Cummins Westport
The Natural Choice

CWI Engine Update

Natural Gas Vehicle Technology Forum

October 21, 2015

Stephen Ptucha

Product Management & Planning
Cummins Westport Inc.

Agenda: Funded Projects / Commercial Products

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

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- ISB6.7 G Update
- ISX12 G Update
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ISB6.7 G Project Introduction

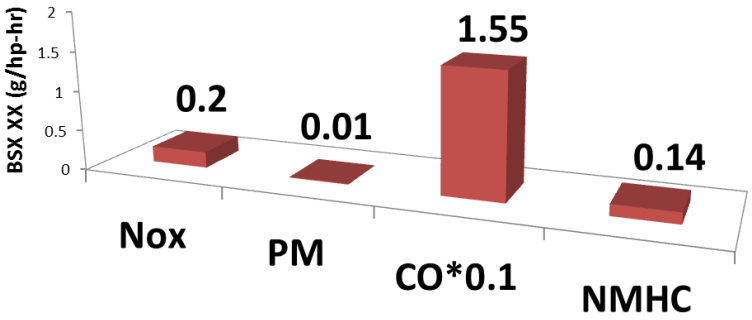
- Cummins Westport (CWI) and Gas Technology Institute (GTI) were awarded $1M from the California Energy Commission Public Interest Energy Research (PIER) program

- 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

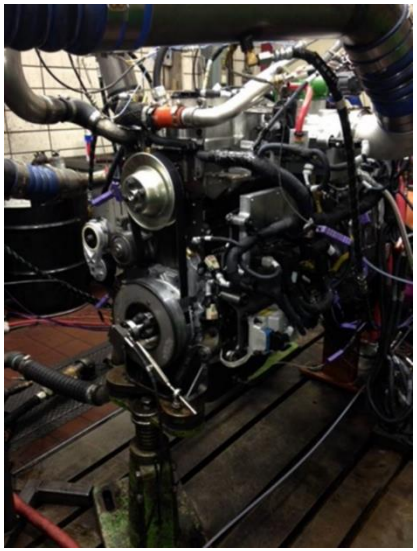
- Analysis tools used prior to engine build and test were:
  - DFMEA (Design Failure Mode Effects Analysis)
  - CAD layout (Pro Engineer by Parametric Technologies)
  - Engine performance model (“GT Power” by Gamma Technologies)
  - Combustion modeling (“KIVA” by Los Alamos National Lab)
  - FEA (Finite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

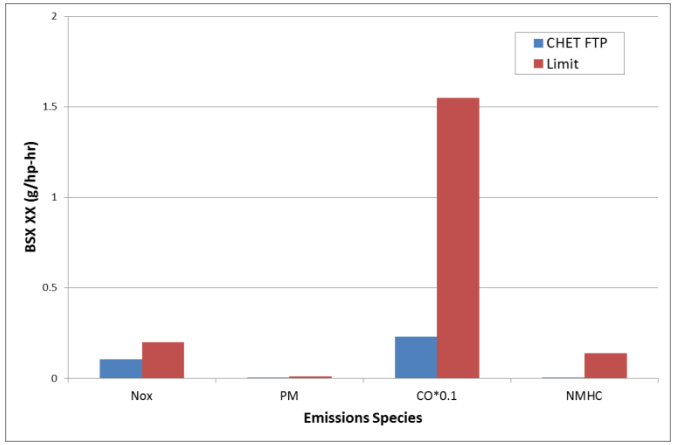
Pre-Alpha Engine Testing

- Demonstrated Engine Performance

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

VOC DELIVERABLE	STATUS
Emissions (NOx, PM, CO, etc)	✓
Green House Gas	✓
Noise	✓
Peak Power	✓
Peak Torque	✓
Responsiveness	✓
Heat Rejection	✓
Fuel Economy	✓
Transmission Compatibility	✓





