Natural Gas as a Vehicle Transportation Fuel: Illustrative Analysis on Light-Duty CNG Vehicles

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http://web.mit.edu/mitei/
Context for Work

• Research part of MIT’s Future of Natural Gas Study
  – Study examines key factors in NG supply/demand in a carbon constrained world
  – Recent development of large unconventional NG resource in US

• NG as a Transportation Fuel
  – Currently area of small demand
    • 0.15% of all US Natural Gas Use
  – Area of Significant Interest for Expanded Use
    • 2 bills in US Congress to increase NG in transportation

This Presentation

• Illustrative analysis focused on the impact of CNG vehicle cost on market penetration in the light-duty sector

• Simplified analysis that does not take into account fueling infrastructure
The Potential Markets

Direct Use of Natural Gas in Transportation
1. Light Duty Compressed Natural Gas (CNG) Vehicles
2. Heavy Duty CNG Vehicles
3. Heavy Duty Liquefied Natural Gas (LNG) Vehicles

Indirect Use of Natural Gas in Transportation
4. Diesel and Alcohol Based Fuel, Electricity, and Hydrogen

CNG Conversion: C.W. Melchers (Singapore)  
2009 VW Passat TSI Eco-Fuel (Sweden)
CNG as a Transportation Fuel

- CNG is Predominantly Methane (CH$_4$) (80-99%) - Remainder inert gases

- Stored on Vehicles in a Steel or Carbon Fiber Tank at 200atm (~2,900 PSI) (139 kilo-pascals)

- CNG has ¼ the energy density of gasoline

- CNG has a lower proportion of C to H (4:1) than gasoline (2.3:1)
  - Combustion of CNG produces about 25% less CO$_2$ for same energy

- CNG is more knock resistant than gasoline allowing engines to operate at a higher compression ratio
  - could improve the efficiency and horsepower of natural gas engines

Image Source: Greencarcongress.com
• There are \(\sim10\) million NGV in the World
• NGV are \(\sim1\)% of the \(\sim860\) million on-road vehicles in the World
The Effect of Payback Period

The Effect of Payback Period

Insignificant Market Penetration in the US

Included for Reference

SURGE IN NATURAL GAS HAS UTAH DRIVING CHEAPLY

By CLIFFORD KRAUSS
Published: August 29, 2008

SALT LAKE CITY — The best deal on fuel in the country right now might be here in Utah, where people are waiting in lines to pay the equivalent of 87 cents a gallon. Demand is so strong at rush hour that fuel runs low, and some days people can pump only half a tank.

It is not gasoline they are buying for their cars, but natural gas.

By an odd confluence of public policy and private initiative, Utah has become the first state in the country to experience broad consumer interest in the idea of running cars on clean natural gas.

Residents of the state are hunting the Internet and traveling the country to pick up used natural gas cars at auctions. They are spending thousands of dollars to transform their trucks and sport utility vehicles to run on compressed gas. Some fueling stations that sell it to the public are so busy they frequently run low on pressure, forcing drivers to return before dawn when demand is down.

It all began when unleaded gasoline rose above $3.25 a gallon last year, and has spiraled into a frenzy in the last
Overall Average Fuel Price in the US on an Energy Equivalent Basis (Source: DOE EIA)

Financial Saving from Using Natural Gas (12K miles/year) (25miles/gallon)

- Over entire time period analyzed (3.6 years): ~$1350 or ~$370/year
- From April 2008 to October 2008 (.5 years): ~360 or ~$715/year
### Two US Vehicle Options: Civic GX or Certified Conversion

<table>
<thead>
<tr>
<th></th>
<th>2009 Honda Civic GX NGV</th>
<th>2009 Honda Civic Sedan</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Engine Displacement</strong> (cc)</td>
<td>1799</td>
<td>1799</td>
</tr>
<tr>
<td><strong>Horsepower @ 6300 rpm</strong></td>
<td>113</td>
<td>140</td>
</tr>
<tr>
<td><strong>Torque (lb-ft @4300 rpm)</strong></td>
<td>109</td>
<td>128</td>
</tr>
<tr>
<td><strong>Compression Ratio</strong></td>
<td>12.5:1</td>
<td>10.5:1</td>
</tr>
<tr>
<td><strong>Cargo Volume (ft3)</strong></td>
<td>6</td>
<td>12</td>
</tr>
<tr>
<td>Fuel (gallon)</td>
<td>8 GGE @ 3600 PSI</td>
<td>13.2</td>
</tr>
<tr>
<td><strong>Fuel Economy</strong> (City/Highway/Combined)</td>
<td>24/36/28</td>
<td>25/36/29</td>
</tr>
<tr>
<td><strong>Vehicle Range</strong></td>
<td>224</td>
<td>382.8</td>
</tr>
</tbody>
</table>

