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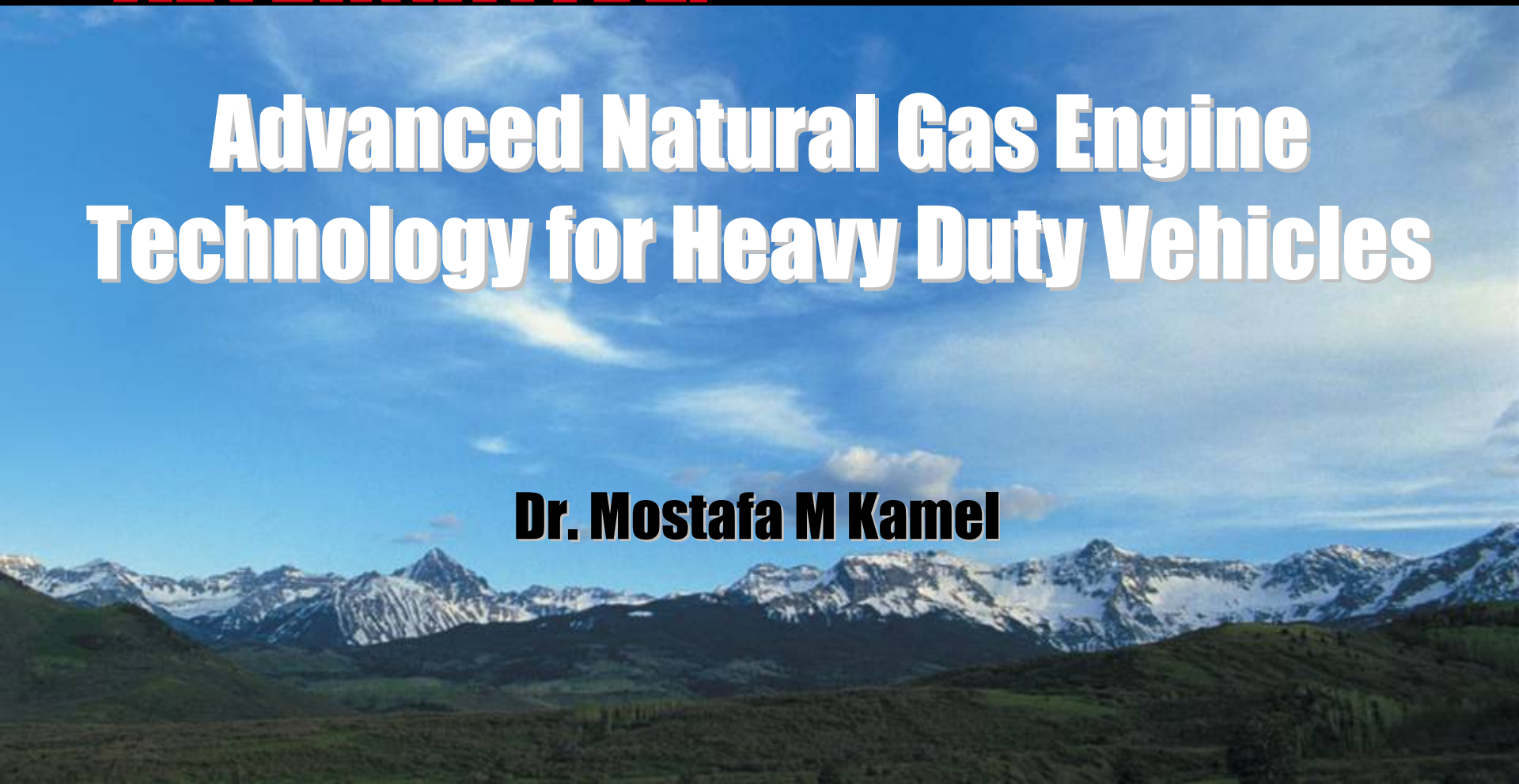
Advanced Natural Gas Engine Technology for Heavy Duty Vehicles



Dr. Mostafa M Kamel

HD Vehicle Environment

- **The economics of HD diesel vehicle operation are changing**
  - Higher vehicle pricing to meet 2007 emissions requirements
  - Further cost increases related to 2010 emissions technology
  - Higher cost of Ultra Low Sulfur diesel fuel
  - Uncertain crude oil pricing
- **Concern about Green House Gases**
- **Advancements in NG engines in HD vehicles**

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What about Natural Gas?

