

Cummins Westport The Natural Choice



CWI Product Update:
Natural Gas Vehicle Technology Forum 2016

October 19, 2016

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Product Management & Planning
Cummins Westport Inc.



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

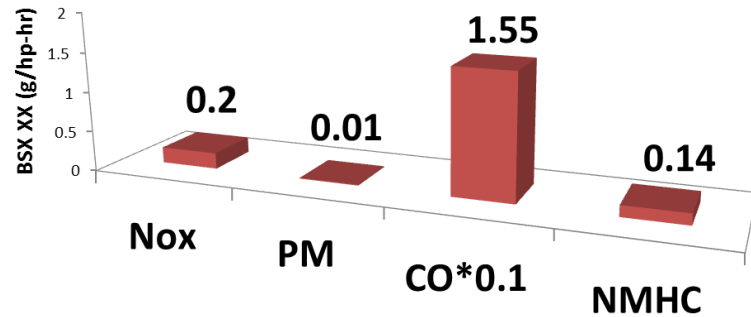
❖ ISX12 G Near Zero

ISB6.7 G Project Introduction

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

ISB6.7 G Project Goal

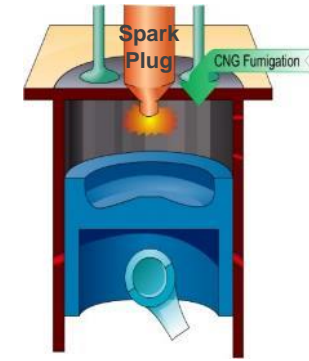
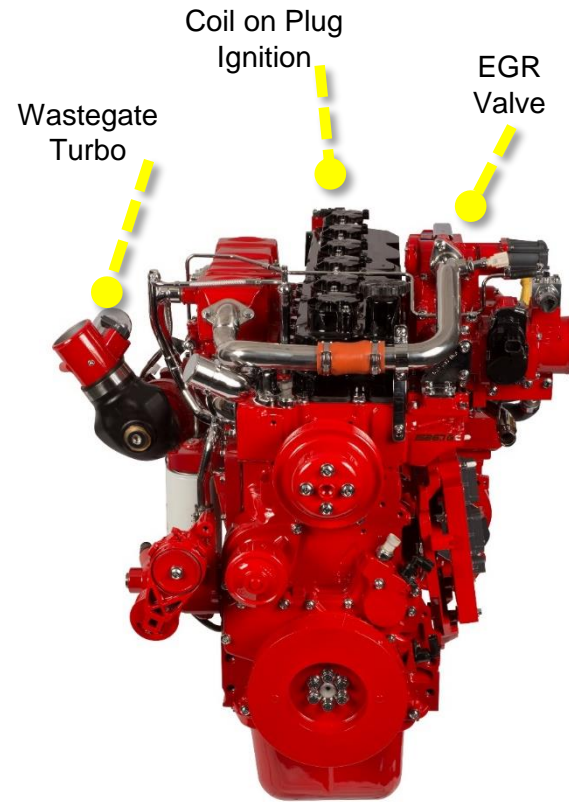
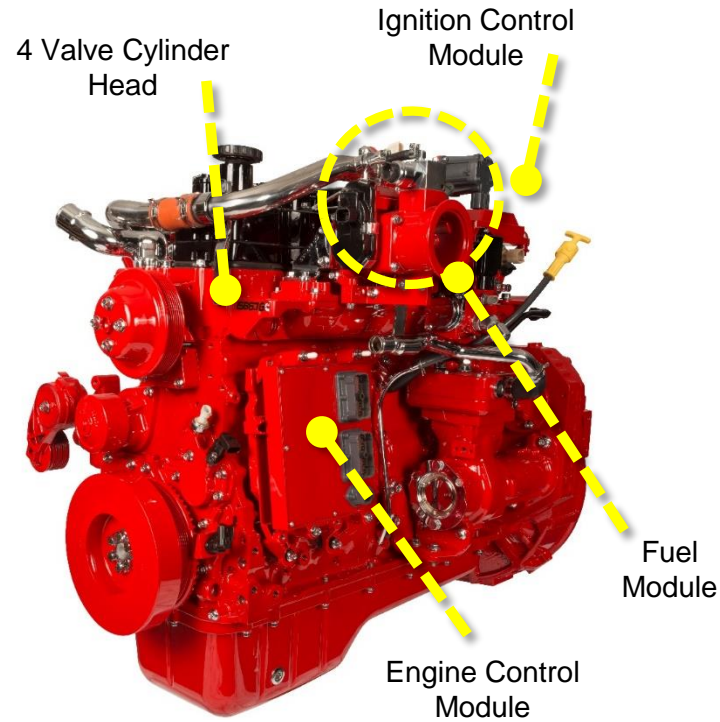
- Demonstrate the performance and emissions capability:
 - U.S. EPA / CARB 2013 emission standards (g/bhp-hr):



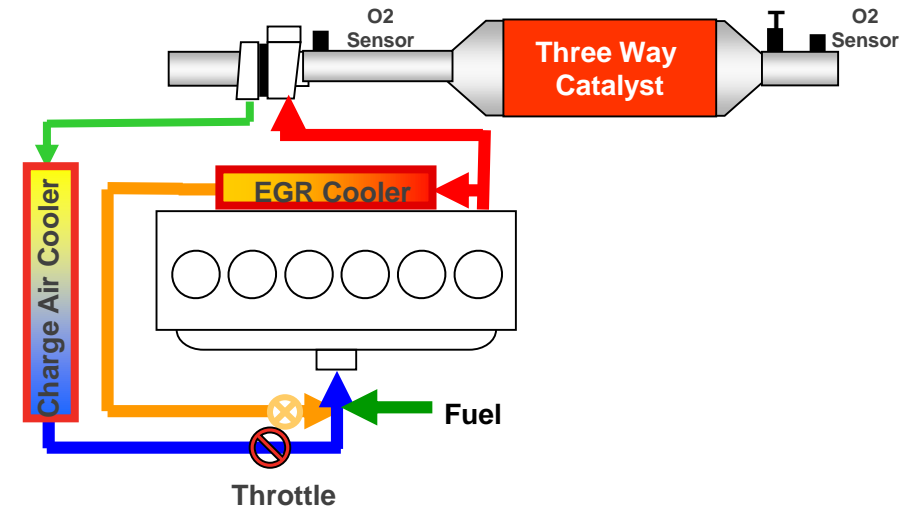
- U.S. EPA 2017 GHG emission standards
 - Peak rating of 260 hp and 660 lb-ft torque.
 - 5 to 10% improved fuel economy over CWI's 5.9l LBSI NG engine (last sold in the North American market through 2009)
- All project goals achieved

ISB6.7G

Design Architecture



Spark Ignited



ISB6.7G

Natural Gas Engine

■ Key Product Attributes

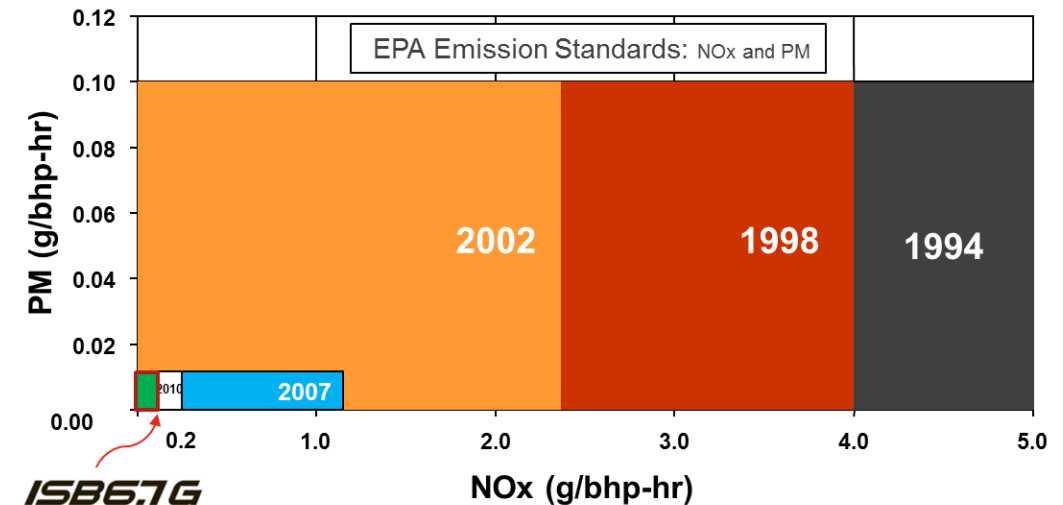
- 4 cycle, spark ignited, in-line 6 cylinder, turbocharged, CAC
- Displacement – 6.7 litres (408.9 cu in)
- Peak rating: 240 hp, 560 lb-ft
- 2016 EPA/CARB certified
- Meet 2017 EPA GHG requirements
- Dedicated 100% natural gas engine
- Three Way Catalyst after-treatment
- Automatic Transmissions
- Base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



