Hydrogen By Wire – Home Fueling System

P. I. Name: Luke T. Dalton
Organization: Proton OnSite
Date: May 15, 2013

Project ID #PD067

Overview

Timeline

- Project Start: 22 Sep 2010
- Project End: 14 Aug 2012
- Percent complete: 100%

Budget

- Total project funding
  - DOE share: $1,000,000
- Funding for FY12
  - DOE share: $500,000

Partners

- Oak Ridge National Lab
- Industry component suppliers

Barriers

- Barriers addressed
  - F: Capital Cost
  - G: System Efficiency
  - H: Footprint
  - I: Grid Electricity Emissions
  - K: Manufacturing
  - L: Operations and Maintenance
  - M: Control and Safety

Table 3.1.4.A Distributed Electrolysis H2A Example Cost Contributions [a, b, c]

Characteristics		Units	2011 Status	2015	2020
Electrolysis System	Cost Contribution [a, b, e]	\$/kg H_2	0.70	0.50	0.50
	Production Equipment Availability [c]	%	98	98	98
Electricity	Cost Contribution	\$/kg H_2	3.00 [i]	3.10 [i]	1.60 [j]
Production Fixed O&M	Cost Contribution	\$/kg H_2	0.30	0.20	0.20
Production Other Variable Costs	Cost Contribution	\$/kg H_2	0.10	0.10	<0.10
Hydrogen Production	Cost Contribution	\$/kg H_2	4.10	3.90	2.30
Compression, Storage, and Dispensing [k]	Cost Contribution	\$/kg H_2	2.50	1.70	1.70
Total Hydrogen Levelized Cost (Dispensed)		\$/kg H_2	6.60	5.60	4.00

Relevance
Project Objectives

- Develop enabling technologies
  - 350-bar differential pressure electrochemical plant
    - Electrochemical cell stack (electrolysis, compression, etc.)
      - Overboard seal
      - Cross-cell seal, membrane support
        - » Differential pressure ***enables*** lowest cost system and highest safety
    - Hydrogen management system
      - Phase separation, sensors, controls with wide applicability for 350-bar electrolysis and compression.
    - Balance of system: substantial overlap with 30-bar product
- Demonstrate prototype operation
  - 350-bar hydrogen generation
  - Fueling capability

Relevance
Addressing Electrolysis Barriers

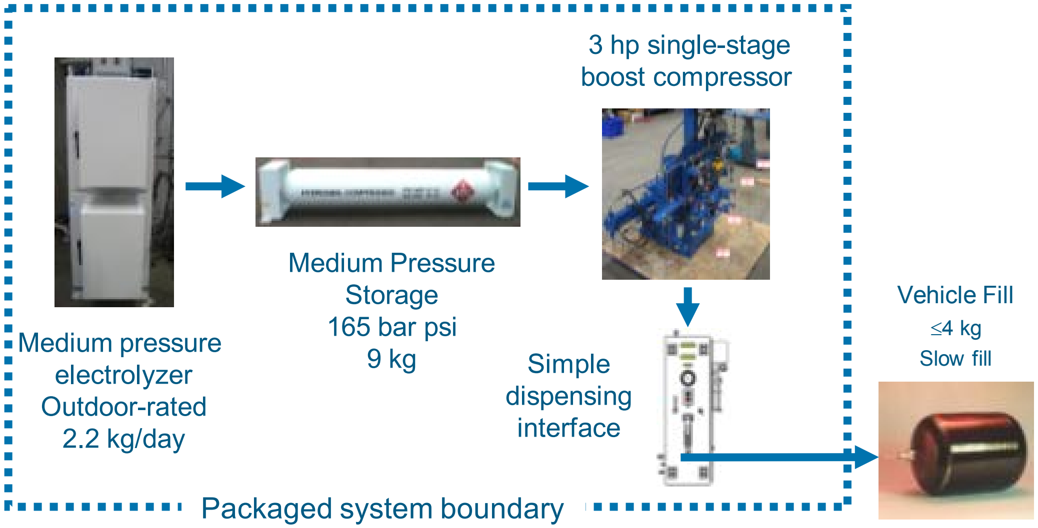
DOE Barriers	Proton Project Impact
F. Capital Cost	Lessons from Proton's product manufacturing experience apply to fueling system design. 2013 technology at manufacturing volume achieves $6/kg, in line with MYRDDP.
G. System Efficiency	Modeling efficiency of electrochemical compressor v. mechanical. Removing mechanical stages improves fueling system efficiency.
H. Footprint	Integrating generation and compression reduces footprint
I. Grid Electricity Emissions	Scale enables integration with residential renewable.
K. Manufacturing	Scale enables ramp up of volume with vehicle introduction, maximizes existing supply chain.
L. Operations and Maintenance	Electrochemical compression requires less maintenance than mechanical.
M. Control and Safety	Fewer subsystems simplifies controls. Direct generation-to-compression minimizes station storage.

