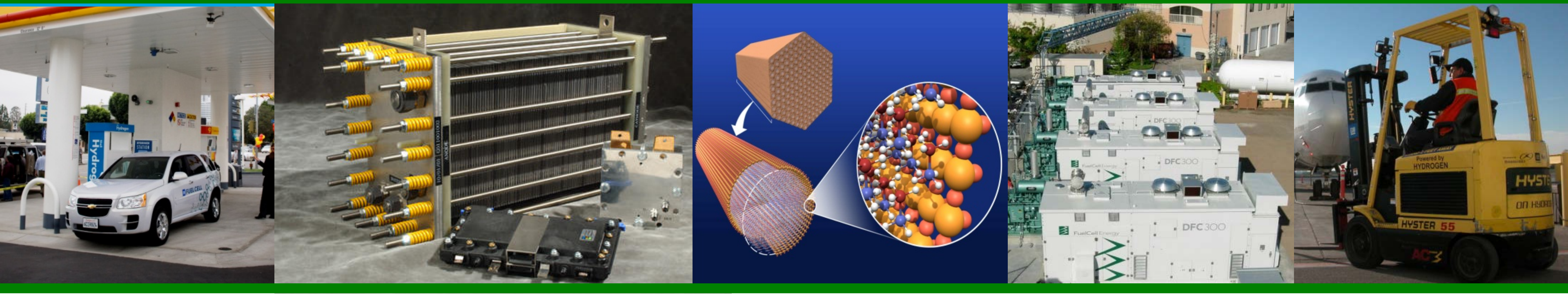
U.S. DEPARTMENT OF ENERGY



Hydrogen Storage Program Area
-Plenary Presentation-

Ned T. Stetson

Fuel Cell Technologies Office

2017 Annual Merit Review and Peer Evaluation Meeting

June 5 - 9, 2017

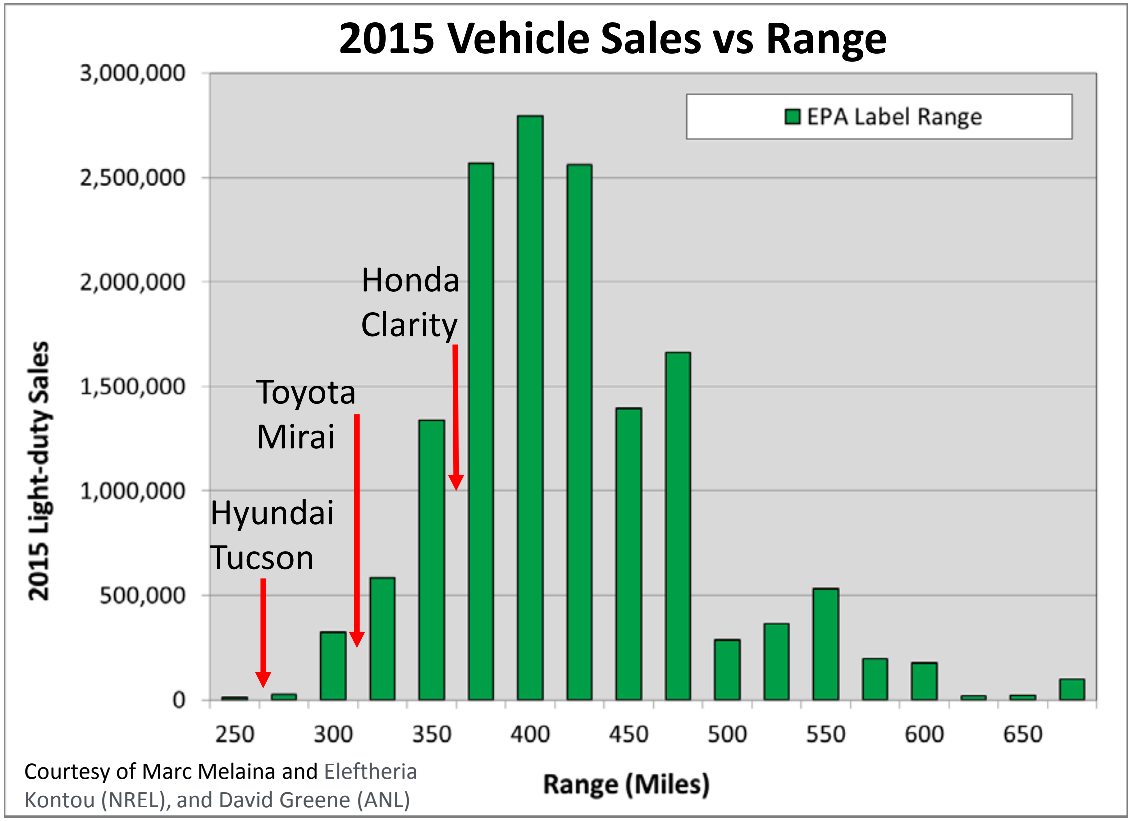
Goals and Objectives

Objective: Develop H_2 storage technologies with performance to enable fuel cell products to be competitive with conventional technologies

For Light-Duty Vehicles:

- Comparable driving range
- Similar refueling time (~3 minutes)
- Comparable passenger and cargo space
- Equivalent level of safety

Onboard H_2 storage targets to be reviewed approximately every five years and revised as appropriate

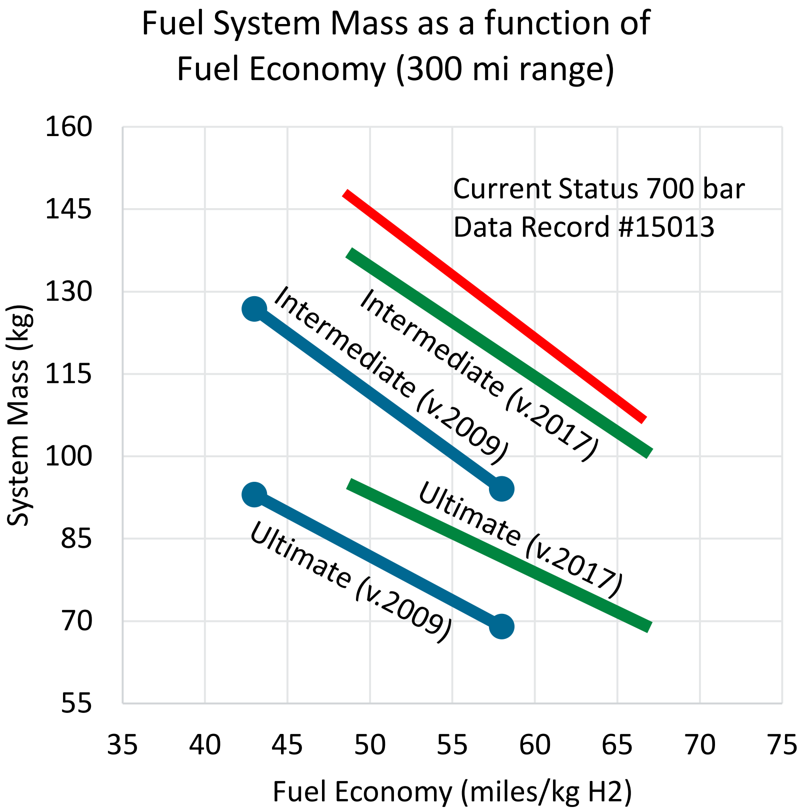


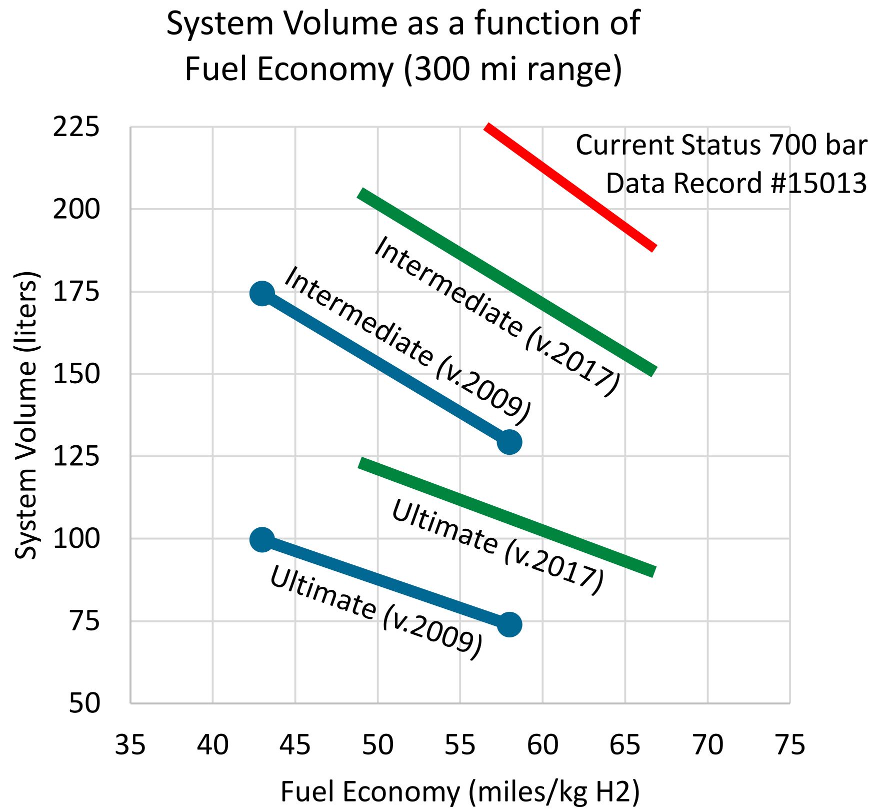
GOAL: Develop advanced hydrogen storage technologies to enable successful commercialization of hydrogen fuel cell products

Onboard Storage Target Revisions

Vehicle performance has improved since the 2008/09 target review

- **Fuel economy range increase from 48-53 to 49-67 miles per kg H_2**
- **Autonomie (ANL) available for full vehicle performance analysis**





Onboard storage targets are periodically reviewed in terms of current vehicle performance data and revised as appropriate

Revised Onboard H_2 Storage Targets

Revised System Targets for Onboard Hydrogen Storage for Light-Duty Fuel Cell Vehicles						
Storage Parameter	**Units**	**2020 (previous)**	**2020 (new)**	**2025 (new)**	**Ultimate (previous)**	**Ultimate (new)**
System Gravimetric Capacity:	kWh/kg (kg H_2/kg system)	1.8 (0.055)	**1.5 (0.045)**	**1.8 (0.055)**	2.5 (0.075)	**2.2 (0.065)**
System Volumetric Capacity:	kWh/L (kg H_2/L system)	1.3 (0.040)	**1.0 (0.030)**	**1.3 (0.040)**	2.3 (0.070)	**1.7 (0.050)**
Storage System Cost :	\$/kWh net (\$/kg H_2)	10 (333)	10 (333)	**9 (300)**	8 (266)	8 (266)
Charging / Discharging Rates: System fill time	min	3.3	**3-5**	**3-5**	2.5	**3-5**

System target revisions considered vehicle performance

New Onboard H_2 Storage Targets

New System Targets for Onboard H_2 Storage for Light-Duty Fuel Cell Vehicles					
Storage Parameter	**Units**	**2020 (new)**	**2025 (new)**	**Ultimate (new)**	**Notes**
Charging / Discharging Rates: Average flow rate	(g/s)/ kW	0.004	0.004	0.004	New target to differentiate between Average flow rate & Minimum full flow rate
Dormancy: Dormancy time target (minimum until first release from initial 95% usable capacity) Boil-off loss target (max reduction from initial 95% usable capacity after 30 days)	Days %	7 10	10 10	14 10	New targets to address Dormancy (a challenge for systems that operate below ambient temperate)

The full set of onboard H_2 storage targets available online at:
https://energy.gov/node/1315186

Current Status vs Targets

Storage Targets	Gravimetric kWh/kg (kg H_2/kg system)	Volumetric kWh/L (kg H_2/L system)	Costs [1] \$/kWh (\$/kg H_2)
2020	1.5 (0.045)	1.0 (0.030)	\$10 (\$333)
2025	1.8 (0.055)	1.3 (0.040)	\$9 (\$300)
Ultimate	2.2 (0.065)	1.7 (0.050)	\$8 (\$266)
Current Status [2]			
700 bar compressed (5.6 kg H_2, Type IV, Single Tank)	1.4 (0.042)	0.8 (0.024)	\$15 (\$500)

The full set of H_2 storage targets can be found on the Program's website: https://energy.gov/eere/fuelcells/downloads/doe-targets-onboard-hydrogen-storage-systems-light-duty-vehicles

[1] Projected at 500,000 units/year

[2] FCTO Data Record #15013, 11/25/2015: https://www.hydrogen.energy.gov/pdfs/15013_onboard_storage_performance_cost.pdf