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

ISL G

ISB6.7

ISB6.7 G

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

Common Base Engine Architecture
- Base Engine
- Cooled EGR

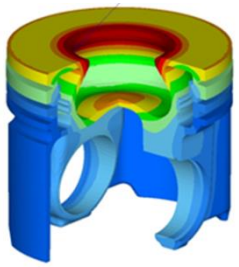
Alpha Design

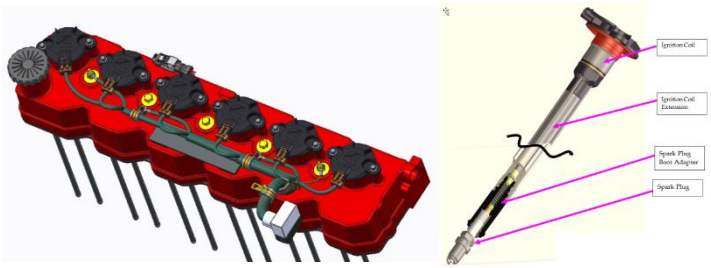
- Goals:
  - apply the learning gained from the concept engine operation
  - begin optimizing the engine and engine component designs
  - further assess the design capability to meet targets

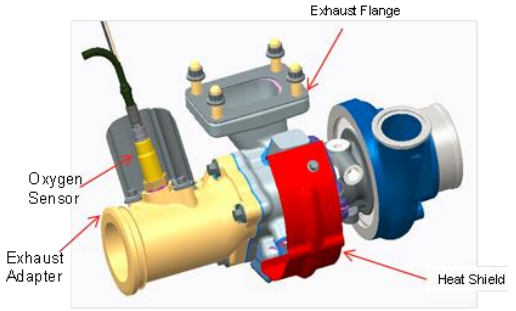
- Differences Concept / Alpha design:
  - Concept design uses existing components wherever possible
  - Alpha design strives for “production-intent” design components.
  - Alpha focuses on creating component and sub-system designs that will enable high-volume manufacturing.

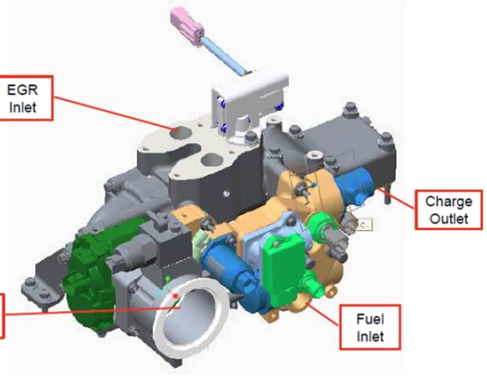
Alpha Design

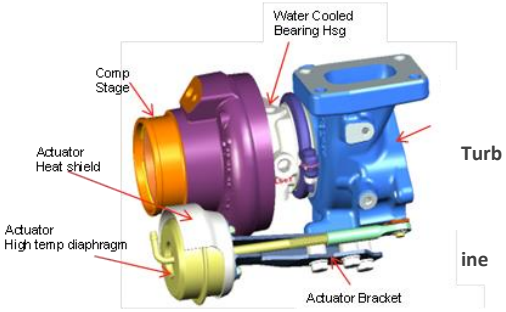
- Alpha design focused on the following components & subsystems
  - Power cylinder
  - Control system
  - Ignition system
  - Cylinder head
  - Air handling (i.e. turbocharger)
  - Fuel supply module
  - Aftertreatment
- Alpha testing
  - Engine Dynamometer
  - Vehicle testing











Westport

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.