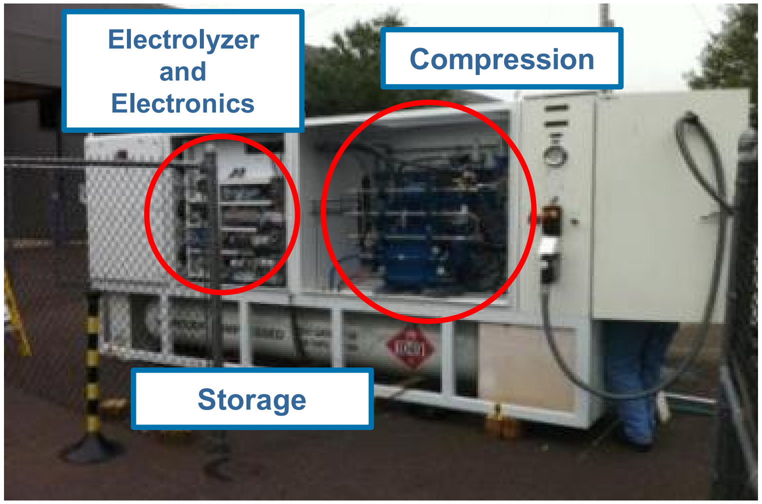
Relevance
Addressing Broad MYRDD Plan

Broad DOE Objectives	**Proton Project Impact**
Other Forecourt Production: Compression	Developed Electrochemical Compression technology applies to all production methods.
Hydrogen Delivery	Small distributed generation reduces delivery costs to near zero. Take advantage of water/electricity infrastructure.
Hydrogen Storage	Eliminates storage for residential station.
Manufacturing R&D	Utilizes and enables growth of factory capacity and supply chain by similarity to product lines for other commercial markets.
Hydrogen Safety, Codes, and Standards	Aligns product design with existing IEC 22734-1 and developing IEC 22734-2. Eliminates station H2 inventory to facilitate AHJ acceptance. Electrical requirements on par with existing residential equipment.

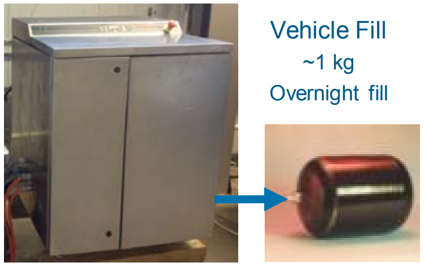
Approach
Eliminate Subsystems, Simplify

- Compare mechanical compressor system:





- To 350-bar electrolysis system:



Approach
Task Breakdown – Phase 1

- Task 1.0: Technical Requirements Analysis
  - 1.1 Capacity:
  - 1.2 Efficiency and power usage
  - 1.3 Physical size
  - 1.4 Preliminary design requirements
- Task 2.0: Cost Analysis
  - 2.1 Cost of hydrogen for different vehicle scenarios
  - 2.2 Effect of technology improvements and production volume increases
- Task 3.0: Installation Analysis
  - 3.1 Cost impact of current code compliance environment, and direction of national and international standards
  - 3.2 O&M and energy comparison to other residential appliances

