Hydrogen Infrastructure Technologies - Potential Roles and Applications for Composites

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- **Job title:** ORISE Science, Technology, and Policy Fellow
- **Focus areas:**
  - Hydrogen delivery and storage infrastructure
  - Multifunctional & autonomous materials, composite materials
  - International collaboration
- **Education:**
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  - M.S. Aeronautics and Astronautics, Stanford University
  - Ph.D. Aerospace Engineering, University of Illinois at Urbana-Champaign
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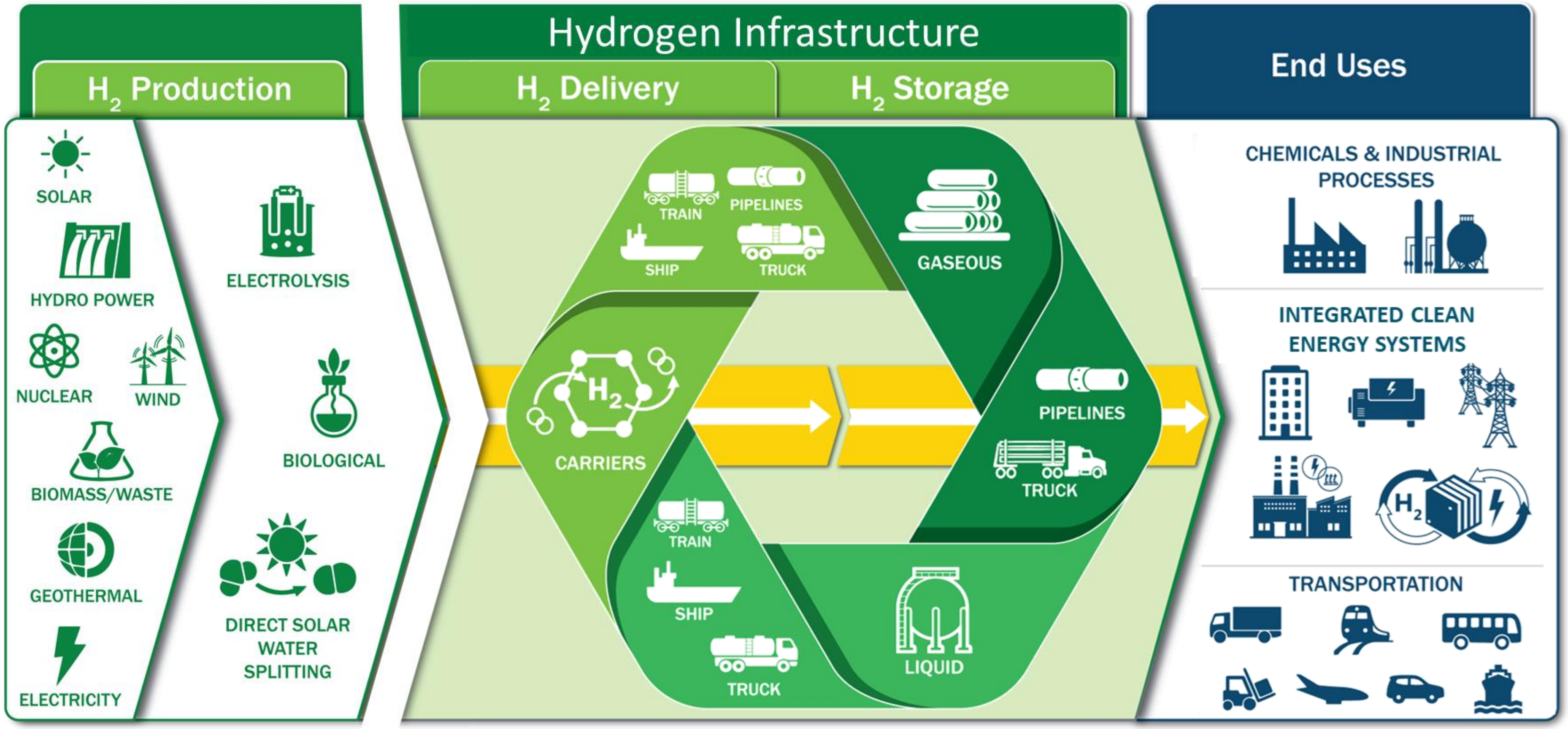
The Role of the Hydrogen Infrastructure Program



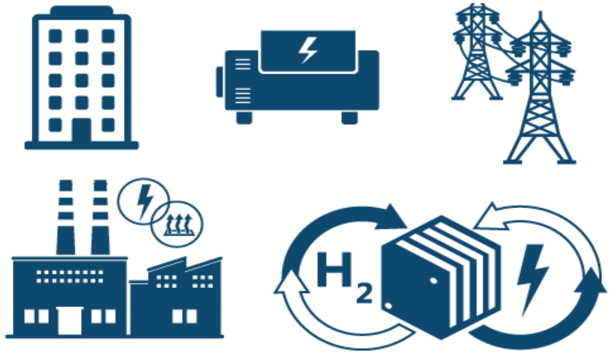
H_2 Production → [H_2 Conditioning → H_2 Transmission → H_2 Distribution → H_2 Conditioning → H_2 Dispensing (general steps)] → H_2 End-Use

Hydrogen Delivery and Storage Requirements

Each end use sector has significantly different delivery and storage needs requiring different technologies

Our team supports projects that address delivery and storage concerns for all these technologies, and analysis to match technologies to end uses

