

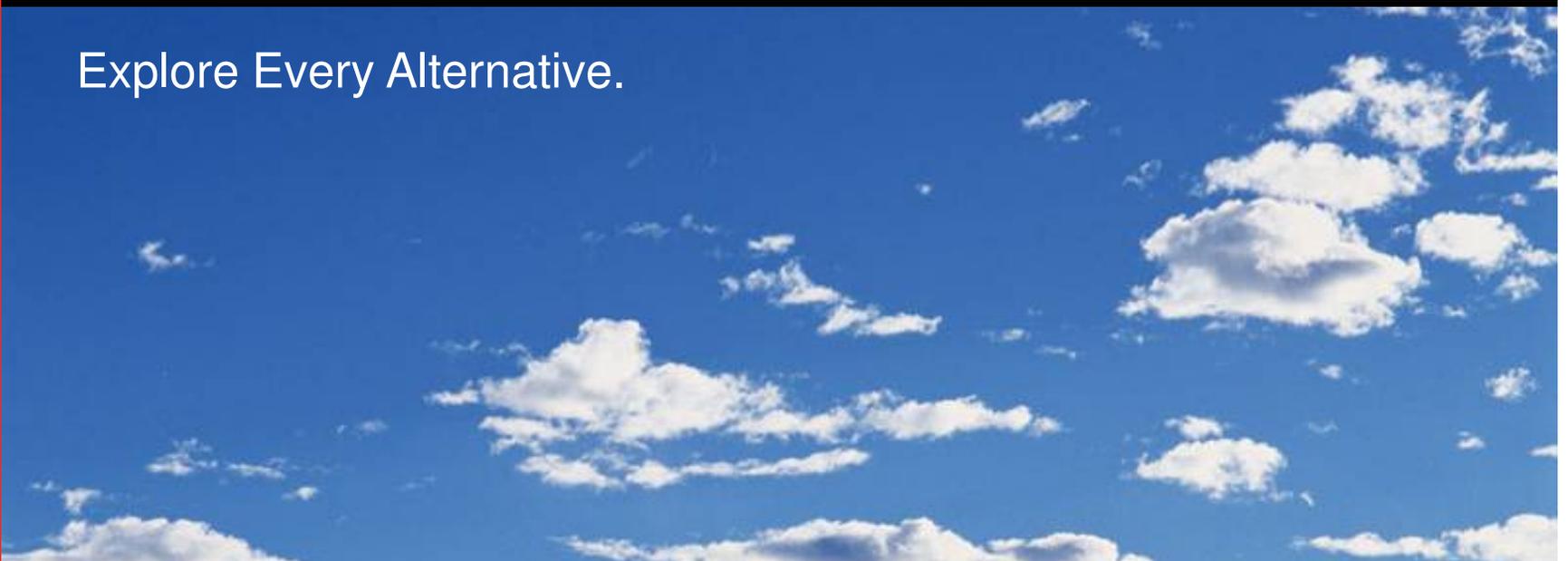


Development, Demonstration and Commercialization of a 0.20 g/bhp-hr NO_x Natural Gas Engine

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25-Aug-10

Explore Every Alternative.



Agenda

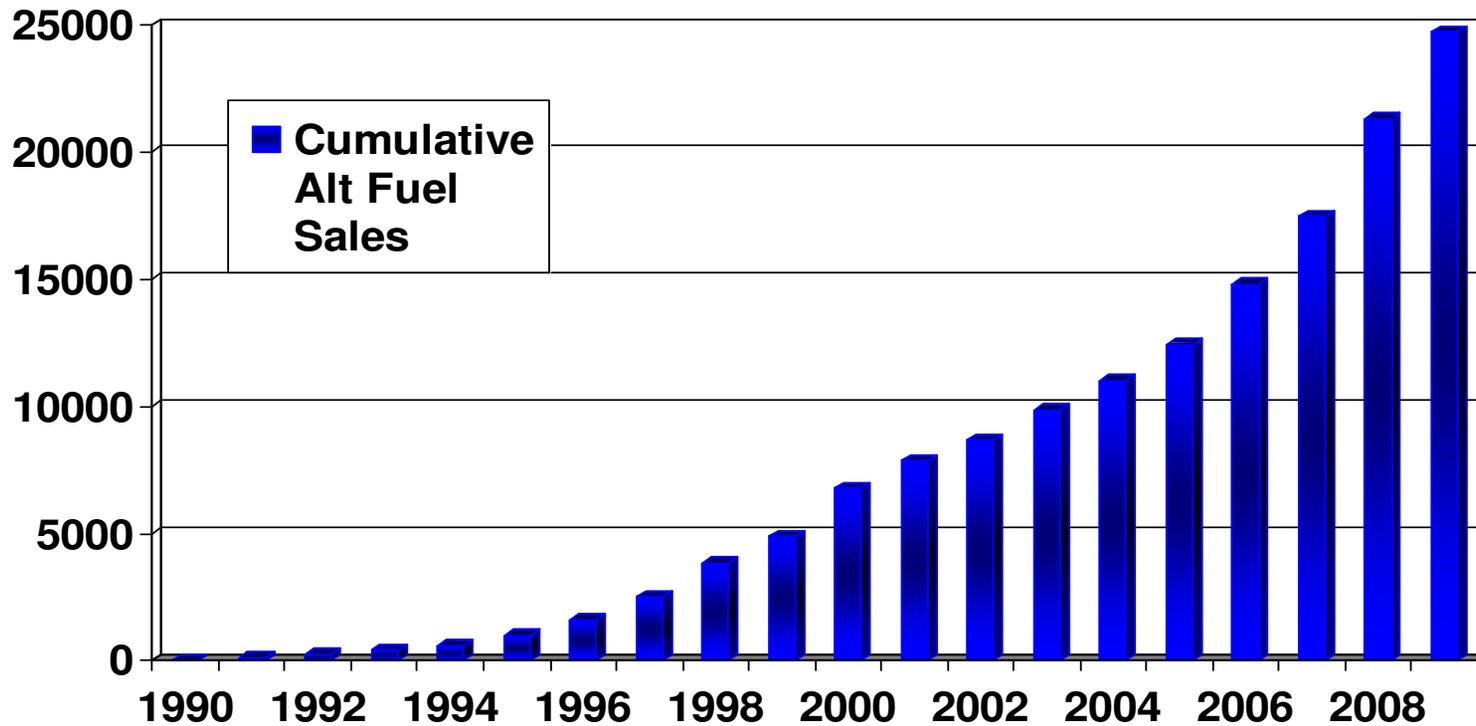
- Cummins Westport Overview
- ISL G Overview
- ICAT Project