**Honda GX: ~$7,000 > Civic LX**

Dedicated NGV = Only runs on NGV

**EPA or CARB Certified Conversions (~$10K >Original Vehicle)**

E.g. Ford Focus = $16,000 and Ford Focus Converted to NGV $26,000

US Requires that all Conversion Kits are Certified

- Based on the Clean Air Act's prohibition against tampering with motor vehicle emission
- Certifications are vehicle model and engine type specific (2009 Ford Focus)
- Certification is expensive >$200,000 - cost is amortized over small volume of conversions

Compare to $2,500 Conversion Cost from German Company Operating in Singapore
European Bi-Fuel Vehicle Options

<table>
<thead>
<tr>
<th></th>
<th>VW Passat</th>
<th>TSI EcoFuel</th>
<th>TSI 160</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engine Displacement (cc)</td>
<td>1390</td>
<td>1798</td>
<td></td>
</tr>
<tr>
<td>Horsepower</td>
<td>150 at 5,550 rpm</td>
<td>160 at 5,000 rpm</td>
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</tr>
<tr>
<td>Torque (lb-ft @4300 rpm)</td>
<td>162 at 1500-4500</td>
<td>184 at 1500</td>
<td></td>
</tr>
<tr>
<td>Acceleration (0-62 m/hr)</td>
<td>9.8</td>
<td>9.9</td>
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</tr>
<tr>
<td>Top Speed m/hr</td>
<td>132</td>
<td>137</td>
<td></td>
</tr>
<tr>
<td>Cargo Volume (ft³)</td>
<td>17</td>
<td>17</td>
<td></td>
</tr>
<tr>
<td>Range (Total/NG/ Petrol) m</td>
<td>572/292/280</td>
<td>577/NA/577</td>
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<tr>
<td>CO₂ emissions (g/km)</td>
<td>119</td>
<td>172</td>
<td></td>
</tr>
</tbody>
</table>

Passat TSI EcoFuel: ~$3,600 Bi-Fuel (CNG and Gasoline)
- Named the Most Environmental Friendly Car in Europe (ADAC)
- The second place went to the Toyota Prius
- [www.jazzcalculator.com](http://www.jazzcalculator.com) (Marketing) - 20g CO₂/km (Biomethane)

FIAT Punto and Panda: ~$2,500 Bi-Fuel (CNG and Gasoline)

![FIAT Punto and Panda](image)
Effect of Additional Capital for NGV and Fuel Price Spread on Payback Period
Miles/yr: 12,000  Miles/gallon: 25  Discount Rate: 5%

Payback Period (Years)

Additional Capital for NGV ($)
Focus on Market Segments

<table>
<thead>
<tr>
<th>Fuel Price Spread</th>
<th>Incremental Cost</th>
<th>12,000 miles per year</th>
<th>35,000 miles per year</th>
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<tbody>
<tr>
<td>$0.50</td>
<td>$3,000</td>
<td>$19.5</td>
<td>$4.9</td>
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<td></td>
<td>$7,000</td>
<td>&gt;100</td>
<td>13.9</td>
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<td>4.7</td>
<td>1.6</td>
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<tr>
<td>$2.50</td>
<td></td>
<td>2.7</td>
<td>0.9</td>
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<tr>
<td></td>
<td></td>
<td>7</td>
<td>2.2</td>
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</table>

Conclusions from Illustrative Analysis

• High Incremental Cost in the US is a Market Barrier to CNG Vehicle Market Penetration

• Reducing this market barrier may facilitate market penetration and reduce need for public subsidy

• There are niche markets were CNG vehicles make economic sense