An Overview of U.S. DOE's Activities for Hydrogen Fuel Cell Technologies

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

Materials Challenges in Alternative & Renewable Energy

Clearwater, Florida

2/27/2012

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Storage Team Lead
U.S. Department of Energy
Fuel Cell Technologies Program

Program Mission

The mission **of the Hydrogen and Fuel Cells Program is to enable the widespread commercialization of hydrogen and fuel cell technologies through:**

- basic and applied research
- technology development and demonstration
- addressing institutional and market challenges

Achieving this mission will help reduce greenhouse gas emissions and oil consumption while advancing renewable energy.

Key Goals: **Develop hydrogen and fuel cell technologies for:**

1. **Early markets** *(e.g., stationary power, forklifts, portable power)*
2. **Mid-term markets** *(e.g., residential CHP, auxiliary power, buses and fleet vehicles)*
3. **Longer-term markets, 2015-2020** *(including mainstream transportation, with focus on passenger cars)*

Fuel Cells: *Benefits & Market Potential*

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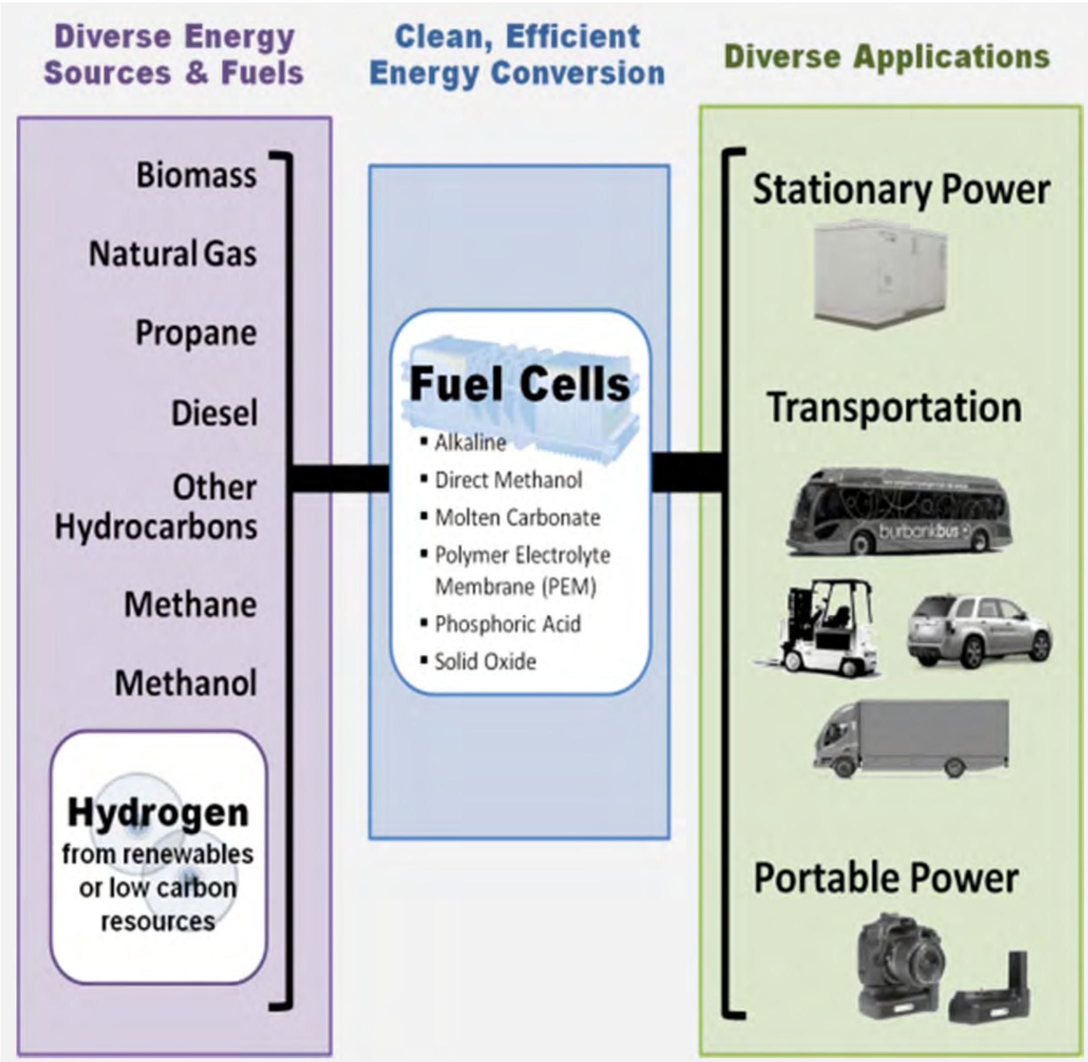
The Role of Fuel Cells



Key Benefits

Very High Efficiency

- **> 60%** *(electrical)*
- **> 70%** *(electrical, hybrid fuel cell / turbine)*
- **> 80%** *(with CHP)*

Reduced CO_2 Emissions

- **35–50%+ reductions** *for CHP systems (>80% with biogas)*
- **55–90% reductions** *for light-duty vehicles*

Reduced Oil Use

- **>95% reduction** *for FCEVs (vs. today's gasoline ICEVs)*
- **>80% reduction** *for FCEVs (vs. advanced PHEVs)*

Reduced Air Pollution

- **up to 90% reduction in criteria pollutants** *for CHP systems*

Fuel Flexibility

- **Clean fuels** — *including biogas, methanol, H_2*
- **Hydrogen** — *can be produced cleanly using sunlight or biomass directly, or through electrolysis, using renewable electricity*
- **Conventional fuels** — *including natural gas, propane, diesel*

DOE H_2 Fuel Cells Program Strategy

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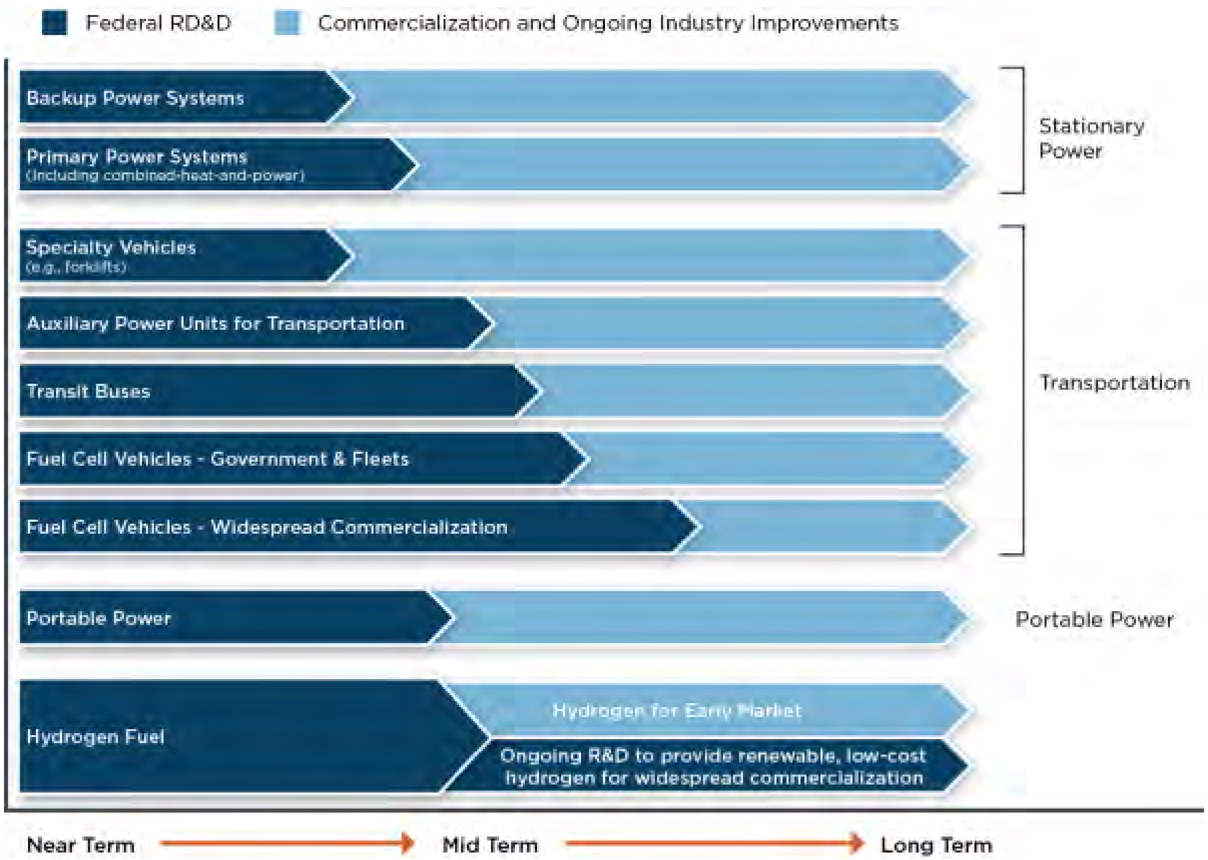
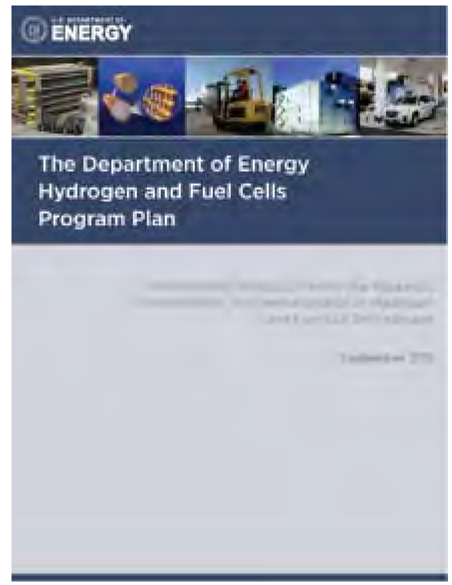
DOE's Hydrogen and Fuel Cells Program follows an integrated strategic plan for research, development, and demonstration activities





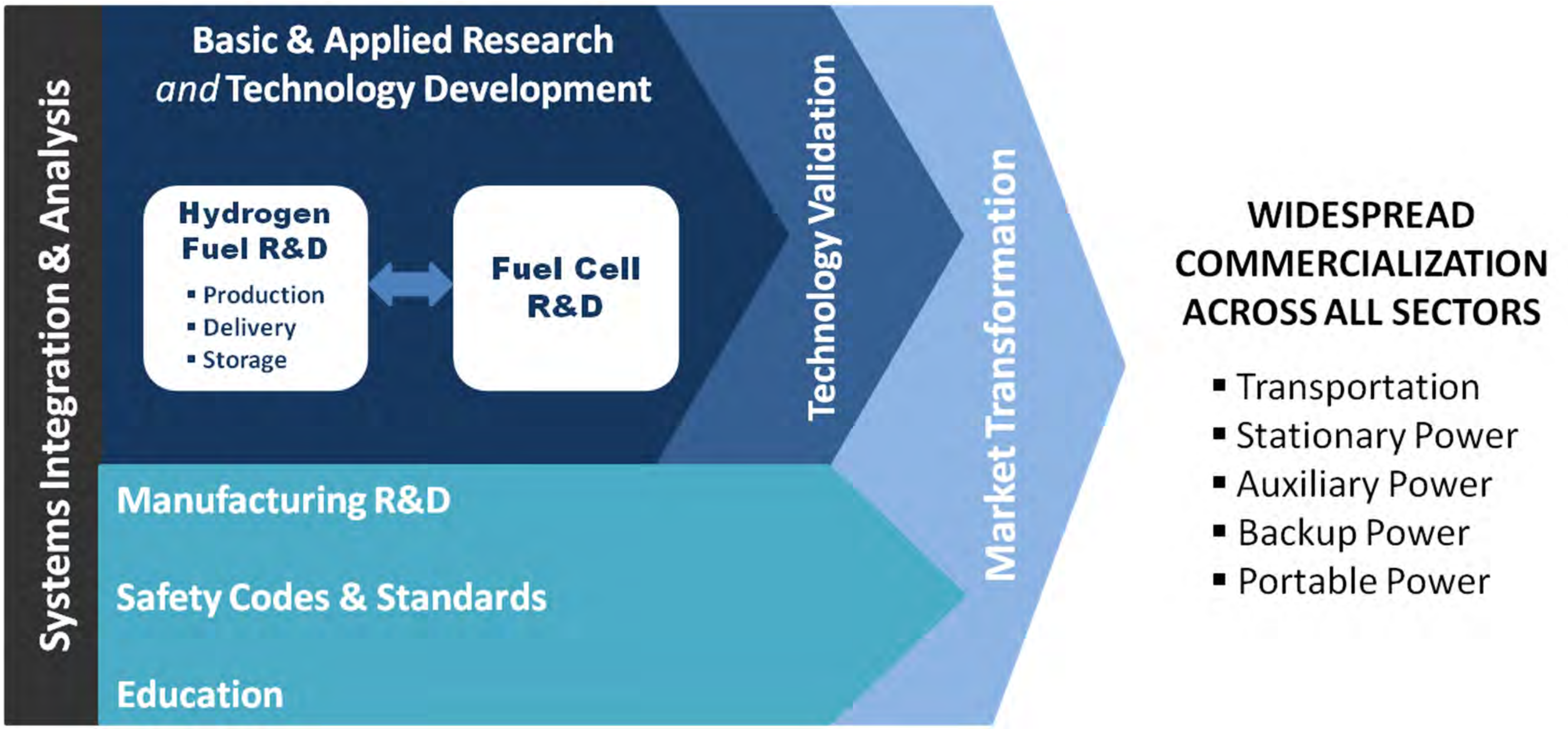
Update to the Hydrogen Posture Plan (2006)

Program efforts are planned to transition to industry as technologies reach commercial-readiness.

