U.S. DEPARTMENT OF
ENERGY

Office of
ENERGY EFFICIENCY &
RENEWABLE ENERGY

HFTO H_2 Infrastructure Technologies Subprogram Overview

Ned Stetson, HFTO – H_2 Infrastructure Technologies Program Manager

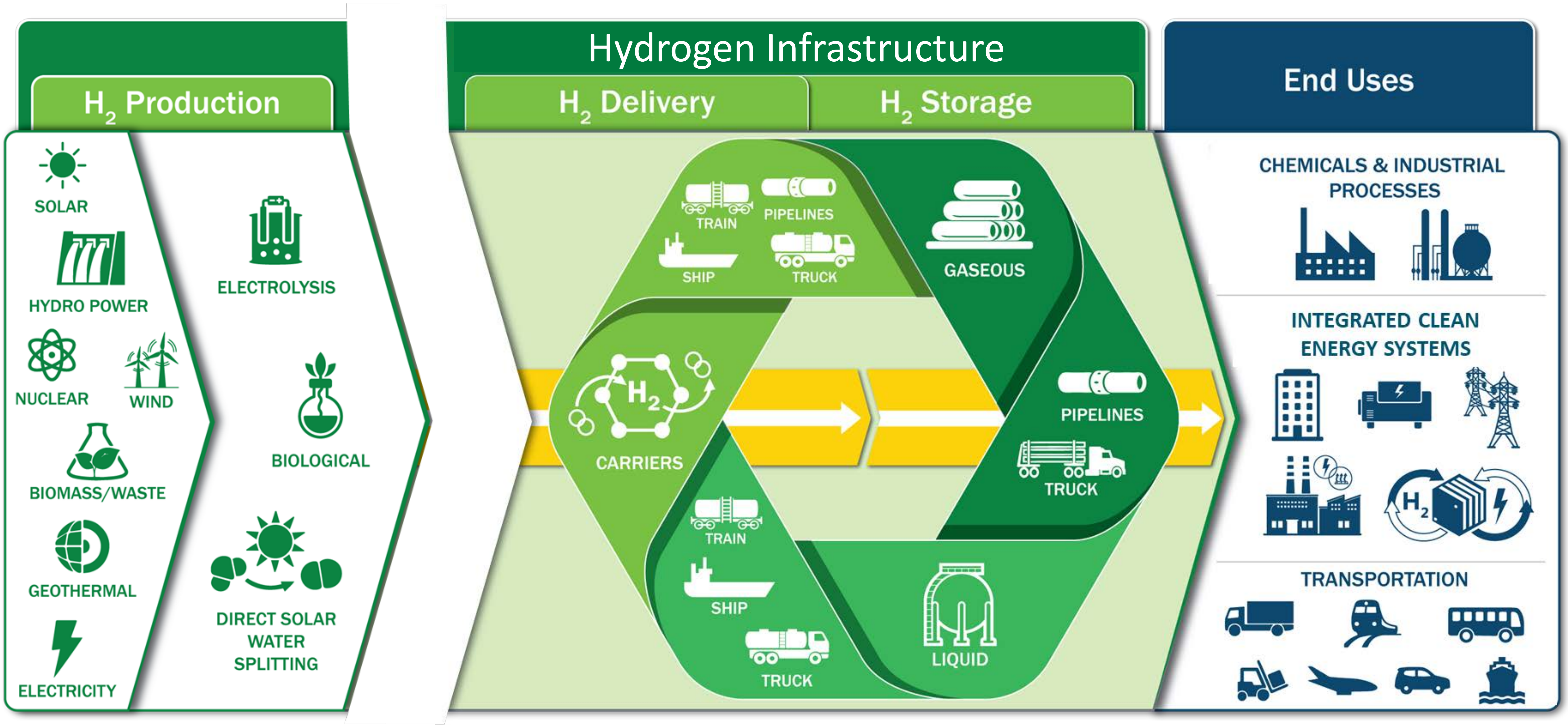
2023 Annual Merit Review and Peer Evaluation Meeting

June 6, 2023 – Arlington, VA





Hydrogen Technologies: Production & Infrastructure



From producing hydrogen molecules through dispensing to end-use applications

The Hydrogen and Fuel Cell Technologies Office (HFTO)

Mission

Support research, development and demonstration (RD&D) of hydrogen and fuel cell technologies to advance:

- Clean Energy and Emissions Reduction Across Sectors
- Job Creation and a Sustainable and Equitable Energy Future

Office Sub-Programs

Hydrogen Technologies

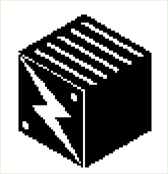
Hydrogen Production

Hydrogen Infrastructure

Fuel Cell Technologies

Materials & Components

Systems



Systems Development & Integration

Transportation

Industrial and Chemical Applications

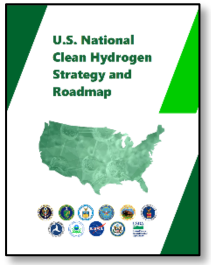
Grid Energy Storage and Power Generation

Data, Modeling, Analysis, Safety, Codes and Standards

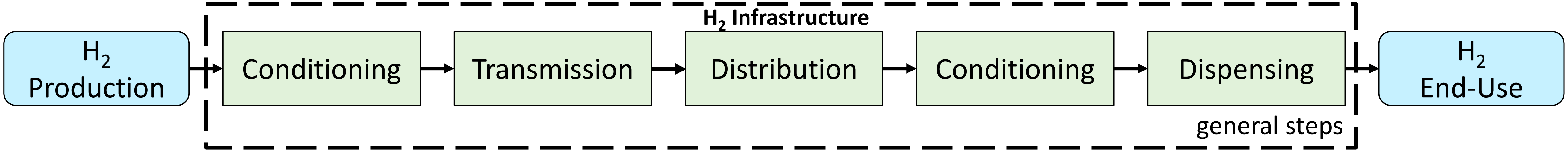
Enabling

ENERGY earthshots U.S. DEPARTMENT OF ENERGY | Hydrogen

H2@Scale U.S. Department of Energy



What are H_2 Infrastructure Technologies?



Hydrogen within the infrastructure may be as a *__gas, cryogenic liquid, or materials-based carrier__*

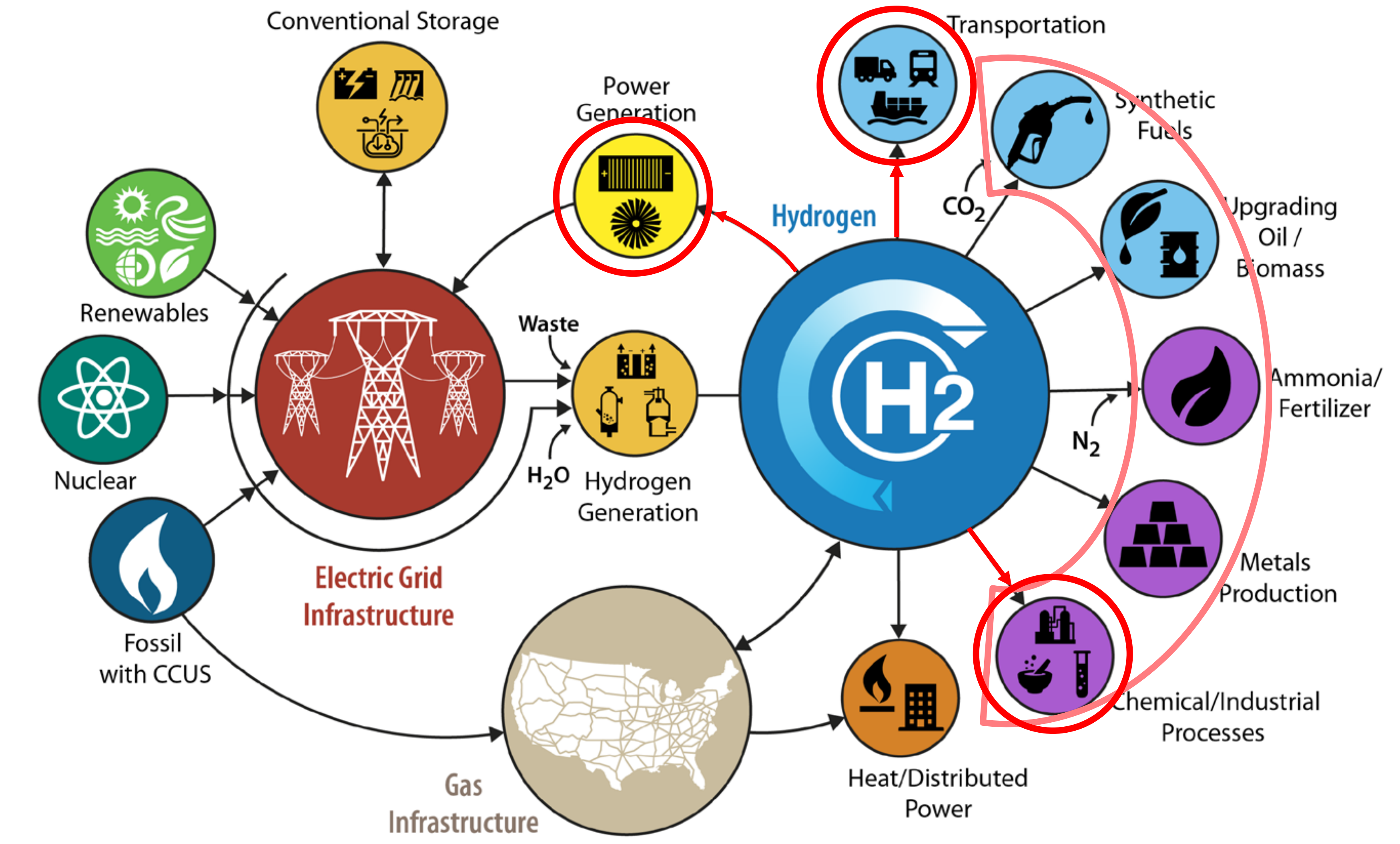
Each step may consist of:

- **Conditioning:** compression, liquefaction/vaporization, H_2 carrier hydrogenation/dehydrogenation, purification, temperature control
- **Transmission/Distribution:** on-road (e.g., tube/tanker trailers), pipelines, rail, marine, bulk buffer storage, transfers, sensors/monitoring
- **Dispensing:** dispensers, metering, nozzles/receptacles, hoses, breakaways, temperature control, sensors/monitoring, cascade storage, compressors, pumps
- **End-Use:** on-site, on-vehicle storage

All infrastructure steps may occur on a single property (e.g., onsite production/use for energy storage or large-scale industry), or could spread across multiple continents (e.g., international export)

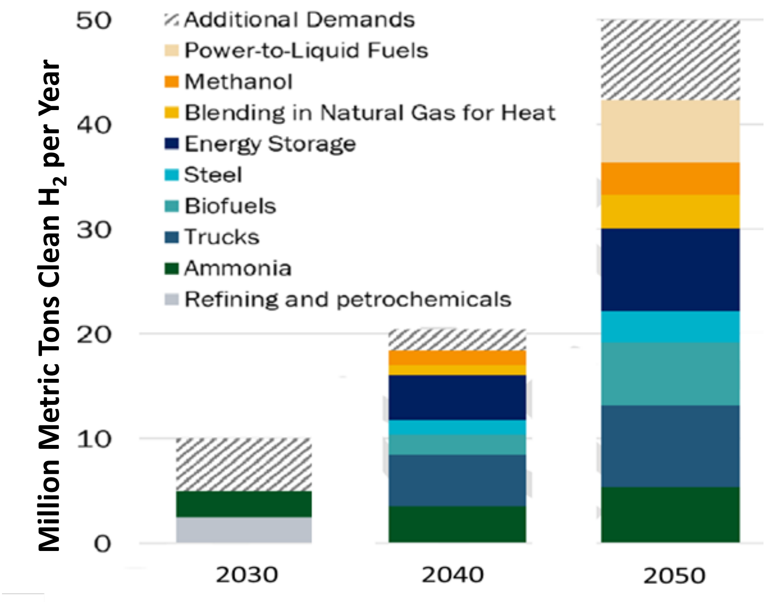
Overarching metric is the cost of H_2 to the end-user: cost of production *__+ total cost of delivery and dispensing__*

H2@Scale Initiative & H_2 Infrastructure Tech Decarbonization Focus Areas



Key Opportunities

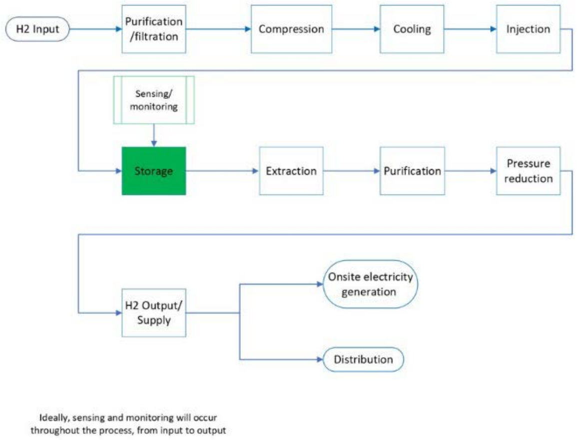
- **Industry and Chemicals**
  Steel, ammonia, cement, syn fuels (e.g., aviation), exports
- **Transportation**
  Trucks, marine, buses, etc.
- **Power and Energy Storage**
  Long duration storage, NG blending, turbines, fuel cells

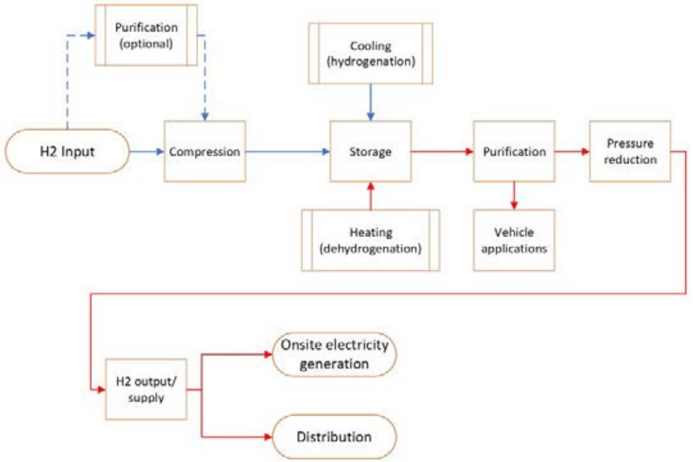


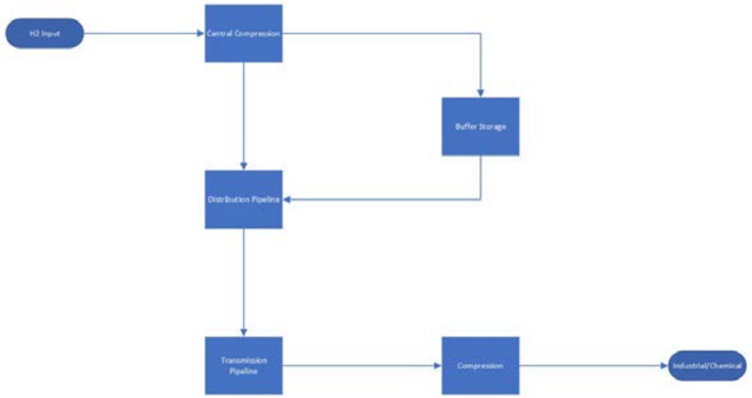
Scenario Planning for Energy Storage and Chemical/Industrial Sectors