Hydrogen Storage Team - Strategy and Barriers

Dual approach

- Hydrogen Storage
  - Near-Term Approach
  - Longer-Term Approach

Technology Focus

Near-Term Approach:

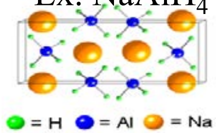
700 bar Compressed

Longer-Term Approach:

Cold / Cryo-Compressed

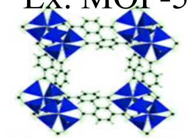
Metal Hydrides

Ex. $NaAlH_4$



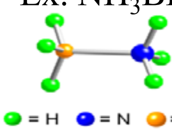
Sorbents

Ex. MOF-5



Chemical H_2 Storage

Ex. NH_3BH_3



Barriers and R&D Focus

700 bar Compressed:
- Lower Cost Carbon Fiber
- Improved Composites
- Conformable designs
- Lower Cost BOP

Cold / Cryo-Compressed:
- System Engineering
- Advanced Insulation
- Improved Dormancy
- Composite Development

Metal Hydrides:
- Higher Material Capacity
- System Cost
- Fill Time
- Onboard Efficiency

Sorbents:
- Higher Material Capacity
- System Cost
- Dormancy
- WTP Efficiency

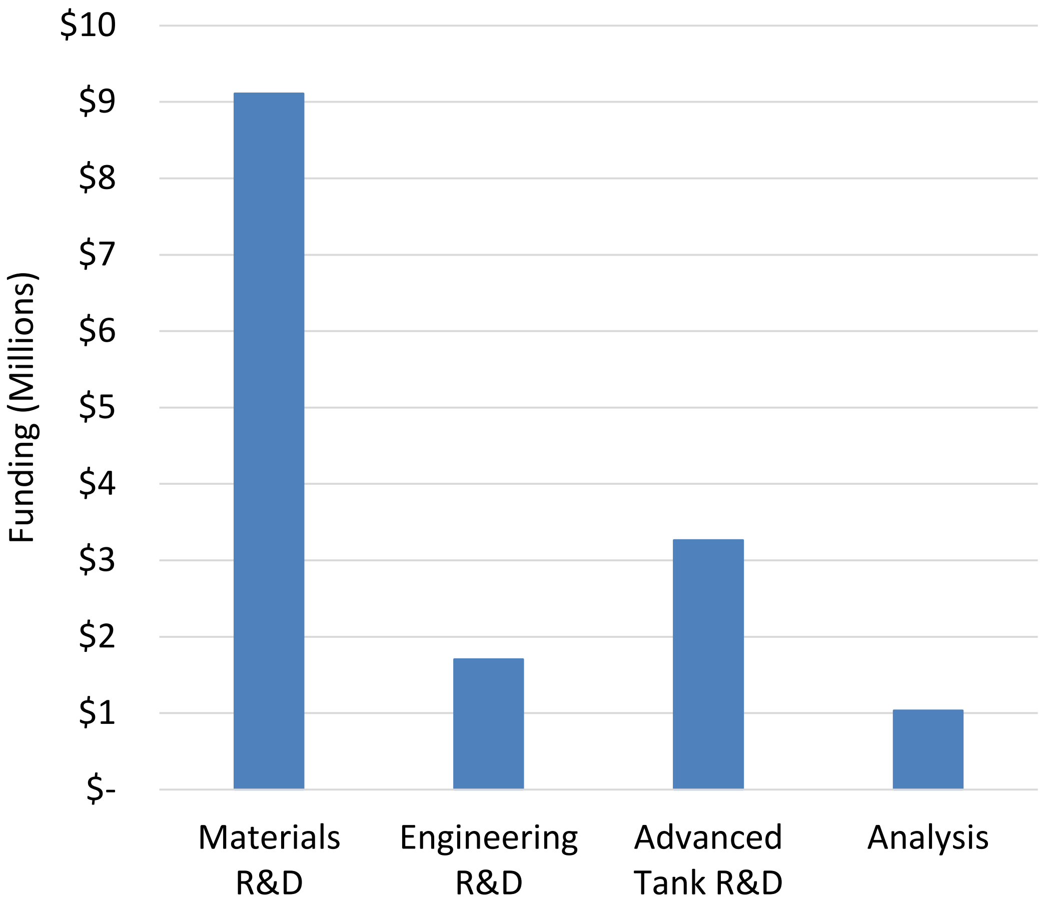
Chemical H_2 Storage:
- Lower Cost Off-board Regen
- System Cost
- Gravimetric Density

Objective: Achieve a driving range competitive with conventional vehicles for full span of light-duty vehicles, while meeting packaging, cost, safety, & performance requirements

Budget

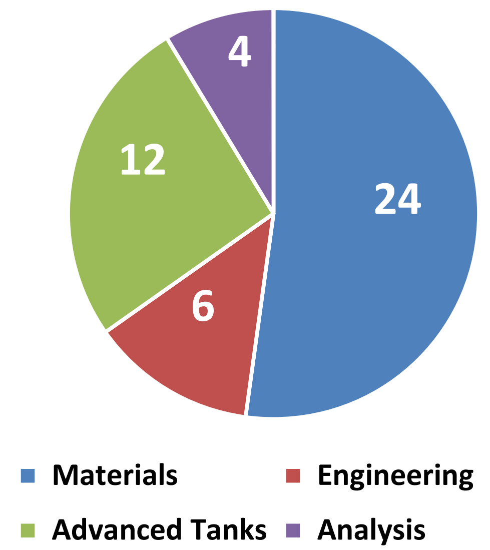
FY 2017 Appropriation = $15.6M

FY2017 Funding Allocations by Focus Area



Emphasis is on early phase R&D for H_2 storage materials and lower cost physical storage

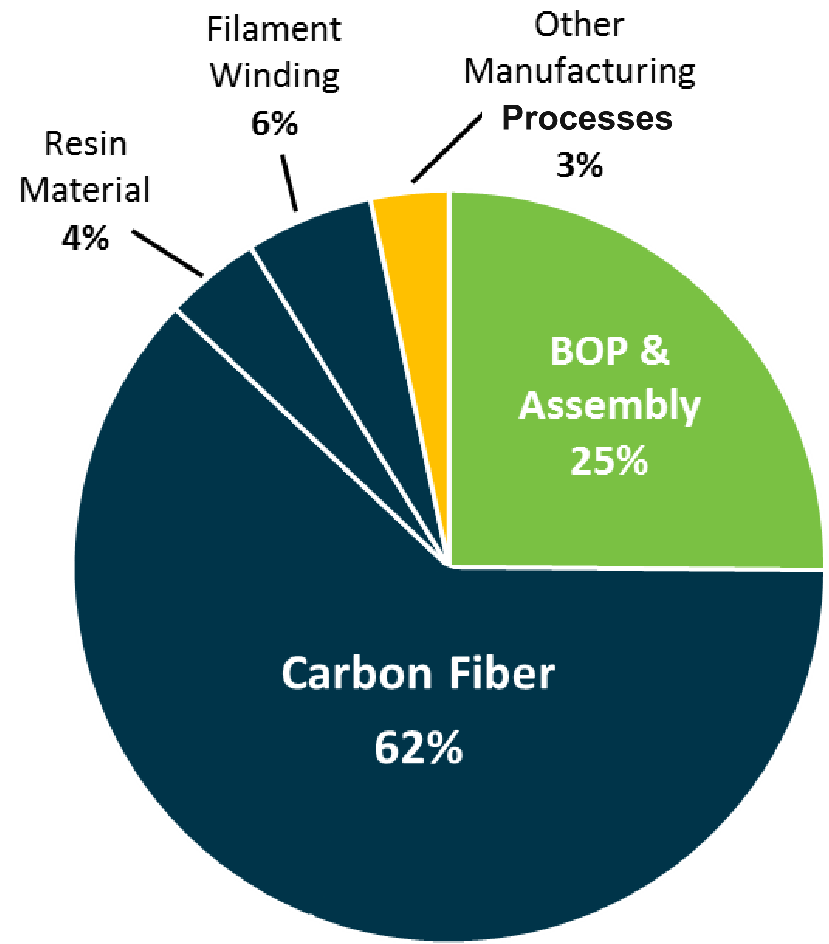
Number of Projects in Portfolio by Focus Area
(Includes subs directly funded by DOE)



Physical Storage Activities

Current Status – 700 Bar System Cost Breakout

- **Cost breakdown** at **500k systems/yr.**
- System cost is **dominated**, 72%, by **composite materials and processing**
- Carbon Fiber composite cost:
  - ~ 50% Carbon fiber precursor
  - ~ 50% Precursor fiber conversion
- BOP costs are a major cost contributor, especially at low annual production volumes



Ordaz, G., C. Houchins, and T. Hua. 2015. "Onboard Type IV Compressed Hydrogen Storage System - Cost and Performance Status 2015," DOE Hydrogen and Fuel Cells Program Record, https://www.hydrogen.energy.gov/pdfs/15013_onboard_storage_performance_cost.pdf, accessed 5 July 2016.

Carbon fiber cost reduction is needed to drive down cost of 700 bar storage systems

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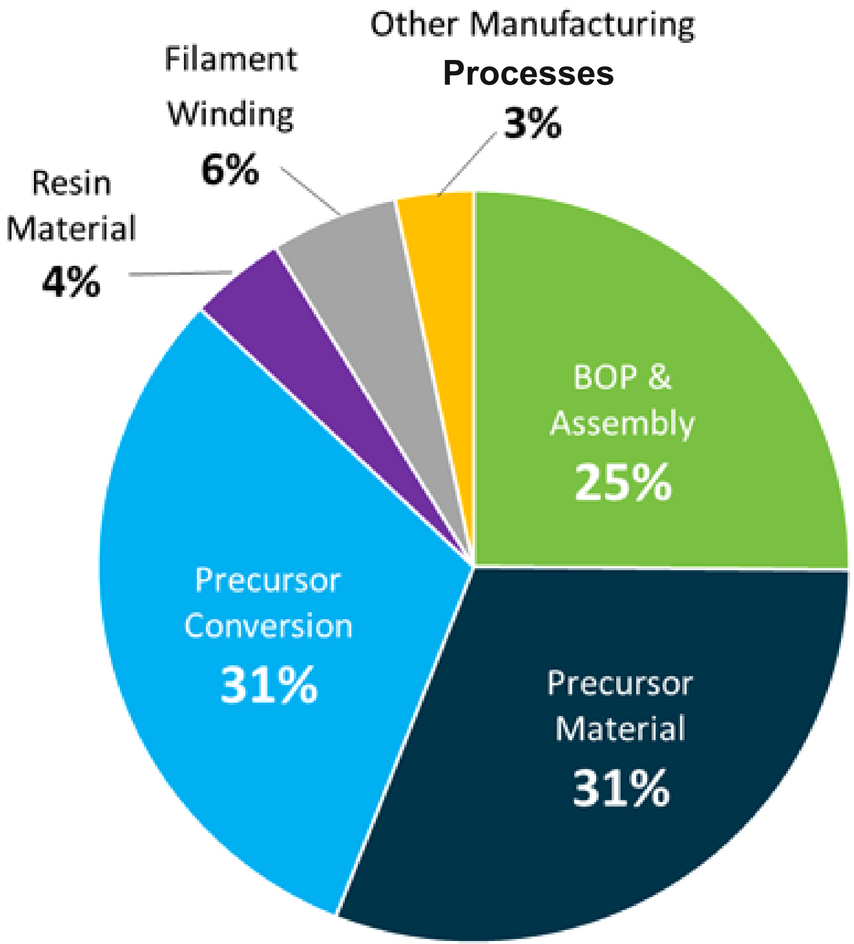


Ordaz, G., C. Houchins, and T. Hua. 2015. "Onboard Type IV Compressed Hydrogen Storage System - Cost and Performance Status 2015," DOE Hydrogen and Fuel Cells Program Record, https://www.hydrogen.energy.gov/pdfs/15013_onboard_storage_performance_cost.pdf, accessed 5 July 2016.

Carbon fiber cost reduction is needed to drive down cost of 700 bar storage systems

FY2017 FOA Topic

- **Precursor development for low-cost, high-strength carbon fiber (CF) for use in composite overwrapped pressure vessel applications**
  - Resulting CF to have properties similar to Toray T700S
  - Target cost of $12.60/kg of CF

- **Areas of interest:**
  - PAN-based fibers formulated with co-monomers and additives that permit lower cost processing to produce the PAN fiber than conventional solution spinning processes, and or that reduce the conversion cost of the PAN-fiber to CF;
  - Polyolefin-based fibers capable of being cost effectively converted into high-strength CF;
  - Novel material precursor fibers that can lead to low-cost, high-strength CF production.