- Clean burning, safe vehicle fuel
- Abundant supply in North America
- Renewable fuel – Landfill Gas, Bio Gas
- Lower GHG emissions
- Lower cost, less volatility
- Engine technology advancements

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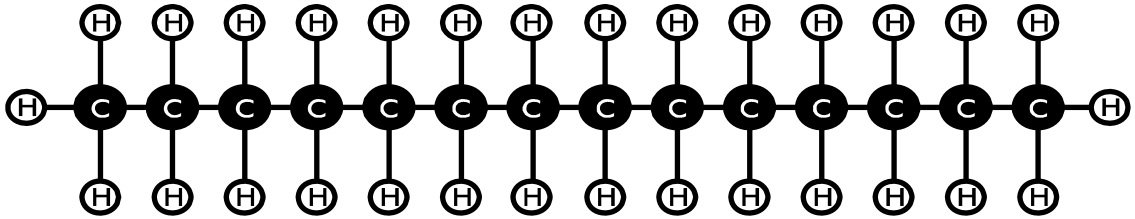
Simpler Cleaner Fuel

Emissions

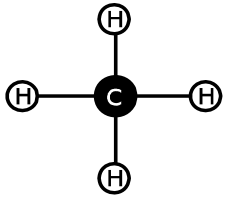
Diesel C_{14} H_{30}

Complex Hydrocarbon



Methane CH_4

Simplest Hydro Carbon



High hydrogen-to-carbon ratio results in GHG advantage

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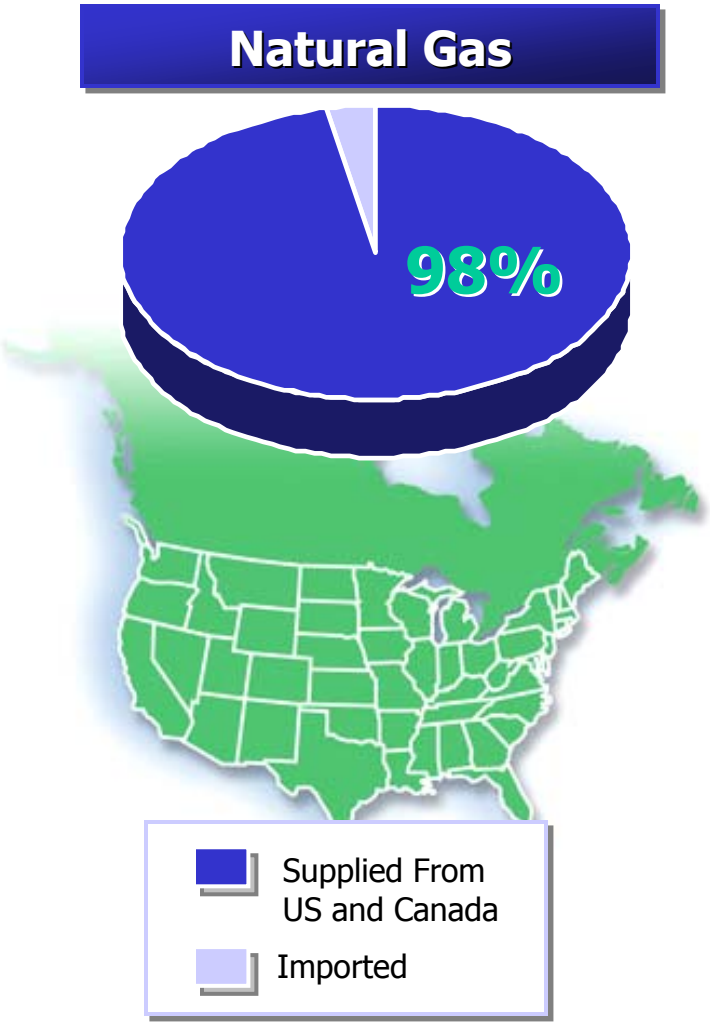
Large & Domestic Fuel