CARB Optional Low NOx 0.1g certified

California Environmental Protection Agency Air Resources Board		CUMMINS INC.						EXECUTIVE ORDER A-021-0650 New On-Road Heavy-Duty Engines Page 1 of 2 Pages				
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	0.10	0.10	*	*	15.5	15.5	0.01	0.01	*	*
CERT	0.01	0.004	0.08	0.001	*	*	3.0	1.9	0.000	0.000	*	*
NTE	0.21		0.20		*		19.4		0.02		*	

* 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



ISB6.7G

Natural Gas Engine



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



ISB6.7G

Natural Gas Engine

■ 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)



Thomas Built C2 CNG: 220 & Counting

June 3, 2016 in *ACT Expo 2015, CNG, Fleet Order, NGVs* by Rich Piellisch | [No Comments](#)

Lots of Orders for New Saf-T-Liner C2 CNG School Bus

Thomas Built Buses has released further details about orders for its new compressed natural gas-fueled Saf-T-Liner C2 CNG school bus, which is entering production this month. *updated June 6 and July 28 (corrected North Kansas City bus count)*

LOWER YOUR FUEL COSTS & EMISSIONS
By using clean-burning, domestic natural gas fuel



Saf-T-Liner C2 CNG bus – the orders are rolling in.

"This will be the first compressed natural gas engine in the industry on the popular Type C product," the company says (*F&F*, June 1).

Orders already in hand include

- 110 Saf-T-Liner C2 CNG buses for North Kansas City (as well as 14 Type A Minter buses);
- 25 for Blue Springs, Mo. (east of Kansas City); and
- 71 for the Los Angeles Unified School District.

The new Type C school bus is powered by the 6.7-liter, dedicated-natural gas, spark-ignition Cummins Westport ISB6.7 G engine. The engine was formally unveiled at ACT

Expo 2015 in Dallas last year (*F&F*, May 5, 2015).

The new Thomas built buses have G-Stor Pro brand Type III CNG fuel cylinders by Luxfer.

Agenda: CWI Product Development Updates




❖ ISB6.7 G

❖ ISL G Near Zero



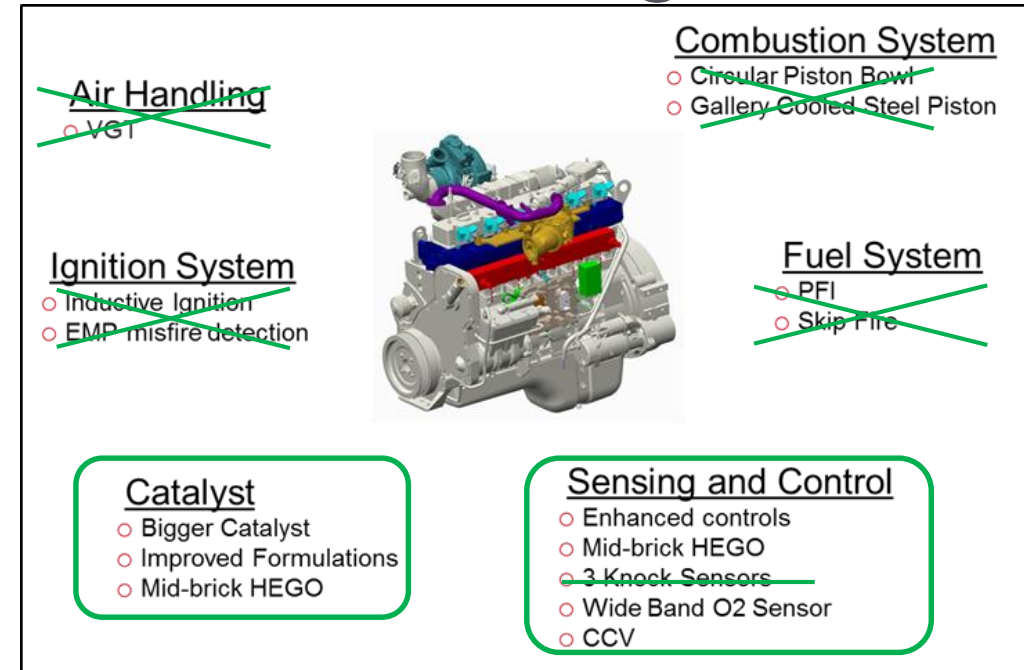
❖ ISX12 G Near Zero

Near Zero NOx Project Introduction

Project Title:	On-Road Heavy-Duty Development, Integration and Demonstration of Ultra-Low Emissions Natural Gas Engines	
Funding Source:	SCAQMD / CEC / SoCal Gas	  
Resulting CWI Engine:	ISL G Near Zero (8.9 liter)	
Award:	\$3.5M	
Scope:	<p>To develop a prototype HD NG engine suitable for on-road heavy-duty vehicle applications...capable of:</p> <ul style="list-style-type: none"> • 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

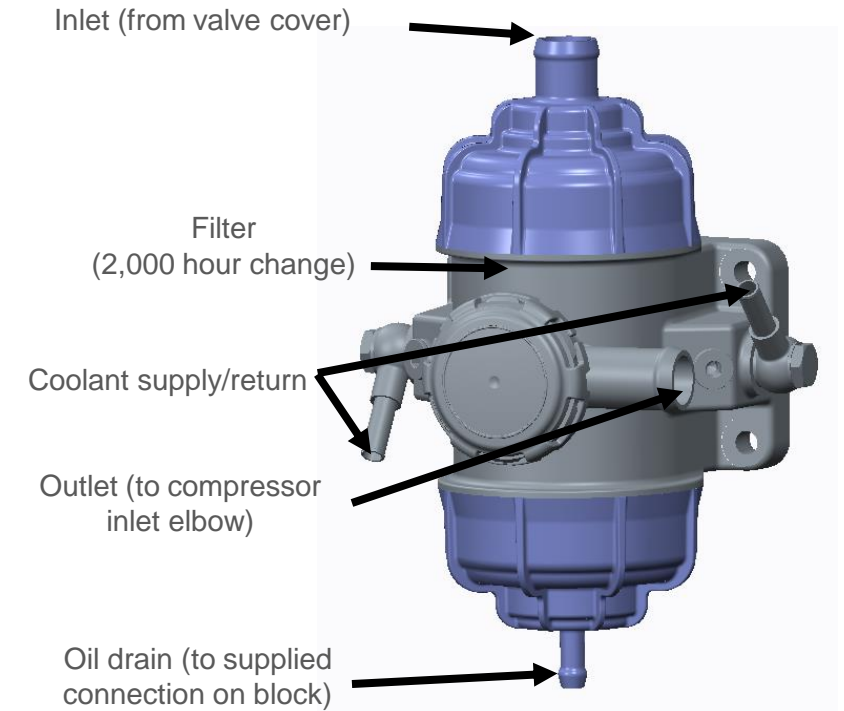
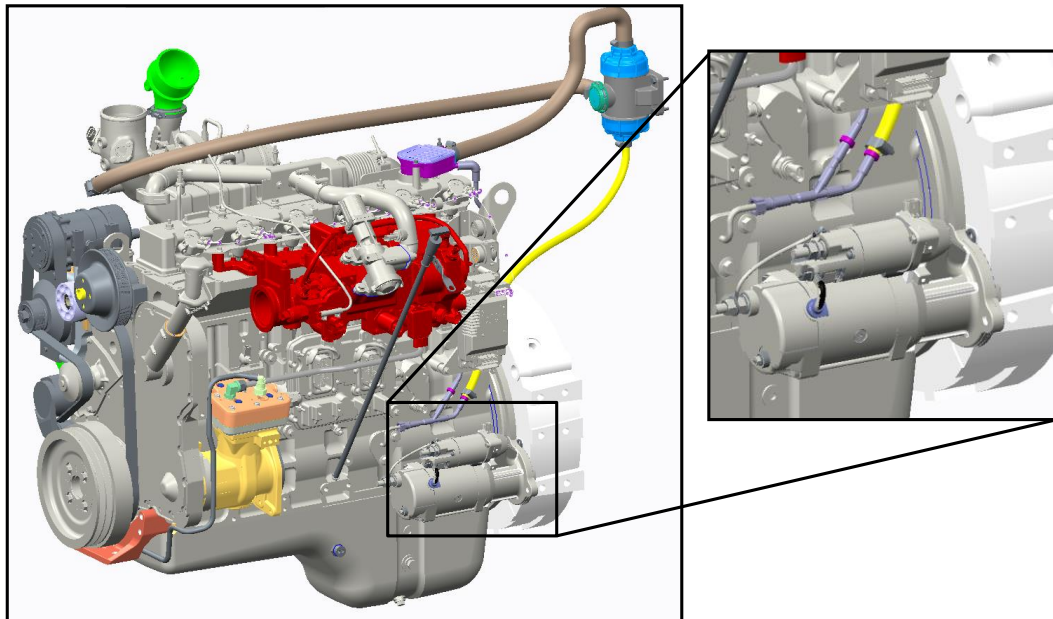
Fuel Efficiency

