Natural Gas
Why Now, and What are the Challenges

October 23, 2013

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Executive Vice President & Chief Engineer
Enovation Controls
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- $250 million in sales
- >1000 employees worldwide
- Three Major Business Segments
  - Natural Gas Vehicles and Engine Fuel Systems (EControls brand)
  - Natural Gas Production Systems (Murphy brand)
  - Controls and Vehicle Systems (both brands)
Focused in Dynamic Markets

Natural Gas Focused Segments (80%)

CNG / LNG Commercial Vehicles

Natural Gas Vehicles & Engine Fuel Systems

40%

Engine OEMs

Gas Compression

Natural Gas Production Systems

40%

Refinement
Focused in Dynamic Markets

Controls and Vehicle Systems Segment (20%)

- Off-Highway
- Marine
- Gen Sets
- Consumer Recreation

Control and Vehicle Systems 20%
Our Global Footprint

- Grants Pass, Oregon
- Tulsa, Oklahoma
- San Antonio, Texas
- Houston, Texas
- Salisbury, United Kingdom
- Birmingham, United Kingdom
- Hangzhou, China
- Shanghai, China

Legend:
- Red Square: Corporate Headquarters & Manufacturing
- Red Circle: Manufacturing
- Red Triangle: Sales/Applications

EControls
Customers Examples

Natural Gas Vehicles & Engine Fuel Systems

Natural Gas Production Systems

Control & Vehicle Systems

Natural Gas Vehicles & Engine Fuel Systems Segment

• Largest provider of natural gas fuel systems for medium and heavy commercial vehicles with over 170,000 systems on the road today
• Installed base of over 1,000,000+ engine control systems
• Engine control systems for CNG, LNG, LPG, gasoline and diesel engines
• Leading alternative-fuel control system manufacturer for on-highway and industrial engines
• Full in-house engine development and emissions certification capability
• Current products meet the most stringent emissions standards in the world
• Market driven design and development
Customers - Heavy-Duty

- Yuchai
- Caterpillar
- Hino Trucks
- Detroit Diesel
- FAW
- CNHTC
- Sinotruk
- SDEC
- ENOVATION Controls

Abu Dhabi, UAE, May 2003

Christian Kraut
Complete Engine Control System Provider

- Control Electronics
- Fuel Metering
- Pressure Regulation
- Turbocharger Control
- Exhaust Aftertreatment
- Spark Control
- Air Control
- Sensors
EControls NG Global Experience

- **170,000+** OEM heavy-duty NG systems on the road today

- 20 Certified production engines for HD/MD
- Dominant supplier in the China HD/MD OEM engine market since 2006
- But... for US HD NG we have been **skeptics** for 15 years!
Fuel Cost Economics

Historical Oil and NG Fuel Prices

United States shale production hits its stride
Fuel Cost Economics

Relative Energy Cost of Oil and Natural Gas

- Sustainable > 2:1 ratio will drive market build-out
- Non-sustainable > 2:1 ratio triggers 1990’s activity
- < 2:1 ratio insufficient for critical mass

US shale production hits its stride

Oil / NG $/Btu wellhead cost ratio

Year
McKinsey Report
Where Shale Gas Resources Are

Global map for technically recoverable shale gas resources

SOURCE: EIA, World Shale Gas Resources
Development of unconventional gas in Europe, Asia and Latin America far behind US and Canada

Country evolution on unconventional s-curve

- **CAPEX**
- **Time**

1. **Land acquisition**
   - No wells drilled
   - Largely ‘known’ basins
   - Limited data (quality, productivity)

2. **De-risking**
   - Exploratory drilling
   - Focus on reservoir quality and learning rates

3. **Commercial pilot**
   - Secure market access
   - Drilling / well design optimization

4. **Development**
   - Manufacturing focus to drive learning curve
   - Focus on long term well performance

5. **Consolidation**
   - Consolidation / optimization of basin ownership

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1. Flags based on most advanced basins in China (Sichuan basin) and Australia (Cooper basin). Other basins in both countries are still at the land acquisition stage.