INTEGRATED CLEAN ENERGY SYSTEMS



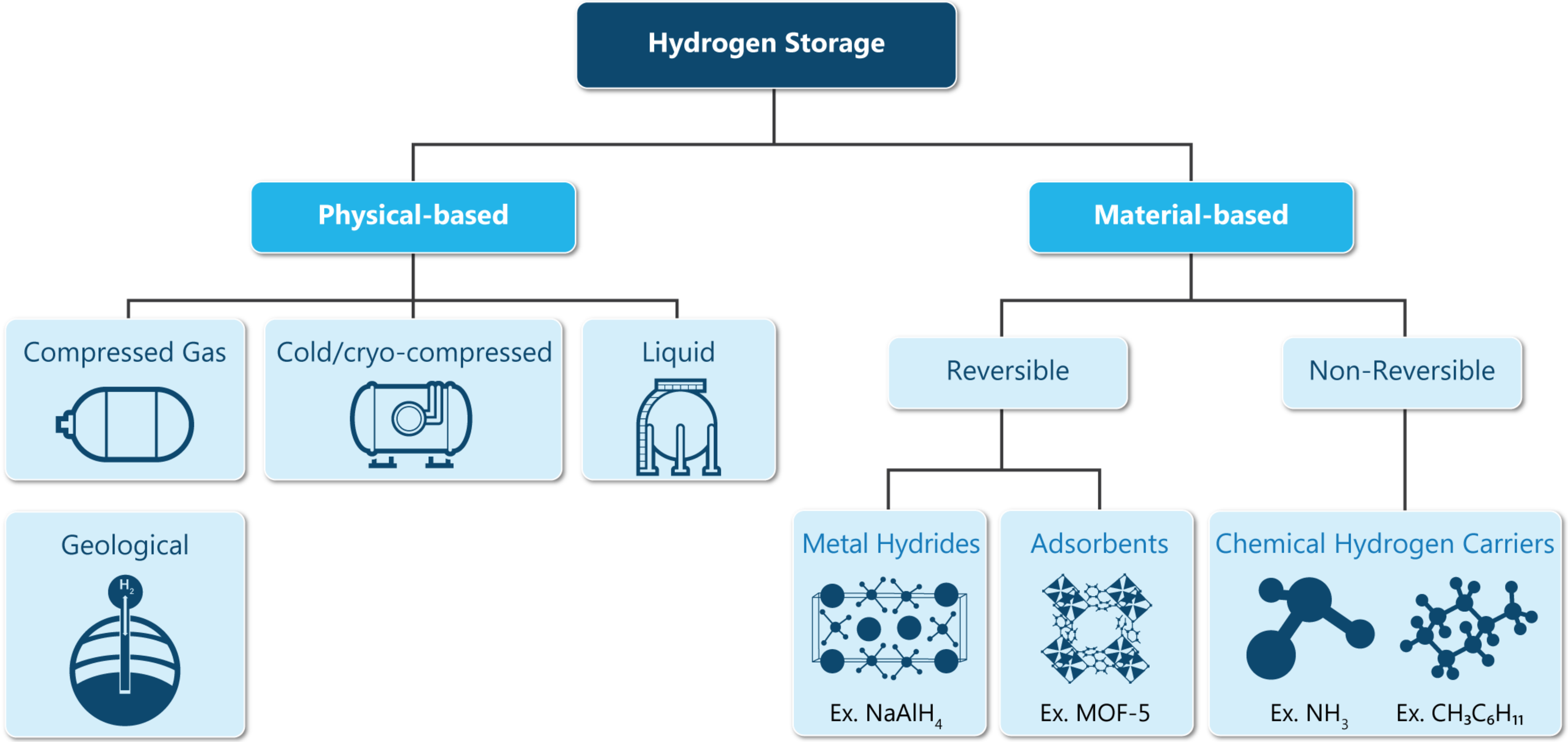
Geologic?
LH2?
Carriers?
Materials?
Pipelines?

CHEMICALS & INDUSTRIAL PROCESSES

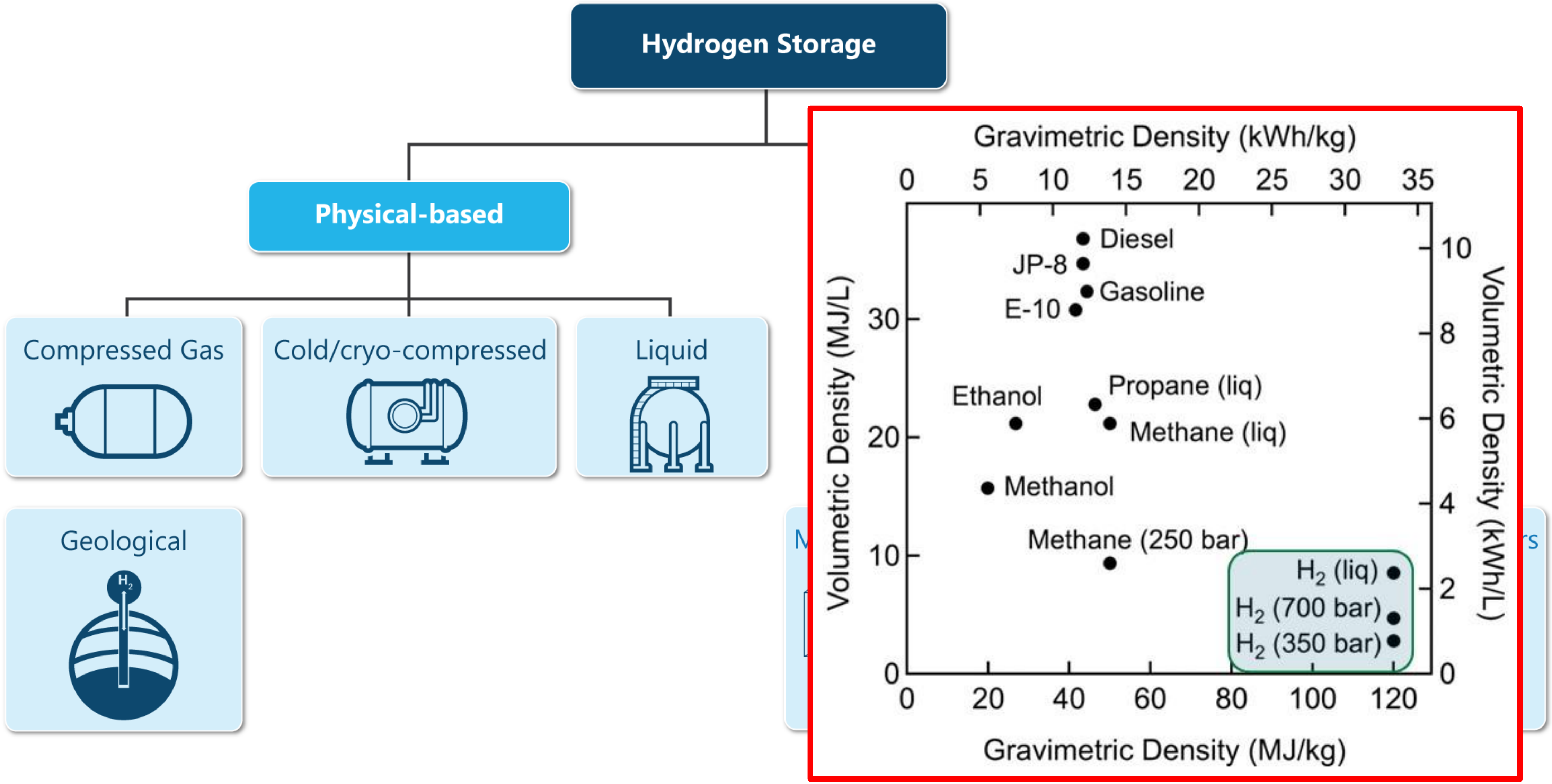
LH2? Pipelines?
Carriers?

