Insulated Pressure Vessels for Vehicular Hydrogen Storage

Presented by:

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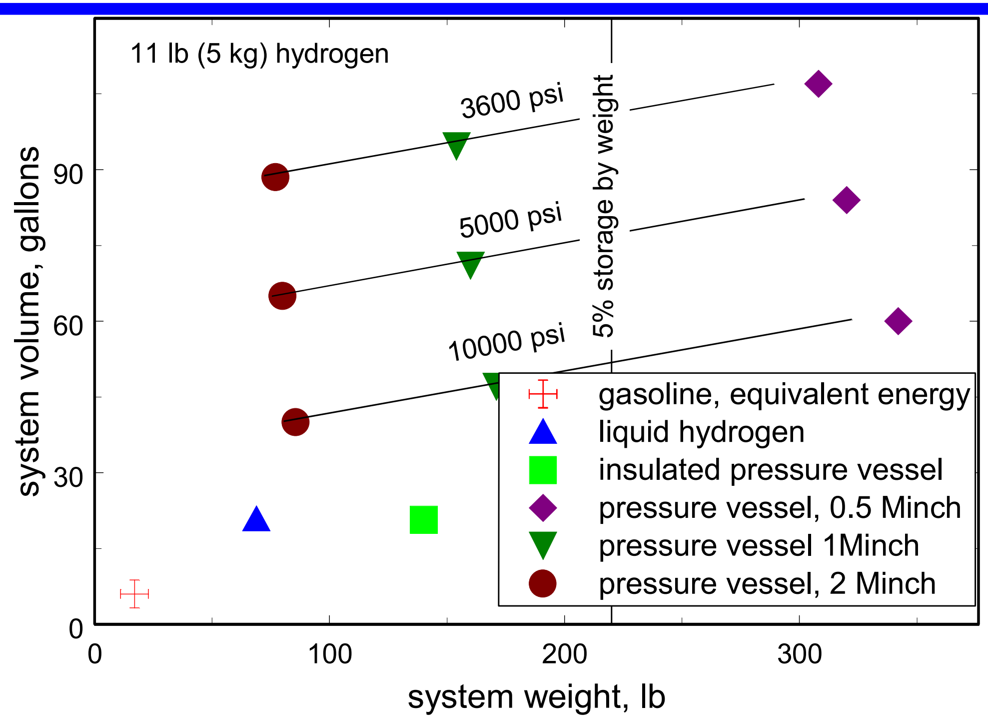
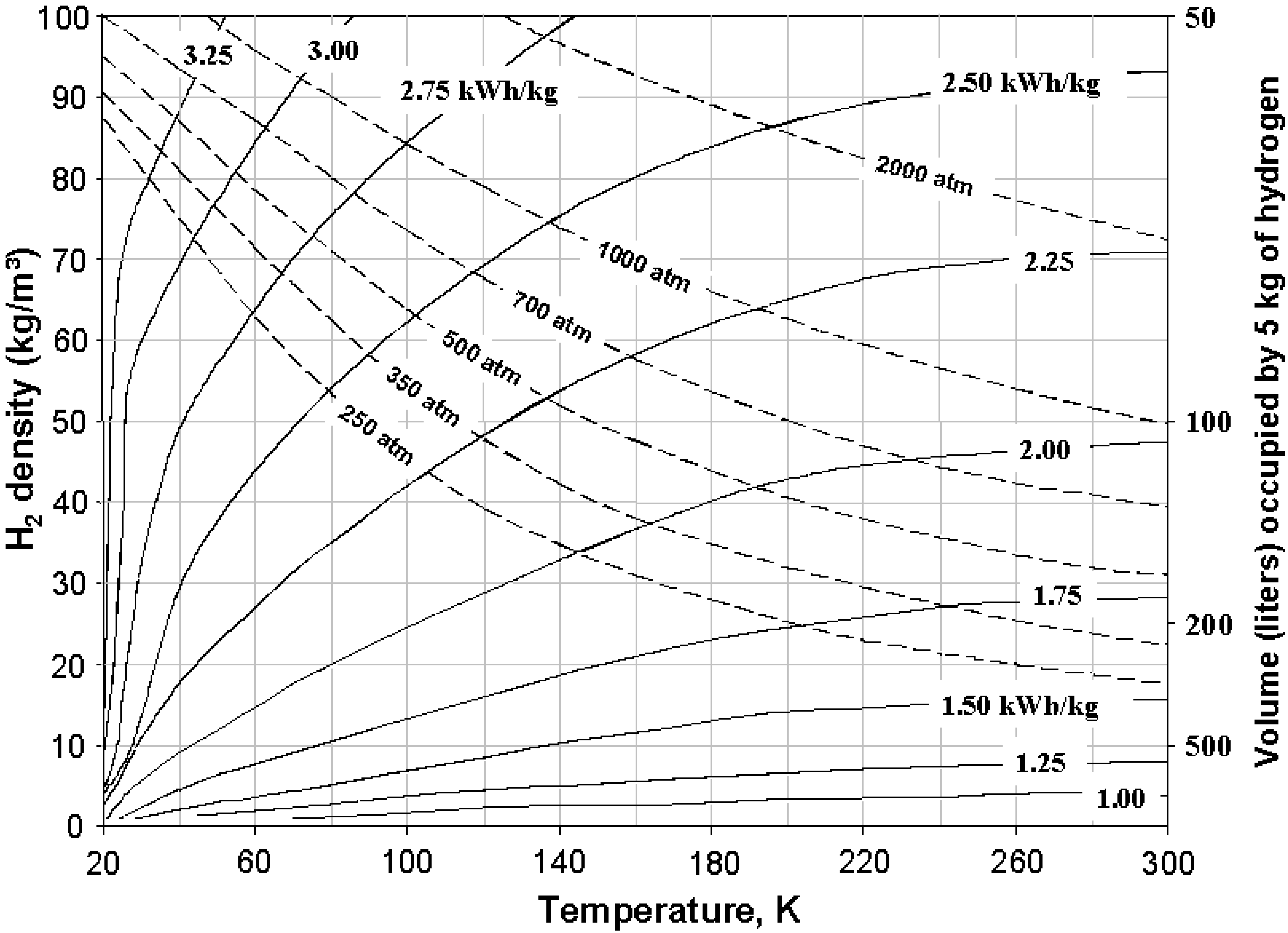
Relevance and Objective: insulated pressure vessels provide low cost, long range and infrastructure flexibility



