Agenda: CWI Product Development Updates

- ISB6.7 G
- ISL G Near Zero
- ISX12 G Near Zero
Agenda: CWI Product Development Updates

- ISB6.7 G
- ISL G Near Zero
- ISX12 G Near Zero
**ISB6.7 G Project Introduction**

<table>
<thead>
<tr>
<th>Project Title:</th>
<th>Advanced 6.7 Liter Natural Gas Engine Development</th>
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</thead>
<tbody>
<tr>
<td>Funding Source:</td>
<td>CEC / GTI</td>
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<tr>
<td>Resulting CWI Engine:</td>
<td>ISB6.7 G (6.7 liter)</td>
</tr>
<tr>
<td>Award:</td>
<td>$1M</td>
</tr>
<tr>
<td>Scope:</td>
<td>Grant funding supports Alpha design, development, demonstration, and Beta design of a new, 6.7 liter natural gas engine</td>
</tr>
<tr>
<td>Term:</td>
<td>Aug/13 thru Dec/14</td>
</tr>
<tr>
<td>Status:</td>
<td>Project completed, ISB6.7 G in production</td>
</tr>
</tbody>
</table>

NGVTF 2016 - Cummins Westport
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)

- All project goals achieved
- 4 cycle, spark ignited, in-line 6 cylinder, turbocharged, CAC
- Displacement – 6.7 litres (408.9 cu in)
- Peak rating: 240 hp, 560 lb-ft
- 2016 EPA/CARB certified
- Meet 2017 EPA GHG requirements
- Dedicated 100% natural gas engine
- Three Way Catalyst after-treatment
- Automatic Transmissions
- Base warranty will be same as ISB6.7 diesel
## Natural Gas Engine

<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>
</tbody>
</table>
**Key Markets**

- Initial launch School Bus
  - Thomas Built Bus Saf-T Liner C2
- Subsequent launches into other segments
  - Yard Spotter
  - Shuttle Bus
  - MD Truck (Class 6-8)
Agenda: CWI Product Development Updates

- ISB6.7 G
- ISL G Near Zero
- ISX12 G Near Zero
# Near Zero NOx Project Introduction

<table>
<thead>
<tr>
<th>Project Title:</th>
<th>On-Road Heavy-Duty Development, Integration and Demonstration of Ultra-Low Emissions Natural Gas Engines</th>
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<tr>
<td>Funding Source:</td>
<td>SCAQMD / CEC / SoCal Gas</td>
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<td>Resulting CWI Engine:</td>
<td>ISL G Near Zero (8.9 liter)</td>
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<tr>
<td>Award:</td>
<td>$3.5M</td>
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</table>
| Scope: | To develop a prototype HD NG engine suitable for on-road heavy-duty vehicle applications…capable of:  
  • Target NOx emissions: 0.02 g/bhp-hr  
  • Capable of CARB and EPA certification |
| Term: | May/15 thru Dec/16 |
| Status: | Project nearing completion, ISL G Near Zero in production |
Near Zero Technology – Path to 0.02 g NOx

- Investigated potential levers:
- Evaluated capability of levers:
- Selected architecture

Solution:
- CCV addition
- TWC Improvements
- Optimized controls

Evaluation Criteria

- Emissions Performance
- Fuel Efficiency
- Cost
- Development Time
Closed Crankcase Ventilation (CCV)

- Filters crankcase emissions,
- Returns engine oil to sump,
- Recirculates and reintroduces “air” to engine intake
- Results in 70% lower engine methane emissions
Three-Way Catalyst Improvements

- Increased working volume
- Improved mixture of precious metals (Platinum, Palladium and Rhodium)
- Addition of mid-bed temperature sensor to enable advanced controls and HD-OBD
Optimized Controls

- Engine exhaust emissions depend on conditions
  - Lean conditions = high NOx
  - Rich conditions = high CO & HC
- TWC operation
  - Lean conditions = low conversion of NOx
  - Rich conditions = low conversion of CO
  - Need to operate stoichiometric for high conversion
  - Feedback allows for dithering around stoichiometric
- Controls optimized for engine operation

**Major Reaction**

- $CO + \frac{1}{2}O_2 = CO_2$
- $H_4C_2 + 3O_2 = 2CO_2 + 2H_2O$
- $CO + NOx = CO_2 + N_2$

Generic TWC Performance chart courtesy of www.nettinc.com
Optimized Controls

- Targeting high NOx forming points in duty cycle
- Conditions are not optimal for TWC operation
  - Example: motoring has air flow but no fuel
    - Lean conditions $\rightarrow$ reduce conversion efficiency
    - Lower temperatures $\rightarrow$ reduce conversion efficiency
- Mid-bed Temperature sensor enables for higher precision and quicker response
What’s Driving Near Zero engines?

