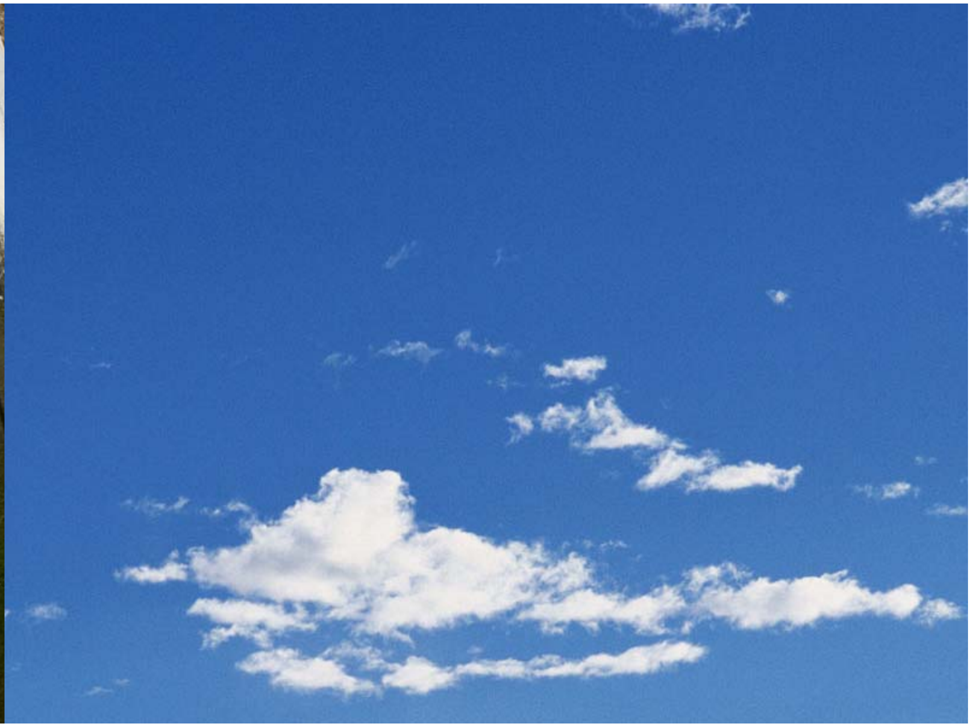
Westport

The global leader in natural gas engines.



Technology Choices for Existing and Up and Coming New Applications of Natural Gas as Transportation Engine Fuel

Patric Ouellette, CTO

Westport Innovations

September 24, 2012

Agenda

- Westport
- Natural Gas as a transportation fuel Today
- Gas Engine Technology Spectrum
- SI Technology for Passenger Cars and Light-Duty Trucks
- SI Technology for Medium-Duty and Medium Heavy-Duty Commercial Vehicles
- HPDI for Heavy Heavy-Duty On-Highway Trucks
- Non Road Mobile High Horse Power Applications

Westport at a Glance

market focus

Leading the global shift from petroleum fuels to natural gas for transportation





position

Strong first mover advantage with unmatched IP, relationships, market coverage, products, capabilities

Caterpillar	Electro Motive
Cummins	General Motors
Kenworth	Weichai Power
Peterbilt	Volvo

opportunity

Immediate profitable expansion from where we are; colonize new territory in light duty; offroad

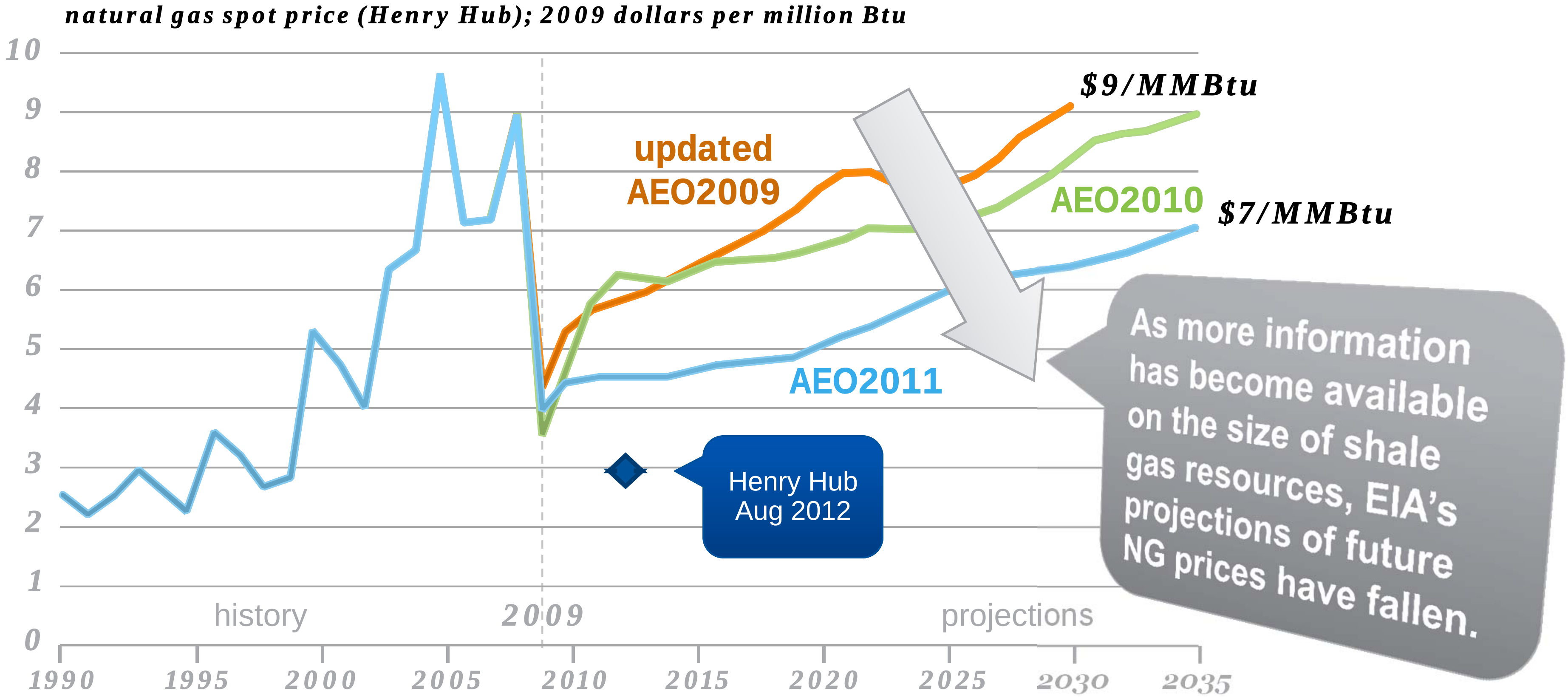



Global Operations

Total Global Employees: 945

Downward Pressure on Natural Gas Prices

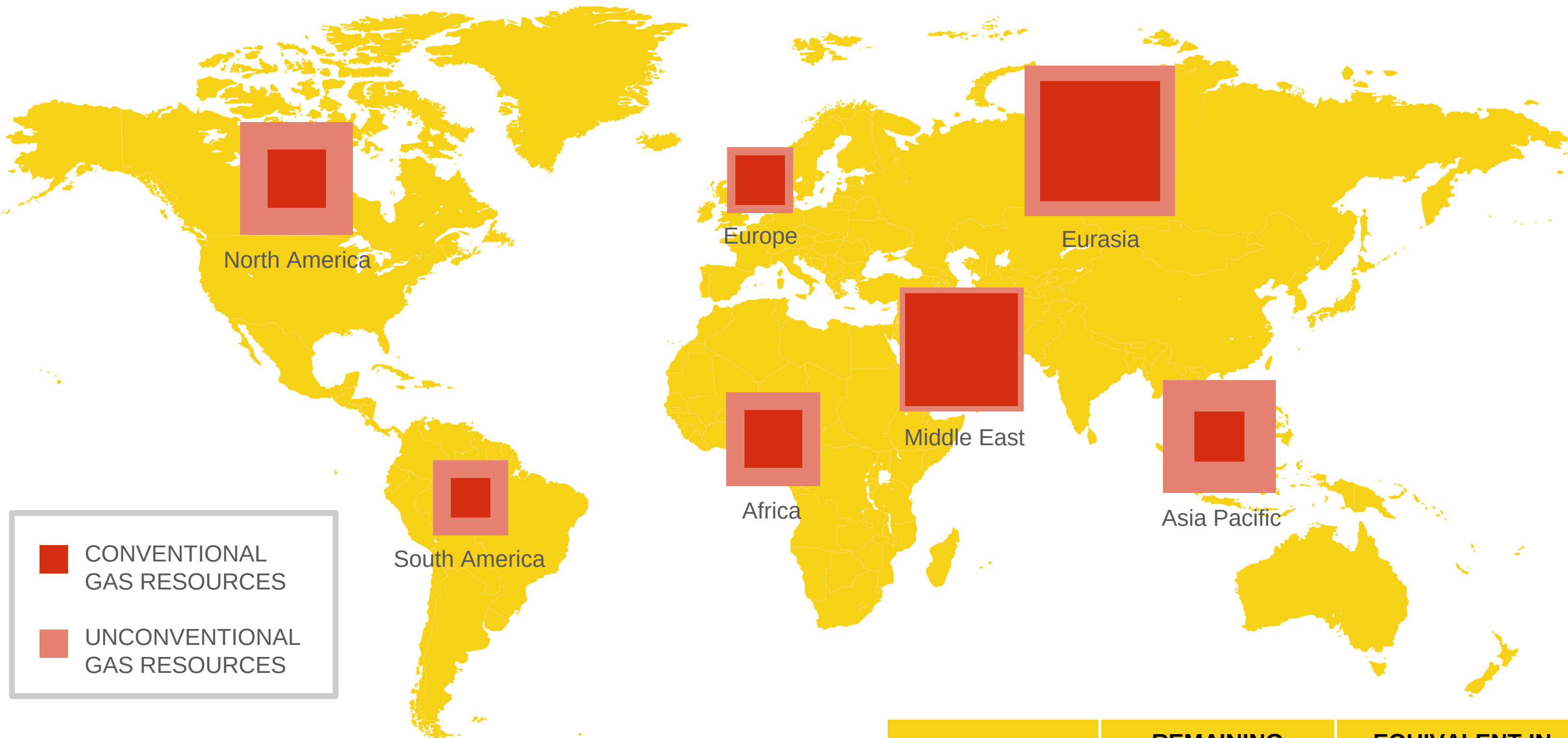
Natural gas price projections are significantly lower than past years due to an expanded shale gas resource base



sources: EIA, Annual Energy Outlook 2011; EIA, Annual Energy Outlook 2010; and EIA, An Updated Annual Energy Outlook 2009 Reference Case via: Shale Gas and the Outlook for U.S. Natural Gas Markets and Global Gas Resources, Richard Newell, June 21, 2011

ABUNDANT: HUGE GLOBAL GAS RESOURCES

GAS RESOURCES ARE PLENTIFUL, GROWING AND GEOGRAPHICALLY DIVERSE

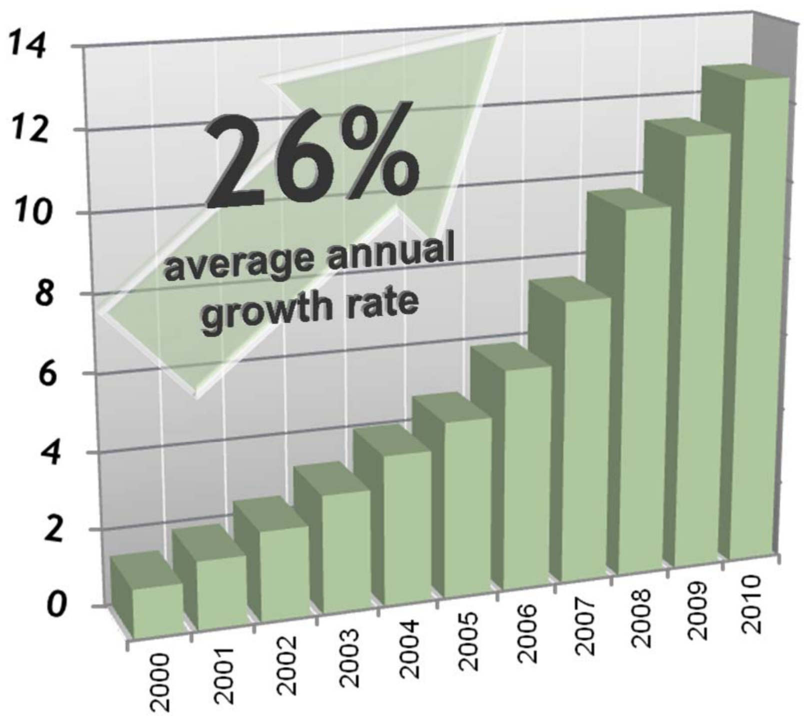


- Conventional and unconventional recoverable gas resources can supply >250 years of current global gas production
- Unconventional gas is transforming the global gas market