Energy Security



- **Less than .01% used for transportation in U.S.**
  - 10 million NGVs would use about 3%
- **World NG reserves estimated at 3x that of oil**
- **Huge advances being made in bio-Methane**
  - landfill gas (LFG), dairy farms, wastewater treatment plants
- **NGVs offer solution to dependence on foreign oil**
  - U.S. imports up to 70% of its oil at a cost of $700 billion a year

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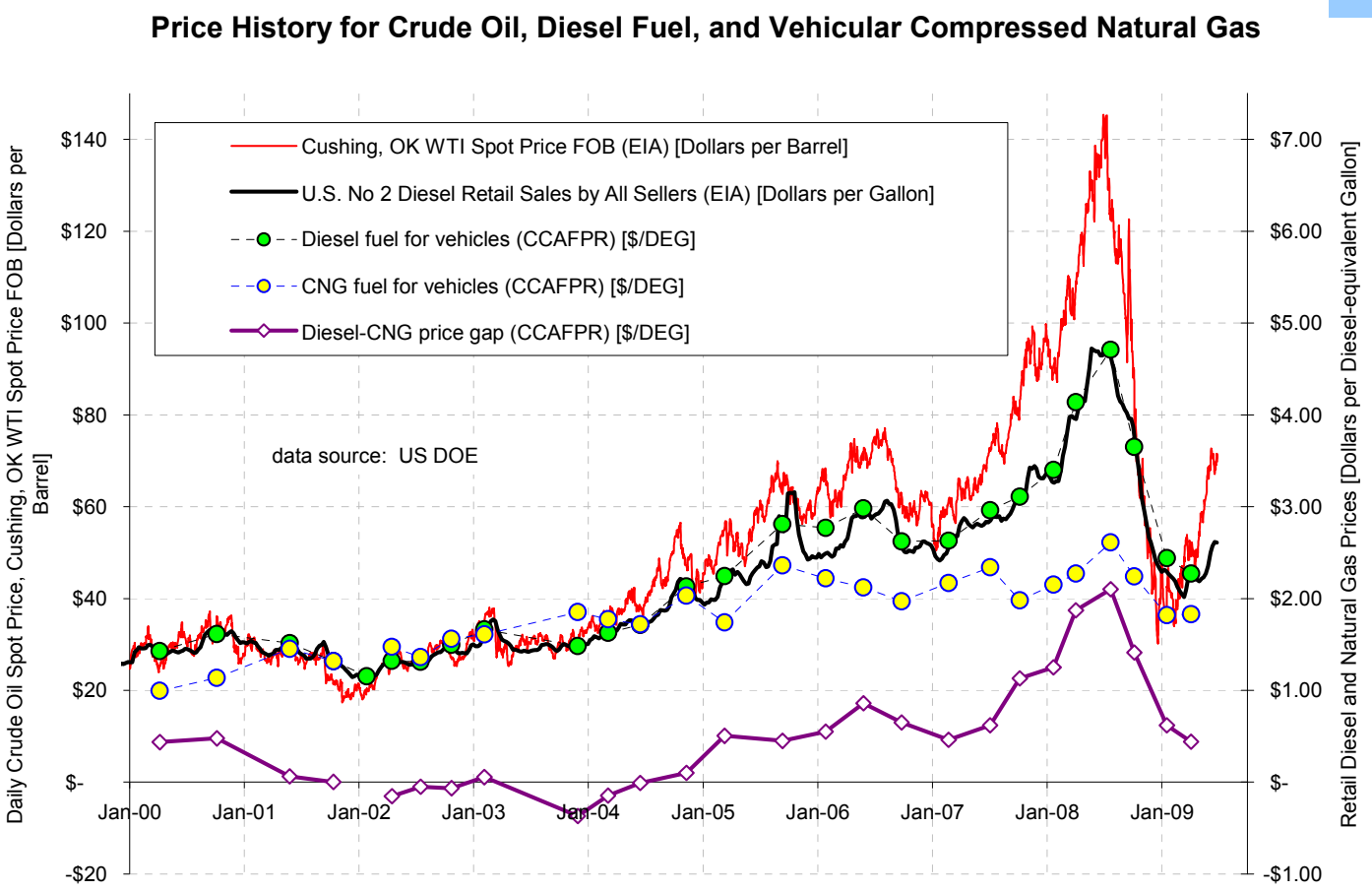
Source – Clean Energy 2009

Lower Fuel Costs

Economics



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Why Natural Gas Engines?