Photo of SLT2 Engine 'Post Test' (note the scale formation due to water spray)

Photo of Combustion Face (no cracks present)

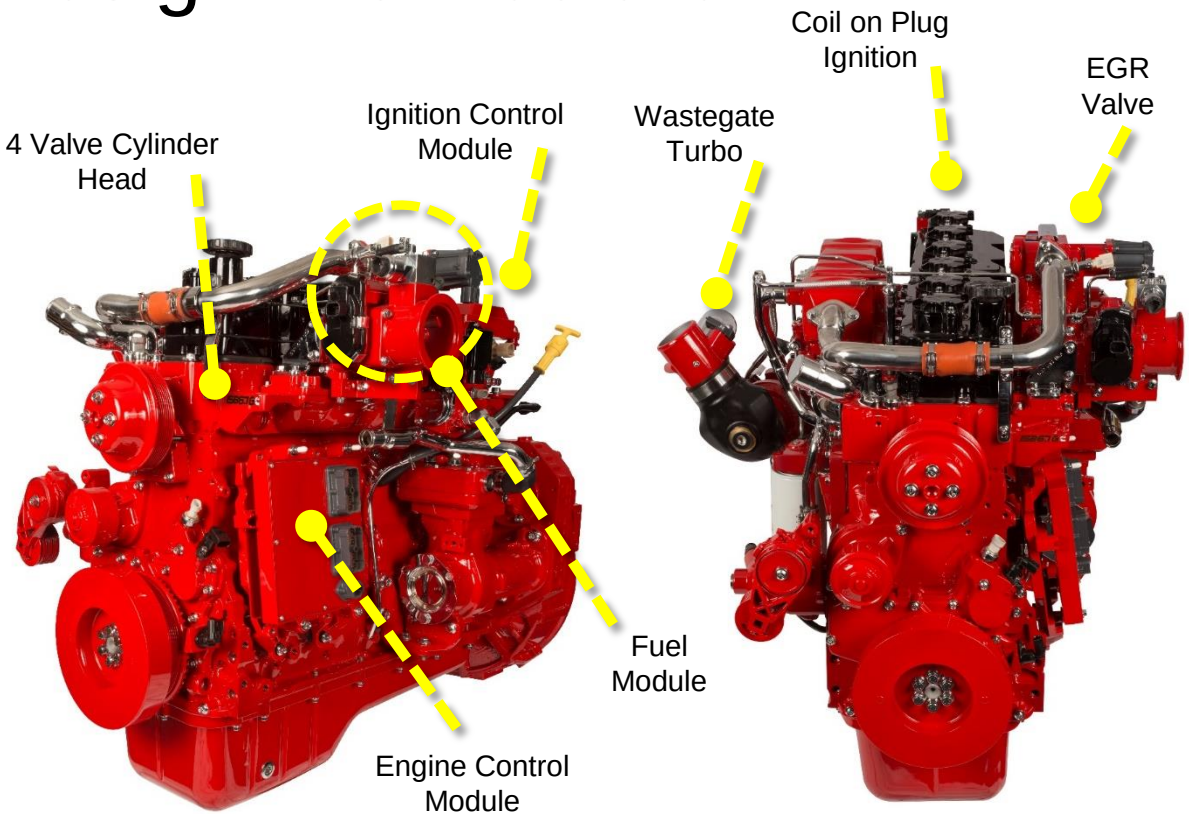
Project Target	Results
EPA 13 criteria emissions standards	All successfully demonstrated – NOx target lowered target to 0.01 g (meet optional Low NOx Standard)
EPA 2017 GHG emissions standards (CO_2, CH_4, & N_20)	Successfully demonstrated
Peak Rating: 260 hp / 660 lb-ft	Successfully demonstrated
5 to 10% improved FE over 2009 5.9l engine	Successfully demonstrated. Also VMS simulations comparing ISB6.7 G to ISB6.7 diesel shows much less than 15% FE penalty

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

TBB C2 with ISB6.7 G on display at ACT Expo 2015

ISB6.7G Design Architecture



ISB6.7 G

Model	Power @ 2400 RPM	Torque @ 1600 RPM
ISB6.7 G 200	200 hp	520 lb ft
ISB6.7 G 220	220 hp	520 lb ft
ISB6.7 G 240	240 hp	560 lb ft
ISB6.7 G 260	260 hp	660 lb ft

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

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ISX12 G - Field Demonstration

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

State	# Field Test Trucks	Comments
California	6	
Utah	5	Base for trucks operating interstate
Indiana	4	Includes CWI-operated Engineering trucks
Arkansas	2	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.
Nebraska	2	Base for trucks operating interstate
Texas	1	
Arizona	1	
Wisconsin	1	Base for trucks operating interstate
New Jersey	1	
Oklahoma	1	
Various	1	OEM demo truck; operated in multiple states

- ~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

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.

