General Motors Perspective

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Center Europe

Compressed & Cryo-
Compressed Hydrogen
Storage Workshop
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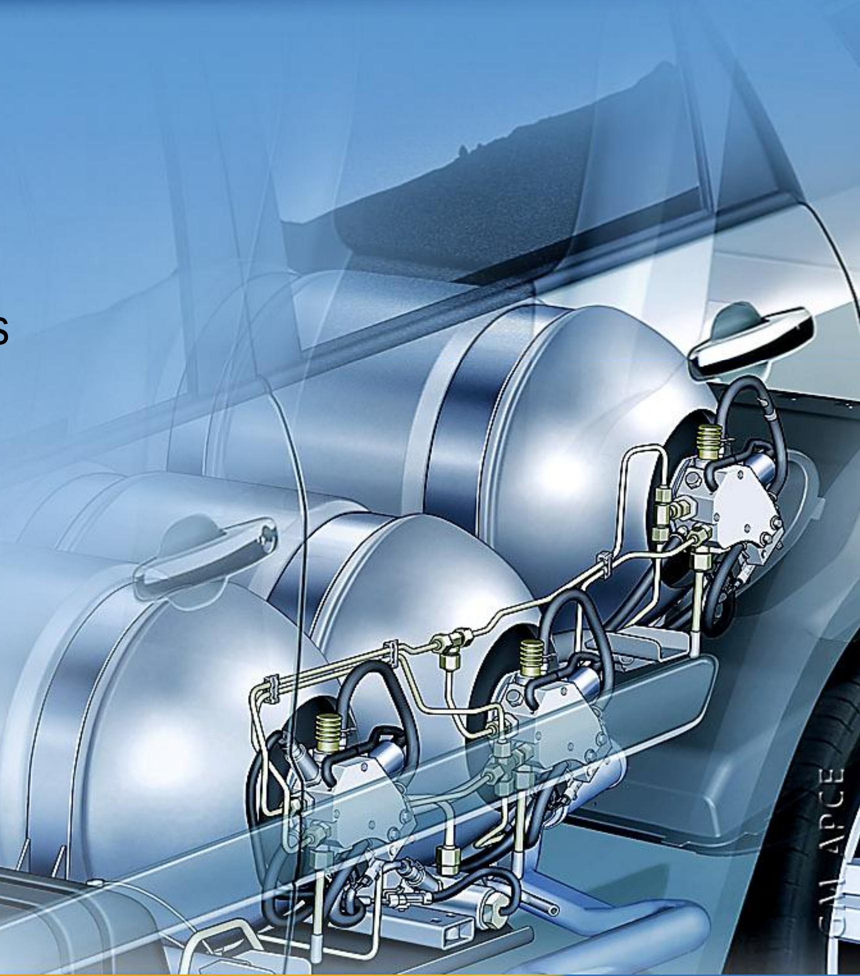
Washington DC

GM APCE

Chevrolet Equinox as Part of GM's Global "Project Driveway"

- Power: 73 kW
- Acceleration (0-100 km/h): 12 s
- Top speed: 160 km/h
- Fuel: 4.2 kg Compressed Hydrogen Gas (70 MPa) in three Type 4 filament wound carbon fiber composite vessels
- Range: 320 km
- Over 2.5 million km (1.5 million miles)
- More than 19,000 fuelings



Key Challenges for Commercialization

Technical challenges

- System reliability / durability
- Fuel cell system cost

Market challenges

- Public confidence on system robustness and benefits of hydrogen and fuel cells
- Codes and standards
- Coordinated hydrogen infrastructure build-up

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Needs enduring joint effort of automakers and energy suppliers as well as strong governmental support

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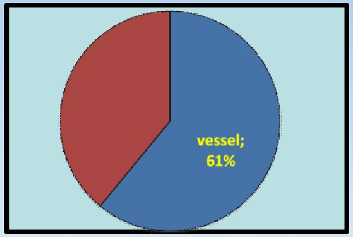
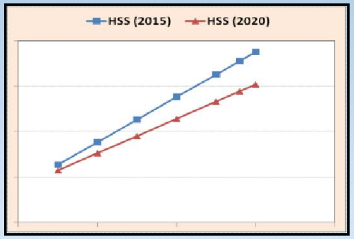
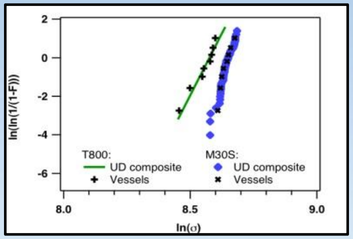
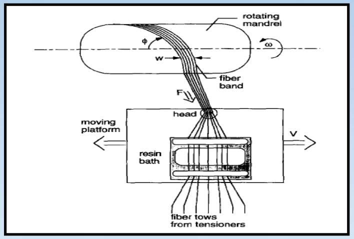
Hydrogen Storage System Costs I

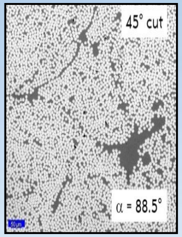
- Tank cost sources: Carbon fiber 40%, other 60%
- Hydrogen storage system costs are linear in Hydrogen capacity
  - GM's 2015 estimates comparable to ANL/TiAX study (2010)
  - 15-20% reduction estimated for 2020
- Biggest impact by carbon fiber translation efficiency