Approach
Task Breakdown – Phase 2

- Task 1: Prototype System Design/Fabrication
  - System and key component design
  - Safety analysis
  - Procurement, fabrication, and acceptance testing
- Task 2: Prototype Stack Design
  - Requirements definition
  - Cell hardware design
  - Stack embodiment hardware design
- Task 3: Prototype Component Verification
  - Cell and stack component verification
- Task 4: Prototype System Testing
  - Stack fabrication and assembly
  - Integrated stack/system testing

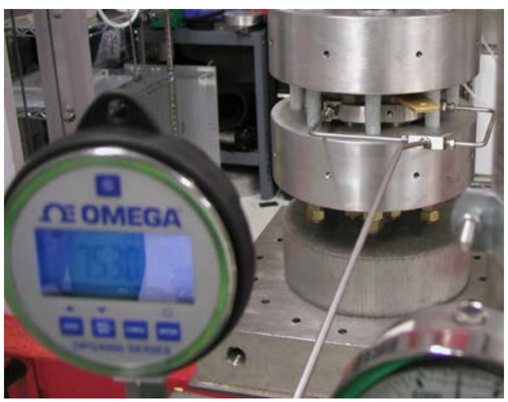
Technical Accomplishments – Phase 2

Task	Task Description	Progress Notes	Completion
1.0	System Design / Fabrication	• Completed component procurement. • Completed fabrication. • Completed hydrogen phase separator fabrication and proof test. • Completed system checkout.	100%
2.0	Stack Design	• Completed full-scale pressure testing. • Completed prototype and final design of cell and stack components.	100%
3.0	Component Verification	• Completed verification of stack embodiment hardware. • Completed verification of cell flow fields. • Completed verification of gas diffusion at full differential pressure. • Completed 350-bar electrolysis stack fabrication and acceptance testing.	100%
4.0	Integrated Testing	• Completed system integration. • Completed system checkout and safety review • Operated system at full 350-bar pressure, full current.	100%

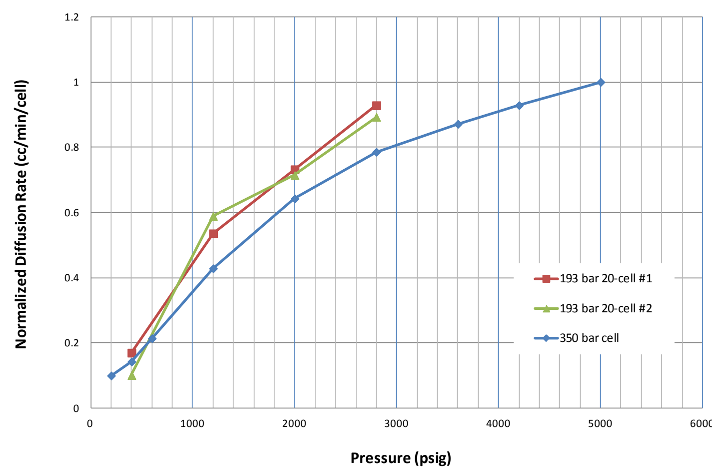
Technical Accomplishments
Re-cap previous work

- Task 1.0 System Design/Fabrication
  – P&ID, electrical schematic, packaging
  – Safety analysis, code review

- Task 2.0 Stack Design
  – Cell components, sealing features
  – Stack compression plates and bolts



