Hydrogen Storage System Challenges

Advanced Composite Materials for Cold and Cryogenic Hydrogen Storage Applications in Fuel Cell Electric Vehicles

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Mike Veenstra

Ford Research & Advanced Engineering
Production fuel cell vehicles are being produced or planned by every major automotive OEM.
Why are we interested?

**Key Importance Factors:**

**Energy Security:** Alternative fuels offer renewable and domestic sources that reduce our offshore energy demands.

**Environment:** Alternative fuels can reduce the greenhouse gases, local air quality, and other smog-causing pollutants.

**Cost of Ownership:** Alternative fuels offer the opportunity for the use of low cost fuels and/or high efficient powertrains.

**Environment:** Zero emission vehicles offer the ultimate choice for reducing CO₂/mile and local air pollution on the road.

**Regulatory:** California Air Resources Board ZEV program requires OEMs to have ZEV credits to allow for vehicle sales in CA.

**Driving Range:** Fuel cell vehicles provide driving range 2 to 3x greater than typical BEVs and near conventional gasoline vehicles.

**Fueling Time:** Fuel cell vehicles provide fueling times in 3 to 5 minutes similar to conventional gasoline vehicles rather than hours for BEVs.
Customer Expectations

- Driving Range
- Refueling Time
- Cargo Space
- Vehicle Weight
- Durability
- Cost
- Safety

Sales (in millions of units)

Range (miles)

- Fuel Cell System
- Hydrogen Tank

Cost

- Low Volume (10k/yr)
- High Volume (500k/yr)

$0
$5,000
$10,000

(credit: SA / ANL)
Energy Density

- Natural Gas (250 bar)
- Hydrogen (700 bar)
- Gasoline

Fuel Economy

- Natural Gas Vehicle
- Hydrogen Fuel Cell Vehicle
- Gasoline Engine

Fuel System Package Space for 300 miles

- Natural Gas Vehicle
- Hydrogen Fuel Cell Vehicle
- Conventional Gasoline Vehicle
## Technical System Targets: Onboard Hydrogen Storage for Light-Duty Fuel Cell Vehicles

### Storage Parameter

<table>
<thead>
<tr>
<th>Storage Parameter</th>
<th>Units</th>
<th>2020</th>
<th>Ultimate</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>System Gravimetric Capacity:</strong></td>
<td>kWh/kg</td>
<td>1.8</td>
<td>2.5</td>
</tr>
<tr>
<td>Usable, specific-energy from H(_2) (net useful energy/max system mass)(^b)</td>
<td>(kg H(_2)/kg system)</td>
<td>(0.055)</td>
<td>(0.075)</td>
</tr>
<tr>
<td><strong>System Volumetric Capacity:</strong></td>
<td>kWh/L</td>
<td>1.3</td>
<td>2.3</td>
</tr>
<tr>
<td>Usable energy density from H(_2) (net useful energy/max system volume)(^b)</td>
<td>(kg H(_2)/L system)</td>
<td>(0.040)</td>
<td>(0.070)</td>
</tr>
<tr>
<td><strong>Storage System Cost:</strong></td>
<td>$/kWh net</td>
<td>10</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>($/kg H(_2))</td>
<td>400</td>
<td>266</td>
</tr>
<tr>
<td></td>
<td>$/gge at pump</td>
<td>2-4</td>
<td>2-4</td>
</tr>
</tbody>
</table>

### Durability / Operability:

- Operating ambient temperature \(^d\) °C  
  -40/60 (sun) 
  -40/85

- Min/max delivery temperature °C  
  -40/85

- Operational cycle life (1/4 tank to full) Cycles  
  1500

- Min delivery pressure from storage system bar (abs)  
  5

- Max delivery pressure from storage system bar (abs)  
  12

- Onboard Efficiency \(^e\) %  
  90

- “Well” to Powerplant Efficiency \(^e\) %  
  60

### Charging / Discharging Rates:

- System fill time (5 kg) min  
  3.3

- Minimum full flow rate (kg H\(_2\)/min)  
  0.02

- Start time to full flow (20°C) s  
  5

- Start time to full flow (-20°C) s  
  15

- Transient response at operating temperature 10%–90% and 90%–0% s  
  0.75

### Fuel Quality (H\(_2\) from storage)\(^f\):

- % H\(_2\)  
  SAE J2719 and ISO/PDTS 14687-2 (99.97% dry basis)

### Environmental Health & Safety:

- Permeation & leakage
  - Meets or exceeds applicable standards

- Toxicity
  - 

- Safety
  - 

### Loss of useable H\(_2\)\(^h\)

- (g/h)/kg H\(_2\) stored  
  0.05

Material-based hydrogen storage systems have higher potential to meet the DOE targets but have increased complexity over physical-based storage options.
700 bar compressed tanks can meet the DOE targets except: cost, volumetric capacity, and weight.

**Options**

- **Material Selection**
  - Reduce material cost
  - Increase performance

- **Tank Design and Manufacturing**
  - Better material use
  - Improve efficiency

- **Operating Conditions**
  - Reduce pressure
  - Increase density
Reduction in wall thickness with pressure

Source: 2014 DOE AMR ST001 ANL

- Type-4 Tank
  - Ambient $H_2$
  - Cold $H_2$
- Type-3 Tank
  - Cold $H_2$
Thermal insulation needs to maintain 5-7 W maximum heat leakage performance over 15 years with minimal additional weight, volume and cost to the storage system.

➢ Degradation of insulation results in lose of fuel and inconsistent fueling.
Great Products
Strong Business
Better World

THANK YOU