2030. At the same time, we must continue efforts to minimize near-source risk and exposure to toxic air contaminants. As illustrated in Figure 2-1, mobile sources and the fuels that power them contribute over 80 percent of on-road non-attainment NOx emissions, 95 percent of the diesel PM emissions, and nearly 50 percent of statewide GHG emissions. Efforts to reduce pollution and fossil fuel use in mobile sources will therefore be essential in creating a future transportation system that provides the foundation for meeting California’s goals.

6. On-Road Heavy-Duty Sector

In order to meet our air quality goals and GHG emission and petroleum use reduction targets, the on-road heavy-duty sector must transition to near-zero emission technology coupled with advanced renewable fuels, and zero emission vehicles and equipment where available.

For heavy-duty vehicles, compression ignition will continue to dominate over the next 15 years. The strategy therefore calls for engine technology that is effectively 90 percent cleaner than today’s current standards, with clean, renewable fuels comprising half the fuels burned. To position the heavy-duty sector for longer-term

Vision Scenarios Planning [Link]
NOx is 90% below STD
PM is 90% below STD
CO2 is 16% below STD
RNG compatibility enables GHG emission reduction to near zero levels as well (landfills, dairies, waste water streams, etc.)
NZ is ready now… how clean do you want to be and how fast?

- Current control programs drive all HD vehicles to 2010 0.2 NOx standard by 2023… rapid progress but still not enough to hit Clean Air targets
- A NZ NGV advocacy program overlay could reduce NOx 90% below current controls (around 60 extra tons per day)

*The scenarios illustrated in this figure reflect natural turnover rates.*
## Certified Emissions

### NOx Standard (g/bhp-hr)

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<thead>
<tr>
<th></th>
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<tbody>
<tr>
<td>NOx Standard</td>
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<td>4</td>
<td>0.2</td>
<td>0.02</td>
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</table>

### ARB Near Zero Emissions

- **NOx Standard**: (g/bhp-hr)

<table>
<thead>
<tr>
<th>Year</th>
<th>1985</th>
<th>2000</th>
<th>2010</th>
<th>2016 CARB Near Zero</th>
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<tbody>
<tr>
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<td>0.2</td>
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</table>

### ISL G Near Zero Emissions

<table>
<thead>
<tr>
<th>Year</th>
<th>2000 model year Bus</th>
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<tbody>
<tr>
<td>NOx Standard</td>
<td>200</td>
</tr>
<tr>
<td>2016 “Near Zero” Buses</td>
<td>200</td>
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</tbody>
</table>

### Emissions Data

#### 1985
- NMHC
- NOx
- NMHC+NOx
- CO
- PM
- HC+HDO

<table>
<thead>
<tr>
<th>g/bhp-hr</th>
<th>FTP</th>
<th>SET</th>
<th>FTP</th>
<th>SET</th>
<th>FTP</th>
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<tr>
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<td>*</td>
<td>15.5</td>
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<td>0.01</td>
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<tr>
<td>CERT</td>
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<td>0.02</td>
<td>0.13</td>
<td>0.01</td>
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<td>*</td>
<td>7.5</td>
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<td>19.4</td>
<td>0.02</td>
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</tbody>
</table>

#### 2000
- NMHC
- NOx
- NMHC+NOx
- CO
- PM
- HC+HDO

<table>
<thead>
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<th>g/bhp-hr</th>
<th>FTP</th>
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<tr>
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<td>0.03</td>
<td>*</td>
<td>*</td>
<td>19.4</td>
<td>0.02</td>
<td>*</td>
<td>*</td>
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<td>*</td>
</tr>
</tbody>
</table>

### Notes
- g/bhp-hr: grams per brake horsepower hour
- FTP: Federal Test Procedure
- SET: Supplemental emissions testing
- NMHC: Non-methane hydrocarbons
- NOx: Oxides of nitrogen
- CO: Carbon monoxide
- PM: Particulate matter
- HC+HDO: Formaldehyde

### CARB Requirements
- **2000 Model Year Bus Equivalent NOx**
- **2016 “Near Zero” Buses**

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NGVTF 2016 - Cummins Westport
New Flyer expands clear air propulsion leadership with the Cummins Westport ISL G Near Zero emissions engine

PETERBILT INTRODUCES CUMMINS ISL G NEAR ZERO EMISSIONS ENGINE FOR MODELS 667, 530 AND 320

DENTON, Texas (August 30, 2016)

Peterbilt Motors Company introduces the Cummins Westport ISL G Near Zero NOx emissions engine for Models 667, 530 and 320.