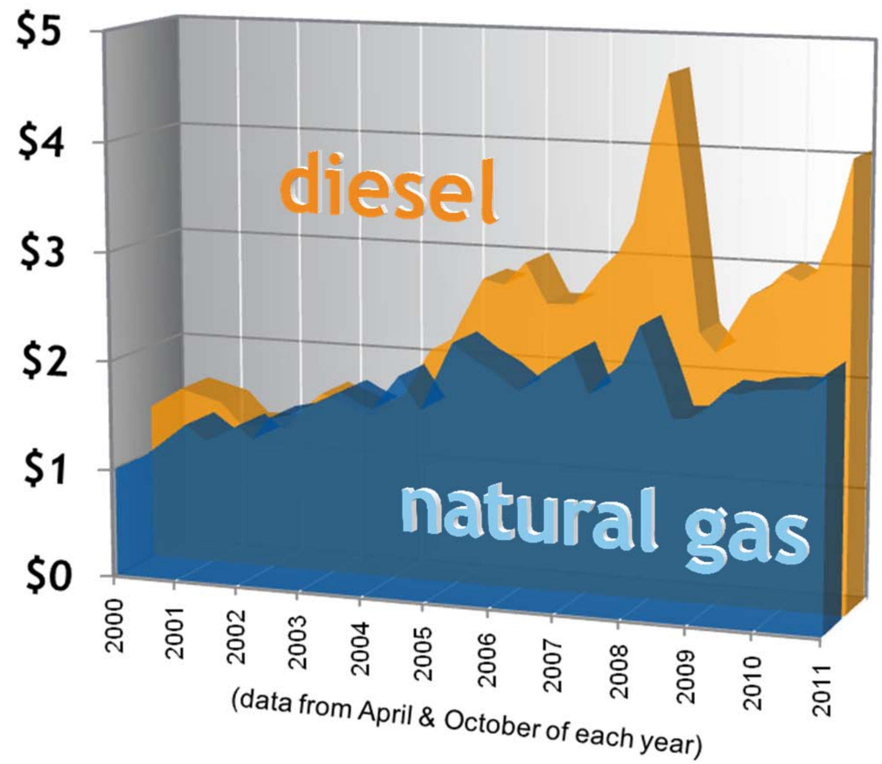
	REMAINING RECOVERABLE RESOURCES (TCM)	EQUIVALENT IN YEARS OF CURRENT PRODUCTION
Conventional	404.5	130
Unconventional	380.5	123
Total	**785**	**253**

Natural Gas Vehicle Market at a Tipping Point*

Global NGV Population
(millions of natural gas vehicles)

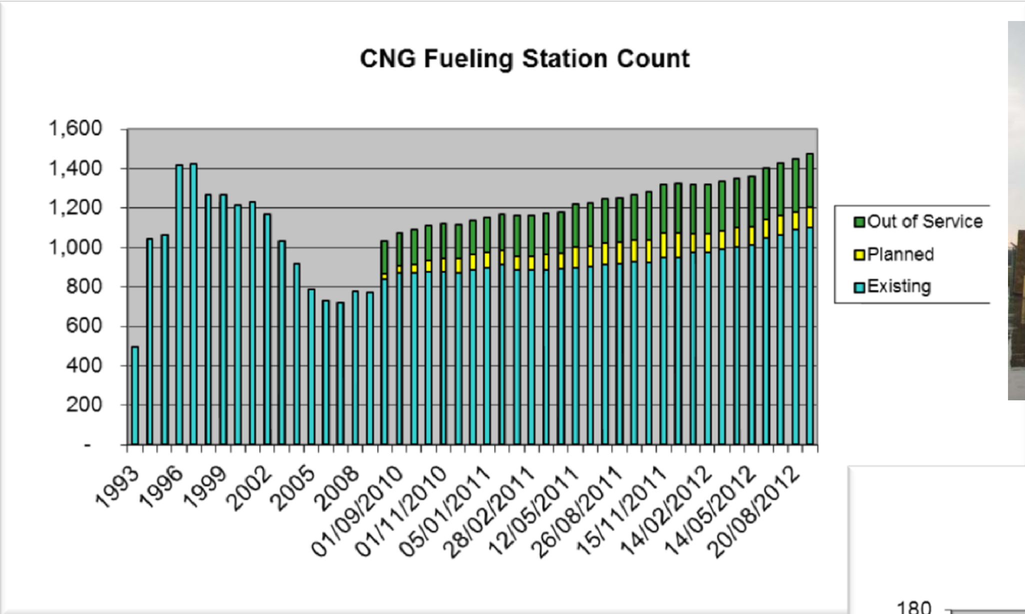


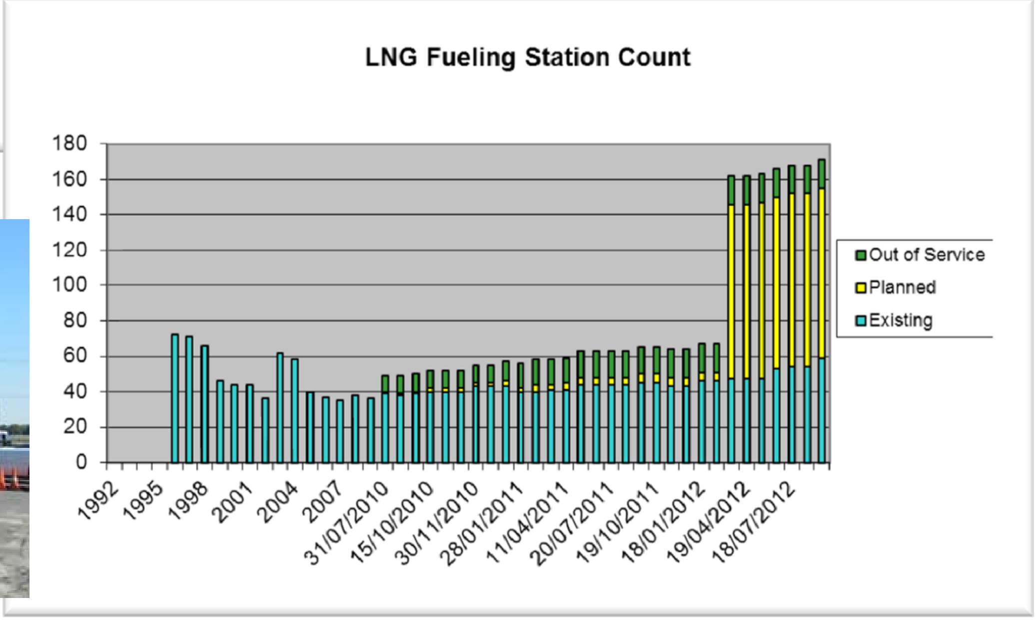
U.S. Retail Fuel Prices
(dollars per diesel gallon equivalent)



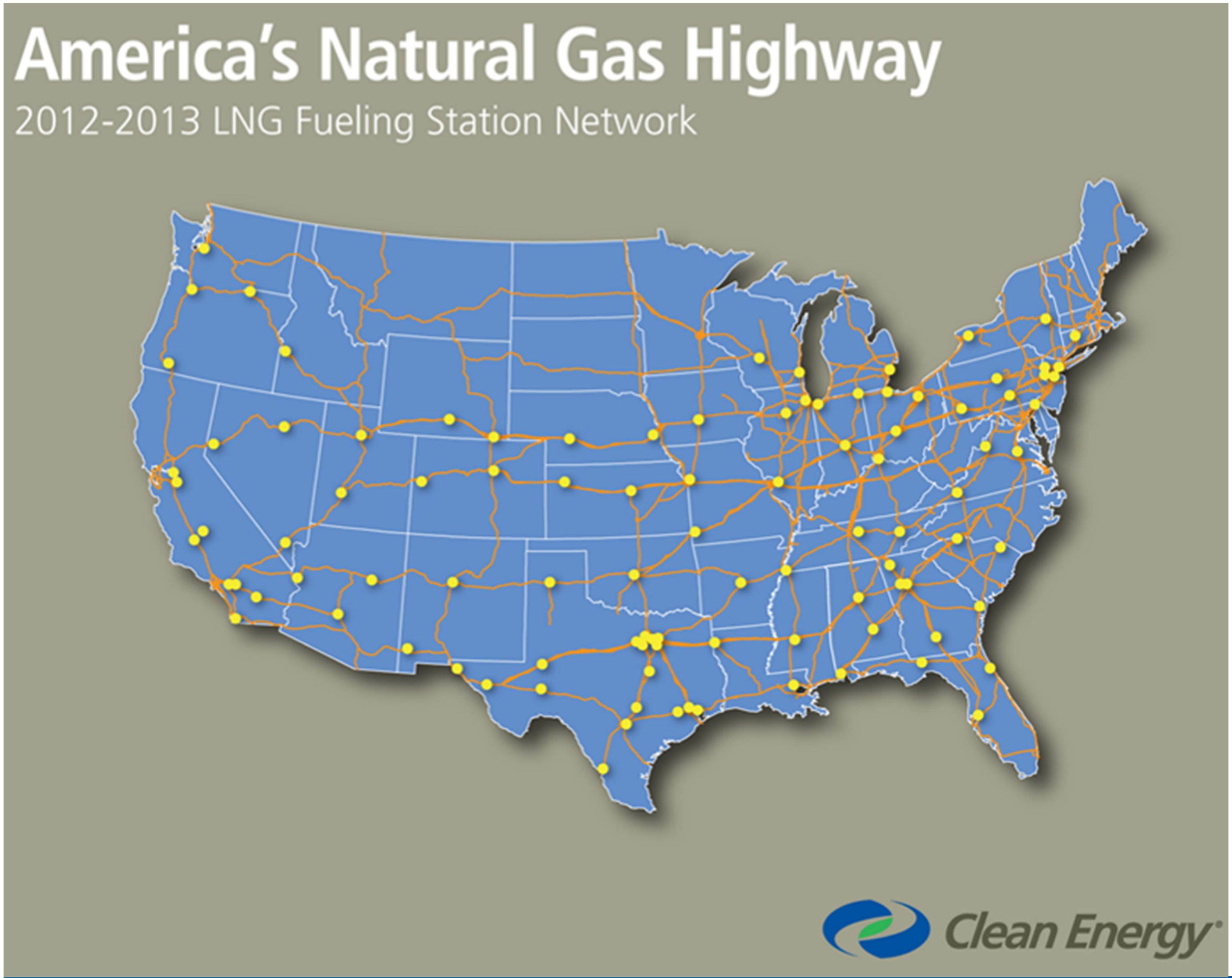
* *In Economics, the point at which a dominant technology or player defines the standard for an industry —resulting in "winner-take-all" economies of scale and scope.*

Infrastructure - North America





Example of LNG Infrastructure Build-Out Planned Clean Energy Retail Locations



- 150 fuelling stations planned
- Approximately 70 anticipated to be open in 33 states by the end of 2012
- Balance (~80 more) in 2013.
- Many will be co-located at Pilot-Flying J Travel Centers already serving goods movement trucking.