ISX12 G

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

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Differences
ISX12 diesel and ISX12 G natural gas

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

Customer Feedback

John Erwin
Director of Operations Support

Saddle Creek TRANSPORTATION

- 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

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

ampCNG Fueling the Future of Trucking

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."

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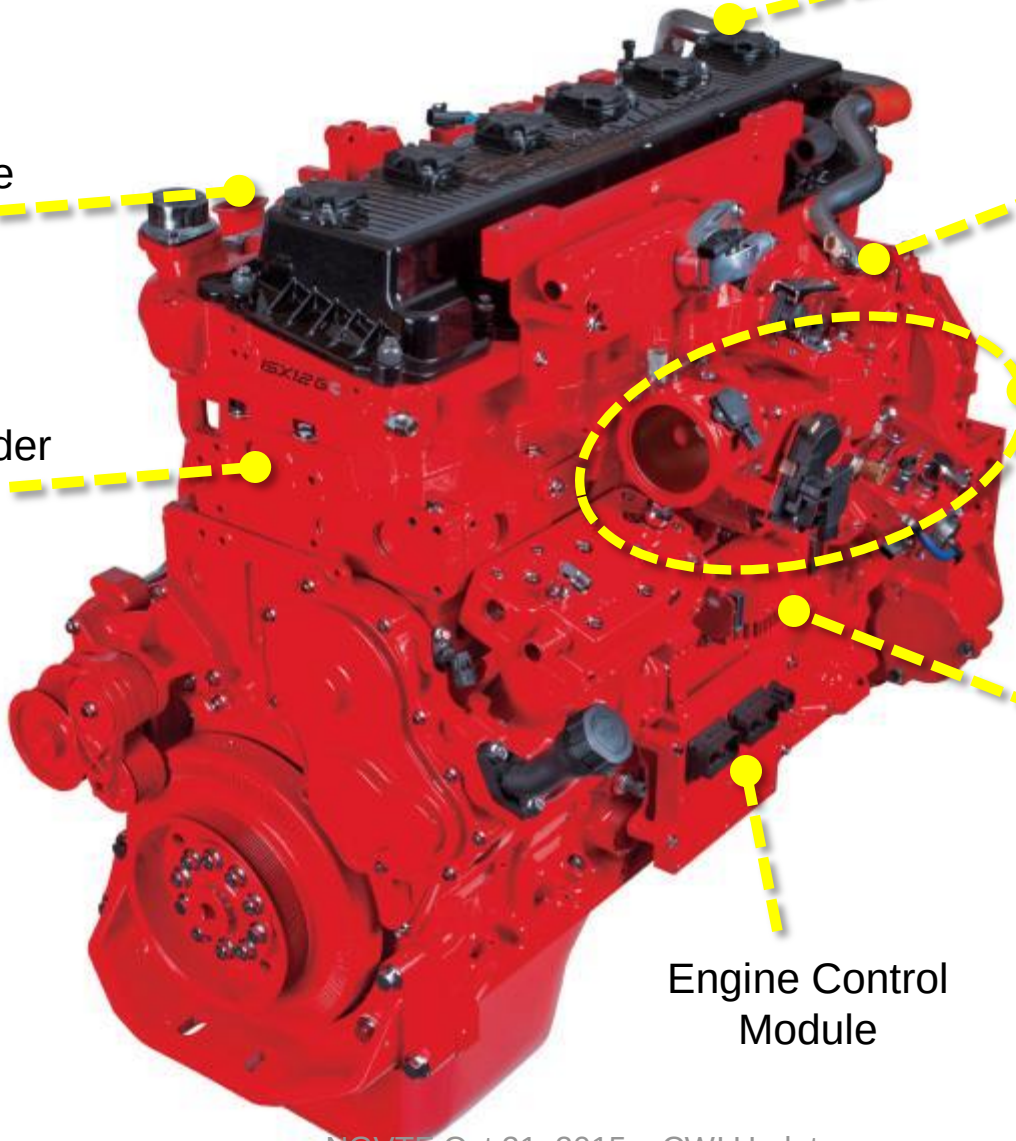
ISX12 G Design Architecture