- **Insulated pressure vessels address the whole range of technical barriers from the Hydrogen Program R&D plan**
- **A. Low cost, due to lower need for fiber. B. Low volume. C. Efficient, due to the dual mode operation. D. Durable, tested over 10000 cycles. E. Short refueling time. F. We are working on codes and standards. G. We have conducted life cycle and efficiency analysis. H. Sufficient fuel storage for long range. J. We are generating tank performance data. K. Testing BOP components. L. Low venting losses.**

Approach: Insulated pressure vessels operate over a very wide range of operating conditions, increasing the infrastructure flexibility and saving energy



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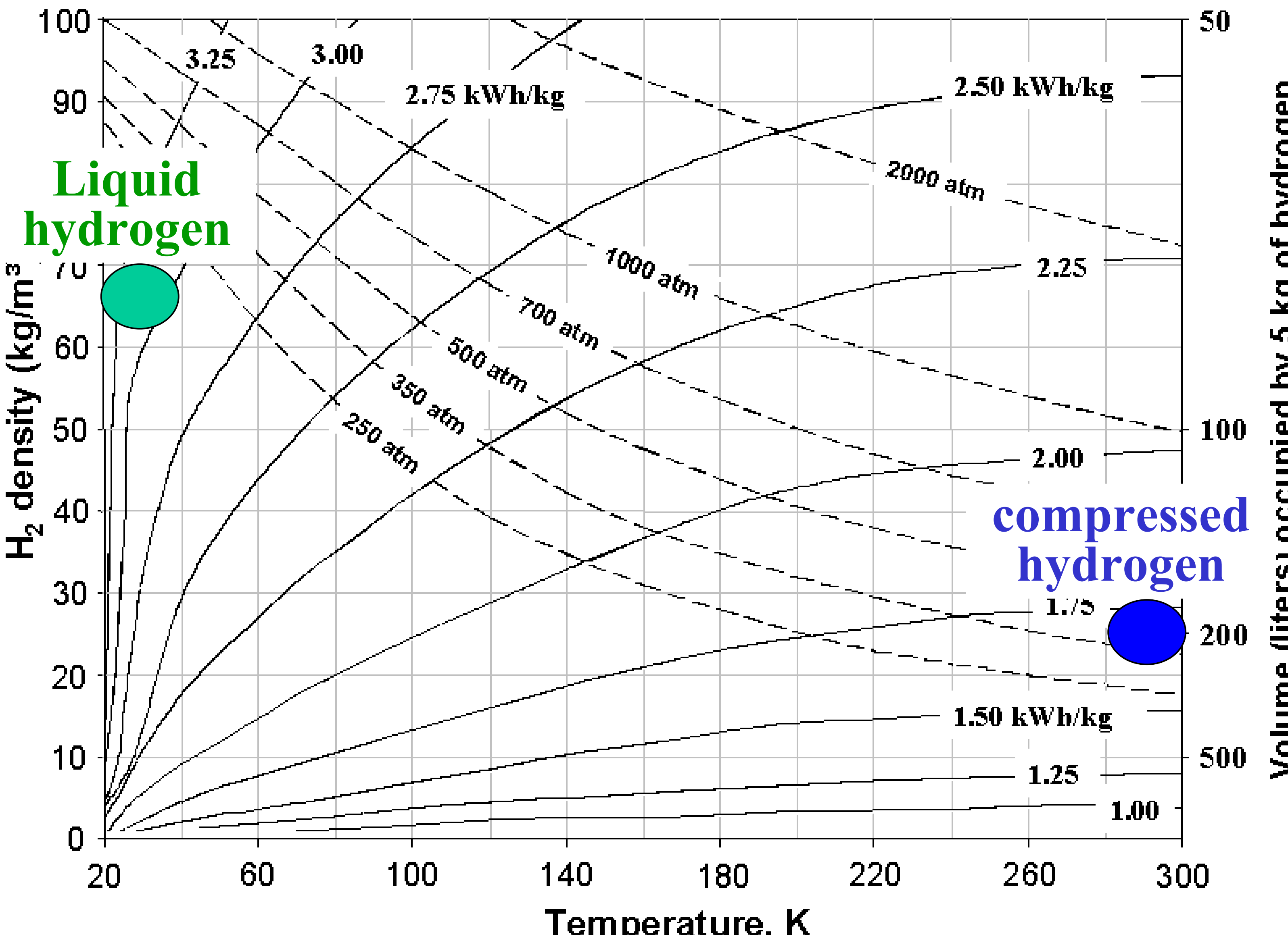