Transportation Technology Spectrum

application	engine displacement	kw/cyl	fuel / year	current uptake	fuel choice	current gas technologies
Large marine	Up to 25,000 L	Up to 1,000	Up to 30,000,000 L	**~100**	LNG	**dual fuel** **SI pre-chamber** **direct injection**
Off-highway • locomotive • mine haul • medium marine	20 to 150 L	150–275	~1,000,000 L	**~0**	LNG	n/a
Heavy-duty vehicles • on-highway trucks	9 to 16 L	~75	~100,000 L	**~10,000**	LNG or CNG	**direct injection** **dual fuel** **spark ignited** ▪ Lean-burn ▪ Stoichiometric
Medium-duty vehicles • buses • refuse haulers	5 to 9 L	~40	~40,000 L	**~100,000**		**MD spark ignited** ▪ Lean-burn ▪ Stoichiometric ▪ Stoichiometric+EGR
Light-duty vehicles • passenger cars • light-duty trucks	Up to 7 L	~40	~5000 L	**>1,000,000**	CNG	**LD spark ignited**

Several Engine Technologies Being Investigated

Relatively Well Established Engine Technologies – Improvements Needed

Values are coarse estimates and information is based on Westport's best knowledge

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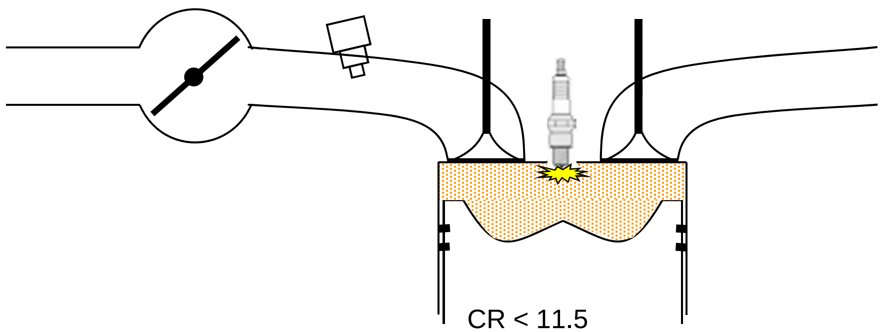
Passenger Cars and Light-Duty Trucks

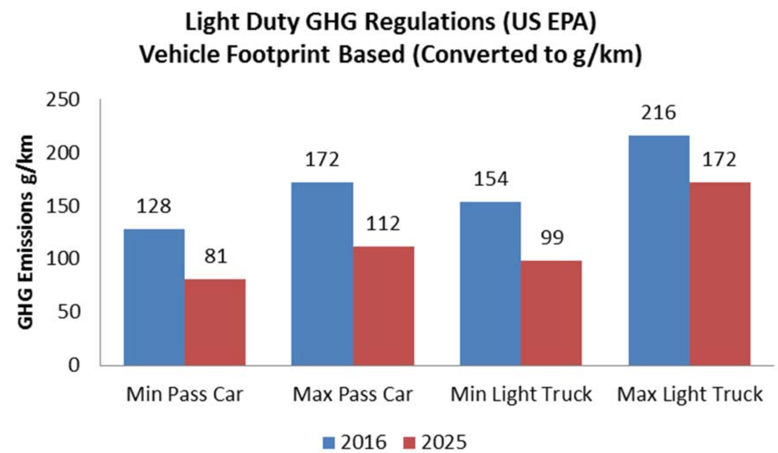
Spark ignition (SI) technology is well suited for **passenger cars** and **light-duty trucks**

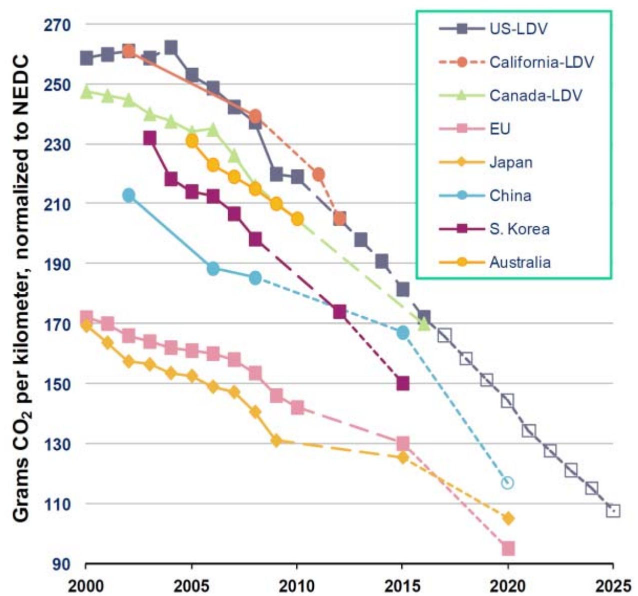
- Easiest approach when adapting gasoline engines
- Most passenger cars and LD trucks are spark ignited gasoline engines
- Most commonly configured as bi-fuel operation today
- Fitted to CNG or LPG fuel systems

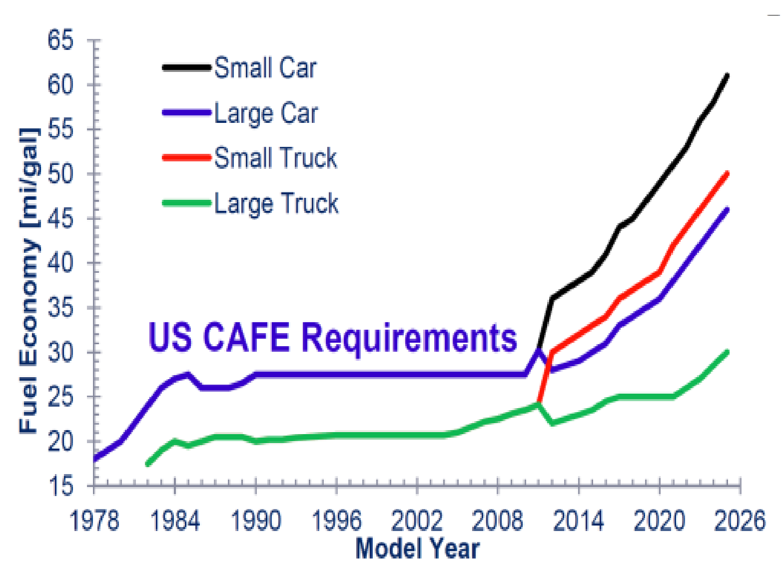


Changing Global Requirements….

- From 2016 for pass car, 2017 for Light Truck, regulated targets will be adjusted according to actual vehicle mass to bring average to 130g/km - Ramped-in penalties for non-compliance thereafter
- EPA/NHTSA GHG/FC rule for passenger car and smaller light duty truck kicking in 2016







Ref: T. Alger, SwRI 2012

Light Duty Engine Trends

- Engines continue to be aggressively downsized in Europe (e.g. 1.0 litre Ecoboost)
- NA and Turbo Petrol DI have been coming to North America
- Many engines have now VVA

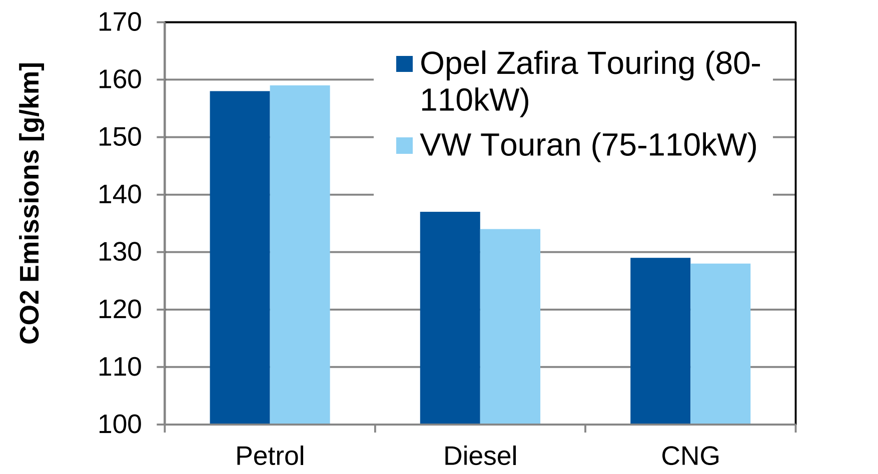
These represent …interesting… challenges for NG fuel systems integration, in particular for aftermarket retrofit or even for zero mile upfit

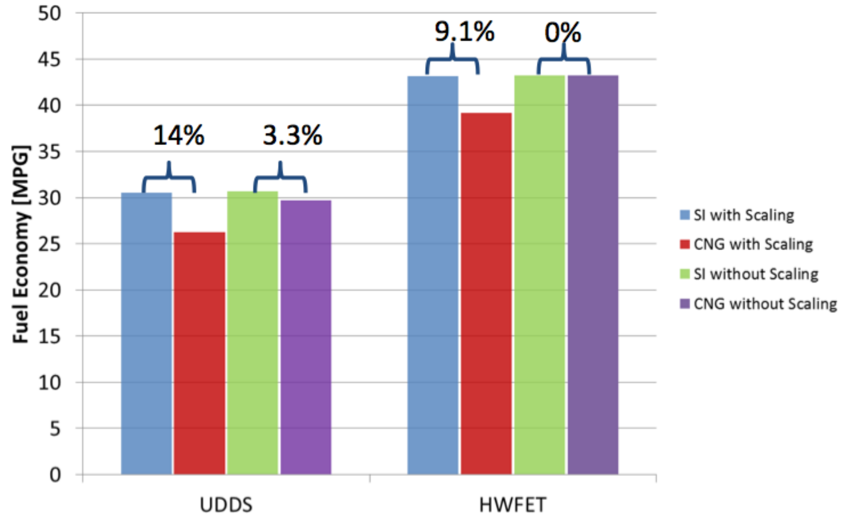
- 1.0 Litre Turbo
- 3 Cylinders
- 125PS
- 170-200Nm

- 7 Passengers

Natural Gas CO_2 benefits but performance shortfall ?

- CNG offers CO_2 benefits
- Expect that most US CNG LD truck models will rate very well on CO_2 with a range of 200-300 miles
- Recent Argonne study indicates 2% fuel efficiency (mpg) penalty for same displacement, 12% penalty for same 0-60mph performance
- Seeing example of engine "upsizing"
  - Opel Zafira Touring – 1.4l turbo petrol vs. 1.6l turbo CNG
  - Supercharging can offset the deficit (e.g. VW Ecofuel)





Storage

- Integrated composite tanks
- Reduced size gasoline tanks

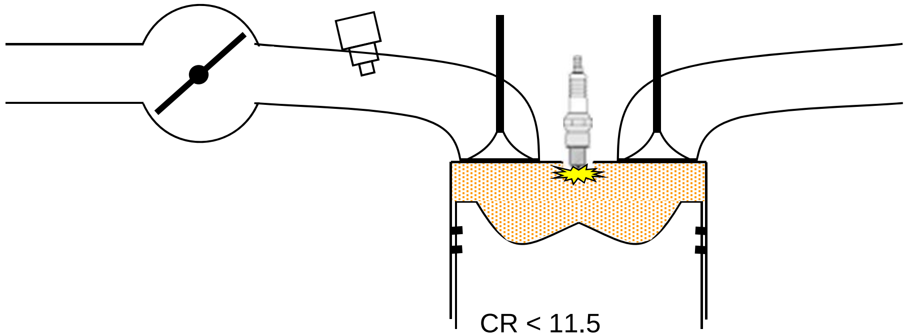
- DOE ARPA-E MOVE (Methane Opportunities for Vehicular Energy)

	Energy Density	
	[MJ/L]	[MJ/kg]
Diesel	37.3	46.2
Gasoline	34.2	46.4
LNG (-162 ºC)	22.2	50
CNG (250 Bar)	9.2	50
CNG + Type I	7.4	5.9
CNG + Type IV	7.4	15.6
ANG (35 bar)	9.2	12

SI Technology for MD and MHD Vehicles

SI Technology is a good compromise in **refuse trucks**, **transit buses**, **delivery trucks**, etc.