Released September 2011

http://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/program_plan2011.pdf

DOE Program Structure



Nearly 300 projects currently funded

at companies, national labs, and universities/institutes

More than $1B DOE funds spent from FY 2007 to FY 2011

Hydrogen Storage Targets

Targets are for complete systems, therefore engineering analysis is needed to project system characteristics/properties

Storage Target	Units	2010	2017	Ultimate
System Gravimetric Capacity: [Usable net energy/H_2]	kWh/kg (kg H_2/kg system)	1.5 (0.045)	1.8 (0.055)	2.5 (0.075)
System Volumetric Capacity: [Usable net energy/H_2]	kWh/L (kg H_2/L system)	0.9 (0.028)	1.3 (0.040)	2.3 (0.070)
Storage System Cost: [initial targets ($/kWh): 4 (2010), 2 (2015)]	$/kWh net ($/kg H_2)	TBD (TBD)	TBD (TBD)	TBD (TBD)

Complete listing of the ***more than 20*** DOE performance targets for onboard hydrogen storage systems for light-duty vehicles can be found online at:
http://www1.eere.energy.gov/hydrogenandfuelcells/storage/pdfs/targets_onboard_hydro_storage.pdf

Challenge of Hydrogen Storage

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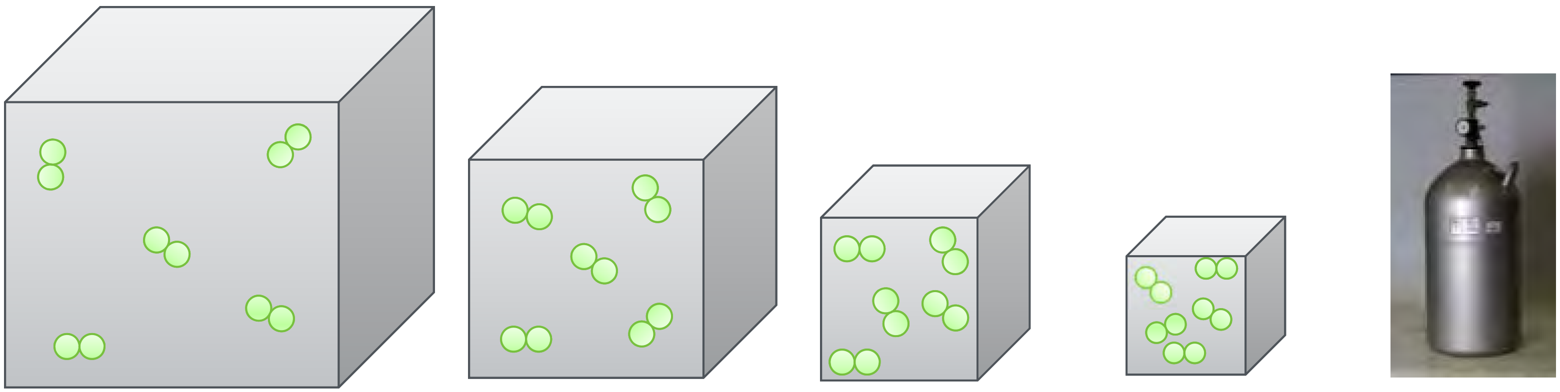
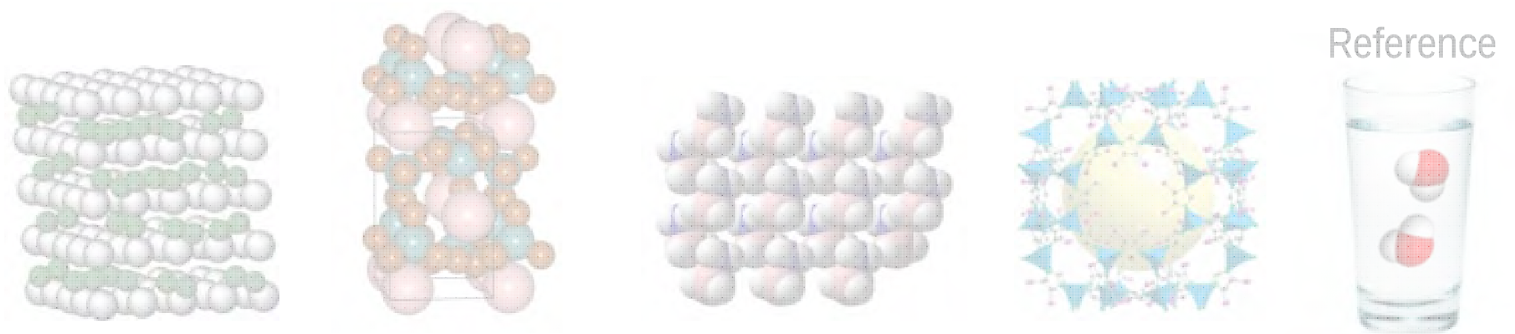
Storing adequate amounts of hydrogen in an acceptably small volume in an efficient and cost-effective way is a critical challenge in commercialization of hydrogen technologies.

Physical Storage



1 bar	150 bar	350 bar	700 bar	liquid H_2
normal	lab cylinders	Gen 1 vehicles	Gen 2 vehicles	71 g H_2/L
0.3 g/L	10 g/L	28 g/L	40g/L	@ 20 K

Materials -based Storage



interstial hydrides	complex hydrides	chemical storage	sorbents	Reference water
~100-150 g H_2/L	~70-150 g H_2/L	~70-150 g H_2/L	$\leq$ 70 g H_2/L	111 g H_2/L

Near-Term Option: Compressed Gas

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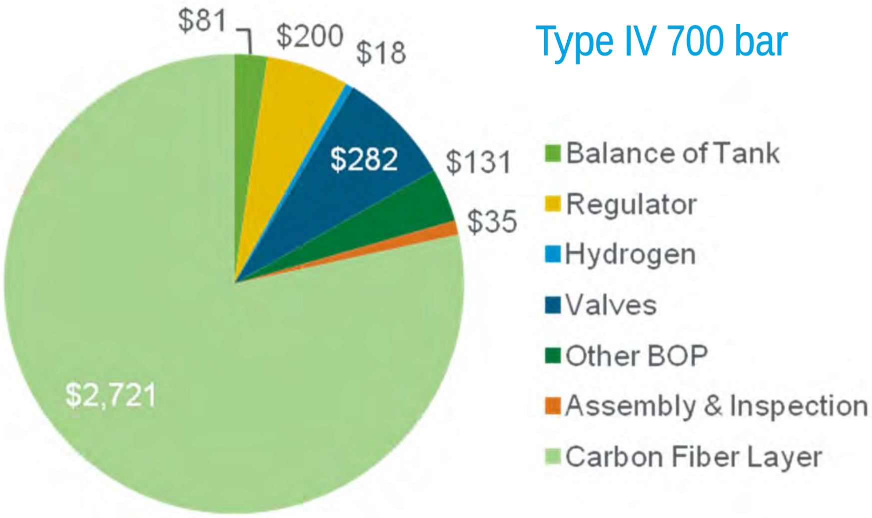
Compressed gas storage offers a near-term option for initial vehicle commercialization and early markets.

Compressed gas storage offers a near-term option for initial vehicle commercialization and early markets

- Cost of composite tanks is challenging
- > 75% of the cost is projected to be due to the carbon fiber layer
- Additional analysis is needed to better understand costs at lower manufacturing volumes

Bulk of composite tank costs are in the carbon-fiber matrix



Tank Accomplishments

- Compressed H_2 tanks can achieve > 250 mile range
- Validated a vehicle that can achieve 430 mile range (with 700 bar Type IV tanks)

Carbon Fiber Cost is Key Focus Area

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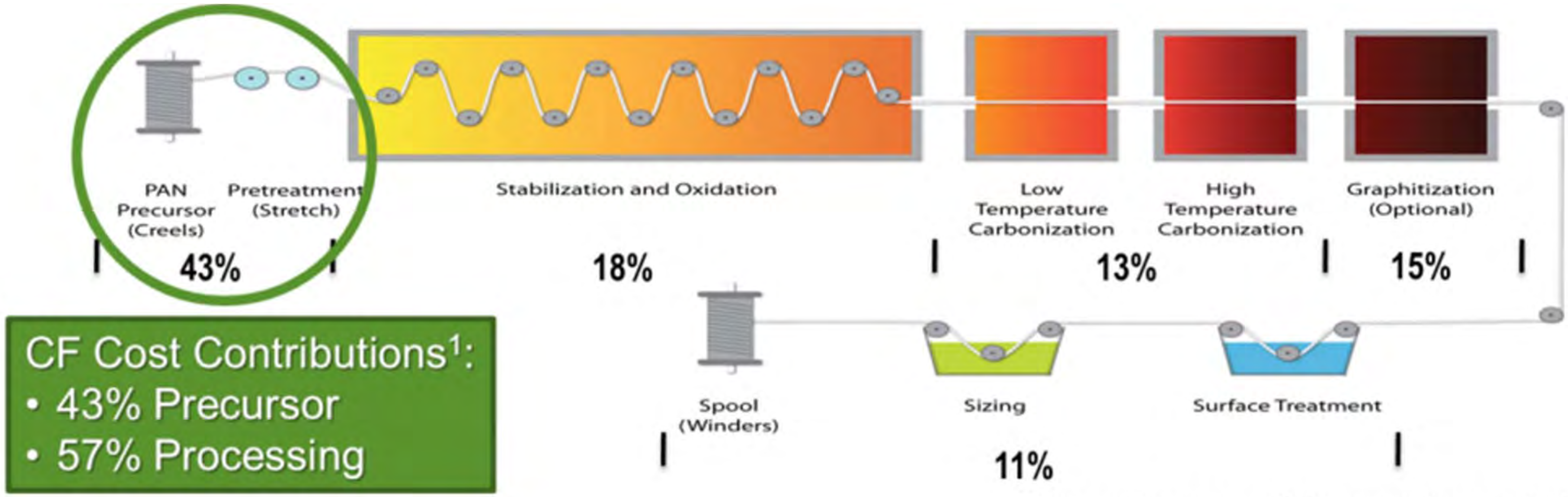
Understanding the costs associated with carbon fiber production is key to addressing barriers to lowering the costs of composite tanks.

Initiated programs to develop low-cost PAN fibers as precursors to reduce costs of high-strength carbon fibers



[1]Kline and Company, 2007, in a study commissioned by the Automotive Composites Consortium.

Objective: To produce low-cost PAN-based precursors for high strength CF[2]:

- Textile-grade PAN fibers with methyl acrylate comonomer – a 30-50% reduction in precursor costs
- Develop melt-spun PAN precursor technology - potential to reduce cost of the high strength CF's by ~ 30%.[3]

OAK RIDGE NATIONAL LABORATORY — MANAGED BY UT-BATTELLE FOR THE DEPARTMENT OF ENERGY | FISIPE | VT

[2]PAN w/ MA precursor: ORNL with FISIPE; Melt-spun PAN precursors: ORNL w/ VT.
[3][Kline & Company, 2007]

Carbon Fiber Cost is Key Focus Area

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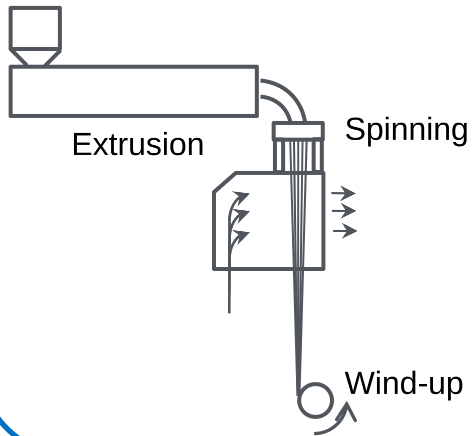
Melt-spun PAN precursor technology has the potential to reduce the production cost of the high strength CF's by ~ 30%.*

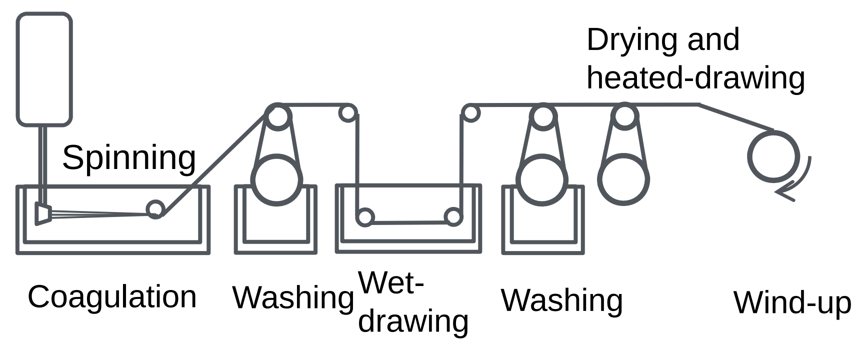
Melt spin processing much less capital intensive than traditional wet spin technology

Melt-processing



- Low production cost
- High production rate
- Environment-friendly

Solution-processing



ORNL-Virginia Tech team has demonstrated melt spinnable PAN/MA with physical properties approaching commodity grade PAN

*: **[Kline & Company, 2007]**

Benefits vs Traditional Wet Spun Processing:

- ~ 30% lower precursor plant capital investment
- ~ 30% lower precursor plant operating cost
- Typical precursor line speed increased by ≥ 4X at winders

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Composite Tank Manufacturing

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Cost Reduction Efforts:

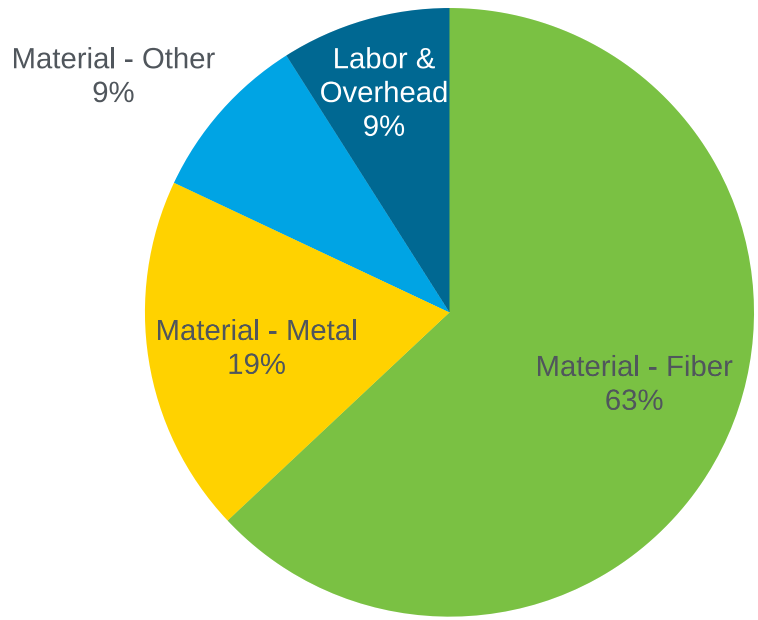
- Advanced manufacturing process combining filament winding with advanced fiber placement
- Hybrid tank design using lower cost carbon fiber on exterior layers
- Alternative fiber evaluation (Basalt)
- Manufacturing Process Automation

Accomplishments

Optimizing elements of advanced fiber placement & commercial filament winding led to a ~23% reduction in composite mass to 58.6 kg.

~25% strain decrease from outside to inside layers using lower cost fibers on exterior. Preliminary analysis shows a weight increase of 2.7% and a cost savings of 4%.

Tank Total Manufacturing Cost



Cost Breakdown Uses Following Assumptions:
125 liter 10,000 psi H_2 tank, Traditional manufacturing processes, Type IV (plastic liner) tank, Annual Production Quantity 10,000, Carbon fiber cost at $15/lb, Metal components are 316L stainless steel

Manufacturing process automation includes automated resin mix system and winding station for increased facility throughput and reduction of product variation.

Composites for Hydrogen Tube Trailers

Use of composite vs. steel tubes increase trailer capacity from 400 kg to 600 kg and reduce capital cost to \$450/kg H_2 stored

Issue:

- Steel tube trailers weight limited
  - Capacities of up to 400 kg H_2 at ≤ 200 bar

Solution:

- Composite tube trailers volume limited
  - Capacities of up to 600 kg H_2 at 250 bar
  - A projected reduction in tube trailer delivery cost of > 33%

Further Improvements Possible:

- Vessel pressure can be increased an additional 100 bar (350 bar)
  - increasing carrying capacity an additional 33% (800 kg H_2)
  - reducing transport costs another 10%
- Identified a route to increase capacity to 1,100 kg H_2 and reduce trailer cost by 50% using cold compressed glass fiber vessels

Lincoln Composites and LLNL

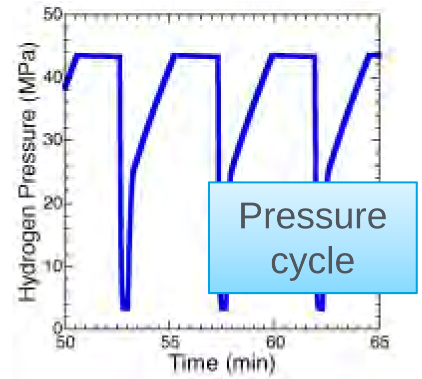
Addressing Performance and Safety: Tank Cycling

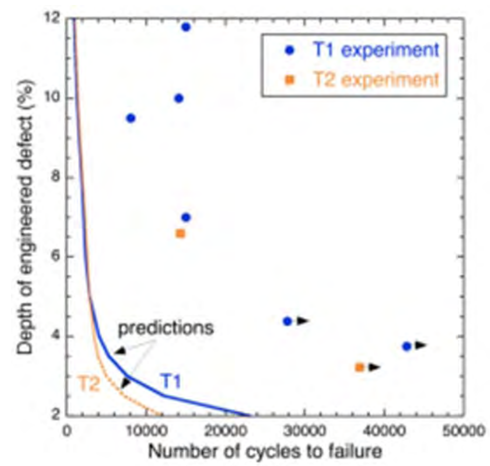
Full-scale pressure vessel testing supporting CSA HPIT1 standard development

Perform testing to simulate service in fuel-cell application

- Engineered defects used to evaluate defect tolerance
- Vessels cycled to failure or >30,000 cycles
- Cycle-life compared to ASME design calculations for hydrogen pressure vessels
- Materials testing in gaseous hydrogen also performed

- All observed failures were leak-before-break
- Cycle-life calculations (with engineered defects) are conservative by factor of 4 or more
- Results used to justify design requirements in CSA HPIT1 standard





Proposed design requirements

- Quench and tempered Cr-Mo steels
- S_u (ultimate strength) ≤ 890 MPa
- hoop stress ≤ 0.4 S_u

Sandia National Laboratories

Hydrogen Storage: Status for Compressed Gas

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Targets are for complete systems, therefore engineering analysis is needed to project system characteristics/properties

Note: there are about 20 specific onboard storage targets that must be met simultaneously

Storage Targets	Gravimetric kWh/kg (kg H_2/kg system)	Volumetric kWh/L (kg H_2/L system)	Costs $/kWh net ($/kg H_2)
2010	1.5 (0.045)	0.9 (0.028)	TBD (TBD)
2017	1.8 (0.055)	1.3 (0.040)	TBD (TBD)
Ultimate	2.5 (0.075)	2.3 (0.070)	TBD (TBD)

Current Status Notes - [a]: ANL/TIAX; [b]: HSECoE	Gravimetric	Volumetric	Costs
700 bar compressed (Type IV)[a]	1.7	0.9	18.9
350 bar compressed (Type IV)[a]	1.8	0.6	15.5
Cryo-compressed (276 bar)[a]	1.9	1.4	12.0*

*: Cost projections are from TIAX analyses of similar systems but not for the exact same design as the performance projections.