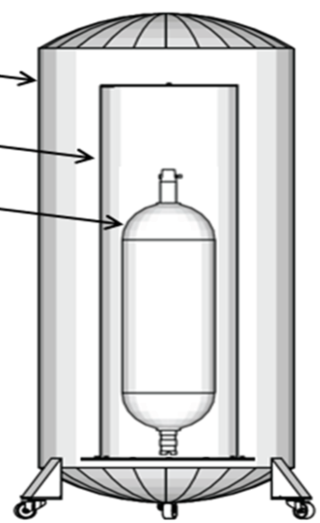
Addressing the cost of high-strength carbon fiber

Accomplishments - Project Highlights

Alternative Resin and Manufacturing [Materia/MSU/Spencer Composites/ Hypercomp Engineering]

- Reducing composite volume/mass through use of alternative resin and manufacturing processes
- **Improved process cut resin infusion time in half for prototype tanks**

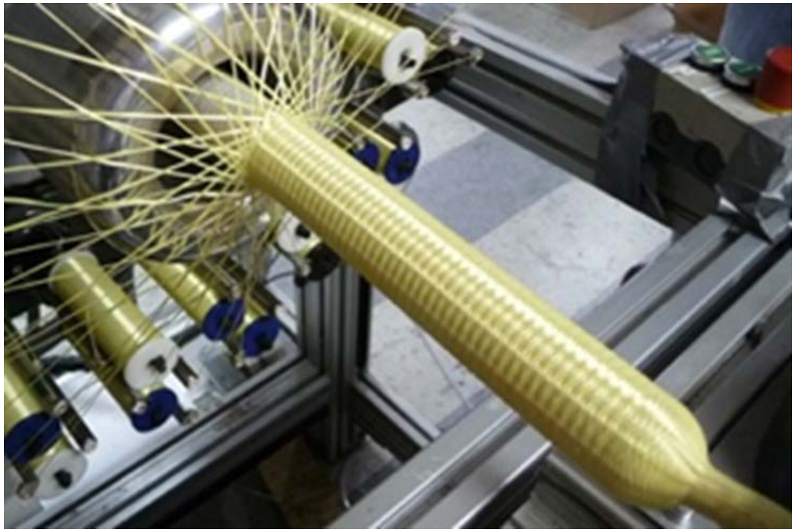
Nested Assembly for New Process



ST114

Conformable 700 bar H_2 Storage Systems [CTE/HECR/UT/Stan Sanders]

- Developing conformable 700 bar pressure vessels without use of carbon fiber composites
- **Demonstrated vessel with a 34,000 psi burst (2345 bar), exceeding the 2.25 safety margin for 700 bar systems**



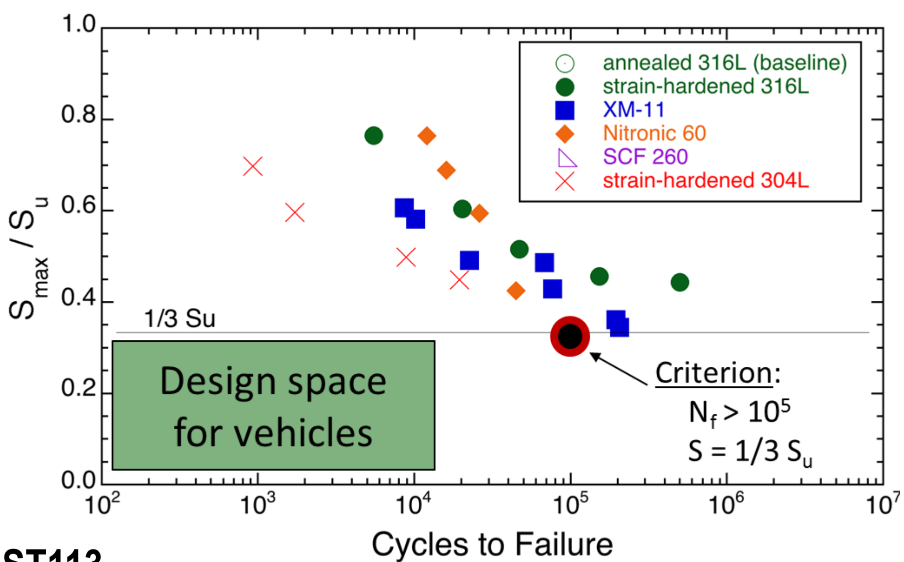
ST126

Addressing cost through reduced carbon fiber use

Accomplishments - Project Highlights

Alternative Materials for BOP [SNL/Hy-Performance Materials]

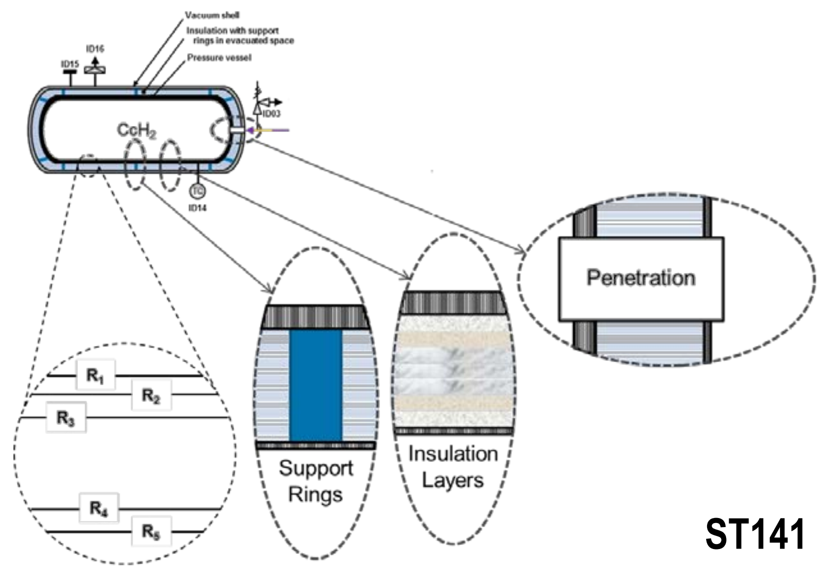
- Identifying alternative alloys to lower BOP cost and weight through testing and computational material screening
- **Identified alloys with potential to reduce cost and weight by >50% compared to 316L SS baseline**



ST113

Insulation for Cryogenic Storage Tanks [Vencore/Aspen Aerogels/Energy Florida/Hexagon Lincoln/IBT/NASA-KSC/SRNL]

- Developing integrated advanced insulation system capable of meeting dormancy requirements for vehicle applications
- **Down-selection of concept technologies in-progress**



ST141

Addressing Balance-of-Plant

Cross-cutting: *IACMI-The Composites Institute*

The Institute for iacmi Advanced Composites Manufacturing Innovation

THE COMPOSITES INSTITUTE

Institute for Advanced Composites Manufacturing Innovation

- Institute of Manufacturing USA
- Managed by the EERE Advanced Manufacturing Office
- Technology Focus Areas:
  - Vehicles
  - Wind Turbine Blades
  - **Compressed Gas Storage Vessels**
  - Design, Modeling & Simulation
  - **Composite Materials & Processes**

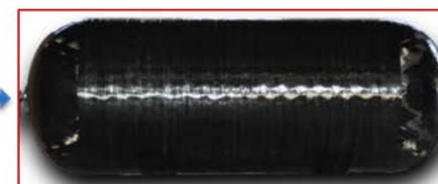
Leveraged project: Thermoplastic Composite Compressed Gas Storage Tanks

- Project lead: DuPont
- Partners:
  - Composite Prototyping Center (CPC)
  - Steelhead Composites
  - University of Dayton Research Institute (UDRI)
- Kick-off: FY2017, Q1

DuPont thermoplastic PA resins

DuPont PA impregnated Tape

Carbon fiber heavy tow



Leveraging efforts of the Institute for Advanced Composites Manufacturing Innovation

Materials-Based Storage Activities

HyMARC: *Hydrogen Materials – Advanced Research Consortium*

Enabling twice the energy density for onboard H_2 storage

Individual projects

- **Applied materials development**
  - Novel material concepts
  - High-risk, high-reward
- **Concept feasibility demonstration**
- **Advanced development of viable concepts**

National Laboratories

Core Team

- **Foundational research**
- **Material development tools**
  - Foundational R&D
  - Computational modeling development
  - Synthetic/characterization protocol development
- **Guidance to individual projects**
- **Database development**

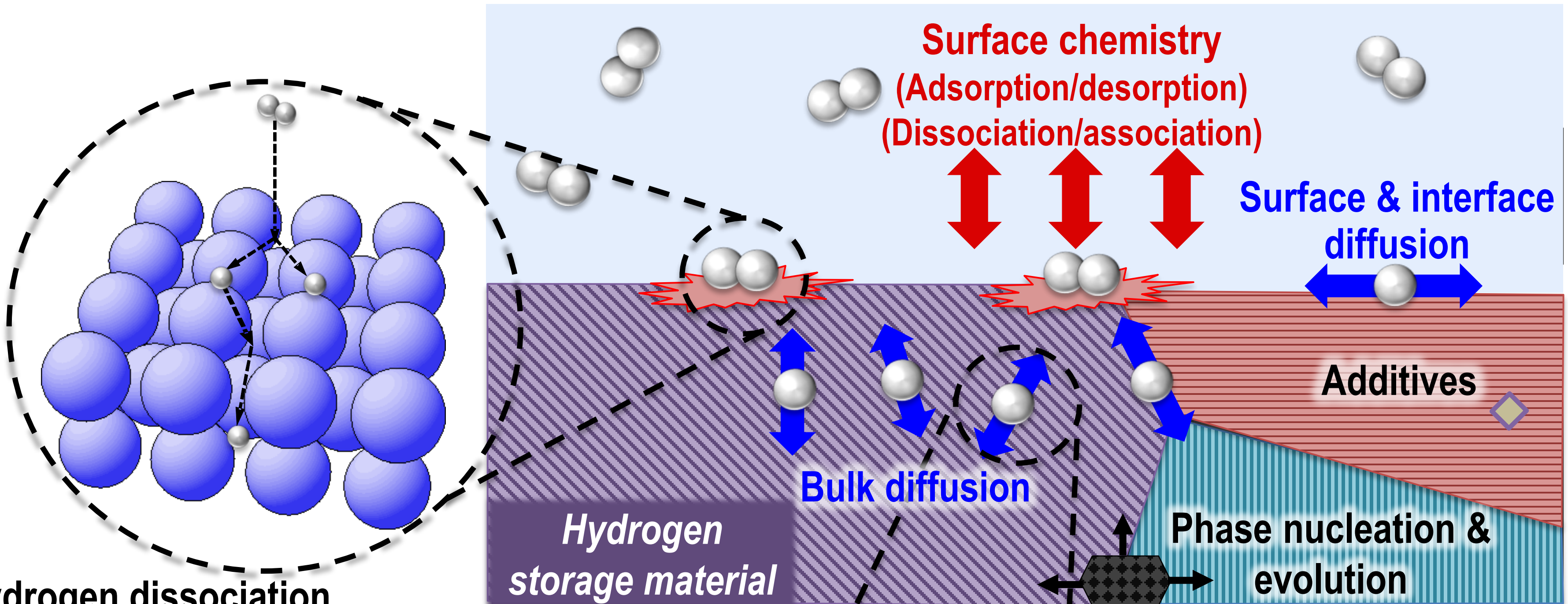
Characterization and Validation Team

- **Characterization resources**
  - "User-facility" for HyMARC projects
- **Characterization method development**
- **Validation activities**
  - Validation of Performance
  - Validation of "Theories"

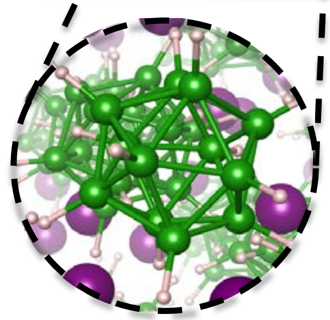
Energy Materials Network
U.S. Department of Energy

HyMARC – Understanding the phenomena of hydrogen interactions with materials

Effective thermal energy for H_2 release: $\Delta E(T) = \Delta H^{\circ}(T) + E_a$



Hydrogen dissociation and absorption



Chemical bonding

Task 1: Thermodynamics
Task 2: Transport
Task 3: Gas-surface interactions
Task 4: Solid-solid interfaces
Task 5: Additives and dopants
Task 6: Materials informatics

HyMARC – Hydrogen Materials Advanced Research Consortium
Enabling twice the energy density for onboard H_2 storage