TRANSPORTATION

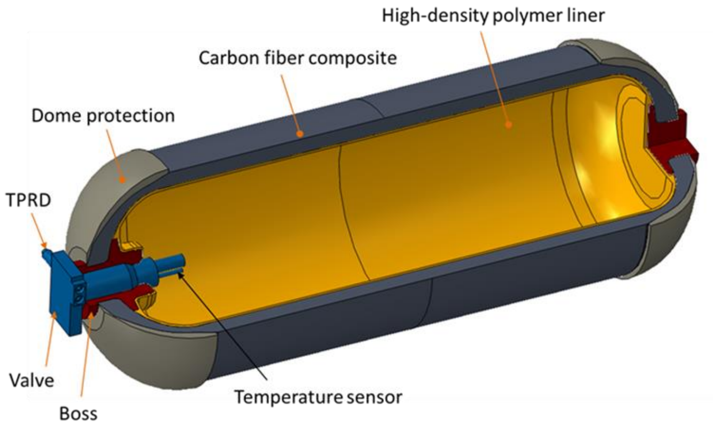
Comprehensive DOE Program on Hydrogen Storage Technologies



Main Challenge of Hydrogen Storage and Transport – Low H_2 Density



How do we move and store hydrogen today?



Gaseous Hydrogen – Onboard Storage

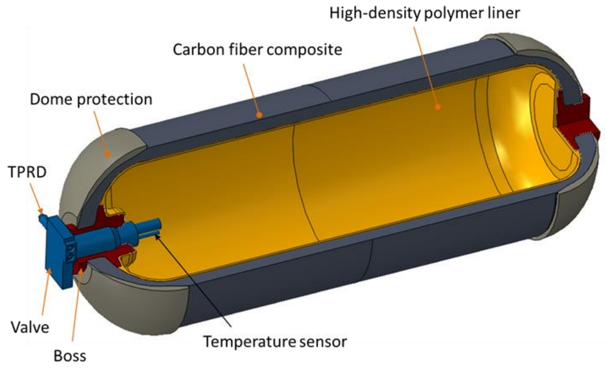
- Compressed hydrogen gas at 350 or 700 Bar
- Type IV Composite Overwrapped Pressure Vessels (COPV)

- **Key considerations for onboard storage systems:**
  - Fiber development
  - Tank design
  - Material and component supply
  - Manufacturing throughput
  - Tank and fiber recycling

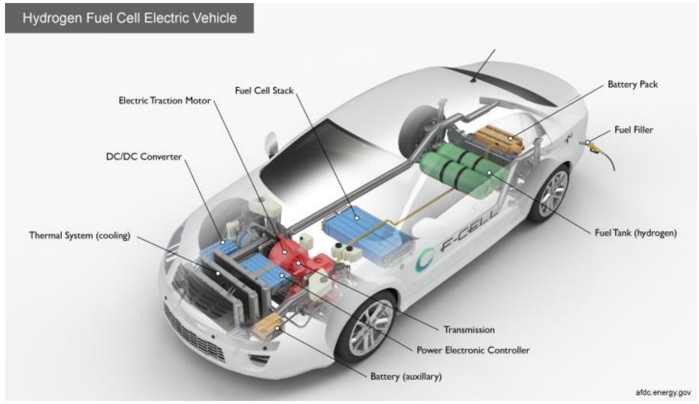
Industry standard for onboard storage tanks:

<u>T700S carbon fiber</u>

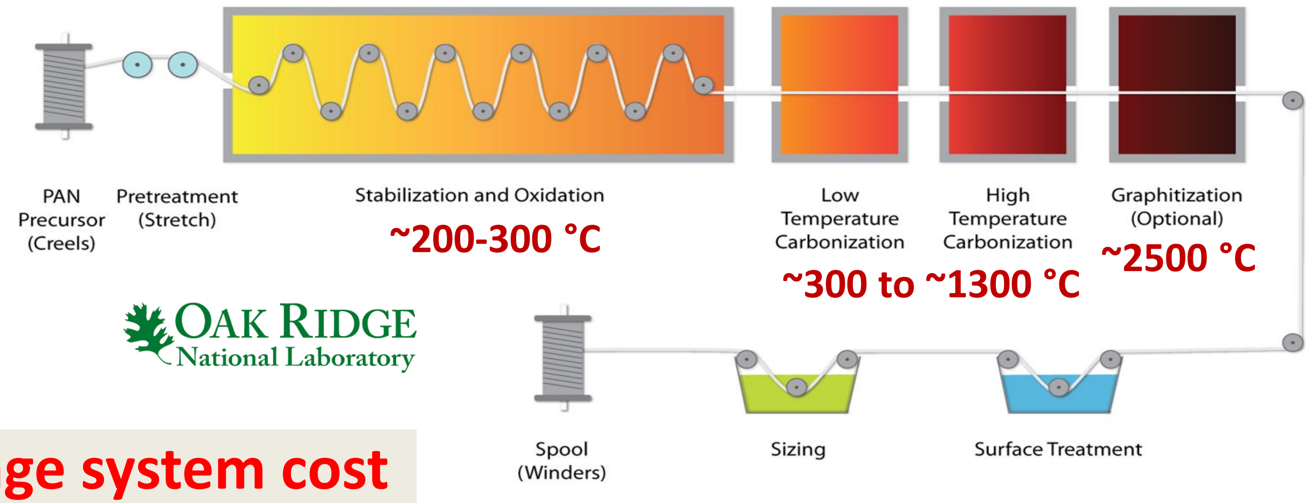
- *Tensile strength*: 711 ksi
- *Tensile modulus*: 33.4 Msi