Challenge of Hydrogen Storage

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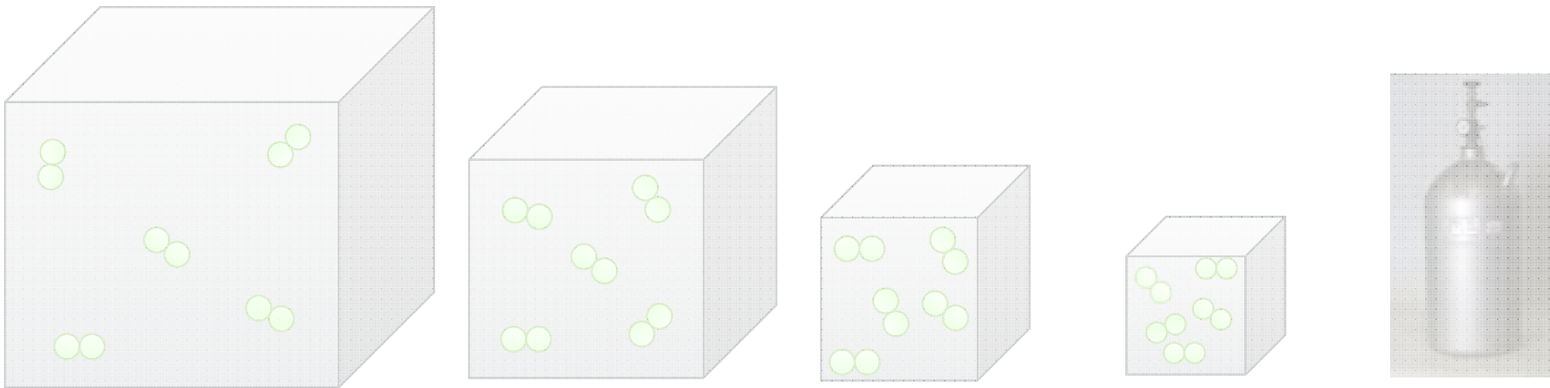
Materials-based storage is considered to be a long-term solution to meet stringent volumetric targets and offer low-pressure storage solutions.

Physical Storage



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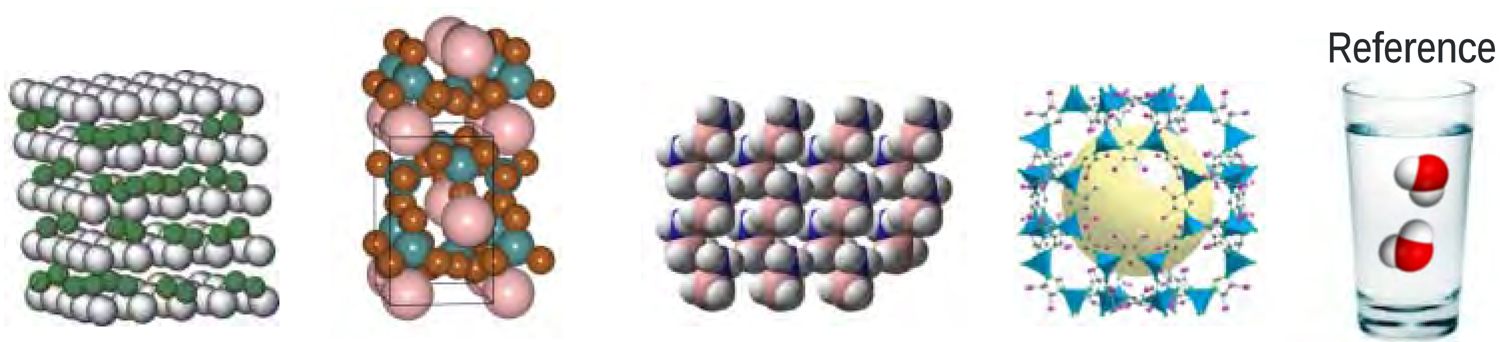
Materials-based Storage



interstial hydrides	complex hydrides	chemical storage	sorbents	water
~100-150 g H_2/L	~70-150 g H_2/L	~70-150 g H_2/L	≤ 70 g H_2/L	111 g H_2/L

Advancements in H_2 Storage Materials Research

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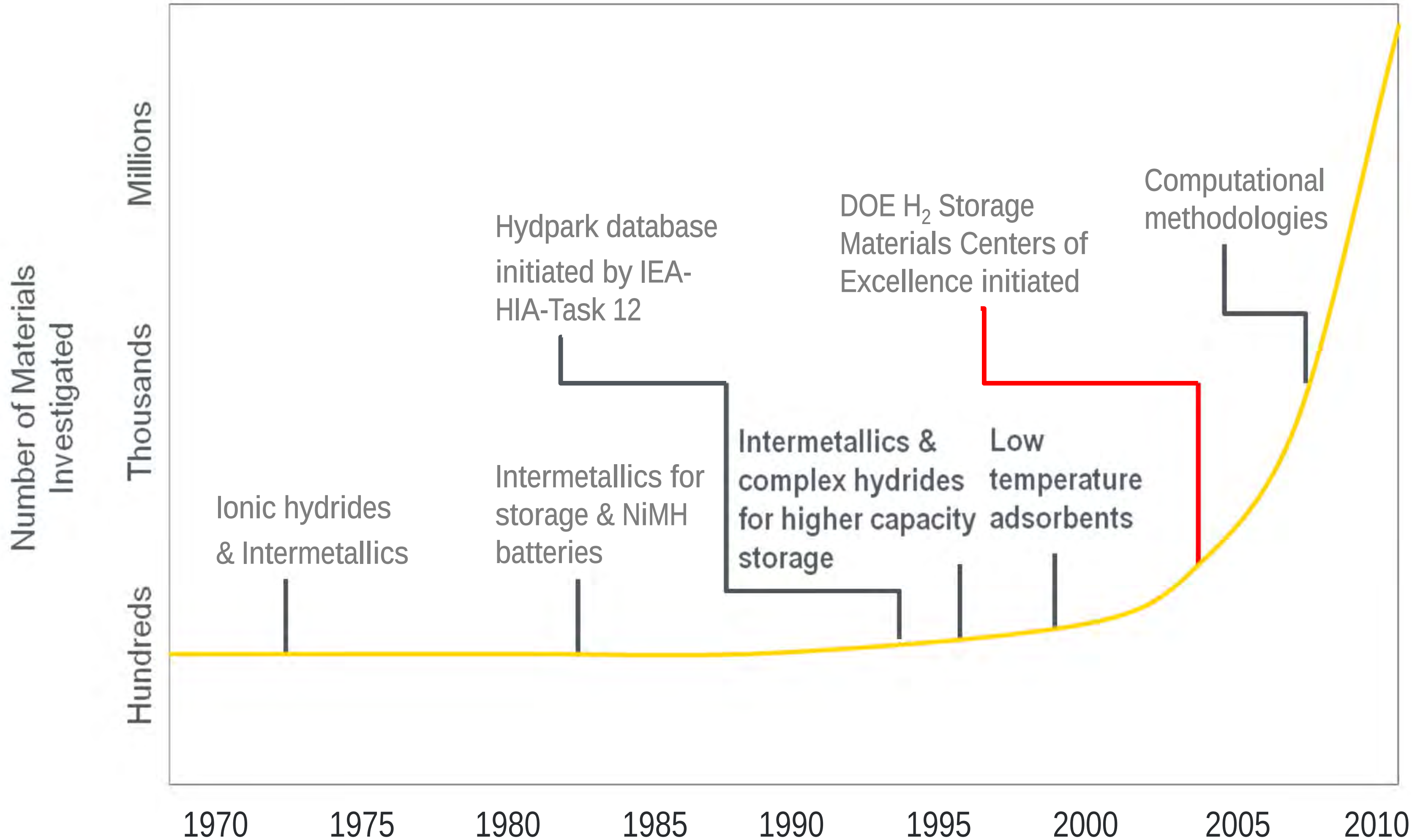
DOE Hydrogen Storage program's investments have led to exponential advances in the number of hydrogen storage materials studied by the end of 2010.



DOE Applied R&D investments on H_2 storage materials since 2001: >$140M

Importance of System Engineering

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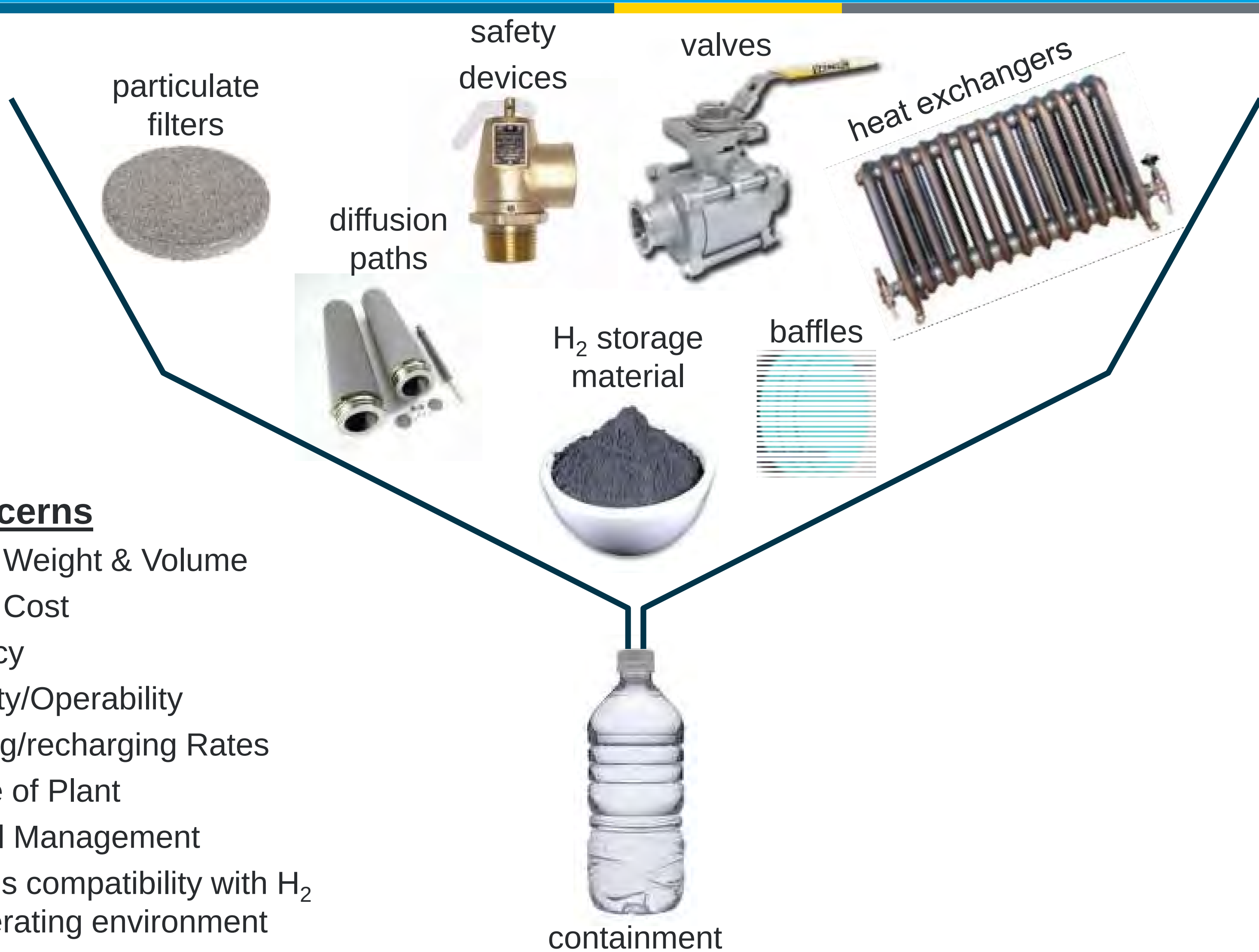
System engineering is critical, enabling the development of complete integrated, low-cost hydrogen storage systems.



Key Concerns

- System Weight & Volume
- System Cost
- Efficiency
- Durability/Operability
- Charging/recharging Rates
- Balance of Plant
- Thermal Management
- Materials compatibility with H_2 and operating environment

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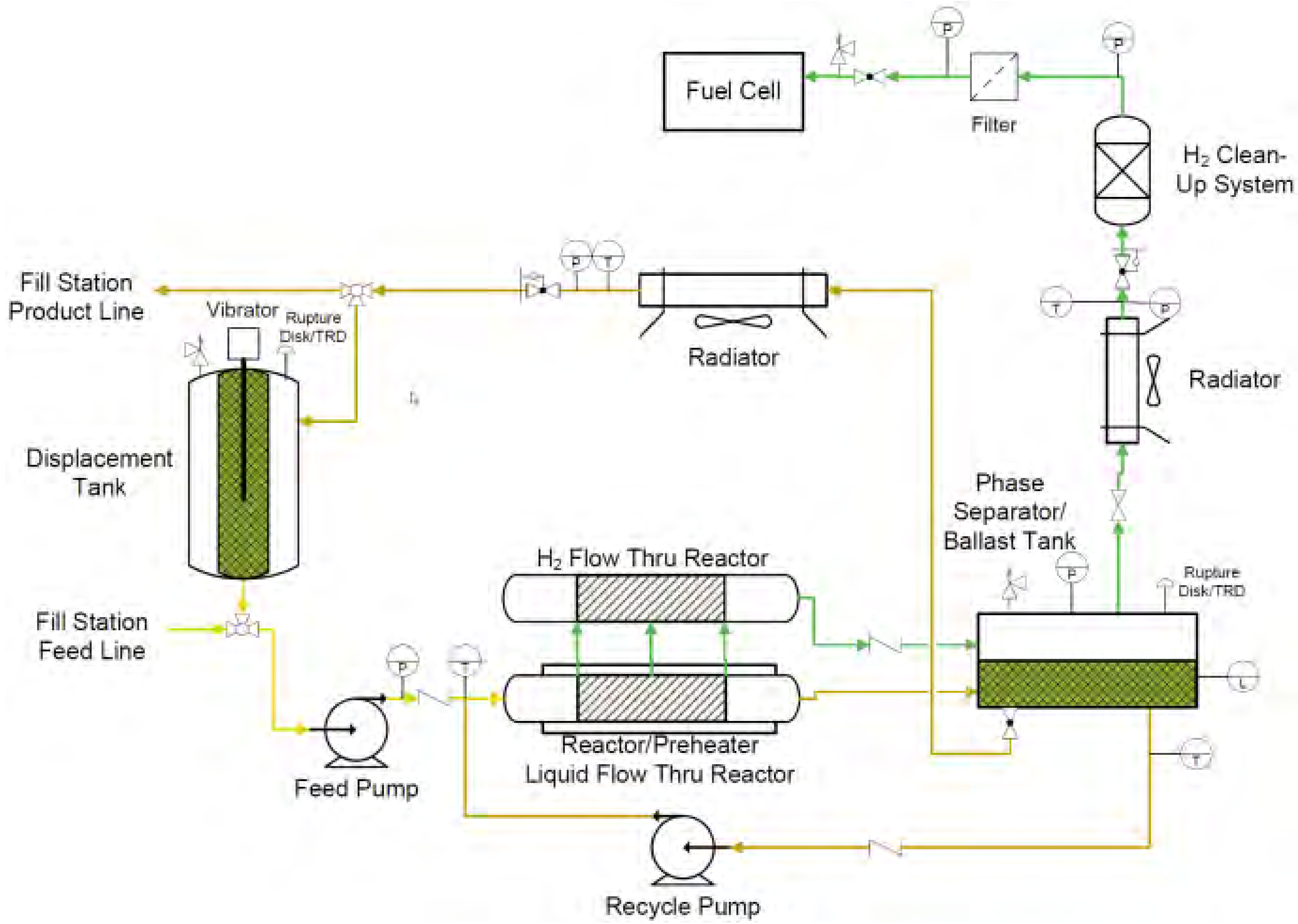