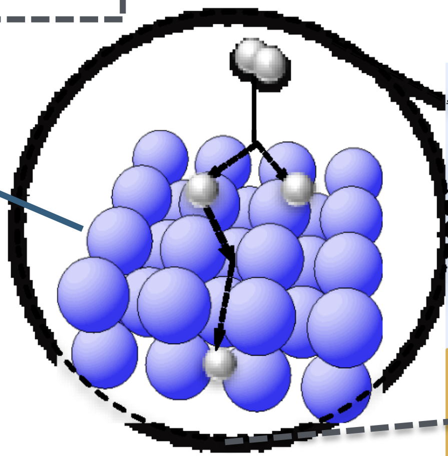
ST127, ST128, ST129, ST130

Focusing on overcoming thermodynamic and kinetic barriers simultaneously

HyMARC – Understanding the phenomena of hydrogen interactions with materials

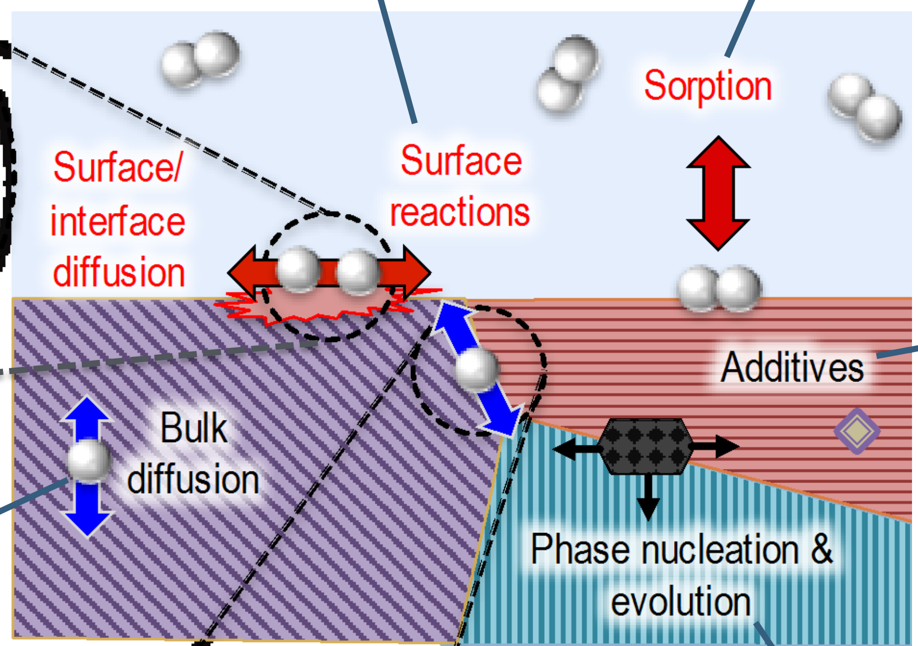
Thermodynamics:
- Mg-B-H, Li-N-H

- LEIS on model metals (Mg, W)



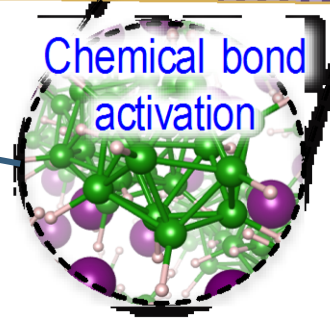
- Oxidation ($NaAlH_4$, $Mg(BH_4)_2$)
- H_2 dissociation (Mg, MgB_2)

- MOF-74, CuBTC
- Graphene (doped/ functionalized)



- $TiF_3/TiCl_3$
- Ti in $NaAlH_4$, $MgB_2/Mg(BH_4)_2$

- Isotropic interstitial diffusion (PdH_x)
- Anisotropic vacancy diffusion (MgH_2)
- Complex hydride diffusion ($Mg(BH_4)_2$)



- Borohydride decomposition pathways in MgB_xH_y

- Interstitial topotactic interface (Pd/PdH_x)
- Simple structural transformation (Mg/MgH_2)
- Complex reactive interface (MgB_xH_y /MgB_nH_m)

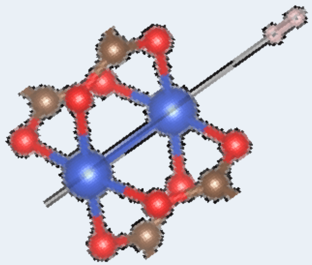
HyMARC
Enabling twice the energy density for onboard H_2 storage

ST127, ST128, ST129, ST130

Studying model systems to isolate physical factors and mechanisms

HyMARC accomplishments – *theory capabilities*

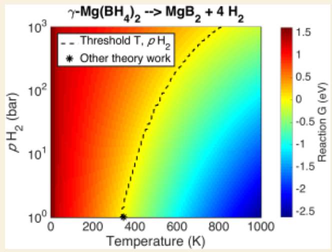
Improved sorbent isotherms



Recipes for integrating different levels of theory in sorbent isotherm models

Seedling: Chung/PSU

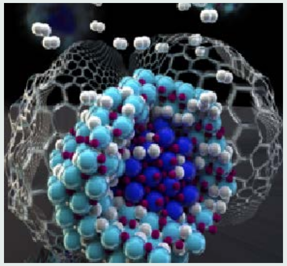
Accurate hydride thermodynamics



Finite-*T* free energy, environment- and morphology-dependent thermodynamics

Seedlings: Liu/ANL, Severa/U. Hawaii

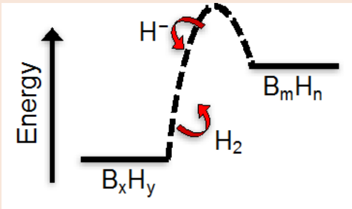
Solid mechanics & interfaces in hydrides



Internal and confinement stress effects; reactive diffuse interfaces

Seedlings: Liu/ANL, Severa/U. Hawaii

Kinetic modeling



Semiempirical kinetic modeling and rate analysis; phase evolution kinetics

Seedlings: Liu/ANL, Severa/U. Hawaii

Additional accomplishments in compiling databases and reference libraries ("Task 6"):

- ***Simulated & measured spectroscopy database (NMR, FTIR, XAS/XES) for identifying MgB_xH_y (preparing manuscript w/LBNL/SNL/HySCORE)***
- ***Library of analytical free energies for Li-N-H (published) and Mg-B-H (preparing manuscript), with validation at a range of pressures via NMR (w/SNL/HySCORE)***
- ***Database of classical potentials for simulating borohydride mixtures and interfaces (w/SNL)***

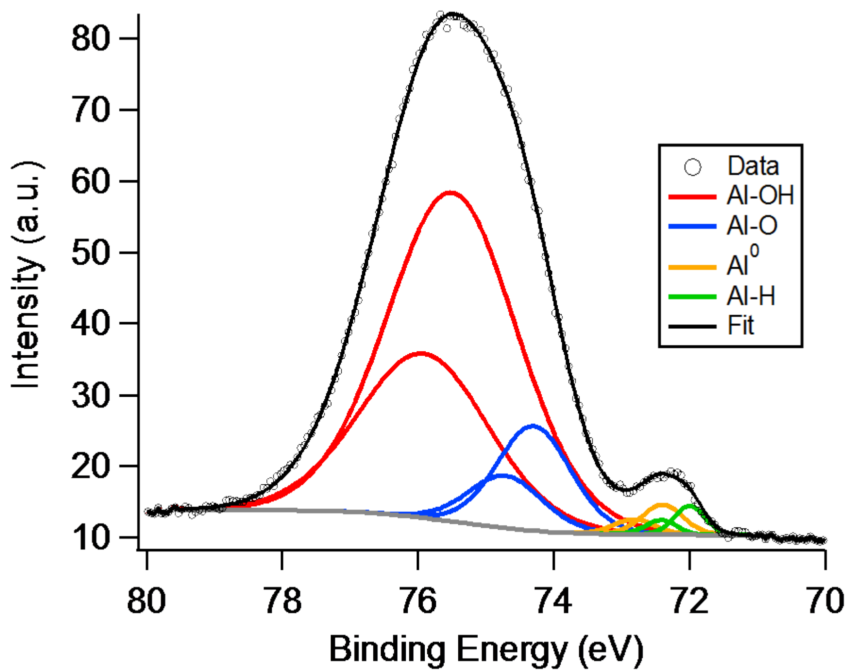
ST129

Seedling projects help focus theory method development prioritization

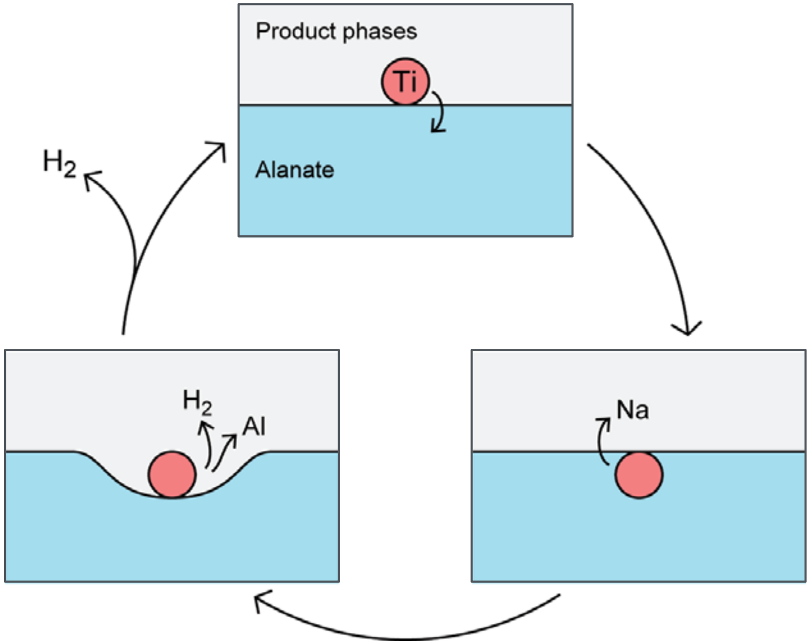
HyMARC accomplishment – understanding role of additives on sorption kinetics

- **Investigated model system Ti-doped $NaAlH_4$ via AP-XPS, LEIS and Auger spectroscopy**
  - Detected no Ti species on sample surface before or during desorption, reappears during absorption
  - Disproved models invoking surface Ti during dehydrogenation reaction

Four Al species detected by AP-XPS during dehydrogenation



Data supports proposed zipper mechanism

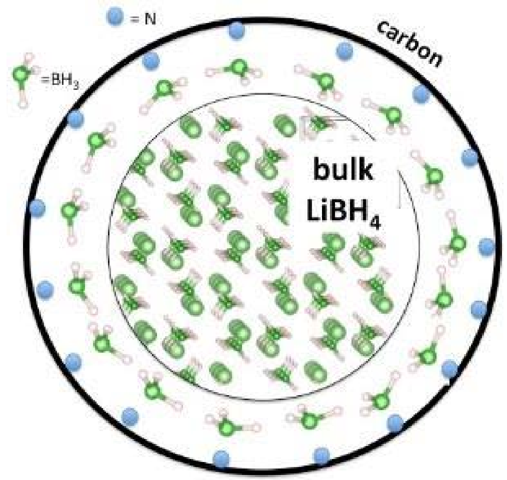


ST128

Chem. Rev. **2012**, *112*, 2164-2178

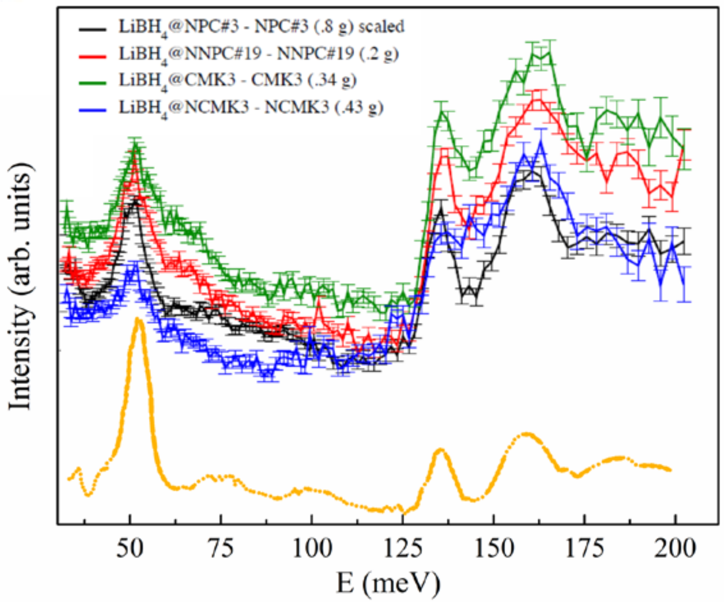
Proposed mechanisms are evaluated based on experimental data

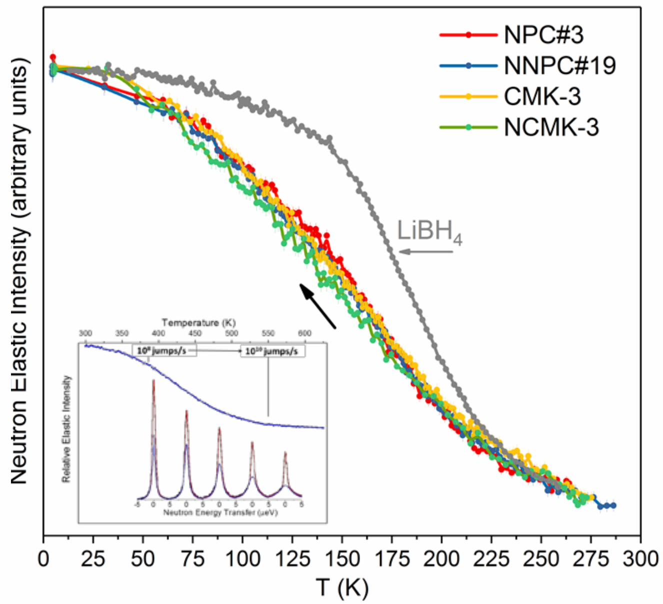
NREL and NCNR carries out neutron vibrational spectroscopy measurements on $LiBH_4$ infiltrated mesoporous carbon samples from UMSL



Can nanoconfinement in functionalized porous materials facilitate reversible hydrogen storage reactions?