Schematic of a 700-bar Type IV COPV for on-board FCEV hydrogen storage
(Credit: Argonne National Laboratory)



Carbon fiber processing



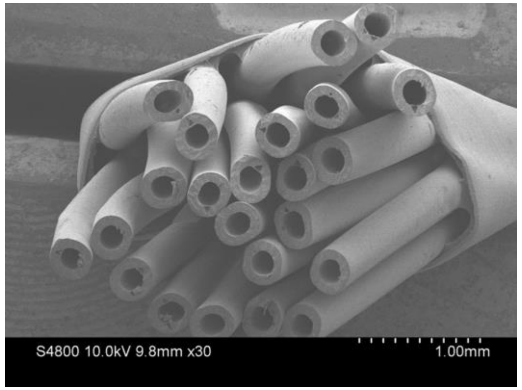
Key metric: storage system cost

Reducing Carbon Fiber Cost through Precursors

UK Center for Applied Energy Research

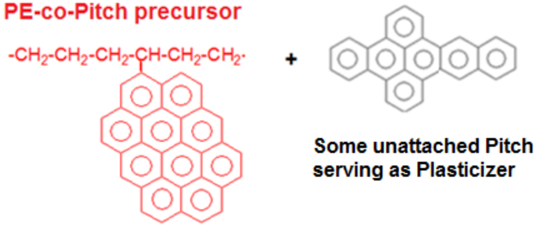
Improved processing and development of hollow PAN precursor fibers

- 50% reduction in wastewater = 5% reduction in carbon fiber cost
- Up to 2.6X faster oxidation

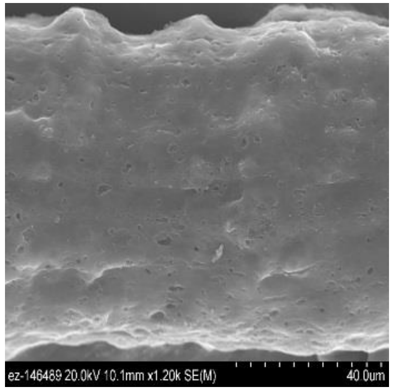


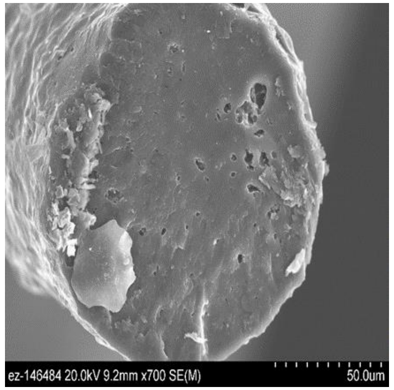
PENNSTATE

Development of low-cost polyolefin precursor fibers with high mass yield



- 70% mass yield demonstrated on carbonization
- Only a single conversion step needed

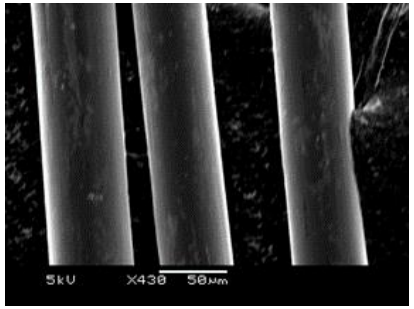




OAK RIDGE National Laboratory

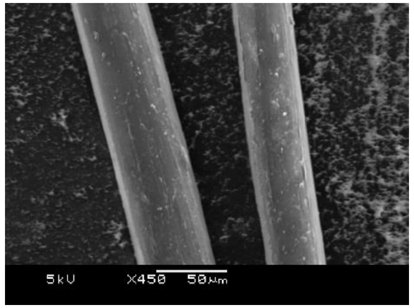
Novel plasticized PAN fibers produced through low-cost melt spinning

Ionic liquid	PAN (%)	As Spun Diameters (µm)	Washed Fiber Diameters (µm)
[C_3mim]Br	30	56.2 +/- 0.16	53.4 ± 7.6
[C_4mim]Br	30	56.8 +/- 0.20	45.6 ± 7.9
[C_4mim]Cl	30	54.7 +/- 0.08	45.3 ± 8.7
[MPCNIm]Br	30	59.6 +/- 0.25	47.9 ± 14.1
[MPCNIm]Cl	30	53.4 +/- 0.17	48.6 ± 10.4