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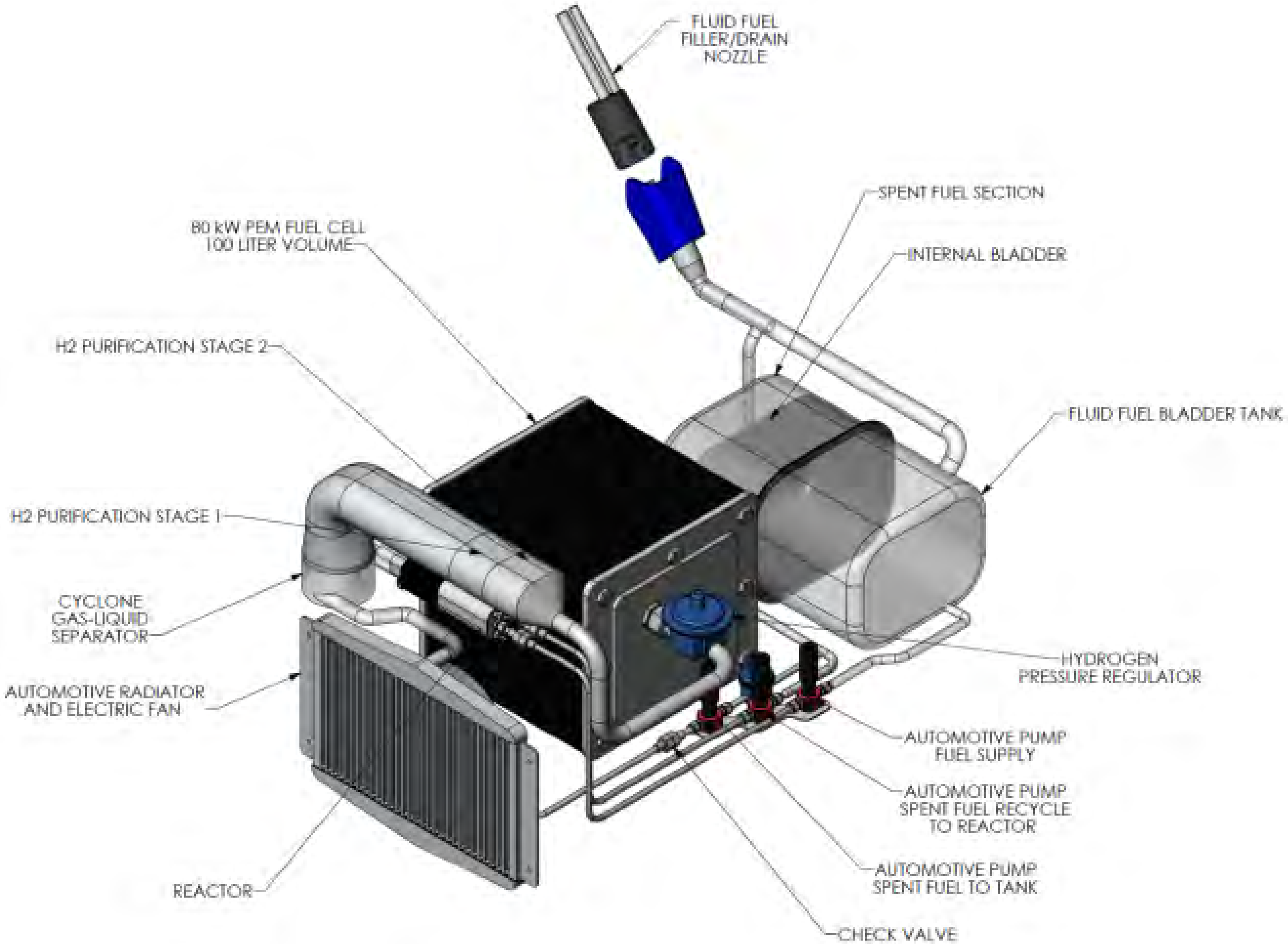

The successful incorporation of all important elements in a practical package appropriate for the application is essential for a successful hydrogen storage system.

H_2 Storage Engineering Center of Excellence (HSCoE)

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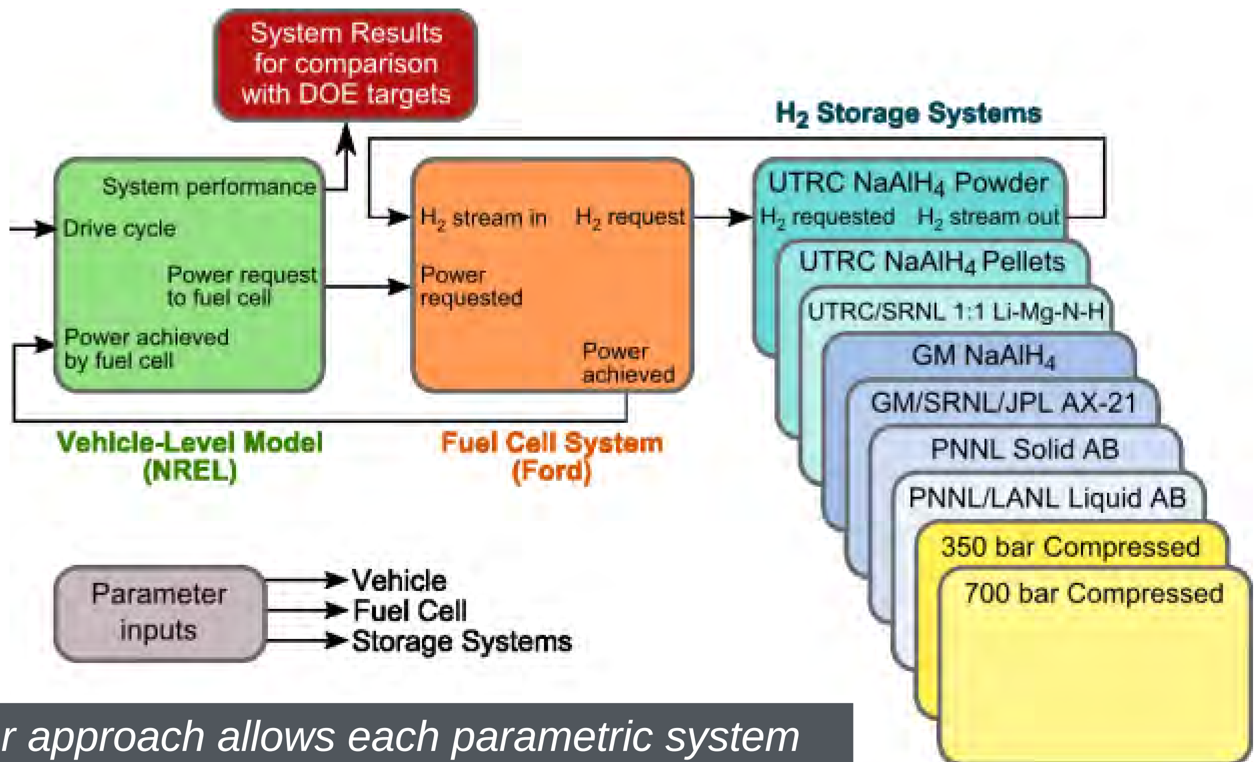
The HSECoE efforts helps to determine required material properties to guide materials development efforts for onboard vehicle storage applications.

- Developed complete, integrated systems models for 3 material classes
- Established baseline system performance with state-of-the -art design and best-of-class materials



Modular approach allows each parametric system model be run through simulated drive cycles with fuel cell and vehicle-level models to predict performance.

Figure courtesy of José Miguel Pasini, UTRC

Status of Metal Hydride Systems

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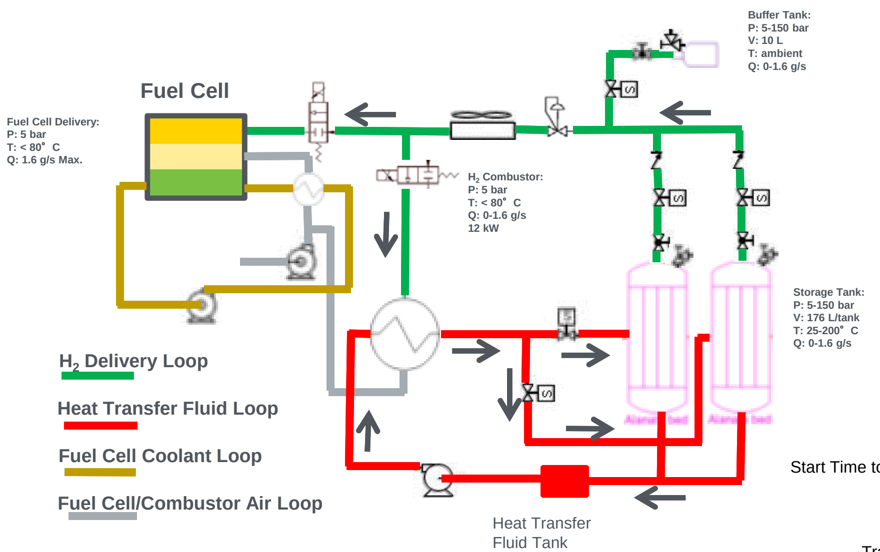
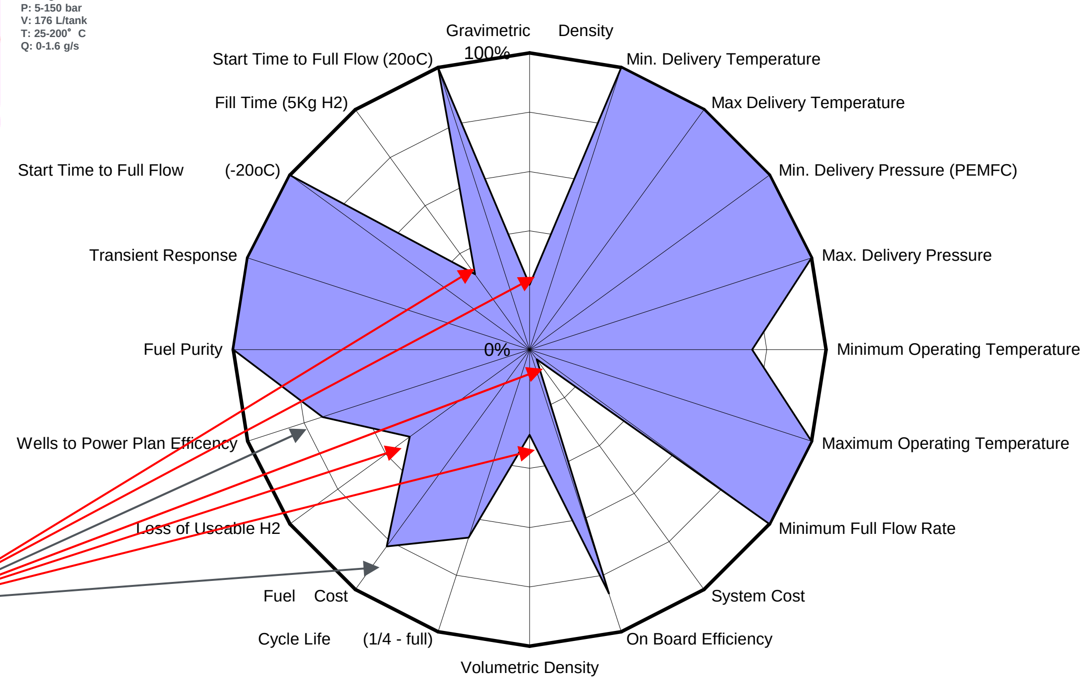
No metal hydride material currently exists that will allow a complete system to meet all key DOE system performance targets for onboard vehicle applications



Results based on a dual tank, Sodium Alanate System



1. **Gravimetric Density**
2. **System Cost**
3. **Onboard Efficiency**
4. **Volumetric Density**
5. **Fill Time**
6. Fuel Cost
7. WPP Efficiency

Metal Hydride Requirements
- Enthalpy such that waste heat use only

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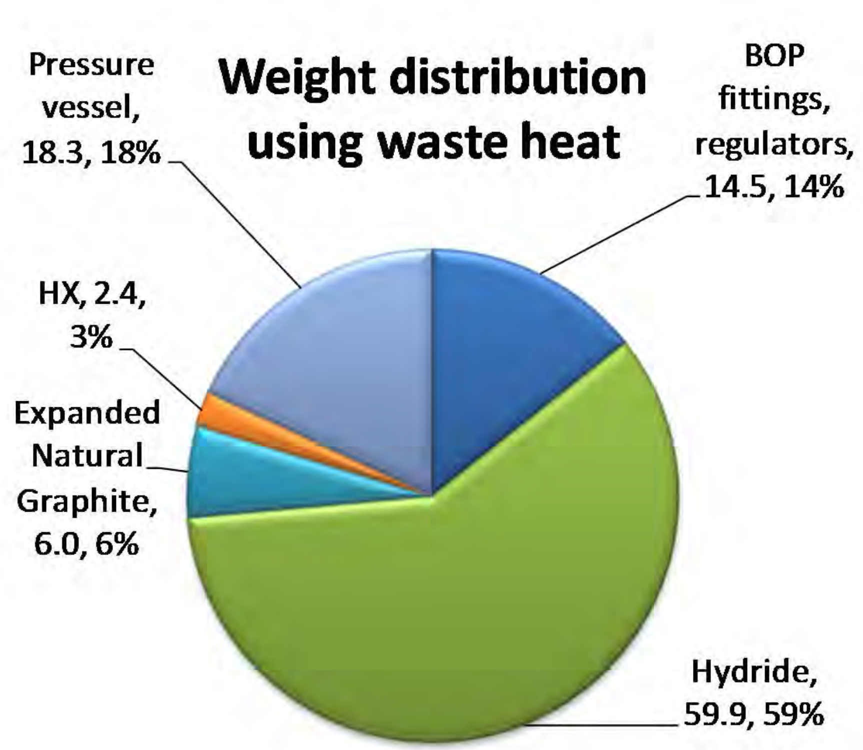
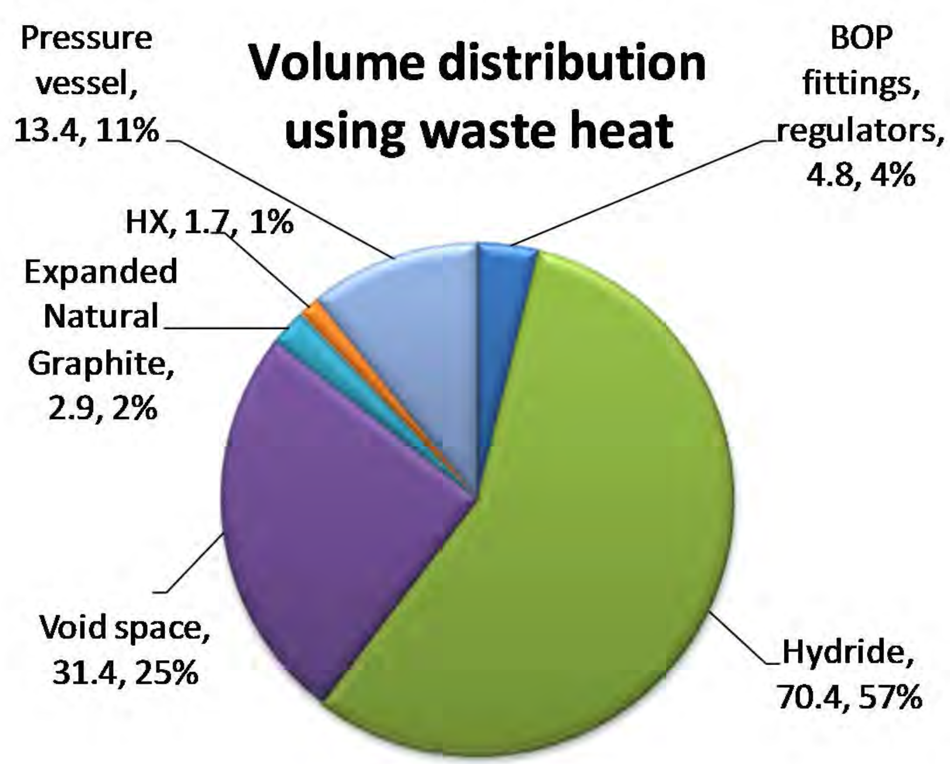
- Satisfies all DOE targets.
- ΔH = 27 kJ/mol-H_2
- ***11 wt% pure material capacity***
- T (5 bar) = 20.7 C
- On-board efficiency: ~100%
- System: 101 kg, 124 liters





