HIGH OUTPUT HIGH EFFICIENCY
LPG ENGINES CLASS 2 TO 7

Propane Autogas Tech Forum (PATF), Chantilly, Virginia

Brad Douville, Vice President, August 10, 2016

Agenda

1. Brief Introduction to Westport Fuel Systems Inc.
2. Current Propane Autogas Offerings (LD)
3. Perspectives for Light Duty
4. Perspectives for Medium Duty
5. Westport ESI Technology and Suitability with Propane Autogas

Merger (June 1st) Combines 17 Brands in the Automotive and Industrial Space

FUEL SYSTEMS SOLUTIONS

- BRC GAS EQUIPMENT
- BRC FuelMaker
- IMPCO AUTOMOTIVE
- mte srl
- DRESSER CUBOGAS
- TA GAS TECHNOLOGY
- ZAVOLI
- Gfi
- IMPCO
- AFS

WESTPORT

- Westport WING POWER SYSTEM
- emer
- OMVL
- Westport iCE PACK LNG TANK SYSTEM
- Prins
- VALTEK
- Westport PARTS + SERVICE

Complementary Customer Bases

FUEL SYSTEMS SOLUTIONS*

Kubota, Ford, KIA, COMBiLIFT, Mitsubishi Motors, Nissan, Caterpillar, Subaru, Hyundai, Honda, Chevrolet, Volkswagen, GM, Linde Material Handling, Kohler, Iveco, dr automobiles groupe, Fiat, Mercedes-Benz, Tailift, Peugeot, Citroën, Ashok Leyland, Isuzu, Mazda, Toyota, Great Wall, Jeep, Tata, Volvo, Renault, Piaggio, SsangYong, Suzuki, Maruti Suzuki, Hexagon Lincoln, Still, 浙江新柴股份有限公司 Zhejiang Xinchai Co., Ltd, Dresser Waukesha, Carrier Transicold, Clark The Forklift, Yuchai, Hino, Cummins Power Generation, Daimler, Jungheinrich, Plug Power, Briggs & Stratton

WESTPORT*

PSA Peugeot Citroën, Ford, Delphi, GM, Cummins, Kenworth, ГАЗ, 潍柴动力 Weichai Power, CAT, Iveco, Mack, MAN, Fiat, Volkswagen, Citroën, Ashok Leyland, Isuzu, Peugeot, PACCAR, Tata, Volvo, Hyundai, Renault, Freightliner, Suzuki, Maruti Suzuki, Cummins Power Generation, EIM, Группа ГАЗ, mtu, Yuchai, Daimler, GE, Peterbilt, Clark The Forklift

Westport is Driving a Shift to Gaseous Transportation Fuels

ENERGY

- Producers
- Distribution & utilities
- Fuel station owners/operators
- Renewable gaseous fuels

Westport™

TECHNOLOGY

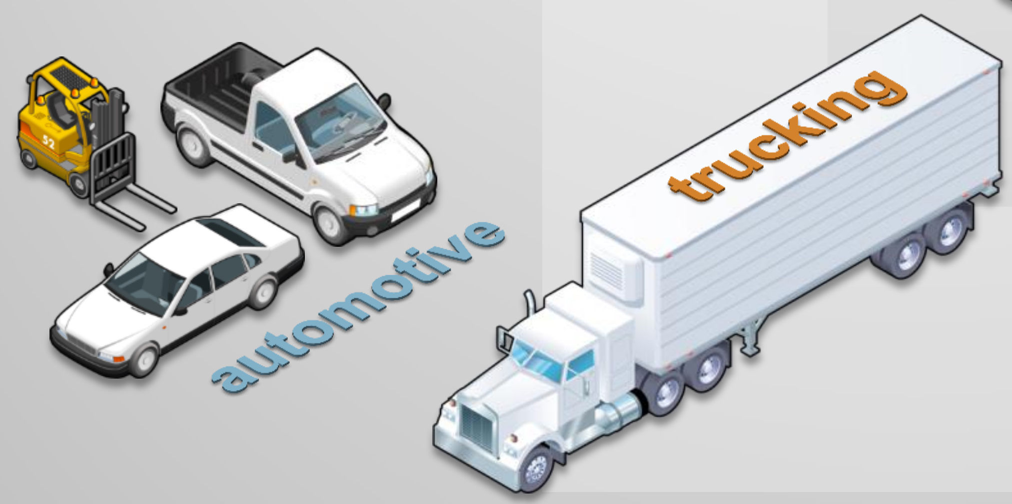
- Engines
- Fuel Storage

TRANSPORTATION

- Engine & vehicle OEMs
- Fleet operators
- Shippers, transportation users
- Consumers

Westport Fuel Systems

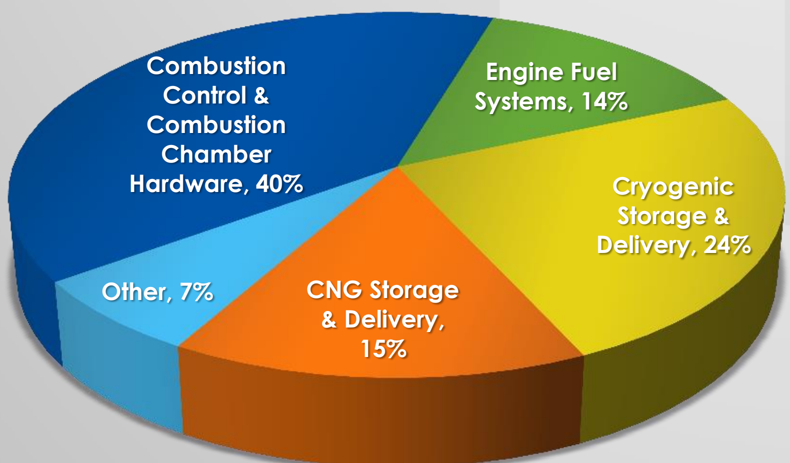
- Moving to capture the global emergence of ***gaseous fuel vehicles*** through a broad range of transport applications.