Cummins Westport Inc.

- Cummins Westport Inc (CWI) is a 50:50 joint venture company based in Vancouver, BC
 - Cummins Inc. - world's largest builder of commercial diesels,
 - Westport Innovations Inc. - world leader in gaseous fuel engine technology
- Globally, CWI offers 6 to 9 litre alternative fuel automotive engines. (CNG, LNG, LPG)
- Engines are manufactured by Cummins
- Over 24,000 engines in service worldwide
- Local parts and service support through Cummins Distributor network



Cumulative Sales Over 24,000 Engines



Why Natural Gas Engines for Buses & Trucks?

Environmental Leadership

- Meets regulated 2010 EPA / ARB / Euro V / EEV
- Lower greenhouse gas emissions



Economic Benefits

- Lower total fuel costs
- Tax incentives in some jurisdictions

Energy Security

- Reduced reliance on oil
- Biomethane capable
- Pathway to hydrogen



Market Leader - Alternative Fueled Engines

- 1988 - **Demonstrated lean burn combustion concepts for HD NG engine**
- 1991 - First new technology HD NG product (L10-240G)
- 1992 - ARB emission certification at 2.0 g/bhp-hr NOx (L10-240G)
- 1994 - Technology / product upgrades (enhanced power / electronics):
 - Re-certified at 1.7 g/bhp-hr NOx (L10-260G)
- 1995 - First full electronic, closed-loop control MD NG engine (B5.9G)
- 1996 - First full electronic, closed-loop control HD NG engine (L10-300G)
- 1996 - First fully integrated natural gas fueled engine:
 - Engine subsystems
 - Electronic controls & diagnostics
- 1997 - First to be ULEV Certified (B5.9G in mid-1997)
- 2001 – **Cummins Westport Inc. - Joint Venture formed**
- 2001 – C Gas Plus introduced, certified EPA / ARB 2004 (1.8 g/bhp-hr)
- 2002 – B Gas Plus introduced
- 2004 – L Gas Plus 8.9 litre engine introduced at 1.5 g/bhp-hr
- 2005 – B Gas International introduced – production in India & China
- 2007 – **ISL G introduced – first 2010 compliant HD engine (0.20 g/bhp-hr NOx)**
 - Stoichiometric, cooled EGR combustion
 - Three Way Catalyst



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ISL G Natural Gas Engine

- 8.9 Litre, in-line 6 cylinder
- Spark ignition, stoichiometric, cooled EGR, three way catalyst technology
- Launched in 2007
 - Developed with support from South Coast AQMD, Department of Energy, and Gas Technology Institute
- First heavy duty engine for bus and truck certified to 2010 EPA / ARB NOx and PM standards
 - 0.20 g/bhp-hr NOx, 0.01 g/bhp-hr PM
 - Also certified to EURO V, EEV
- Manufactured in Cummins engine plant - Rocky Mount, North Carolina



ISL G



ISL G Vehicle Applications at Launch

- ISL G developed for transit bus & refuse truck markets
 - Commercial launch in June, 2007



- ICAT project 06-08 initiated Sept, 2007
 - ICAT objective was to tailor the ISL G to suit additional commercial vehicle applications, and enable broader market penetration of ISL G

ISL G - Three Key Emission Technologies

- Cooled Exhaust Gas Recirculation (CEGR)