Sensitivity Analysis: System Gravimetric & Volumetric Capacity

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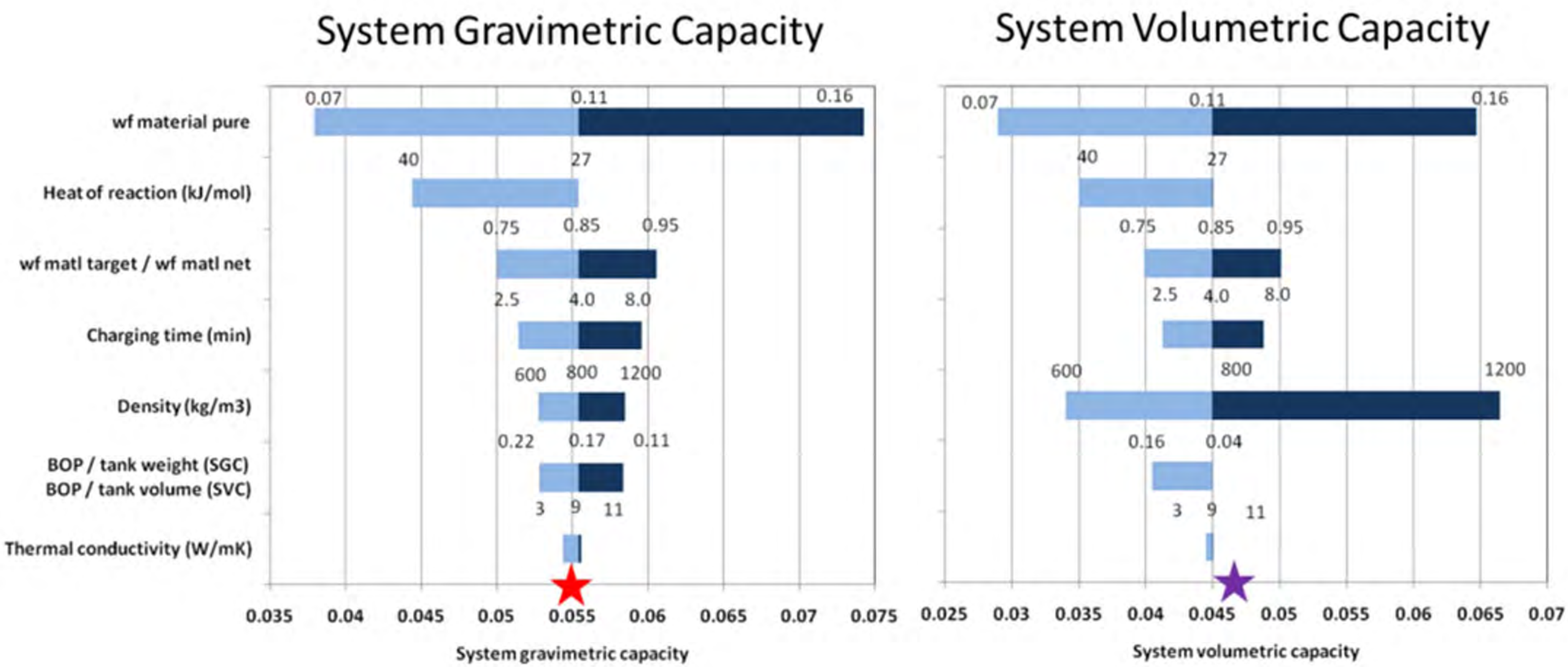

★ ★ **DOE 2017 targets, gravimetric and volumetric capacity, respectively**

Sensitivity Parameters (Baseline case)

- Wf matl = 11%
- Heat of reaction = 27 kJ/molH2
- Wf matl target / wf matl net = 85% *
- Charging time = 4 min
- Bulk density = 800 kg/m^3
- BOP weight / tank weight = 17%
  BOP volume / tank volume = 4%
- Thermal conductivity = 9 W/mK *

Status: Gravimetric Capacity vs. Enthalpy

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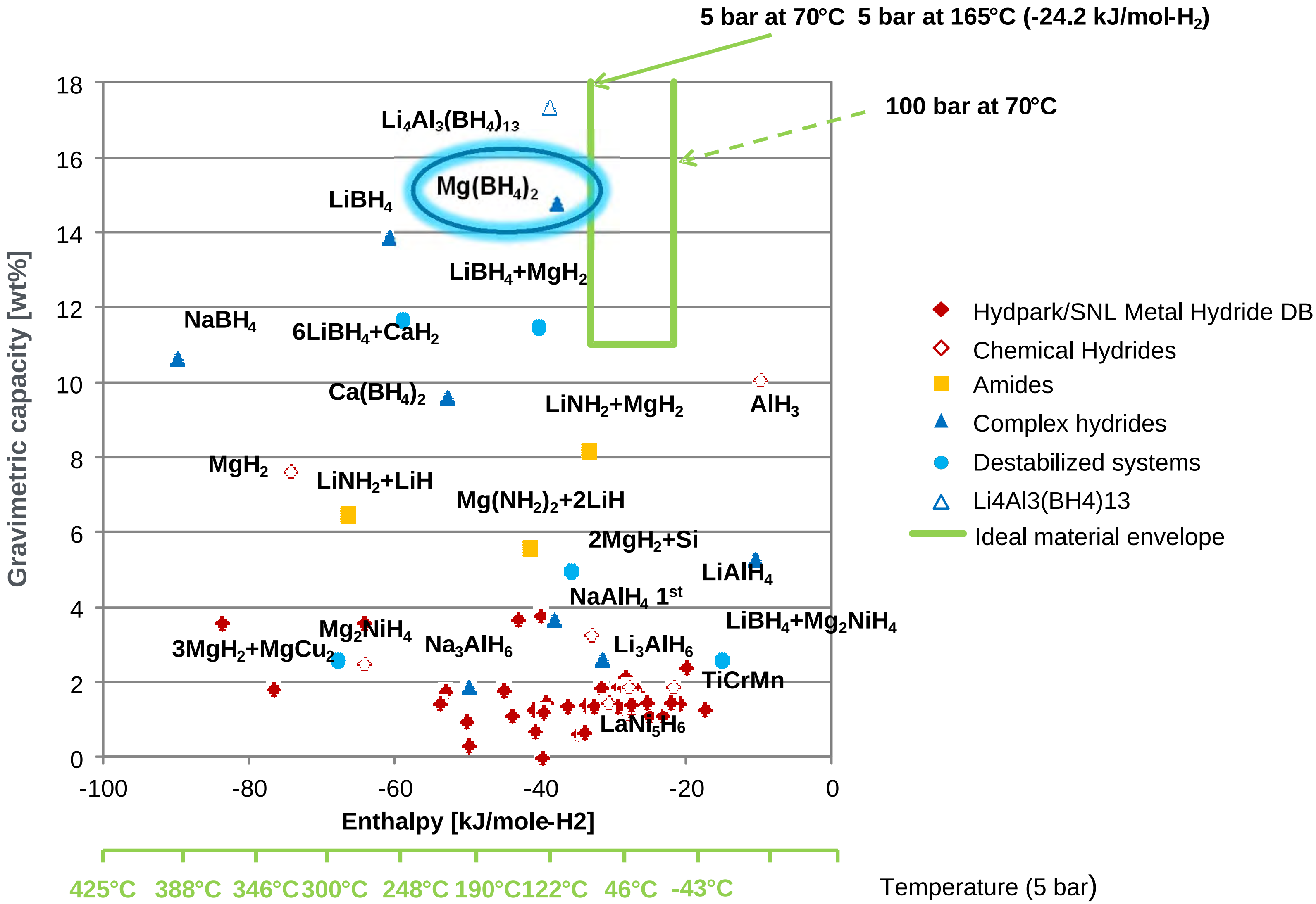

Recent Accomplishments for Metal Hydrides

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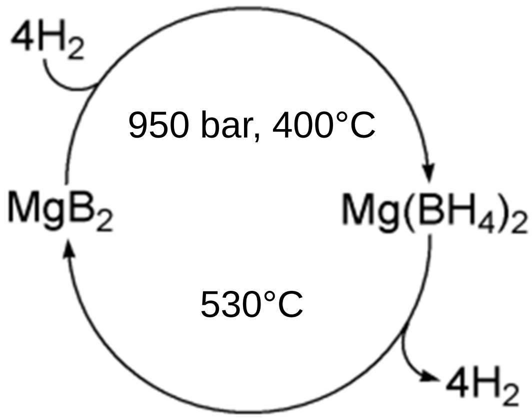
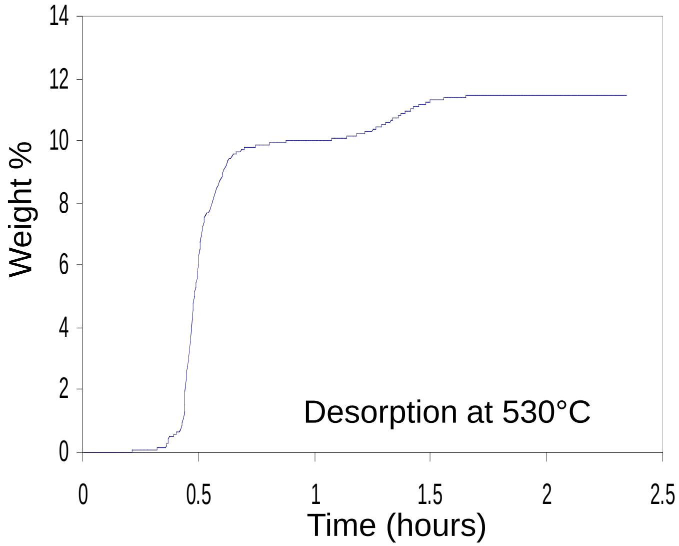
12 wt.% reversible capacity demonstrated for $Mg(BH_4)_2$



Evidence indicates that >14wt.% might be possible (theoretical capacity 14.8 wt.%)



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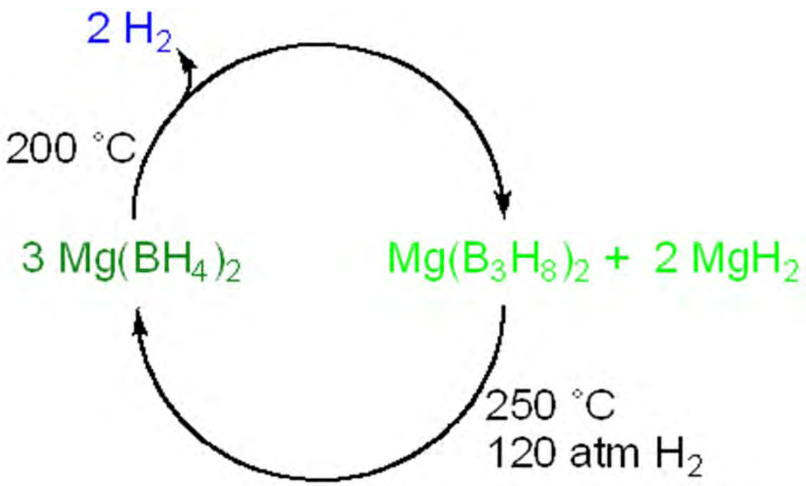
2.5 wt.% can obtained under milder conditions by cycling between $Mg(BH_4)_2$ and magnesium triborane [$Mg(B_3H_8)_2$]



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Pacific Northwest NATIONAL LABORATORY

Status of Cryo-Sorbent Systems

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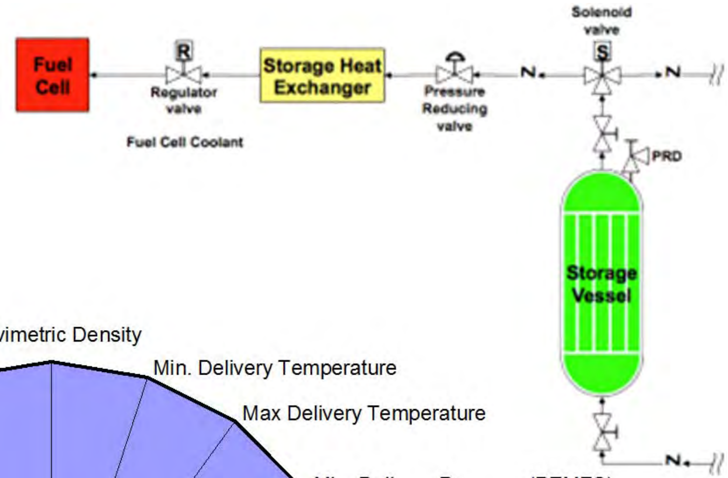
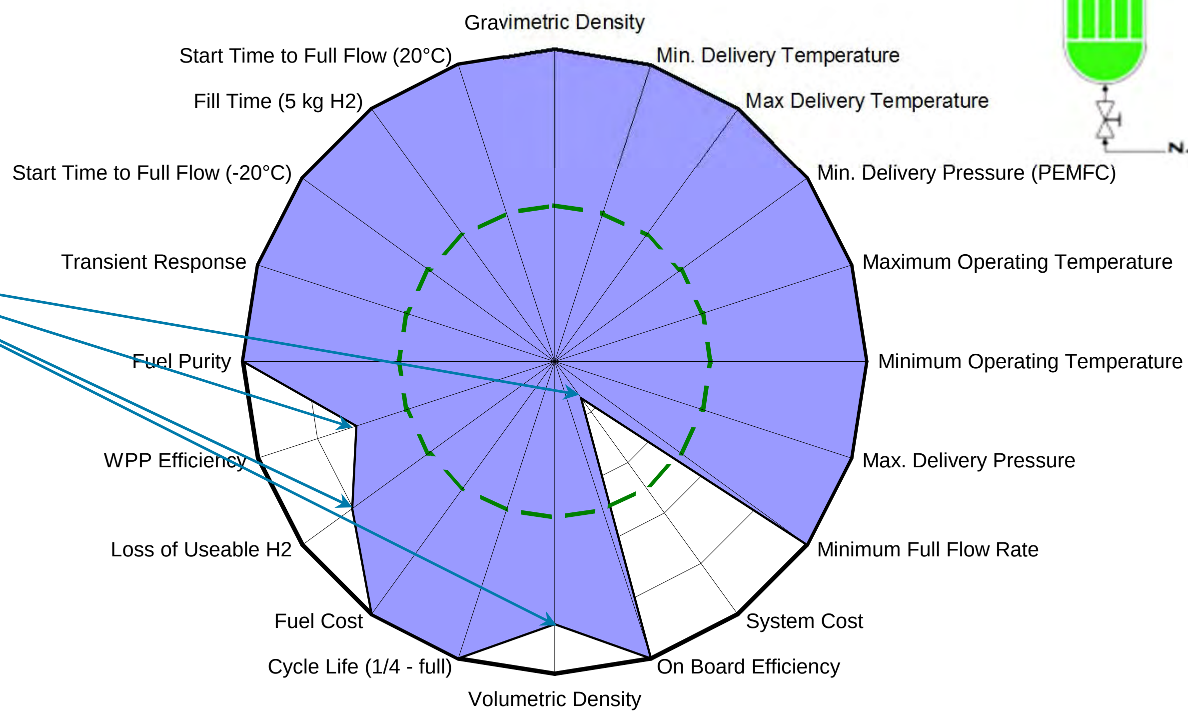
Current cryo-sorbent system designs are projected to meet most DOE performance targets for onboard vehicle applications

