



Compressed Gas Storage Workshop for Medium and Heavy Duty Transportation

OEM Perspective
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Mike Veenstra



Medium and Heavy Duty Vehicles Serve Many Essential Roles





COMPRESSED NATURAL GAS



BIODIESEL



HYBRID



ALL-ELECTRIC



PROPANE AUTOGAS



ETHANOL



PLUG-IN HYBRID



HYDRAULIC-HYBRID



	Transit Connect Cargo Van/ Passenger Wagon	Transit Cargo Van/ Passenger Wagon	Transit Cutaway/ Chassis Cab	E-350/E-450 Cutaway	E-350/E-450 Stripped Chassis	F-150 Pickup	F-250/F-350/F-450 Super Duty® Pickup	F-350/F-450/F-550 Super Duty Chassis Cab	F-650/F-750 Medium Duty Chassis Cab
Advanced Fuel Type									
Ethanol (E85)	✓*	✓**	✓**	✓	✓	✓	✓	✓	
Biodiesel (B20)	✓	✓	✓	✓	✓	✓	✓	✓	✓
CNG	✓	✓	✓	✓	✓	✓	✓	✓	✓
Propane		✓	✓	✓	✓	✓	✓	✓	✓
Electrification Options									
HEV		✓	✓	✓	✓		✓	✓	
PHEV						✓***	✓		
BEV		✓	✓	✓	✓				
Hydraulic Hybrid				✓	✓			✓ ³	✓
GVWR (lbs.)	Gas 5,110 - 5,420 Diesel 5,060 - 5,450	8,550 - 10,360	9,000 - 10,360	E-350: 10,050 - 12,500 E-450: 14,000 - 14,500	E-350: 11,500 - 12,500 E-450: 14,000 - 14,500	6,070 - 7,850	9,900 - 14,000	9,800 - 19,500	Gas: 22,000 - 33,000 Diesel: 20,500 - 37,000
GCWR (lbs.)	Gas 5,930 - 6,380 Diesel 5,930 - 6,500	10,400 - 13,500	12,000 - 13,500	E-350: 13,000 - 18,500 E-450: 18,000 - 22,000	E-350: 17,000 - 18,500 E-450: 18,000 - 22,000	9,600 - 18,400	19,500 - 43,300	19,500 - 40,000	37,000 - 50,000
Payload (lbs.)††	Gas 1,250 - 1,570 Diesel 1,140 - 1,570	2,610 - 4,640	4,760 - 6,020	E-350: 5,120 - 7,330 E-450: 8,610 - 9,040	E-350: 6,870 - 7,910 E-450: 9,230 - 9,690	1,280 - 3,270	2,260 - 7,640	2,260 - 12,750	11,814 - 26,592

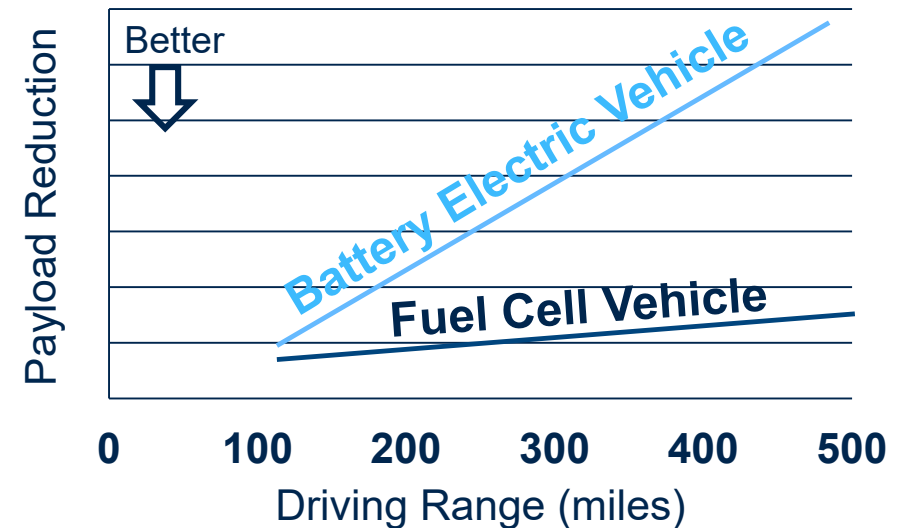
Ford Offers Extensive Alternative Fuel Choices For Customers