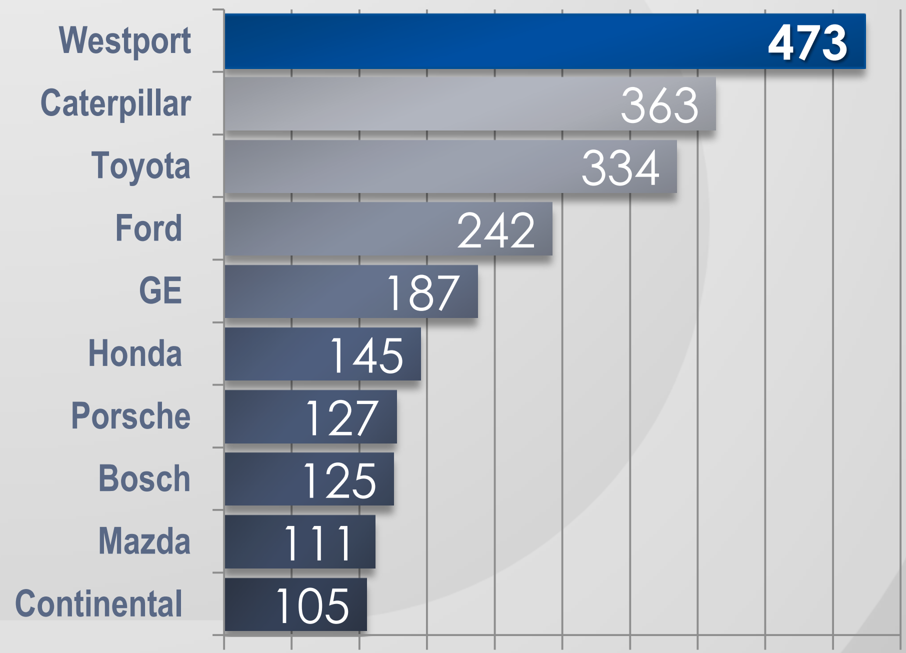
Westport's Strong Intellectual Property

- Strong global patent portfolio pivotal to market leading position with OEMs
- Worldwide, Westport and its affiliates have filed over ***950*** patent applications

Westport Patent Portfolio Technology Breakdown



Top 10 Companies with Natural Gas Engine Related Patents*



* *As of January 15, 2015 and based on the patent search results of publicly available data within the International Patent Classification F02, meeting the search term criteria: one of ("engine" or "combustion" or "injector" or "injection valve") and ("natural gas" or "methane" or "gaseous fuel") and in the claims, not ("fuel cell" or "turbine"). This chart includes issued or granted patents from: Argentina, Australia, Austria, Belgium, Brazil, Bulgaria, Canada, China, Czech Republic, Denmark, Eurasian Patent Organization Grants, European Patent Office Grants, Finland, France, Georgia, Germany, Greece, Hong Kong, Hungary, India, Ireland, Italy, Japan, Latvia, Lithuania, Malaysia, Mexico, Moldova, Monaco, Morocco, Netherlands, Norway, OAPI grants, Philippines, Poland, Portugal, Romania, Russian Federation, Singapore, Slovakia, Slovenia, South Africa, South Korea, Spain, Sweden, Switzerland, Taiwan, Tajikistan, Turkey, UK, Ukraine, USA, USSR, Yugoslavia, and pending published patent applications from: Canada, China, the European Patent Office, USA, and the World Intellectual Property Office.*

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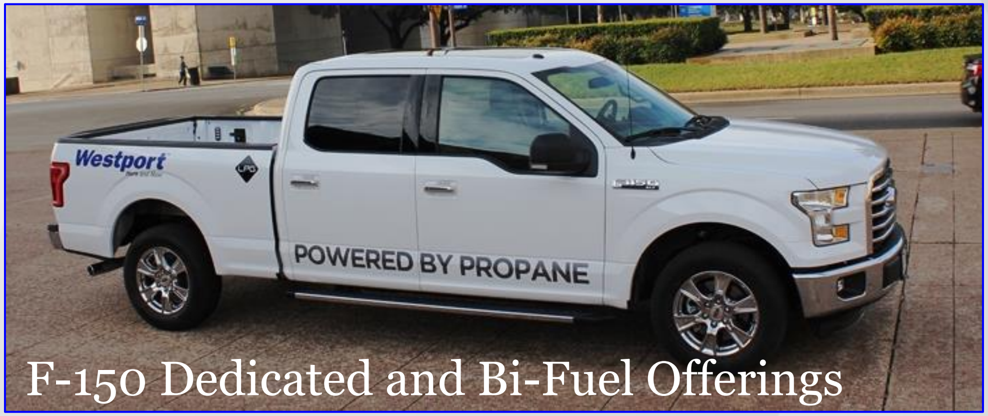
Ford F-150 and Transit Van/Wagon MY2017

- As Ford's Largest Qualified Vehicle Modifier (QVM) and Installer, Westport/IMPCO offer the only Ford recognized **F-150** and **Transit** Propane Autogas systems in the market
- Conversion system qualifies for Ford financing and is fully backed by Ford's OEM warranty
- High utility – options to store fuel underbody
- Ship-Thru with Ford to minimize Transportation costs



F-150 Dedicated and Bi-Fuel Offerings

Transit Cargo Van / Passenger Wagon Bi-Fuel

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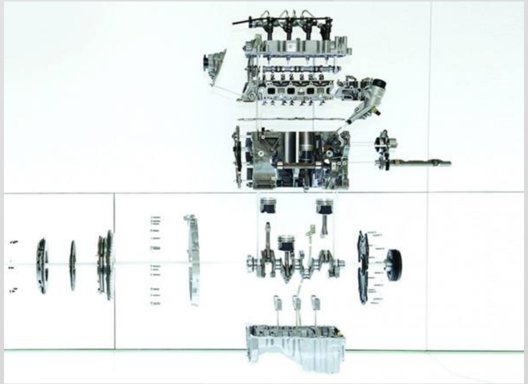
Technology Trend
Convergence b/w Gasoline & Diesel

- Gasoline engines are beginning to look more and more like diesels
  - Highly boosted
  - Direct injection
  - Higher compression ratio
  - High cylinder pressures

BMW, Volvo and JLR have launched common and modular platforms for both fuels providing fuel flexibility and future proofing

