Natural Gas Use for Transportation

Guild of Gas Managers
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Paul Armstrong
Director of Business Development
Natural Gas for Transportation

- Transportation Sector
  - Overview & Assessment
  - Natural Gas Vehicle Markets
- Fueling Infrastructure and Challenges
- NGV Technology Development Update
## U.S. and International NGV Markets
Different Paths & Market Attributes

<table>
<thead>
<tr>
<th>Country</th>
<th>Natural Gas Vehicles</th>
<th>GGE/Year</th>
<th>BCF/year</th>
<th>GGE/Vehicle/Year</th>
<th>Tank Technologies</th>
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</thead>
<tbody>
<tr>
<td>Iran</td>
<td>2,859,386</td>
<td>1,608,972,185</td>
<td>198</td>
<td>563</td>
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<tr>
<td>Pakistan</td>
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<td>1,374,930,471*</td>
<td>169</td>
<td>482*</td>
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<td>Argentina</td>
<td>2,044,131</td>
<td>827,655,981</td>
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<td>569,204,057</td>
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<td>India</td>
<td>1,100,000</td>
<td>530,581,834*</td>
<td>65</td>
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<td>United States</td>
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<td>361,760,341</td>
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<td>3,230</td>
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<td>Ukraine</td>
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<td>China</td>
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<td>289,408,273*</td>
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<td>482*</td>
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<td>Italy</td>
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<td>213,714,228</td>
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<td>281</td>
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<td>204,894,167</td>
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<td>Colombia</td>
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<td>149,527,608*</td>
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<td>482*</td>
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<td>Egypt</td>
<td>162,000</td>
<td>130,922,790</td>
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<td>Thailand</td>
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<td>129,141,207*</td>
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<td>Russia</td>
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<td>Armenia</td>
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<tr>
<td>Bolivia</td>
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<td>90,537,020</td>
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<td>645</td>
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<tr>
<td>Peru</td>
<td>122,221</td>
<td>56,163,706</td>
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<td>Germany</td>
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<td>50,301,914</td>
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<td>530</td>
<td>Type I, II, III</td>
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<td>Venezuela</td>
<td>90,000</td>
<td>28,086,570</td>
<td>3</td>
<td>312</td>
<td>Type I</td>
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</tbody>
</table>

Source: N. Sirosch, Quantum Technologies

* Estimated values

Per vehicle US NGV use is substantially greater than other markets.

Could move into top position based on consumption by 2020-2025.

US is ranked 6th in NGV natural gas consumption (but 17th in vehicle count).

Heavy reliance on more expensive composite cylinders (Type 3, 4).
U.S. Transportation Sector Situation Assessment

> Transportation market, by far, most concentrated energy sector in US
  > Very high reliance on liquid fuels
  > Low natural gas market penetration
  > Other sectors range from 20-45%

> Over 27 Quads of energy use, led by on-road vehicles
  > Light-duty (16.1 Quads)
  > Heavy-duty (5.3 Quads)

> Market factors point toward growth opportunity
  > However, requires major capital investments & time for energy transition
Transportation Sector and Natural Gas Vectors

> Direct use in NGVs
  - CNG and LNG vehicles
    > About 40-45 bcf now (0.045 Quads)
    > Large upside, particularly for medium/heavy duty fleets
    > Latest DOE forecast: 84 bcf (2020)
      - Likely a low estimate given current market conditions
  - Product availability & price definitely going in right direction

Note: DOE-EIA’s methodology for NGV use tracking is not currently robust like other sectors. Their data and forecast may be understating the rate of market change.
Heavy-Duty Vehicles Represent Key Target Market

- Over 1.2 TCF market scenario, with long-term core around freight vehicles
- High-fuel-use fleets see good payback periods today
  - Over 5-10K gallons/year (as high as 20-25K gallons/year)

### Vehicle Class

<table>
<thead>
<tr>
<th>Vehicle Class</th>
<th>Fuel Displaced (Million Gasoline Gallon Equivalent)</th>
<th>Natural Gas Demand (bcf)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Freight Trucks</td>
<td>8,913</td>
<td>1,096</td>
</tr>
<tr>
<td>Refuse Trucks</td>
<td>579</td>
<td>71</td>
</tr>
<tr>
<td>Transit Buses</td>
<td>557</td>
<td>68</td>
</tr>
<tr>
<td>School Buses</td>
<td>432</td>
<td>53</td>
</tr>
</tbody>
</table>