- Cost-effective method to use natural gas
- Well suited to CNG or LNG
- Achieves low emissions with passive exhaust after-treatment



SI Technology for MD and MHD Vehicles

Westport JVs integrate fuel system components, ignition system with advanced electronic controls on modified base diesel engines to provide industry-leading engines

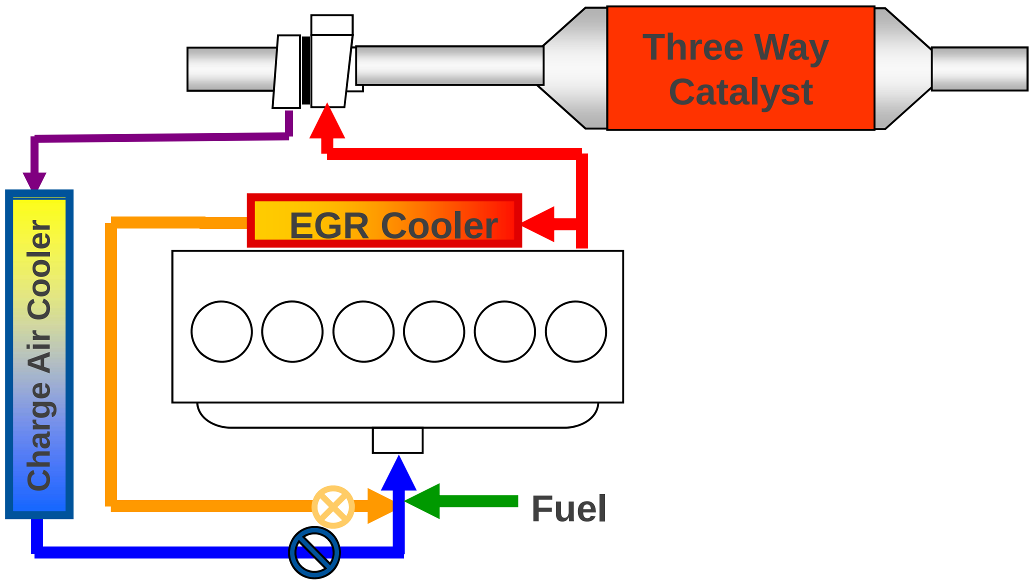
Kenworth T440
2 X 40.5 DGE Rail Mount CNG tanks - 81 DGE

- Electronically controlled Lean Burn
- Stoichiometric Cooled EGR

Shanqi LNG Truck with WWI WP12NG380 LB Engine

CWI Combustion Technology
Spark Ignited Stoichiometric with Cooled EGR

Stoichiometric EGR
Three Way Catalyst
Architecture



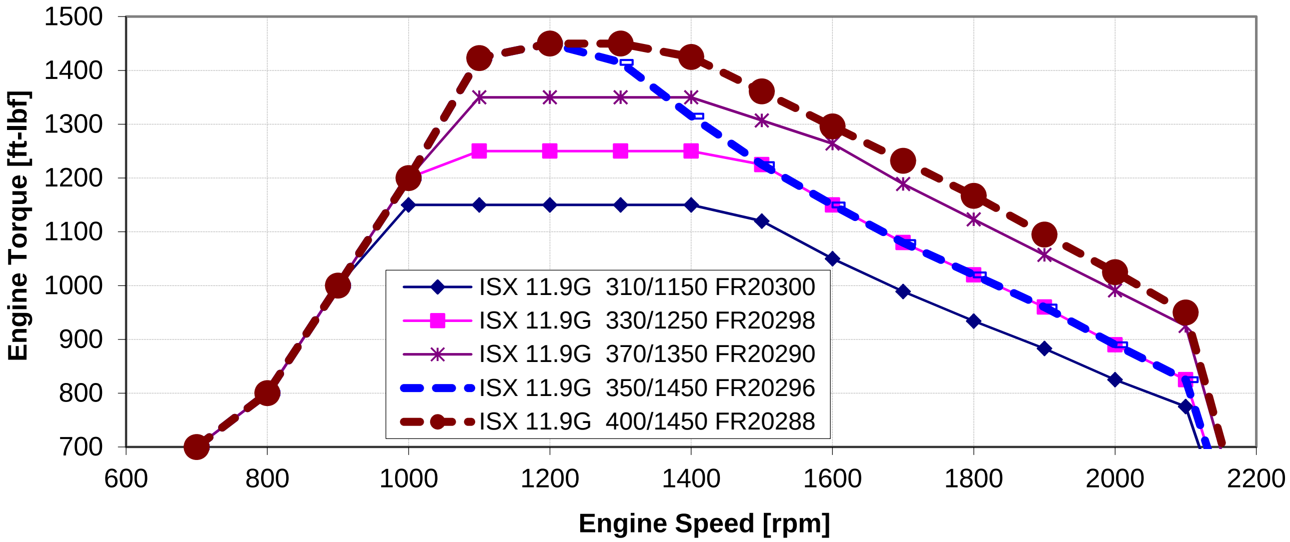
Key difference with automotive engines

Applications
- Average loads are higher
- Efficiency matters at higher loads
- Reliability and durability expectations

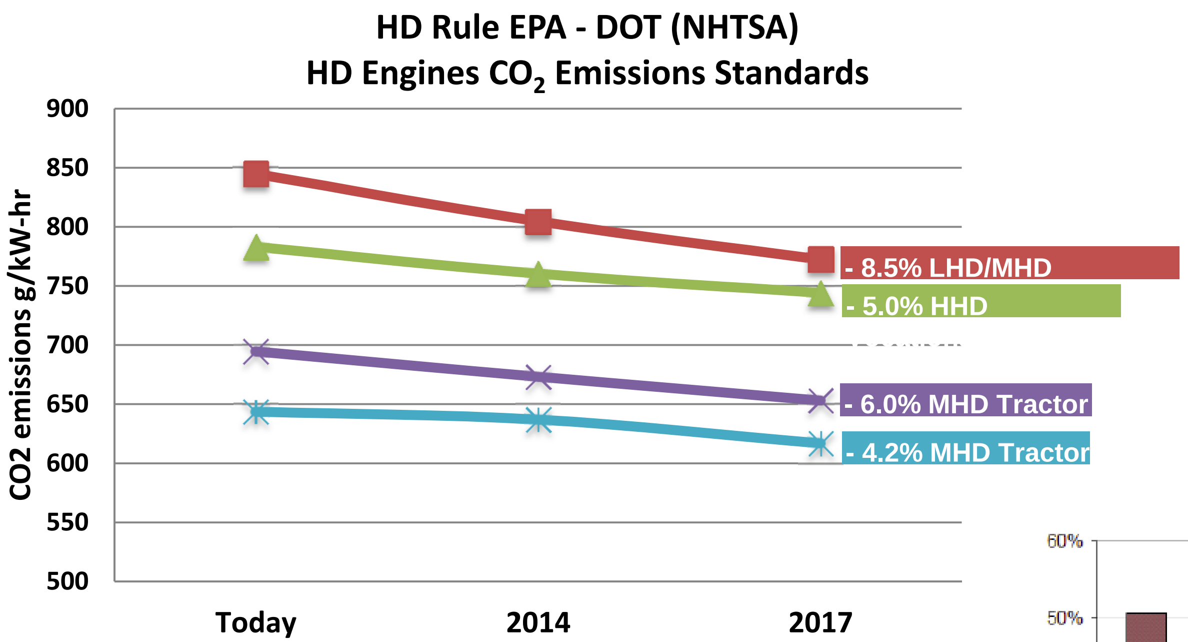
Architecture
- Base engine is diesel
- Firing pressures are higher
- Some constraints on air motion/piston shape

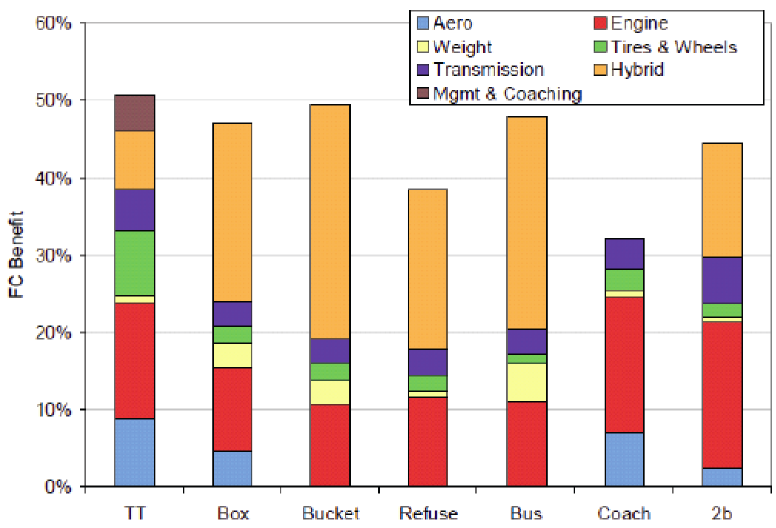
Differences:
Cummins ISX12 diesel and CWI ISX12 G natural gas

	ISX 12	ISX 12G
Performance	310-425 hp 1150-1650 ft-lb	320-400 hp 1150-1450 ft-lb
Torque at idle	800 ft-lb	700 ft-lb
Exhaust Emissions Control	DPF+SCR	Three Way Catalyst
Engine Brake	380 hp	240 hp



SI Technology for MD and MHD Vehicles





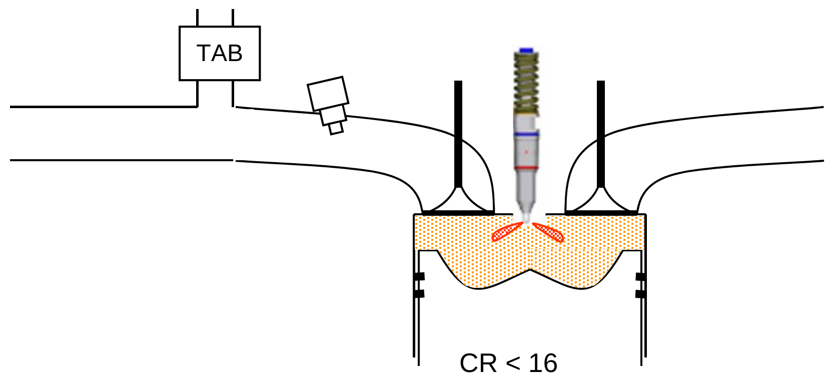
Fuel Storage Choice – LNG / CNG

- Desired vehicle range
  - Ideally same as diesel
  - Vehicle chassis space a premium
- Infrastructure availability
  - CNG leading, but many legacy LD focused
  - >150 Public LNG Stations in 2013
- Fuel Costs
  - CNG has slight advantage
  - Both provide savings over diesel
- Ease of Use
  - LNG fill speeds same as diesel
  - Slower CNG fills may be acceptable for some fleets

	CNG Net 125 DEG	LNG Net 125 DEG
Effective DEG	155	140
Weight Penalty over diesel	2500 lbs	1100 lbs
Space Penalty over diesel	x 6	x 2

Dual Fuel Engine Technology

- Engine that can operate under diesel or diesel-gas mode
- Diesel-gas mode is diesel ignition of pre-mixed gas
- Engine is diesel engine, and new engines must be certified as a diesel engine (and also as a gas engine)
- Engine not optimized for natural gas operation which is compromised at low and high operating loads
  - Methane emissions are a challenge for emissions compliance
- Implementation reported to offer between 50% and 75% substitution
- Retrofit Opportunities
- Technology not currently offered by Westport



Age Category	EPA Requirement	EPA Testing
New (< 2 years old)	Full Certification	FTP Data / EVAP Data / OBD Data
Intermediate (> 2 years old and <435,000 miles)	On-line Approval	Engine Dyno Meets Standards / OBD Scan by Engine Family
Outside Useful Life (> 10 years old or any age greater than 435,000 miles)	On-line Approval	Chassis Dyno – Road Test Technical Description / OBD Scan by Engine Family