BMW Efficient Dynamics

Volvo Drive-e



Jaguar Ingenium

- Ideal for fully exploiting high octane / high latent heat of vaporization performance fuels such as propane
- Higher cylinder pressure capability of diesel bottom end allows higher compression ratio and advanced combustion phasing
- Gasoline engine elements such as cam phasing, ignition system, etc. for optimized Otto cycle combustion

SI Engine Technology Advancements and Downsizing (ex. Pickup Trucks)

2016 Ford F150 Pickup 2WD FFV	2016 Ford F150 Pickup 2WD	2016 Ram 1500 2WD
E85 Flexible-Fuel Vehicle Gasoline-Ethanol (E85)	Gasoline Vehicle	Diesel Vehicle
		
5.0 L, 8 cyl, Automatic (S6)	2.7 L, 6 cyl, Automatic (S6), Turbo	3.0 L, 6 cyl, Automatic 8-spd, Turbo
387 lb.-ft @ 3850 rpm	375 lb.-ft @ 3000 rpm	420 lb.-ft @ 2000 rpm
Regular Gasoline	**Regular Gasoline**	**Diesel**
18 combined city/highway MPG; 15 city, 22 highway; 5.6 gal/100mi	**22** combined city/highway MPG; 19 city, 26 highway; 4.5 gal/100mi	**23** combined city/highway MPG; 20 city, 28 highway; 4.3 gal/100mi

