Compressed Natural Gas On-Board Storage

ARPA-E NATURAL GAS VEHICLE TECHNOLOGIES WORKSHOP

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Chief Technology Officer, Quantum Technologies Inc.

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Houston, TX

NASDAQ: QTWW
Compressed Natural Gas Storage
Compressed Gas Storage

Industrial

Fire Extinguishers

Life Support (SCBA)

Automotive

Pressure Range
230-10,000 psi

SCBA

Aircraft

Paintball Guns
(5,000 psi)
<table>
<thead>
<tr>
<th>Country</th>
<th>Natural Gas Vehicles (a)</th>
<th>N/m³ monthly sales average</th>
<th>Refuelling stations</th>
<th>Tank Technologies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iran</td>
<td>2,859,386</td>
<td>467,000,000</td>
<td>1,800</td>
<td>Type I</td>
</tr>
<tr>
<td>Pakistan</td>
<td>2,850,500</td>
<td></td>
<td>3,300</td>
<td>Type I</td>
</tr>
<tr>
<td>Argentina</td>
<td>2,044,131</td>
<td>240,225,000</td>
<td>1,902</td>
<td>Type I, III</td>
</tr>
<tr>
<td>Brazil</td>
<td>1,702,790</td>
<td>165,210,000</td>
<td>1,792</td>
<td>Type I</td>
</tr>
<tr>
<td>India</td>
<td>1,100,000</td>
<td></td>
<td>683</td>
<td>Type I</td>
</tr>
<tr>
<td>Italy</td>
<td>761,340</td>
<td>62,030,000</td>
<td>858</td>
<td>Type I, II, III</td>
</tr>
<tr>
<td>China</td>
<td>600,000</td>
<td>2,500</td>
<td></td>
<td>Type I, III, IV</td>
</tr>
<tr>
<td>Colombia</td>
<td>348,747</td>
<td>45,000,000</td>
<td>651</td>
<td>Type I</td>
</tr>
<tr>
<td>Uzbekistan</td>
<td>310,000</td>
<td></td>
<td>175</td>
<td>Type I</td>
</tr>
<tr>
<td>Thailand</td>
<td>267,735</td>
<td></td>
<td>444</td>
<td>Type I</td>
</tr>
<tr>
<td>Armenia</td>
<td>244,000</td>
<td>26,520,000</td>
<td>345</td>
<td>Type I</td>
</tr>
<tr>
<td>Ukraine</td>
<td>200,019</td>
<td>83,000,000</td>
<td>294</td>
<td>Type I</td>
</tr>
<tr>
<td>Bangladesh</td>
<td>200,000</td>
<td>59,470,000</td>
<td>600</td>
<td>Type I</td>
</tr>
<tr>
<td>Egypt</td>
<td>162,000</td>
<td>38,000,000</td>
<td>143</td>
<td>Type I</td>
</tr>
<tr>
<td>Bolivia</td>
<td>140,400</td>
<td>26,278,135</td>
<td>156</td>
<td>Type I</td>
</tr>
<tr>
<td>Peru</td>
<td>122,221</td>
<td>16,301,370</td>
<td>170</td>
<td>Type I</td>
</tr>
<tr>
<td>United States</td>
<td><strong>112,000</strong></td>
<td><strong>105,000,000</strong></td>
<td><strong>1,100</strong></td>
<td>Type I, III, IV</td>
</tr>
<tr>
<td>Russia</td>
<td>100,053</td>
<td>28,750,000</td>
<td>250</td>
<td>Type I</td>
</tr>
<tr>
<td>Germany</td>
<td>94,890</td>
<td>14,600,000</td>
<td>900</td>
<td>Type I, II, III, IV</td>
</tr>
<tr>
<td>Venezuela</td>
<td>90,000</td>
<td>8,152,054</td>
<td>166</td>
<td>Type I</td>
</tr>
</tbody>
</table>
Market focus on return to base, high fuel use fleet vehicles (highest fuel consumption/vehicle in the world):

- Transit Buses
- Refuse Trucks
- Regional Trucks
- Airport Shuttles
- Taxis
- Government Fleets
• Receive fuel, store without loss and release on demand

• Fitness for purpose considerations:
  • Safety
  • Cost
  • Weight
  • Volume

Refueling
• Allow up to 25% over-pressurization to account for gas temperature rise during fast-refueling
• Accommodate temperature spikes
• 3,000 or 3,600 psi service pressure
Storage Requirements

Inside-Out: Corrosion, Fast-fill temperature, Repeated fills and discharges, Permeation, Leakage

Shocks, vibrations, abrasions, cuts, gouges, pre-installation drop

Outside-In: UV, moisture, salts, acids, bases, cleaning agents, high and low ambient temperatures (-40 to 185° F)

Crash impact, gunfire, bonfire
### Standard
- ISO 11439 - **International**
- NGV2 - **US/Japan/Mexico**
- FMVSS 304 - **United States**
- NFPA 52 - **United States**
- KHK - **Japan**
- CSA B51 - **Canada**
- TÜV - **Germany**