Energy Storage		Chemical/Industrial Use

Develop process flows for H_2 transport, storage and dispensing needs

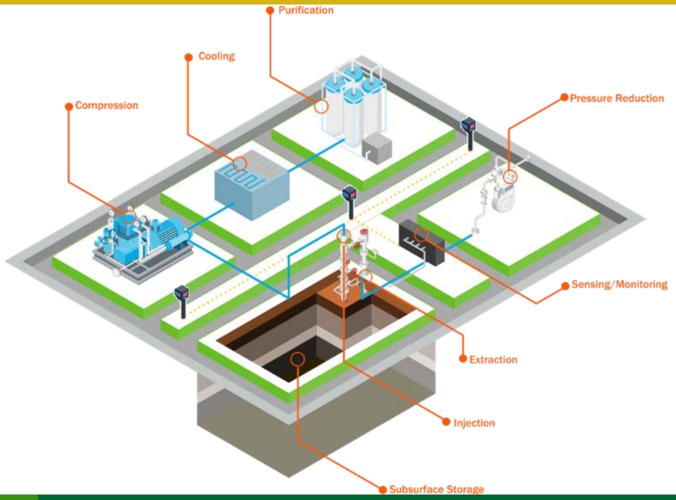


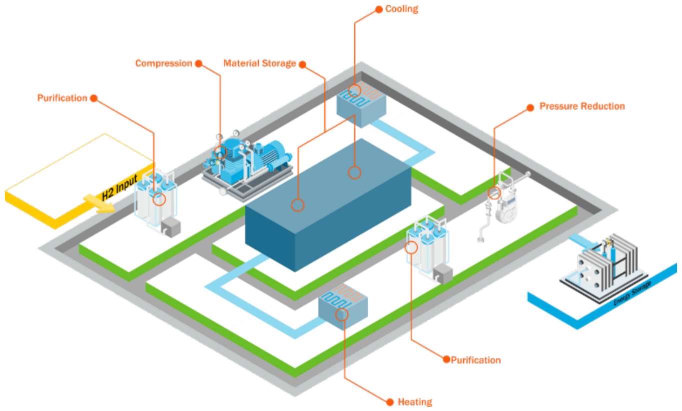


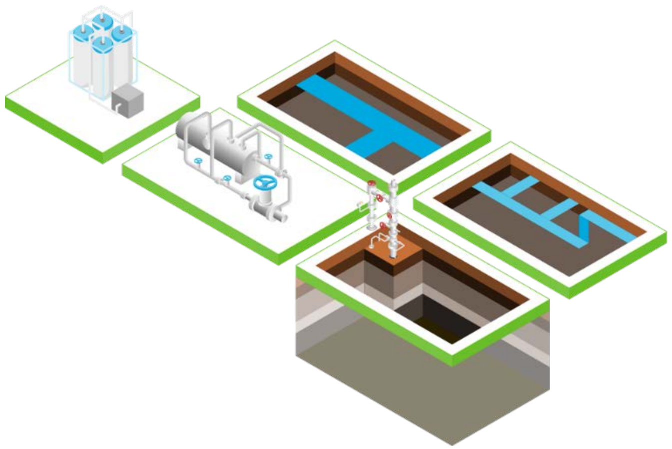


Subsurface Storage	Materials-based Storage	Chemical/Industrial Use

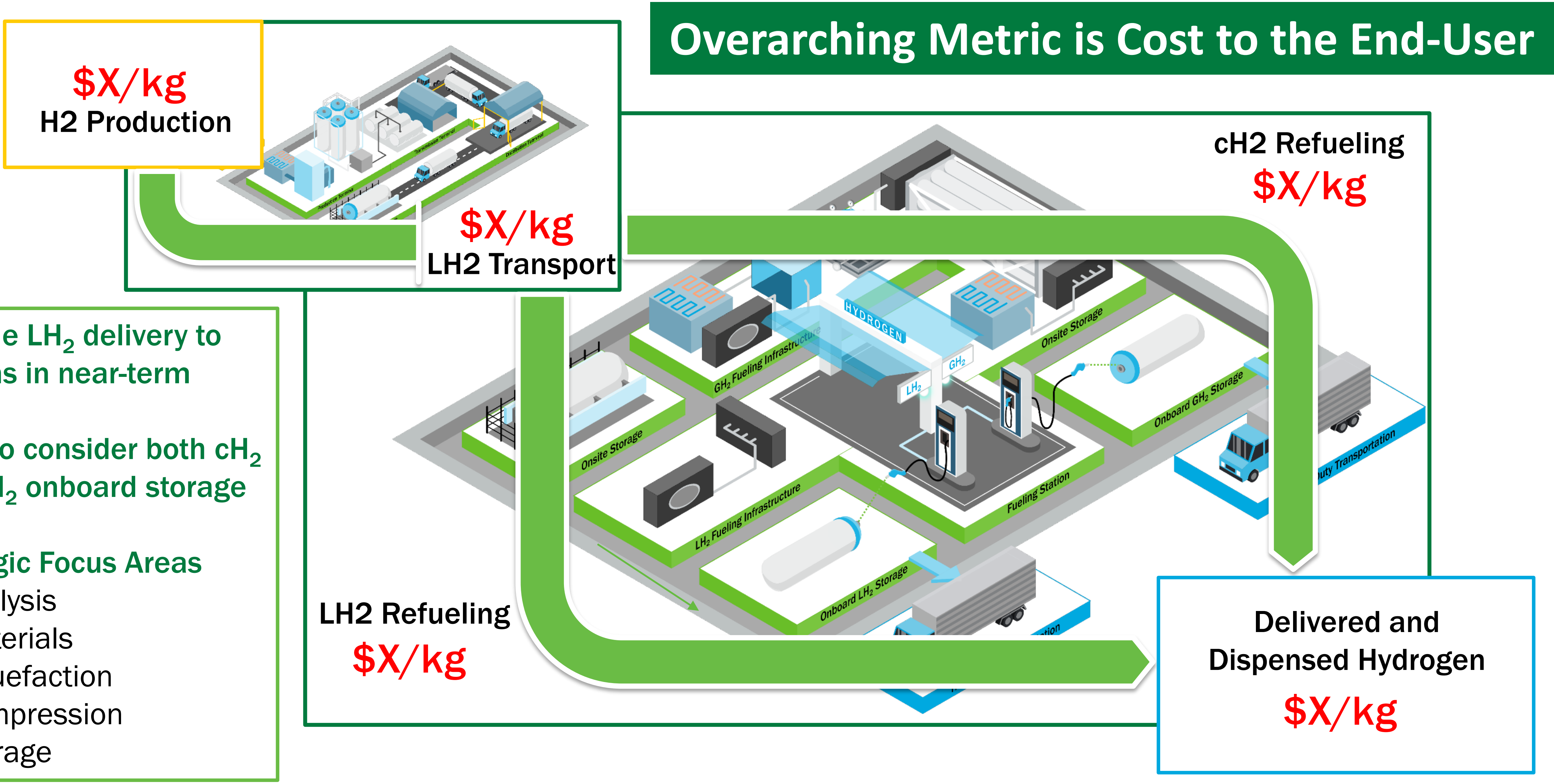
Illustrate key components and processes







Scenario Planning for MD/HD H_2 Fueling



Assume LH_2 delivery to stations in near-term

Need to consider both cH_2 and LH_2 onboard storage

Strategic Focus Areas

- Analysis
- Materials
- Liquefaction
- Compression
- Storage

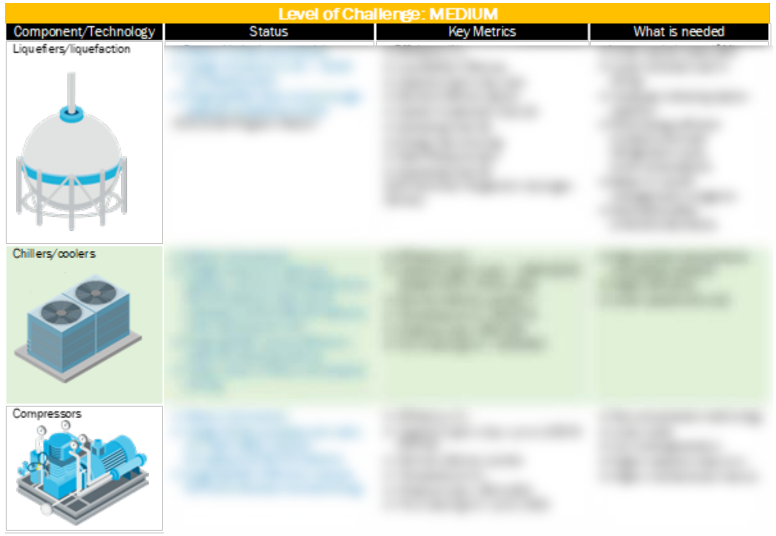
MD/HD Fueling Scenario Analysis using HDSAM