22%

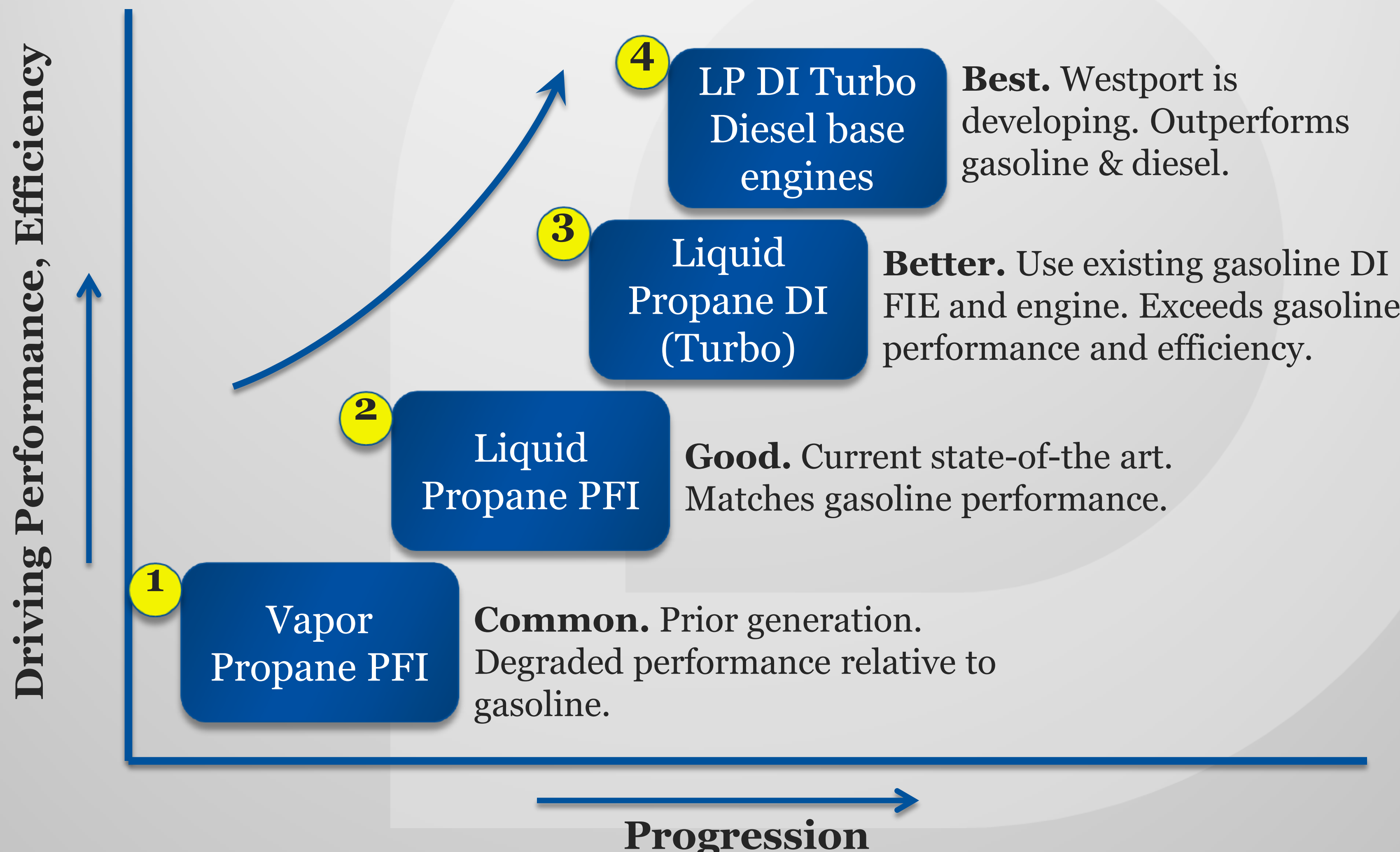
10%

MPG Improvement

20 Gasoline Equivalent MPG

Source: www.fueleconomy.gov

Progression of Propane Powertrain Technology – Outperform Gas, Diesel



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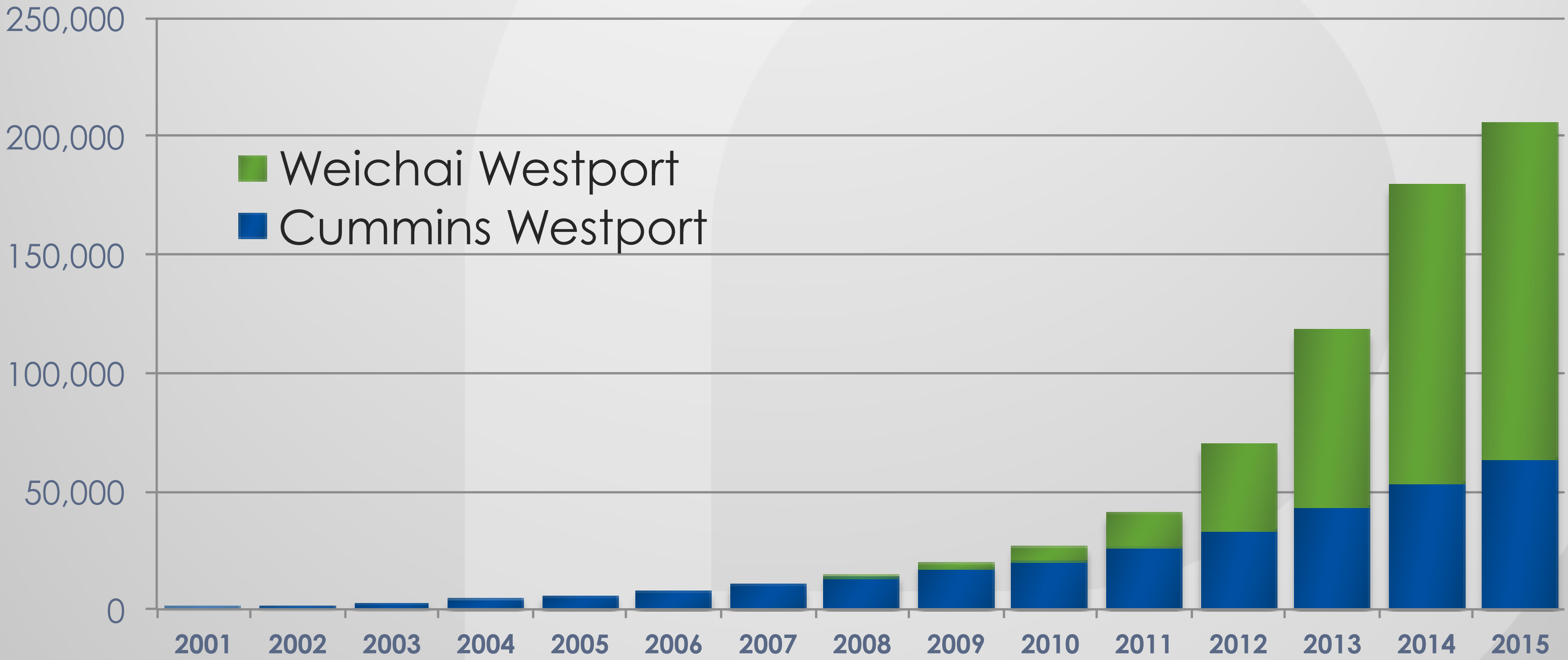
Cumulative Truck & Bus Shipments



Spark Ignited Diesel Derived Engines from 5 to 12 liters in displacement. Mostly natural gas.

Enhanced SI will Set the Benchmark For the Next Decade for Work Trucks

Lean Burn SI Engines

2007

- L10G launched 1992
- First CNG engine certified in California
- Innovation was high excess air with turbocharging to achieve much lower NOx and PM than diesel
- 25% lower peak torque output than diesel

Stoichiometric with EGR SI

- First demonstrated in 2004
- Global launch in 2007 with CWI ISL G – EPA 2010 levels 3 years ahead of time
- Innovation was oxygen-free exhaust using EGR in place of air to allow use of simple, low cost 3-way catalyst
- 15%-25% lower peak torque output than diesel

Enhanced SI (ESI)

- First demonstrated in 2014
- Retains stoich+EGR
- Innovation is to remove constraint of using common cylinder head w/ diesel
- Higher peak torque output than diesel

1992 2004 2014

Timeline of Diesel-Derived Natural Gas Engine Innovations

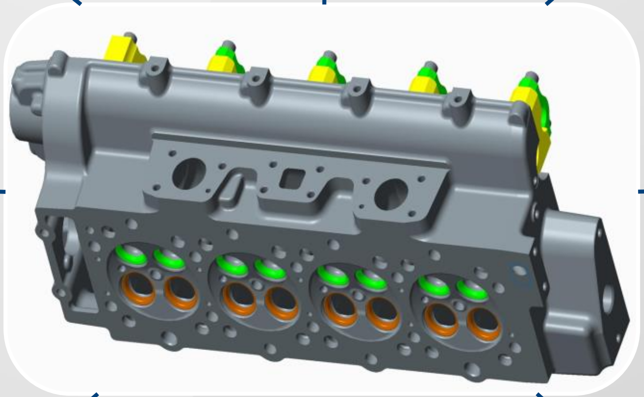
Re-Imagine Possibilities with Completely Redesigned Engine Cylinder Head

Even airflow distribution cylinder-to-cylinder

Tumble air motion – fast, combustion and simple piston

Integrated EGR – high flow for knock control and de-throttling

Optimized thermal management – no hot spots and increased knock resistance



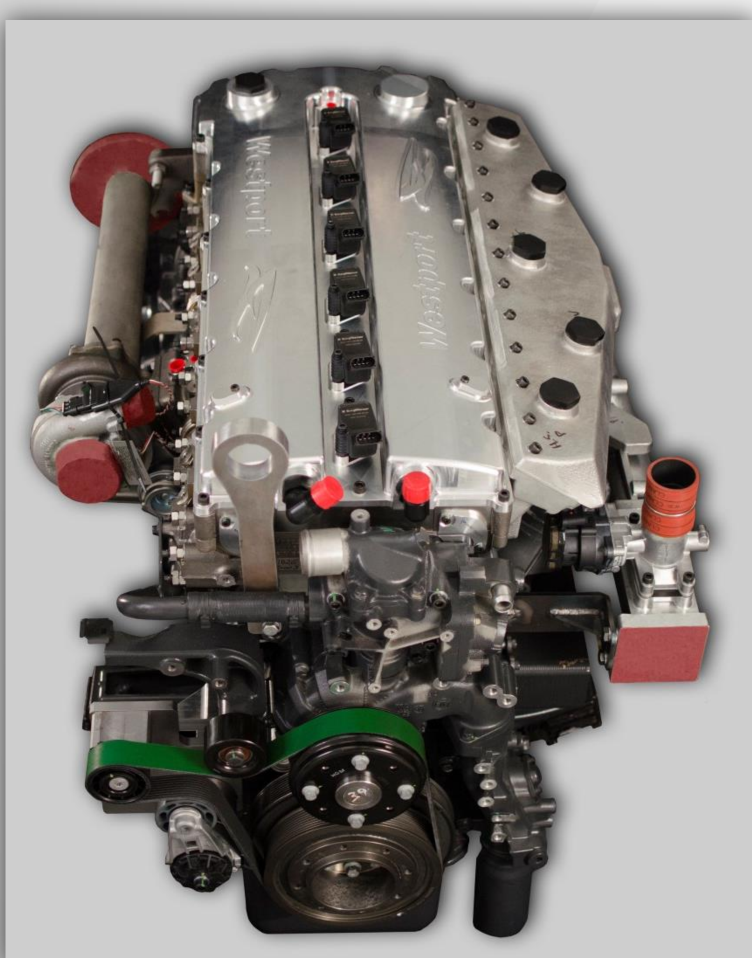
VVT – residuals control, combustion optimization and de-throttling