The ISL G near-zero engine emissions are 95 percent lower than the current EPA limits and the introduction of a unique three-way catalytic after-treatment advanced engine calibration and a cooled exhaust gas recirculation system (CEGR).

Kenworth T680 and T880 Add Cummins Westport ISL G Near Zero Emissions Natural Gas Engine

LAS VEGAS, Nev. – Kenworth announced that it will offer the Cummins Westport ISL G Near Zero NOX emissions natural gas engine for the Kenworth T680 and T880.

"The Kenworth T680 and T880 engaged with the ISL G Near Zero emissions engine is well suited for regional haul, vocational and refuse fleet owners to reduce the total environmental impact of natural gas use and reducing their operating costs," said Jason Shope, Kenworth assistant general manager for sales and marketing.

The 9.9-liter Cummins Westport ISL G Near Zero comes with ratings up to 320 hp and 1,000 lb-ft of torque. The engine can operate on 100 percent natural gas, which can be carried on the vehicle as either compressed natural gas (CNG) or liquefied natural gas (LNG) form. The new ISL G Near Zero is also compatible with renewable natural gas (RNG) which allows for even further reductions in GHG emissions.

The new engine will become available in the Kenworth T680 and T880 in early 2017. Kenworth is the driver’s truck. See what drivers are saying at www.kenworth.com/kdrivers.

Kenworth Truck Company is the manufacturer of The World’s Best Heavy and medium-duty truck. Kenworth’s complete truck page is at www.kenworth.com. PACCAR is a member of the Fortune 500.

City of Santa Monica Approves Multi-Year Contract with Clean Energy's Redeem™; Fuel to Support Deployment of CWI Near-Zero 0.02 NOx Engine

June 2, 2016

NEWPORT BEACH, Calif. — Clean Energy Fuels Corp. (NASDAQ: CLNE) announced that the City of Santa Monica has awarded Clean Energy a multiyear (liquefied natural gas or LNG) contract to fuel its Big Blue Bus fleet of 76 vehicles. The City of Santa Monica is the 46th public-sector agency that Clean Energy has signed up since the launch of Redeem™, the nation’s cleanest transportation fuel.

LG&R LNGR 0.02 NOx engine.

"The City of Santa Monica has a deep commitment to the people and environment in our community. By continuing the environmental benefits of Clean Energy’s liquefied natural gas technology, we not only create clean and efficient local transportation, but also create value for our residents," said Robert Willard, City Manager.

"The City of Santa Monica is nationally recognized leader for its sustainability policies and actions. Clean Energy has progressively contributed to the City’s sustainability narrative through its use of alternative fuel and emissions plugging out of diesel fueled motor coaches. Through this commitment, clean burning LNGR and the new 0.02 NOx engine will power BBB’s entire fleet.

"Big Blue Bus has always been a leader in sustainability, and with our new LNGR and the implementation of one new Clean Energy liquefied natural gas motor coach, the City has once again set a new goal for the transportation industry and the incredible advancements we are making in reducing the impact on the environment," said Peter Grace, Clean Energy’s senior vice president for sales and finances.

For more information about the Clean Energy fueling service visit www.CLEAN.png

Clean Energy believes that Redeem™ is the cleanest transportation fuel commercially available in the U.S. according to EPA data regarding carbon emissions for transportation fuel. Redeem™ is a renewable natural gas vehicle fuel, often referred to as biomethane. It is derived from biogas or biomethane, that is naturally generated by the decomposition of organic waste that is manufactured, processed and sent into the intermodal natural gas pipeline and made available exclusively to Clean Energy customers.

Clean Energy operates an extensive network of biomethane production facilities, including two plants and operated by Clean Energy.

PETROBILT INTRODUCES CUMMINS ISL G NEAR ZERO EMISSIONS ENGINE FOR MODELS 667, 530 AND 320

DENTON, Texas (August 30, 2016)

Peterbilt Motors Company introduces the Cummins Westport ISL G Near Zero NOx emissions engine for Models 667, 530 and 320.

The ISL G near-zero engine emissions are 95 percent lower than the current EPA limits and the introduction of a unique three-way catalytic after-treatment advanced engine calibration and a cooled exhaust gas recirculation system (CEGR).

"Petrobilt is producing exceptionally products," said Steve Martin, Petrobilt Chief Engineer. "The addition of the ISL G Near Zero emissions engine strengthens our position as an engine solution provider for the on-highway market.

"The new engine's performance and efficiency match the current ISL G-350 horsepower and 1,000 lb-ft torque available. Customers with industrial, vocational and refuse applications will benefit from the extended option.

"Petrobilt continues to lead the industry with the highest performing engines on the road," said Robert Willard, Petrobilt Assistant General Manager of Sales and Marketing. "We're pleased to offer the ISL G near-zero engine as an excellent choice for our partners.