Results based on a MOF-5 system, 200 bar, 80 K



1. Volumetric Density
2. System Cost
3. Loss of Usable H_2
4. WPP Efficiency



Recent Accomplishments in Cryo-sorbents

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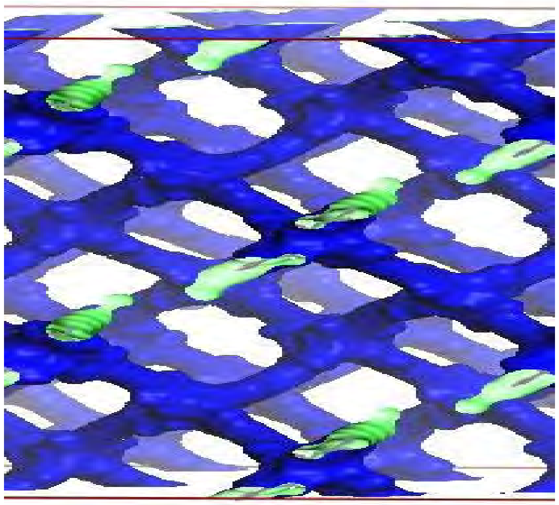
New sorbent materials synthesized with surface areas of >6000 m^2/g with material capacities over 8 wt% at 77K and <100bar



- Verified excess capacities greater than 8 wt.% at ≤ 70 bar and 77 K
- BET surface areas exceeding 6000 m^2/g

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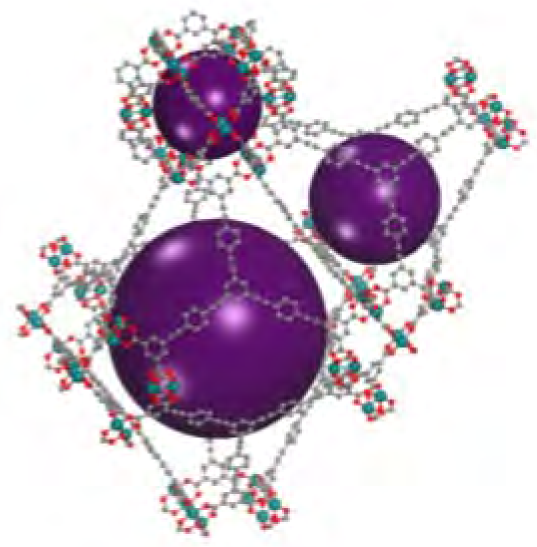

- **Future efforts:**
  - need to increase isosteric heats of adsorption to increase sorption capacities at temperatures greater than cryogenic
  - materials with higher hydrogen densities are needed

NORTHWESTERN UNIVERSITY

Status of Chemical Hydrogen Systems

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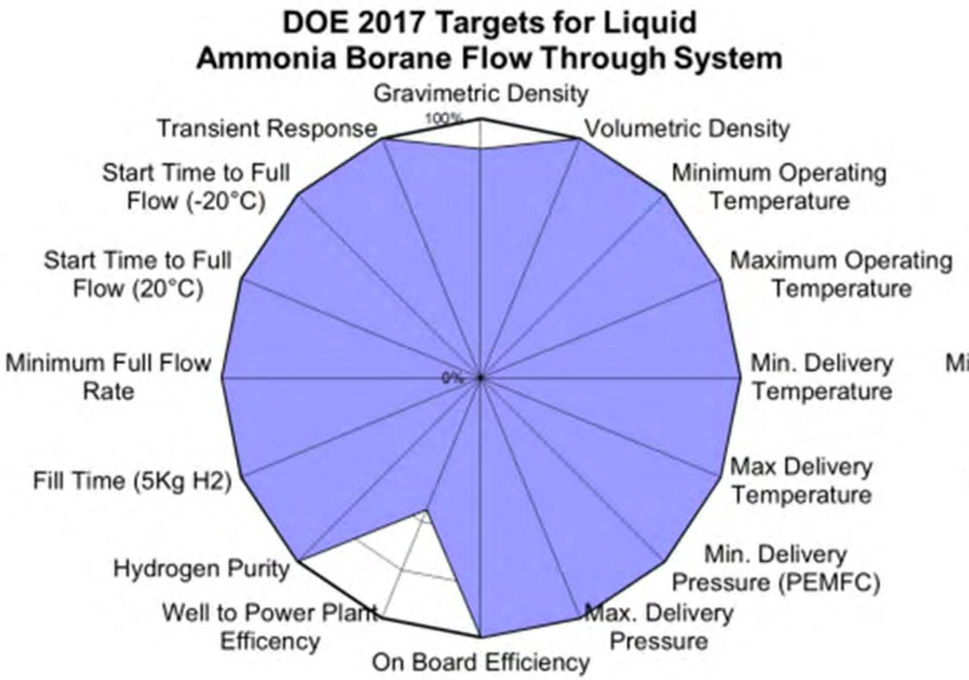
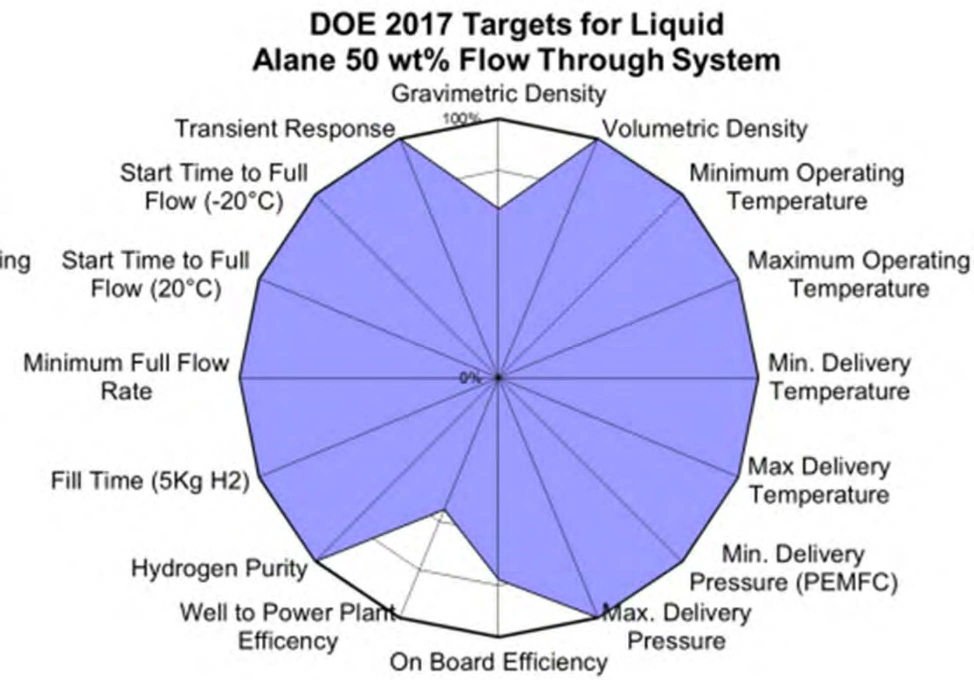
Endo- and Exothermic release material systems can meet most key DOE system performance targets for onboard vehicle applications

Projections for Exothermic (Ammonia Borane) and Endothermic (Alane) Hydrogen Release Systems – 50% mass loaded fluids





Off-board regeneration efficiency is still an issue

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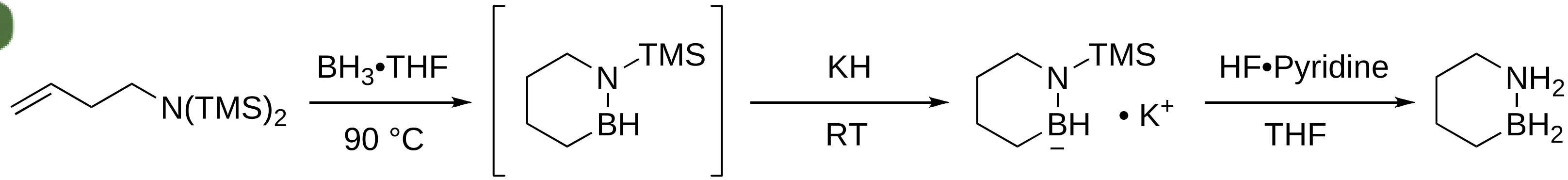
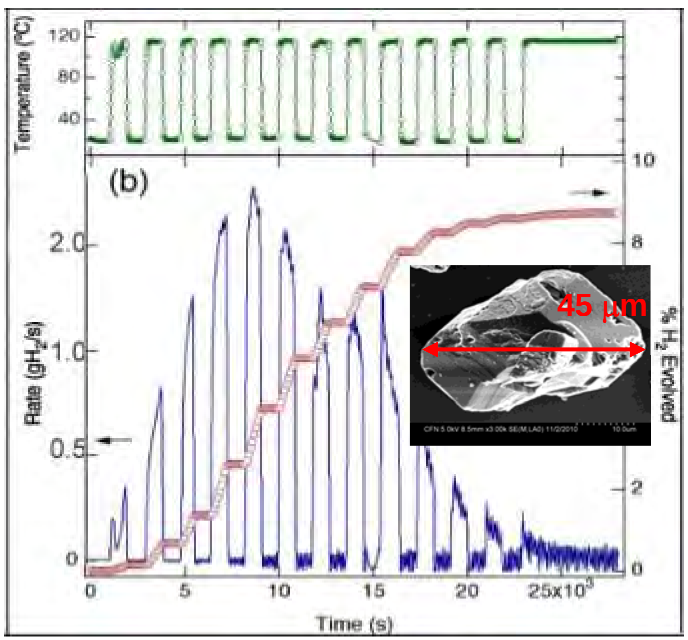
Catalysts and novel syntheses demonstrate improvements in kinetics and thermal control

Parent CBN synthesized that is air and thermally stable and delivers up to 1.5 equiv. H_2

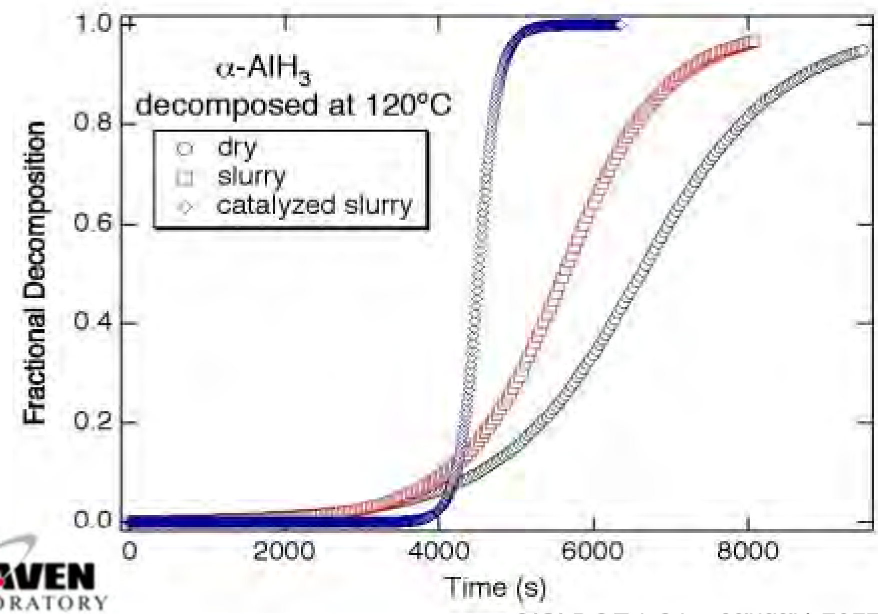


62% over two steps 94%

Synthesis of larger AlH_3 particles allows thermal control of decomposition



Ti Catalyzed 60 wt.% AlH_3 slurry demonstrates 2x faster H_2 than dry powder



BROOKHAVEN NATIONAL LABORATORY

Status for Materials-based Hydrogen Storage Systems

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

Targets are for complete systems, therefore engineering analysis is needed to project system characteristics/properties

Note: there are about 20 specific onboard storage targets that must be met simultaneously

Storage Targets	Gravimetric kWh/kg (kg H_2/kg system)	Volumetric kWh/L (kg H_2/L system)	Costs \$/kWh net (\$/kg H_2)
2010	1.5 (0.045)	0.9 (0.028)	TBD (TBD)
2017	1.8 (0.055)	1.3 (0.040)	TBD (TBD)
Ultimate	2.5 (0.075)	2.3 (0.070)	TBD (TBD)

Current Status Notes - [a]: ANL/TIAX; [b]: HSECoE	Gravimetric (kWh/kg sys)	Volumetric (kWh/L sys)	Costs (\$/kWh)
Metal Hydride ($NaAlH_4$)[b]	0.4	0.4	11.3*
Sorbent (MOF-5, 200 bar)[b]	1.7	0.9	18.0*
Off-board regenerable (AB)[b]	1.4	1.3	NA

*: Cost projections are from TIAX analyses of similar systems but not for the exact same design as the performance projections.