- Task 3.0 Component Verification
  – Cross-cell permeation measurements

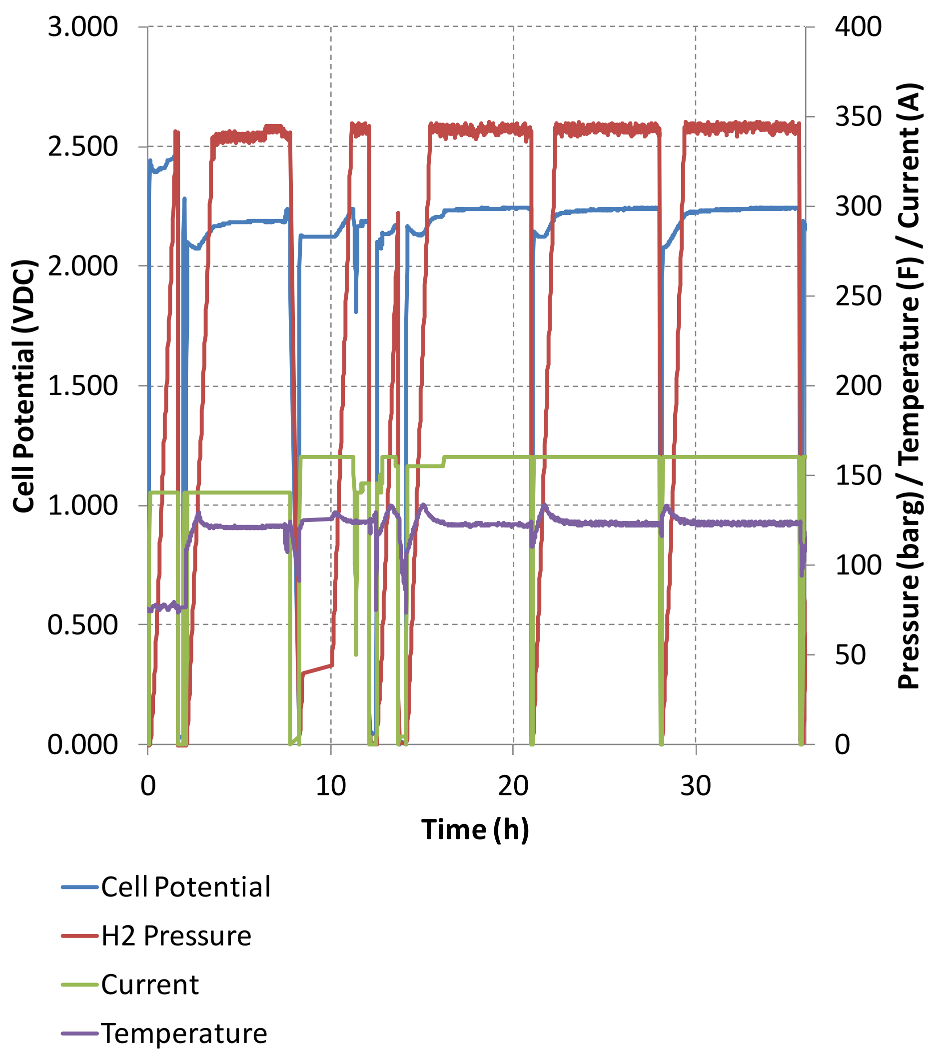


Technical Accomplishments
Task 4.0: Integrated Testing

- 350-bar differential pressure stack installed
- Integrated system checkout completed
- Initial testing enabled system tuning (valve timing, etc.)
- Extended testing executed at full pressure
  - Steady state & start-up / shut-down conditions verified