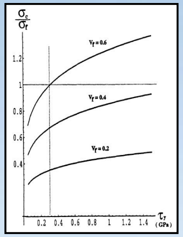






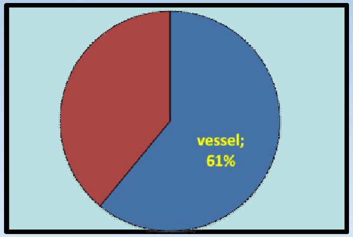


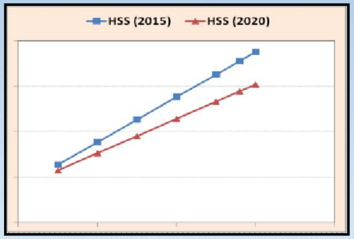


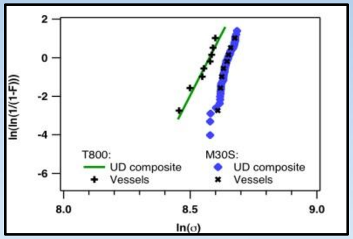


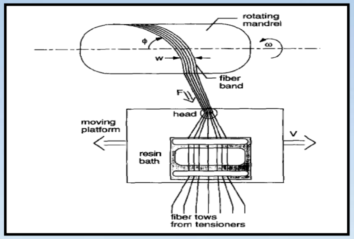
Hydrogen Storage System Costs II

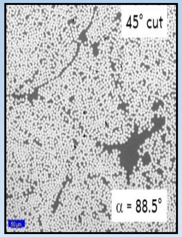
- Potential measures to increase effective composite strength:
  - Materials: fiber strength variability, translation efficiency
  - Design: winding pattern, liner contour, boss integration (Type 4 only)
  - Manufacturing: winding tension, fiber damage during winding, resin content, layer thickness
- Stress rupture resistance performance per SAE J2579
- System integration: crash worthiness, fire performance, service interval

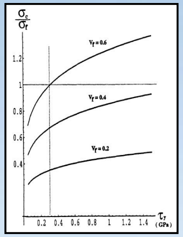






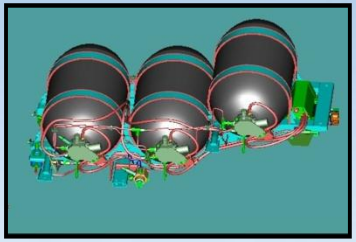






Activities / Recommendation

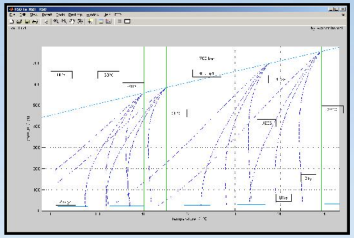
- Next Generation Hydrogen storage system in supplier screening phase
  - Stable supplier base for new technology needed
  - Supplier business case requires OEM volume commitment
- German funded project:
  - Vessel design, filament winding, translation efficiency
  - Completion date: Dec 2011; follow-ups recommended
- Support C&S work: verify test procedures, including
  - Localized/engulfing fire test, stress rupture resistance test (SAE J2579)
  - Hydrogen embrittlement test (SANDIA-led proposals to SAE, CSA, ISO)
- Seal materials for widened temperature performance (<-40 °C / > +85 °C gas temperature)



HESSEN
Hessisches Ministerium für Wirtschaft, Verkehr und Landesentwicklung

CSA STANDARDS

SAE

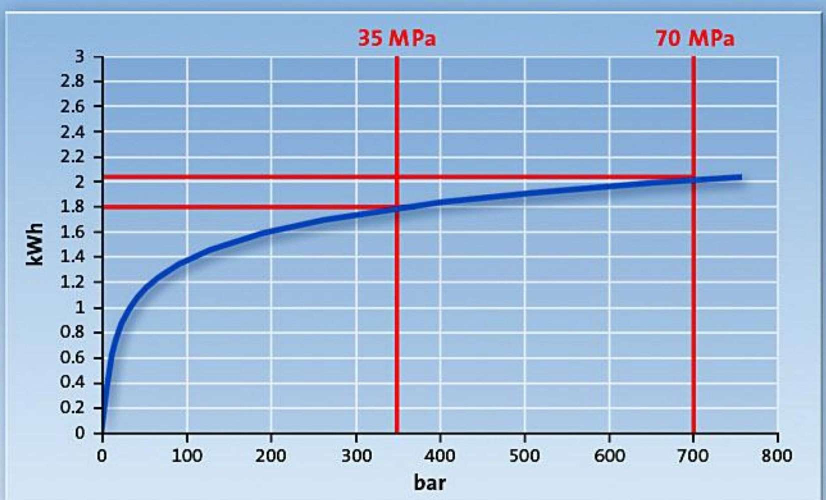


Energy Implications of 700 bar Hydrogen Storage Systems

350 bar
4.0 kg hydrogen
133 kWh

+ 10% compression energy
+ 55% energy content

700 bar
6.2 kg hydrogen
207 kWh



- Most compression energy is expended at lower pressures
- 10% additional compression energy to get from 350 bar to 700 bar …
- … leads to 55% increase in energy content

GM APCE

700 Bar Hydrogen Refueling

Customer friendly refueling:

- One single physical connection
- Infrared communication interface (tank pressure/temperature)
- Fast fill: 3 min. at -40°C pre-cooling

Future stations need to be:

- Fully integrated
- 24/7 accessible and operational
- Designed to fuel per SAE J2601