- NVS show $LiBH_4$ infiltrated
- Shifting and broadening show there is an effect of confinement
- Degree of N-doping enhances BH_4^- orientational mobilities





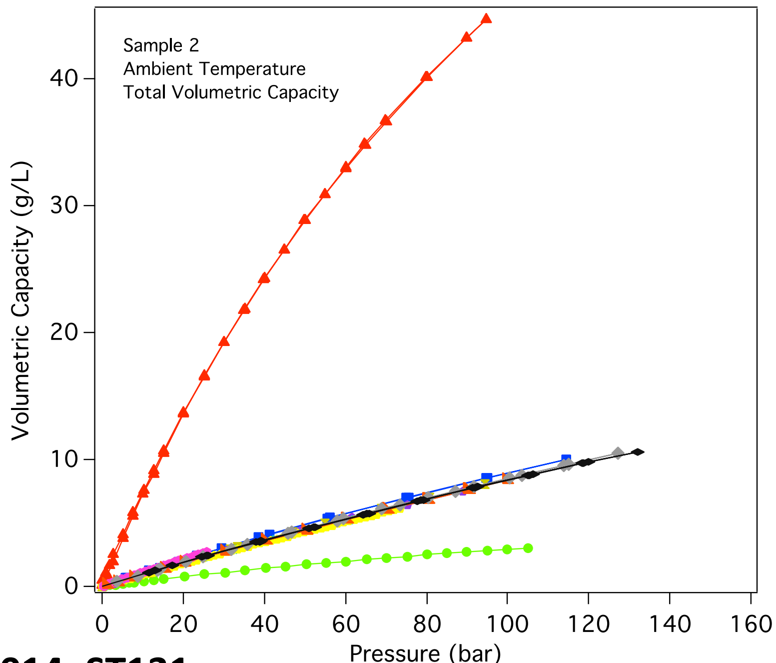
ST135, ST139

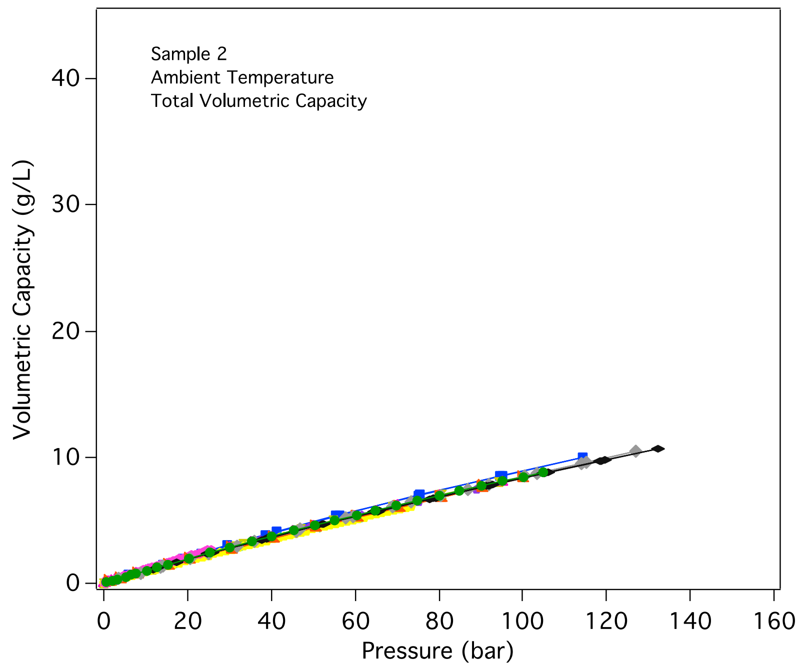
Accelerating rate of progress in the development of H_2 storage materials

HyMARC accomplishment – Validating hydrogen sorption measurements and reporting

Led an international inter-laboratory volumetric capacity H_2 adsorption measurement round-robin study

- Promoted valid comparisons of hydrogen-storage materials
  - necessary to evaluate implementations of protocols
- Decreased irreproducibility due to systematic and "black box" errors
  - NREL gives direct feedback on data
- Determining a "natural" spread of data from instrument and operator variables





ST014, ST131

Promoting standard protocols for performing and reporting sorption measurements

HyMARC accomplishment – Validating hydrogen sorption measurements and reporting

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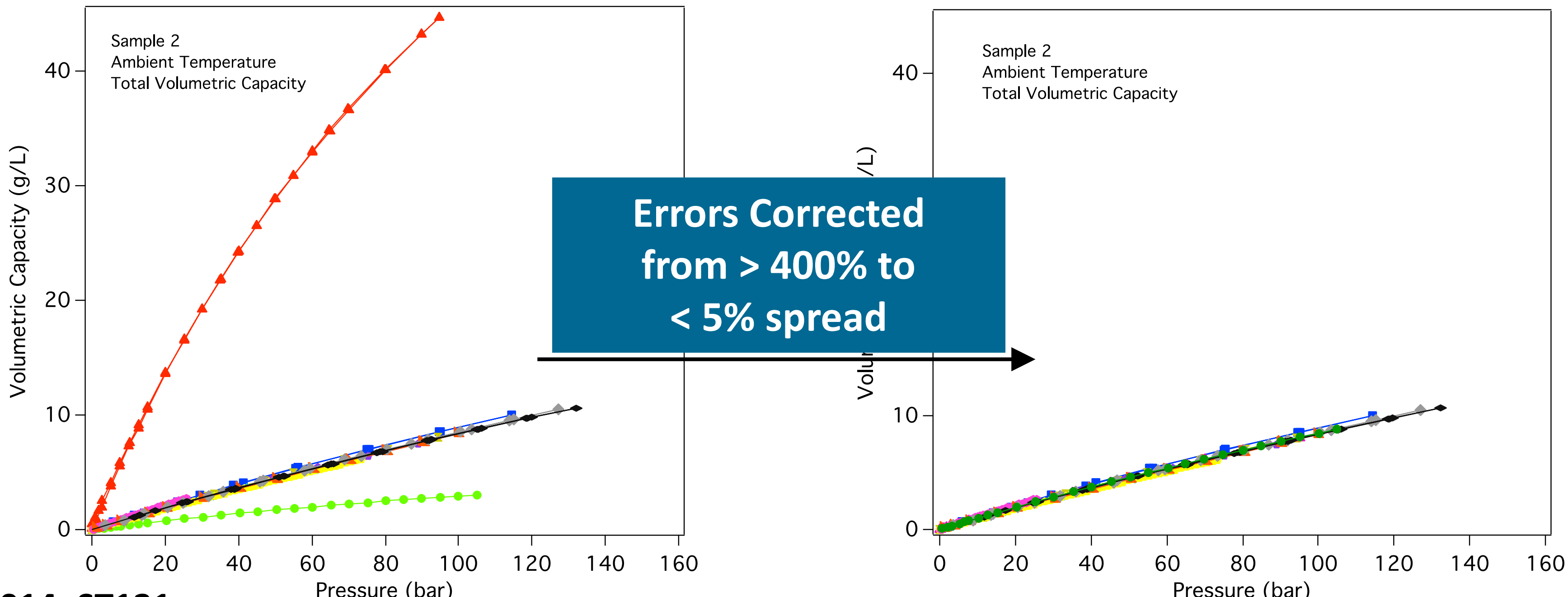


ST014, ST131

Promoting standard protocols for performing and reporting sorption measurements

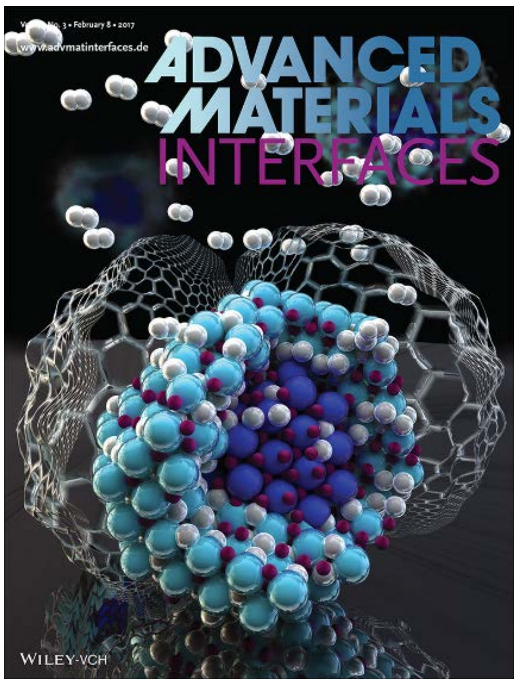
Accomplishments: Lab Team Publications

32: Publications published or submitted for publication

4: Patents applications submitted

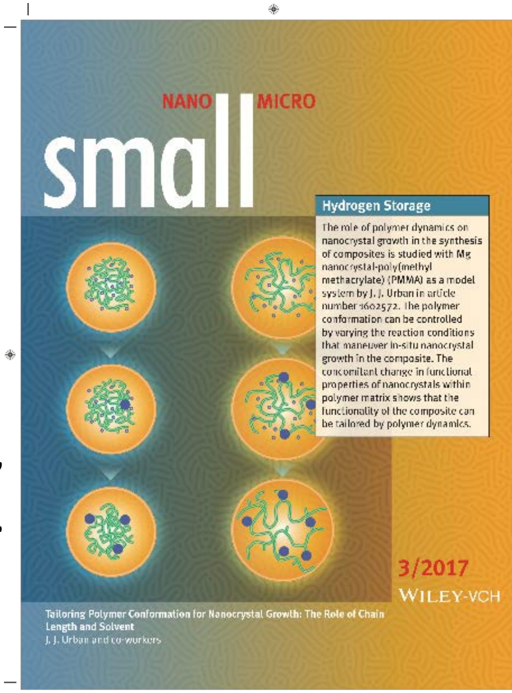
7: Manuscripts in preparation as of April 2017

2: Selected as cover features



B. C. Wood et al., *Advanced Materials Interfaces*, **2017**, *4*, 1600803.

E. S. Cho, J. J. Urban et al., *Small, in press* (2017).

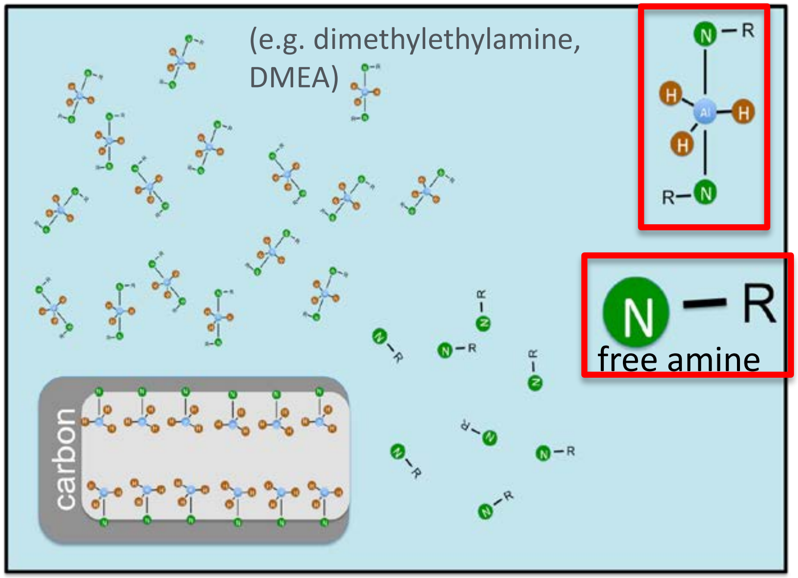


The lab teams are producing high-value R&D and disseminating it to the R&D community