Emissions Leadership

- Heavy Duty engines at or lower than legislated limits
- Greenhouse gas advantages

Economic Benefits

- Lower cost fuel
- Improved Efficiency
- Life Cycle Cost advantage

Energy Security

- Reduced reliance on imported oil
- Renewable (Bio-methane)

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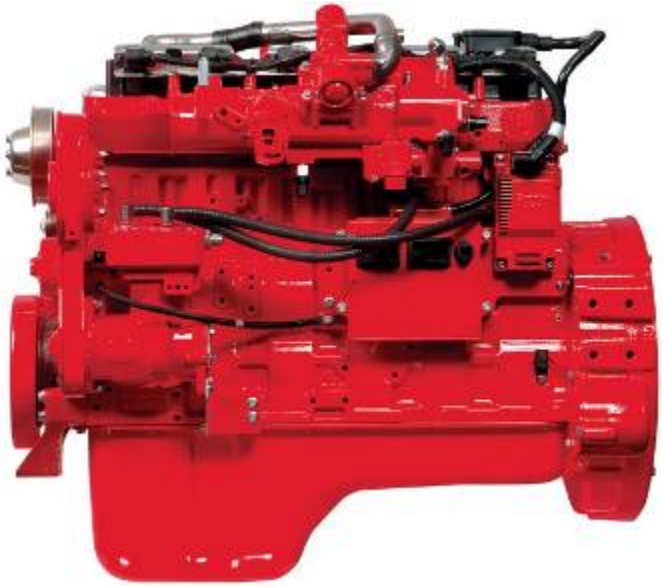
Natural Gas Engine for HD Applications



ISL G

- **8.9 litre Stoichiometric Cooled EGR**
  - Ratings from 250 to 320 hp
  - 1000 ft.lb peak torque
- **Low emissions**
  - 0.20 g/bhp-hr NOx
  - 0.01 g/bhp-hr PM
- **Three Way Catalyst Aftertreatment**
  - Maintenance Free
- **CNG, LNG, or BioMethane**

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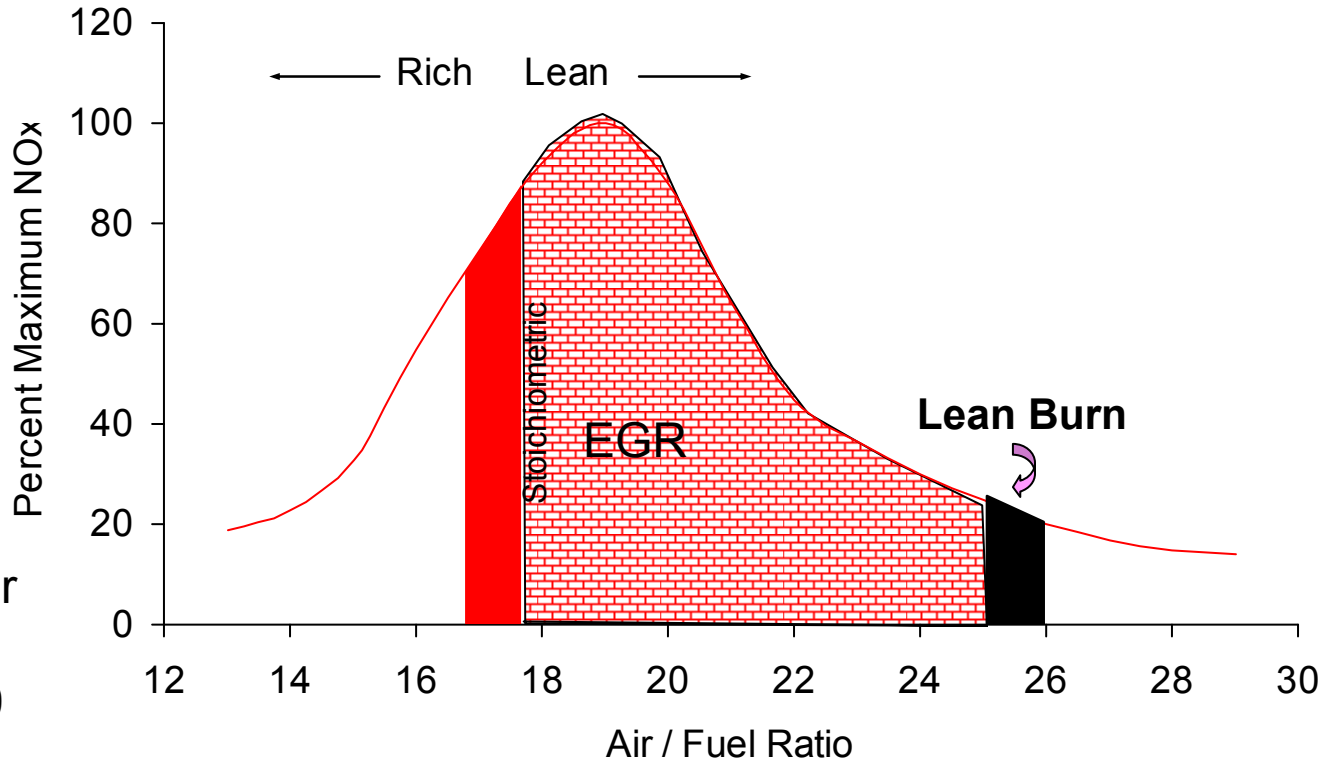
Natural Gas Engine Technology Evolution