Cummins

- Stoichiometric Combustion

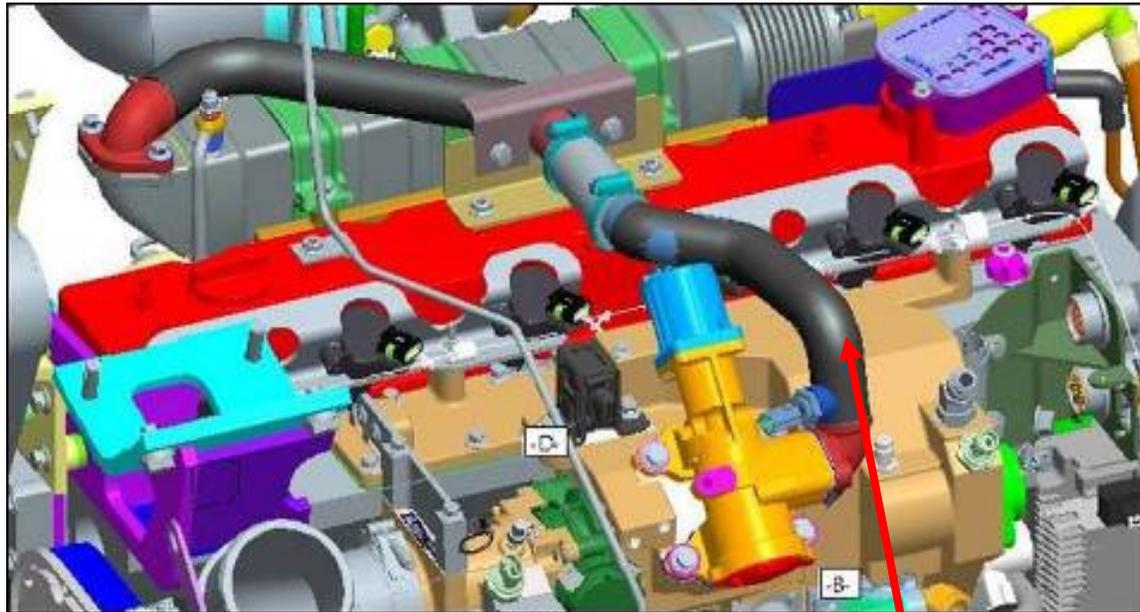
Cummins Westport

- Three Way Catalyst (TWC)

**Cummins
Emission Solutions**

Exhaust Gas Recirculation (EGR)

- Cooled exhaust gases are mixed with intake air
- Exhaust gas in place of excess air creates Lean Burn-like combustion conditions, with oxygen-free exhaust
- Oxygen-free exhaust enables a three way catalyst for NOx control