Cascading design improvements to piston, fuel, intake and exhaust systems

Compact combustion chamber with maximum heat dissipation

- Cylinder head is a fundamental enabling technology that determines design of other engine components.
- When attached to a pre-existing diesel engine bottom end (engine block, crankshaft, main bearings, etc.), it enables high efficiency, high output Otto-cycle combustion.

Enhanced Spark Ignited Technology



- Next generation spark ignited engine architecture
- Designed to provide:
  - 10% improvement in power and torque over state-of-the-art diesel engines
  - 40% peak brake thermal efficiency
  - 15% product cost reduction compared to diesel engine plus after-treatment
  - Much higher fuel economy compared to current SI engines with downsizing
  - Near Zero NOx capability
- Stoichiometric operation and simple three-way catalyst after-treatment

Example – 5L ESI Engine Downsizing with Upsized Performance and Efficiency

FCCC S2G with 8.0L Propane GM Engine from PI, CleanFUEL USA

Only ~15% market share with propane distributors. Why?

ESI 5L LPG engine: 660 - 830 lb-ft / 260 hp

Propane Type C School Buses

Total Type C School market in US/Can is ~25K units/yr

IC Bus (NAV) | Thomas Built (FL) | Blue Bird

I C B U S

PSI 8.8L LPG

565 lb-ft / 270 hp


C2 PROPANE

Propane is the world's most popular clean-burning alternative fuel. In North America we have an abundant domestic supply, and it's about 40% less expensive than a gallon of diesel on a btu basis. That's why Thomas Built Buses is pleased to offer a propane-fueled Saf-T-Liner® C2 bus as part of our robust alternative-powered product line-up. Setting up the propane infrastructure is an easy and relatively low-cost proposition. So you can help the environment while providing safe, reliable transportation. In fact, the C2 Propane provides outstanding maneuverability, state-of-the-art driver ergonomics and the most visibility among all Type C buses. So it just makes sense to consider the propane-fueled Saf-T-Liner C2 bus for your fleet.

SPECIFICATIONS

Passenger capacity
Up to 81

Wheelbase
219", 238", 259", 279"

GVWR
Up to 33,000 lbs.

Engine
8.0L V-8 LPG by Powertrain Integration with fully-integrated liquid propane injection system
HP: 339hp @ 4100 rpm
Torque: 495 lb-ft @ 3100 rpm

Engine Warranty
5 years/100,000 miles

Transmission
Allison 2300 PTS Series

Thomas BUILT BUSES
Because every mile matters.™

PI 8.0L LPG

495 lb-ft / 339 hp

ROUSH® CLEANTECH

Ford 6.8L V10

460 lb-ft / 362 hp

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ESI Study with LPG in early 2016

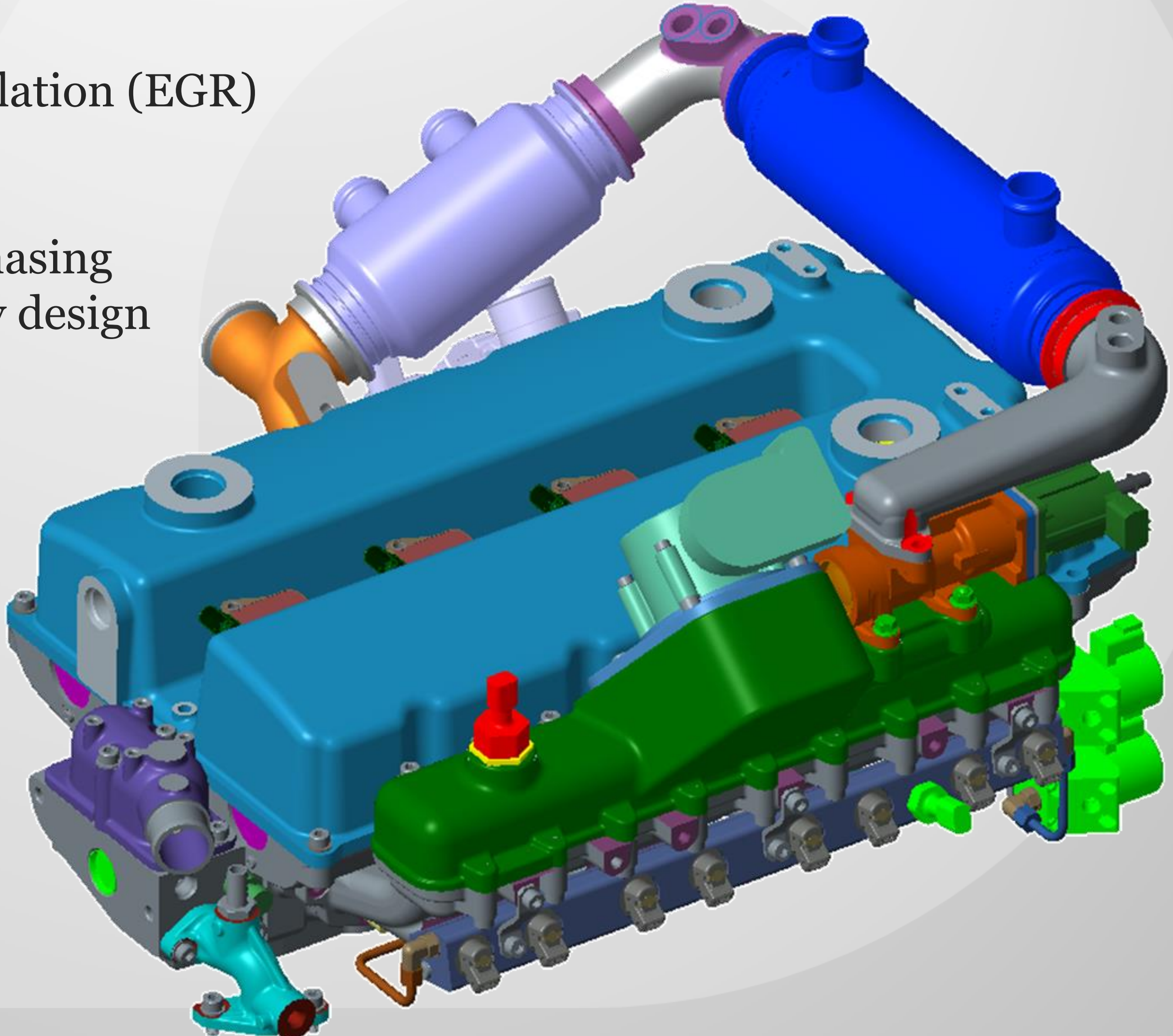
- LPG had not been a focus area of ESI technology development, which necessitated work to better understand implications and design considerations related to this fuel
- Goal of study was to complete engineering analysis of ESI technology using LPG as fuel instead of natural gas
- Specifically, this project set out to answer:
  - Suitability of engine architecture and degree of change required
  - 2018 EPA/CARB OBD requirements specifically related to LPG
  - GHG compliance considerations (upcoming EPA Phase 2 rules)

