U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

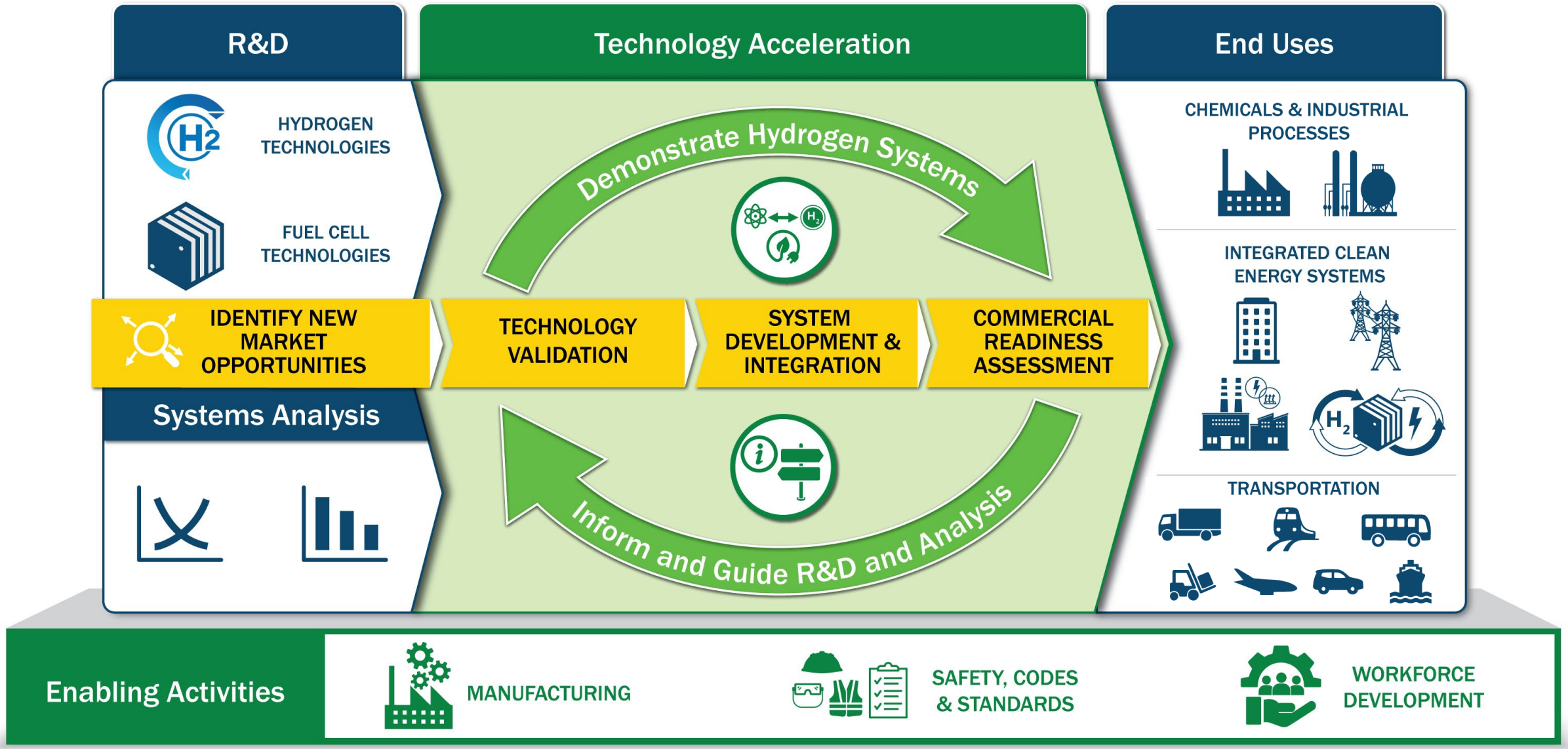
Technology Acceleration Overview

Jesse Adams, HFTO - Technology Acceleration Program Manager

2021 Annual Merit Review and Peer Evaluation Meeting

June 7, 2021

Technology Acceleration Subprogram Overview



Evolution of Technology Acceleration Subprogram & Priorities

circa FY17

- **TECHNOLOGY ACCELERATION R&D**
- Technology Validation
- Market Transformation
- Manufacturing R&D
- Safety, Codes & Standards R&D
- Systems Analysis