High fuel displacement scenario
Source: NGV America
Heavy-Duty Truck Payback

Class 8 Truck
Effect of NG Truck Price Premium on Fuel Price Spread Required For Economic Payback

High fuel price differential
Lower cost NGV options (as volume grows)

120,000 miles/year; 6.1 mpg
NGV Heavy-Duty Sector
Market Outlook

> Attractive payback potential
> 150 bcf+ market feasible by 2020
> Continued progress in bus, refuse markets
> Freight truck adoption & infrastructure investment are key determinants
> Significant upside exists but requires product and investment for this segment

<table>
<thead>
<tr>
<th>Vehicle Class</th>
<th>Natural Gas Demand Scenario (bcf)</th>
<th>Estimated Current/2011 Use (bcf)</th>
<th>% of Goal in 2011</th>
<th>Estimated 2020 Use (bcf)</th>
<th>% of Goal in 2020</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transit Buses</td>
<td>68</td>
<td>23</td>
<td>34%</td>
<td>54</td>
<td>79%</td>
</tr>
<tr>
<td>Refuse Trucks</td>
<td>71</td>
<td>5</td>
<td>7%</td>
<td>40</td>
<td>56%</td>
</tr>
<tr>
<td>Freight Trucks</td>
<td>1,096</td>
<td>5*</td>
<td>&lt;1%</td>
<td>50+*</td>
<td>5%</td>
</tr>
<tr>
<td>School Buses</td>
<td>53</td>
<td>0.5*</td>
<td>1%</td>
<td>5*</td>
<td>9%</td>
</tr>
<tr>
<td><strong>Goal:</strong></td>
<td><strong>1,288</strong></td>
<td><strong>33.5</strong></td>
<td><strong>3%</strong></td>
<td><strong>~150+</strong></td>
<td><strong>12%+</strong></td>
</tr>
</tbody>
</table>

* SWAG

Market leading segment in 2011

Market leading segment in 2020?
NGV Market Adoption
Over-The-Road (Freight) Trucks

> Substantial market opportunity for NGVs
  > Includes Full Truckload (TL) and Less-Than-Truckload (LTL) segments
  > Long-haul, regional, local

> Traditional HD vehicle OEMs genuinely on-board with NGVs
  – Seeing market pull from customers (not gas industry push) due to fuel savings
  – Price and Product improving
  > Significantly enhanced vehicle and engine products entering the market

Then...

Now...

High-performance engines with improved cost differential; no urea SCR or particulate filters as seen on diesel platforms

Substantial 155 diesel gallon equivalent on-board storage; 700-900 mile range possible.
Over-the-Road Freight Market
Connecting the Dots

> Efforts to expand regional & interstate stations
  – CNG, L-CNG, LNG
  – Some regions currently have decent coverage (e.g., UT, CA, TX)
  – LTL, regional, and local delivery companies

> Expansion and linking paves way to interstate delivery market
  > Tractor-trailer combinations

> Significant capital investment needed in high-output 24/7 stations

<table>
<thead>
<tr>
<th></th>
<th>Single Unit Trucks (Up to 40 ft)</th>
<th>Combination Unit Trucks (Over 40 ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicles (millions)</td>
<td>8.36</td>
<td>2.62</td>
</tr>
<tr>
<td>Fuel Use (million gallons)</td>
<td>16,342</td>
<td>28,130</td>
</tr>
<tr>
<td>TCF equivalent</td>
<td>2.27</td>
<td>3.91</td>
</tr>
</tbody>
</table>

The move to combination truck fleets is a meaningful change in station requirements.
Fueling Infrastructure

> Capital investment to fuel 1 Tcf/year is substantial (about $6-9 billion)

> Fueling stations can come in a variety of sizes and configurations
  — CNG, L-CNG, LNG

> Fuel delivery performance is key attribute – and a major challenge for vehicles with over 75 gallon capacity **repeatedly refueling** at 24/7 stations
  — Filling quickly, accurately, completely – no long waits
  — Significant CNG compression and storage capacity needed