As spun fibers

Washed fibers



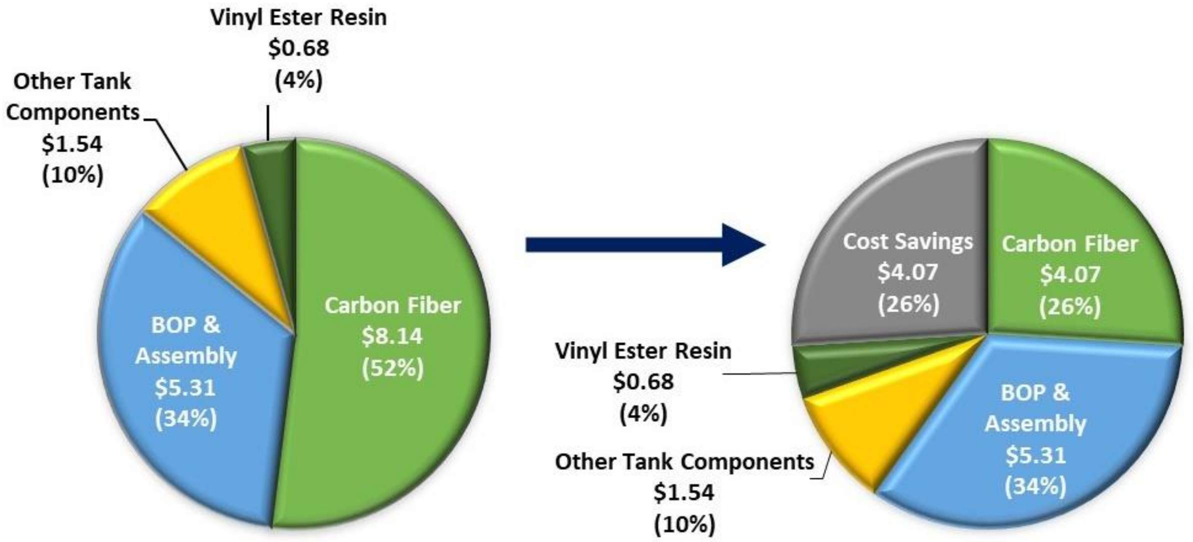
Development of Advanced Low-cost Carbon Fiber

Objectives:

- *Target:* 50% cost reduction in carbon fiber used in onboard tanks
- Four teams during initial phase (2 years) -> down-selected to a single team for final phase (3 years)
- *End of project deliverable:* fully wound tanks using carbon fiber developed during project

Recent Accomplishments:

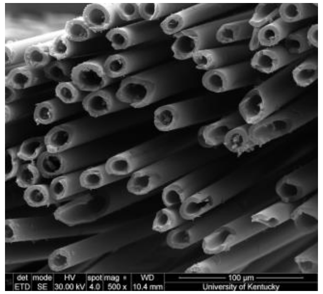
- **Projected CF cost: \$15/kg - \$20/kg**
- **Projected tank cost: \$12.8/kWh**
- Reclaimed continuous CF and matrix from pressure vessels
- Reduced-diameter hollow carbon fibers with improved tensile properties



Present-day, from storage record
Total cost: **\$15.67/kWh**

Projected after 50% CF reduction
Total cost: **\$11.60/kWh**

Note: cost analysis for a 700-bar onboard system with 5.6 kg usable H_2 capacity, manufactured at 100,000 systems per year



Hollow carbon fibers

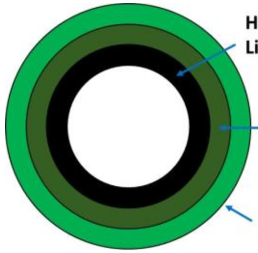
Precursor fibers

Type 4 sub-scale vessel

Fiber-Reinforced Polymer (FRP) Pipelines for Hydrogen Transmission

Advantages:

- Excellent burst and collapse pressure ratings
- Good chemical and corrosion resistance; not susceptible to embrittlement
- Can be deployed in spools over > 0.5 mile long
  - **25% reduction in installation costs expected (compared to steel pipes)**
  - Lower labor costs with future onsite manufacturing R&D
- Can be pulled through existing oil & gas pipelines to enable refurbishment
  - **Leverage existing rights-of-way**



FRP Cross-Section

DOE-funded work

- *Team*: Savannah River National Lab & Oak Ridge National Lab
- Evaluated mechanical properties of FRP pipeline
  - Establish viability in high-pressure (170 bar), long-duration (50-year) hydrogen service
- *Key metrics*: fatigue life, burst strength, stress rupture time, and permeation rates

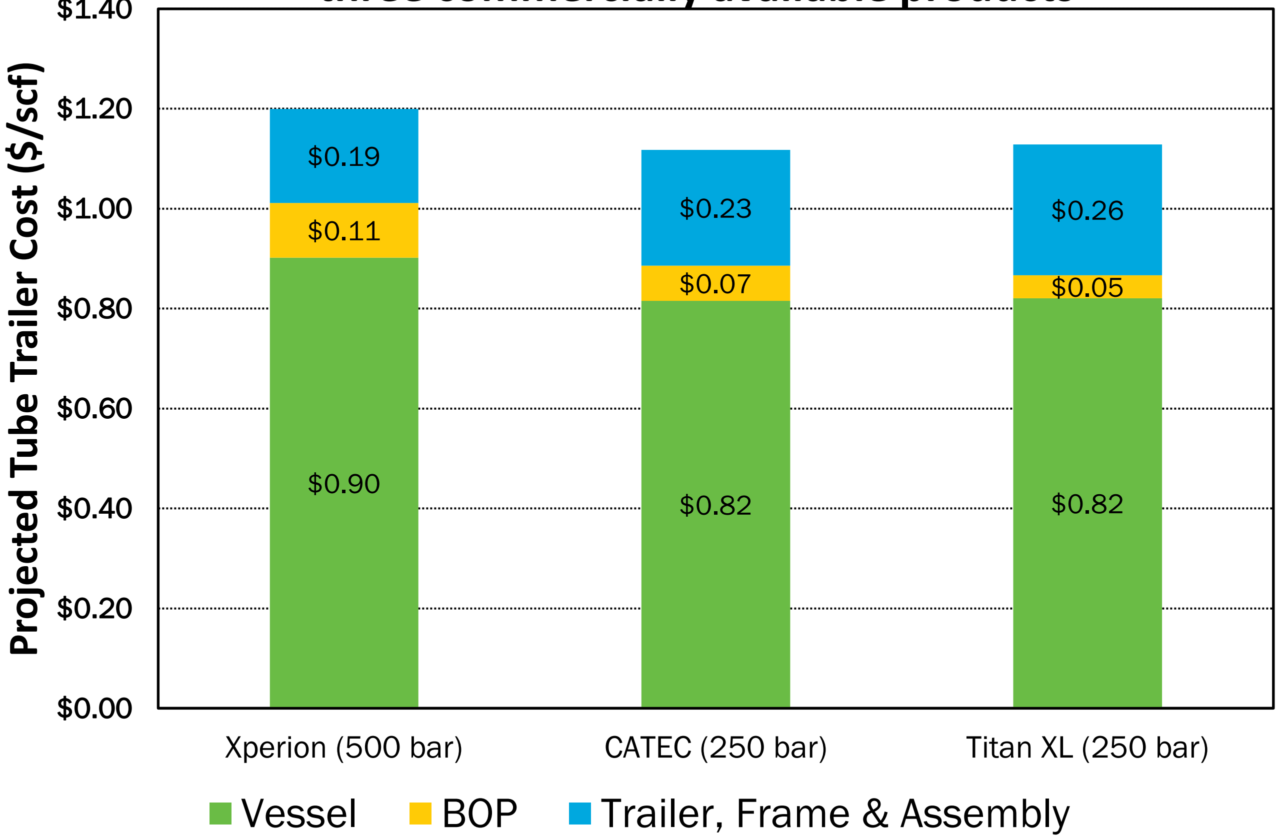
10 years of data collection resulted in acceptance of FRP into the ASME B31.12 Hydrogen Piping and Pipelines Code in 2017!