Compressed Gas Storage System

- Compressed gas storage influences the key factors of alternative fuel vehicles:
 - Driving Range: is 1.5x to 3x greater than battery electric vehicles and near conventional gasoline vehicles
 - Fueling Time: is in 3 to 5 minutes similar to conventional gasoline vehicles rather than hours for battery electric vehicles
 - Specific Energy: is significantly better than a battery electric vehicle as the driving range and energy increases
 - System Cost: is the highest cost on a CNG vehicle and close 2nd to the fuel cell system on a fuel cell vehicle.

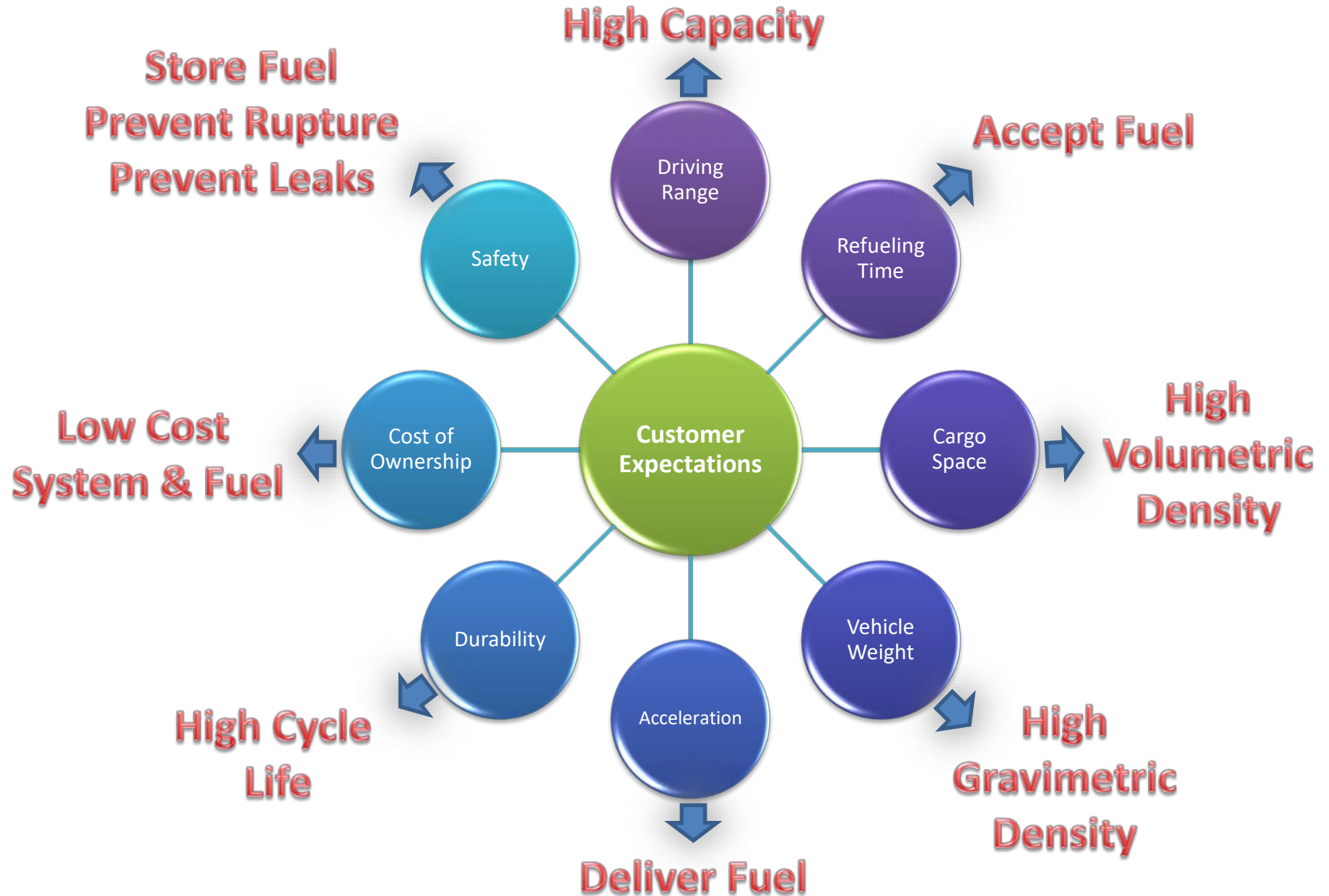
MD/HD Payload Reduction vs. Driving Range