Westport

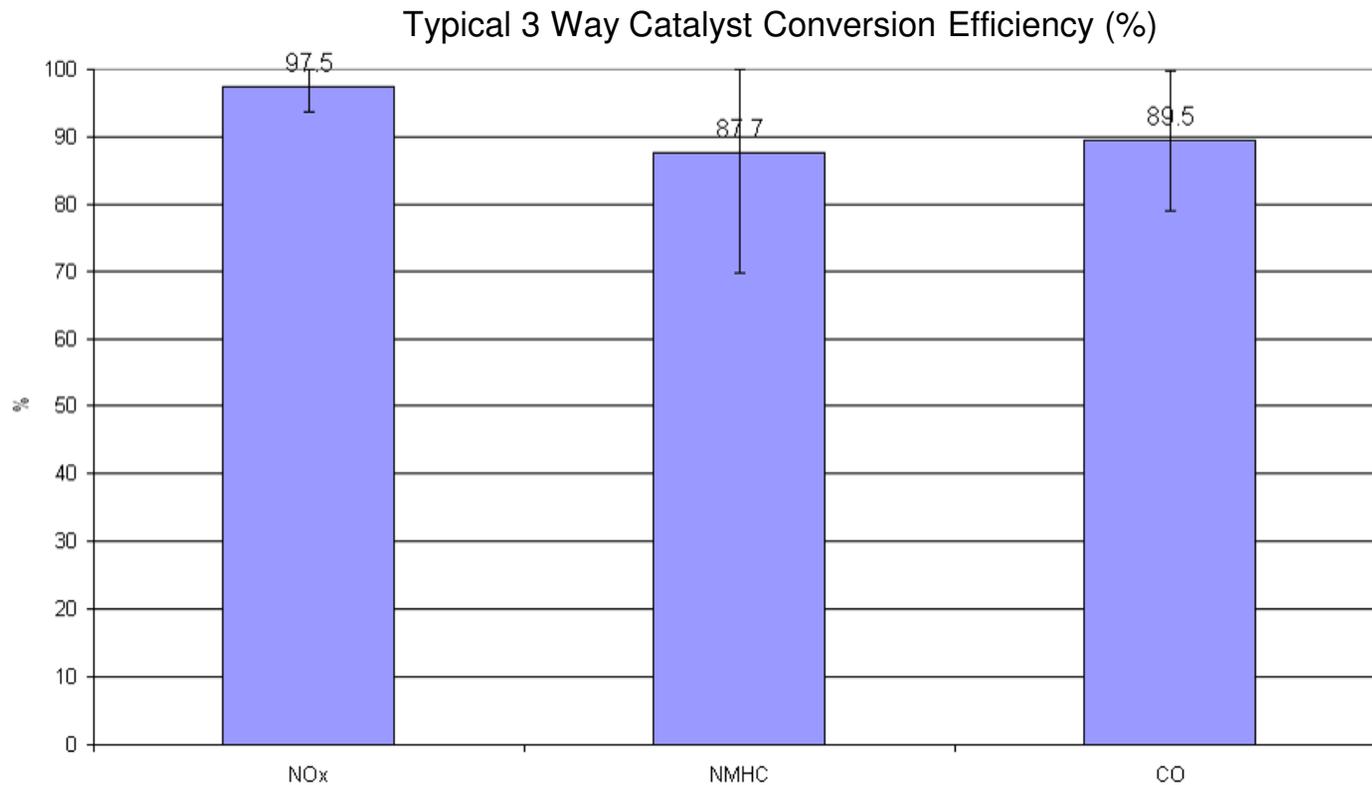
Three Way Catalyst Aftertreatment

- Similar to catalyst on gasoline passenger cars.
- Packaged as a muffler. Vertical or horizontal mount.
- Passive, maintenance-free device



Three Way Catalyst Effectiveness

- High effectiveness of emissions reductions
 - NOx conversion is highly dependant on oxygen free exhaust