Current Focus Areas

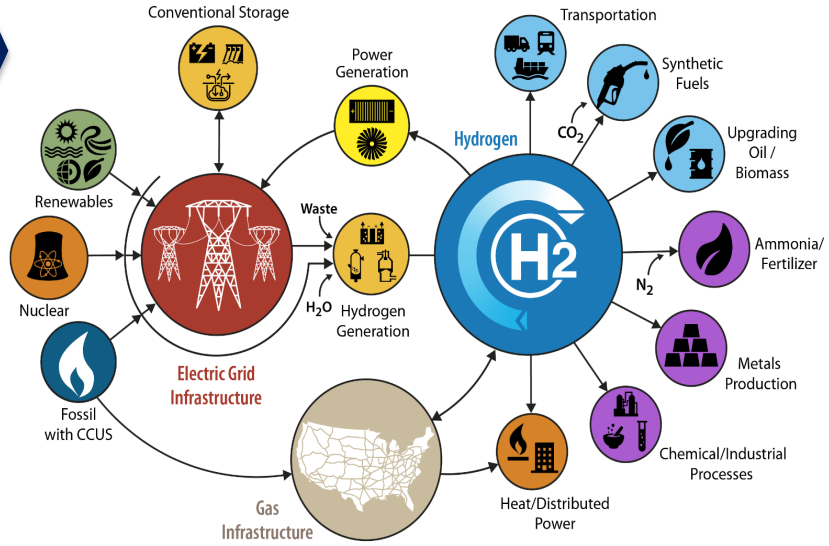
- **Integrated clean energy systems** including hybrid approaches and energy storage

- **Chemical and industrial processes** integrating H_2 technologies focusing on decarbonization

- **Transportation** and H_2 fueling demonstrations

- **Enabling activities** including manufacturing, safety codes & standards, and workforce development

Demonstrations of H_2 and fuel cell end uses that accelerate technology and reduce GHG emissions **to enable H2@Scale vision**