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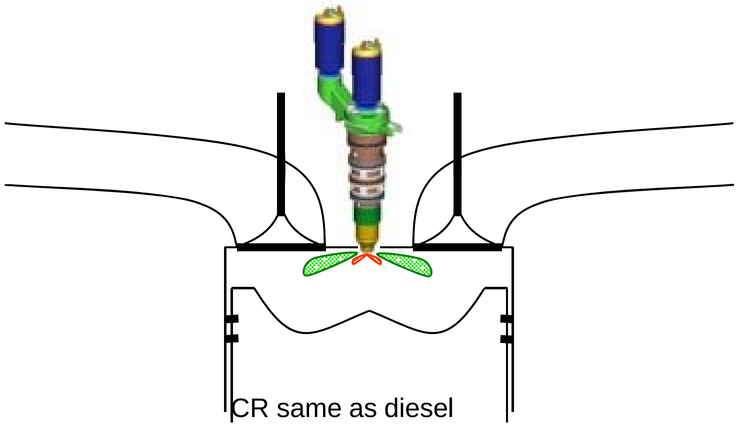
Direct Injection Engine Technology

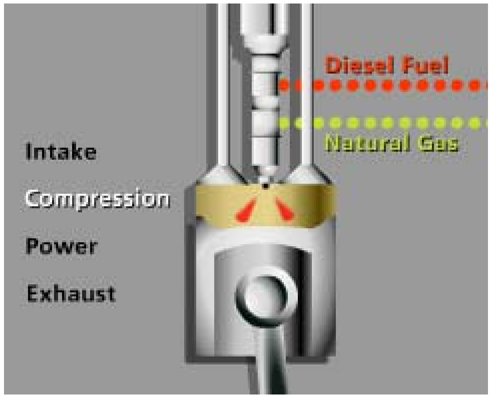
Direct Injection is ideally suited for **heavy-duty (HD) trucks** and **high-horsepower (HHP)** applications (e.g. locomotives, large mining trucks)

- Only technology that maintains full diesel torque and cycle efficiency while providing high diesel substitution



The Westport HD System

- Cummins ISX base engine platform
- Compression ignition
- Direct injection high pressure natural gas
- High diesel substitution (up to 95%)
- Liquefied Natural Gas (LNG) fuelled heavy-duty engine
- Diesel Engine Performance remains
- EPA/CARB 2010 certified
- DPF/SCR-equipped



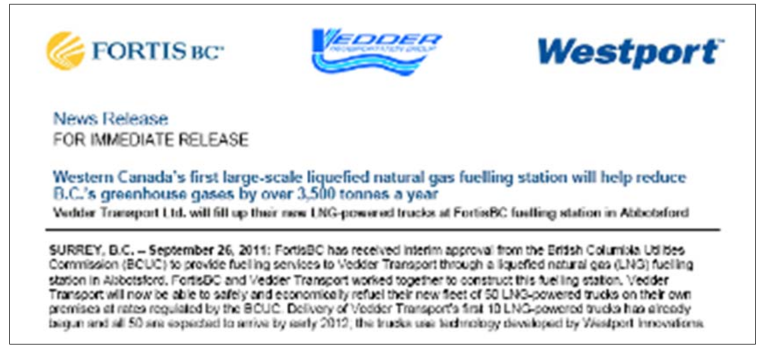
Applications Today

ADR 02	• 400 kW (550 hp) • 2500 N-m • 24 bar BMEP • Cooled EGR • Peak Efficiency 44.4% • Cruise Efficiency 43.3% • BSFC benefit ~ 5% • GHG benefit >25%
ADR 03	• Development in Progress • Cooled EGR + DPF • Maintain GHG benefit

EPA 2007	• 330 kW (450 hp) • 2375 N-m • 21 bar BMEP • Cooled EGR + DPF • Peak Efficiency 42% • Cruise Efficiency 41.8% • NOx benefit 33% • GHG benefit >20%
EPA 2010	• Cooled EGR, DPF, SCR • 4% BSFC improvement • Maintain/increase GHG benefits

Case Study: Vedder Transport

- Largest fleet in BC – high environmental commitment
- 50 new Peterbilt 386s with Westport HD 15L
- Hauling milk/food products, waste & wood chips in dedicated service
- 3500 tonne annual GHGe reductions from implementation
- Cost reductions result in ~16 month payback



FORTIS BC

Westport

News Release

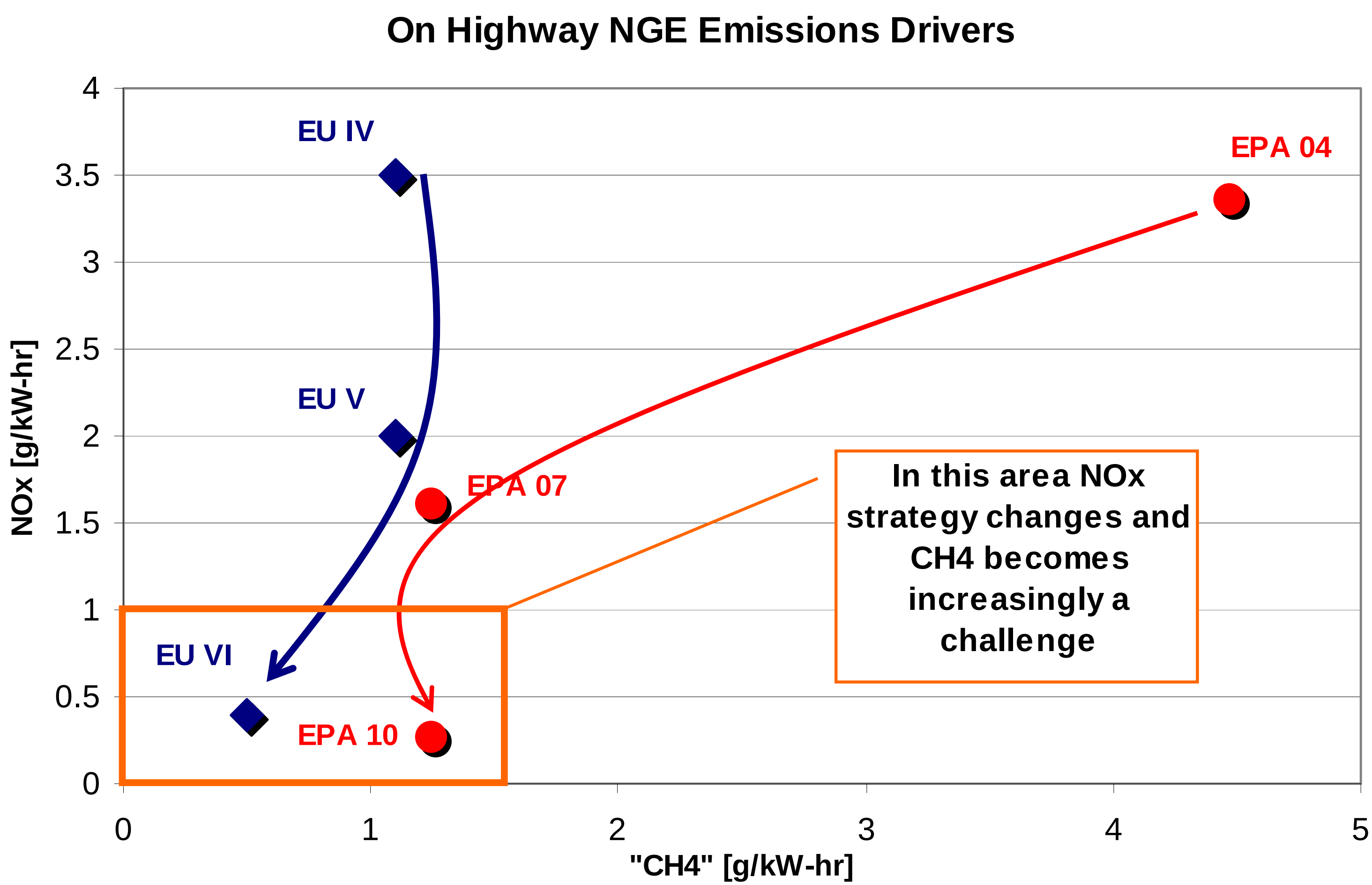
FOR IMMEDIATE RELEASE

Western Canada's first large-scale liquefied natural gas fuelling station will help reduce B.C.'s greenhouse gases by over 3,500 tonnes a year

Vedder Transport Ltd. will fill up their new LNG-powered trucks at FortisBC fuelling station in Abbotsford

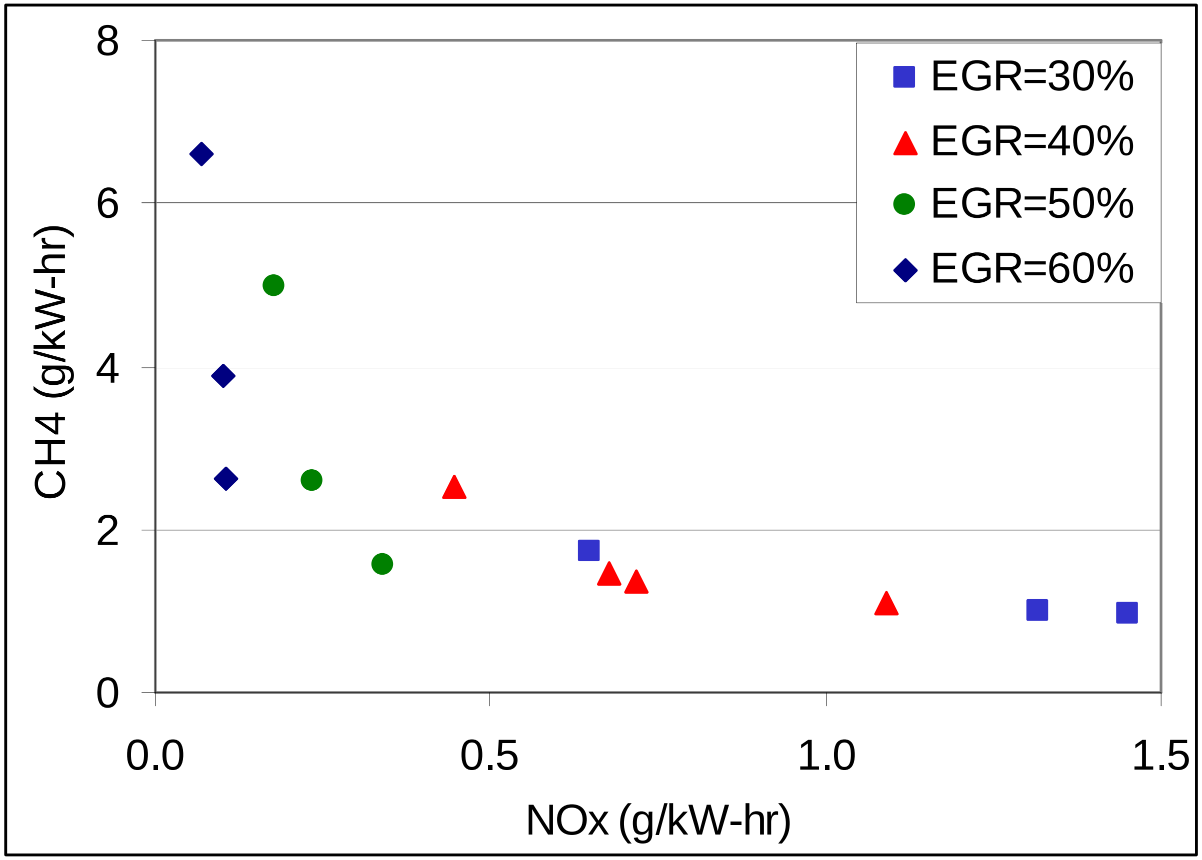
SURREY, B.C. – September 26, 2011: FortisBC has received interim approval from the British Columbia Utilities Commission (BCUC) to provide fuelling services to Vedder Transport through a liquefied natural gas (LNG) fuelling station in Abbotsford. FortisBC and Vedder Transport worked together to construct this fuelling station. Vedder Transport will now be able to safely and economically refuel their new fleet of 50 LNG-powered trucks on their own premises at rates regulated by the BCUC. Delivery of Vedder Transport's first 10 LNG-powered trucks has already begun and all 50 are expected to arrive by early 2012, the trucks use technology developed by Westport Innovations