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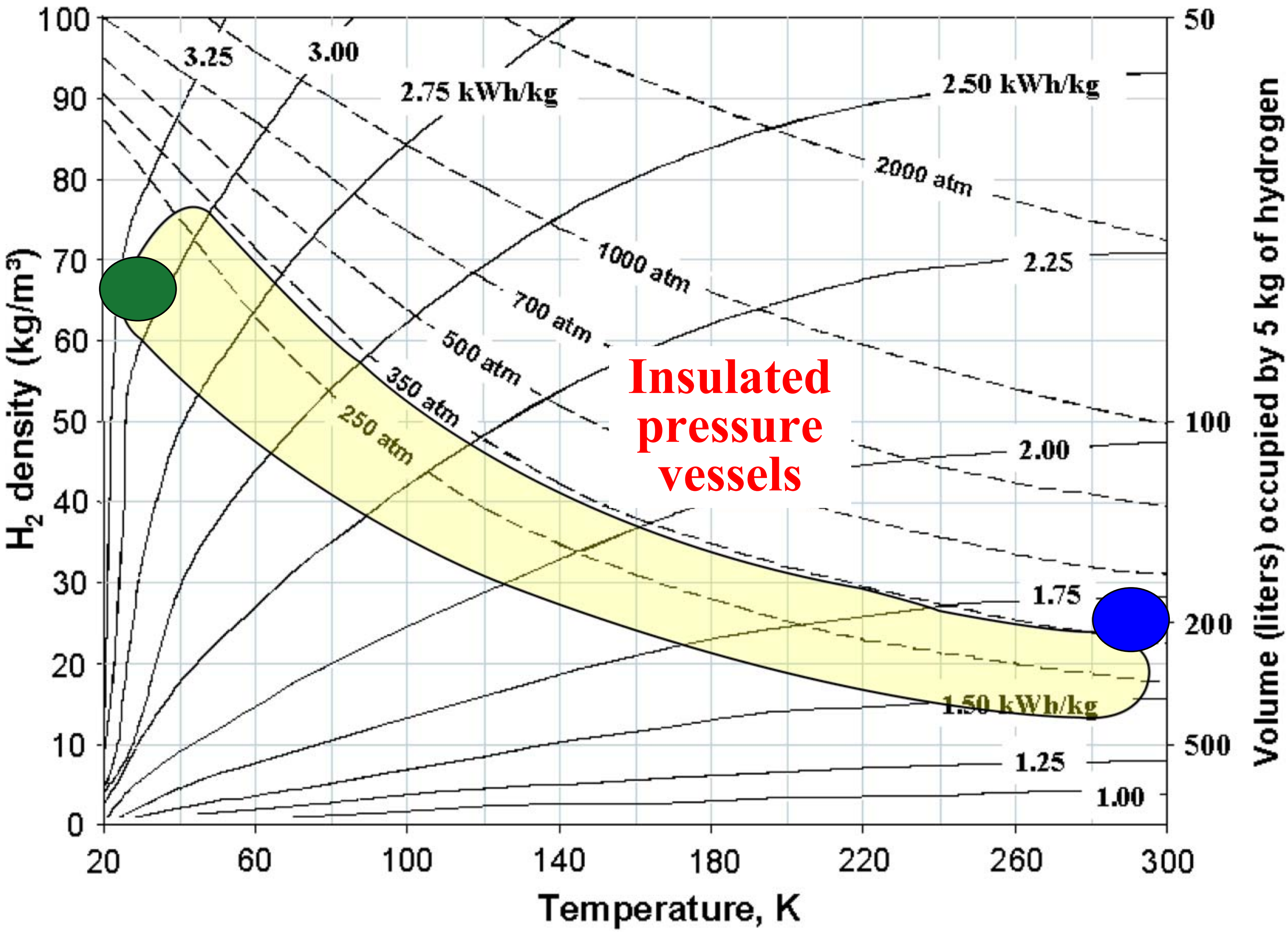
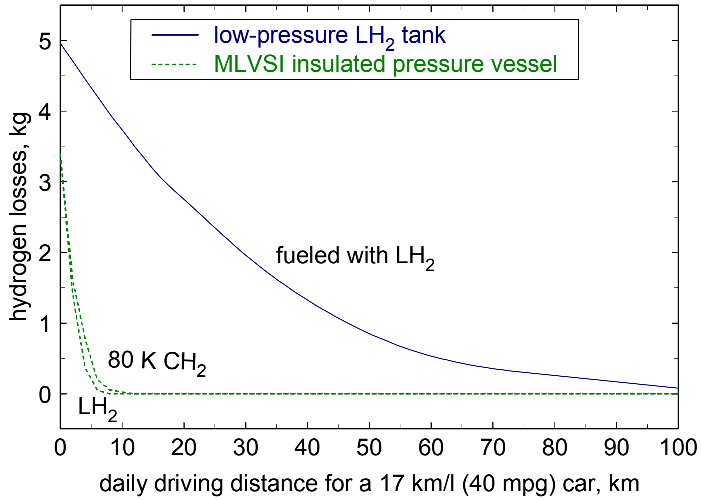


Project timeline: We have carried this project from concept to proof of principle into demonstration



1998: thermodynamic analysis

1999: cryogenic cycling

2001: DOT/ISO Tests

2003: Demonstration

Accomplishments and Progress: We are performing certification tests to demonstrate the safety of this technology

1. **Perform the SAE cryogenic drop and bonfire tests. Tests complete. The insulated pressure vessels successfully passed both tests**
2. **Sign SCAQMD Contract. Task complete. The contract was signed and SCAQMD funding is being received**
3. **Study fueling system of SunLine truck. Task complete. We have generated an overall system for fueling the truck**
4. **Study current standards for hydrogen tanks. Task complete. We have generated a preliminary list of tests for insulated pressure vessel certification**