Scope of Study – 5L 4 cyl. MHD Engine

- Preliminary Design
  - LPG fuel injector sizing and specification
  - On engine fuel system design
  - Intake manifold design
  - Piston assembly design
- Analysis
  - 1D performance simulation
  - Compression ratio evaluation
  - Heat balance study
- Supply Chain Review
  - Review of injector suppliers
- Regulatory Compliance Review

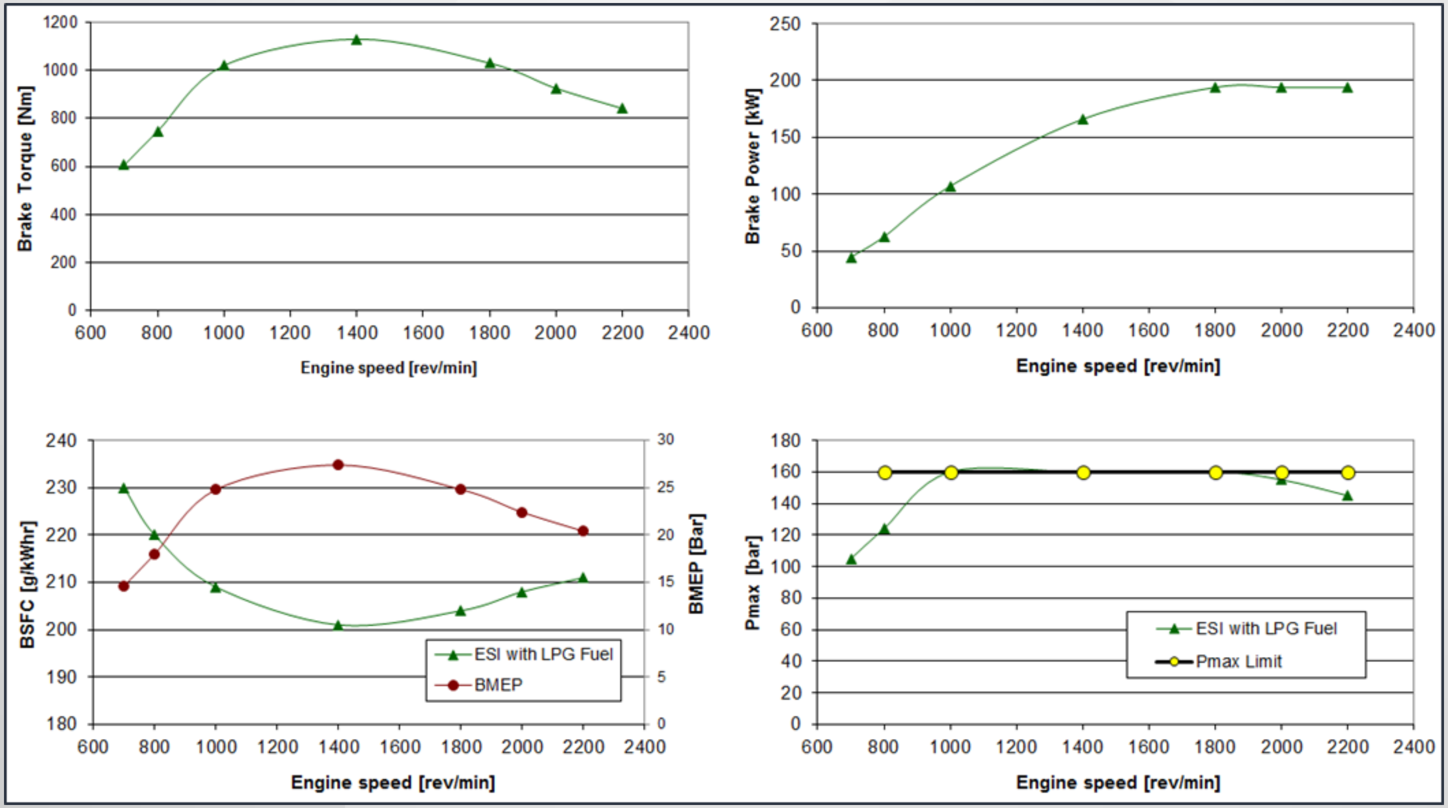
Westport ESI LPG Top End Assembly

Key System Design Features
- Cooled exhaust gas recirculation (EGR)
- Liquid port fuel injection
- Dual overhead camshafts
- Intake and exhaust cam phasing
- Optimized piston assembly design
- CR 12:1 to 13:1