Stoichiometric

- Low NOx with TWC
- Limited power density, efficiency, durability

Lean Burn

- Lean combustion improves power density, efficiency, durability
- NOx control is in-cylinder
- Capable of EPA07 emissions, but not EPA10



Stoichiometric with Cooled EGR

- Combines the attributes of Stoichiometric & Lean Burn combustion
  - Oxygen-free exhaust enables TWC for NOx control
  - Cooled EGR delivers power density & efficiency
  - Sub-EPA10 emissions with passive aftertreatment

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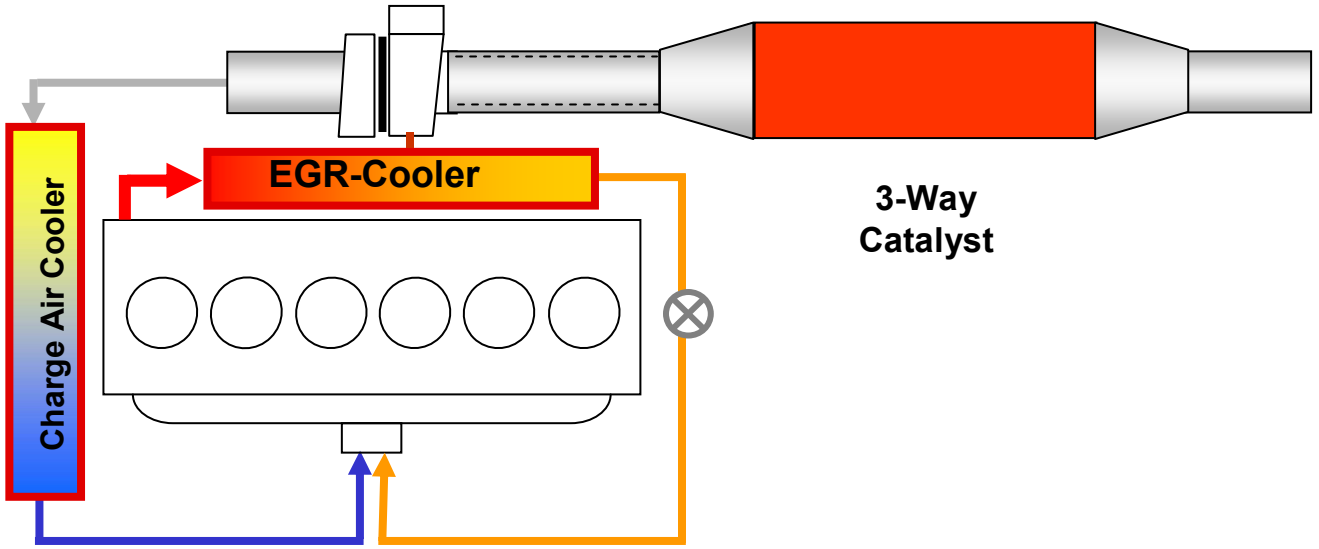
ISLG Schematic