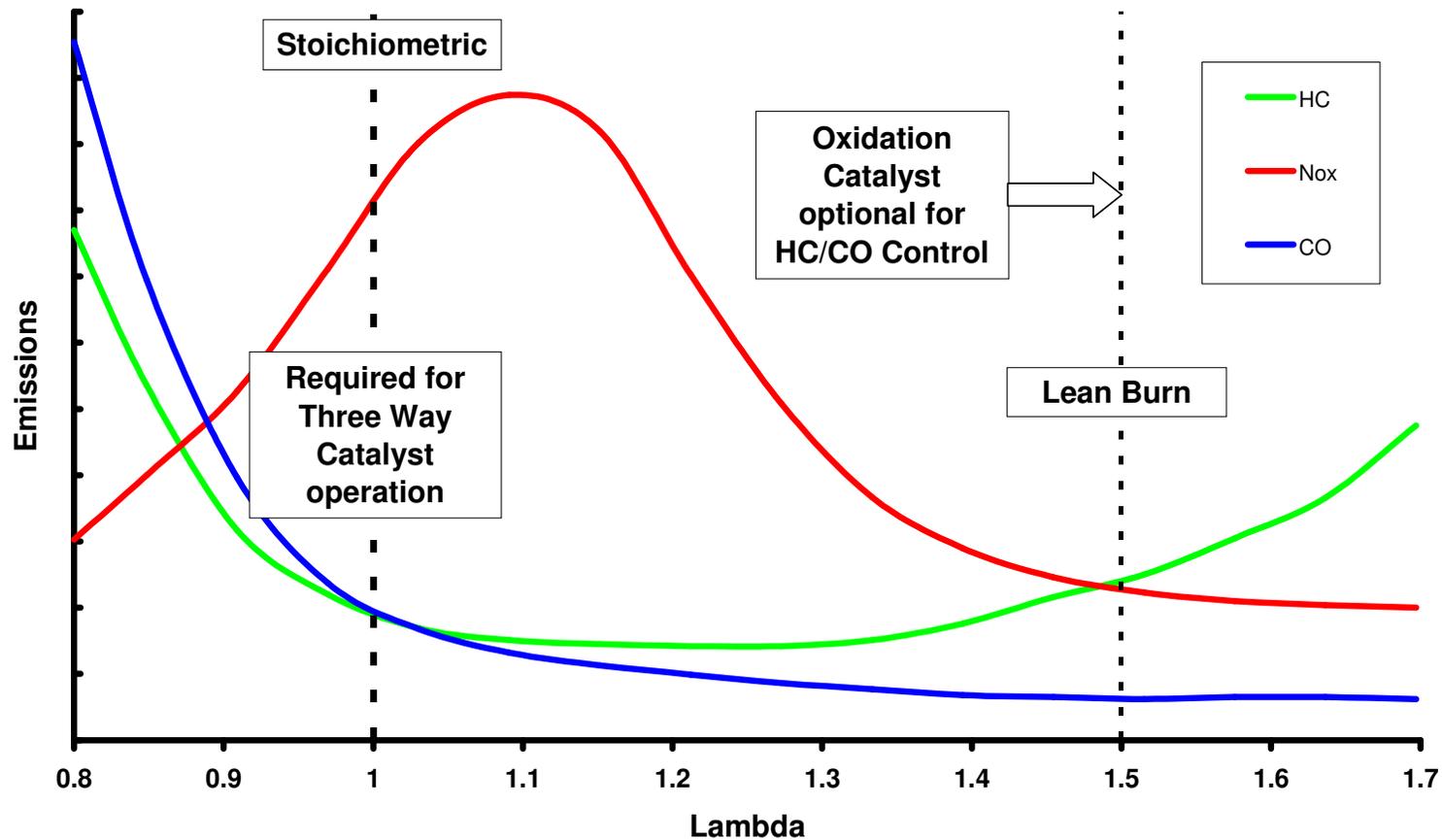


Evolution of Natural Gas Engine Technology

- **Stoichiometric combustion** is the ideal combustion process during which fuel and oxygen are burned completely
 - Early heavy duty (HD) natural gas engines were stoichiometric
 - Ideal air/fuel ratio - chemically correct mixing of fuel and air
 - Consumes all fuel & air without excess of either in exhaust
 - Three way catalyst (TWC) aftertreatment is highly effective at NOx reduction, but only if there is no oxygen in exhaust stream
- **Lean Burn combustion** adds excess air to the air fuel mixture so the air content is higher than the stoichiometric ratio
 - Evolution from stoichiometric combustion to meet market demands in HD applications
 - Lean Burn in HD natural gas enabled better efficiency, power density and durability than conventional stoichiometric combustion
 - Excess air leads to reduced exhaust temperatures
 - Oxygen in exhaust enables oxidation catalyst, not TWC
- **Stoichiometric combustion with cooled EGR** combines & improves the best attributes of both Stoichiometric & Lean Burn combustion.
 - Cooled EGR (CEGR) replaces the additional air in Lean Burn combustion
 - CEGR reduces exhaust temperature similar to Lean Burn engines
 - Better efficiency and power density compared to Lean Burn and Stoichiometric technologies
 - Enables a TWC for NOx control



Engine-Out Emissions vs. Air / Fuel Ratio



Natural Gas Engine Technology Evolution

1. Stoichiometric

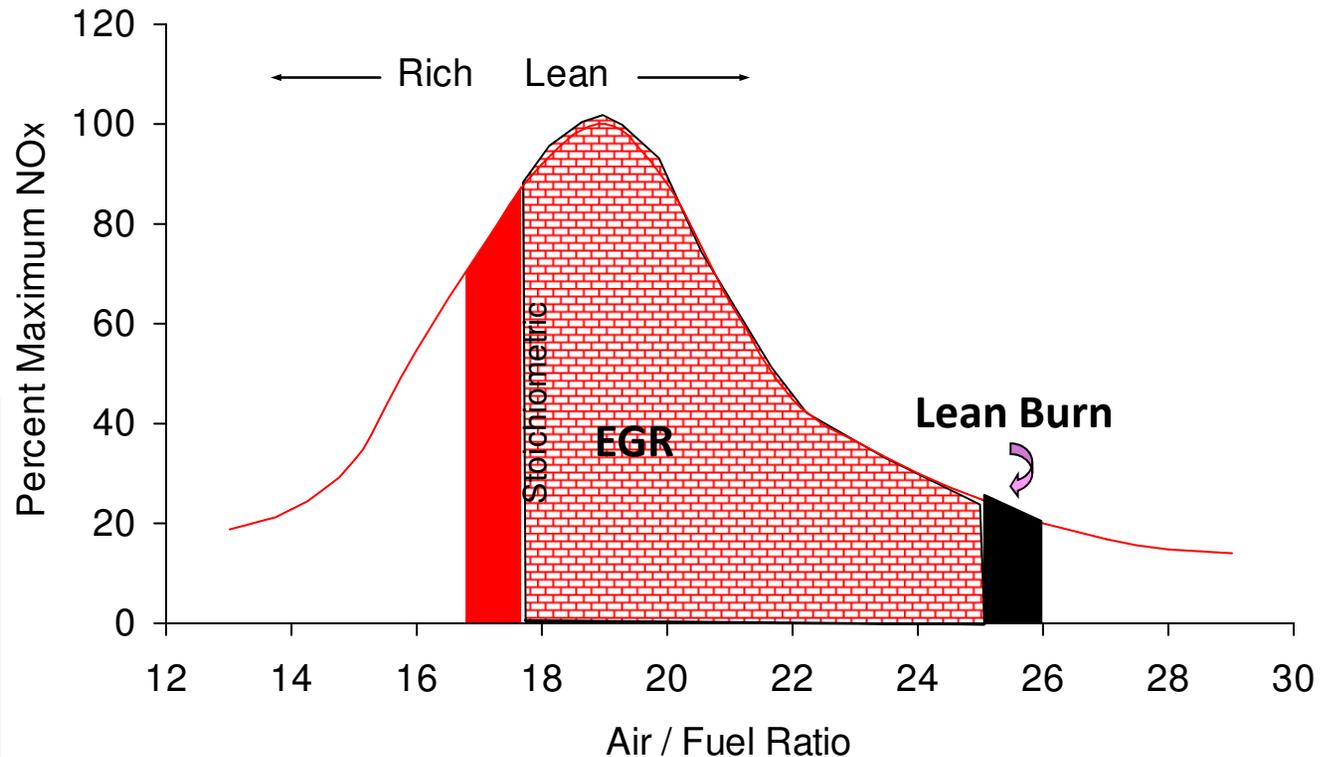
- Low NOx with TWC
- Combustion temperatures limit power density, efficiency and durability
- First technology used in HD natural gas engines