Cost

Development Time

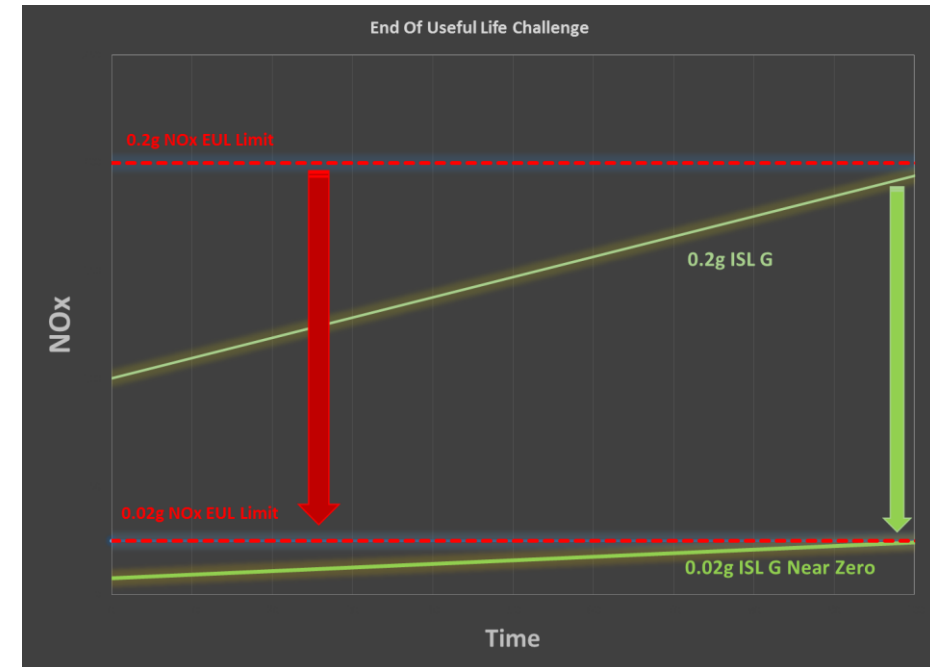
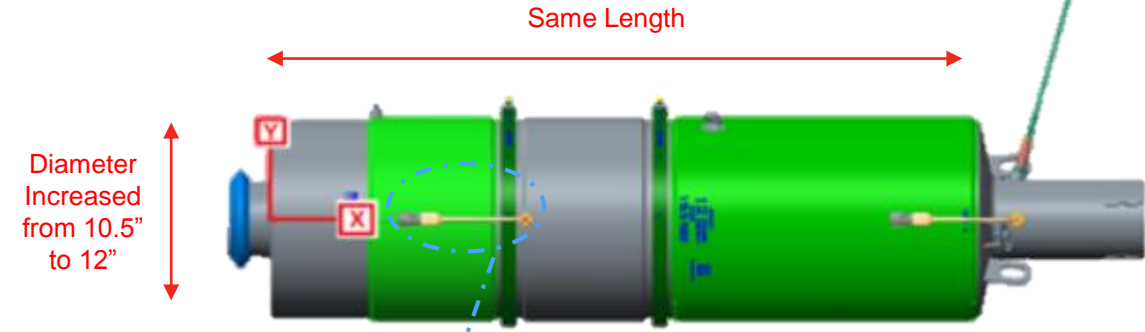
Closed Crankcase Ventilation (CCV)

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



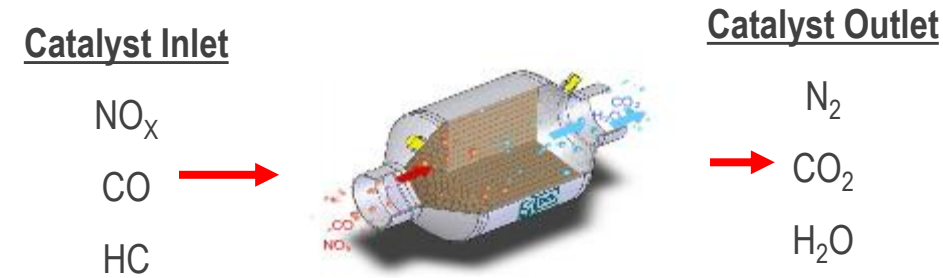
Three-Way Catalyst Improvements

- 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

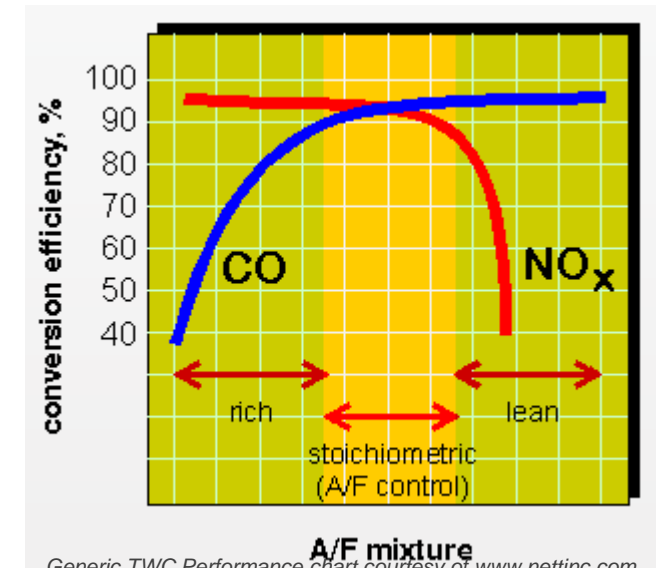
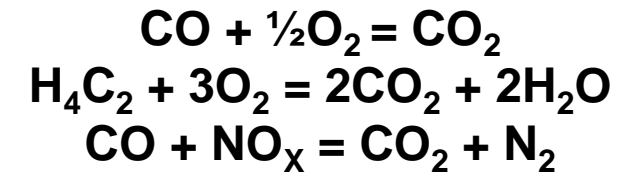