Emissions Changes and NG Engines



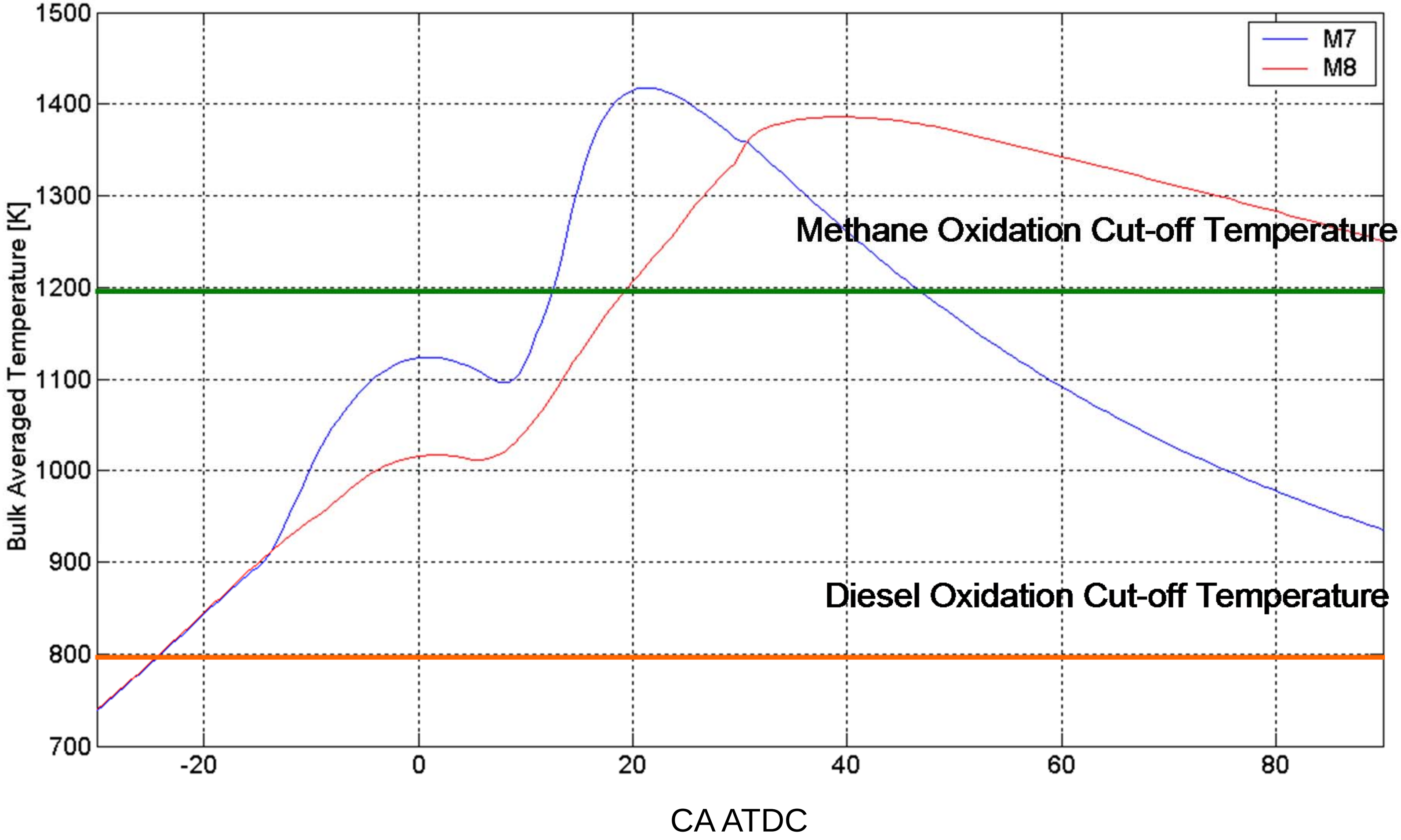
While EPA does not regulate CH4 emissions, it is assumed here that nmHC/CH4~0.15

CH4 - NOx Trade- Off (Single Cylinder Engine)

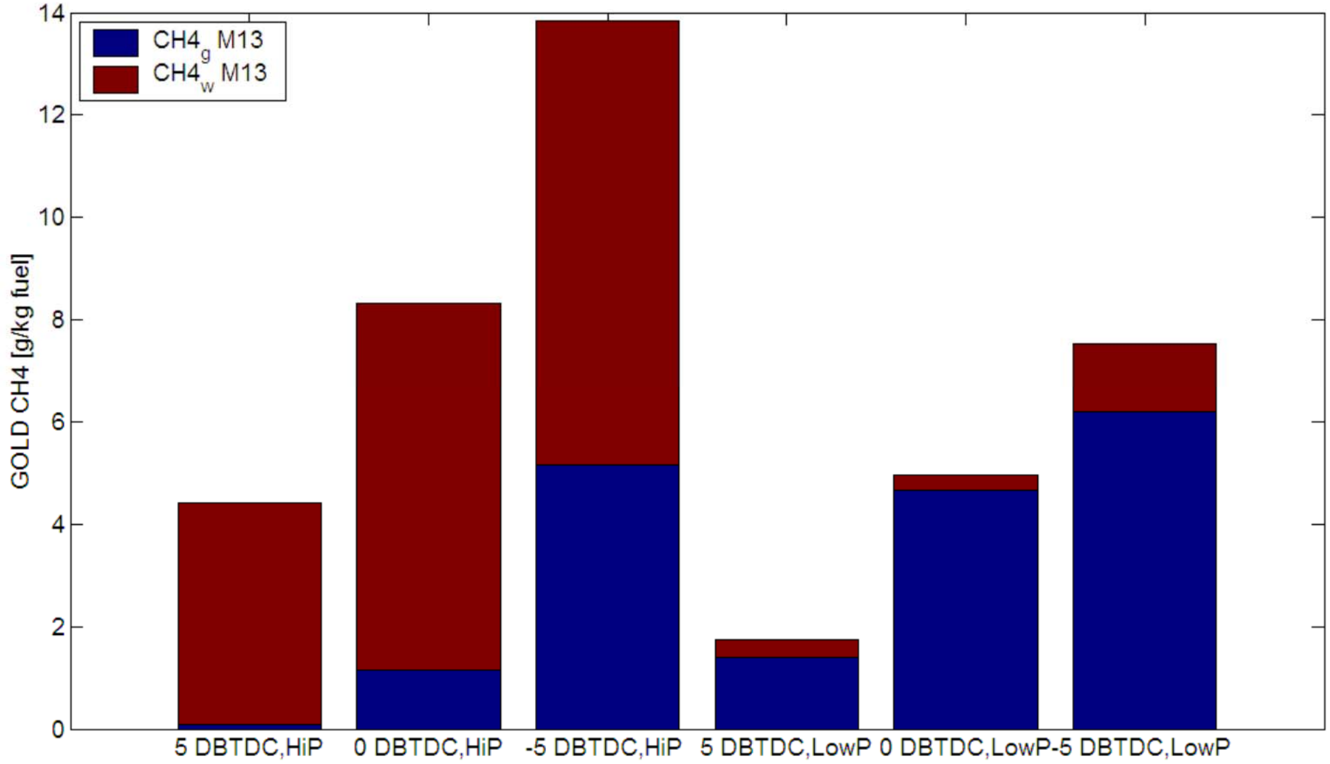


Effect of EGR on unburned methane
1200 RPM, 8.5 Bar, Gas Rail Pressure of 20 MPa
50% IHR at 5, 10 and 15 ATDC