2. Lean Burn

- Introduced in '90s
- NOx control is in-cylinder
- Proven reliability/durability in heavy duty applications
- Lean combustion reduces in-cylinder temperatures
- Capable of EPA / ARB 07 emissions

3. Stoichiometric with Cooled EGR

- Combines & improves the best attributes of Stoichiometric & Lean Burn combustion
 - TWC for NOx control - Sub-EPA / ARB 2010 emissions with passive aftertreatment
 - Cooled EGR in place of air in Lean Burn reduces in-cylinder combustion temperatures
 - Improved low end torque and fuel economy



Benefits of Stoichiometric EGR Combustion

- Increased power density
 - Torque curves are virtually the same as diesel
 - Diesel-like transient response/performance
 - Increased torque at idle
- Increased thermal efficiency
 - 5% fuel economy improvement vs. lean-burn natural gas engines
 - Lower methane emissions (GHG benefit)
- Decreased emissions
 - Beats 2010 emission standards
 - Simple, passive, maintenance-free aftertreatment

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ISL G Usage Prior to ICAT Project

- ISL G originally developed for primary markets with established natural gas demand
 - Transit bus, refuse collection
- CWI wanted to offer ISL G for niche markets with historical natural gas demand
 - Utility trucks, street sweepers, shuttle buses, school buses, yard hostlers
- CWI also aware of emerging natural gas demand in the broader commercial truck market
 - Short haul truck & tractor, pickup & delivery

ICAT Grant 06-08

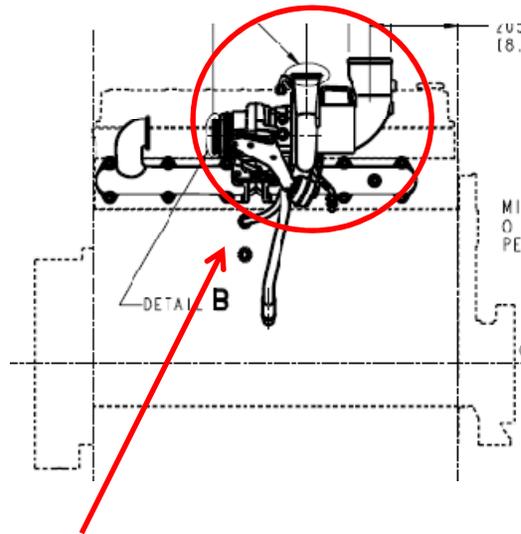
- CWI & ARB initiated this project to continue developing ISL G to expand vehicle availability and increase market penetration
- Due to lower power requirements, different duty cycles, and typically smaller engine compartments than buses & refuse trucks, the target markets required different hardware and/or performance rating options
 - Commercial engines are highly customized with various options to suit a variety of vehicle installations and customer requirements
 - OEMs specify the size and geometry of hardware such as oil pans, starter motors, alternators, engine mounts, oil dipstick locations, etc, to suit their vehicle
 - End users specify the power & torque rating to suit their productivity & pricing needs

ICAT Grant 06-08 Objectives

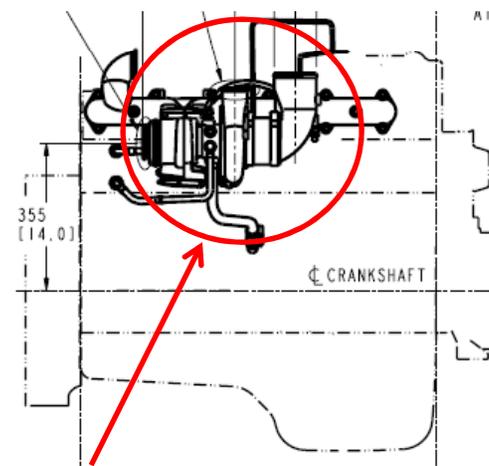
1. Design & develop a new “low-mount” turbo-charger option
2. Develop one new performance rating (nominally 250 hp)
3. Integrate ISL G into a Freightliner M2 truck
4. Demonstrate ISL G-powered Freightliner M2 at a California fleet
5. Expand OEM availability of ISL G in additional target markets

1. New Turbo-Charger Option

- CWI designed, developed and released a new “low mount” turbo-charger option to enable ISL G to fit within the engine bay of the popular Freightliner M2 truck
- Side views of ISL G engine showing turbo-charger locations:



Turbo in original “high-mount” configuration. This configuration won't fit Freightliner M2 engine compartment.



New “low-mount” configuration is lower and further rearward, to suit Freightliner M2.