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Three Way Catalyst

- Reduces three harmful emissions: NO_X, CO, HC
- End products are: N_2, CO_2, H_2O
- Simple, passive, maintenance-free

Catalyst Inlet

NO_X

CO

HC

Catalyst Outlet

N_2

CO_2

H_2O

ISL G TWC - similar package size to current mufflers

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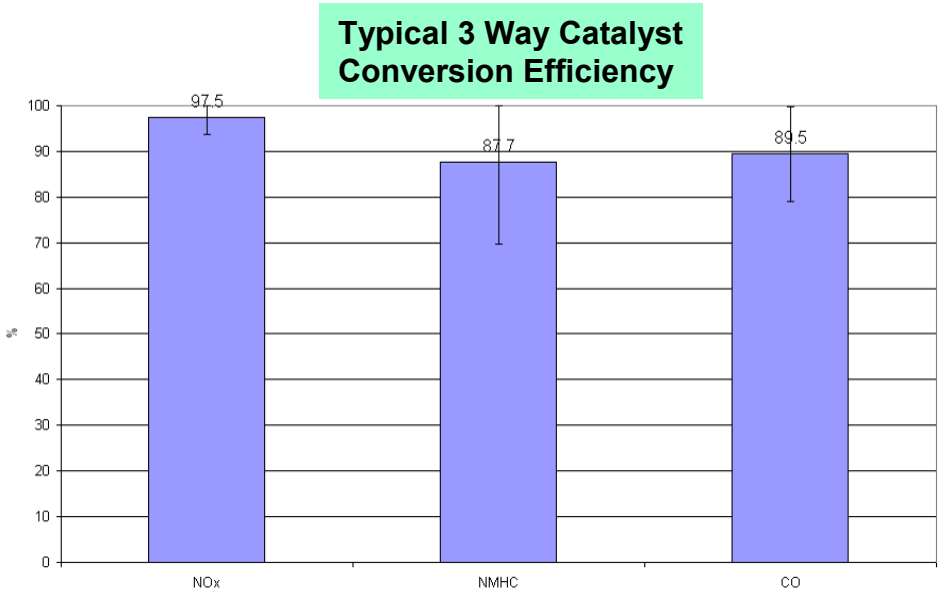
Technology Advantages

- **Separation of Combustion and Emissions control functions allows:**
  - Optimization of the catalyst design to produce the highest conversion efficiencies



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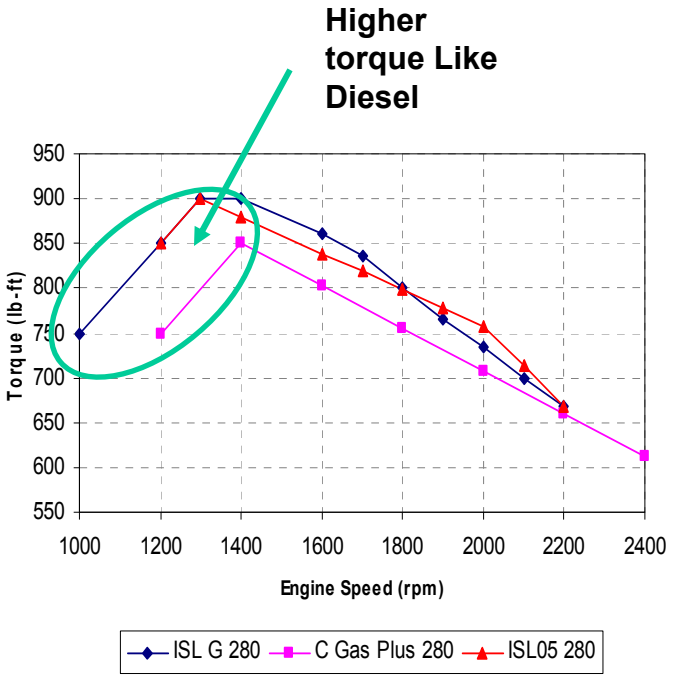
Technology Advantages