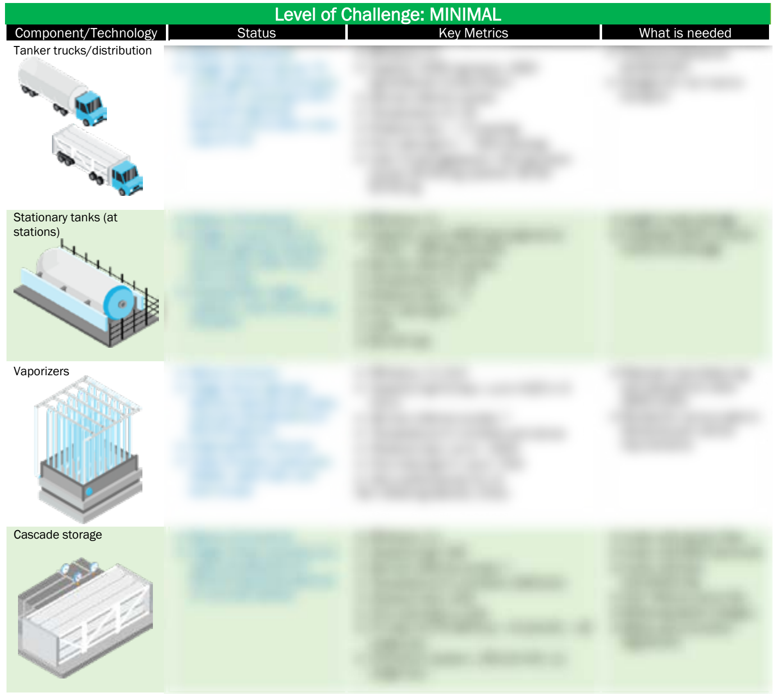
	LH2	350 bar pump	700 bar pump	350 bar compressor	700 bar compressor	Interim	Ultimate
Production			$4			$2	$1
Delivery Subtotal			$3.11			$3.00	$3.00
Liquefaction			$2.47				
Storage			$0.41				
Other terminal			$0.01				
Transmission/distribution			$0.22				
Dispensing Subtotal	$0.29	$1.95	$2.90	$4.42	$8.70	$2.00	$1.00
Storage	$0.10	$0.41	$0.59	$0.40	$0.57		
Dispenser	$0.04	$0.03	$0.03	$0.03	$0.03		
Compressor/pump	$0.02	$1.15	$1.88	$3.45	$7.16		
Refrigeration	$0.00	$0.00	$0.00	$0.02	$0.03		
Electrical	$0.02	$0.02	$0.07	$0.07	$0.07		
Controls/other	$0.11	$0.34	$0.33	$0.45	$0.84		
Delivery/Dispensing Total	$3.40	$5.06	$6.01	$7.53	$11.81	$5.00	$3.00
End Use Total ($/kg)	$7	$9	$10	$12	$16	$7	$4
Onboard Storage ($/kWh, $/kg stored)			$10 333			$9 300	$8 266

Analysis used to establish current baseline of various fueling options and identify key cost contributors to prioritize RD&D efforts

- Generic scenario – fleet of 50 HD vehicles, 60 kg H2, 10 min fueling
- Estimate relative cost contributions of different components and technologies

Identify and Prioritize Component/Technology Challenges





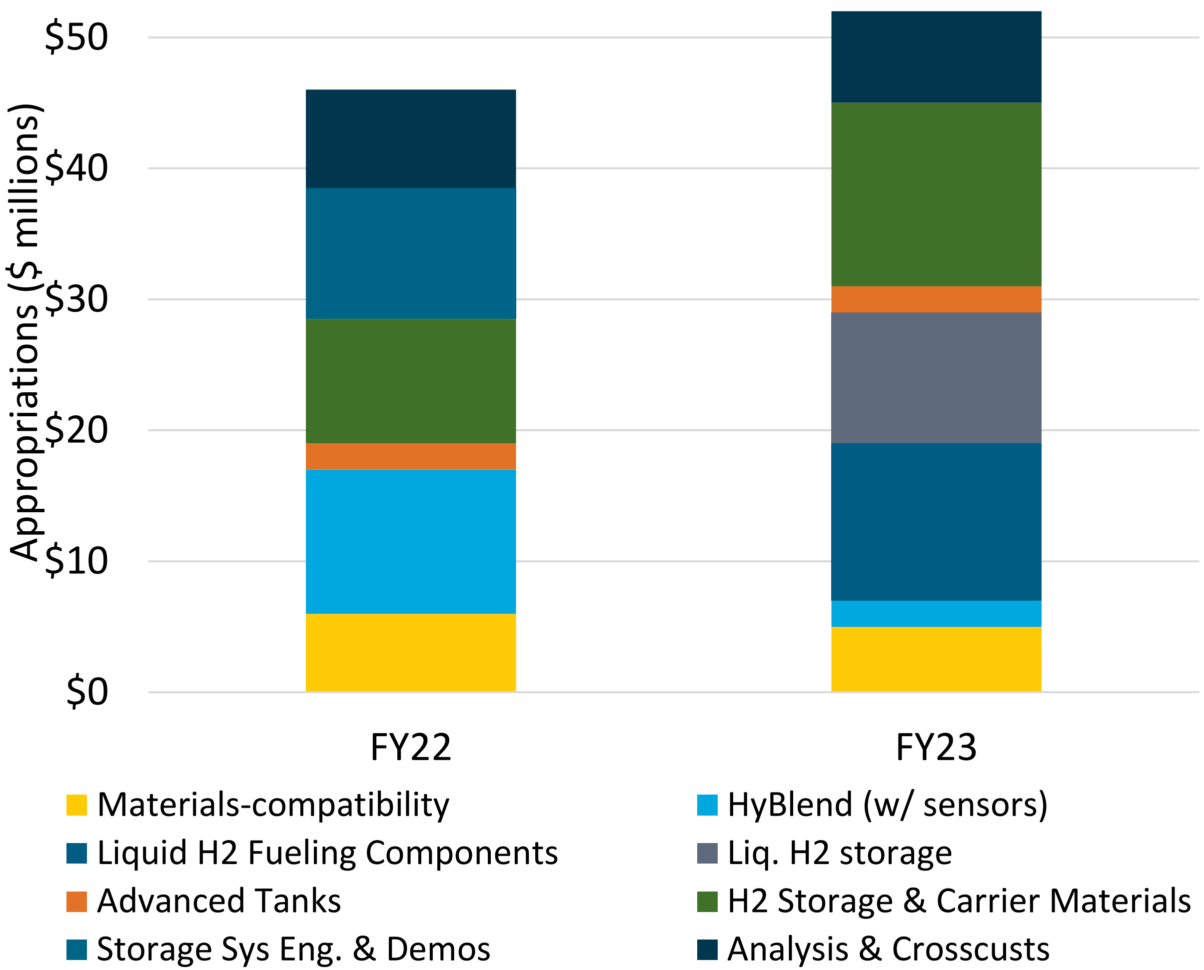
- Components and processes grouped into high, medium, low level of challenge
- Assessed by status and key metrics versus needed cost and performance

Objective is to prioritize RD&D efforts and establish cost and performance targets

H_2 Infrastructure Technologies Appropriations

FY22 Appropriations
$46 million

FY23 Appropriations
$52 million



Program Direction

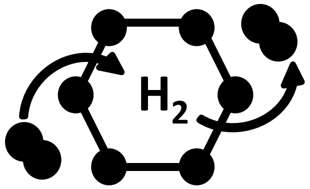
H_2 Infrastructure – Delivery, Storage & Dispensing

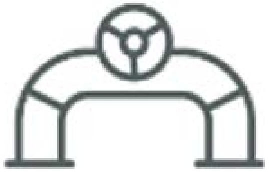
- Materials-compatibility for H_2 Service
- Blending of H_2 with natural gas
- Advanced tanks
  - Low-cost carbon fiber for COPVs
  - Ultra-large scale-LH_2 storage vessels
  - Onboard LH_2 storage tanks
- High-throughput fueling components
  - High-pressure gaseous refueling
  - Low-loss LH_2 refueling
- H_2 Storage & Carrier Materials
- H_2 Storage System Engineering & Demonstration
- Analysis and Cross-cuts

FY24 Request
$56 million

H_2 Infrastructure Technologies RD&D Portfolio Areas

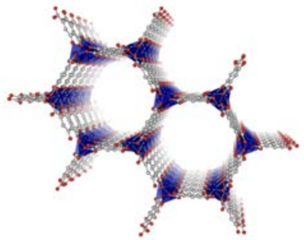
- **H_2 Infrastructure**
  - Transport
    - H_2 Carriers
    - Pipelines
    - Sensors/monitoring

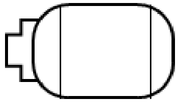




  - Fueling/Dispensing
    - Processes
    - Hardware Components

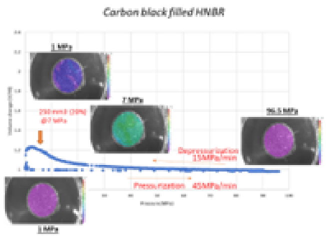
- **H_2 Storage**
  - Bulk Stationary Storage
    - Physical Storage
    - Materials-based Storage
  - Onboard Vehicle Storage



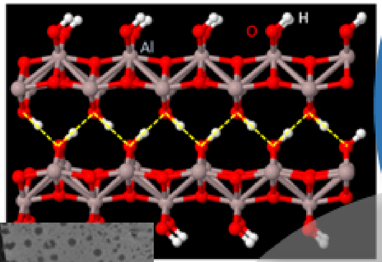


Key H_2 Infrastructure Activities

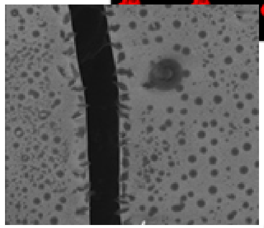
Hydrogen Materials Compatibility Consortium