2. New Performance Ratings

- ISL G was launched with three ratings
 - 320 hp, 1000 lb-ft
 - 300 hp, 860 lb-ft
 - 280 hp, 900 lb-ft
- Additional rating(s) required for many of the target markets
 - Lower duty cycles
 - Less expensive driveline components (e.g. transmissions, axles)
- Based on extensive discussions with vehicle manufacturers, driveline component suppliers, and review of historical diesel rating usage in the target markets, CWI identified two new ratings:
 - 260 hp, 660 lb-ft
 - 250 hp, 730 lb-ft



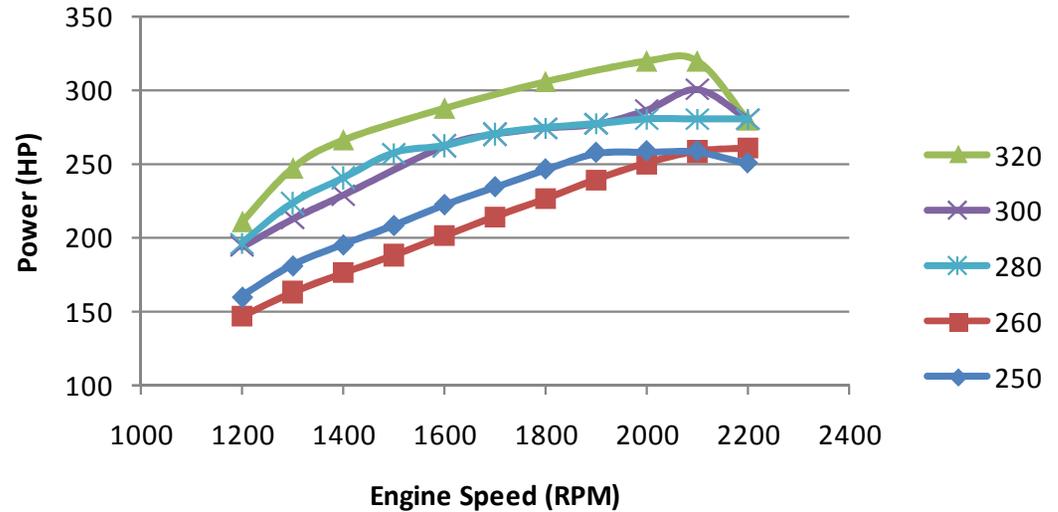
New Ratings

- Rating development included
 - Calibration development to meet performance requirements
 - Validation of intake & exhaust temperature limits, boost pressures, and emissions
- Following extensive rating development & validation work, CWI submitted documentation to EPA & ARB to add the new ratings to the ISL G emission certification
- The new ratings were released into the Cummins engine specification system, enabling customers to order ISL G engines with the new ratings

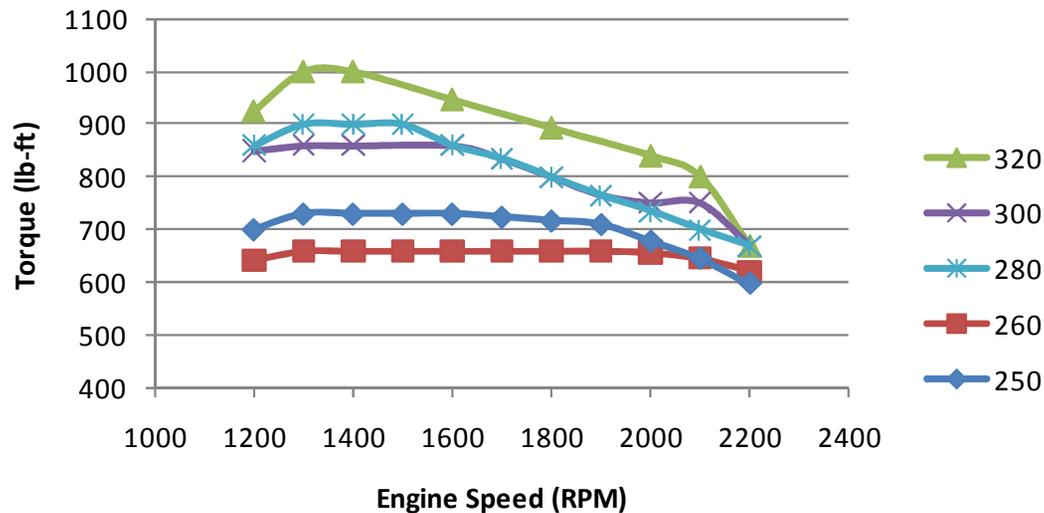
ISL G Ratings

ISL G Ratings	
Rated Power	Peak Torque
(HP)	(lb-ft)
320	1000
300	860
280	900
260	660
250	730

ISL G Power Curves



ISL G Torque Curves



New Ratings

- ARB Executive Order (Feb/09) with new ISL G ratings

 AIR RESOURCES BOARD	CUMMINS INC.	EXECUTIVE ORDER A-021-0491 New On-Road Heavy-Duty Engines Page 1 of 1 Pages
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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-02-003;

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 ⁴
			CNG/LNG				
2009	9CEXH0540LBC	8.9					
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 320 / 0887;FR92424 (320), ISL G 300 / 0887;FR92104 (300)					
8.9		ISL G 260 / 0887;FR92738 (260), ISL G 260 / 0887;FR92739 (260), ISL G 250 / 0887;FR92847 (250)					
*		*					
*		*					