Optimized Controls

- Engine exhaust emissions depends on conditions
 - Lean conditions = high NO_x
 - Rich conditions = high CO & HC
- TWC operation
 - Lean conditions = low conversion of NO_x
 - 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

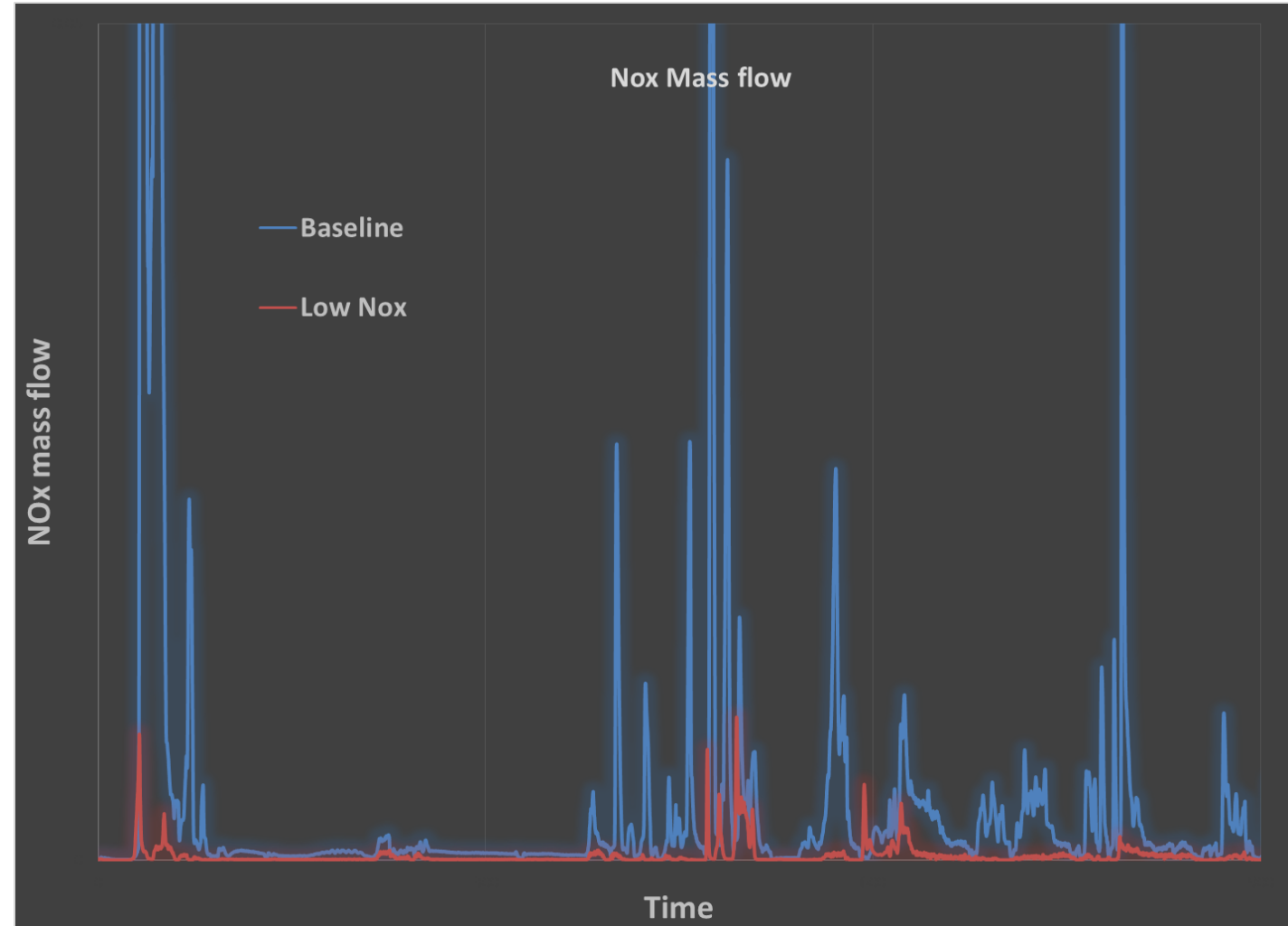


Generic TWC Performance chart courtesy of www.nettinc.com

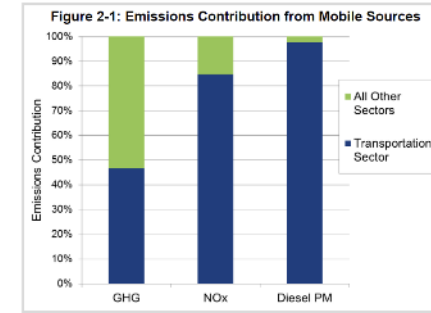
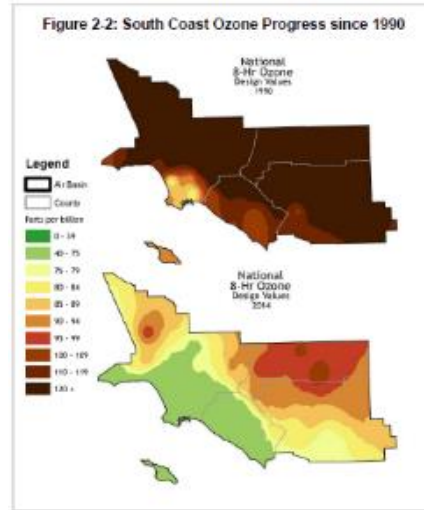


Optimized Controls

- 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 → reduce conversion efficiency
 - Lower temperatures → 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 smog forming 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.

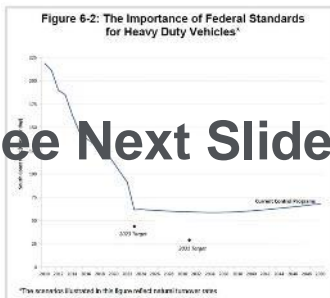
6. On-Road Heavy-Duty Sector

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.

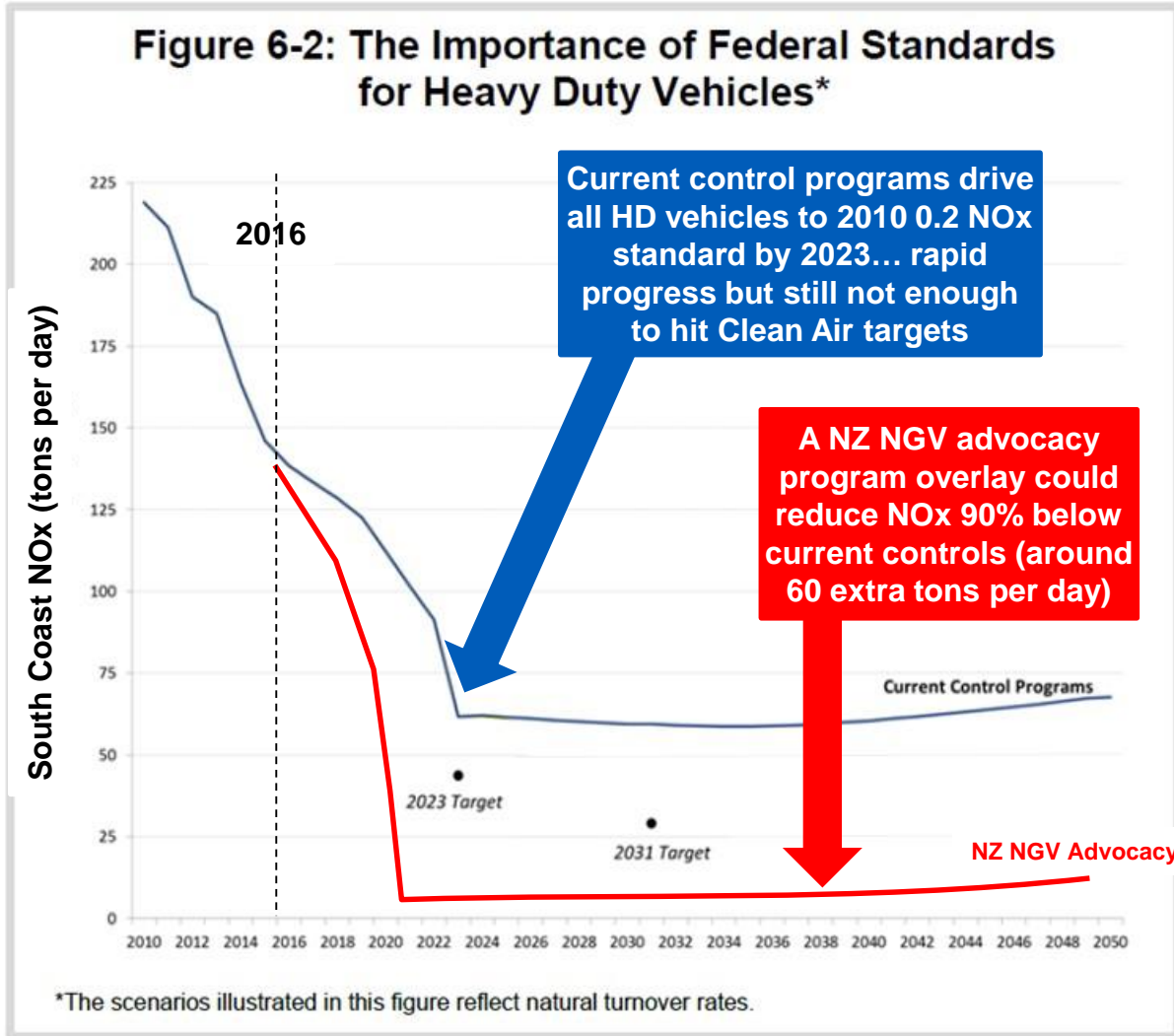
For heavy-duty vehicles, combustion technology will continue to dominate over the next 15 years. The strategy therefore calls for engine technology that is effectively 90 percent cleaner than today's current standards, with clean, renewable fuels comprising half the fuels burned. To position the heavy-duty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