Methane Oxidation Quenching - CFD



Methane Oxidation Quenching - CFD

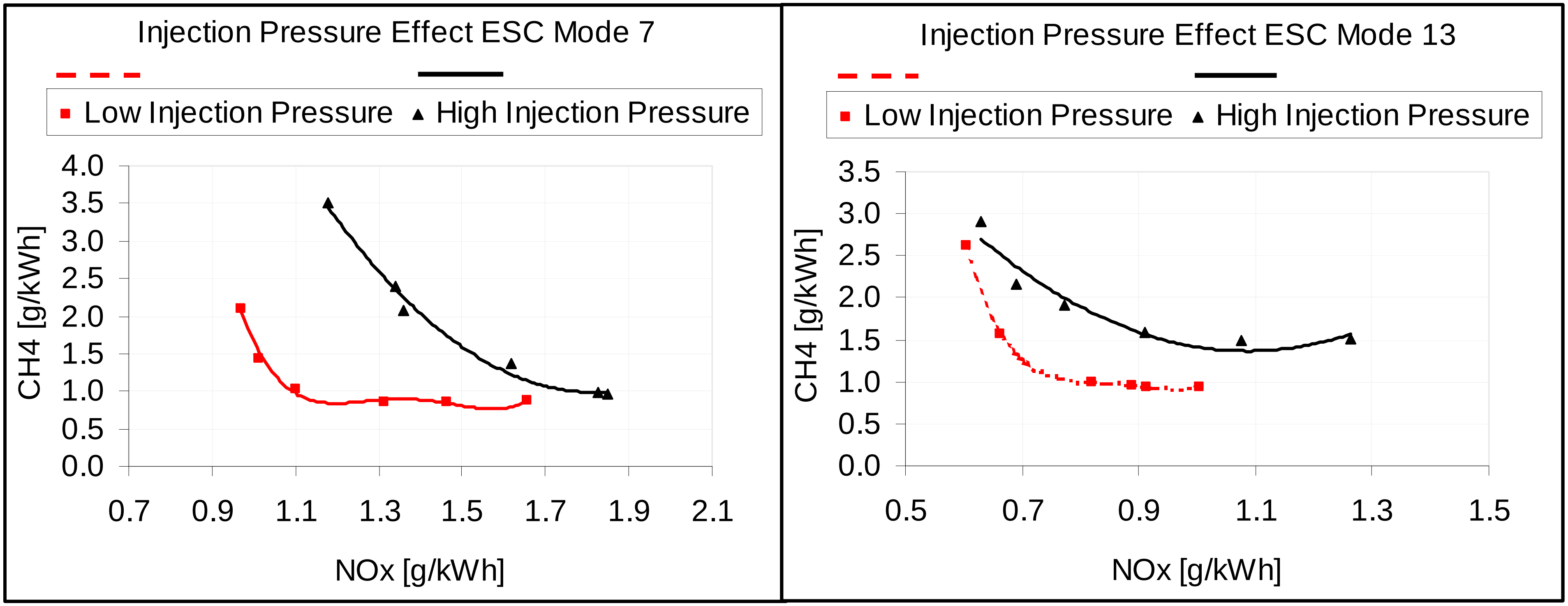


Effect of gas injection pressure on unburned methane

Mode 13 (7.9 Bar, 1800 RPM) , HiP = 195 bar, LowP = 100 bar

CH4g is unburned methane from bulk gases quenching, CH4w is from wall quenching

Impact of Injection Pressure – 6 Cyl. Engine

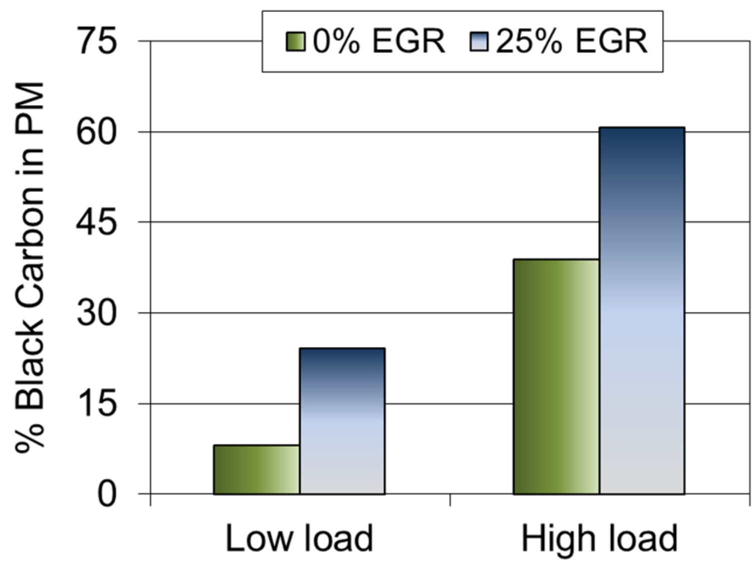


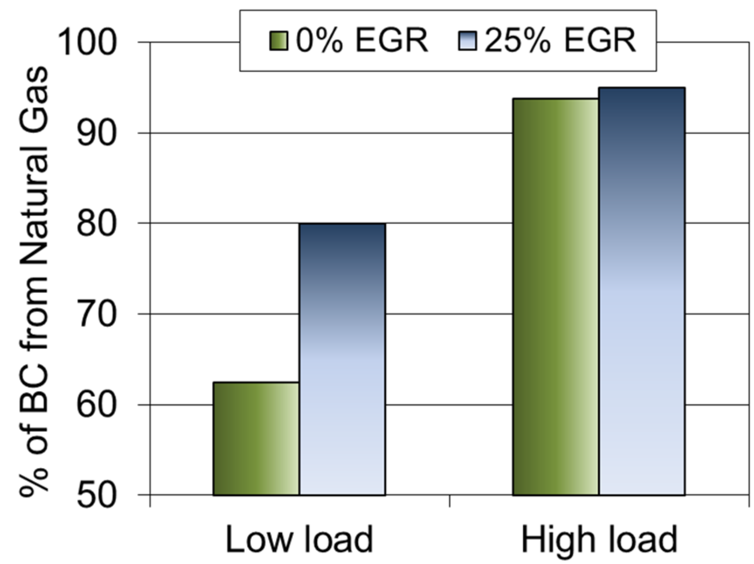
Effect of Injection Pressure on unburned methane

Mode 7 (4.9 bar, 1200 RPM), Mode 13 (7.9 bar, 1800 RPM)

CH4g is unburned methane from bulk gases quenching, CH4w is from wall quenching

Where is the PM coming from?



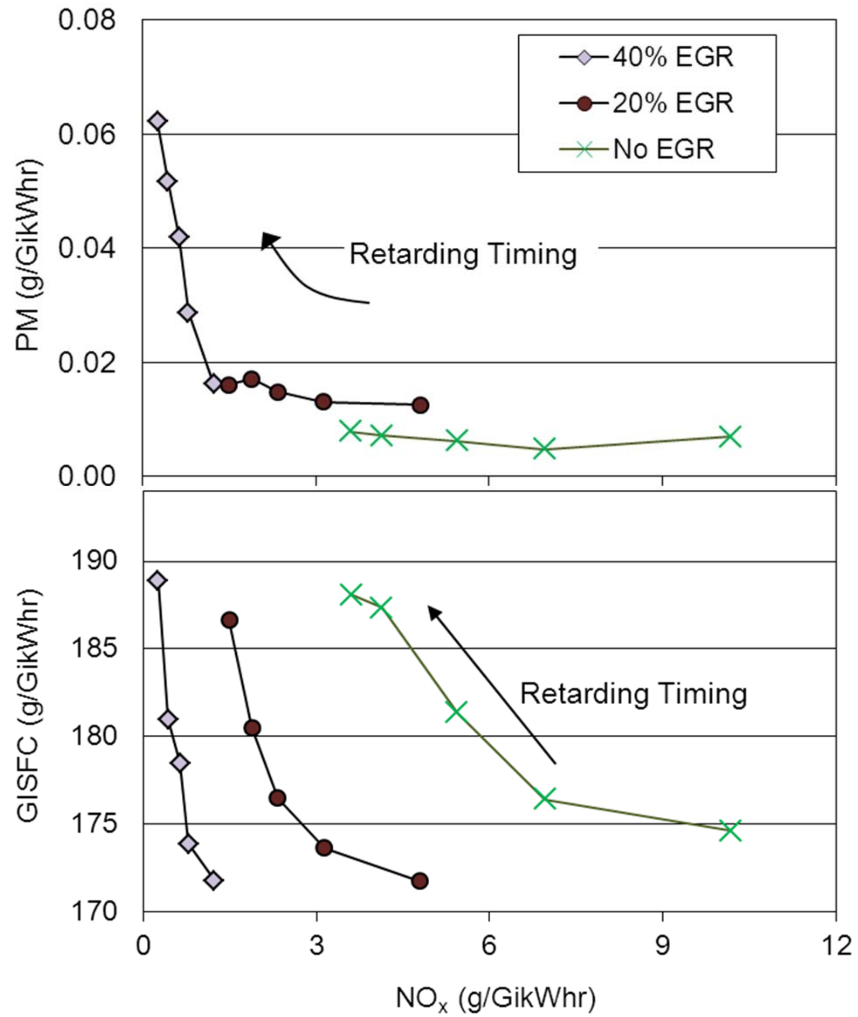


- Black Carbon content in PM measured using filters, light-scattering instruments
- BC concentrations increase with load, addition of EGR

- Contribution of NG to BC PM evaluated using C^{14}/C^{12} isotope ratio
- Majority of the BC is from NG
- With higher PM (higher load, EGR) more PM is from NG

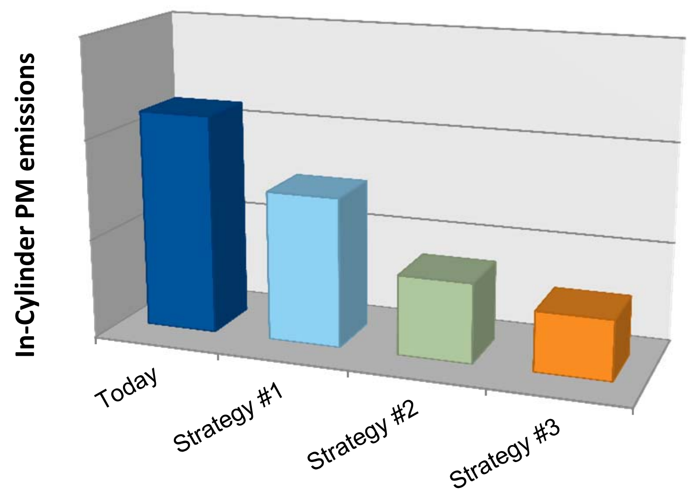
NOx - PM trade-off

- Reductions in NOx achieved with EGR come at the expense of increased PM
- Delaying combustion (delaying both gas and diesel injections) can also reduce NOx
  - But impacts fuel efficiency
- Optimal trade-off between GISFC, PM, and NOx emissions as a function of timing, EGR level
  - Equivalent to conventional diesel combustion

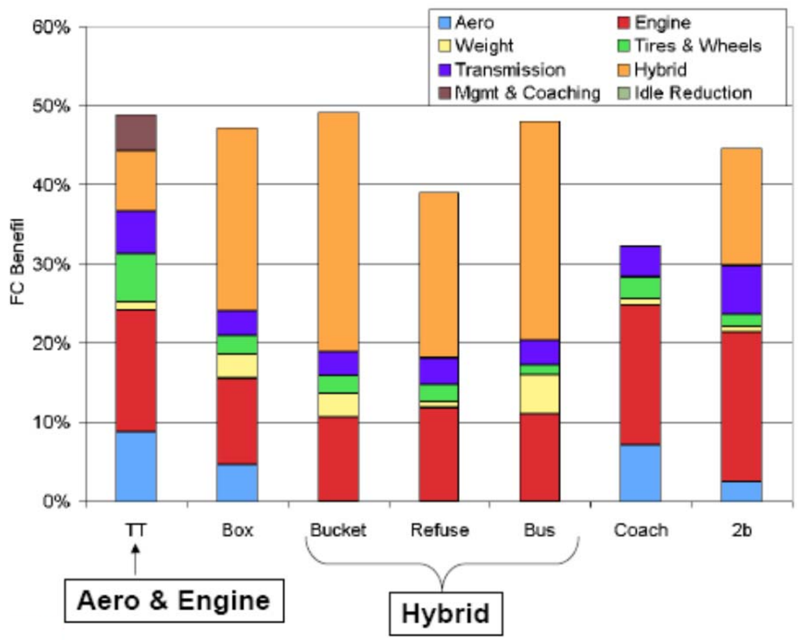


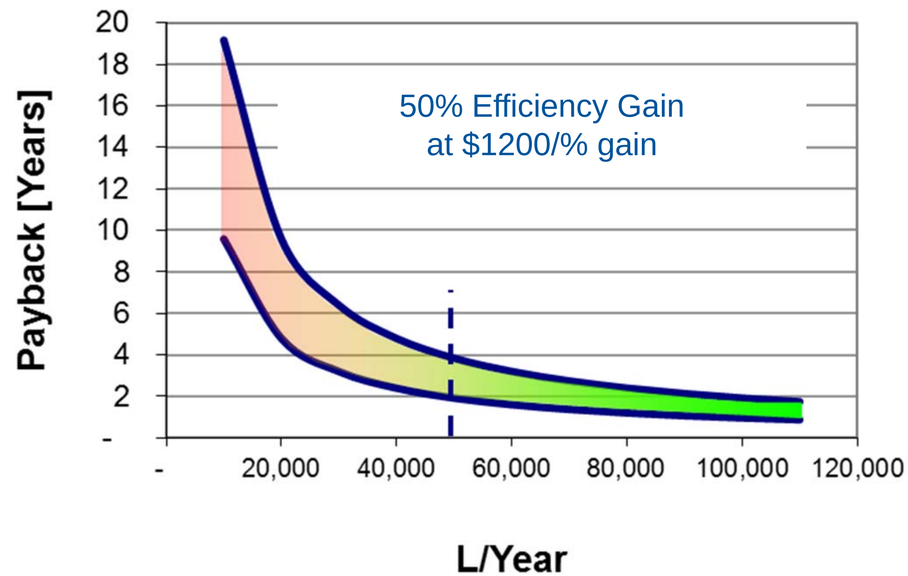
Continuing HPDI Improvements

- **Higher torque/horsepower capability**
  - Higher torque and horsepower used in Australia for several years
  - Achieved through higher flow injectors and engine calibration
- **Emissions after-treatment improvements**
  - Westport HD 15L engine uses identical after-treatment as diesel engine, despite reduced engine out emissions
  - Westport evaluating options to exploit cleaner-burning properties of natural gas to simplify emissions control equipment
  - Several identified strategies are being validated in our laboratories



Continuing Changes





Combustion
Ex. Heat Recovery
Auxiliaries
No Idle

Engine

Transmissions
Hybrids

Aerodynamic

Tires

Source: Commercial Vehicle Innovation Summit, Sept 2011

Westport™ HHP

Exploring New Market Opportunities

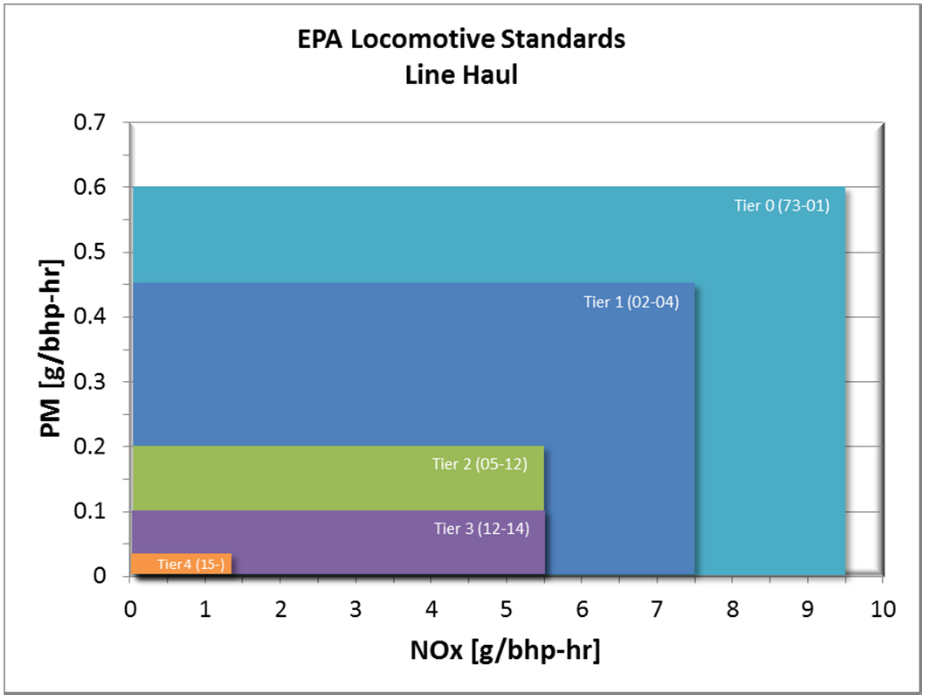
Significant High-Horsepower Opportunities