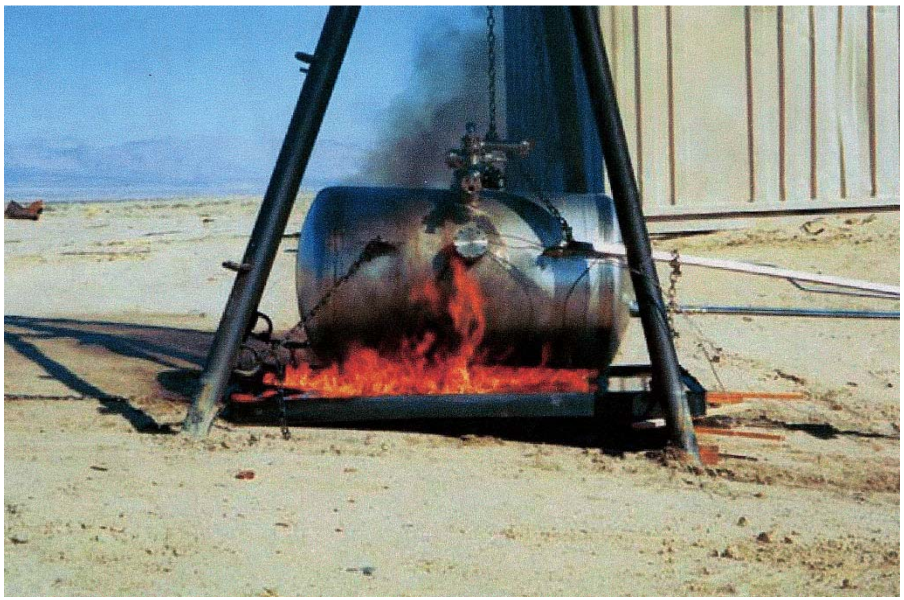
Accomplishments and Progress: We are working on demonstrating insulated pressure vessels

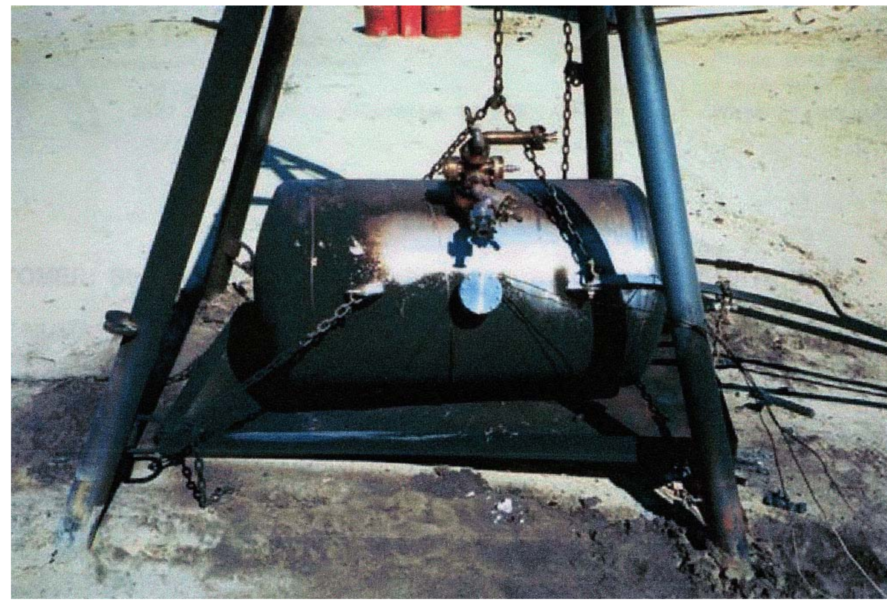
5. Test 5000-psi vessels at cryogenic temperature. Task complete. The pressure vessels were burst tested after cycling, and they met the required burst pressure criterion
6. Prepare a preliminary procedure for insulated pressure vessel certification. Task complete. We have written a certification procedure for pressure vessel certification and submitted it to SCI and the AQMD
7. Demonstration of an insulated pressure vessel in a vehicle. Task in progress. We are receiving all the required parts and we are working on the safety approvals for operation at the LLNL site.

Accomplishments and progress: We have passed the two remaining certification tests

SAE cryogenic drop test

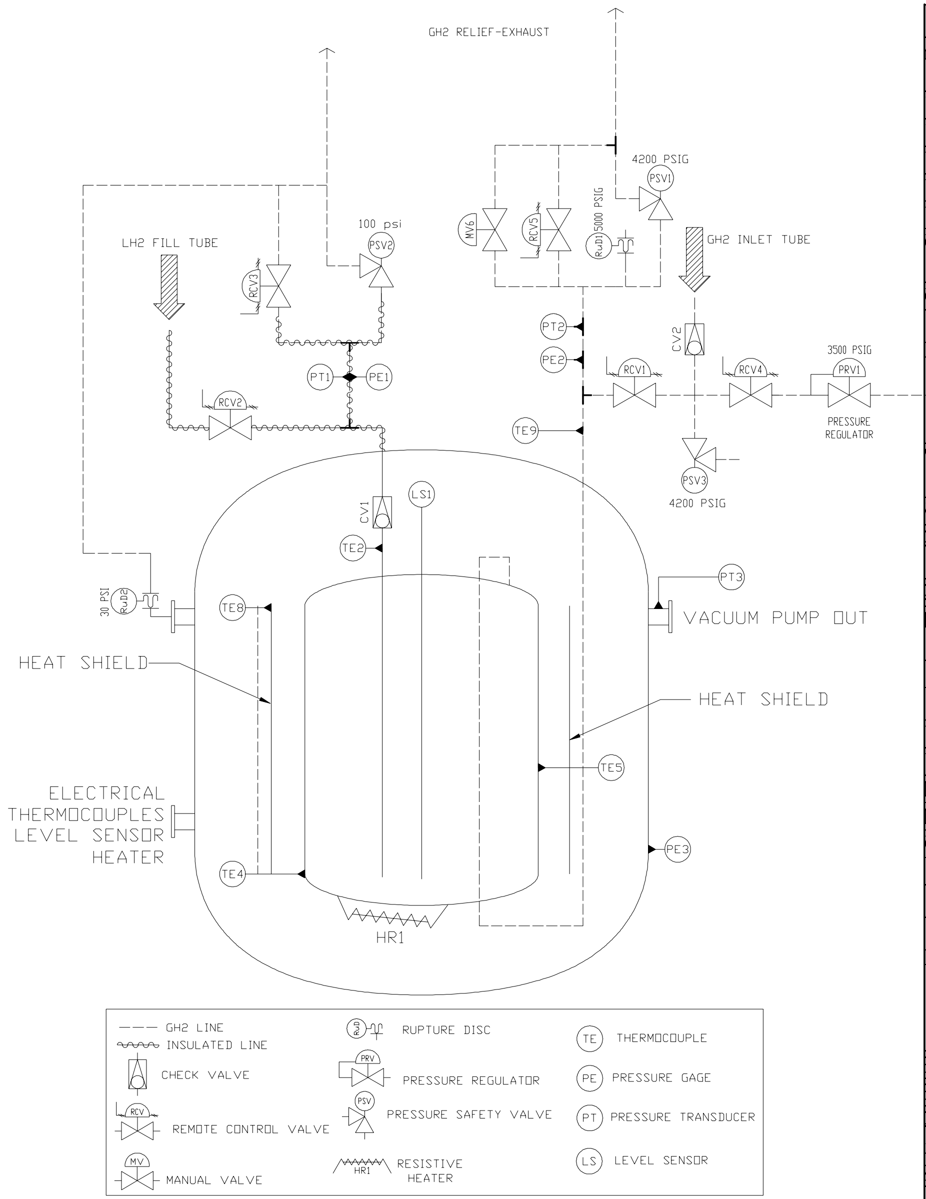
Accomplishments and progress: We have passed the two remaining certification tests