ISX12 G Availability

OEM	Freightliner	Peterbilt	Kenworth	Volvo	Mack	Autocar
						
Model	Cascadia Day Cab, **Sleeper** **114SD****	320 384 365 **579** **567**	W900S T660 T800 SH **T680**	VNL	Pinnacle	Xpeditor
Engine	ISX12 G	ISX12 G	ISX12 G	ISX12 G	ISX12 G	ISX12 G
Application	Tractor	Refuse Tractor Vocational	Tractor Vocational	Tractor	Tractor Vocational	Refuse

CNG LNG

** New chassis for 2015

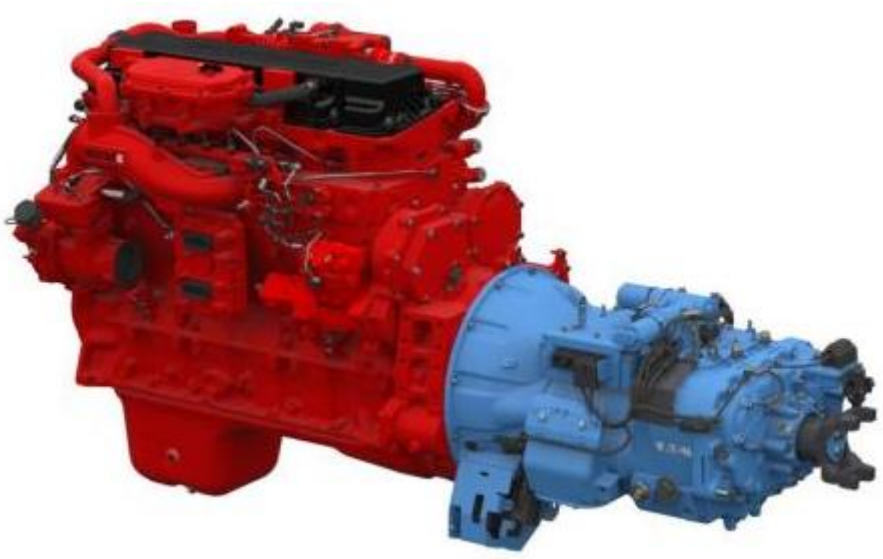
Fuel Economy Feature Comparison

Feature	ISX12 G	ISX12/15
Adaptive Cruise Control	Yes*	Yes
Ambient Idle Shutdown	No	Yes
Cruise Control	Yes	Yes
Driver Reward	No	Yes
Engine Brake Controls	Yes	Yes
Gear Down Protection	Yes	Yes
Idle Shutdown	Yes	Yes
Load Based Speed Control	Yes	Yes
Powertrain Protection	Yes	Yes
Road Speed Governor	Yes	Yes
Vehicle Acceleration Management	No	Yes

*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



OEM
KENWORTH
Peterbilt
VOLVO
MACK
FREIGHTLINER

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Agenda: Funded Projects / Commercial Products