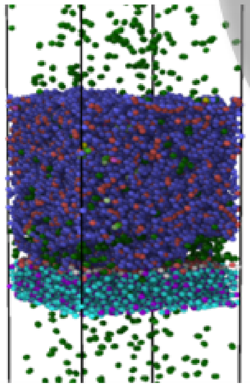
Non-linearity between pressure and swell during RGD



Environmental boundary conditions



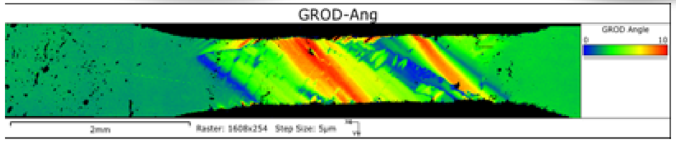
Phase separation

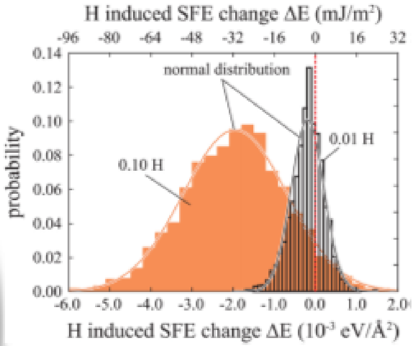


Environment
- Partial pressure
- Impurities
- Thermodynamics

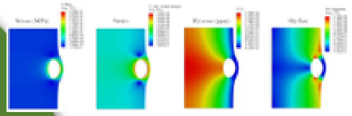
Materials
- Strength
- Microstructure
- Chemical structure

Mechanics
- Stress
- Damage evolution
- Kinetics

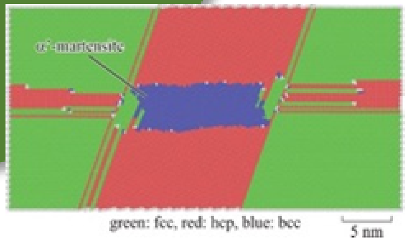




Hydrogen-induced changes to system energy



FE simulations predict damage initiation and propagation



Hydrogen-induced changes to deformation character

Objective:

Elucidate the mechanisms of hydrogen-materials interactions to inform science-based strategies to design materials with improved resistance to hydrogen degradation

- Integrate innovative computational and experimental activities to inform mechanistic understanding at nm-length scales
- Employ models systems to describe materials performance in high-pressure hydrogen environments
- Build scientific framework across length scales to engineer hydrogen compatibility performance at the component scale

Hydrogen Blending in Natural Gas Pipelines

HyBlend
U.S. DEPARTMENT OF ENERGY

Led by:

NREL – National Renewable Energy Laboratory
Sandia National Laboratories
Argonne National Laboratory
Pacific Northwest National Laboratory

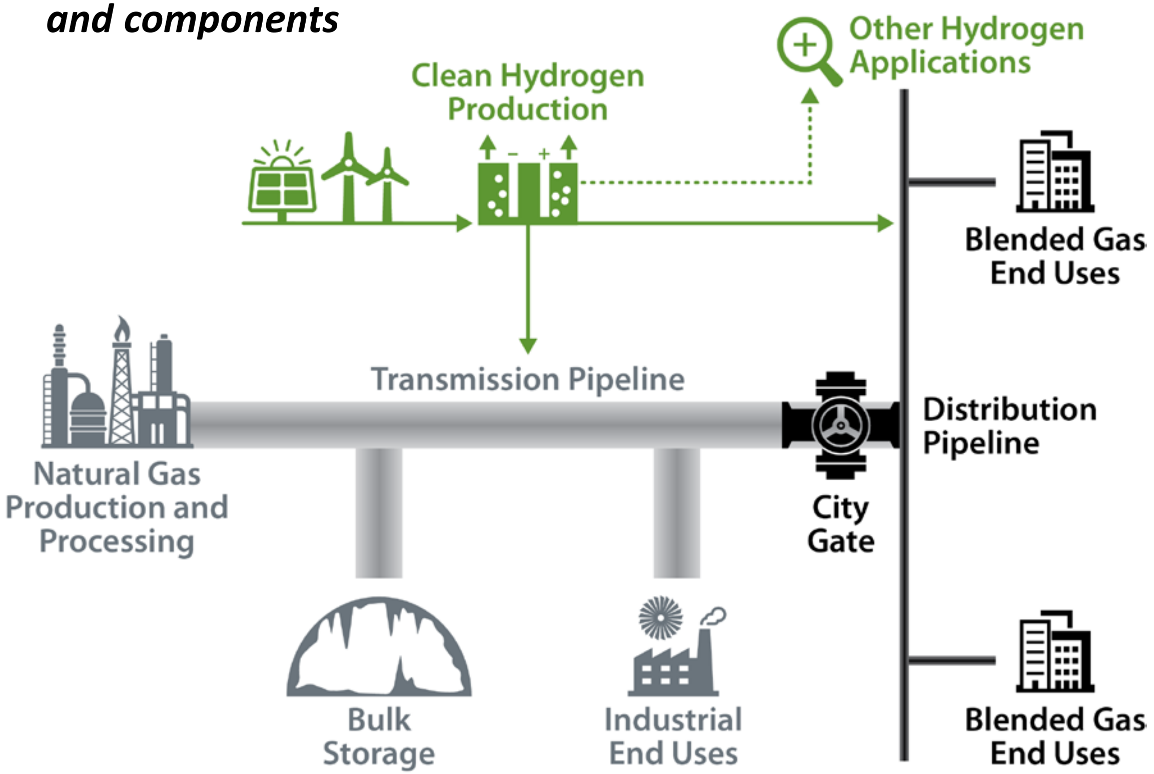
Supported by:

Oak Ridge National Laboratory
National Energy Technology Laboratory

Project numbers:

- 4 national laboratories
- CRADA with 31 industry, academia, and consortium partners
- Phase 1:
  - Oct. 2022 – Sept. 2023
  - $15M Project
    - $11M Federal funds
    - $4M cost share
- 2 key technical tasks:
  - Pipeline material testing
  - TEA/LCA

Hydrogen blending supply chain and components



Objectives:

- Laboratory **testing of metal and polymer pipe materials** in varying pressures, temperatures, and gas compositions **to develop structural integrity models** for uncertainty for inspection intervals and evaluation of rupture probability.
- Develop a **public tools for pipeline integrity** and to conduct sensitivity analyses that can **inform pipeline operating conditions**.
- **Technoeconomic and life cycle analysis** of blending relative to renewable natural gas.

Motivation

~3 million miles of natural gas pipeline in U.S. → 36 quads of natural gas consumed/year by 2050

Varying impact of H_2 on pipeline materials → Systematic testing needed to inform codes → Codes guide industry deployment

Heavy-Duty Fast-Flow Fueling R&D

- Commissioned first-of-its-kind, experimental research capability for medium and heavy-duty fast-flow fueling R&D – fully operational July 2022
- Demonstrated multiple fast flow fueling events at 70 MPa (nominal) and -40 °C precooling, meeting and exceeding DOE and industry targets for 10 kg/min average mass flow (20 kg/min peak)
  - Benchmark fill on 10/2022 with ***82.3 kg in 6.6 minutes* at 12.6 kg/min average and 23 kg/min peak**
- Successfully installed and commissioned a commercial dispenser and demonstrated fast flow fills with a modified version of SAE J2601 MC method
- Received and installed first sets of heavy-duty fast-flow commercial hardware (nozzles, receptacles, hoses, and breakaway devices)

Date (mo./yr.)	Fill Mass (kg)	Time (mins)	Average (Peak) Mass Flow Rates (kg/min)	SOC (%)	Notes
08/2022	61.5	4.7	13.2 (18.7)	94%	Type IV Only (60 kgs)
10/2022	**82.3**	**6.6**	**12.6 (23)**	**100%**	Complete HDVS (>80 kgs)

NREL's Heavy-Duty Hydrogen Fast-Flow Research Station

Equipment located at NREL's Energy Systems Integration Facility (ESIF) in Golden, Colorado, USA