- Optimization of combustion to produce best performance and efficiency
  - Transient response improved and low end torque increased
  - Fuel economy improvement of 5% achieved and demonstrated in the field compared to Lean Burn product



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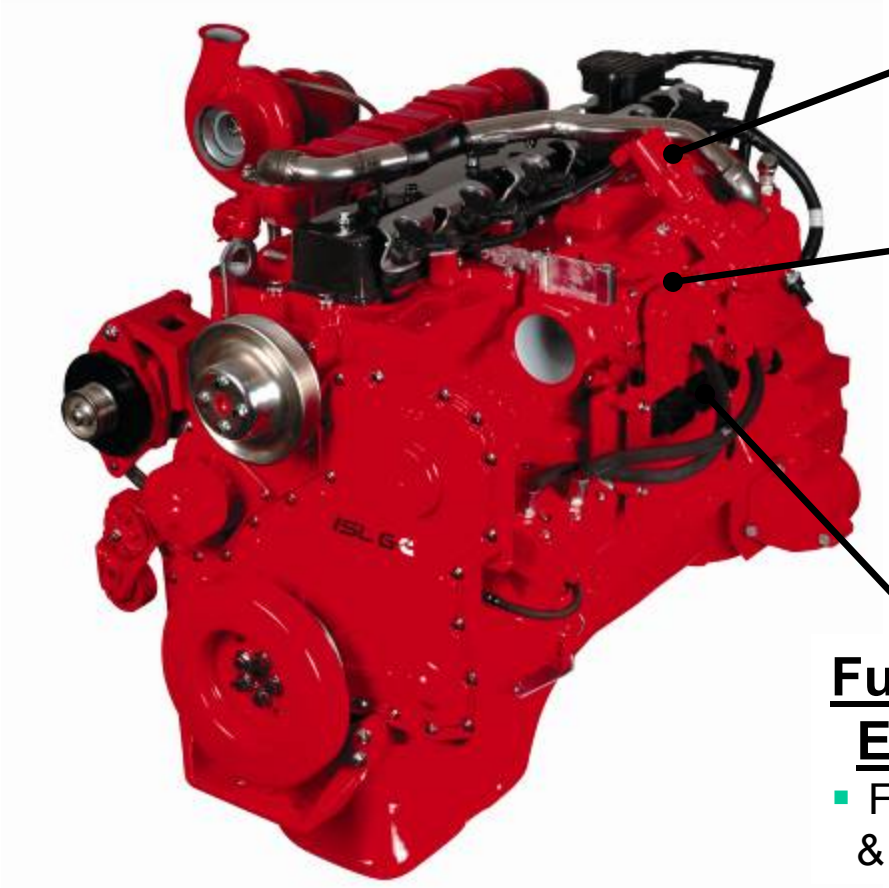
2010 ISL G



Cooled EGR

- Cold-Side EGR Valve

Integrated Fuel Housing

- Compact one piece design
- Throttled air mixed with fuel and EGR

Fully Integrated Electronic Controls

- Fuel, Ignition, Catalyst, EGR & Air Handling Controls

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GHG Well to Wheel for Urban Bus - GH Genius

Post 2010 Results (Vancouver, Canada)

	Extraction	Processing	Transportation and storage	End user	Total
Natural Gas	 115 g/km	 49.5 g/km	 53.9 g/km	 1,183.9 g/km	1,402.4 g/km
Diesel	 268.8g/km	 179.5 g/km	 9.7 g/km	 1,353.7g/km	1,811.7 g/km

22.6% GHG reduction

Including vehicle material and assembly - 21.9% GHG

Source:http://www.nrcan.gc.ca/es/etb/ctfca/PDFs/GHGenius/gh_genius_pamphlet0405_e.html

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In-Use Emissions

- In-use emissions measured (by Sensors Inc.) in a Sacramento Transit Bus in service
- Used EPA in-use test procedure
- Emissions were significantly lower than the 2010 EPA Heavy Duty emissions regulations