Composite Tube Trailers for Compressed Hydrogen Transport

- Lightweight, bulk transportation of compressed hydrogen via composite tube trailers

	CATEC	Xperion	Titan XL
Vessels	Type 4	Type 4	Type 4
Pressure (bar)	250	500	250
Number or tanks	8	100	4
Capacity (kg/scf)	1,000/423,300	1,100/465,630	885/374,620

Projected cost breakdowns for tube trailers based on three commercially available products



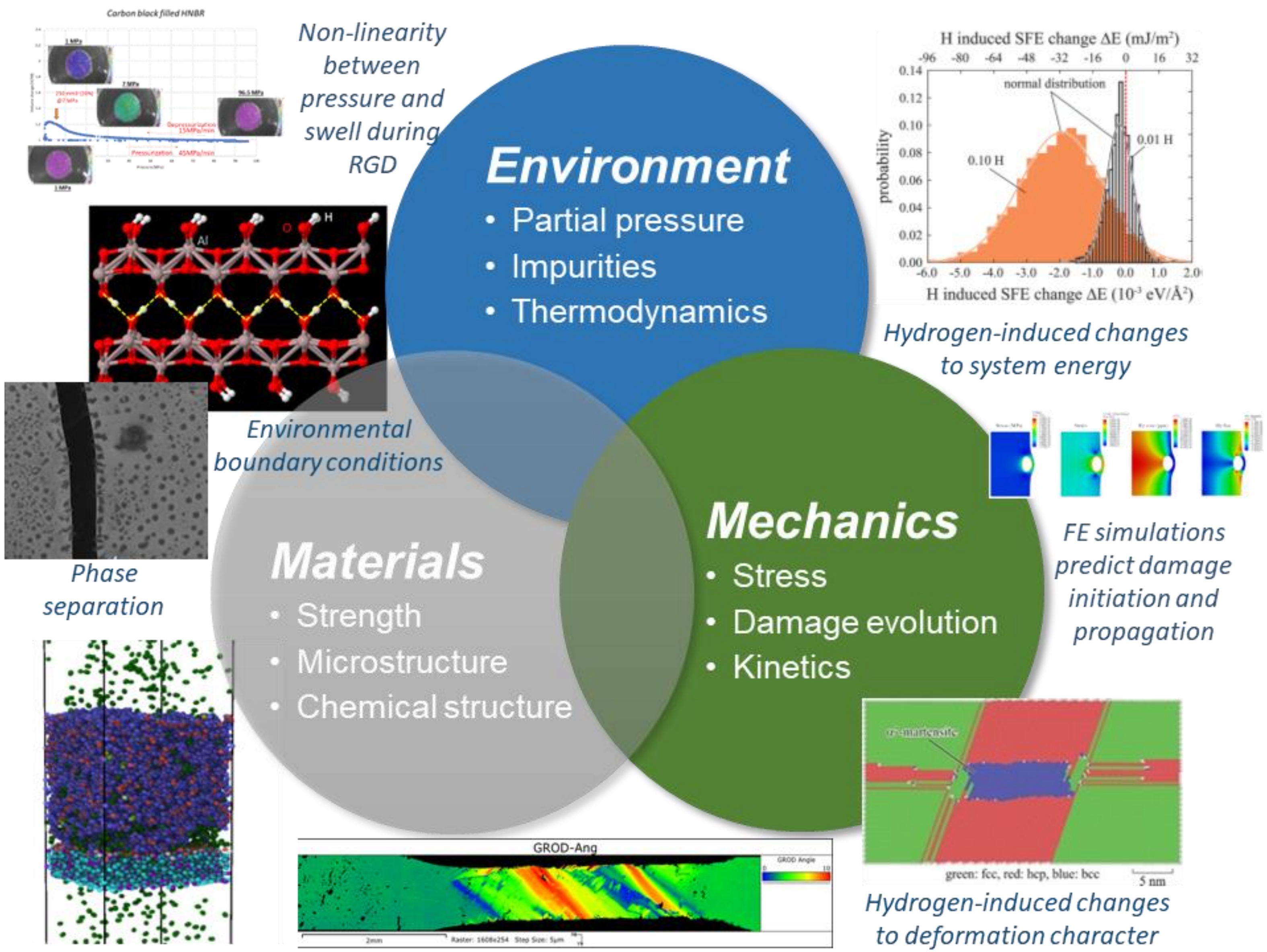
Source: Hexagon Purus

Source: CATEC Gases

Source: Hexagon Purus

Hydrogen Materials Compatibility Consortium

H-Mat Hydrogen Materials Compatibility Consortium SM



Sandia National Laboratories

Pacific Northwest National Laboratory

Oak Ridge National Laboratory

Argonne National Laboratory

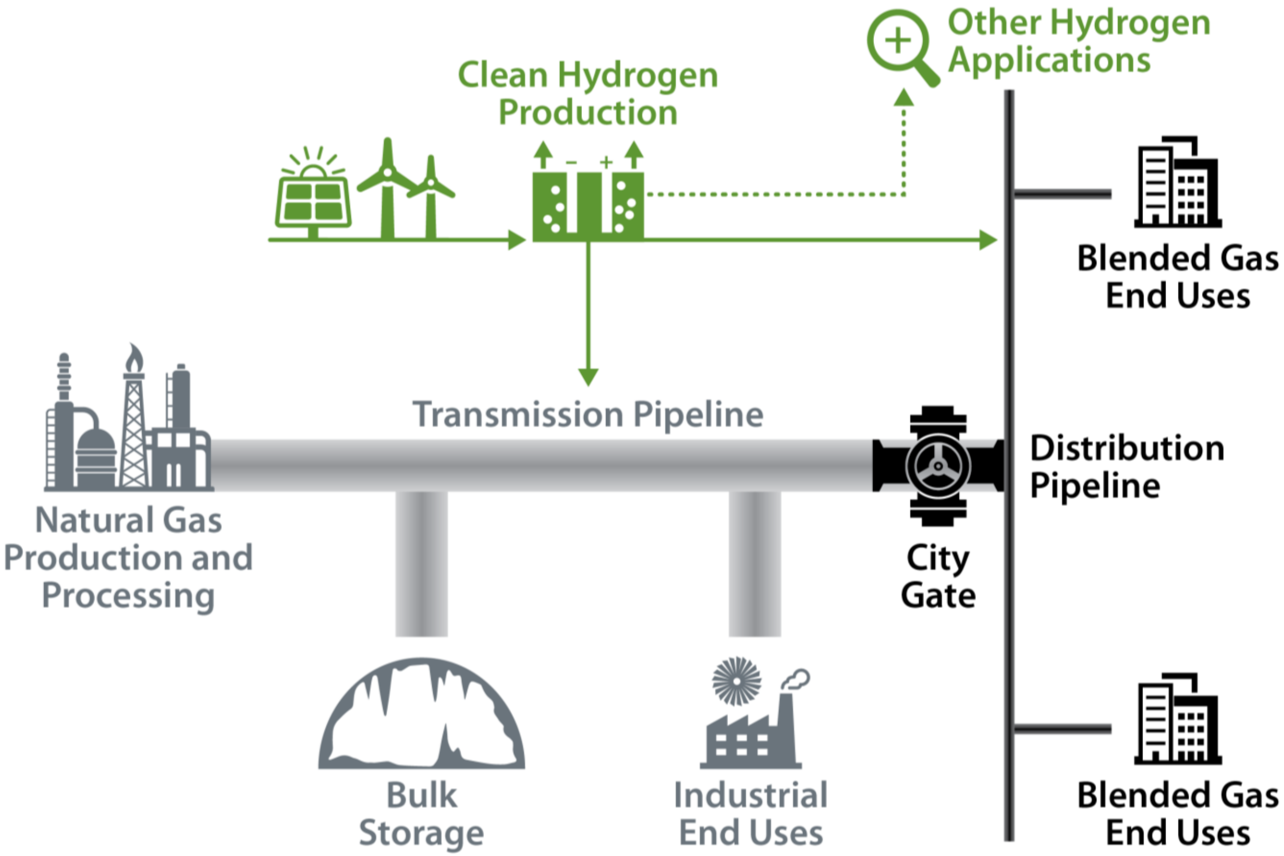
Objective