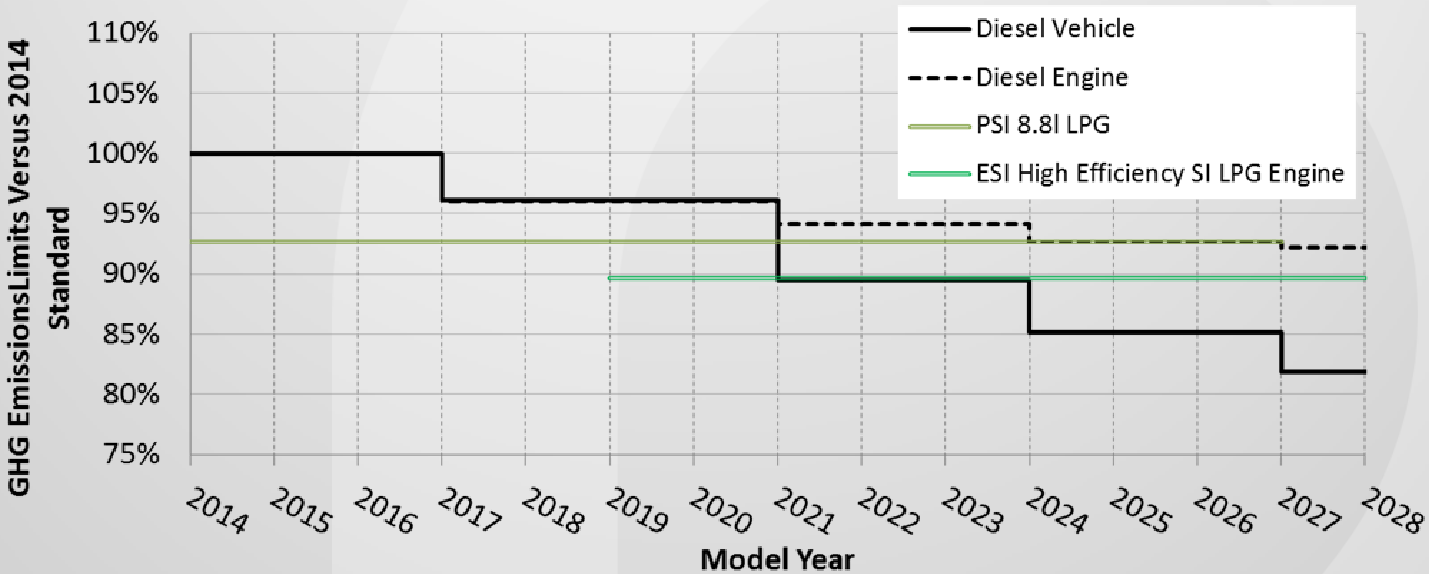
Thermal Considerations
- Icing in fuel expansion zone post injection
- Heat transfer from fuel system, engine, vehicle environment

Performance Simulation Results (HD5 fuel) – 5L 4 cyl. MHD Engine



- Power and torque targets achieved (slight shortfall with HD10 fuel)
- Strong low end torque supporting down-speeding of engine and driveline
- Engine performance limited by max cylinder pressure at over 1000 rpm
- Minimum full load BSFC 201 g/kWh

Regulatory Compliance Review
Phase II GHG Standards



- Current EPA proposal requires all class 6/7 engines to meet the diesel standard
- Project ESI LPG engine to comfortably meet standard through to 2027
- This provides some capacity for vehicle simplification (e.g. avoid electrification, hybridization)

Regulatory Compliance Review
Fuel Sulphur Level

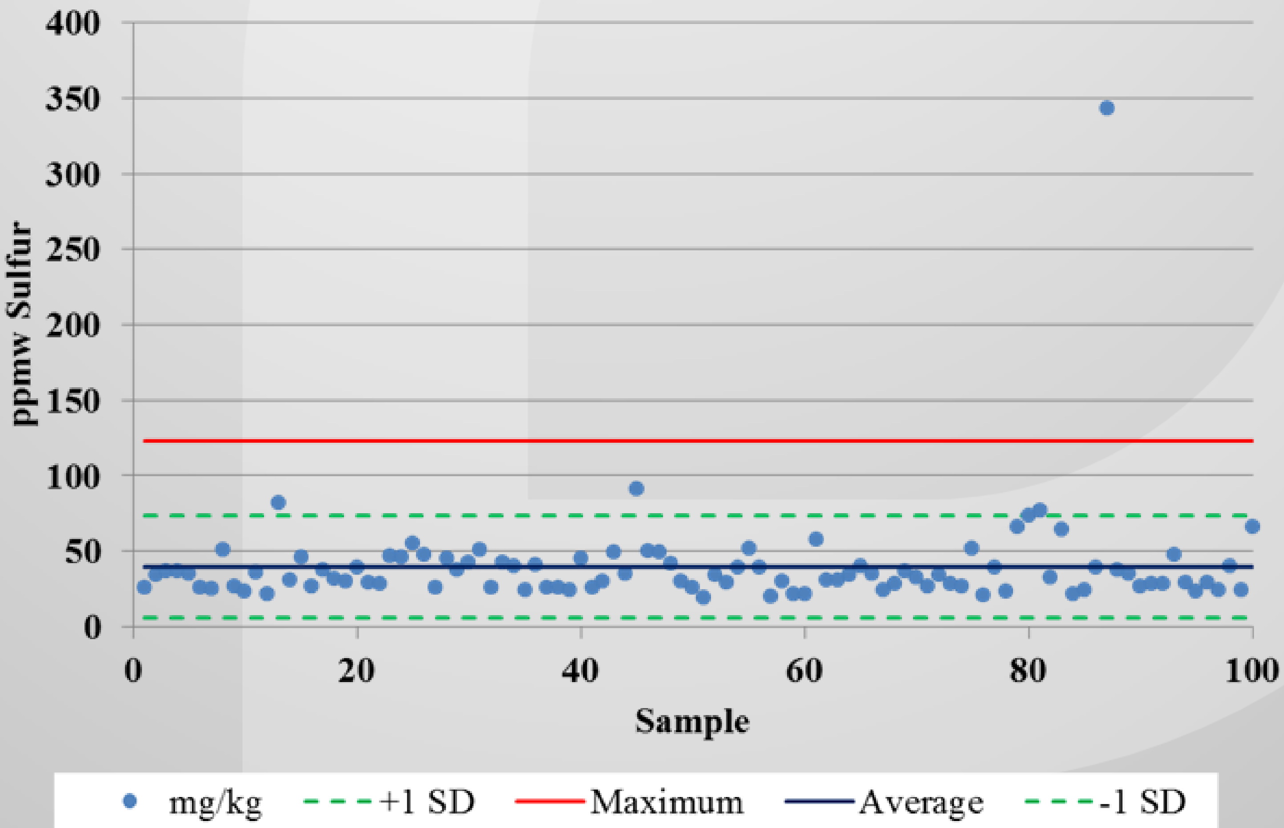
- HD5 and HD10 specifications both have significantly higher levels of sulphur allowable (at 123 and 80 ppm, Table 2) than other automotive fuels such as ULSD Diesel (15 ppm), Tier III gasoline (10 ppm from 2017), CARB natural gas (16 ppm by vol). (ref PERC fuel quality data, ITA Meeting)