SAE cryogenic bonfire test

Accomplishments and Progress: We have designed a complete system for fueling the SunLine pickup truck



m #	Description	Manufacture and catalog number	M.A.W.P. (psig)
Components in the compressed hydrogen fill zone			
1	Check Valve	Circle Seal Controls CV04-17	6000
2	Check Valve	Circle Seal Controls CV04-17	6000
V1	Solenoid Valve	Circle Seal Controls 16304-002P1AA1C	6000
V4	Solenoid Valve	Circle Seal Controls 16304-002P1AA1C	6000
V5	Solenoid Valve	Circle Seal Controls 16304-002P1AA1C	6000
V1	Press. Relief Valve	Crosby Valve and Gage Co. # 9551118A	4200
V3	Press. Relief Valve	Swagelock SS-4R3A5	4200
D1	Rupture disc	Continental Disc Corporation Rupture Disc Standard S.S. 5000 psigg Burst Pressure With Teflon gasket, holder UT6U ½ in. Pipe, Schedule 80, 316 S.S.	5000
V1	Pressure Regulator	TESCOM Corporation # 20-1231-1405	5000
76	Manual Needle valve	Autoclave Engineers 20A-1876-6	6000
2	Pressure transducer	GP50 Corporation 242E-RV-6-AA/AA/GZ	5000
2	Pressure Gage	McMaster-Carr; #4016K1 (0-6000 psig)	6000
1	Level Sensor	American Magnetics, Level Sensor Drawing No. SKV-10819	4200
Components in the liquid hydrogen fill zone			
V2	Solenoid Valve, cryogenic	Circle Seal Controls 16300-001P4AA5C	125
V3	Solenoid Valve, cryogenic	Circle Seal Controls 16300-001P4AA5C	125
1	Pressure gage	Swagelock PG1-63C-PG200-CAQX-F	200
1	Pressure transducer	GP50 Corporation 242-RB-6-AA	300
V2	Press. Relief Valve	Circle Seal; K520T1-6MP-100	100
Components in the vacuum space			
D2	Rupture Disc	Continental Disc Corporation Rupture Disc Standard S.S. 30 psigg Burst Pressure With Teflon gasket, holder UT6U ½ in. Pipe, Schedule 80, 316 S.S.	30
3	Pressure Gage	McMaster-Carr; #4017K3 (0-15 psig)	15
3	Vacuum Press. Transducer	GP50 Corporation 242-PP-4AA	30
2 ugh 9	Thermocouple	Thermocouple type K	
1	Resistive heater	Tempresco Pancake heater	

Accomplishments and Progress: We have generated a draft certification procedure for insulated pressure vessels

- 1 tensile tests for steel and aluminum cylinders and liners
- 2 impact test for steel cylinders and steel liners
- 3 sulfide stress cracking test for steel
- 4 corrosion tests for aluminum
- 5 sustained load cracking (SLC) tests for aluminum
- 6 leak-before-break (LBB) test
- 7 extreme temperature pressure cycling
- 8 Brinell hardness test
- 9 coating tests
- 10 leak test
- 11 hydraulic test
- 12 hydrostatic pressure burst test
- 13 ambient temperature pressure cycling
- 14 acid environment test
- 15 bonfire test
- 16 penetration tests
- 17 composite flaw tolerance tests
- 18 high temperature creep test
- l9 accelerated stress rupture test
- 20 impact damage test
- 21 coating batch tests
- 22 hydrogen compatibility test
- 23 resin shear strength
- 24 hydrogen gas cycling test
- 25 Leak testing
- 26 destructive and non destructive tests of welding seams
- 27 cryogenic drop test
- 28 cryogenic flame test