Compressed Gas Storage Is A Key Enabler For Alternative Fuel Vehicles

Compressed Gas Storage - Requirements

Linkage from Customer Expectations to Compressed Gas Storage System High Level Functions



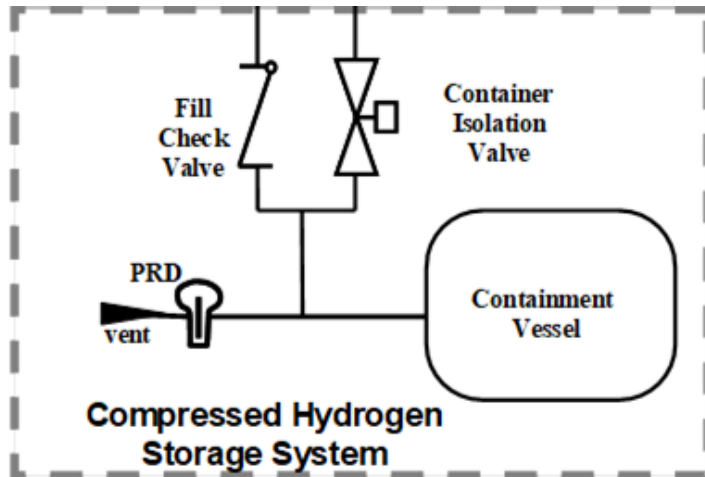
Compressed Gas Storage – Hydrogen Requirements

High Level Function	Light Duty Target	Heavy Duty Target	Medium and Heavy Duty Comments
High Capacity	< 10 kg	>> 10 kg	Minimum goal is 300 miles driving range with additional driving range needed to match conventional powertrains
Accept Fuel	~2 kg H ₂ / min*	8 kg H ₂ / min**	Need significantly higher fill flow rate for heavy duty
High Volumetric Density	> 30 g/l*	> 30 g/l	Larger vehicle platforms still have package challenges
High Gravimetric Density	> 4.5 wt%*	>> 4.5 wt%	Weight is a significant attribute since equates to payload
Deliver Fuel	> 1.6 g/s*	>> 1.6 g/s	Need significantly higher delivery flow rate for heavy duty
High Cycle Life	5,500 cycles	11,000 cycles**	Additional cycles needed for increased MD/HD vehicle life
System Cost	\$333/kg H ₂ stored*	\$300/kg H ₂ stored**	Critical factor for the break-even and total cost of ownership
Fuel Cost	< \$4/gge*	< \$4/gge	Critical factor for the break-even and total cost of ownership
Safety	Established Codes and Standards	Refine Codes and Standards	Additional complexity for multiple tank and higher capacity