Accomplishments - HyMARC Project Highlights

Surface functionalized mesoporous carbons [HyMARC seedling—UMSL]

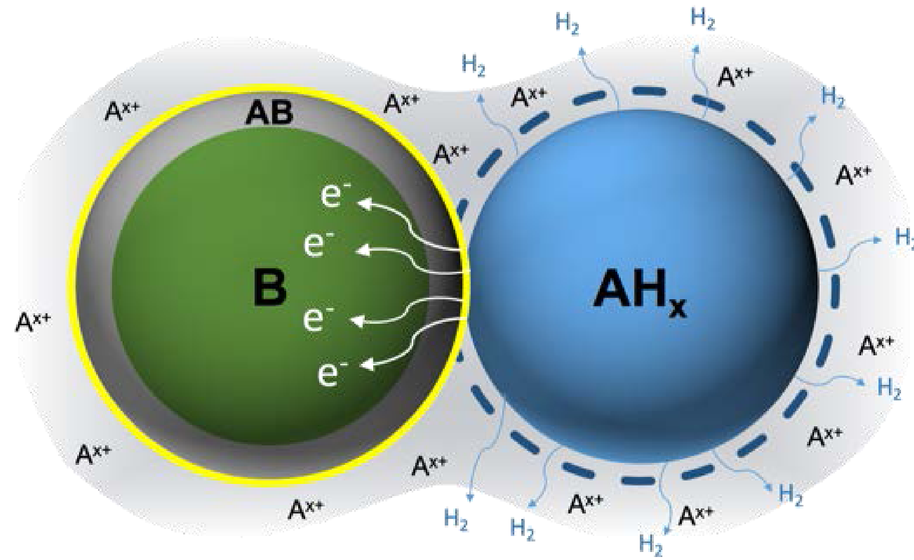
- Demonstrating ability of functionalized mesoporous carbons to facilitate reversible H_2 sorption reactions of hydride materials
- **Prepared N-doped carbons and demonstrated infiltration of Al and B-based materials**



ST139

Electrolyte Assisted Storage Reactions [HyMARC seedling—Liox Power]

- Improving reaction kinetics through use of electrolytes to facilitate atomic rearrangement and diffusion
- **Have carried out initial screening studies of possible electrolytes**



ST137

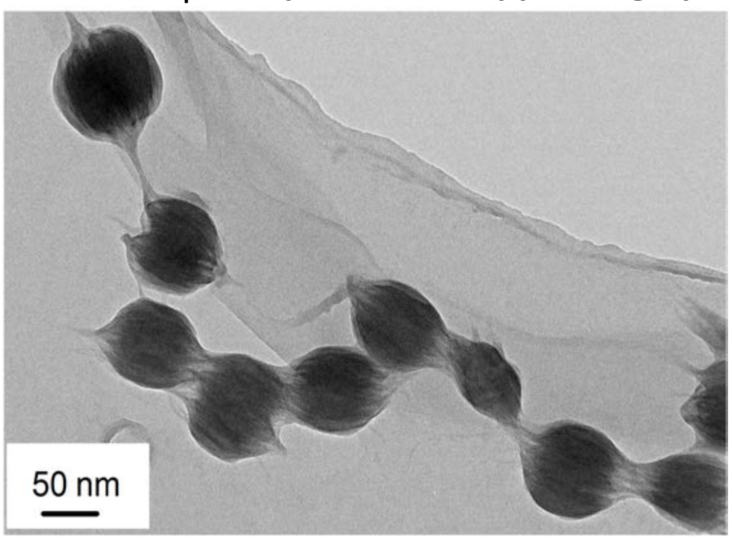
Accelerating development of improved hydrogen storage materials

Accomplishments - HyMARC Project Highlights

"Graphene-wrapped" hydrides [HyMARC seedling—ANL]

- Encapsulating nanoparticles of complex hydrides with graphene to enhance reversibility and kinetics
- **Demonstrated 9 wt% uptake in $NaBH_4$ systems with 80% regenerable release over 6 cycles**

SEM of $NaBH_4$ nanoparticles wrapped in graphene

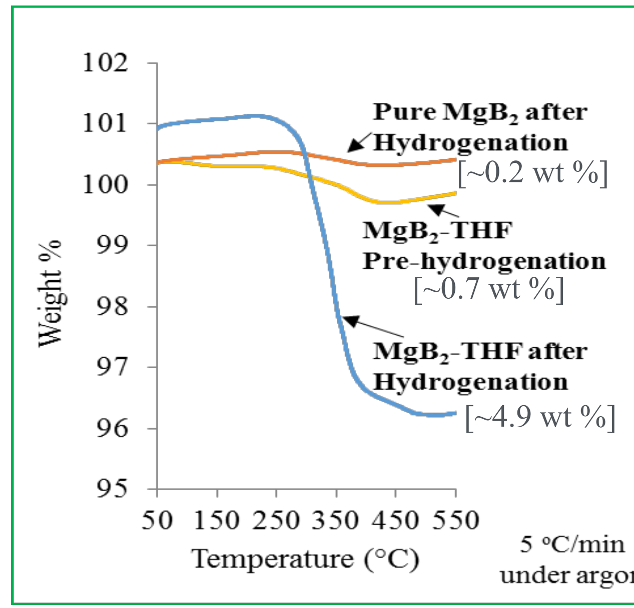


ST136

Magnesium boride etherates [HyMARC seedling—U. Hawaii]

- Improve reversibility of $Mg(BH_4)_2$ through formation of MgB_2-etherates
- **Demonstrated the formation of significant amounts of β-$Mg(BH_4)_2$ at 300 °C**

TGA of hydrogenated ball milled MgB_2-THF



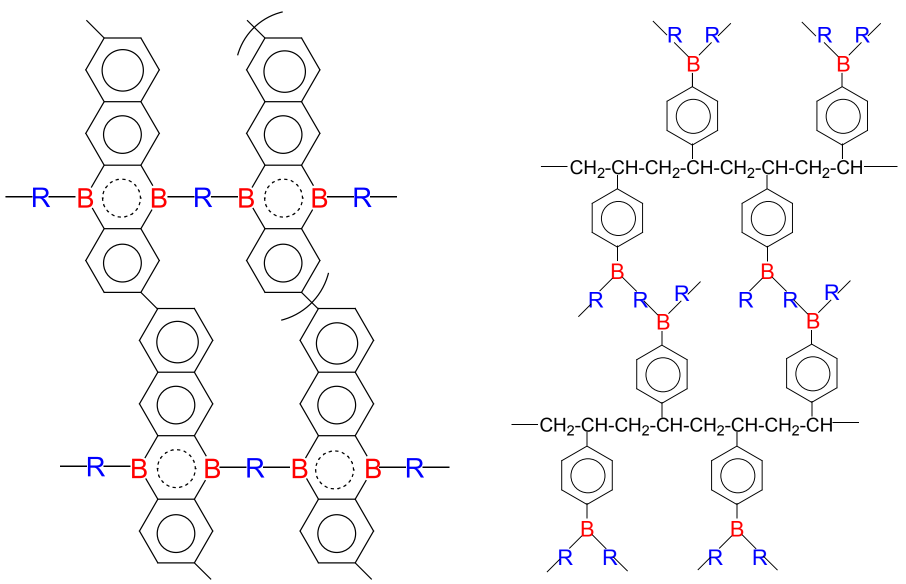
ST138

Accelerating development of improved hydrogen storage materials

Accomplishments - HyMARC Project Highlights

Novel boron-containing polymers [HyMARC seedling—Penn State]

- Developing novel boron containing porous polymers with higher H_2 binding energy
- **Designed and synthesized two new classes of microporous polymers that contain boron.**

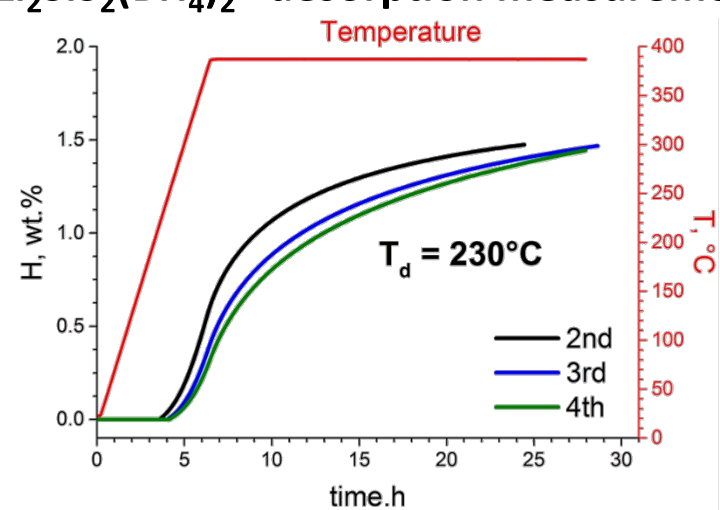


ST140

High-capacity Hydrogen Storage Materials via Mechanochemistry [Ames Laboratory]

- Prepare high hydrogen capacity silicon-based borohydrides through mechanochemical methods
- **Demonstrated several new materials with reversibility for part of their total capacity**

“$Li_2SiS_2(BH_4)_2$” desorption measurements



ST119

Accelerating development of improved hydrogen storage materials

FY2017 FOA Topic

- **Hydrogen Storage Materials Discovery (HyMARC)**
  - innovative, high-risk, high-payoff concepts for hydrogen storage materials
  - project teams will be integrated into HyMARC as individual projects
  - phase I Go/No-Go milestone must provide confidence that the proposed concept has reasonable potential to result in a hydrogen storage material capable of meeting automotive performance requirements

- Areas of interest:
  - novel, advanced <u>onboard-rechargeable</u> hydrogen storage materials
  - physi- and chemisorption materials acceptable

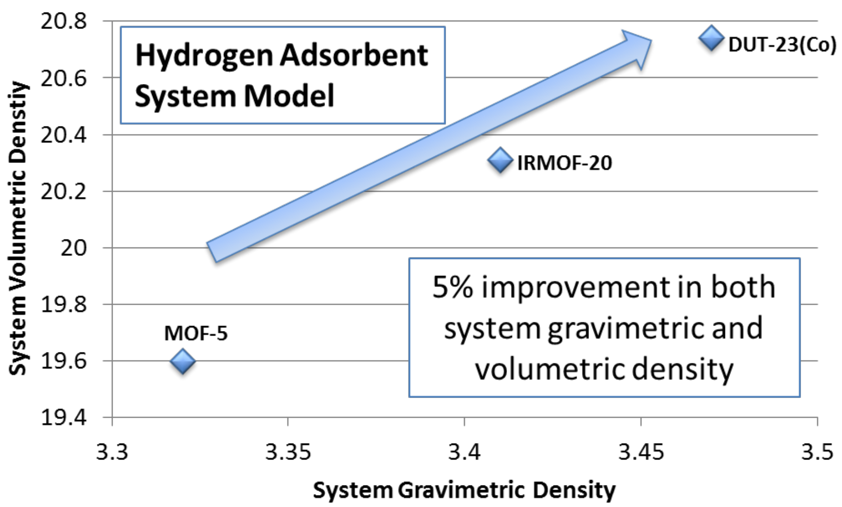
- Only Phase I effort will be supported until Go/No-Go criteria is met, additional support will be contingent on meeting criteria

Accelerating development of improved hydrogen storage materials

Accomplishments - Project Highlights

Computational Screening of MOFs with High Volumetric Density [U. Michigan]

- Identifying high-performing MOF's through screening of large structure databases
- **Synthesized and tested several MOFs for their H_2 adsorption properties; IRMOF-20 and DUT-23(Co) both projected to surpass MOF-5 in system performance**

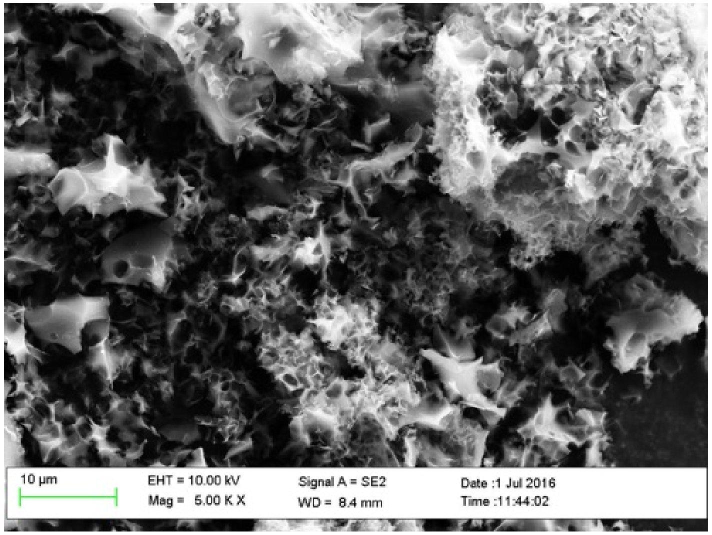


ST122

Graphene-based carbon sorbents [Caltech]