Hydrogen Safety: An Overarching Priority

Enabling the safe deployment of hydrogen and fuel cell technologies

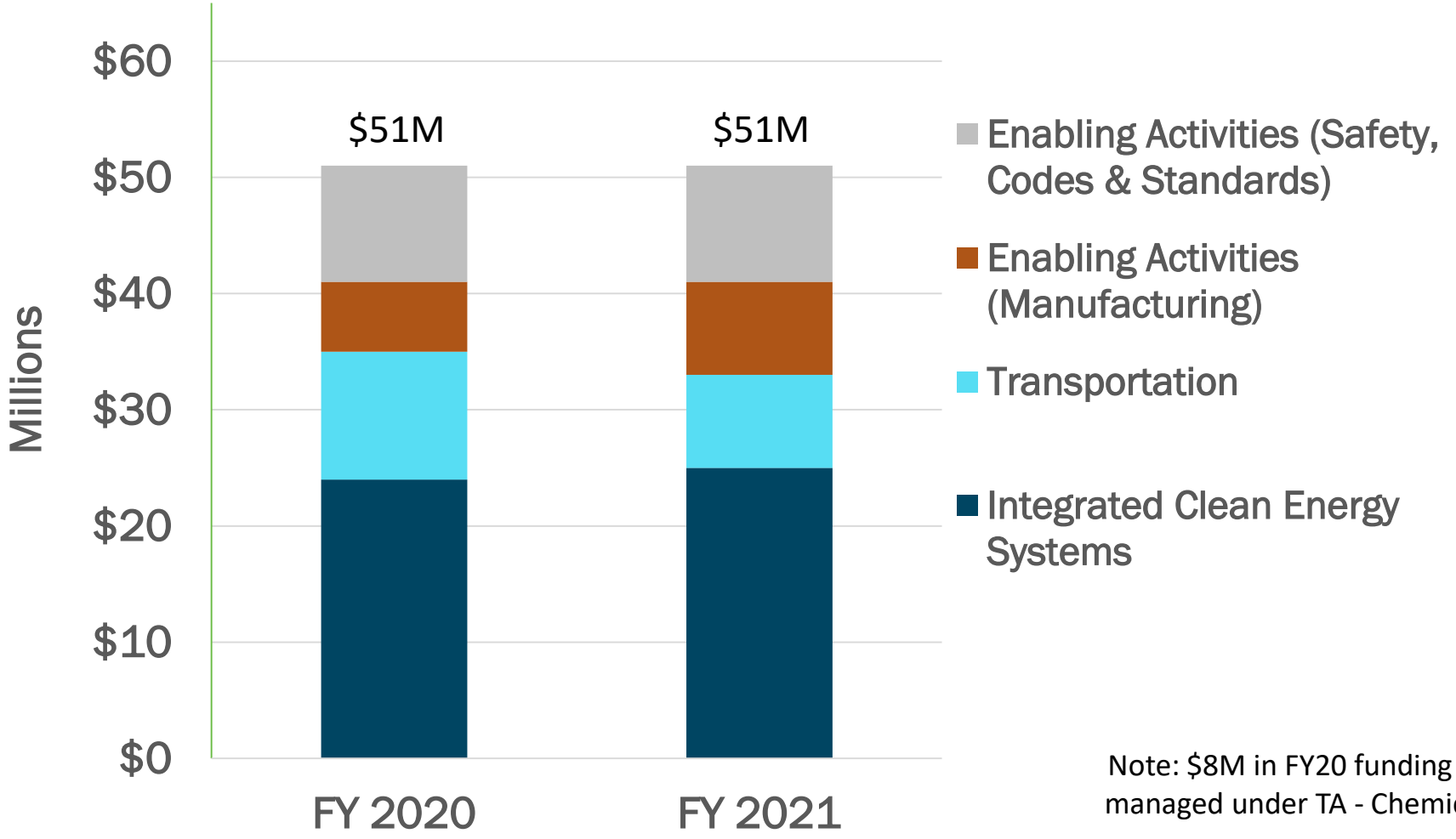
Codes & Standards

- **Goal**: Support and facilitate **development of essential codes and standards** to enable widespread deployment of hydrogen and fuel cell technologies and completion of essential regulations, codes and standards
- **Approach**: Conduct **RD&D to provide scientific basis** needed to define requirements in developing codes and standards

Safety

- **Goal**: Support **best safety practices** for hydrogen and fuel cell deployments and ensure their use in DOE-funded projects
- **Approach**: Develop and enable **widespread sharing** of **safety-related information resources** and lessons learned with key stakeholders