Bennett HD Dispenser

NREL HD Vehicle Simulator

FOA Topics for H_2 Infrastructure Activities

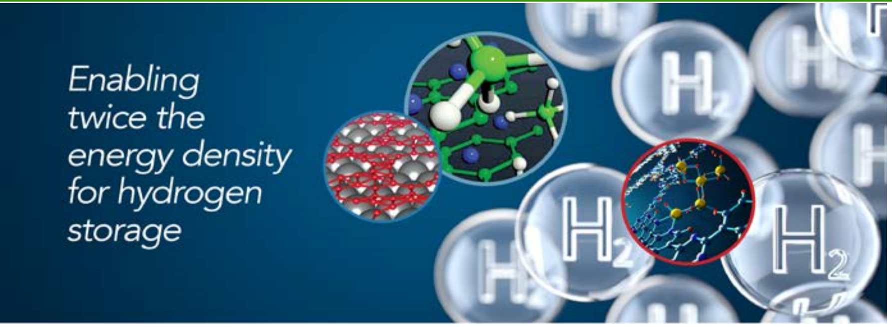
- **FY22**
  - **HBCU/MSI FOA (Joint with FECM)**
    - University of California Riverside – *Large-Scale Density Functional Tight Binding (DFTB) Calculations to Probe Structural Effects and Bridge Multiple Scales in Hydrogen-Metal Systems*
  - **HFTO FOA**
    - Development and Validation of Sensor Technology for Monitoring and Measuring Hydrogen Losses (Jointly funded with Safety, Codes & Standards Sub-Program)

Institution	Project Title
Indrio Technologies Inc.	*Multipass Palladium Optical Cavities for ppb-level Quantification of Hydrogen Concentrations*
Iowa State University	*Sensing Hydrogen Losses at 1 ppb-Level for Hydrogen-Blending Natural Gas Pipelines*
University of Georgia	*The Electrical Hydrogen Sensor Technology with a Sub-minute Response Time and a Part-per-Billion Detection Limit for Hydrogen Environmental Monitoring*
Oakland University	*Real-time Ionic Liquid Electrochemical Sensor for Highly Sensitive and Selective hydrogen Detection and Quantification*
Palo Alto Research Center	*DEtection system Comprising Inexpensive Printed sensor arrays for Hydrogen gas Emission monitoring and Reporting (DECIPHER)*
General Electric	*Hydrogen Loss Quantification Technology Enabled by Networked Dielectric Excitation Gas Sensors*

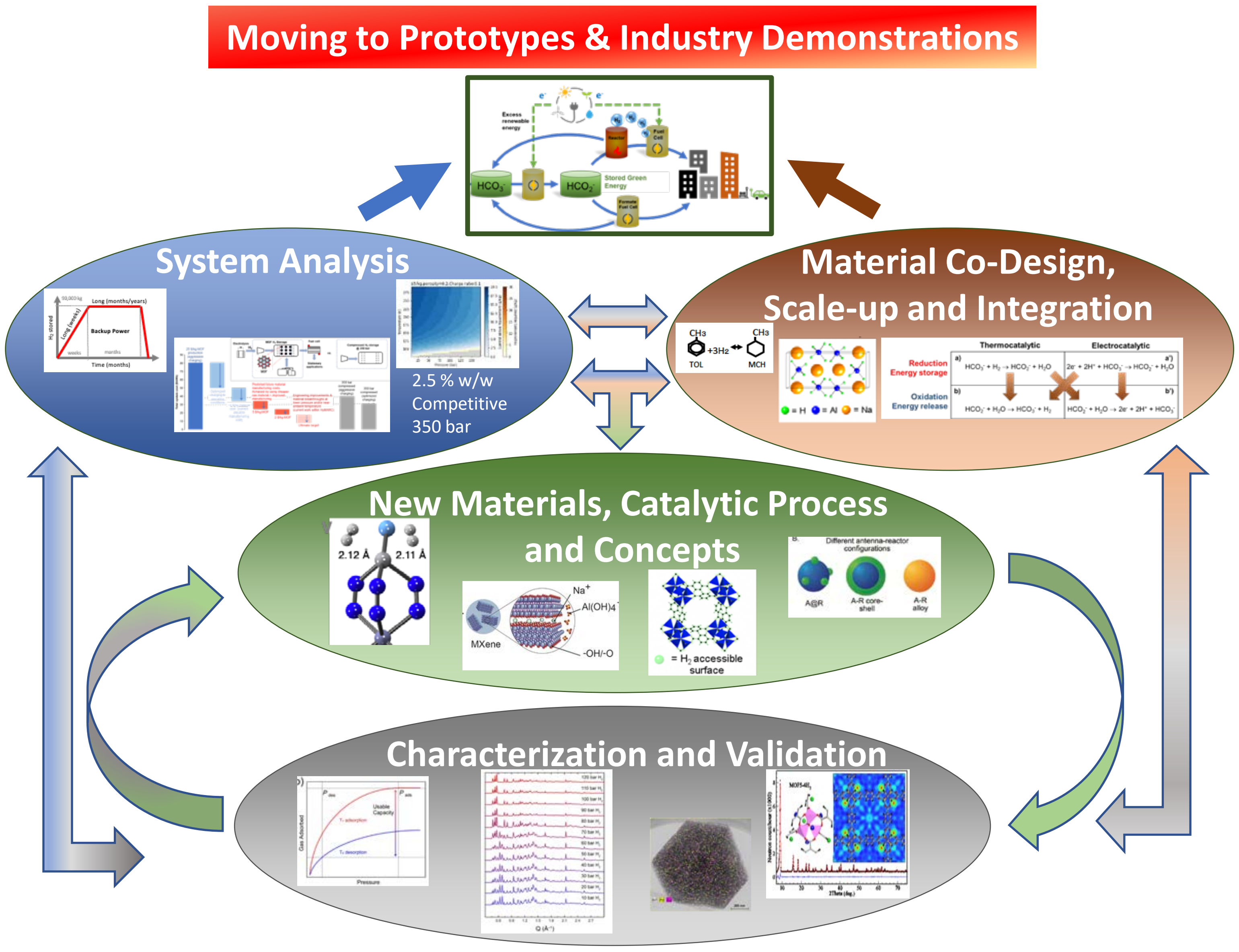
- **FY23 HFTO FOA**
  - Topic 1: Hydrogen Carrier Development (Joint with Storage) - $10M (FOA + Lab)
  - Topic 3: Liquid Hydrogen Fueling/Transfer Components and Systems - $12M

Key H_2 Storage Activities

HyMARC: Addressing Barriers and Defining Material/System Properties to Enable the Widespread Use of Hydrogen as an Energy Carrier



- Identify and/or develop hydrogen storage materials, targeted for specific use cases that exceed the capabilities of physical storage at reduced costs and improved safety as we meet DOE targets
- Establish an effective co-design initiative (coupled numerical modelling and technoeconomic analyses) to optimize materials for specific storage and especially transport applications
- Develop a pilot STEM internship program with Minority-Serving Institutions



Low-Cost Carbon Fiber to Reduce the Cost of H_2 Pressure Vessels

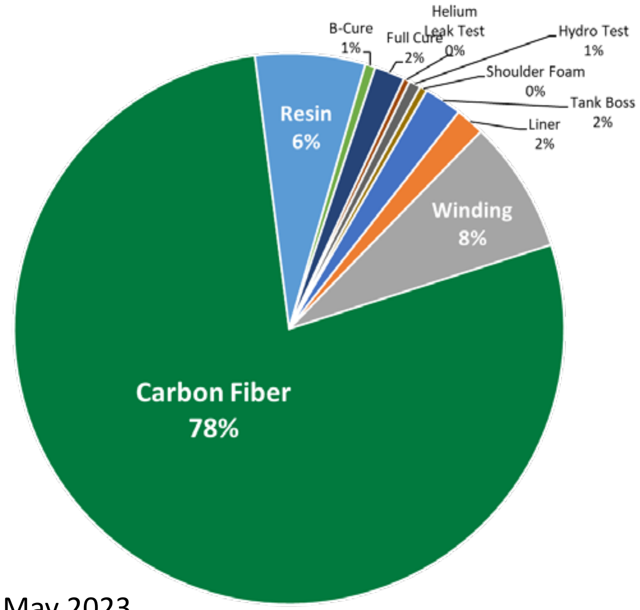
High-tensile-strength carbon fiber is the largest cost contributor to H_2 tanks

- **Teams targeting 50% reduction in carbon fiber cost contribution to tanks**
- **Down-select to one project by end of FY23**