3. Freightliner M2 Integration

- To maximize market penetration, CWI wanted to achieve ISL G availability in the popular Freightliner M2 truck
 - Freightliner M2 is widely used in a variety of truck & tractor configurations, including street sweepers, pickup & delivery, short haul tractor/trailer, utility



Freightliner M2 configured with utility body

Freightliner M2 Integration

- In 2007/08 Freightliner parent company (Daimler Trucks) declined to offer ISL G in Freightliner M2
- Rather, Daimler elected to install ISL G in its Sterling brand for truck / tractor applications
 - E.g. Port drayage tractors
- Good news for CWI in terms of market expansion, but Sterling tractor was considered too big by some customers in established natural gas niche markets (e.g. street sweepers, utility trucks)
- CWI & ICAT staff agreed to proceed with a repower to demonstrate ISL G in the Freightliner M2
 - Pacific Gas & Electric (PG&E) supplied a truck for field demonstration
 - CWI provided ISL G engine & catalyst
 - Complete Coach Works performed repower & validated vehicle performance



Freightliner M2 Integration

- Complete Coach Works installed ISL G engine with low mount turbo hardware, 260 hp rating, and catalyst into new Freightliner M2 ordered by PG&E
- Complete Coach Works validated acceptable engine operation and vehicle performance
- Complete Coach Works led the public introduction of the ISL G-powered Freightliner M2 repower at the Alternative Fuels & Vehicles (AFVI) conference in Las Vegas, May 2008
- Vehicle delivered to PG&E mid 2008

4. Field Demonstration

- PG&E configured the truck for fleet operation as a crew truck
 - 33,000 lb crew truck
 - Equipped to tow 40,000 lb trailer
- April 2009: truck entered revenue service in PG&E's Concord CA operations
- Through 12 months operation, PG&E accumulated mileage & engine operating hours consistent with diesel powered crew trucks in the fleet
- Truck continues to operate in PG&E's fleet



ISL G-powered Freightliner M2 in PG&E fleet

Freightliner M2 with ISL G

- Oct/08: Daimler announces obsolescence of Sterling brand by early 09
 - Planned to offer ISL G in Freightliner M2 to maintain Daimler factory availability of ISL G-powered truck / tractor product
 - ISL G installation in M2 required low-mount turbo, which was already under development within this ICAT project
- CWI provided low-mount turbo hardware on very short notice for Freightliner factory integration of ISL G
- Daimler launched ISL G-powered Freightliner M2 in mid-2009
- The expedited ISL G transition from Sterling to Freightliner is directly attributable to this ICAT project
 - ICAT development of low-mount turbo hardware enabled little / no interruption in factory availability of ISL G-powered Daimler trucks

Freightliner M2 with ISL G

- Due to unanticipated business decisions by Daimler, this project has resulted in two parallel vehicle integration activities
 - ISL G available from Freightliner in M2-112 model
 - ISL G-powered M2-106 (with shorter hood) is available as a repower option from aftermarket conversion specialists, including Complete Coach Works



Factory-built ISL G-powered Freightliner M2-112 tractor with CNG storage



5. Expanded OEM Availability (North America)

Prior to ICAT Project	Additional OEMs during ICAT Project
<i>Transit Bus</i>	
NABI, New Flyer, Orion	Foton America Bus Company
<i>Refuse Collection</i>	
Autocar, Peterbilt	Mack Trucks, American LaFrance, Crane Carrier
<i>Medium Duty / Heavy Duty Truck & Tractor</i>	
N/A	Freightliner, Kenworth, Peterbilt
<i>Shuttle Bus</i>	
N/A	ElDorado National
<i>School Bus</i>	
N/A	Blue Bird, Thomas Built
<i>Yard Hostler</i>	
N/A	Capacity of Texas, Autocar
<i>Street Sweeper</i>	
N/A	Elgin, Schwarze
<i>Re-Power</i>	
N/A	Complete Coach Works (Freightliner M2-106)
	Fontaine Modification (Freightliner M2-106)

- CWI has achieved broad OEM availability in the target markets
 - The new options developed in this project have directly enabled many of the new OEM installations listed above
 - Additional OEMs offer ISL G outside North America



Project Accomplishments vs. Goals

1. Design & develop a new “low-mount” turbo-charger option
 - Complete – new “low mount” option developed & released
 2. Develop one new performance rating (nominally 250 hp)
 - Complete – two new ratings developed, certified & released
 3. Integrate ISL G into a Freightliner M2 truck
 - Complete
 - Aftermarket repower by Complete Coach Works (M2-106)
 - Factory installation by Freightliner (M2-112)
 4. Demonstrate ISL G-powered Freightliner M2 at a California fleet
 - Complete – ISL G truck in regular operation at PG&E
 5. Expand OEM availability of ISL G in additional target markets
 - Complete – Broad OEM availability in all target markets
- Thank you to ARB staff for your support!





Questions?

www.cumminswestport.com