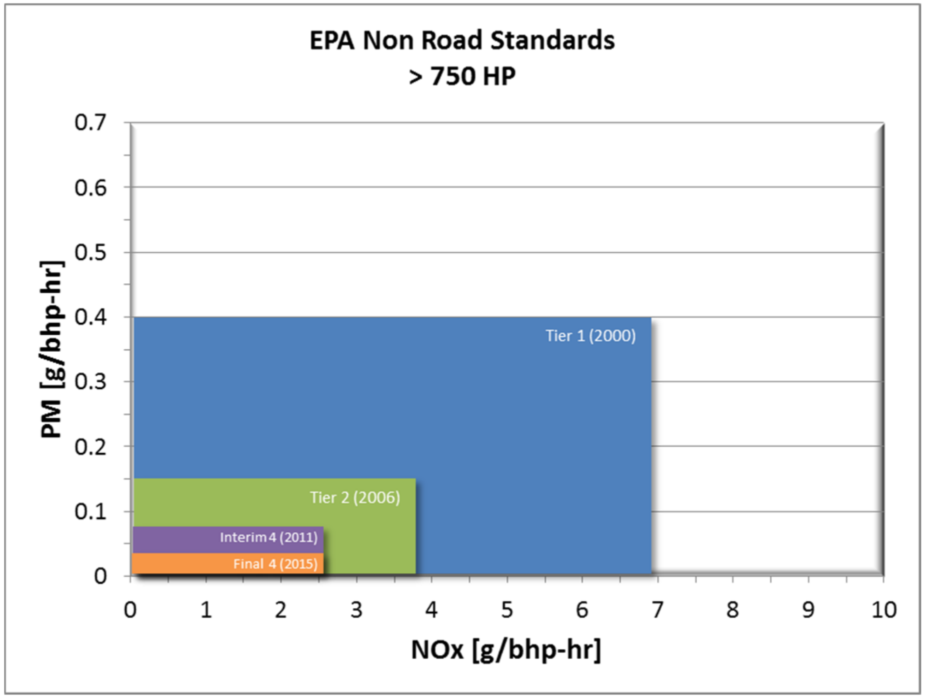
target vehicles		current issues	engine OEMs
MINING (RESOURCE EXTRACTION) 	mine haul trucks drill rigs and frac pumps	2bn gal of diesel consumed annually by the top 10 mining companies alone[1] with 28,600 large mine haul trucks (>100 ton capacity) operating around the world[2] 2,035 onshore drilling rigs working in U.S. and Canada[3] with estimates of the pressure pumping horsepower in North America set to top 10mn hp in 2011[4]	CATERPILLAR KOMATSU Cummins mtu
RAIL 	diesel mainline freight locomotives diesel passenger locomotives	Rail industry consumes 9bn gal of diesel fuel annually, half of this in North America[5] Fuel represents approximately 24% of US railroad operating costs[6]	GE mtu ELECTRO MOTIVE
MARINE 	ferries tugboats PSVs work and crew boats	Marine industry consumes 13bn gal of diesel fuel annually[5] Emissions reduction in sensitive coastal and inland waterways are a priority Some examples of LNG ferries and platform support vessels (PSV) in Scandinavia, but no widespread adoption yet	mtu MAN CATERPILLAR GE WÄRTSILÄ ELECTRO MOTIVE Rolls-Royce Cummins

Caterpillar and Electro Motive agreement for off-road equipment, including mine haul trucks and locomotives, announced June 5, 2012

1. Westport analysis
2. Morgan Stanley/Parker Bay
3. Baker Hughes report, August 2010
4. United Holdings investor information presentation 2011
5. UN Energy Statistics Database 2008
6. Burlington Northern 2008 Annual Report

Tier 4 Emissions





Not just NOx...

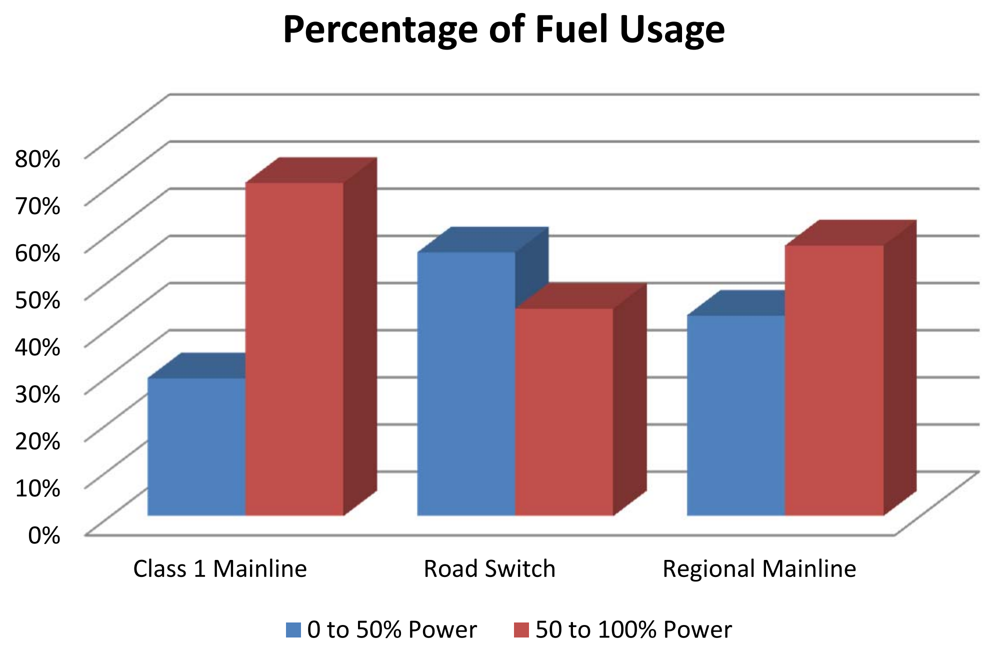
US - EPA Emissions Legislation (g/kWh)

Engine Class	Start year	Cycle	Size	NOx	NMHC	CO	PM
HD On-highway	2010	FTP	> 14000 lb	0.27	0.19	21	0.013
Locomotive (line haul)	2015	1033.53	> 750 kW	1.7	0.19	2.0	0.04
Marine (Category 1/2)	2014-2017	ISO 8178	< 3700 kW	1.8	0.19	5.0	0.04
Mobile non-road	2015	ISO 8178	> 560 kW	3.5	0.19	3.5	0.04

THC requirements of ~ 1 to 1.9 g/kW-hr

Locomotive Fuel Usage

Part Load Efficiency very important in Locomotive Applications



Sources: Transport Canada, EPA , internal data

Technologies profile

	Spark-Ignited or Pilot Ignited Lean Burn Premixed	Dual Fuel	High Pressure Direct Injection
Benefits	• No DPF/No SCR for Tier 4 • Well understood • Full Substitution	• Full Operation under diesel mode • Full performance and efficiency • No change to base engine	• No DPF/SCR for Tier 4 • 90% substitution • Low HC emissions • Full performance and efficiency • No changes to base engine • Limited limp home
Drawbacks	• Part load efficiency • HC emissions • Very tight A/F ratio control needed to maintain emissions and performance • No limp home • Significant changes to base engine	• Limited substitution • HC emissions • Full Tier 4 diesel emissions system	• Requires some in-cylinder NOx reduction • High Pressure Fuel System required

Tender Car?

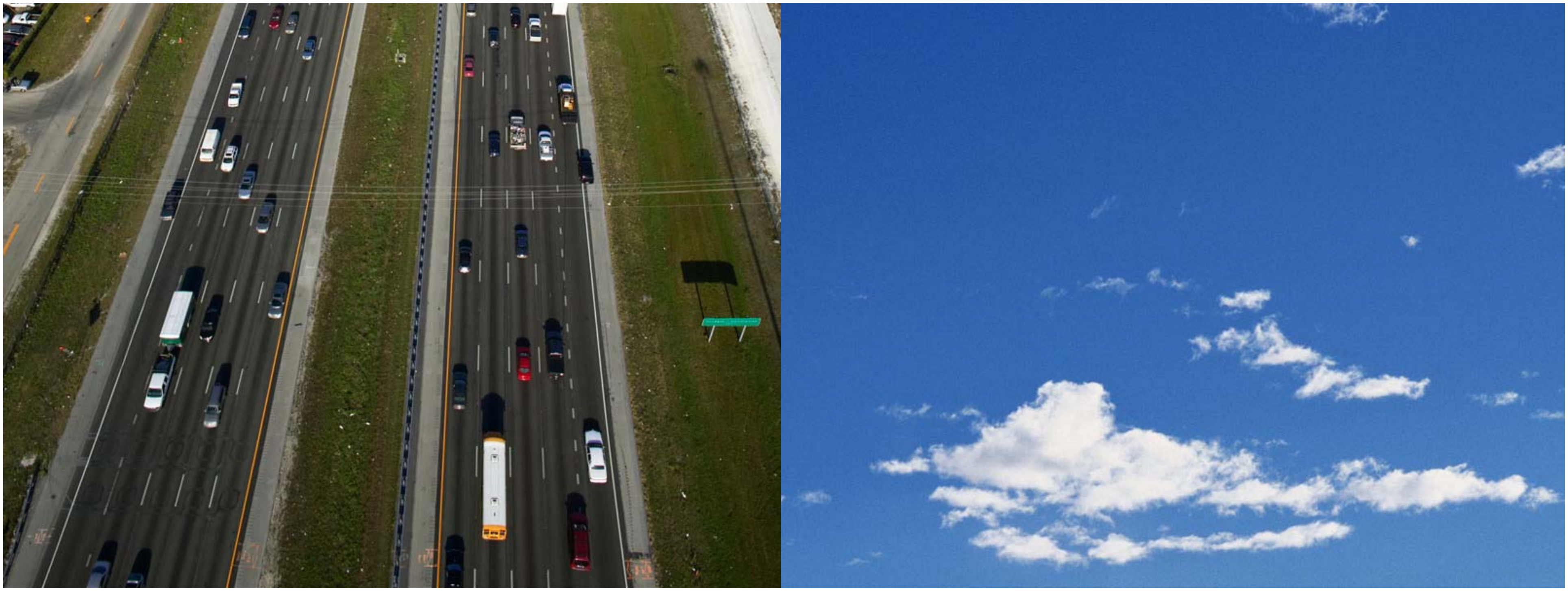
LNG Transport Already Common

Special consideration for fueling locomotive however

- Needs to be coupled with locomotive
- Could be standard well car and ISO tank
- May need to fuel locomotives with different powertrains
- Multiple alternative configurations of rail car, tanks, coupling

Conclusions

- Conditions are set for an increased in availability in NG engines, and for volumes to increase
- This opens opportunities for greater investment in NG engine technologies, including more optimization specific to gas
  - Several OEMs already building platforms that are better suited for gas
- Continuing evolution of petrol and diesel platforms means that NG technology must find ways to adapt



Thank You

pouellette@westport.com