2. Algerian government has announced its intention to begin shale gas exploration with help from international players.

SOURCE: McKinsey oil and gas practice; Expert interviews; CST analysis
<table>
<thead>
<tr>
<th>Rank</th>
<th>Country</th>
<th>Shale gas (trillion cubic feet)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>China</td>
<td>1,115</td>
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<tr>
<td>2</td>
<td>Argentina</td>
<td>802</td>
</tr>
<tr>
<td>3</td>
<td>Algeria</td>
<td>707</td>
</tr>
<tr>
<td>4</td>
<td>U.S.A</td>
<td>665</td>
</tr>
<tr>
<td>5</td>
<td>Canada</td>
<td>573</td>
</tr>
<tr>
<td>6</td>
<td>Mexico</td>
<td>545</td>
</tr>
<tr>
<td>7</td>
<td>Australia</td>
<td>437</td>
</tr>
<tr>
<td>8</td>
<td>South Africa</td>
<td>390</td>
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<td>9</td>
<td>Russia</td>
<td>285</td>
</tr>
<tr>
<td>10</td>
<td>Brazil</td>
<td>245</td>
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<tr>
<td></td>
<td>World Total</td>
<td>7,299</td>
</tr>
</tbody>
</table>

EIA estimates
China Challenges for Shale Gas

- Far behind in development of technology
- Gas is deeper and tighter
- Not enough pipeline infrastructure
- Geography not as conducive to exploration

- **China has the resources to be energy independent with NG**
Current Vehicle Fuel Average Prices in Diesel Gallon Equivalent

Current NG Pump Prices in Diesel Gallon Equivalent

- Diesel China
- LNG-low
- LNG-high
- CNG- Nei Monggol
- CNG-Jinan
- Diesel USA
- LNG USA
- CNG USA

Price Range and Location

$USD
Vehicle Market Challenges

• Infrastructure
  – Asia (China, Thailand, Korea) have the most built out fueling infrastructures in the world for MD/HD applications, but in centralized locations
  – China needs more expansion to continue the large market growth in HD truck
  – The US infrastructure is inadequate currently for HD truck, but developing at a rapid pace. Built by private entities and fuel companies

• Fuel cost concerns

• Durability of engines and systems (mainly an issue in China)

• LNG or CNG decision
  – Not a huge concern in China due to shorter route target customers currently. Is LNG needed for long haul? More stations?
  – Large concern for HD truck in the US as these are mostly long haul. Customers do not know which to purchase even though most believe LNG will win
  – LCNG stations may be needed to eliminate the concern
Critical Fuel System Technologies

- Major Technology Areas:
  - Vehicle fuel storage type
    - CNG = Compressed Natural Gas
    - LNG = Liquefied Natural Gas
  - Engine fuel delivery system
    - Air/Fuel pre-mix
    - Port Injection
    - Direct NG injection
  - Engine ignition system
    - Spark
    - Micro-pilot diesel
    - Standard diesel
Engine Fuel Delivery System

- **Air/Fuel Pre-Mix (NG mixed into incoming air stream)**
  - Lowest cost and lowest complexity
  - Low fuel pressures at the engine (similar to gasoline)
  - Continuous flow possible = high valve durability
  - Requires throttling = reduced light-load efficiency
  - US example: Cummins ISLG, ISX12G, ISX15G
  - Asia example: All

- **Direct NG Injection (NG delivered in-cylinder like diesel)**
  - Higher cost and higher complexity
  - High fuel pressures at the engine (cryogenic pumps for LNG)
  - Must be pulsed injection = finite valve cycle life
  - No throttling required = increased light-load efficiency
  - US example: Westport HD 15L
Engine Ignition System

• **Spark Ignition** (similar to gasoline engines)
  - Electronic spark initiates combustion
  - Lowest cost and lowest complexity
  - Current systems limited to ≈ 21 bar bmep

• **Micro-pilot diesel ignition** *(very small common-rail injection)*
  - Small diesel quantity initiates combustion
  - High cost and high complexity
  - Ignition system does not limit bmep
  - Engine is not true “dual fuel” (i.e. cannot make >10% torque without NG)

• **Standard diesel ignition** *(standard common-rail injection)*
  - Diesel injector initiates combustion
  - Highest cost and highest complexity
  - Ignition system does not limit bmep – but does pose emissions challenges
  - Maximum of ≈ ¾ power from NG fuel (remainder from diesel)
  - True “dual fuel” (i.e. engine can run full power on diesel)
Vehicle Fuel Storage

- **CNG = Compressed Natural Gas** (3000+ psi gas)
  - 6:1 tank dimensions for diesel range
  - Lower tank price, but more tanks
  - Least expensive pump delivery price
  - User-friendly filling
  - Indefinite fuel storage

- **LNG = Liquefied Natural Gas** (cryogenic low-pressure liquid)
  - 2:1 tank dimensions for diesel range
  - Higher tank price, but less tanks
  - More expensive than CNG at the pump
  - Limited time after filling before tank vents (days to weeks) since tank is essentially a large “thermos” bottle.
  - Results in fuel “aging” (higher ethane is result causing knock concern)
Tanks

• Tank cost in the US is much too high currently
  – Most HD trucks currently using type 4 cylinders for CNG
  – Volume and competition is poor
• Tank cost in China is much more reasonable but should improve.
  – Type 1 and 2 cylinders are the only legal selection. Less expensive for CNG
  – Type 2 tanks sizes too small for most efficient storage on HD trucks
  – LNG tank manufacture competition has driven price down over time
  – Production volume
Combustion Approaches for Optimum BTE at Low Emissions Levels

- Stoichiometric with a Three-Way Catalyst (TWC)
- Add EGR
- Add SCR

E6 (high BMEP E5)

Euro 4 (Euro 5 ?)