Polymeric Pipeline Materials

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

Projected reduction in installed pipeline costs of 15%

U. Illinois, SECAT, SNL, ORNL, SRNL

Issue:

- Capital costs are driven by joining and installation costs for current pipelines

Solution:

- Fiber reinforced polymer (FRP) pipelines
  - Longer sections between joints and lower installation costs
  - Demonstrated a 3x design margin for FRP through flaw tolerance testing
  - Projected reduction in installed pipeline cost of 15%

Future Work

- Determined that the level of H_2 permeation through materials will meet DOE targets and FRP burst strength
- Demonstrated no degradation in FRP after 8mo of accelerated aging (equivalent to 5yrs at room temperature)

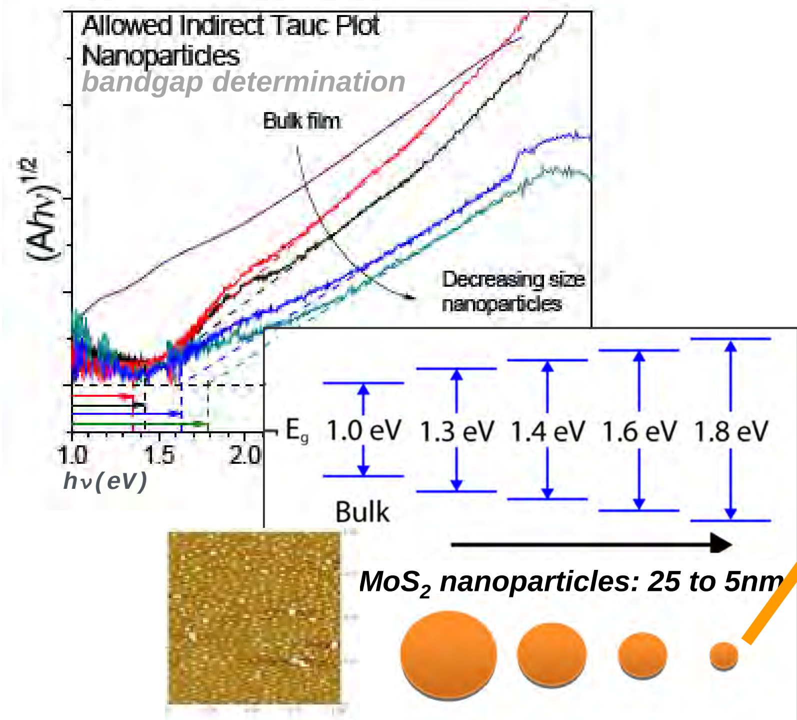
Nano-Catalyst System for Solar Hydrogen Production

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

Discovering new MoS_2 nano-catalysts, and developing novel macro-structures for integration into practical photoelectrochemical (PEC) hydrogen production devices

Fundamental Science:

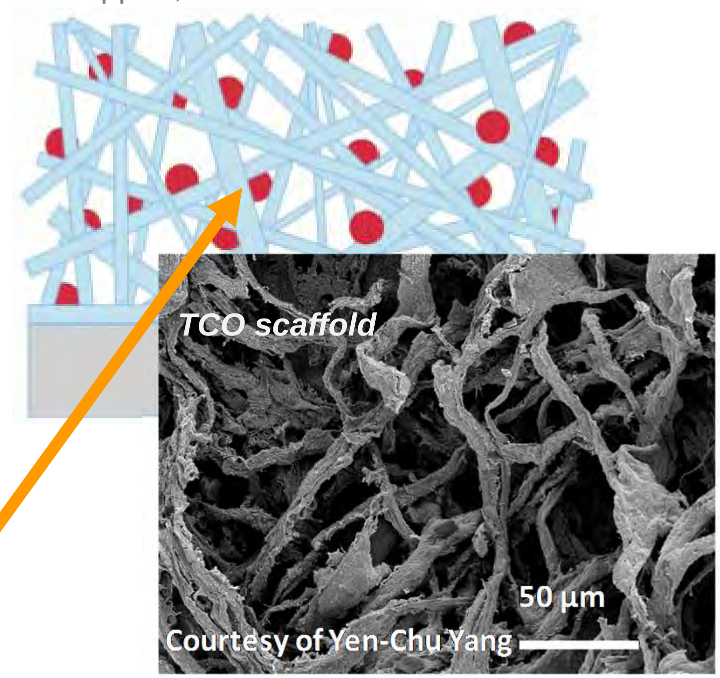
Based on fundamental principles of quantum confinement, nanoparticle MoS_2 catalysts exhibit bandgap enlargement from 1.2 eV (bulk) to ~1.8 eV when diameter is reduced to ~5 nm.



Bandgap blueshift in 5 nm MoS_2 nanoparticles sensitizes catalyst to efficiently absorb light in the solar spectrum

Applied R&D:

A macroporous scaffold consisting of a transparent conducting oxide (TCO) is being developed upon which the MoS_2 nanoparticles can be vertically integrated for support, confinement and electronic contact.



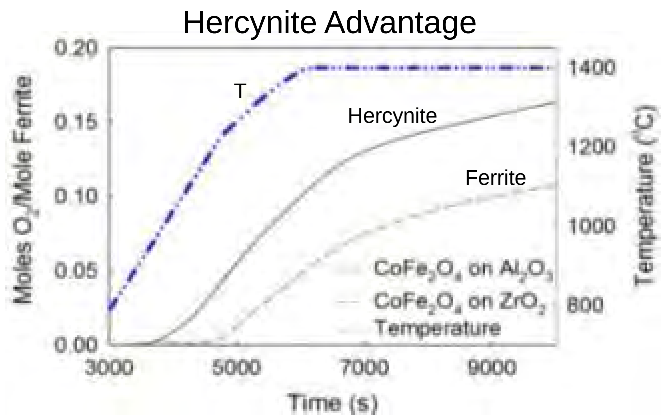
Stanford University | Louisville | NREL

Scaffold is enabling technology for development of MoS_2 photoelectrodes for effective solar H_2 production

Source: T. Jaramillo, et al. *Science 2007, 317, 100122;* Y. Aoki, J. Huang, T. Kunitake, *J. Mater. Chem., 2006, 16, 292-297*

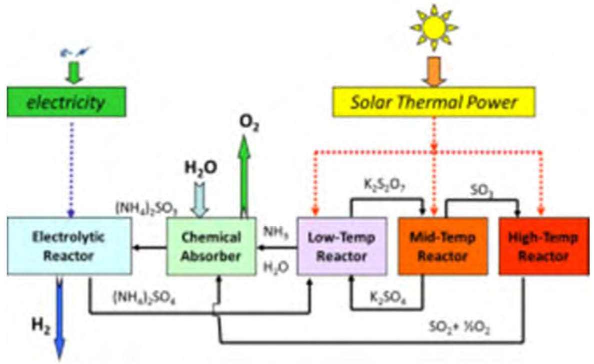
[Coordinated effort between SC-EFRC and EE-FCT]

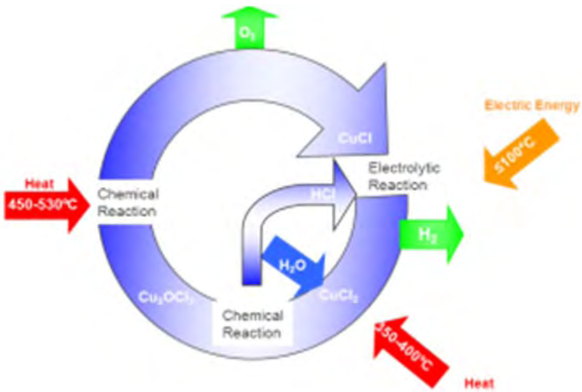
Advanced Materials: Key to Progress in STCH Production



Using ALD Ferrite, increased thin film peak production rate ~100x faster than bulk. Hercynite route shows advantages in reduced reduction temperature and larger operating window. (U of Colorado)

Down select of electrode and catalyst materials for high T, P testing. Voltage of the electrolytic cell has been reduced to values at 80ºC, close to those previously obtained at 130ºC. (SAIC)





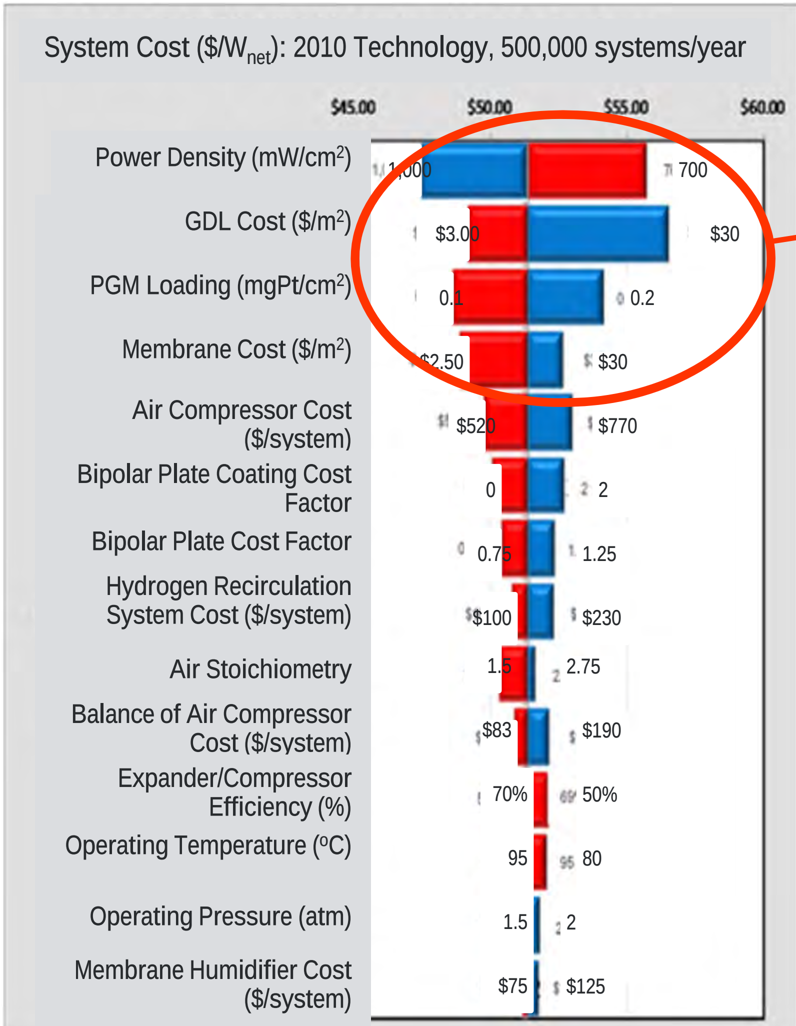
Two best membranes identified for Cu-Cl cycle with Cu diffusivity <10% of Nafion that are chemically and thermally stable at 80 C for over 40 hours. (ANL)

Fuel Cell Stacks – Costs and Durability

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

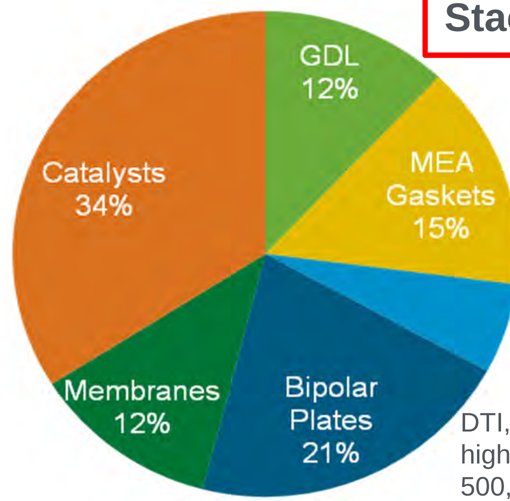
Challenges: **Cost and Durability—must be met** *simultaneously*

Platinum cost is ~34% of total stack cost. Catalyst durability needs improvement



Key Focus Areas for R&D

Stack Cost - $25/kW



DTI, **2010 analysis**, scaled to high volume production of 500,000 units/yr. Used $1100/Troy Ounce for Pt Cost

Strategies to Address Challenges—Examples

- **Lower PGM Content**: Improved Pt catalyst utilization and durability
- **Pt Alloys**: Pt-based alloys with comparable performance to Pt and cost less
- **Novel Support Structures:** Non-carbon supports and alternative carbon structures
- **Non-PGM catalysts:** Non-precious metal catalysts with improved performance and durability

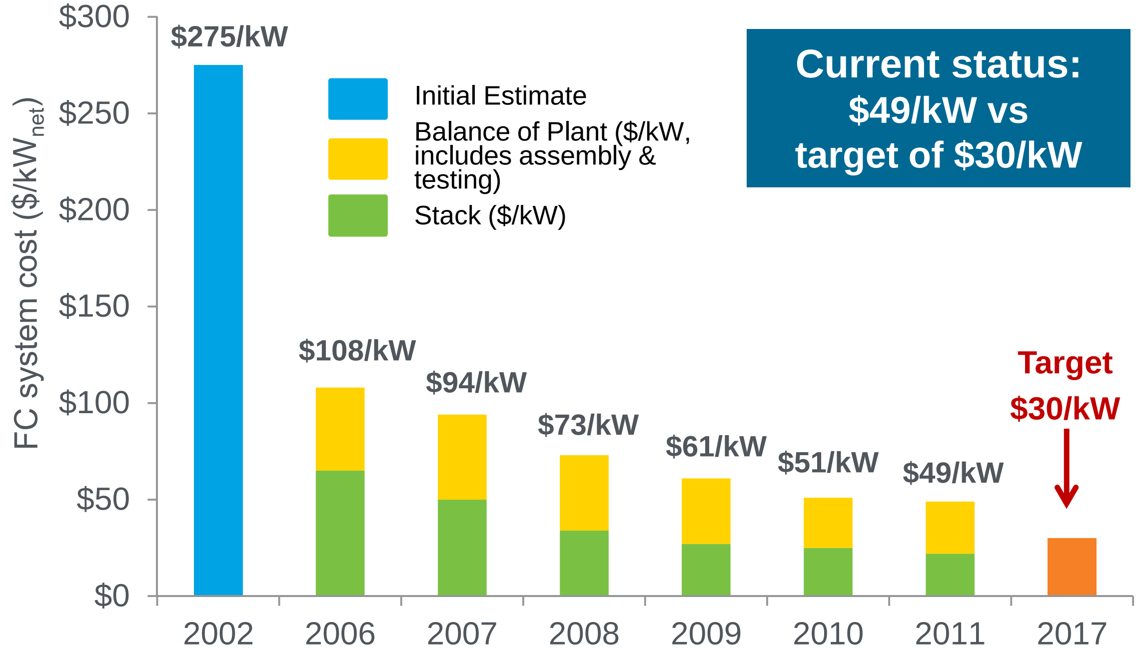
Programmatic Progress – Fuel Cells

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

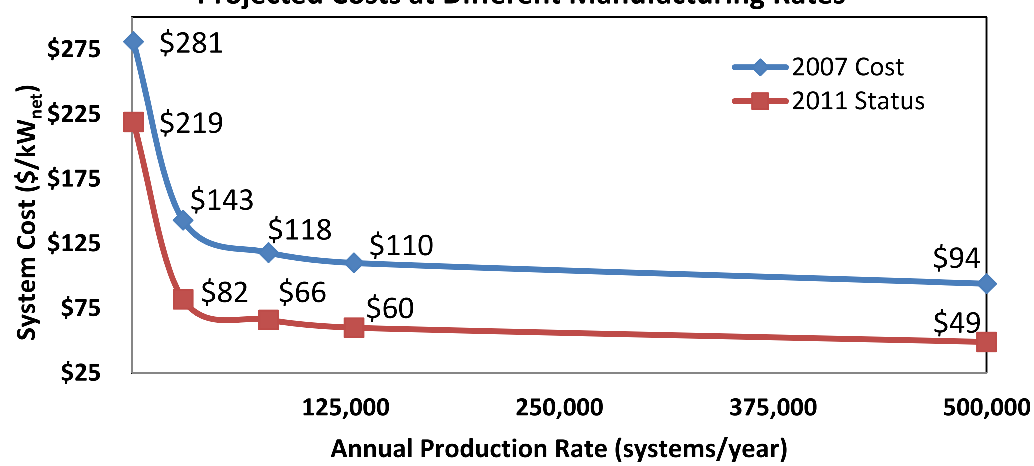
Projected high-volume cost of fuel cells has been reduced to $49/kW (2011)*

- ***More than 30% reduction since 2008***
- ***More than 80% reduction since 2002***

Projected Transportation Fuel Cell System Cost
-projected to high-volume (500,000 units per year)-



Projected Costs at Different Manufacturing Rates



***Based on projection to high-volume manufacturing (500,000 units/year).**
The projected cost status is based on an analysis of state-of-the-art components that have been developed and demonstrated through the DOE Program at the laboratory scale. Additional efforts would be needed for integration of components into a complete automotive system that meets durability requirements in real-world conditions.

Programmatic Progress – H_2 Production & Delivery

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

The revised hydrogen threshold cost is a key driver in the assessment of Hydrogen Production and Delivery R&D priorities.

