Agenda

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

WESTPORT

BRC
BRC FuelMaker
IMPCO
impcosolutions.com

FU
EL SY
STEMS SOL
UTIONS

WESTPORT

BRC
GAS EQUIPMENT

IMPCO
AUTOMOTIVE

WESTPORT
WING
POWER SYSTEM

OMVL

BRC
FuelMaker

CUBIO
GAS

TA
GAS TECHNOLOGY

ZAVOLI

Gfi

IMPCO

WESTPORT

ICE PACK
END TANK SYSTEM

emer

Prins

WESTPORT
PARTS + SERVICE

WESTPORT

Prins

OMVL

VALTEK

Westport

Here and Now.
Complementary Customer Bases

**FUEL SYSTEMS SOLUTIONS**

- Kubota
- CATERPILLAR
- Ford
- KIA
- HYUNDAI
- COMBILIFT
- MITSUBISHI
- NISSAN
- SUBARU
- ASHOK LEYLAND
- IVECO
- DR
- FORD
- CHEVROLET
- VOLVO
- GREAT WALL
- TATA
- ISUZU
- MAZDA
- MAHINDRA
- VOLKSWAGEN
- Renault
- Piaggio
- SAIKONG
- SUZUKI
- MARUTI
- HR REFRIGERATION
- Waukesha
- DAIMLER
- JUNGHEINRICH

**WESTPORT**

- PSA PEUGEOT CITROËN
- Ford
- DELPHI
- CAT
- IVECO
- MAN
- FIAT
- VOLVO
- HYUNDAI
- RENAULT
- FREIGHTLINER
- Power Generation
- EIM
- PETERBILT
- CLARK

Westport

Here and Now.
Westport is Driving a Shift to Gaseous Transportation Fuels

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

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

- Combustion Control & Combustion Chamber Hardware, 40%
- Engine Fuel Systems, 14%
- CNG Storage & Delivery, 24%
- Other, 7%

Top 10 Companies with Natural Gas Engine Related Patents*

<table>
<thead>
<tr>
<th>Company</th>
<th>Patents</th>
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<tbody>
<tr>
<td>Westport</td>
<td>473</td>
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<tr>
<td>Caterpillar</td>
<td>363</td>
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<tr>
<td>Toyota</td>
<td>334</td>
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<tr>
<td>Ford</td>
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<tr>
<td>GE</td>
<td>187</td>
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<td>Honda</td>
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<td>Mazda</td>
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<td>Continental</td>
<td>105</td>
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</table>

* 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, Serbia, 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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4. Perspectives for MD
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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
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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

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
- E85 Flexible-Fuel Vehicle
- Gasoline-Ethanol (E85)
- 5.0 L, 8 cyl, Automatic (S6)
- 387 lb.-ft @ 3850 rpm

2016 Ford F150 Pickup 2WD
- Gasoline Vehicle
- 2.7 L, 6 cyl, Automatic (S6), Turbo
- 375 lb.-ft @ 3000 rpm

2016 Ram 1500 2WD
- Diesel Vehicle
- 3.0 L, 6 cyl, Automatic 8-spd, Turbo
- 420 lb.-ft @ 2000 rpm

Regular Gasoline
- 2016 Ford F150 Pickup 2WD FFV
  - 18 combined city/highway
  - 15 22 city highway
  - 5.6 gal/100mi

Regular Gasoline
- 2016 Ford F150 Pickup 2WD
  - 22 combined city/highway
  - 19 26 city highway
  - 4.5 gal/100mi

Diesel
- 2016 Ram 1500 2WD
  - 23 combined city/highway
  - 20 28 city highway
  - 4.3 gal/100mi

22% MPG Improvement
10% Gasoline Equivalent MPG

Source: www.fueleconomy.gov
Progression of Propane Powertrain Technology – Outperform Gas, Diesel

**Common.** Prior generation. Degraded performance relative to gasoline.

**Vapor Propane PFI**

**Liquid Propane PFI**

**Liquid Propane DI (Turbo)**

**LP DI Turbo Diesel base engines**

**Best.** Westport is developing. Outperforms gasoline & diesel.

**Better.** Use existing gasoline DI FIE and engine. Exceeds gasoline performance and efficiency.

**Good.** Current state-of-the-art. Matches gasoline performance.
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Cumulative Truck & Bus Shipments

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

- 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

Timeline of Diesel-Derived Natural Gas Engine Innovations
Re-Imagining 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?
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

PSI 8.8L LPG
565 lb-ft / 270 hp

PI 8.0L LPG
495 lb-ft / 339 hp

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

Ford 6.8L V10
460 lb-ft / 362 hp
# Agenda

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

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

* 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
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
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
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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