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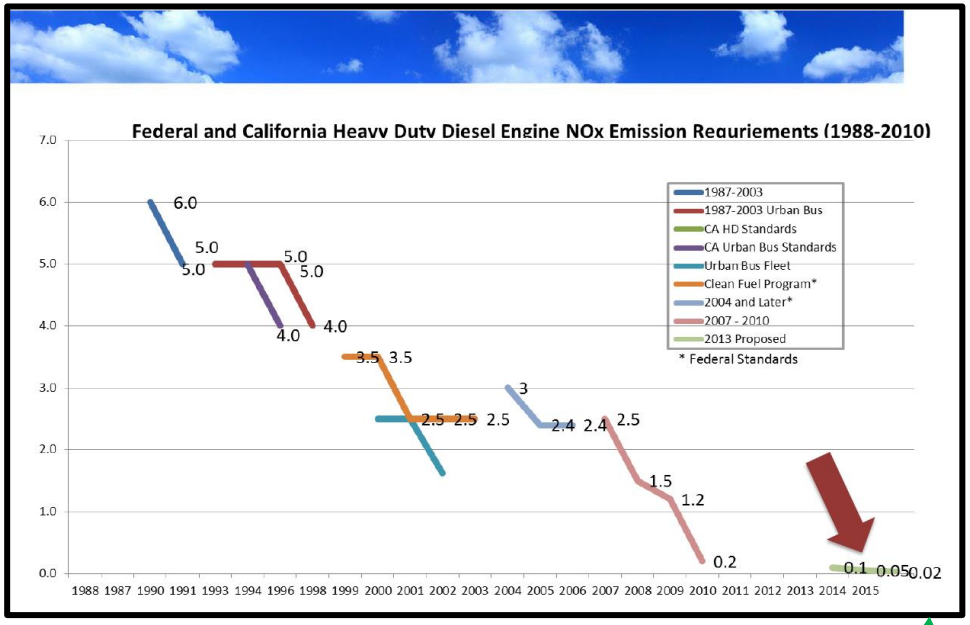
California (ARB) Has Plans to Lower NOx

- 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!



0.2 g/bhp-hr	**Current EPA NOx standard**
0.1 g/bhp-hr	ARB optional low NOx standards
0.05 g/bhp-hr	
0.02 g/bhp-hr	

“Near Zero”