¹ Vision Scenario Planning <http://www.arb.ca.gov/planning/vision/vision.htm>

See Next Slide



What's Driving Near Zero engines?



ISL G NEAR ZERO

	NMHC		NOx		CO		PM	
	FTP	EURO	FTP	EURO	FTP	EURO	FTP	EURO
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

- 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?



Certified Emissions



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	0.20	0.20	*	*	15.5	15.5	0.01	0.01	*	*
CERT	0.05	0.02	0.13	0.01	*	*	7.5	6.1	0.002	0.001	*	*
NTE	0.21		0.30		*		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.

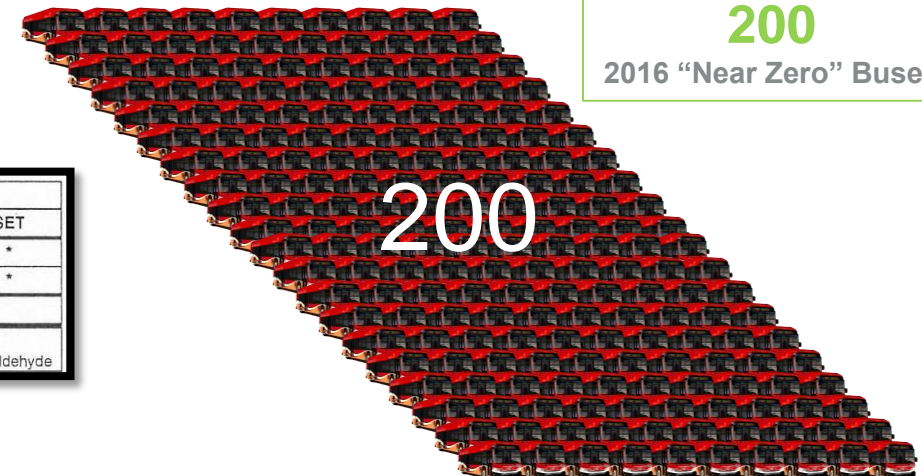
Emissions year:	1985	2000	2010	2016 CARB Near Zero
NOx Standard: (g/bhp-hr)	10.7	4	0.2	0.02



1
2000 model year Bus

equivalent NOx to:

200
2016 "Near Zero" Buses



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.

in g/bhp-hr	EPA CERTIFICATE OF CONFORMITY			PRIMARY INTENDED SERVICE CLASS	
	CO ₂			VOCATIONAL	
	FTP	SET		CH ₄	N ₂ O
STD	555	*		0.10	0.10
FCL	476	*		*	*
FEL	450	*		0.65	*
CERT	255	*		0.56	0.02

⁴ g/bhp-hr=grams per brake horsepower-hour; FTP=Federal Test Procedure; SET=Supplemental emissions testing; STD=standard or emission test cap; FEL=family emission limit; FCL=family certification level; CERT=certification level; CO₂=carbon dioxide; CH₄=methane; N₂O=nitrous oxide; VOCATIONAL=vocational engine; TRACTOR=tractor engine.

OEM & Fleet Announcements

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

The screenshot shows a press release from New Flyer Industries Inc. dated August 17, 2016. It features the New Flyer logo and the Cummins Westport ISL G Near Zero engine. The text highlights that the engine is the first original equipment manufacturer (OEM) installation of a 2016 Cummins Westport ISL G Near Zero engine in the third quarter of 2016. It also mentions that the engine is used to power a New Flyer Xcelior XM40 bus for the Los Angeles County Metropolitan Transportation Authority (LA Metro).

PETERBILT INTRODUCES CUMMINS ISL-G NEAR ZERO EMISSIONS ENGINE FOR MODELS 567, 520 AND 320 DENTON, Texas (August 30, 2016)

Peterbilt Motors Company introduces the Cummins Westport ISL-G Near Zero NOx emissions natural gas engine for Models 567, 520 and 320.

The ISL-G Near Zero engine emissions are 90 percent lower than the current EPA NOx limit through the introduction of a unique three way catalyst in the after-treatment, advanced engine calibration and a closed crankcase ventilation system (CCV).

"Peterbilt is producing increasingly efficient products," said Scott Newhouse, Peterbilt Chief Engineer. "The addition of the ISL-G Near Zero emissions engine strengthens Peterbilt as an environmental leader."

The new engine's performance and efficiency match the current ISL-G, with 320 horsepower and 1,000 lb-ft torque available. Customers with linehaul, vocational and refuse applications will benefit from the efficient option.

"Peterbilt continues to lead the industry with the highest performing trucks on the road," said Robert Woodall, Peterbilt Assistant General Manager of Sales and Marketing. "We're pleased to offer the ISL-G Near Zero engine as an excellent choice for our customers."

Like the currently available ISL-G engine, the ISL-G Near Zero operates on 100% 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 emissions engine will become available for production in Models 520 and 320 by year-end. The new engine will become available in the Model 567 in early 2017.



Organization Profile

New Flyer Industries Inc.



Washington, DC Exercises Options for an Additional 100 New Flyer Buses

New Flyer Industries Inc. announces the third quarter 2016 dividend

LA Transit Contract Update and Reaffirmation of 2016 Bus/Coach Delivery Guidance

More on this organization



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.



Cummins Westport ISL G Near Zero Natural Gas Engine

Emissions from the ISL G Near Zero natural gas engine are 90 percent lower than the current NOx limit of 0.2 gram per brake horsepower-hour, and meet the 2017 EPA greenhouse gas emission reduction requirements. The new engine achieves this reduction through the introduction of advanced engine calibration, a unique maintenance-free, three-way catalyst after-treatment system, and a closed crankcase ventilation system.

"The Kenworth T680 and T880 equipped with the ISL G Near Zero emissions engine is well suited for regional haul, vocational and refuse fleets focused the reduced environmental impact of natural gas use and reducing their operating costs," said Jason Skoog, Kenworth assistant general manager for sales and marketing.

The 8.9-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 in 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/drivers.