"Like the currently available ISL-G engine, the ISL G Near Zero operates on 100 percent natural gas, which can be carried on the vehicle in either compressed CNG or liquefied LNG form. The new ISL G Near Zero can also run on renewable natural gas (RNG).

"The Cummins ISL-G Near Zero engine will become available in production in Models 530 and 320 by year-end. The new engine will become available in the Model year 2017.
Agenda: CWI Product Development Updates

- ISB6.7 G
- ISL G Near Zero
- ISX12 G Near Zero
# ISX12 G Near Zero Project

<table>
<thead>
<tr>
<th>Project Title:</th>
<th>Develop, Integrate &amp; Demonstrate Ultra-Low Emissions Natural Gas 12 Liter Engine For On-Road Heavy Duty Vehicles</th>
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<tbody>
<tr>
<td>Funding Source:</td>
<td>SCAQMD / CEC / SoCal Gas / Clean Energy</td>
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<tr>
<td>Resulting CWI Engine:</td>
<td>ISX12 G Near Zero (11.9 liter)</td>
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<td>Award:</td>
<td>$5.25M</td>
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<tr>
<td>Scope:</td>
<td>To develop a 12 liter HD NG engine suitable for on-road heavy-duty vehicle applications…capable of:</td>
</tr>
<tr>
<td></td>
<td>• Target NOx emissions: 0.02 g/bhp-hr</td>
</tr>
<tr>
<td></td>
<td>• CARB and EPA certified</td>
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<tr>
<td>Term:</td>
<td>May/16 thru March/18</td>
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<tr>
<td>Status:</td>
<td>Project underway, Targeting 2018 production for ISX12 G Near Zero</td>
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</table>
Scope

The objective of the work contained in these progress reports is to develop and demonstrate a 12-liter natural gas engine, and associated exhaust after-treatment technologies, that is (1) suitable for on-road heavy-heavy duty vehicle applications such as Class 8 trucks and buses; (2) commercially viable; and (3) capable of:

- Achieving emissions targets of 0.02 g/bhp-hr NOx, 0.01 g/bhp-hr PM, 0.14 g/bhp-hr NMHC, and 15.5 g/bhp-hr CO or lower as determined by the heavy duty engine FTP,
- Keeping exhaust NH\(_3\) emissions as low as achievable while targeting average NH\(_3\) emissions at 10 ppm or lower,
- Achieving minimal, fuel economy penalties relative to 2010 U.S. Environmental Protection Agency (EPA) and California Air Resources Board (CARB) certified diesel engines on similar duty cycles; and
- Being certified by the EPA and CARB
  - Heavy Duty On-Board Diagnostics required in 2018
Project Status

- Previously completed using ISL G
- Determined Near Zero architecture
  - Closed Crankcase Ventilation
  - Three-way Catalyst Improvements
  - Optimized controls
Alpha Prototype Highlights

Fuel Control Valve
Compressor Recirculation Valve
Fuel/EGR Manifold
EGR Crossover Tube and Flow Measurement Orifice
EGR Valve
Closed Crankcase Breather
Ignition Control Module
Engine Control Module

Fuel System Close Up
Alpha Prototype: Closed Crankcase Ventilation

Current Product – ISX12 G

ISX12 G NZ Alpha Prototype
Alpha Prototype: ECM & Wire Harness

The main engine harness routing looks similar to current product but has several routing changes to adjust to new connector(s), connector location, and to improve the support and routing of the harness. Relays have been added to control the ICM and ITV power supply.

This nut will not be present on the Volvo version of the harness. A fit tree will be used instead.
Alpha Prototype: Exhaust Gas Recirculation

Two EGR routing designs to accommodate OEM vehicle installations.
Alpha Prototype: Aftertreatment

Typical end-in, end-out configuration
CWI Product Line-Up

(Near Zero: Certified to ARB Near Zero NOx standard - 0.02 g/bhp.hr.)

<table>
<thead>
<tr>
<th>Engine</th>
<th>2016</th>
<th>2017</th>
<th>2018</th>
<th>2019</th>
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<tbody>
<tr>
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<td></td>
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<tr>
<td>ISB6.7 G NEAR ZERO</td>
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<td>ISL G</td>
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<td>ISL G NEAR ZERO</td>
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<td>ISX12 G</td>
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</table>

* ISB6.7 G is certified to California ARB optional Low NOx (0.1 g/bhp-hr)

“Near Zero” – refers to California ARB optional low NOx 0.02 g/bhp-hr level
Questions

Stephen Ptucha
Product Management & Planning
Cummins Westport Inc.