*DOE Target Value from 2020 Light-Duty References

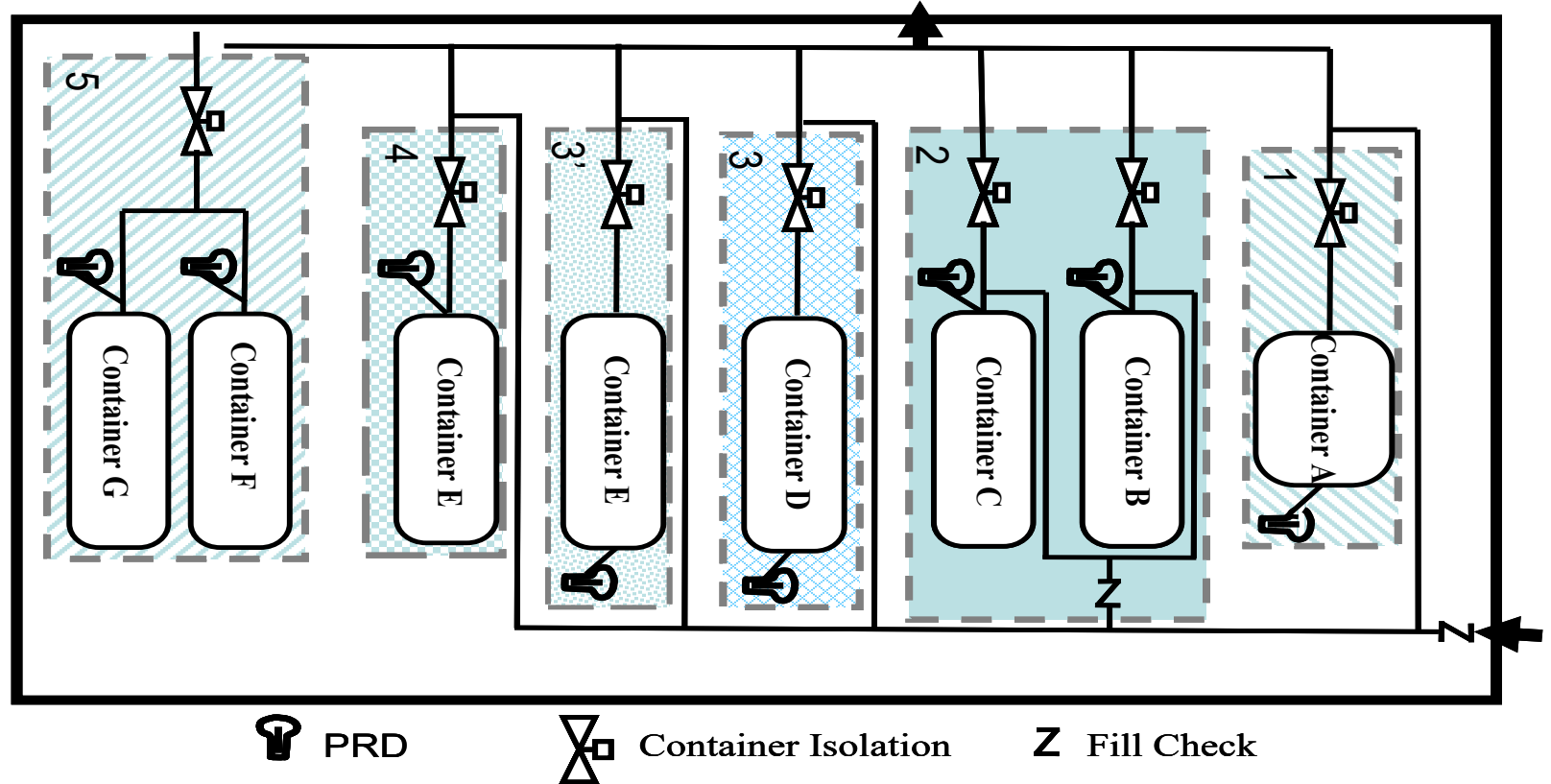
** *DOE Target Value from 2030 Heavy-Duty References

Compressed Gas Storage System



Per SAE J2579, the Compressed Hydrogen Storage System is defined by the interfaces which can isolate stored high pressure hydrogen from the remainder of the fuel system and the environment

Each Compressed Gas Storage System needs to be tested / certified.



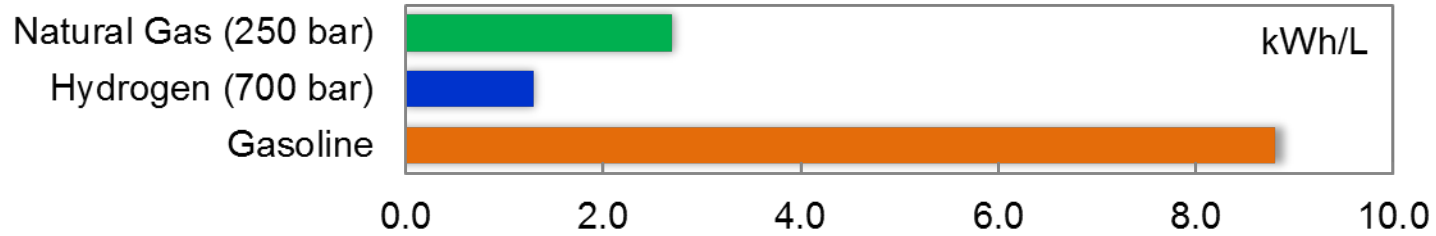
Compressed Gas Storage Systems Can Have Additional Testing Complexity