Kenworth Truck Company is the manufacturer of The World's Best® heavy and medium duty trucks. Kenworth's Internet home page is at www.kenworth.com. Kenworth is a PACCAR company.

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

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 (LNG) contract to fuel its Big Blue Bus (BBB) fleet of vehicles. The 5-year deal, worth an estimated \$3 million per year, will enable BBB to continue using Clean Energy's Redeem™ brand of renewable natural gas (RNG), rated up to 90 percent cleaner than diesel and considered the cleanest transportation fuel available. BBB began using Redeem™ by Clean Energy in January 2015.

BBB, one of the first transit agencies in the nation to contract for Redeem™, will also become one of the first agencies to incorporate the new Cummins-Westport 8.9L ISL G Near-Zero 0.02 NOx engine, the first mid-range engine in North America to receive emission certifications from both U.S. Environmental Protection Agency (EPA) and Air Resources Board (ARB) in California that meet the 0.02 g/bhp-hr optional Near Zero NOx Emissions standards.

Big Blue Bus, which includes 200 natural gas buses, plans to replace over 100 of their existing bus engines with the new Near-Zero natural gas engine over a three-year period, making BBB one of the cleanest transit agencies in the nation. When the transition is complete, BBB is expected to have reduced their NOx emissions by over 90 percent and their GHG emissions by 8,000 Metric Tons, annually. Introduced by CWI earlier this year, the new Cummins ISL G 8.9L Near Zero 0.02 NOx engine is designed for medium-duty truck, urban bus, school bus and refuse applications and is available on the market today. Cummins-Westport plans to begin delivering an 11.9L version that is also EPA and ARB certified for the heavy-duty trucking industry in 2018.

"The City of Santa Monica has a deep commitment to the people and environment in our community. By combining the environmental benefits of RNG with the technological advances of this engine, we are proud to say that we are in fact, one of the cleanest transit agencies in the nation," said Ed King, BBB's Director of Transit.

The City of Santa Monica is a nationally recognized leader for its sustainability policies and actions. BBB has progressively contributed to the City's sustainability narrative through its use of alternative fuel and ultimate phasing out of diesel-fueled motor coaches. Through this commitment, clean burning RNG 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 Redeem™ RNG and the implementation of the new Near-Zero engine, we are about to witness the future of the transportation industry and the incredible advances we've made in reducing the impact on the environment," said Peter Grace, Clean Energy's senior vice president for sales and finance.

For more information about the BBB's Redeem fueling success story [click here](#). 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 biogenic methane or biogas, which is methane that is naturally generated by the decomposition of organic waste. The methane gas is processed, purified and sent into the interstate natural gas pipeline and made available exclusively to Clean Energy customers. Redeem™ biomethane vehicle fuel is procured from biomethane production facilities, including two owned and operated by Clean Energy.

Agenda: CWI Product Development Updates





❖ ISB6.7 G

❖ ISL G Near Zero

❖ ISX12 G Near Zero



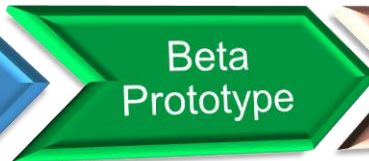
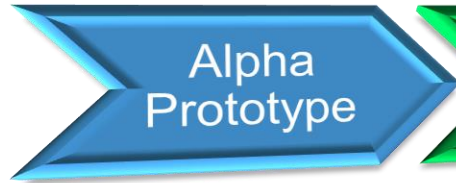
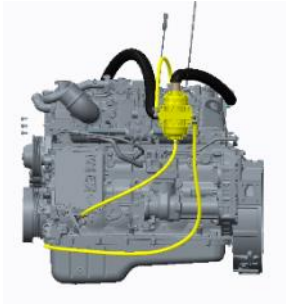
ISX12 G Near Zero Project

Project Title:	Develop, Integrate & Demonstrate Ultra-Low Emissions Natural Gas 12 Liter Engine For On-Road Heavy Duty Vehicles		
Funding Source:	SCAQMD / CEC / SoCal Gas / Clean Energy		  
Resulting CWI Engine:	ISX12 G Near Zero (11.9 liter)		
Award:	\$5.25M		
Scope:	To develop a 12 liter HD NG engine suitable for on-road heavy-duty vehicle applications...capable of: <ul style="list-style-type: none"> • Target NOx emissions: 0.02 g/bhp-hr • CARB and EPA certified 		
Term:	May/16 thru March/18		
Status:	Project underway, Targeting 2018 production for ISX12 G Near Zero		

Scope

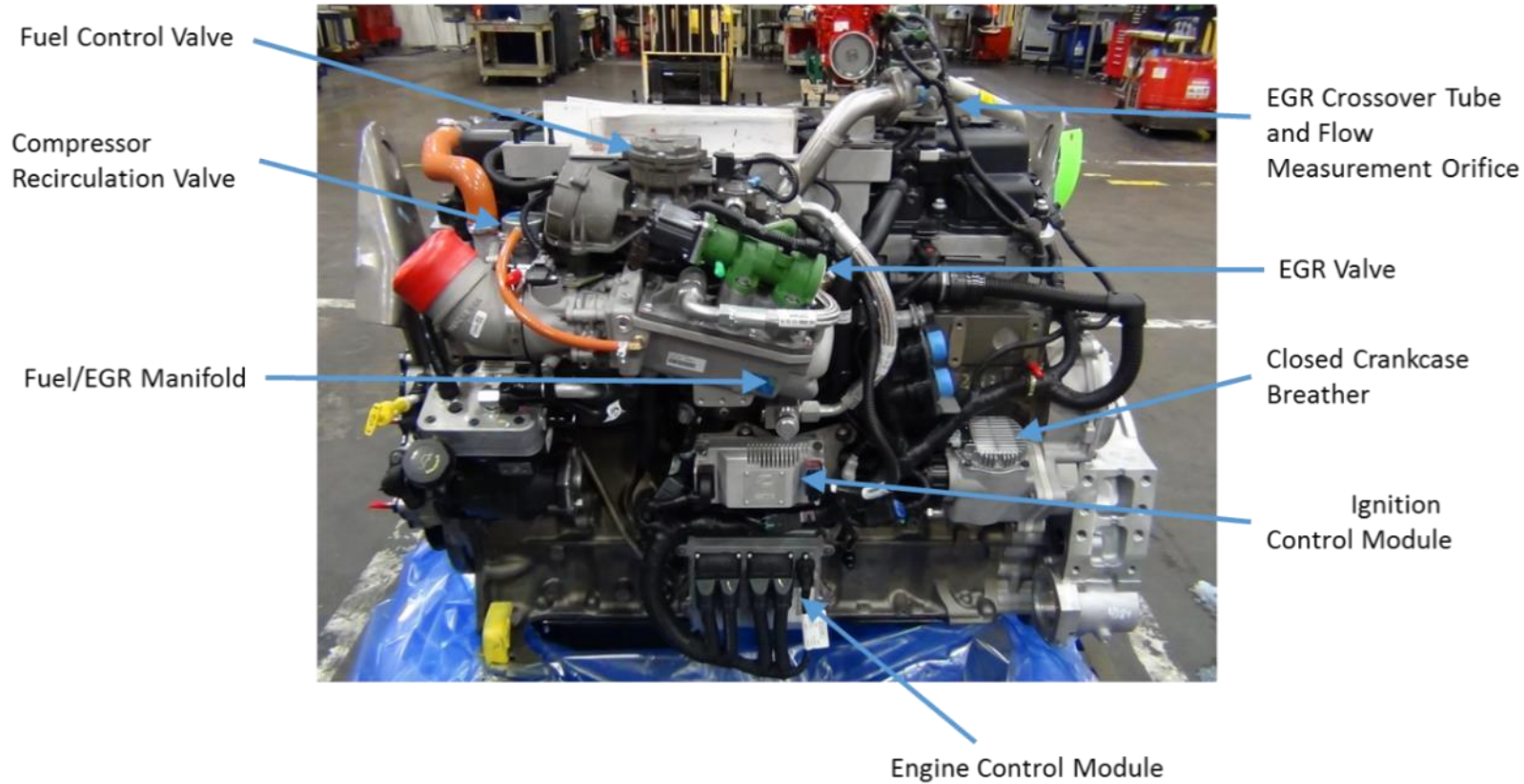
- The objective of the work contained in these progress reports is to develop and demonstrate a 12-liter natural gas engine, and associated exhaust after-treatment technologies, that is (1) suitable for on-road heavy-heavy duty vehicle applications such as Class 8 trucks and buses; (2) commercially viable; and (3) capable of:
 - Achieving emissions targets of 0.02 g/bhp-hr NO_x, 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 NH₃ emissions as low as achievable while targeting average NH₃ 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