Cost Breakdown of HD Vehicle *Tanks*

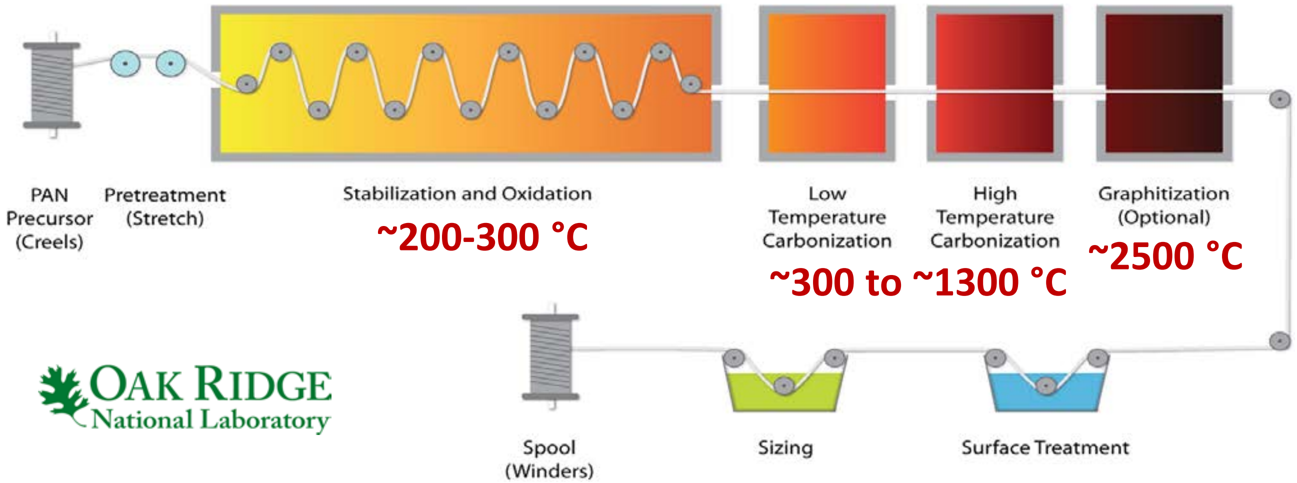
Type IV, 700 Bar Tank @ 50k tanks/yr

11.7 kg usable H_2/tank; $14/kWh complete system @ 10k/yr



SA Analysis, May 2023

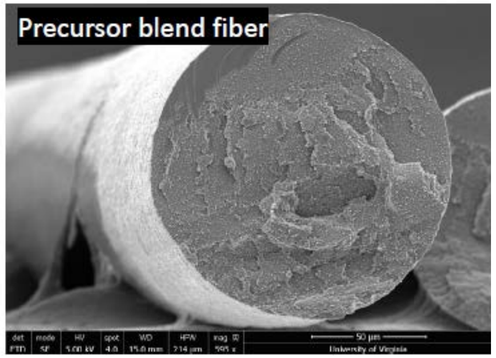
Carbon fiber processing



Oak Ridge National Laboratory

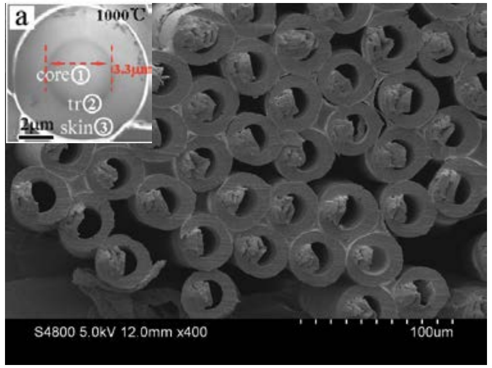
Warren, C. D., "Carbon Fiber Precursors and Conversion", Oak Ridge National Laboratory, Department of Energy Physical-Based Storage Workshop: Identifying Potential Pathways for Lower Cost 700 Bar Storage Vessels, Aug 24, 2016.

Alternative Precursors

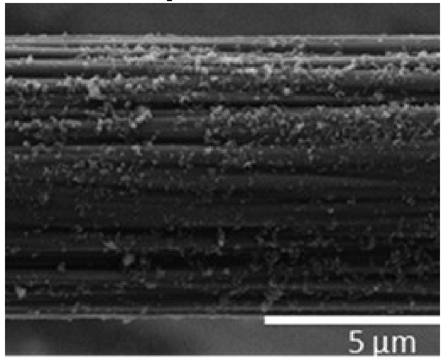


University of Virginia

Hollow Fibers



Full Optimization



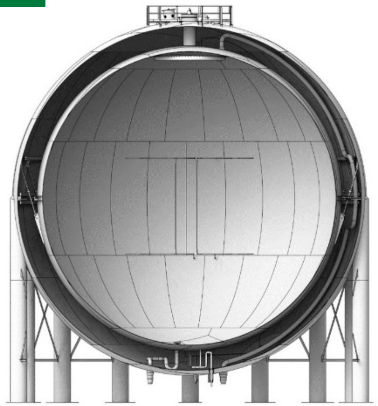
HEXAGON

Commercial-Scale Liquid H_2 Energy Storage for International Trade

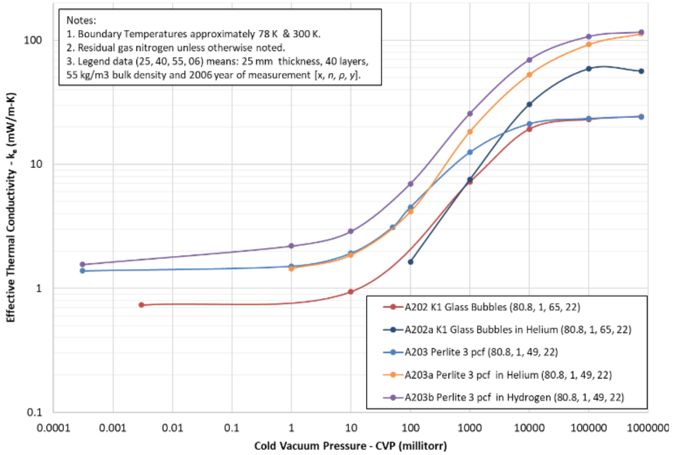
- First-of-its-kind, affordable tank design for large sale LH_2 storage
- Storage capacity: 20,000 m^3 – 100,000 m^3 (1420 – 7100 tons)
- Double-walled, insulated tank

Recent Accomplishments:

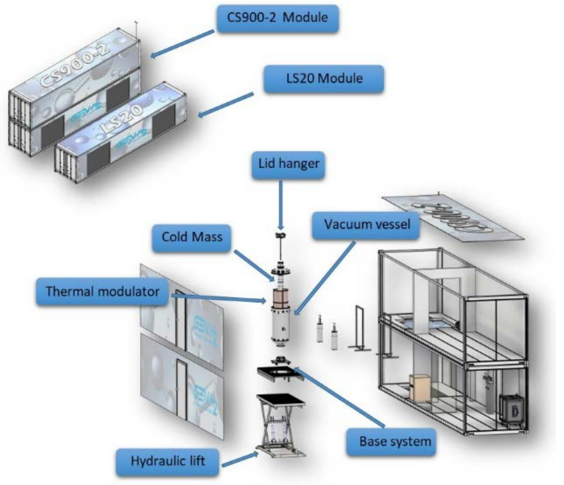
- Selected final tank design
  - Criteria: technical feasibility, cost estimation, risks & uncertainties
- Finalized design of 20 m^3 demo tank
- Selected NASA Marshall Space Flight Center (NASA-MSFC) as location for demo tank
- Measured K_e of glass bubbles in N_2 and He, and perlite in N_2, He and H_2
- Established 3D thermal model for insulation and tank performance
- Finalized design of LH_2-based Cryostat CS-900
- Identified gaps in current safety codes & standards related to large scale LH_2 storage



Thermal conductivity of insulation materials



Cryostat CS-900 Module



FOA Topics for H_2 Storage Activities

- **FY22**
  - **HBCU/MSI FOA (Joint with FECM)**

Institution	Project Title
Univ. Texas – El Paso	*Combustion Synthesis of Nanoscale Magnesium Borides with Improved Hydrogen Uptake and Release*
Cal. State Univ. Los Angeles	*Developing Highly Porous Metal-Organic Frameworks and Composite Materials for Hydrogen Storage*

  - **HFTO FOA**
    - Materials-based H_2 Storage Demonstrations

Institution	Project Title
OCOchem, Inc.	*Formic Acid-Based Hydrogen Energy Production and Distribution System (Formic-HEPADS)*
GKN Hydrogen	*Metal Hydride Hydrogen Storage Supporting Onsite Hydrogen Infrastructure at WGL/Washington Gas*