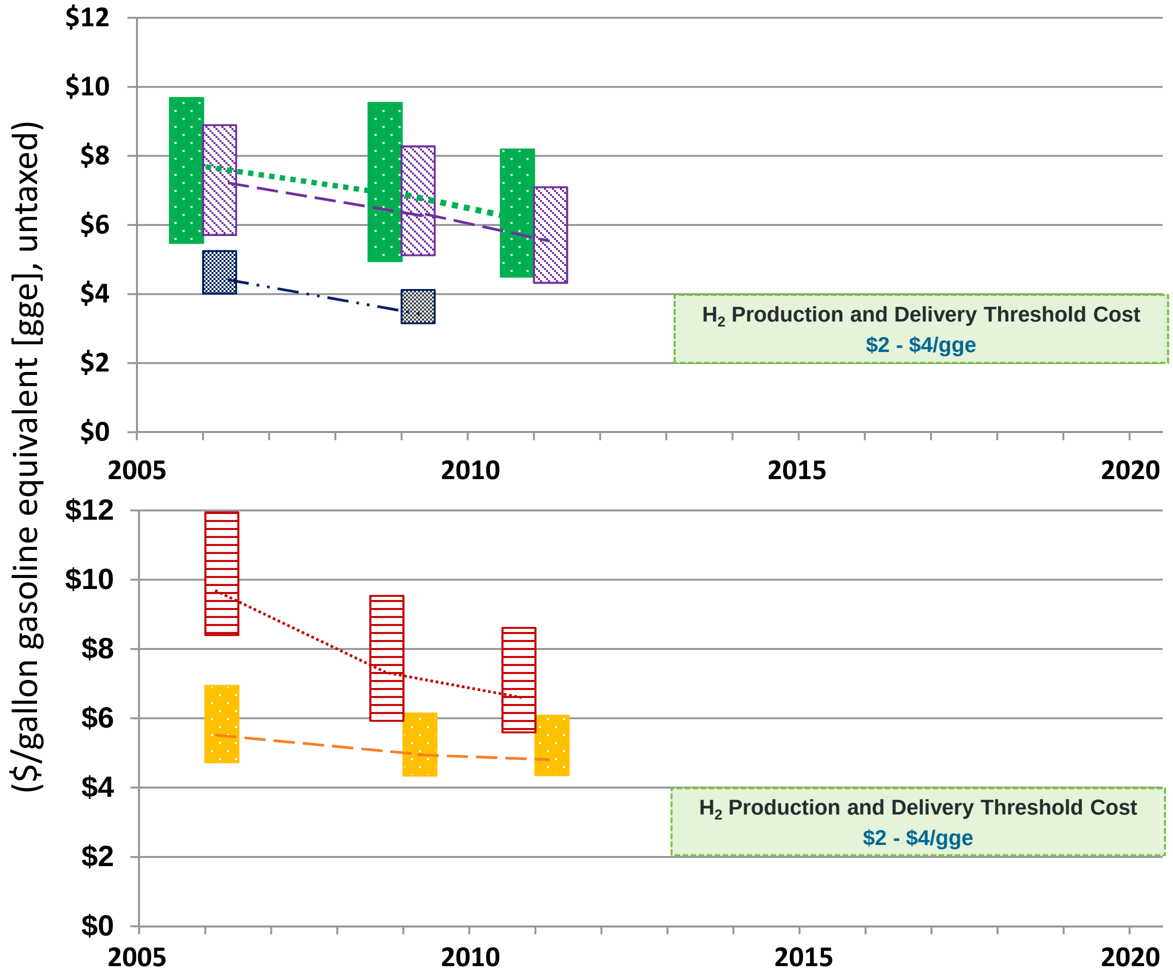
Projected High-Volume Cost of Hydrogen Production[1] (Delivered[2])—Status

Distributed Production (near term)

- Electrolysis
  Feedstock variability: $0.03 - $0.08 per kWh
- Bio-Derived Liquids
  Feedstock variability: $1.00 - $3.00 per gallon ethanol
- Natural Gas Reforming[3]
  Feedstock variability: $4.00 - $10.00 per MMBtu

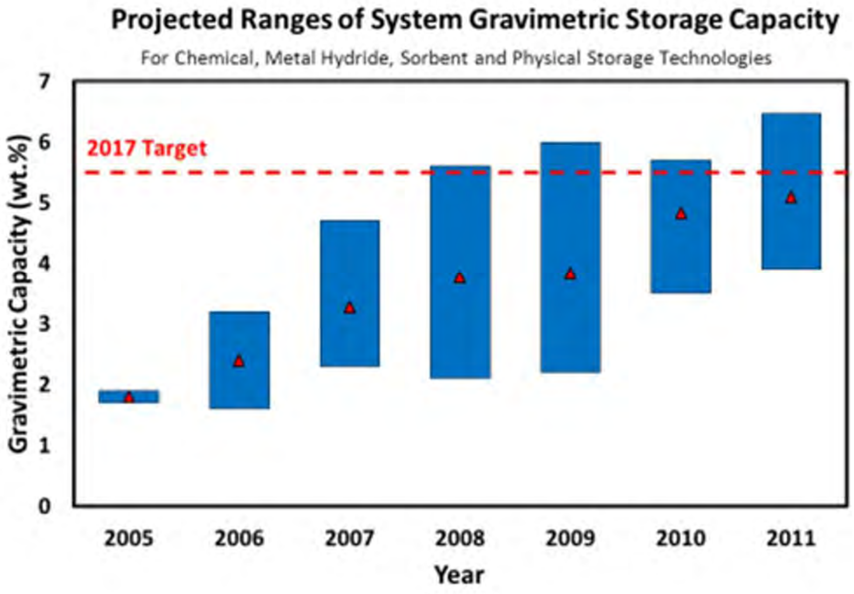
Central Production (longer term)

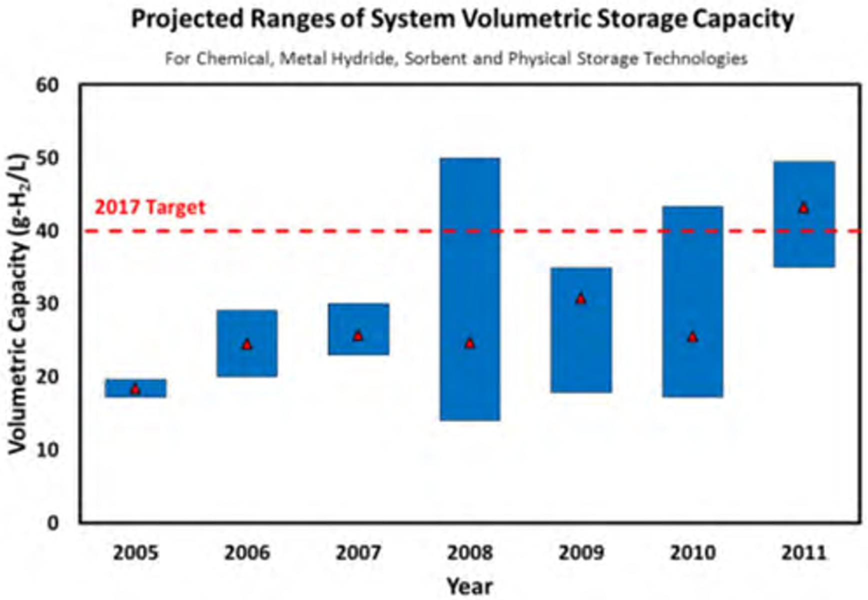
- Electrolysis
  Feedstock variability: $0.03 - $0.08 per kWh
- Biomass Gasification
  Feedstock variability: $40- $120 per dry short ton



Notes:
[1] Cost ranges for each pathway are shown in 2007$ based on high-volume projections from H2A analyses, reflecting variability in major feedstock pricing and a bounded range for capital cost estimates.
[2] Costs include total cost of production and delivery (dispensed, untaxed). Forecourt compression, storage and dispensing added an additional $1.82 for distributed technologies, $2.61 was added as the price of delivery to central technologies. All delivery costs were based on the Hydrogen Pathways Technical Report (NREL, 2009).
[3] Analysis of projected costs for natural gas reforming indicated that the threshold cost can be achieved with current technologies or with incremental improvements made by industry. FCTP funding of natural gas reforming projects was completed in 2008.

Projected Capacities for Complete 5.6-kg H_2 Storage Systems





Progress is being made, but no technology meets all targets simultaneously.

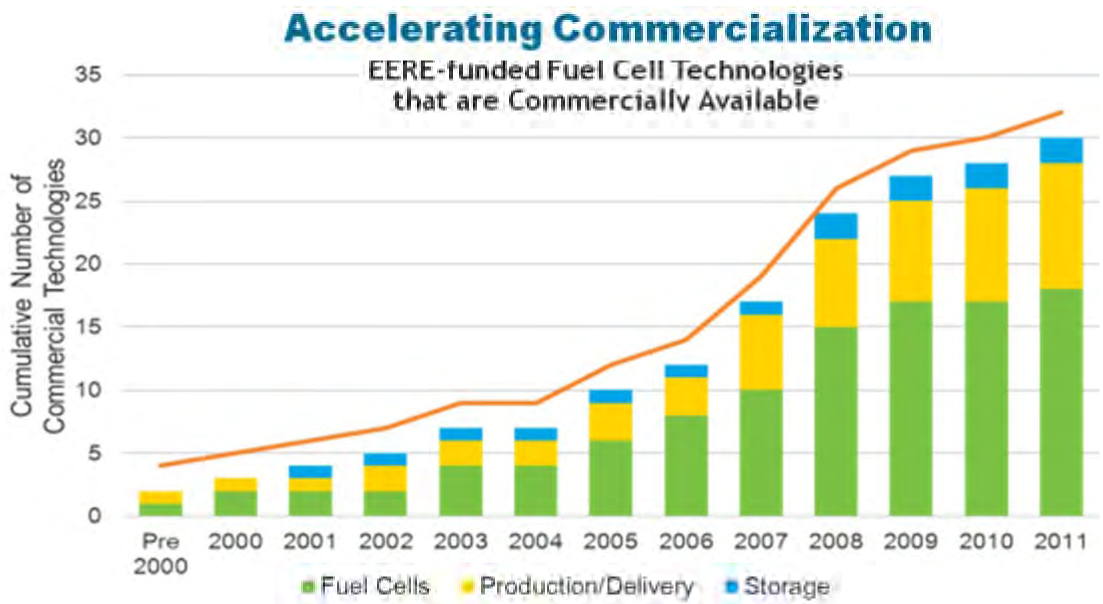
- Bars represent the capacity range of technologies modeled in the given year, overall average for all technologies analyzed indicated.
- Projections performed by Argonne National Laboratory using the best available materials data and engineering analysis at the time of modeling.

http://www.hydrogen.energy.gov/pdfs/review11/st002_law_2011_o.pdf

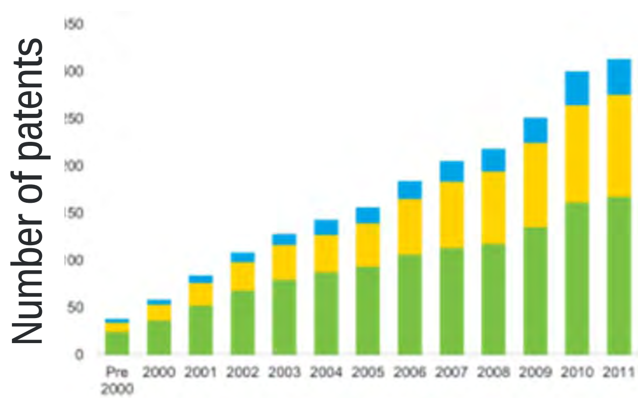
H_2 Fuel Cell Technologies are being commercialized!

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

DOE funding has led led to 313 patents, ~30 commercial technologies and >60 emerging technologies.
DOE's Impact: ~$70M in funding for specific projects was tracked – and found to have led to nearly $200M in industry investment and revenues.



Source: Pacific Northwest National Laboratory
http://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/pathways_success_hfcit.pdf

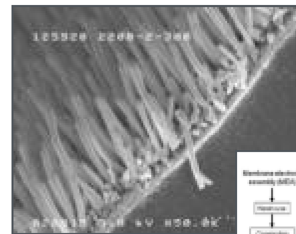


>310 PATENTS resulting from EERE-funded R&D:
- *Includes technologies for hydrogen production and delivery, hydrogen storage, and fuel cells*

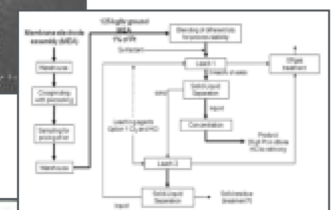
http://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/pathways_2011.pdf

Examples

3M



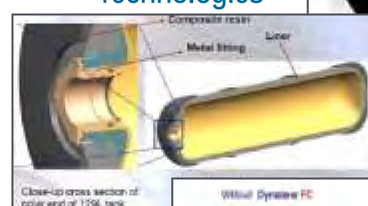
BASF Catalysts LLC



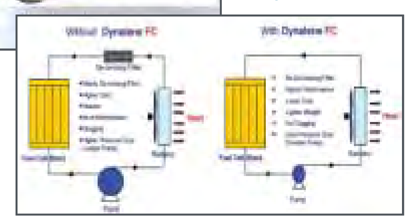
Proton Energy Systems

DuPont

Quantum Technologies



Dynalene, Inc.



Market Transformation – Addressing Market Barriers

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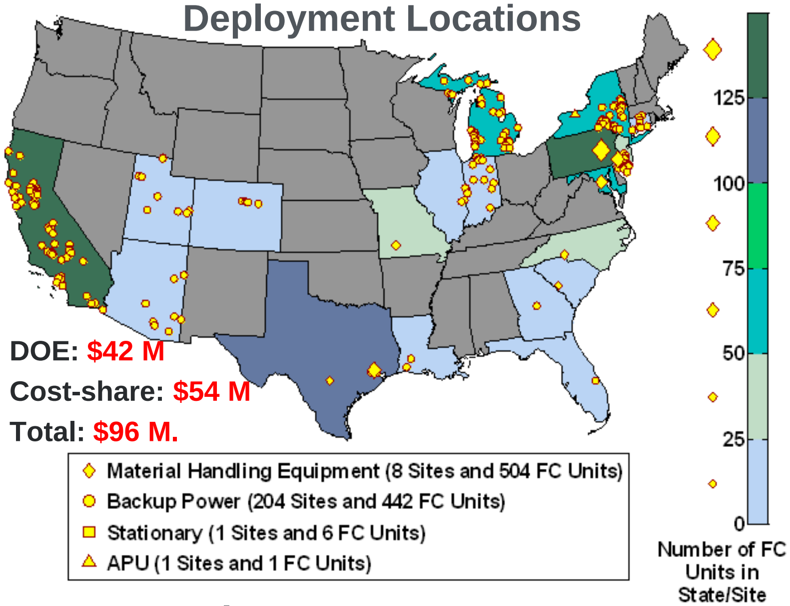
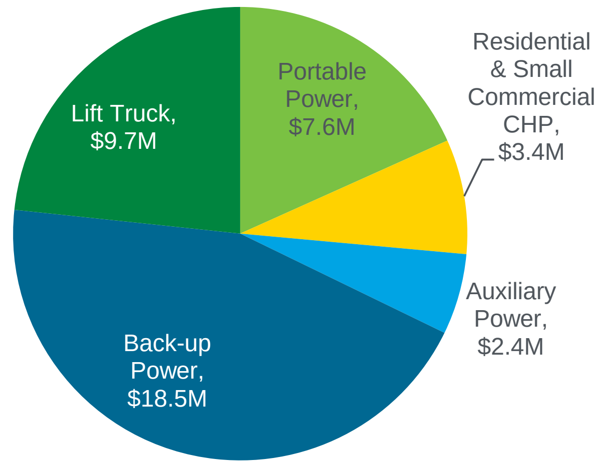
Deployments help ensure continued technology utilization growth and catalyze market penetration while providing data and lessons learned.

Deployment Locations



DOE: $42 M
Cost-share: $54 M
Total: $96 M.



FedEx, Sprint, at&t, GENCO, SYSCO, Wegmans

ARRA Deployment Status – August 2011

Fuel Cell Application	Operational Fuel Cells	Total Fuel Cells Planned
Backup Power	371	539
Material Handling	467	504
Stationary	2	6
APU	0	4
Total	**840**	**> 1,000**

Coca-Cola, Whole Foods Market, Kimberly-Clark

NREL ARRA Data Collection Snapshot

ARRA Material Handling Equipment Data	As of 9/30/2011
Hydrogen Dispensed	>51,500 kg
Hydrogen Fills	>88,000
Hours Accumulated	>380,000 hrs

MORE >3,000 ADDITIONAL FUEL CELL LIFT TRUCKS PLANNED with NO DOE funding

Acknowledgements

I wish to thank:

- My colleagues in the DOE Fuel Cell Technology Program;
- All the researchers whose work I borrowed from for my presentation and whom are too numerous to list individually here;
- **And especially the conference organizers for the invitation and you for listening!**

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Thank you

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