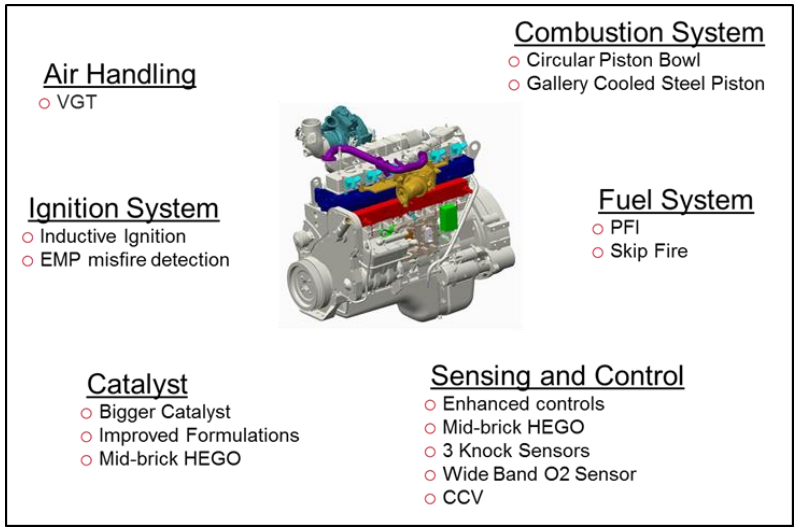
Near Zero Emissions Natural Gas Engine

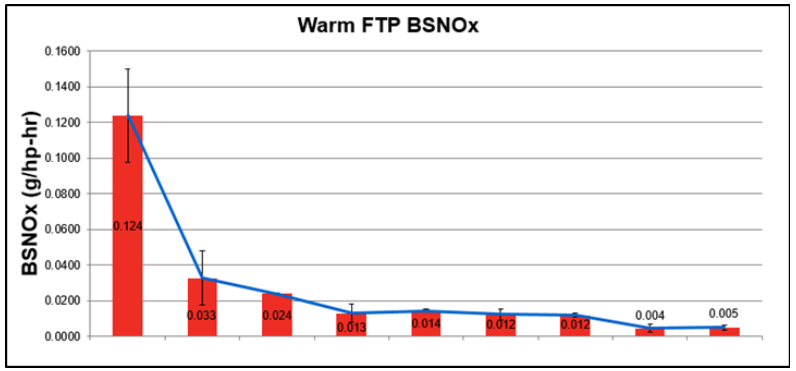
- NOx Emissions Target: 0.02g/bhp-hr
- Near Zero Technology developed through funding from:
  - South Coast Air Quality Management District
  - California Energy Commission
  - Southern California Gas

- 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

California Environmental Protection Agency
Air Resources Board

ISL G NEAR ZERO

EXECUTIVE ORDER A-021-0629
New On-Road Heavy-Duty Engines
Page 1 of 2 Pages

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.

MODEL YEAR	ENGINE FAMILY	ENGINE SIZES (L)	FUEL TYPE [1]	STANDARDS & TEST PROCEDURE	INTENDED SERVICE CLASS [2]	ECS & SPECIAL FEATURES [3]	DIAGNOSTIC [6]
2016	GCEXH0540LBI	8.9	CNG/LNG	Diesel	UB	TBI, TC, CAC, ECM, EGR, TWC, HO2S	EMD+

PRIMARY ENGINE'S IDLE EMISSIONS CONTROL [5]	ADDITIONAL IDLE EMISSIONS CONTROL [5]
EXEMPT	N/A

ENGINE (L)	ENGINE MODELS / CODES (rated power, in hp)
8.9	ISL G 250 / 4836;FR95359 (258), ISL G 280 / 4836;FR95354 (280), ISL G 300 / 4836;FR95351 (300), ISL G 320 / 4836;FR95348 (320)

in g/bhp-hr	NMHC		NOx		NMHC+NOx		CO		PM		HCHO	
	FTP	SET	FTP	SET	FTP	SET	FTP	SET	FTP	SET	FTP	SET
STD	0.14	0.14	0.02	0.02	*	*	15.5	15.5	0.01	0.01	*	*
CERT	0.01	0.000	0.01	0.004	*	*	1.5	0.3	0.001	0.000	*	*
NTE	0.21		0.03		*		19.4		0.02		*	

[4] **g/bhp-hr**=grams per brake horsepower-hour; FTP=Federal Test Procedure; **SET**= Supplemental emissions testing; **NTE**=Not-to-Exceed; **STD**=standard or emission test cap; **FEL**=family emission limit; **CERT**=certification level; **NMHC/HC**=non-methane/hydrocarbon; **NOx**=oxides of nitrogen; **CO**=carbon monoxide; **PM**=particulate matter; **HCHO**=formaldehyde