### Validation Tests
- Hydrostatic Burst
- Extreme Temperature Cycle
- Ambient Cycle
- Acid Environment
- Bonfire
- Gunfire Penetration
- Flaw Tolerance
- Accelerated Stress
- Drop Test
- Permeation
- Natural Gas Cycle
- Softening Temperature
- Tensile Properties
- Resin Shear
- Boss End Material
Validation Testing

Burst Testing

Gas Cycling

Environmental Testing

Gunfire Testing

Bonfire Testing
• **Type I** steel tanks are the most common (>90% worldwide)
  • Heritage: Industrial gas storage tanks
  • Economies of scale in small diameters

• Hoop-wrapped & full-wrapped tanks (**Type II** & **Type III**) have load-sharing between metal and composite
  • Composite materials provide weight reduction

• All-composite tanks (**Type IV**) yield further weight reduction, corrosion resistance & flexibility
## Pressure Vessel Types

<table>
<thead>
<tr>
<th>Tank Type</th>
<th>Weight per Litre*</th>
<th>Weight Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type 1 - CrMo Steel</td>
<td>0.80 kg</td>
<td>-</td>
</tr>
<tr>
<td>Type 1 - Modified CrMo Steel</td>
<td>0.72 kg</td>
<td>-10%</td>
</tr>
<tr>
<td>Type 2 - Steel &amp; Glass Fibre</td>
<td>0.68 kg</td>
<td>-15%</td>
</tr>
<tr>
<td>Type 2 - Steel &amp; Carbon Fibre</td>
<td>0.52 kg</td>
<td>-35%</td>
</tr>
<tr>
<td>Type 3 - Steel &amp; Carbon Fibre</td>
<td>0.41 kg</td>
<td>-48%</td>
</tr>
<tr>
<td>Type 3 - Aluminum &amp; Carbon Fiber</td>
<td>0.50 kg</td>
<td>-38%</td>
</tr>
<tr>
<td>Type 4 - Polymer &amp; Glass/Carbon Hybrid</td>
<td>0.33 kg</td>
<td>-59%</td>
</tr>
<tr>
<td>Type 4 - Polymer &amp; Carbon Fiber</td>
<td>0.24 kg</td>
<td>-70%</td>
</tr>
</tbody>
</table>

* Based on approximately 140L tank-size
Small Car Example

- Lighter natural gas tank leads to a lighter overall fuel system

<table>
<thead>
<tr>
<th></th>
<th>Type IV Tank</th>
<th>Type I Steel Tank</th>
</tr>
</thead>
<tbody>
<tr>
<td>CNG Tank</td>
<td>32 kg</td>
<td>105 kg.</td>
</tr>
<tr>
<td>Fuel</td>
<td>13 kg.</td>
<td>13 kg.</td>
</tr>
<tr>
<td>Brackets</td>
<td>5 kg.</td>
<td>21 kg.</td>
</tr>
<tr>
<td>Spare Tire</td>
<td>N/A</td>
<td>9 kg.</td>
</tr>
<tr>
<td><strong>Total Weight:</strong></td>
<td><strong>50 kg.</strong></td>
<td><strong>148 kg</strong></td>
</tr>
</tbody>
</table>

(<5% of vehicle wt)
Storage System Example

FUEL FILL RECEPTACLE (INCLUDES CHECK VALVE)

HIGH PRESSURE FUEL FILL

Stainless Steel
3/8" OD x .065" wall

TO CONTROLLER

1/4" TURN VALVE

DEFueling RECEPTACLE

FILL RECEPTACLE PROTECTIVE CAP

EXCES S FLOW VALVE

1/4" TURN VALVE W/ DETENT

1/4" TURN VALVE

COALESCING FILTER

TURBINE FLOW METER

TURBINE FLOW METER

AMPLIFIER / TRANSMITTER

PRESSURE RELIEF
PRD VENT TO ATMOSPHERE

PRESSURE RELIEF

PS MANIFOLD

2ND STAGE REGULATOR

PRD VENT TO ATMOSPHERE

T REGULATOR

REGULATOR BODY

THERMAL RELIEF DEVICE

PS MANUAL LOCK-OFF

MANUAL LOCK-OFF

SOLENOID

LOCK-OFF

INLET PORT

OUTLET PORT
### Storage System Example

<table>
<thead>
<tr>
<th></th>
<th>Type IV Tank</th>
<th>Type I Steel Tank</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CNG Tank</strong></td>
<td>200 kg</td>
<td>750 kg.</td>
</tr>
<tr>
<td><strong>Fuel</strong></td>
<td>185 kg.</td>
<td>185 kg.</td>
</tr>
<tr>
<td><strong>Brackets</strong></td>
<td>50 kg.</td>
<td>100 kg.</td>
</tr>
<tr>
<td><strong>Reinforcement</strong></td>
<td>N/A</td>
<td>75 kg.</td>
</tr>
<tr>
<td><strong>Total Weight:</strong></td>
<td>435 kg</td>
<td>1110 kg</td>
</tr>
</tbody>
</table>

Lighter tanks lead to:
- Increased payload capacity
- Reduced wear and tear
- Improved fuel efficiency
- Better vehicle handling
Type IV Tank Example

- Polar Boss (interface seal)
- Foam Dome (impact protection)
- Carbon Composite Shell (structural)
- Protection Layer (damage resistant)
- High Molecular Weight Polymer Liner (gas barrier)
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