Configuration	Rated H_2 Flow
System w/ 20-cell stack	0.1 kg/h

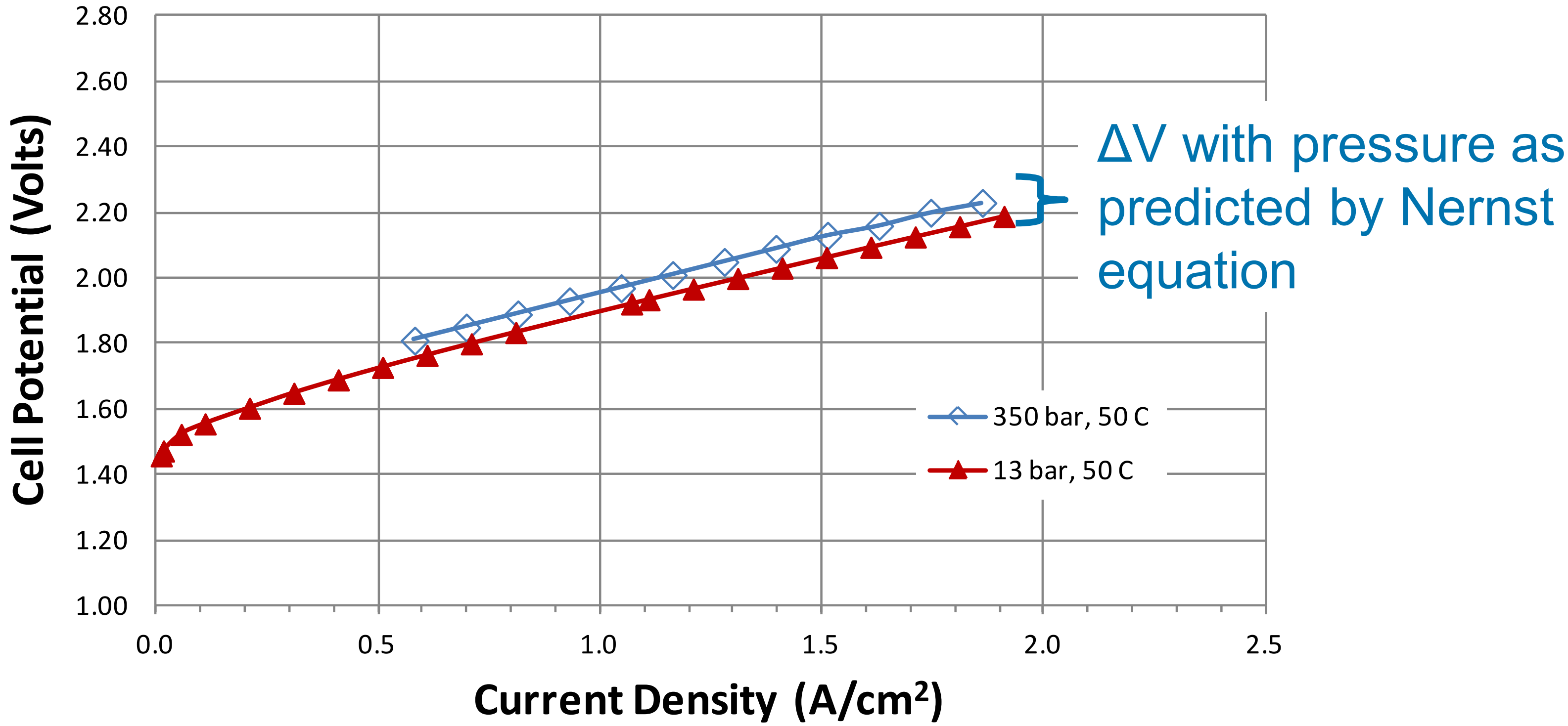
Technical Accomplishments
Task 4.0: Integrated Testing



- 350-bar differential pressure electrolysis demonstrated
- Pressure controls were steady
- Cell voltage as expected
- System cycle testing
  - Cell stack & controls operated flawlessly
  - Level sensor had internal failure

Technical Accomplishments
Task 4.0: Integrated Testing

- 350-bar differential pressure performance
  - 55% LHV (66% HHV) stack efficiency @ rated current



- Further efficiency improvements:
  - Advanced membrane, catalyst from Proton's other DOE projects.