> LNG is an alternate solution (i.e., LNG has high fuel transfer rates), BUT:
  > Fuel cost premium, history of higher “unaccounted for” gas, and cryogenic handling inconveniences are real concerns
  > Poor LNG tax treatment
    — LNG fuel road tax is 16 cents/gallon higher than diesel (equal energy basis); CNG is 4.7 cents/gallon lower
    — Vehicle owner/operators could pay $1.5 billion more PER YEAR in fuel taxes with LNG (over CNG)

<table>
<thead>
<tr>
<th>1 TCF Equivalent Vehicle Use</th>
<th>Road Taxes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diesel</td>
<td>$1.79 Billion</td>
</tr>
<tr>
<td>LNG</td>
<td>$2.89 Billion</td>
</tr>
<tr>
<td>CNG</td>
<td>$1.44 billion</td>
</tr>
</tbody>
</table>
Capital Intensive Fueling Infrastructure Requirements

At 1 Tcf/year, capital investment could range from $6-9 billion. Large savings potential exists.

We Are Here
Addressing Capital Intensive Needs:
Align Gas Industry Investments & NGV Infrastructure Needs

Gas Industry Plant Investments

> Transmission Pipelines
  — $6-10 billion per year
  — Over 10 million hp of installed COMPRESSION capacity

> Local Distribution Pipelines
  — $12 billion year
    > $8.2 billion repair/replace
    > $4.0 billion new construction

> Natural Gas STORAGE
  — Substantial volumes of stored CNG, LNG

NGV Infrastructure Needs

— $6-9 billion investment needed to get to 1 TCF market

— COMPRESSION, STORAGE, LNG PRODUCTION, dispensing
Light-Duty Vehicle Market

> Light-duty vehicles are an important long-term option (16 Quad potential)

> More challenging value proposition
  – Higher fuel economy
  – Generally, fewer miles traveled
  – Key segments: taxi, high-mileage fleets where payback possible

> Key issues are lowering first-cost premium, building volume, expanding product offerings
  – Classic “chicken & egg” situation

> Home fueling enables convenience, time savings, new gas industry market & services
GTI’s NGV RD&D Program

> GTI has a portfolio of NGV RD&D projects that target vehicle & infrastructure needs

> Vehicles
  - Demonstrate & deployment new engines & vehicles
  - Work with OEMs on high-efficiency, high-horsepower, low-emission engines
  - New vehicle platforms, including medium/ heavy duty hybrids
  - Components: NGV storage advances (CNG, LNG, ANG) and related fuel delivery devices

> Infrastructure
  - Demonstrate & deploy new products and stations
  - Components: new compressors, dispensing, fuel quality, small fleet and home fueling
NGV Fueling Infrastructure

> USDOE Chicago Clean Cities project
  - $15 million proposal prepared by GTI, awarded to City of Chicago, & now being managed by GTI
  - One of 25 awards (from 120+ proposals)
  - Leveraging another $25 million in cost share
  - Includes 16 fleets resulting in 16 CNG shared access stations & 100+ EV chargers
  - Includes 230 NGVs & ~400 hybrids
  - Refuse trucks: Waste Management, Groot
  - CNG green taxi program
  - Pursuing follow-on program with Chicago area council of governments & fleet partners
Cylinders are Critical Vehicle Components

- Composite cylinder costs can incrementally improve with sales volume (and actual cylinder size).
- However, composite cylinder manufacturing is a challenge due to (1) time-intensive winding and curing operations and (2) use of high-performance (i.e., high-cost) materials
  - This is an intrinsic issue with composites in high-volume transportation applications.
- Process improvements from other uses may help lower production costs.
Low Cost & Scalable CNG Cylinder

> With UTD support, assisted HyPerComp Engineering Inc. in product development & certification stages of:
  ─ Type 4 all-composite cylinder
  ─ Scalable design (7-17 gge)
  ─ Targeting a market introduction price at $115 per gge
  ─ 3rd Party Certification Testing performed

> Helped lead to collaboration by 3M & Chesapeake JV
Industry-Leading NGV Engines
Cummins ISX12 G

> Cummins Westport Inc. (CWI)
  Critical next-generation NGV engine
  – Major new product for NGVs!
  – Nearing culmination of over three-year, multi-
    million development
  – GTI played key role in securing $3 million in
    government & industry funding
  – Continuation of over two decade relationship
    with Cummins and CWI