Collaborations and tech transfer

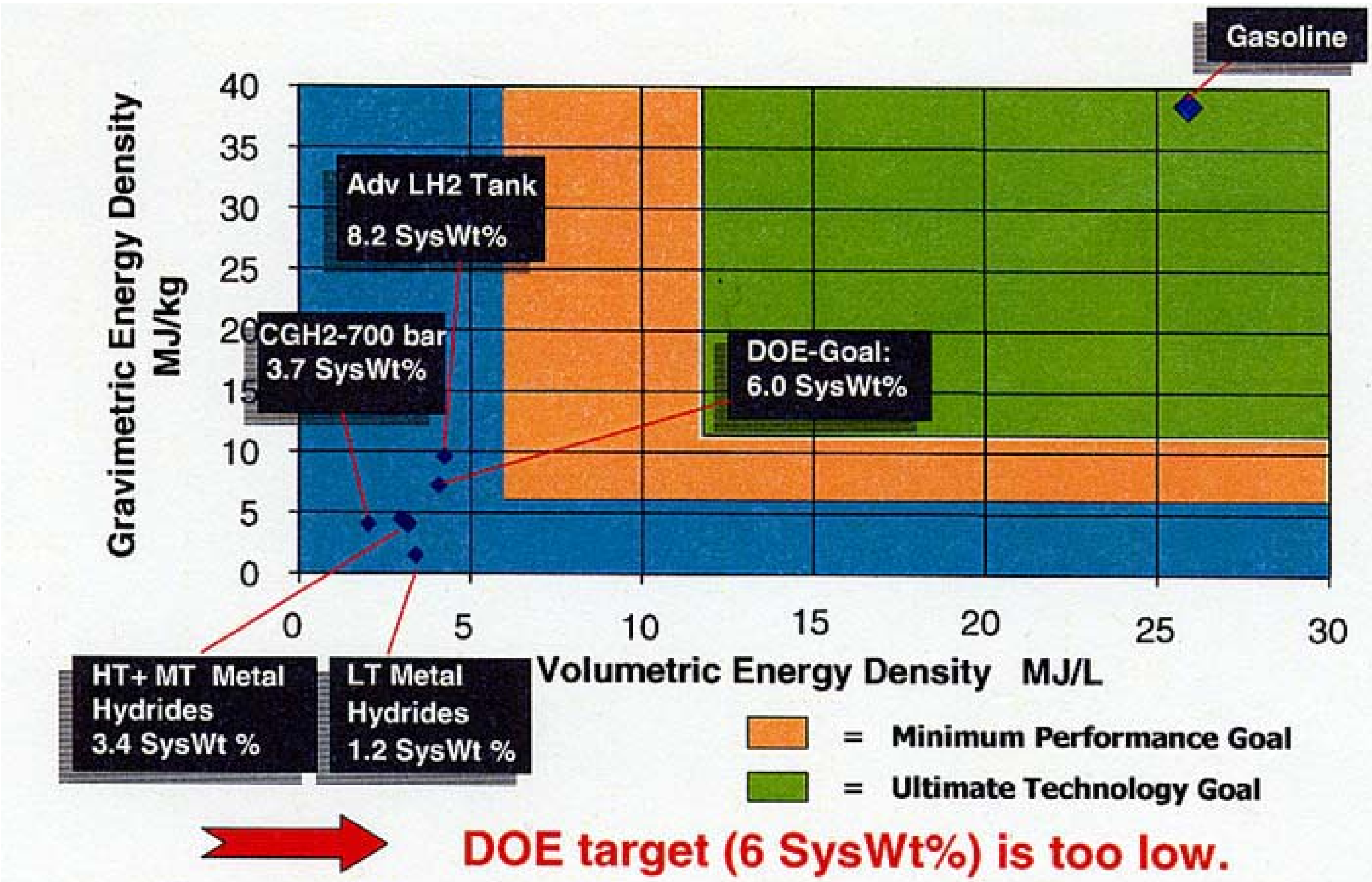
We have teamed up with SunLine and Structural Composites Industries (SCI) to do a demonstration project where the insulated pressure vessels will be installed into two of the SunLine fleet vehicles (Ford Ranger and Ford F-250).

SCI STRUCTURAL COMPOSITES INDUSTRIES

AQMD

SunLine TRANSIT AGENCY

Plans and future milestones: hydrogen energy density is limited by fundamental physics



Solution: conformable pressure vessels allow hydrogen storage in otherwise unusable space

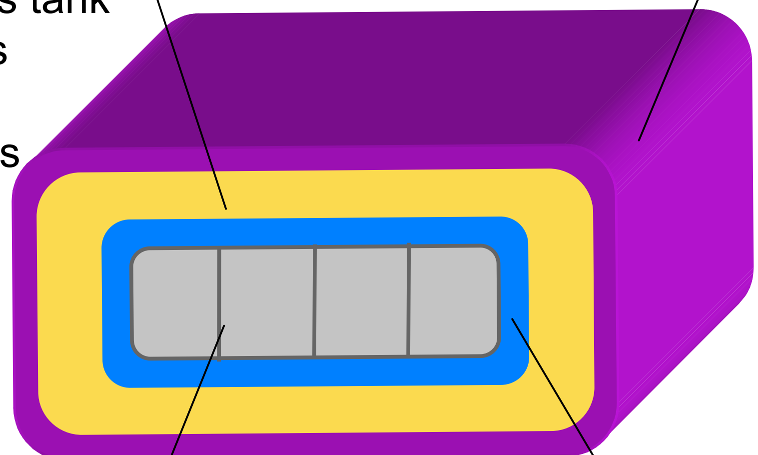
Cryogenic Conformable Tank : Components of a "Conceptual Design"

Insulation

- Supports and insulates tank
- Discrete or continuous
- Candidate materials:
  - Closed cell foams

Vacuum Shell

- Holds vacuum to insulate inner tank and provides mounting surface for external supports.