Technical Accomplishments Task 4.0: Integrated Testing

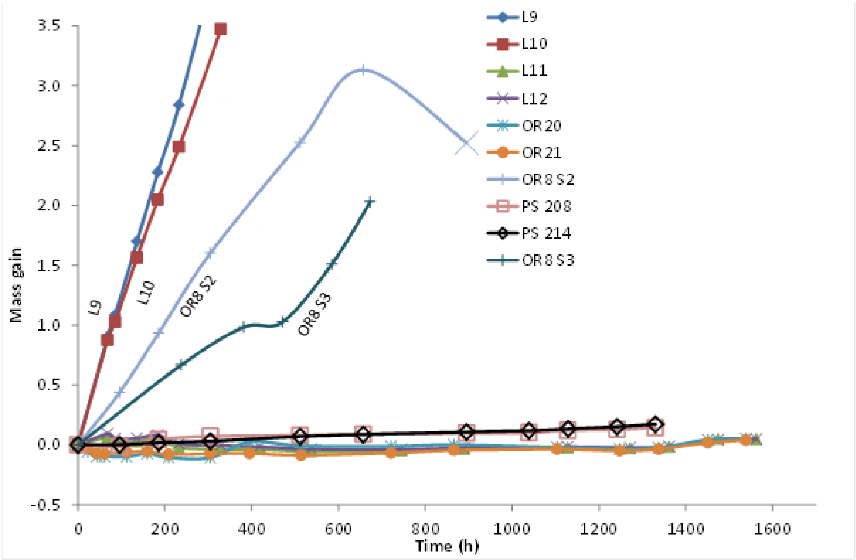
- Cost analysis refinement
  - Cost of hydrogen

	2013 Status	2015 Target	2020 Target
Production (Electrolysis)	$5.99/kg	$3.90	$2.30
Compression, Storage, Dispensing	$0.00*	$1.70	$1.70
Total	$5.99	$5.60	$4.00

*Compression and dispensing done by electrolyzer, no storage required.

Collaborations

- Oak Ridge National Laboratory
  - Durability of metallic and coated separator materials, including nitride and other processes
  - Focused on applicability to high pressure hydrogen compatibility
  - ORNL has unique expertise in nitride development and analysis