> 400 hp for larger vehicles
  – Perfect fit for high GVW regional haulers,
    refuse collection, concrete mixers, etc
  – Fills out product line above highly
    successful, world-leading ISL-G (8.9L)
    sold worldwide

Engine Profile
11.9L displacement
400 hp / 1450 ft-lb rating
Spark ignited; stoichiometric with cooled EGR
Out-perform strict CARB emission standards
Maintenance-free aftertreatment
CNG / LNG / biomethane capable
Commercial availability by Q1, 2013

Cummins Westport Announces New Heavy-Duty Natural
Gas Engine; ISX12 G Natural Gas Engine Targets
Regional Trucking, Vocational and Refuse Markets in
North America
February 20th, 2012

VANCOUVER, BC – Cummins Westport Inc., announced today the ISX12-G, a 12 litre heavy-
duty, factory built dedicated natural gas engine for regional haul truck / tractor, vocational and
refuse applications. The new ISX12 G is currently in field trials with full production expected to
commence in early 2013.
CEC Award- Advanced Heavy-Duty Vehicle Technologies Pre-Commercial Demonstrations

$4.33 million award on Feb. 10, 2012
- $2.7 million Navistar Natural Gas MaxxForce 13-liter
- $1.63 million US Hybrid Plug-in LNG Hybrid Truck

Navistar demo - 12 Class 8 Tractors for goods movement
- Dual Fuel compression ignition, 430HP 1550 lb-ft torque
- Partners: Clean Air Power & Navistar

US Hybrid demo – Cargo from ports
- 3 On-road Drayage Trucks
- CWI 8.9 ISLG + 320kW motor drive + 100kW Li-ion battery pack
- Partners: US Hybrid, Freightliner, UC Riverside, Calko Transport
Compressed Gas Vehicle Fuel Dispensers

> Dispenser design

> Dispenser performance
  – Addresses critical issue of achieving full fill in CNG vehicles
  > Using GTI-patented AccuFill® technology
  > Several current and new licensees
    – Including designs for vehicles with very large storage

> Safety and certification
  – Weights and measure
  – Compliance with industry standards
Small-Scale Liquefaction

World’s largest landfill gas to LNG facility
Linde-Waste Management Altamont Landfill
in California (13,000 LNG gallons per day)

Remote gas recovery and use for
LNG vehicles (Tasmania, Australia)

> GTI-licensed small-scale liquefaction technology

> Being deployed by Linde at stranded gas and bio-methane facilities around the world

> Potential application for natural gas E&P operations

> Running vehicles, pumps, compressors, generators using LNG in lieu of diesel
Home Fueling Development

> Coordination with natural gas industry and other stakeholders (UTD, AGA, ANGA)
  – Current work funded by UTD, SoCal Gas

> Assess worldwide options
  – Target Features
    • 0.8-2 scfm (0.4-1 gallon/hour)
    • 120 VAC, <15 amp
    • 40 dBA @ 20 feet; Indoor/outdoor location
    • Over 4000 hour service interval
    • <$2000

> Working with several compressor companies on product development, modeling, assessment, testing…more support needed
Advanced Storage Solutions

> Developing advanced solid-state storage technology
  – Proprietary program with industrial partner
  – Metal-organic framework (MOF) adsorbents
  – White paper submitted to ARPA-E

> Several additional efforts targeting CNG storage
  – Including non-destructive evaluation techniques
New NGV Joint Industry Project (JIP) and Other Initiatives

> Developing range of JIP options for industry
  – Initiatives to move the market

> Including:
  – Align gas utility operations with NGV market needs
  – Novel distributed storage
  – Heavy-duty vehicle storage advancements
  – Home fueling
  – Remote gas recovery and small-scale liquefaction for E&P operations
Summary

> NGV market is an attractive growth opportunity for the natural gas industry
  - Heavy-duty market is the prime growth segment
  - Light-duty vehicles provide complementary long-term growth

> Major opportunity for new regulatory approaches and business models that align gas industry investment and NGV fueling infrastructure

> GTI/Industry has an extensive portfolio of ongoing RD&D efforts to improve vehicles and infrastructure options
  - More technology advances needed to cost effectively meet vehicle technology and infrastructure challenges