Product Characteristics	Commercial Propane *	HD-5 *	CARB Engine Fuel Specification HD-10 **
Hydrocarbon composition	Predominately propane and/or propylene	≥ 90 liquid volume percent propane ≤ 5 liquid volume percent propylene	≥ 85 volume percent propane ≤ 10.0 propylene
Vapor pressure at 100F, max	208 psig	208 psig	208 psig
Volatile residue: temperature at 95% evaporation, max	-37F	-37F	-37F
Or	Or	Or	Or
Butane and heavier, liquid volume percent	≤ 2.5%	≤ 2.5%	≤ 5% butane ≤ 2% butane ≤ 0.5% pentene and heavier
Residual matter (from evaporation of 100ml), max	0.05 ml	0.05 ml	0.05 ml
Total sulfur	185 ppmw	123 ppmw	80 ppmw
Moisture content, freeze valve {Approximate equivalent ppmw⁺}	Pass {40 ppmw}	Pass {40 ppmw}	Pass {40 ppmw}

* GPA 2140-97, ASTM D1835-05
** California Air Resource Board specification, as given in California Code of Regulations, Title 13, Section 2292.6
⁺ Approximation comes from Totten, 2003, page 48

Regulatory Compliance Review
Fuel Sulphur Level

- Concern is long-term damage to catalyst over emissions useful life (185,000 miles)
- Average levels may be below 50ppm (PERC fuel quality data, ITA Meeting)
- Near-zero NOx target may require development of lower S standards for LPG

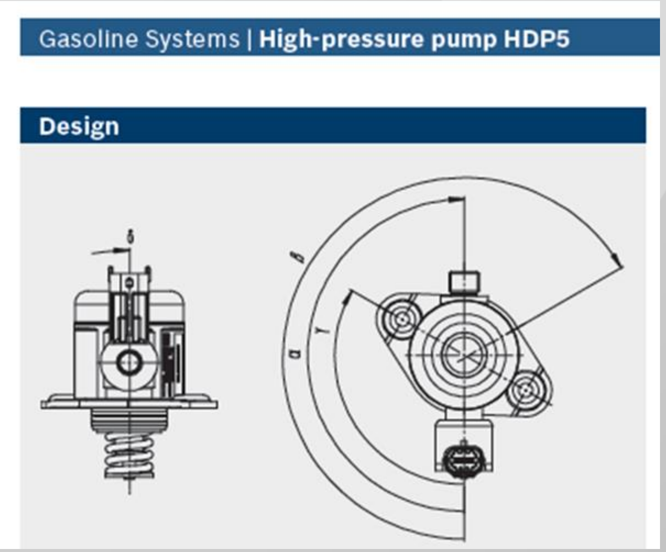


Potential Benefits of DI LPG (vs. LPI LPG) 5L 4 cyl. MHD Engine

- Octane enhancement due to evaporative charge cooling
  - For LD applications that are knock limited, this translates into capability to run optimum more of the time and to reduce fuel enrichment
  - For optimised engines, expectation is approximately 1 CR increase may be possible (e.g. 12:1→13:1) which would possibly reduce fuel consumption by 1-2%
- Volumetric efficiency improvement due to evaporative charge cooling
  - Based on gasoline experience, about 2-3%
  - Only translates into a torque improvement for naturally aspirated engines
- Improved scavenging for additional torque at low speeds
  - Good strategy for LD engines – demonstrated in GDI today and not generally applicable for vapor port fuel injection approaches
  - Aggressive scavenging limited by HDE Not To Exceed (NTE) emissions requirements (NOx emissions, catalyst life)

Fuel System Implications of DI ESI 5L 4 cyl. MHD Engine

- Gasoline DI injectors not Tier 1 approved for LPG
  - Durability concerns (although LD field experience is positive but not comprehensive yet)
- Gasoline DI injectors are not designed or approved for MHD applications
  - 50% more injector cycles over the life-time
  - Greater quantity of fuel per injection
- Finding a high flow HP pump could be an issue
  - Gasoline DI pumps are typically cam driven. The engine speed (and cam speed) is lower for a given fuel flow than for an LD engine, and the fuel is less dense (e.g. 1.9cc/rev vs 1.2cc/rev)
- The engine needs a more capable ECU
  - Gasoline DI injectors require high voltage boost circuit to develop the correct drive waveform
- **Westport working with Tier 1 FIE suppliers to develop requirements for MHD DI LPG fuel system components**



Study Conclusions: 5L 4 cyl. MHD Engine

1. No issues identified in meeting 2018 EPA / CARB OBD requirements with system architecture (electronic controls, engine and evaporative emissions controls)
2. Expect to comply with Phase 2 GHG rules with potential to generate credits or allow vehicle simplification (by avoiding electrification / hybrid systems) - Subject to final rulemaking (expected Q3)
3. ESI well suited to the LPG application - however, current HD5 & HD10 fuel specs have fuel sulphur limits significantly higher than those used in other automotive fuels, raising catalyst poisoning concerns

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