- Design and synthesize porous graphene materials as high-capacity H_2 sorbents
- **Demonstrated progress in preparing high-surface area carbons and inserting metal atoms to achieve higher heats of adsorption**

SEM of high surface area graphene prepared from graphene oxide



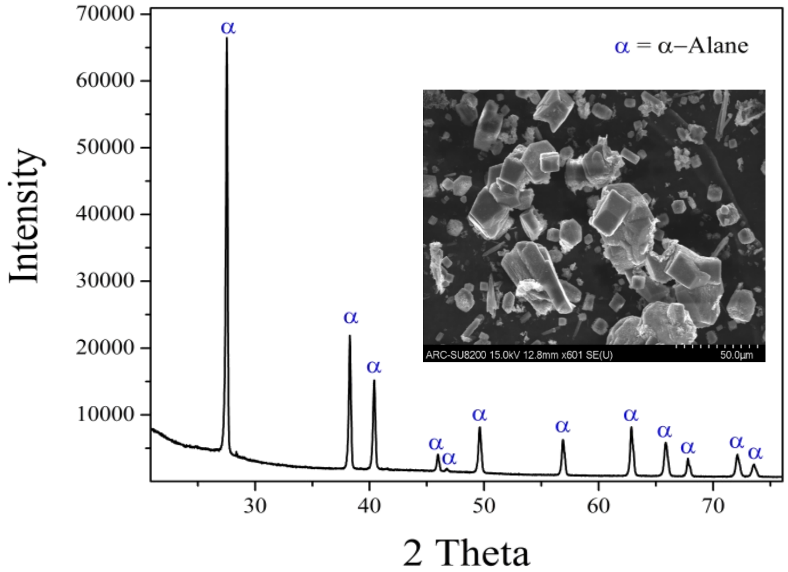
ST120

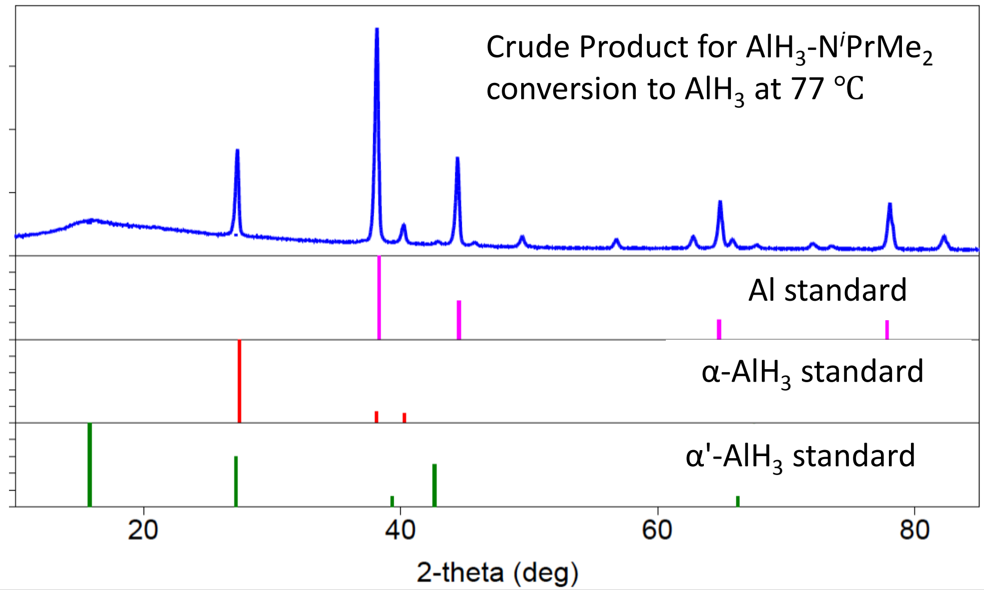
Developing improved adsorbent storage materials

Low-cost methods for α-alane production [SRNL, Greenway; Ardica, SRI]

- Developing and demonstrating low-cost processes for scale-up of alane (AlH_3) preparation
- **Demonstrated improved crystallization and passivation process to produce high-purity, stable α–alane from chemical synthesis in batches of up to 200 grams (SRNL, Greenway)**
- **Demonstrated ability to yield α-alane from electrochemical synthesis, however further improvements are needed (Ardica, SRI)**

XRD of crystalized α-alane from chemical (left) and electrochemical (right) syntheses





ST063 **ST116**

Developing low-cost α-alane (AlH_3) production processes

Engineering

Accomplishments - Project Highlights

Maintenance and Enhancements for HSECoE Models [NREL/PNNL/SRNL]

- Collaborative effort to maintain, update and enhance system models developed under HSECoE to provide a resource to hydrogen storage materials developers
- Posted models include metal hydride, chemical, and sorbent H_2 storage systems
- **Improved framework utility for materials researchers through new isotherm fitting and estimator tools.**

Improved Website
HSECoE.org

Materials Properties

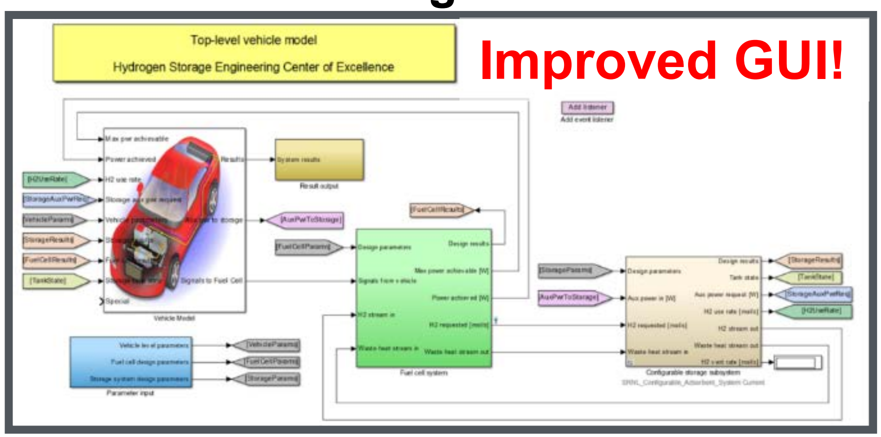
New Isotherm Fitting Tool

New System Estimator Tool

Stand-Alone Values

Estimated Gravimetric & Volumetric Capacity

Modeling Framework



DOE Technical Targets

HSECoE

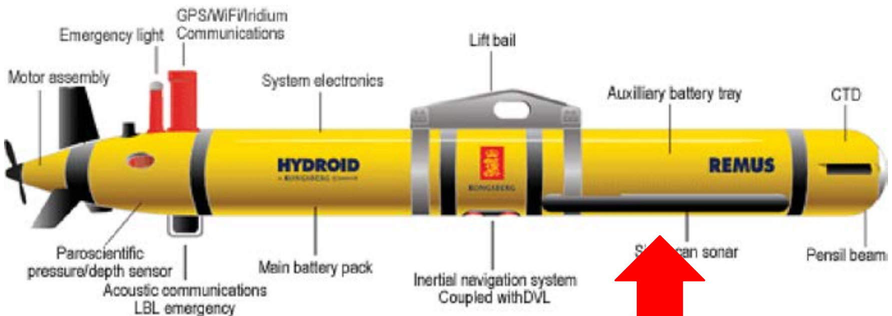
ST008

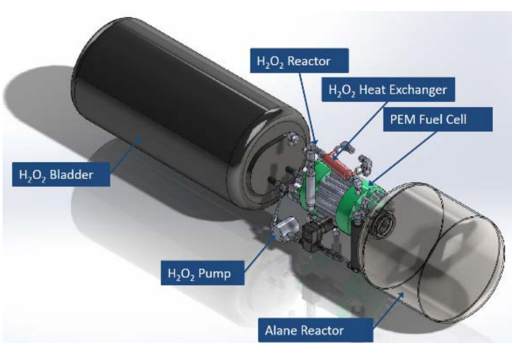
Online system models maintained and accessible to the research community

Accomplishments - Project Highlights

Materials-based H_2 Storage for UUV Applications [SRNL/US Navy/Ardica]

- Developing a materials-based H_2 storage system to extend UUV mission duration
- **Preliminary analysis indicate ≥2 times longer mission capability over battery operation**





Fuel cell system to replace the auxiliary battery tray

Metal Hydride H_2 Storage for Forklift Applications [Hawaii H_2 Carriers/SRNL]

- ***Small Business Voucher*** project to demonstrate MHHS performance on a forklift under realistic conditions and its fast fill capabilities; perform preliminary DFMA analysis
- **System originally designed and built under a SBIR program**

ST134

Leveraging HSECoE models and capabilities for high-value applications

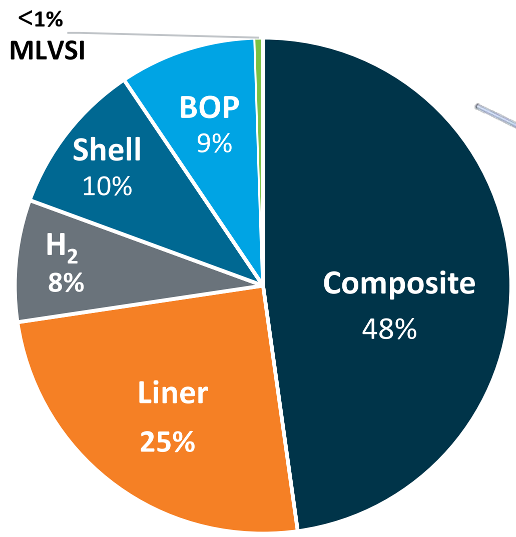
Analysis

Hydrogen Storage System Performance [ANL] and Cost Analyses [SA/PNNL/ANL]

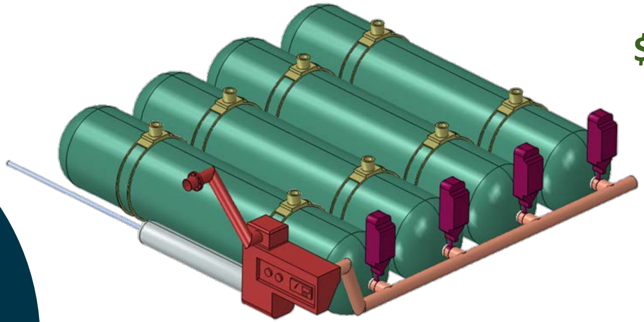
- Analyses are carried out to estimate system performance and cost of various technologies to help identify focus areas for the Program and to gauge technology development progress
- Cryo-compressed H_2 storage systems were evaluated for heavy duty fleet (bus) applications
- **500 bar, 40 kg H_2 capacity systems projected to be able to achieve 7.3 wt.% and 43 g/L storage densities with a cost of $15/kWh**

Analysis of a 40 kg H_2 capacity, 500 bar cryo-compressed system for bus applications

Weight breakdown

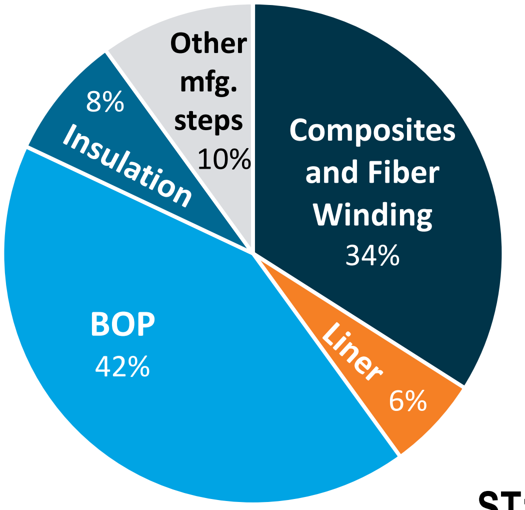


ST001



Cost Breakdown @ 5000/yr

$19,907/System @ $14.93/kWh



ST100

Techno-economic and performance analyses used to target key R&D areas

Collaborations

Energy Materials Network
U.S. Department of Energy

DOE – EERE - FCTO
Hydrogen Storage Applied R&D

- Physical Storage
- Fiber Composites
- Materials-based Storage
- System Engineering
- Testing and Analysis

INDUSTRY

- U.S. DRIVE
  Tech teams:
  - H_2 Storage
  - H_2 Delivery
  - Codes & Standards
  - Fuel Cells
  - Fuel Pathways
  - Vehicle Systems

INTERNATIONAL ACTIVITIES

- IEA HIA Task 32
  Hydrogen-based Energy Storage

TECHNOLOGY VALIDATION

National Collaborations (inter- and intra-agency efforts)