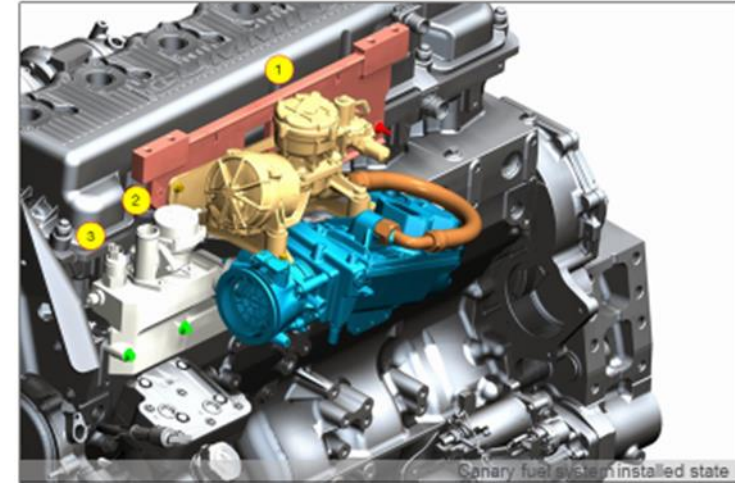


- Previously completed using ISL G
- Determined Near Zero architecture
 - Closed Crankcase Ventilation
 - Three-way Catalyst Improvements
 - Optimized controls