Explore hydrogen/material interaction interactions to inform science-based strategies for material design to improve resistance to hydrogen degradation

Hydrogen Blending in Natural Gas Pipelines

HyBlend
U.S. DEPARTMENT OF ENERGY

Reducing the Carbon Intensity of the Natural Gas Grid via Hydrogen Blends



Objectives

- Pipeline materials compatibility R&D
- Public tools for pipeline integrity and sensitivity analyses
- Technoeconomic and life cycle analyses

Phase I: Two-year, $15M CRADA Project

- 4 National Labs + 31 partners from industry & academia

Phase II: Three-year CRADA (In planning stage)

- 4 National Labs + ~40-50 partners from industry & academia
- Open to new partners

Visit the HyBlend™ Initiative webpage for details and links to tools and publications

Led by:

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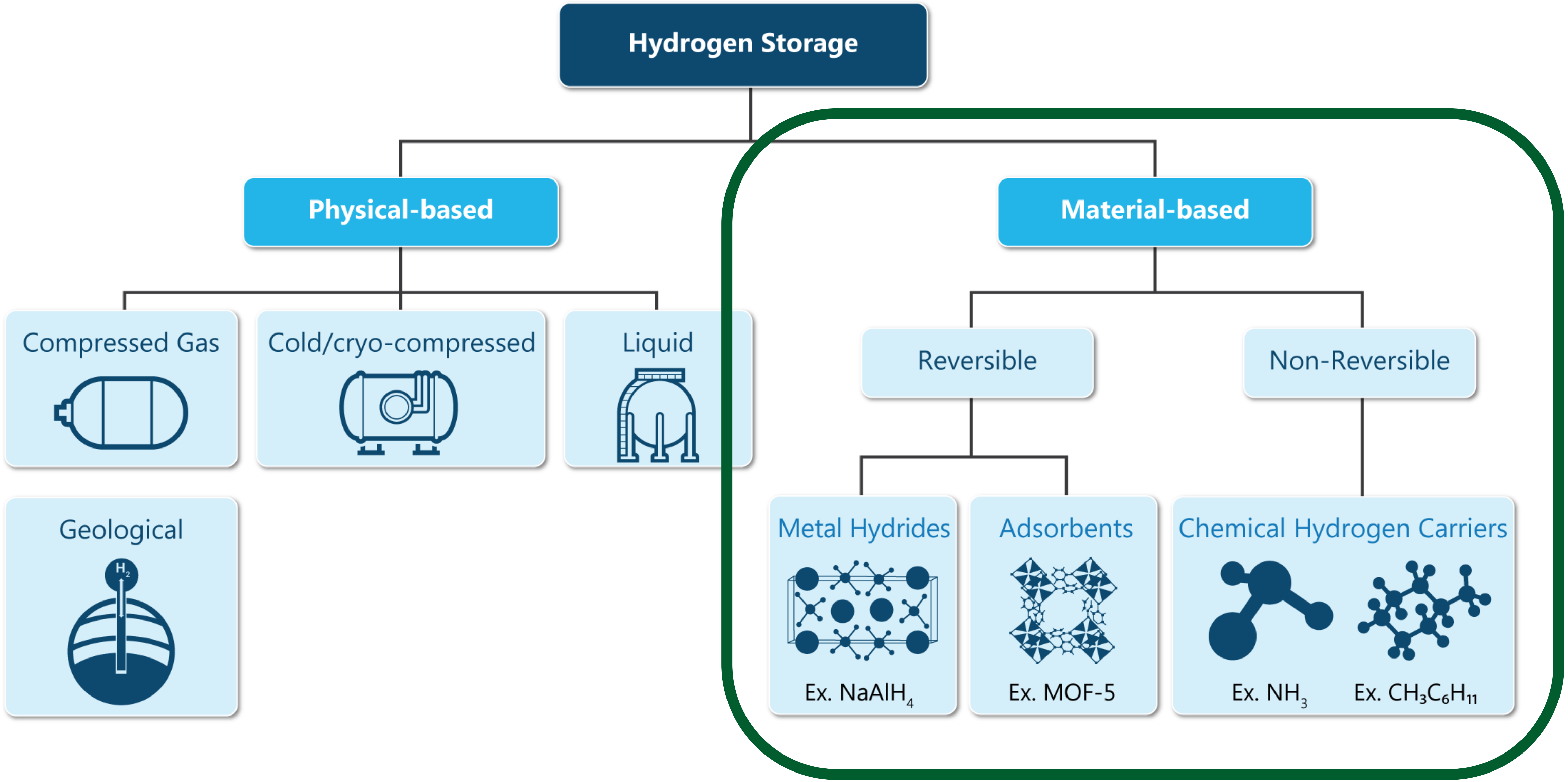
Comprehensive DOE Program on H_2 Storage Technologies