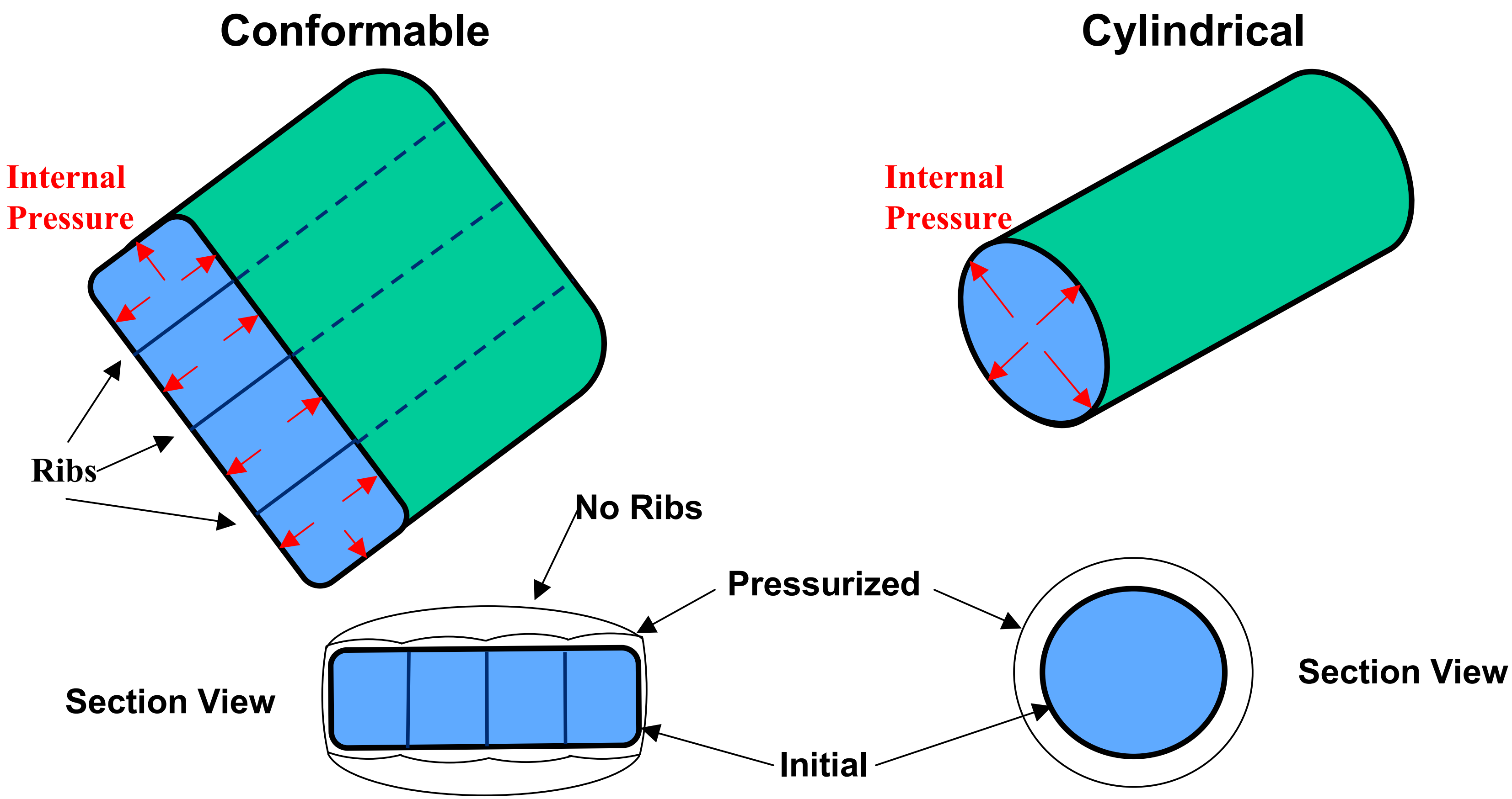
Integrated Bladder - Stiffener

- Retains hydrogen, provides "radial" support, & connects to piping
  - Integrated webbed or ribbed stiffeners (*e.g.,* metal coated composites)
- Candidate materials: formable metals

Composite Overwrap

- Structural member to "confine" internal pressure.
- Fiber: Kevlar or carbon fiber
- Manufacturing:
  - wet filament wound
  - dry textile with RTM

Conformable Tanks Require Internal Structure

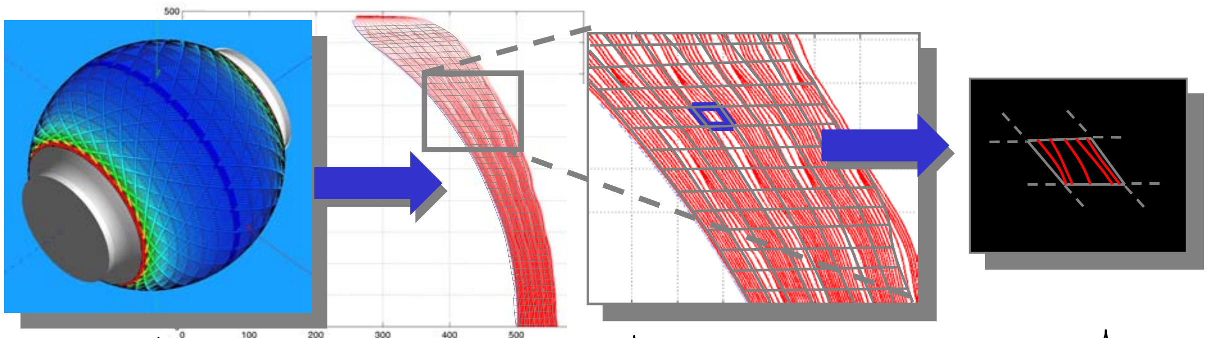


Conformable tanks require internal stiffeners to efficiently support the pressure and minimize bending stresses.

Spherical and cylindrical tanks naturally resist "bending" without internal stiffeners.