Higher thermal loading

NO$_x$ Emissions [ppm]

5-10
25-40
> 100

Brake Thermal Efficiency
Stoichiometric with High EGR
Spark Ignited

- Allows same efficiency as lean burn (Euro 3)
- Reduces exhaust after-treatment cost greatly *(lowest cost Euro V and Euro VI solution)*
- Meets current emission regulations worldwide
- Engine durability and temperatures similar to or better than lean-burn
EGR Dilution Rate at Peak Efficiency

EGR% = Int. CO2 / Exh. CO2% * 100

Stoich. + EGR Intake Dilution [EGR %]

BMEP [bar]

Speed [RPM]
Peak Efficiency (no emissions) Combustion Strategy Comparison

Lean Burn Brake Specific Fuel Consumption [g/kW-hr]
Peak Efficiency (no emissions) Combustion Strategy Comparison

Stoich. + EGR Brake Specific Fuel Consumption [g/kW-hr]
Peak Efficiency (no emissions) Combustion Strategy Comparison

Diff. % = (Lean – EGR)/Lean × 100
Negative percentage means higher Stoich. + EGR number.

Lean Burn vs Stoich. + EGR Brake Specific Fuel Consumption Difference [%]

BMEP vs Speed [RPM]
Peak Efficiency Lean-Burn vs. Euro V Lean Burn

Peak Efficiency v Euro V Brake Specific Fuel Consumption Difference [%]

Diff. % = (Euro V Efficiency) - Efficiency)/Euro V \times 100
Fuel Systems

• HPDI (Westport) and dual-fuel
  – Too expensive with two fuel systems and high pressure LNG pumps
  – Exhaust after-treatment more expensive than diesel with SCR

• MPI (Multi-Point Injection)
  – Too much air/fuel variation cylinder to cylinder hurts fuel consumption and emissions

• PWM inj (pulse width modulated on/off CPI)
  – Current injectors not durable enough for HD market on CNG and worse on LNG

• Air fuel pre-mix (Continuous Flow Central Point Injection)
  – Cummins, Yuchai, CNHTC, FAW, etc.
  – For the future expect most successful engines to be continuous flow, spark ignited with EGR to meet emission, cost and durability requirements
Only 3 OEM “Heavy-Duty” NG engines are EPA 2013 certified:

- **Cummins ISLG:**
  - 9L, 6-cylinder
  - Spark ignition (SI)
  - Standard CNG or LNG tank system compatible
  - Up to 320 bhp, 1000 ft-lbs @ 1300 rpm

- **Cummins ISX12G:**
  - 12L, 6-cylinder
  - Spark ignition (SI)
  - Standard CNG or LNG tank system compatible
  - Up to 400 bhp, 1450 ft-lbs @ 1200 rpm

- **Westport HD15:**
  - 15L, 6-cylinder
  - Micro-pilot diesel compression ignition (CI)
  - Requires special LNG tank system with high-pressure cryogenic pump
  - Up to 475 bhp, 1750 ft-lbs @ 1200 rpm
  - Now not being produced since the Cummins ISX12G was released
Initial Truck Cost Considerations

- Westport HD15
- Cummins ISX12G, ...
- Cummins ISX12G, ...
- Cummins ISX12G, ...

- Diesel Engine
- Current Micro-Pilot NG Engine
- Current Spark NG Engine
- High-Volume Spark NG Engine

Diesel + DEF Tanks
LNG+Diesel+DEF Tanks
LNG or CNG Tanks
LNG or CNG Tanks

Baseline Diesel Truck
ISX12, ISX15, ...

Truck Cost Contribution
Initial Truck Cost Considerations – The **Engine**

- **Why are HD NG** engines **more expensive than diesel??**

  **They should be cheaper because...**
  - Spark ignited, pre-mix NG fuel system = HPCR diesel fuel system cost
  - Spark ignited NG engine after-treatment is about $1000-$2000 (12L)
  - Tier4 diesel after-treatment is about $5000-$8000

  **But...**
  - Low volume production by US manufacturers = higher cost
  - Extremely limited US engine competition = higher cost
  - US market will currently **bear a higher price** because NG vehicle buying decisions are driven by fuel cost advantages – not engine cost
Initial Truck Cost Considerations – The **Engine**

- **Baseline Diesel**
  - ISX12, ISX15, ...
  - Common-Rail Diesel
  - Exhaust Aftertreat
  - Engine Long-Block
  - Diesel Engine