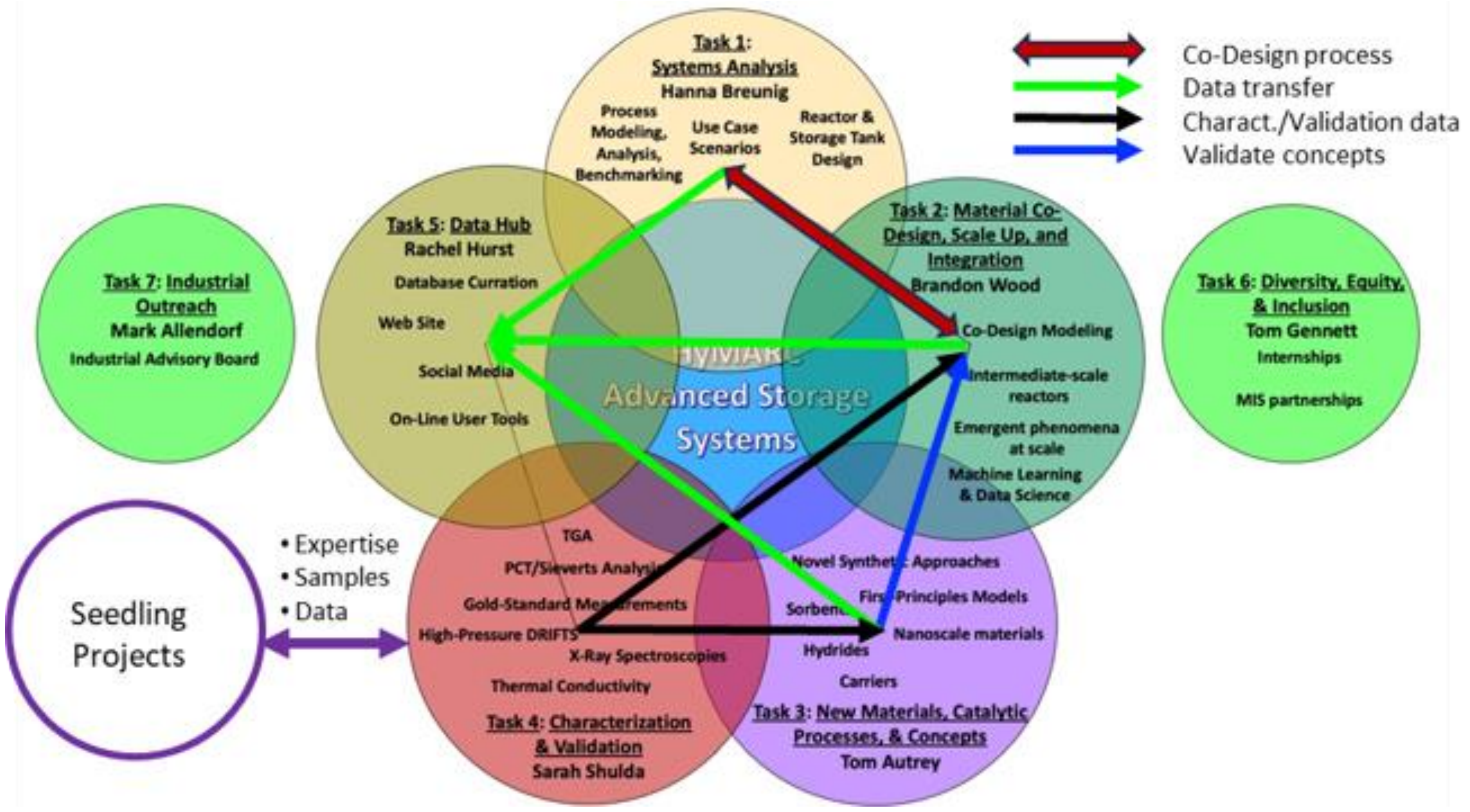


Hydrogen Materials – Advanced Research Consortium

HyMARC Hydrogen Materials Advanced Research Consortium

Accelerating development of H_2 storage materials that meet levelized performance and cost of physical storage methods for specific use cases

- Synergistic approach incorporating system analysis, modeling and materials characterization to focus on most promising applications
- Iterative co-design approach to optimize material and system performance to meet application needs – focusing on higher TRL activities
- World-class characterization and validation capabilities
- Support other DOE-supported RD&D efforts
- Engage with industry stakeholders



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Thank You

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