equation

<table>
<thead>
<tr>
<th>Greenhouse Gas Emissions Criteria</th>
<th>Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engine related Methane (CH$_4$)</td>
<td>↓ 70% reduction (crankcase and tailpipe)</td>
</tr>
<tr>
<td>Greenhouse Gases (CO$_2$ equivalent)</td>
<td>↓ 9% reduction (technology pathway for further reduction in 2019/2020)</td>
</tr>
</tbody>
</table>

### MHHD Service Class

<table>
<thead>
<tr>
<th></th>
<th>ISL-G</th>
<th>ISL-G NZ</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO2 FCL</td>
<td>483.5</td>
<td>476</td>
</tr>
<tr>
<td>CO2 FEL</td>
<td>499</td>
<td>490</td>
</tr>
<tr>
<td>N2O FEL</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>CH4 FEL</td>
<td>2.36</td>
<td>0.65</td>
</tr>
<tr>
<td>Weighted CO2</td>
<td>499</td>
<td>490</td>
</tr>
<tr>
<td>Weighted N2O</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Weighted CH4</td>
<td>59</td>
<td>16.25</td>
</tr>
<tr>
<td>CO2e FEL</td>
<td>558</td>
<td>506</td>
</tr>
</tbody>
</table>

Table and chart courtesy of GNA

Source: US EPA GHG Certification data for 2015 ISL-G and ISL-G NZ engines for MHHD service class
• Production to start April 2016
• Base ISL G engine design is the same
  – Engine will be factory built at Cummins Rocky Mount Engine Plant
  – Ratings and operational / maintenance procedures will be the same
  – Warranty and Extended Coverage will be the same
  – No change in technician service certification requirements
  – Package size similar
• Closed Crankcase Ventilation (CCV) will be added to engine
  – Current ISL G has an open breather system.
  – CCV Filter is chassis mounted
  – CCV filter change required at 2,000 hours
• Three Way Catalyst will change to meet next level emissions
  – Remains maintenance free
  – Larger size catalyst with addition sensor added
• Next level calibration leading to OBD in 2018
## Ratings

<table>
<thead>
<tr>
<th>ENGINE MODEL</th>
<th>ADVERTISED HP(KW) @ RPM</th>
<th>PEAK TORQUE LB-FT @ RPM</th>
<th>GOVERNED SPEED</th>
</tr>
</thead>
<tbody>
<tr>
<td>ISL G NZ 320</td>
<td>320 (239) @ 2000</td>
<td>1000 (1356) @ 1300</td>
<td>2200 RPM</td>
</tr>
<tr>
<td>ISL G NZ 300</td>
<td>300 (224) @ 2100</td>
<td>860 (1166) @ 1300</td>
<td>2200 RPM</td>
</tr>
<tr>
<td>ISL G NZ 280</td>
<td>280 (209) @ 2000</td>
<td>900 (1220) @ 1300</td>
<td>2200 RPM</td>
</tr>
<tr>
<td>ISL G NZ 260</td>
<td>260 (194) @ 2200</td>
<td>660 (895) @ 1300</td>
<td>2200 RPM</td>
</tr>
<tr>
<td>ISL G NZ 250</td>
<td>250 (186) @ 2200</td>
<td>730 (990) @ 1300</td>
<td>2200 RPM</td>
</tr>
</tbody>
</table>
Questions

Stephen Ptucha
Product Management & Planning
Cummins Westport Inc.