Alpha Prototype Highlights

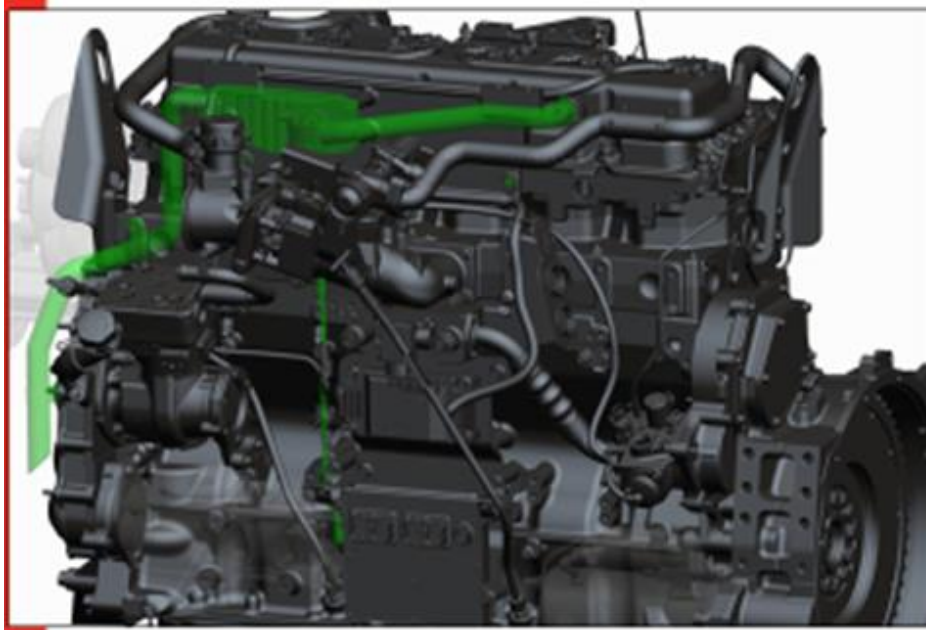


Fuel System Close Up

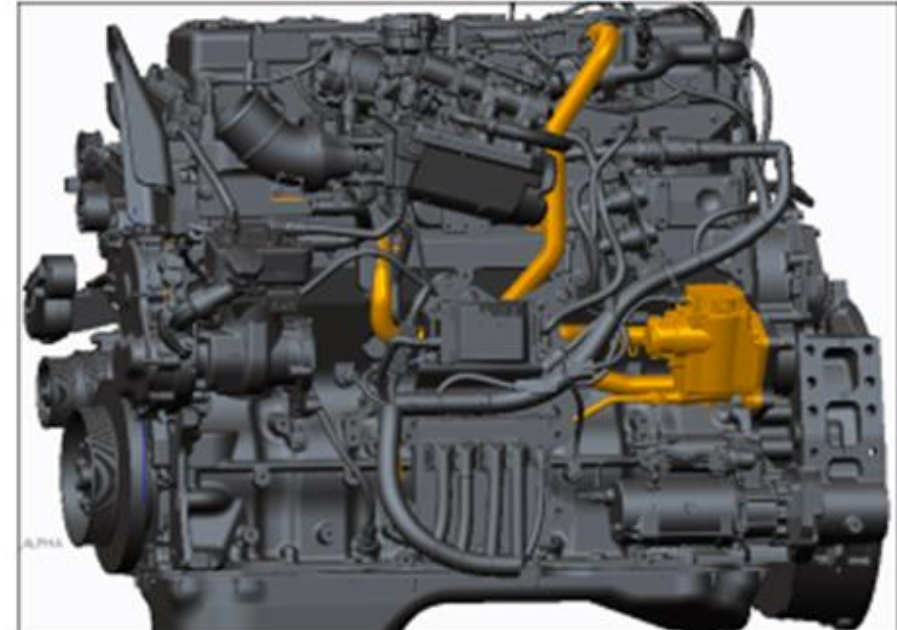


Alpha Prototype: Closed Crankcase Ventilation

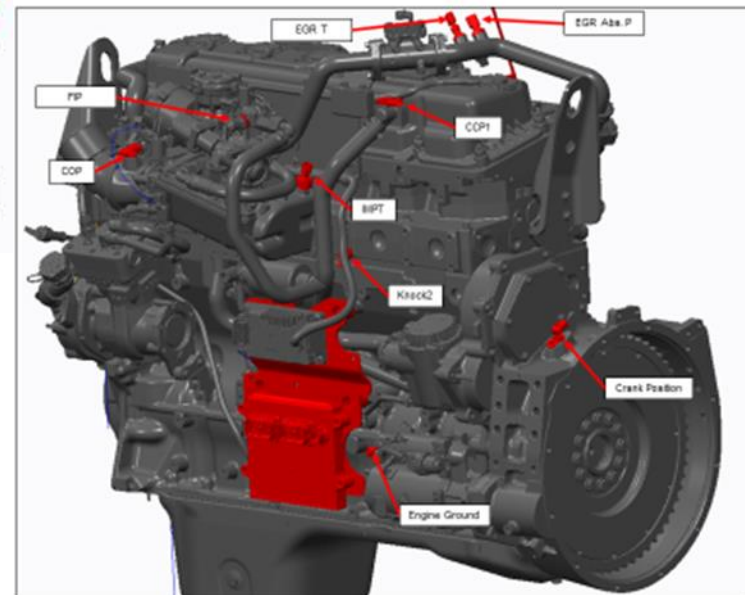
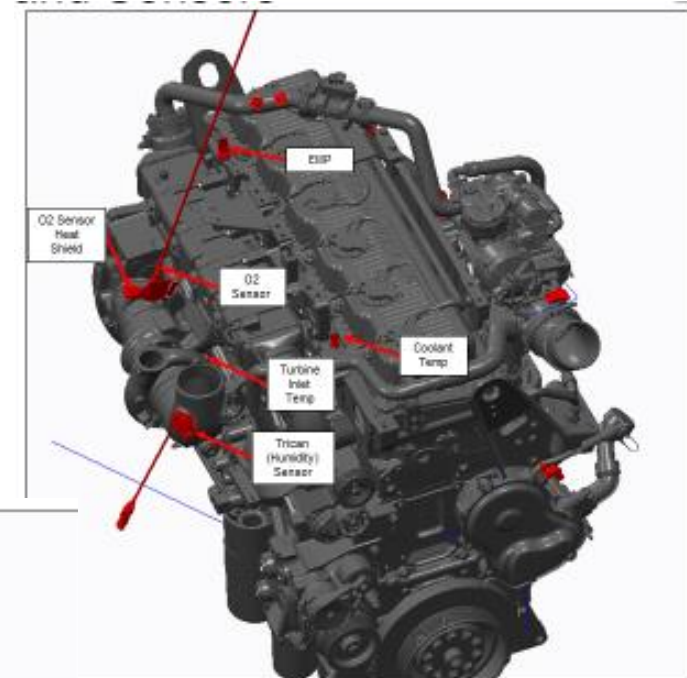
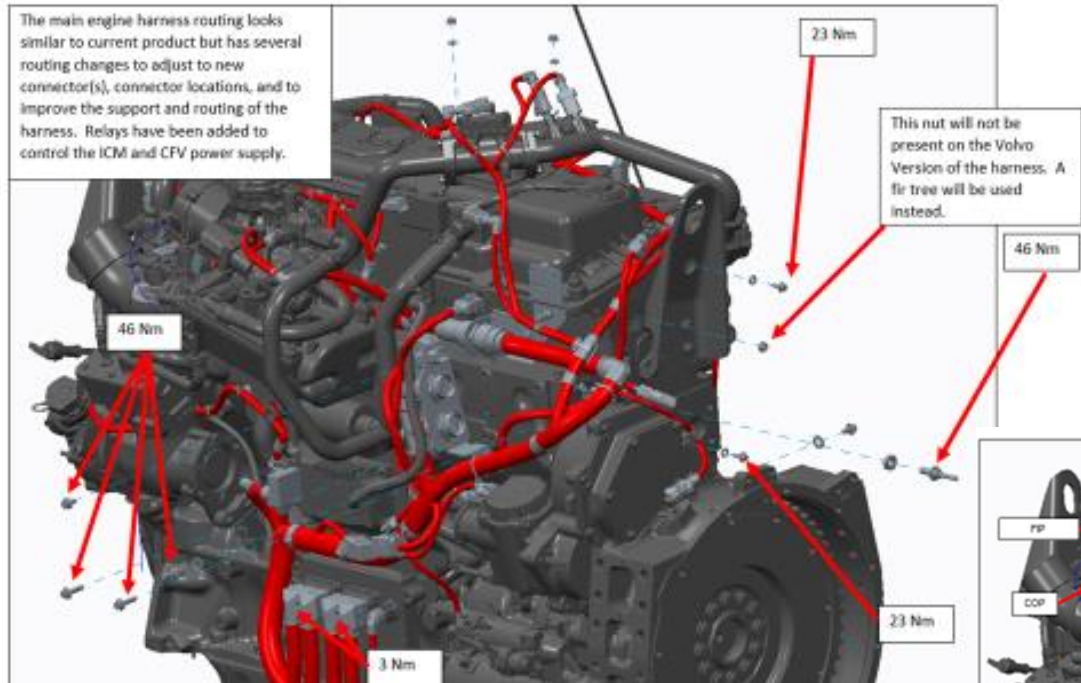
Current Product – ISX12 G



ISX12 G NZ Alpha Prototype

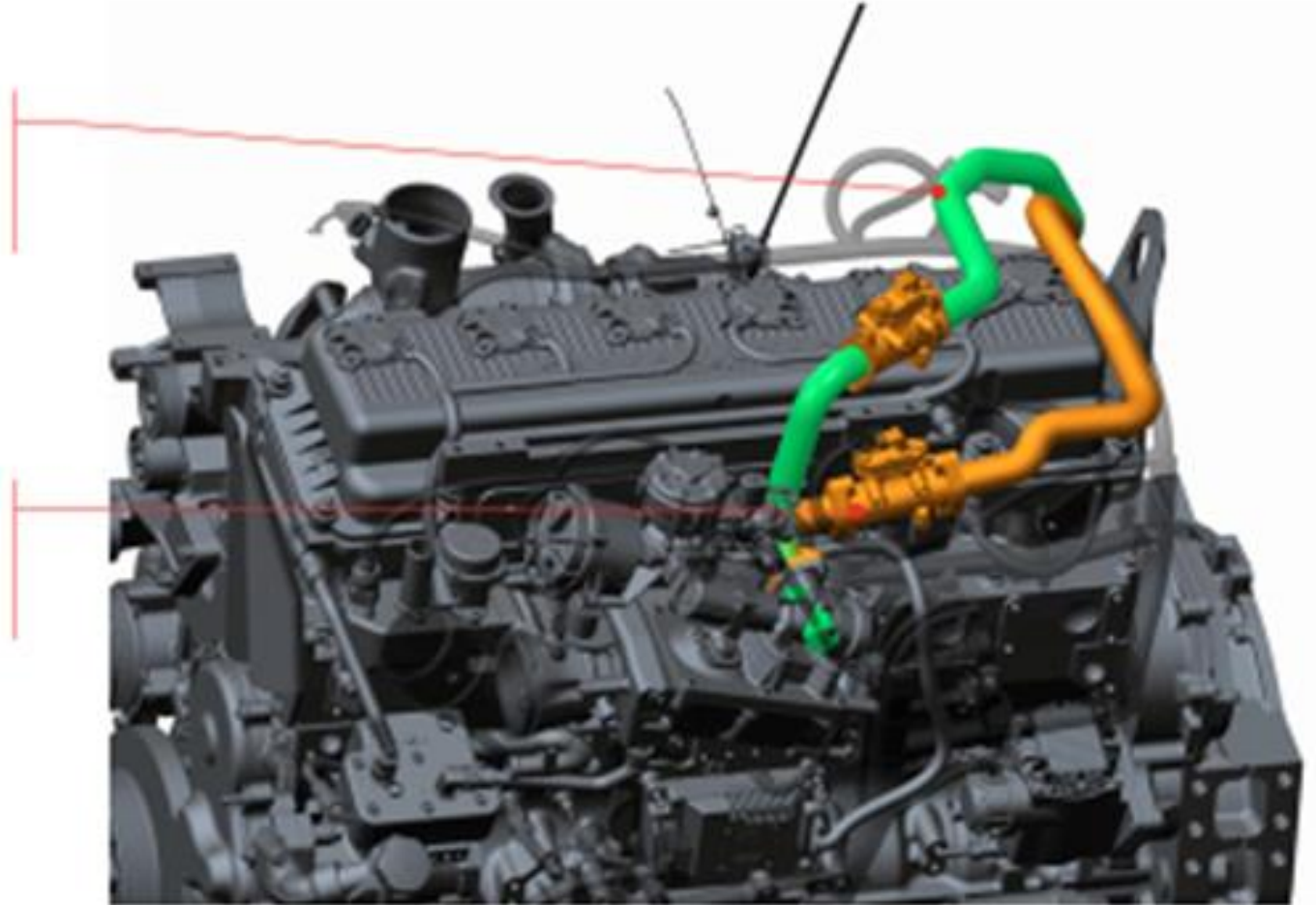


Alpha Prototype: ECM & Wire Harness



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.)

Engine	2016	2017	OBD	2018	2019
ISB6.7G *	Available	Available		Available	Available
ISB6.7G NEAR ZERO	Not Available	Not Available		Development Program Not Funded	
ISL G	Available	Available		Not Available	Not Available
ISL G NEAR ZERO	Available	Available		Available	Available
ISX12G	Available	Available		Not Available	Not Available
ISX12G NEAR ZERO	Not Available	Not Available		Available	Available

Legend

Available

Not Available



* 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.