- **High-Pressure NG Fuel**
  - Cummins ISX12G, ...
  - Pre-Mix NG Fuel
  - Exhaust Aftertreat
  - Engine Long-Block
  - Current Micro-Pilot NG Engine

- **Pre-Mix NG Fuel**
  - Cummins ISX12G, ...
  - Pre-Mix NG Fuel
  - Exhaust Aftertreat
  - Engine Long-Block
  - Current Spark NG Engine

- **High Volume NG Price ≈ Diesel**
  - Cummins ISX12G, ...
  - Pre-Mix NG Fuel
  - Exhaust Aftertreat
  - Engine Long-Block
  - High-Volume Spark NG Engine

**Westport HD15**

+ Premium Margin
+ Premium Margin
+ Premium Margin

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ENOVATION CONTROLS
Initial Truck Cost Considerations – The **Tanks**

**What does the fuel tank system cost??**

- In the US Both CNG and LNG tankage are currently ≈ $300 / DGE – **This is too high!**
- In **high-volume** (i.e. mature market), both CNG and LNG should be ≈ $100 / DGE – **Asia**
- Mounting brackets and tank to engine plumbing are more expensive than diesel
- Fuel heat exchangers required on LNG systems, may also be used with some CNG systems
- No SCR required for spark-ignited systems means no DEF related tankage
- The Westport HD15 requires an extremely expensive special LNG tank with a high-pressure in-tank cryogenic hydraulic pump costing ≈ $500 / DGE

*DGE = Diesel Gallon Equivalent*
Initial Truck Cost Considerations – The **Tanks**

Westport HD15

- **Tank Packager Premium**
- **Hydraulic Power Unit**
- **Cryogenic In-Tank Pump**
- **Diesel Pilot Tank**
- **DEF Tank**

**Main LNG Tank**

**Main LNG or CNG Tank**

Cummins ISX12G, ...

Cummins ISX12, ISX15, ...

DEF Tank

Main Diesel Tank

**Current Micro-Pilot**

NG Engine

**Current Spark**

NG Engine

**High-Volume Spark**

NG Engine

**Diesel Engine**
## Fuel Cost Operating Advantages

### Basic Assumptions:

<table>
<thead>
<tr>
<th>Basic Assumptions</th>
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</thead>
<tbody>
<tr>
<td>Truck miles per year</td>
<td>100,000 miles</td>
</tr>
<tr>
<td>Diesel cost</td>
<td>4.00 $/gallon</td>
</tr>
<tr>
<td>LNG cost per DGE</td>
<td>2.50 $/DGE</td>
</tr>
<tr>
<td>CNG cost per DGE</td>
<td>2.00 $/DGE</td>
</tr>
<tr>
<td>Diesel fuel economy</td>
<td>7.0 miles/DGE</td>
</tr>
<tr>
<td>NG fuel economy - CI</td>
<td>7.0 miles/DGE</td>
</tr>
<tr>
<td>NG fuel economy - SI</td>
<td>6.3 miles/DGE</td>
</tr>
</tbody>
</table>

### Fuel Operating Cost Advantage Analysis:

<table>
<thead>
<tr>
<th>Engine Platform</th>
<th>Truck Premium</th>
<th>Diesel Fuel Cost</th>
<th>NG Fuel Savings</th>
<th>Payback (Months)</th>
<th>ROI - 5 year (avg % / year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Westport HD15 (LNG)</td>
<td>$90,000</td>
<td>$57,143</td>
<td>$21,429</td>
<td>50</td>
<td>3.8%</td>
</tr>
<tr>
<td>Cummins ISX12G (CNG) - Current</td>
<td>$45,000</td>
<td>$57,143</td>
<td>$25,397</td>
<td>21</td>
<td>36.4%</td>
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<tr>
<td>Cummins ISX12G (CNG) - Future/Mature</td>
<td>$23,000</td>
<td>$57,143</td>
<td>$25,397</td>
<td>11</td>
<td>90.4%</td>
</tr>
<tr>
<td>Yuchai 6112 (CNG) – Current</td>
<td>$18,000</td>
<td>$57,143</td>
<td>$25,397</td>
<td>9</td>
<td>121.1%</td>
</tr>
</tbody>
</table>
How Can We Accelerate US HD NG Buildout?

• Broad-based availability of HD ready CNG (or LCNG) refueling stations

• Create engine competition against Cummins by encouraging truck manufacturers to develop NG engines or bring in foreign competition

• Drive tank pricing down toward high-volume levels through competition and truck manufacturer integration assistance

• Work with CNG based refueling stations to negotiate industrial NG pricing (instead of commercial)

• Most HD industry experts believe NG will power >20% of the fleet in 5-10 years in the US