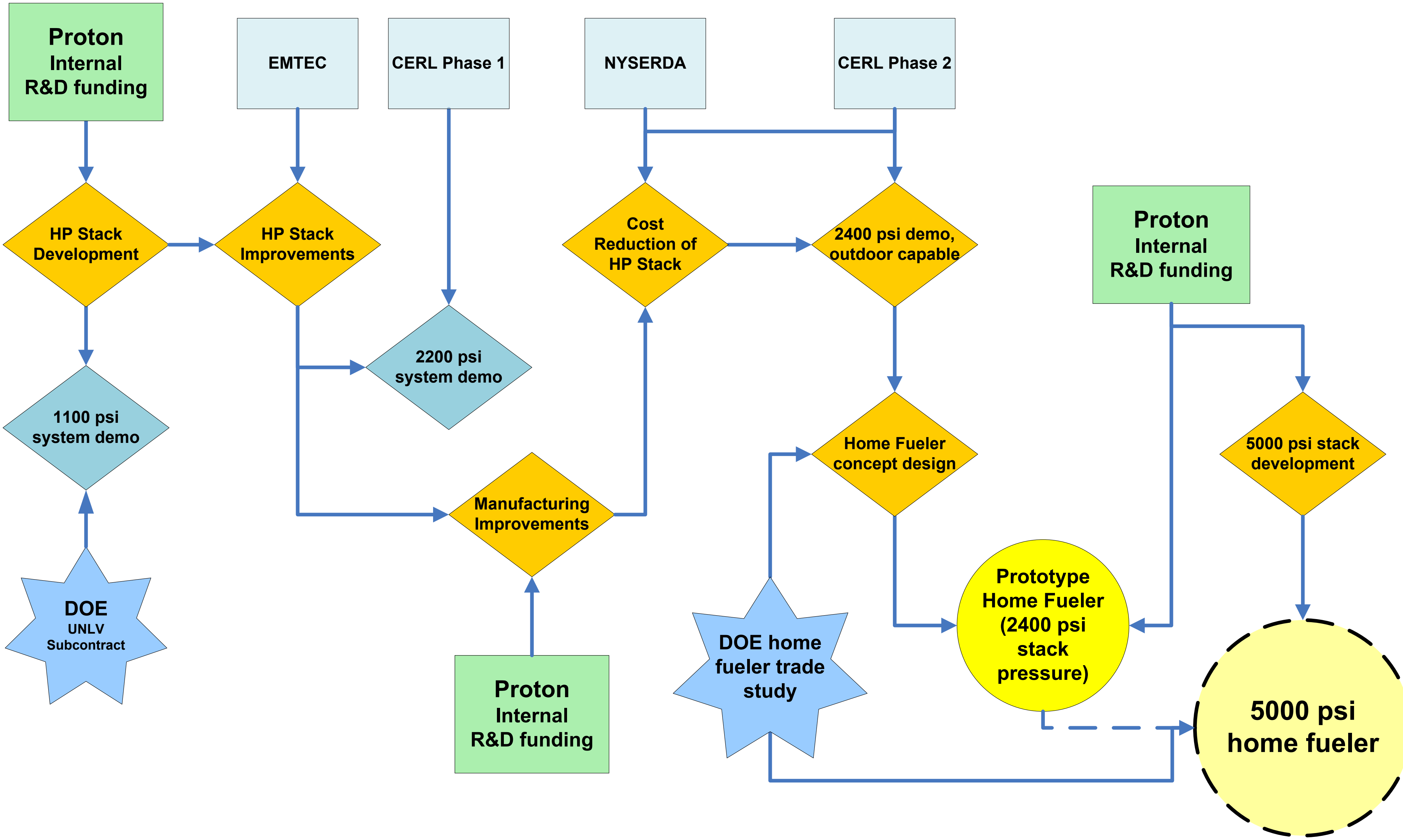


- Industry component suppliers
  - Collaborated to identify appropriate components for pressure, temperature, and fluid compatibility requirements.

Future Work

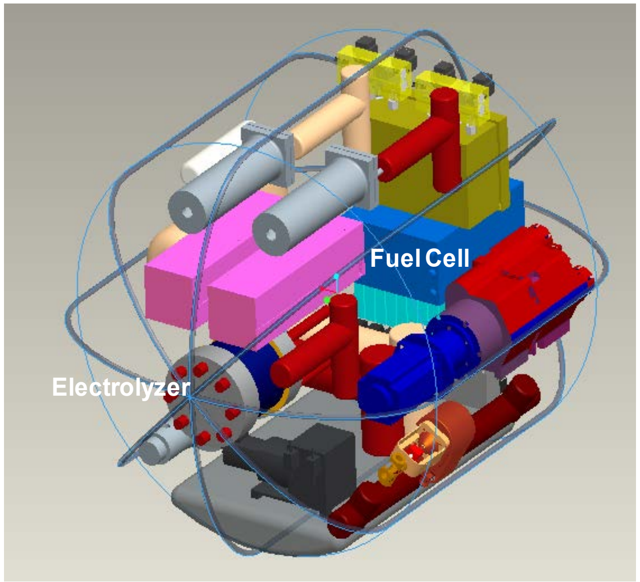
- Extended durability testing
- Scale up cell count to increase total output
- Optimize system packaging for siting requirements and cost effectiveness