Compressed Gas Storage System

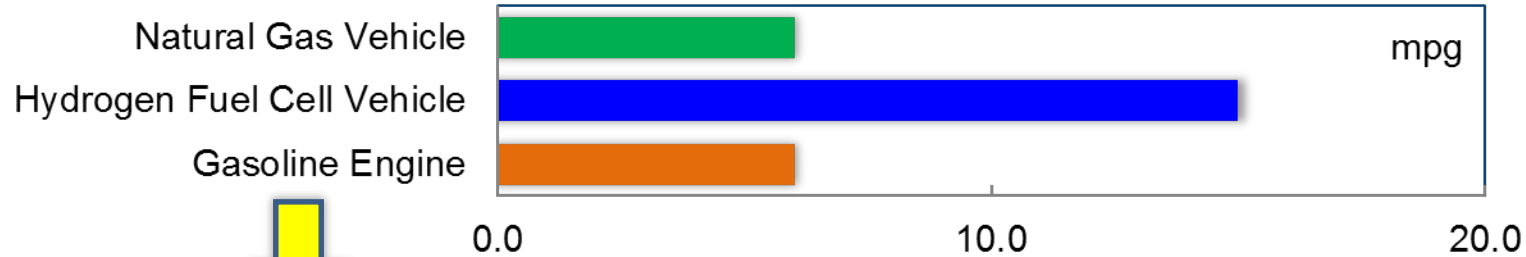
Property	Natural Gas	Hydrogen
Chemical Structure	CH ₄ (83-99%) Methane	H ₂
Physical State	High Pressure Gas Europe: 200 bar (3,000 psi) North America: 250 bar (3,600 psi)	High Pressure Gas 700 bar (10,000 psi)
Feedstock	Underground Reserves	Natural Gas (mainly), opportunity for renewable with water electrolysis
Toxicity	No	No
Energy Content by weight	Same as gasoline	3x better than gasoline
Energy Density by volume	3.5x worst than gasoline	7x worst than gasoline

Compressed Gas Storage System

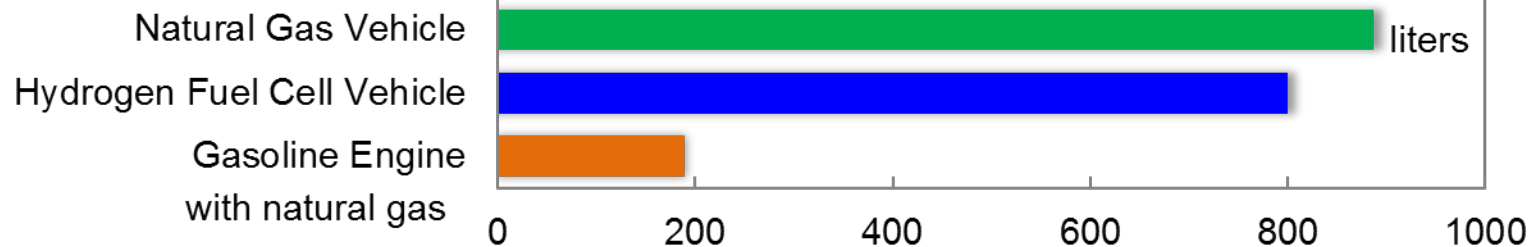
Energy Density



Fuel Economy (MD/HD example)



Fuel System External Package Space for 300 miles



Compressed Gas Storage System – MD/HD Challenges

Storage Capacity

- Need novel solutions to maximum capacity without compromising the customer utility

Infrastructure

- Need fueling protocols and hardware for high capacity, fast, complete, and consistent fueling
- Need public and/or local fueling station deployment with higher capacity and lower fuel cost

Storage System Cost

- Need to reduce the high storage system cost due to the compressed gas tanks and carbon fiber
- Need to reduce carbon fiber cost, increase performance, and optimize material usage and design

Codes and Standards

- Need further refinement to recognize the various system complexities and vehicle applications

Natural Gas And Hydrogen Have Similar Challenges And Opportunities