Optimized Design Requires Integrated Approach

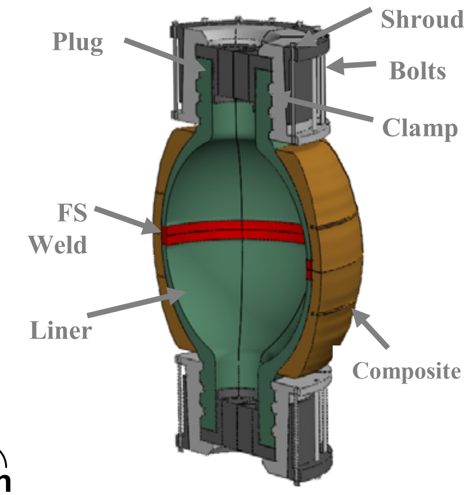
- Team with industry to design "next" generation conformable vessels for cryogenic and high pressure conditions.
- Advanced concepts will necessitate state of the art design and analysis tools.
  - e.g., New high fidelity 3-D analyses allow complex stress states to be fully characterized



Winding Simulation Tool - Cadwind©

Finite Element Model (cross section) with superimposed composite lay up

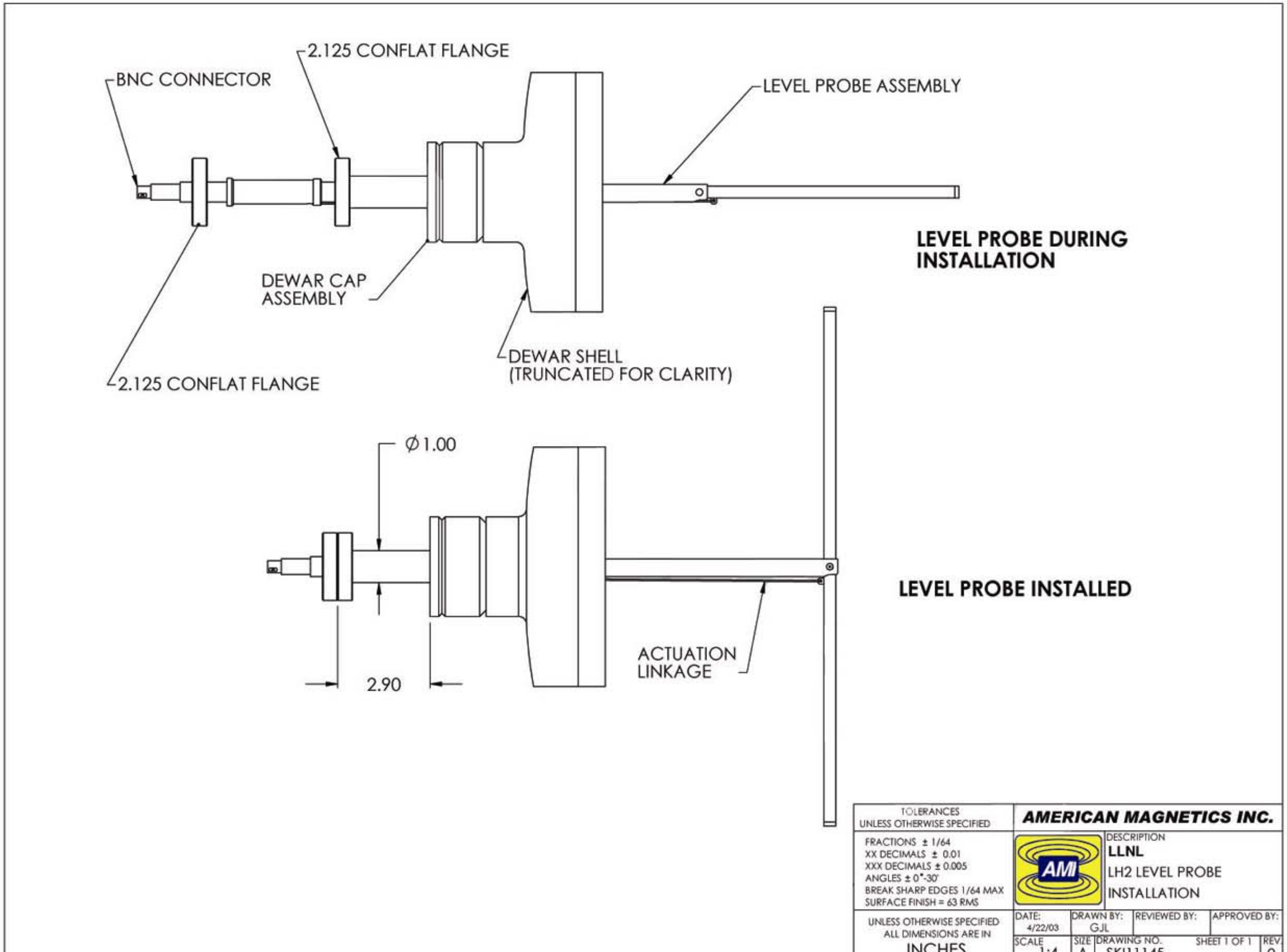
Ply representation within a single element



e.g., High Pressure Containment Vessel

Current LLNL analysis tools analyze the mechanical response of each composite ply

Responses to reviewers' comments: how to install tank in the horizontal direction



Response to reviewers' comments: Is it feasible to have both liquid and gaseous hydrogen at refueling stations? YES

Capital cost of a liquid hydrogen fueling station	$250 k
Capital cost of a compressed hydrogen fueling station:	$1250 k
A station supports	4000 cars
Cost per vehicle for a liquid hydrogen fueling station:	$ 62.5
Cost per vehicle for a compressed hydrogen fueling station:	$ 312

Cost of infrastructure is negligible compared to the cost of fuel, pressure vessels, and potential evaporative losses