U.S. DEPARTMENT OF ENERGY — Energy Efficiency & Renewable Energy

U.S. DEPARTMENT OF ENERGY — Office of Science

arpa·e

NIST Center for Neutron Research

Department of the Navy · Department of the Army

Collaborating and leveraging of national and international activities

Summary

- **Physical Storage**
  - Focus is on developing technologies to lower the cost of 700 bar systems
  - On-going projects on alternative materials and manufacturing processes
  - Conformable tank designs may provide improved packaging onboard vehicles
  - FOA topic on low-cost, alternative precursors for high-strength carbon fiber
- **Materials-based Storage**
  - Focus is to accelerate development of H_2 storage materials with targeted properties
  - HyMARC core team performing foundational research to develop computational tools
  - Rechargeable metal hydrides and hydrogen sorbents are primary materials areas
  - First round of seedling projects underway and FOA topic to select second round
  - Engineering activities leverage prior work to meet needs of high-value applications

FY 2017	FY 2018
• HyMARC team to prepare sorbent strategy prioritization • First round of seedlings working with HyMARC • Second round of seedlings to be selected • Low-cost high-strength CF precursor projects to be selected	• First round of seedlings have go/no-go decisions • Second round of seedlings working with HyMARC • Low-cost high-strength CF precursor projects up and running

Contacts – H_2 Storage Team

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http://energy.gov/eere/fuelcells/fuel-cell-technologies-office

BACK UP

HyMARC: Accelerating the discovery of breakthrough H_2 storage materials

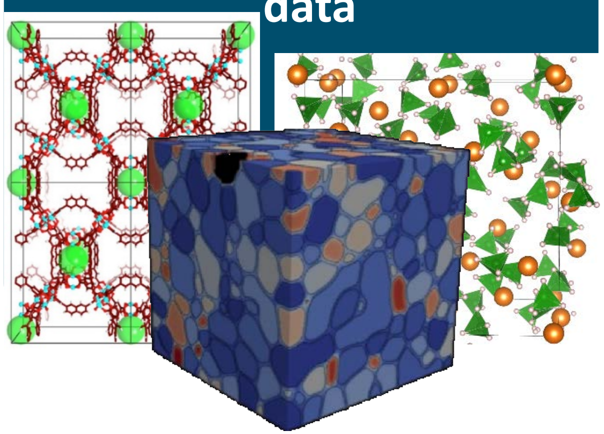
HyMARC provides **capabilities** and **foundational understanding** of phenomena governing thermodynamics and kinetics for the development of solid-state hydrogen storage materials

HyMARC delivers **community tools and capabilities:**

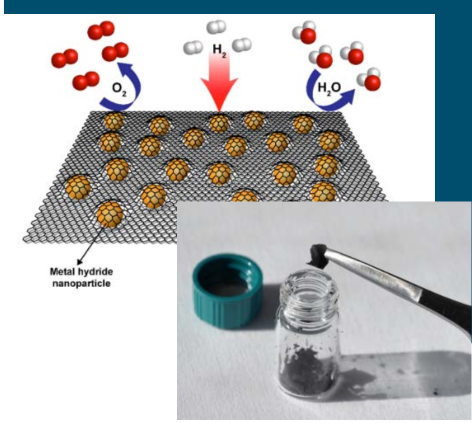
- **Computational models and databases** for high-throughput materials screening
- **New characterization tools and methods** (surface, bulk, soft X-ray, synchrotron)
- **Tailorable synthetic platforms** for probing nanoscale phenomena

Website: hymarc.org

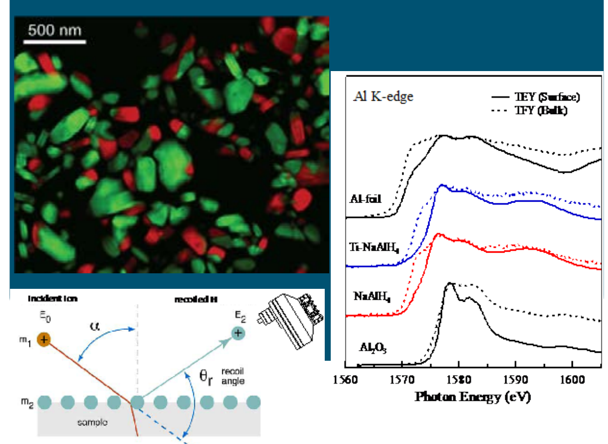
Theory, simulation, & data



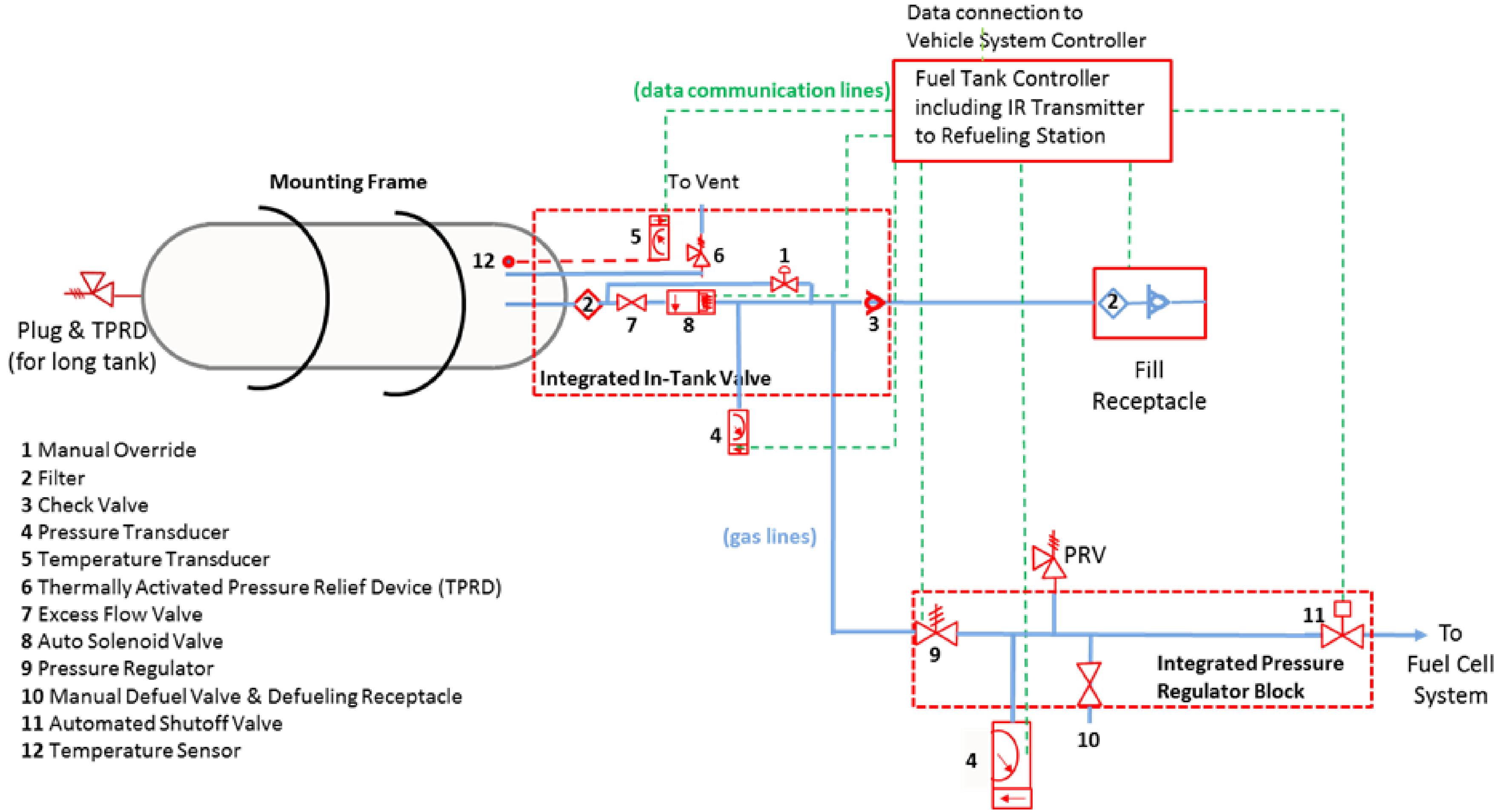
Controlled synthesis



In situ characterization



Single tank system schematic

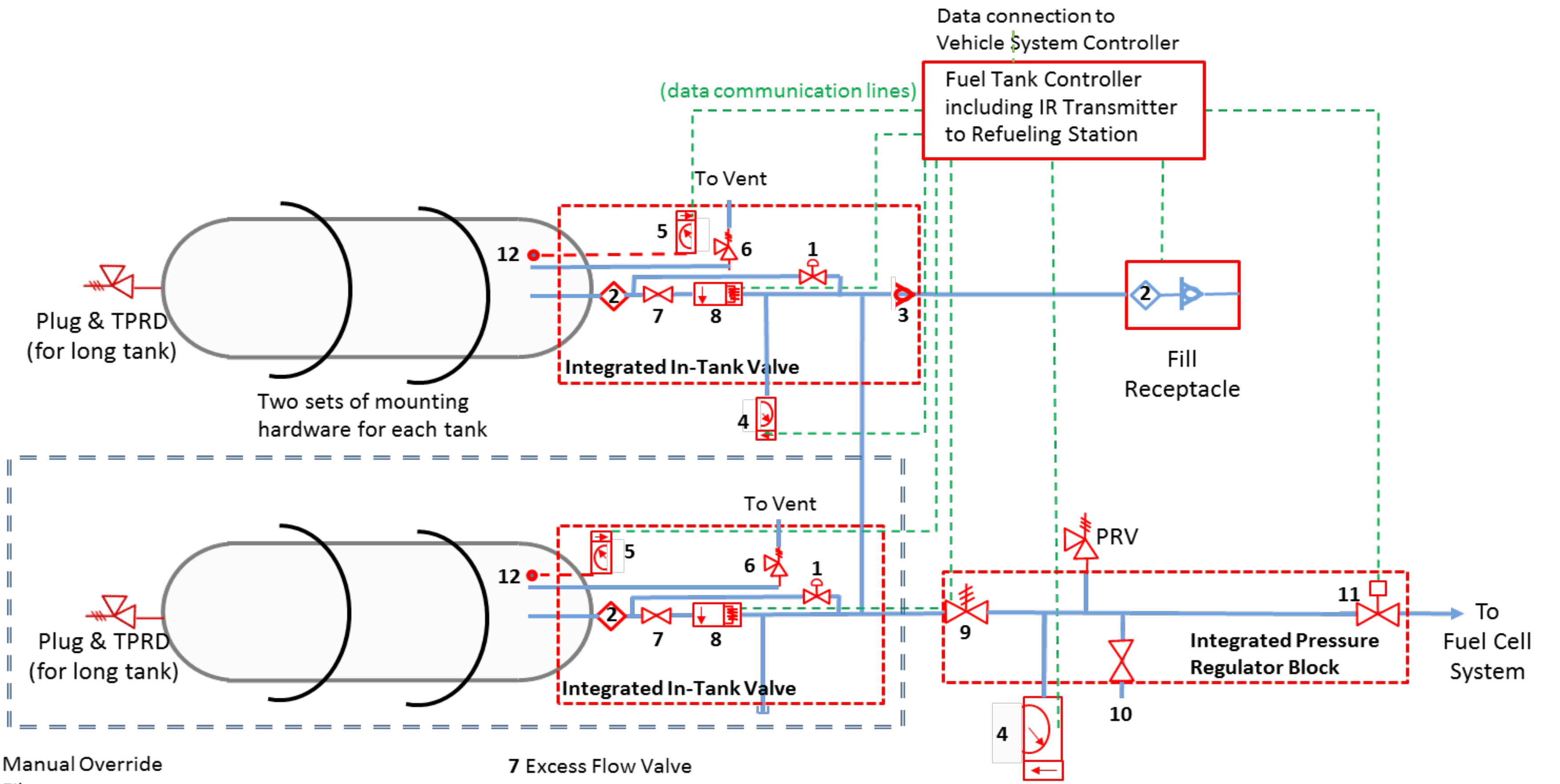


1 Manual Override
2 Filter
3 Check Valve
4 Pressure Transducer
5 Temperature Transducer
6 Thermally Activated Pressure Relief Device (TPRD)
7 Excess Flow Valve
8 Auto Solenoid Valve
9 Pressure Regulator
10 Manual Defuel Valve & Defueling Receptacle
11 Automated Shutoff Valve
12 Temperature Sensor

Lowest cost, but most difficult to package onboard a vehicle

Baseline system projections based on single tank design

Dual tank system schematic



1 Manual Override
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8 Auto Solenoid Valve
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10 Manual Defuel Valve & Defueling Receptacle
11 Automated Shutoff Valve
12 Temperature Sensor

Higher cost, but most easier to package onboard a vehicle

All current commercial FCEVs have dual tank designs