Future Work: Home Fueler Roadmap



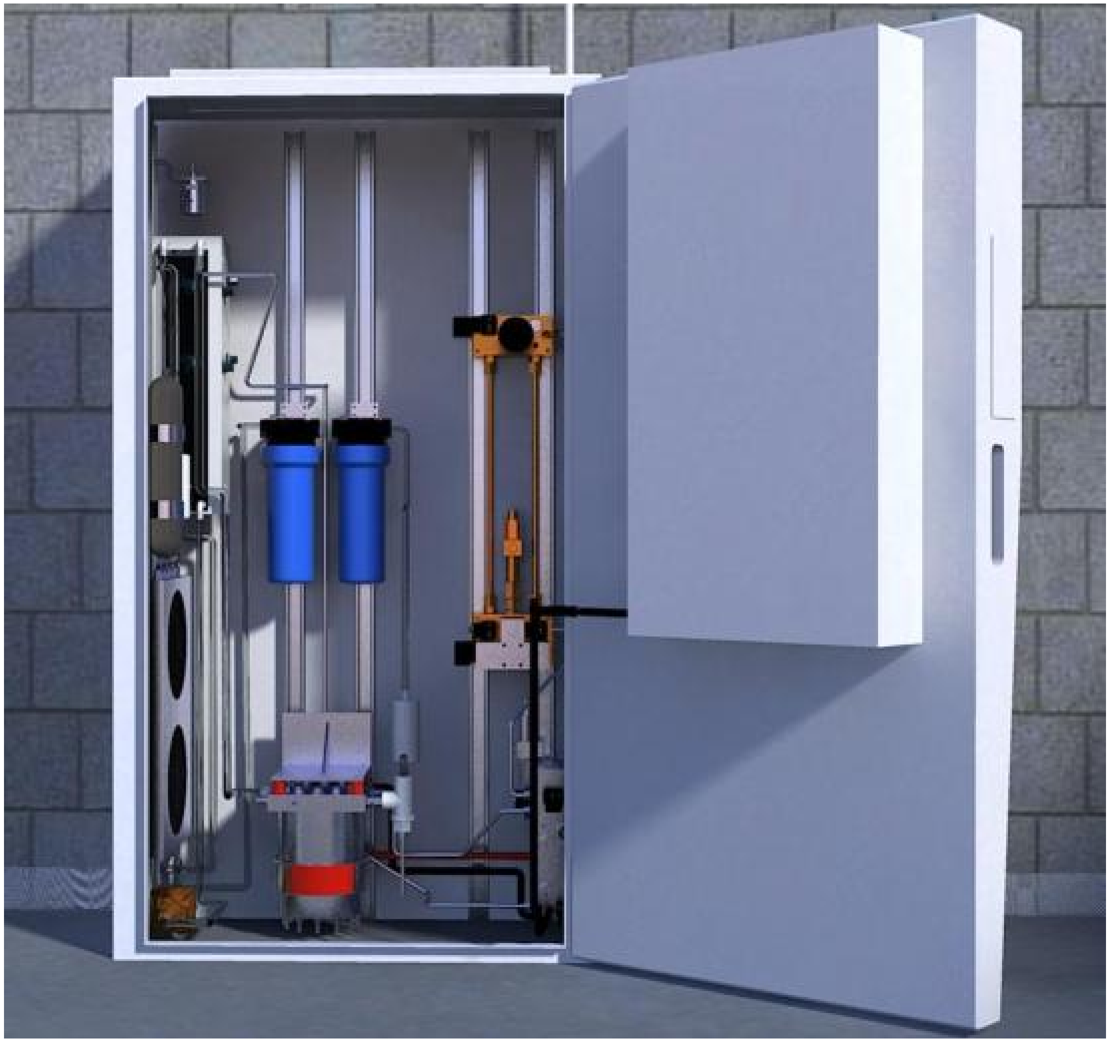
Future Work: Undersea Energy

- U.S. Navy Office of Naval Research
  - Parallel related development
  - Balanced pressure version of cell stack
  - Applied to air independent energy storage need



Future Work
Product Package Development

- Physical Size – 2’ x 3’ x 5’



Summary

- **Relevance:**
  - Home fueling addresses many challenging barriers for forecourt electrolysis as well as key objectives of the broader MYRDDP. PEM electrolysis is ideal technology for small footprint, easy maintenance.
- **Approach:**
  - Execute development of key enabling technologies including PEM electrolysis cell stack and balance-of-plant components for 5,000 psi operation. Draw upon *Proton's experience with commercial products* to inform the design and safety analysis.
- **Technical Accomplishments:**
  - Completed prototype stack and system development, fabrication, and demonstration at 350-bar differential pressure.
- **Collaborations:**
  - ORNL supported analysis of metallic separator durability.
- **Proposed Future Work:**
  - Extended durability testing of cell stack in system. Packaging optimization and fueling demonstrations.