Manufacturer: **CUMMINS INC**

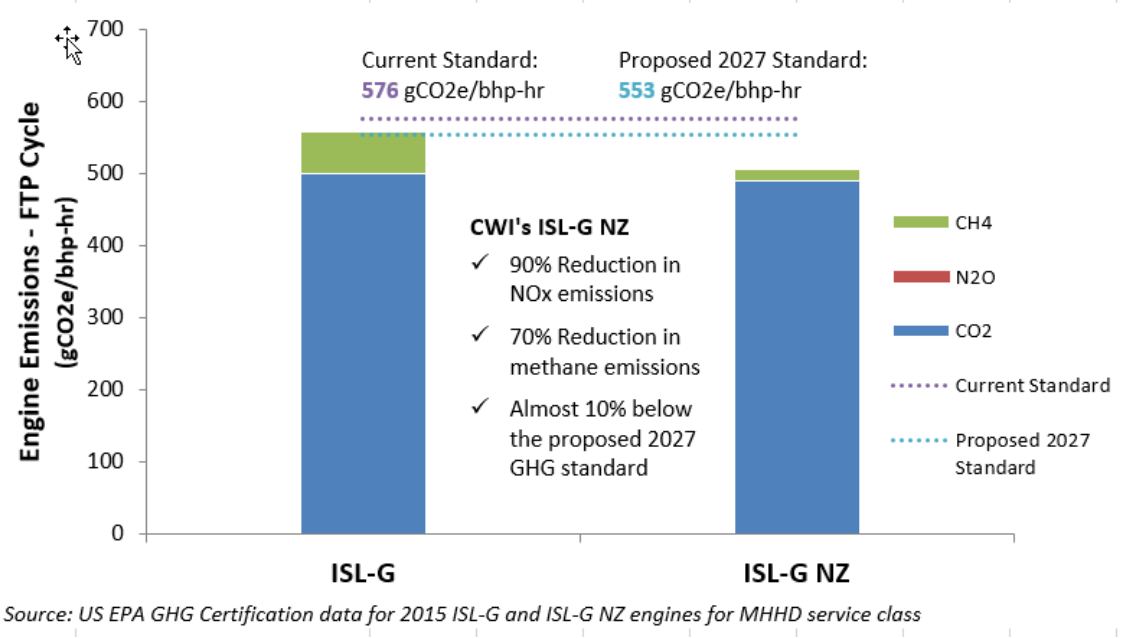
Engine Family: **GCEXH0540LBI**
Certificate Number: **CEX-ONHWY-16-01**
Intended Service Class: **URBAN BUS**
Fuel Type: **NATURAL GAS**
FELs: **G/BHP** NMHC +NOx: **N/A**
NOx: **N/A**
PM: **N/A**

Greenhouse Gas Info.
Primary Intended Service Class: **VOCATIONAL**
Primary Test Configuration FTP (if applicable):
CO_2 FCL value (g/hp-hr) **476**
CO_2 FEL value (g/hp-hr) **490**
N_2O FEL value (g/hp-hr) **0.10**
CH_4 FEL value (g/hp-hr) **0.65**
Primary Test Configuration Ramped-modal(if applicable):
CO_2 FCL value (g/hp-hr)
CO_2 FEL value (g/hp-hr)

EPA GHG Standards

Greenhouse Gas Emissions Criteria	Reduction
Engine related Methane (CH_4)	↓ **70%** reduction (crankcase and tailpipe)
Greenhouse Gases (CO_2 equivalent)	↓ **9%** reduction (technology pathway for further reduction in 2019/2020)

- Two compliance paths:
  1. Engine emissions < standards for each GHG pollutant, **or**
  2. CO_2-equivalent path
     $CO_{2eq} = CO_2 + CH_4*25 + N_20*310$
- If N20 below std then don't include in equation



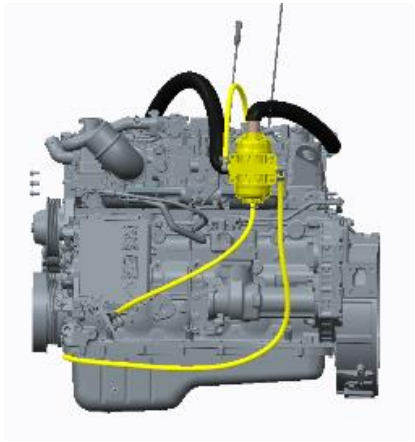
Source: US EPA GHG Certification data for 2015 ISL-G and ISL-G NZ engines for MHHD service class

MHHD Service Class	ISL-G	ISL-G NZ
CO2 FCL	483.5	476
CO2 FEL	499	490
N2O FEL	0	0
CH4 FEL	2.36	0.65
Weighted CO2	499	490
Weighted N2O	0	0
Weighted CH4	59	16.25
CO2e FEL	**558**	**506**

Table and chart courtesy of GNA

ISL G NEAR ZERO

- 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



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ISL G NEAR ZERO

Ratings

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

Cummins Westport

Questions

Stephen Ptucha
Product Management & Planning
Cummins Westport Inc.