- **FY23 HFTO FOA**
  - Topic 1: Hydrogen Carrier Development (Joint with Infrastructure) - $10M (FOA + Lab)
  - Topic 3: Onboard Storage Systems for Liquid Hydrogen - $10M

H_2 Infrastructure Technologies Highlights and Milestones Summary

FY2022	FY2023	FY2024
BIL signed into law	Selections announced for the HBCU-MSI FOA	Carbon Fiber Project down-select decision to be announced
Bulk H_2 Storage workshop	NREL demonstrates 82 kg H_2 fill in 6.5 minutes	FY24 FOA to be released
2nd Liquid Hydrogen workshop	HFTO FY23 FOA released	Workshop on H_2 Infrastructure Technologies
HBCU-MSI joint FOA with FECM released	US DOT released "Charging and Fueling Infrastructure (CFI) Discretionary Grant Program" solicitation	H_2 Infrastructure Technologies Scenario report and priorities to be released
HFTO FY22 FOA released	Inaugural Joint USDRIVE/21st Century Truck Partnership Technical Team meeting held	Program Record for H_2 Infrastructure Technologies to be published
	Selections announced for the FY22 HFTO FOA	Updated Cost and Performance Targets for HD Applications to be published

H_2 Infrastructure Technologies Program: Collaboration Network

Fostering technical excellence, economic growth and environmental justice

Efforts Support Over:
9 national laboratories
24 universities
11 companies

DOE H_2 Program Collaborations		
VTO	AMMTO	BETO
SETO	BTO	ARPA-E
SC	FECM	NE

DOE Cross-Cutting Initiatives		
Energy Storage Grand Challenge	Advanced Transportation	Advanced Manufacturing
Space	Alternative Fuels	AI/ML
Decarbonize Agriculture/Buildings/Electricity/Industry/Transportation		

Cross-Agency Collaborations				
DOC-NIST	DOC-NOAA	NASA	DOD	DOT

Regional and International Collaborations		
IEA H_2 TCP	ISO TC197 US TAG	Bilateral Collaborations

Industry Engagements
U.S. DRIVE
21st Century Truck Partnership
HyMARC
H-MAT
HyBlend
Workshops/RFIs

The Hydrogen Infrastructure Technologies Team

Program Manager

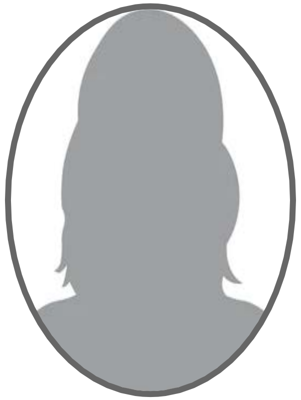
Ned
Stetson

Technology Managers

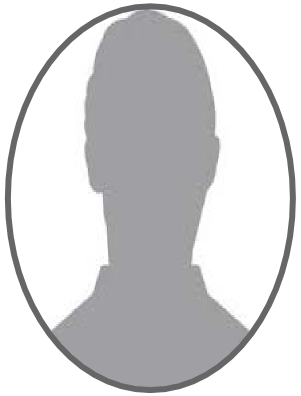
Mark
Richards

Marika
Wieliczko

Zeric
Hulvey



New
TM/TPO



New
TM/TPO

ORISE Fellows

Asha-Dee
Celestine

Zakaria
Hsain

Lab Detailee

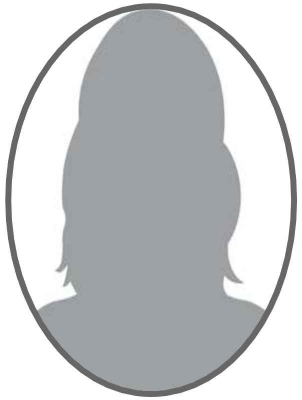
Abhi
Karkamkar

Support Contractors

Eric
Heyboer

Nikkia
McDonald

Cassandra
Osvatics



New
Contractor

H_2 Infrastructure Technologies Project Presentations

- Orals – Regency Ballroom F (this room) – Storage through this afternoon, Infrastructure late afternoon through tomorrow
- Posters – Independence AB - This evening (Tuesday, June 6, 5:30 – 7:00 pm)

Tuesday

9:30 AM 10:00 AM	ST127 HyMARC Overview Mark Allendorf, SNL
10:30 AM	**Break**
11:00 AM	ST238 Low-Cost, High-Strength Hollow Carbon Fiber for Compressed Gas Storage Tanks Matthew Weisenberger, University of Kentucky
11:30 AM	ST236 Low-Cost, High-Performance Carbon Fiber for Compressed Natural Gas Storage Tanks Xiaodong Li, University of Virginia
12:00 PM	ST237 Carbon Composite Optimization Reducing Tank Cost Don Baldwin, Hexagon R&D
12:30 PM	**Lunch**
1:45 PM	ST240 Cost-Optimized Structural Carbon Fiber for Hydrogen Storage Tanks Amit Naskar, ORNL
2:15 PM	ST241 First Demonstration of a Commercial Scale LH2 Storage Tank Design for International Trade Applications Kun Zhang, Shell
2:45 PM	IN025 ANL-H2 Delivery Technologies Analysis Amgad Elgowainy, ANL
3:15 PM	**Break**
3:45 PM	IN034 HyBlend: Pipeline CRADA Cost and Emissions Analysis Mark Chung, NREL
4:15 PM	IN035 HyBlend: Pipeline CRADA Materials R&D Chris San Marchi, SNL
4:45 PM	

Wednesday

9:00 AM	TA049 High Pressure, High Flow Rate Dispenser and Nozzle Assembly for Heavy Duty Vehicles Spencer Quong, Electricore
9:30 AM	IN001a H-Mat Overview: Metals Chris San Marchi, SNL
10:00 AM	IN001b H-Mat Overview: Polymers Kevin Simmons, PNNL
10:30 AM	**Break**
11:00 AM	IN021 Microstructural Engineering and Accelerated Test Method Development to Achieve Low Cost, High Performance Solutions for Hydrogen Storage and Delivery Kip Findley, Colorado School of Mines
11:30 AM	IN022 Tailoring Carbide Dispersed Steels: A Path to Increased Strength and Hydrogen Tolerance Gregory Thompson, The University of Alabama
12:00 PM	IN026 Tailoring Composition and Deformation Modes at the Microstructural Level for Next Generation Low-Cost High-Strength Austenitic Stainless Steels Jessica Krogstad, University of Illinois Urbana-Champaign
12:30 PM	**Lunch**
1:45 PM	IN030 Micro-Mechanically Guided High-Throughput Alloy Design Exploration towards Metastability-Induced H Embrittlement Resistance C. Cem Tasan, Massachusetts Institute of Technology
2:15 PM	IN020 Self-Healable Copolymer Composites for Extended Service Hydrogen Dispensing Hoses Marek Urban, Clemson University
2:45 PM	H2041 H2@Scale CRADA: CA Research Consort. (Ref. Station, Fueling Perf. Test Device, Station Cap Model) Ethan Hecht & Taichi Kuroki, NREL
3:15 PM	**Break**
3:45 PM	IN016 Free-Piston Expander for Hydrogen Cooling Devin Halliday, GTI Energy
4:15 PM	IN019 Ultra-Cryopump for High Demand Transportation Fueling Kyle Gross, RotoFlow
4:45 PM	IN040 The HyRIGHT Project: 700 bar Hydrogen Refueling Interface for Gaseous Heavy-Duty Trucks Will James, SRNL

Session Logistics

General Information

- This meeting is a review, not a conference
  - **Questions will be taken first from reviewers**, and then from other audience members as time allows
  - Remote reviewers are reminded to enter their questions in CHAT
  - Remote general attendees can enter questions or comments into Q&A
- The schedule will be strictly followed so that reviewers can move between sessions
- Presentations are 20 minutes followed by 10 minutes Q&A

Thank You, Reviewers!

Your input on our Program and subprograms and projects helps guide our decisions.

Thank you for your thoughtful, objective, and timely feedback!

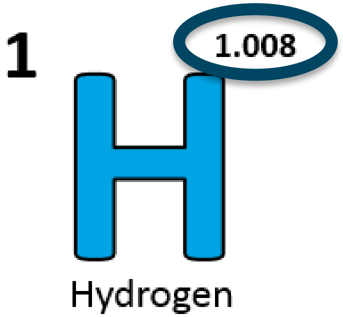
Resources and Opportunities for Engagement

Save the date!

2024 DOE Annual Merit Review and Peer Evaluation Meeting
May 6-9, 2024

Hydrogen and Fuel Cells Day
October 8

- Held on hydrogen's very own atomic weight-day



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Thank You

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