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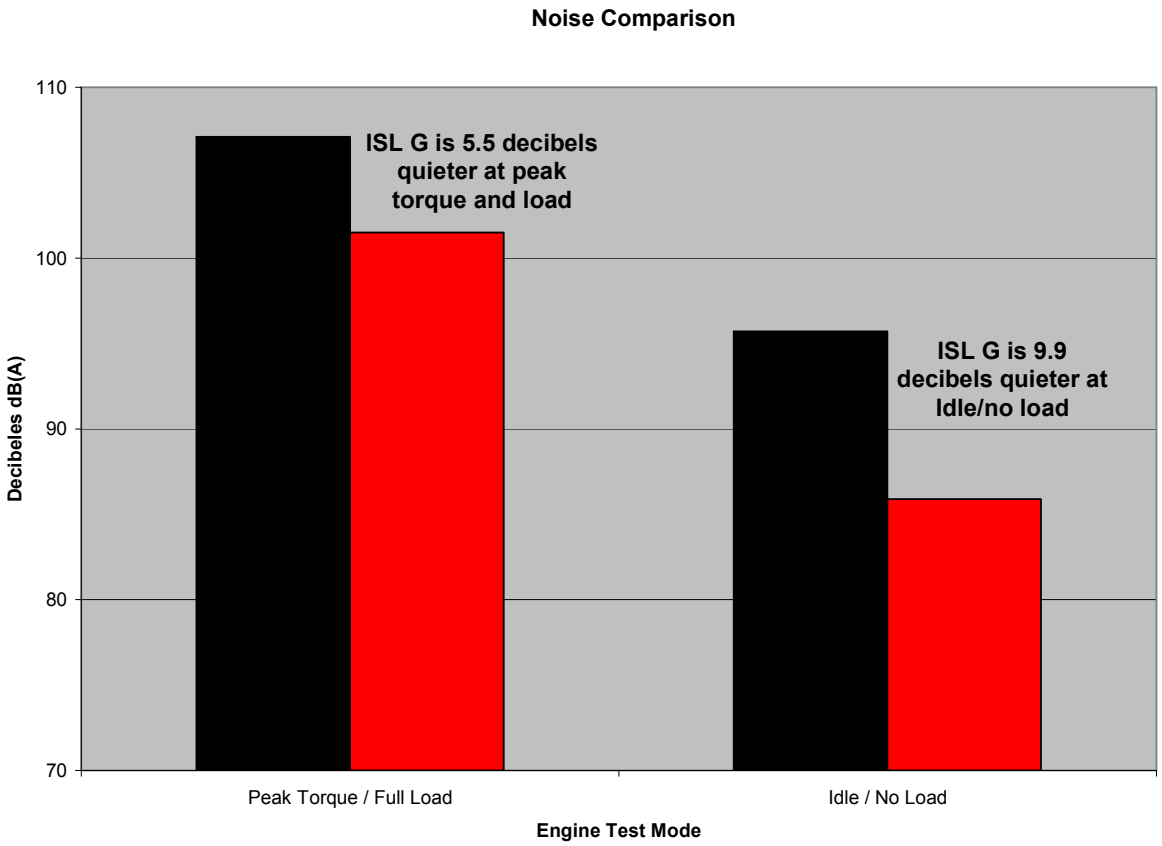
Reduced Noise

Communities notice the natural gas noise advantage.

ONE Diesel engine idling is louder than TEN natural gas engines idling together



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Natural Gas Applications

TRUCK

SPECIALTY

BUS

REFUSE

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Biomethane Profile

- Hilarides Dairy uses manure produced by 10,000 cows to generate 226,000 cubic feet of biomethane daily — enough to reduce the Central Valley farm's diesel fuel consumption by 650 gallons a day
- Two 18 wheel tractor trailers powered by ISL G 320 operating on compressed Biomethane
- Project financed with a grant from the California ARB Alternative Fuel Incentive Program

Hilarides Dairy - Lindsay, California

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Summary

- **Natural gas engine technology has evolved to meet the requirements of HD vehicle applications**
- **CWI technology can meet the toughest emissions requirements while delivering**
  - Economics advantage
  - Simple aftertreatment
  - Lower GHG emissions
- **Natural Gas engines use an abundant North American fuel and are compatible with Biomethane as a renewable fuel**

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