Technology Acceleration Funding



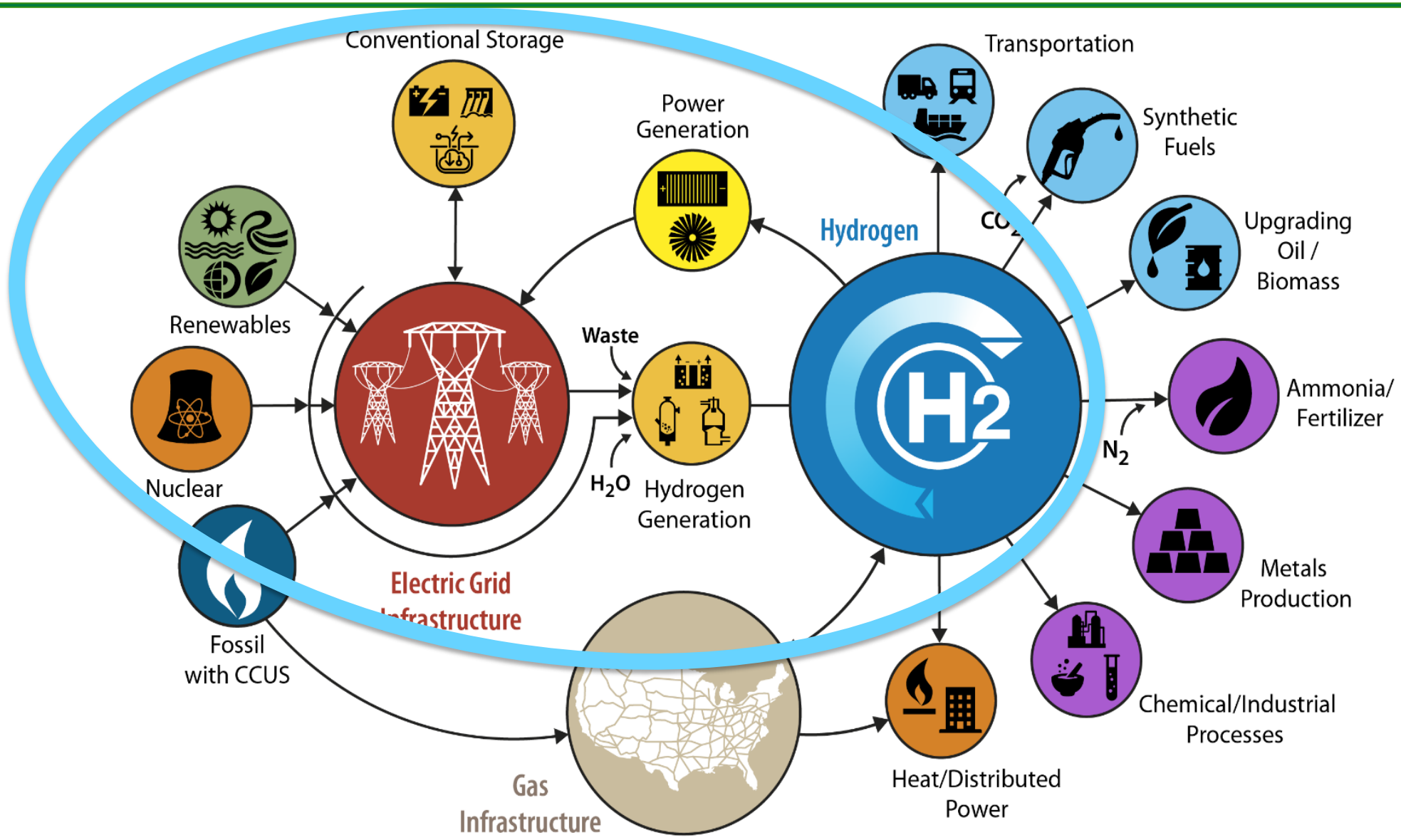
Program Direction

- Decarbonize Ammonia / Steel
- Integration with Nuclear & Renewables
- Offshore Wind to Hydrogen
- SuperTruck III
- Safety, Codes & Standards
- Manufacturing

Note: $8M in FY20 funding for HySteel projects now managed under TA - Chemical & Industrial Processes

FY21 budget supports focus on demonstration of novel H_2 end uses to enable H2@Scale vision

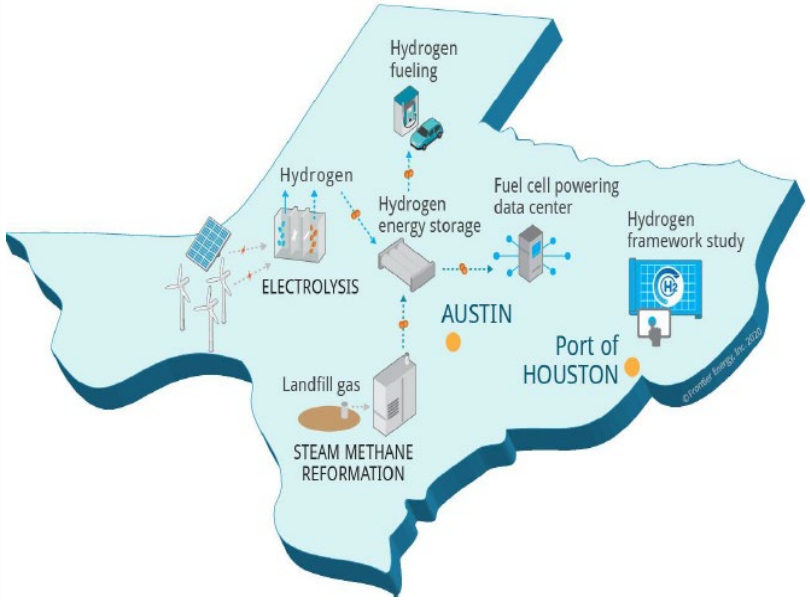
Technology Acceleration: Integrated Clean Energy Systems



Technology Acceleration: Integrated Clean Energy Systems

Demonstration of H2@Scale: Different Regions, Hydrogen Sources & End Uses

Frontier Energy – H2@Scale Demo in TX (TA037)



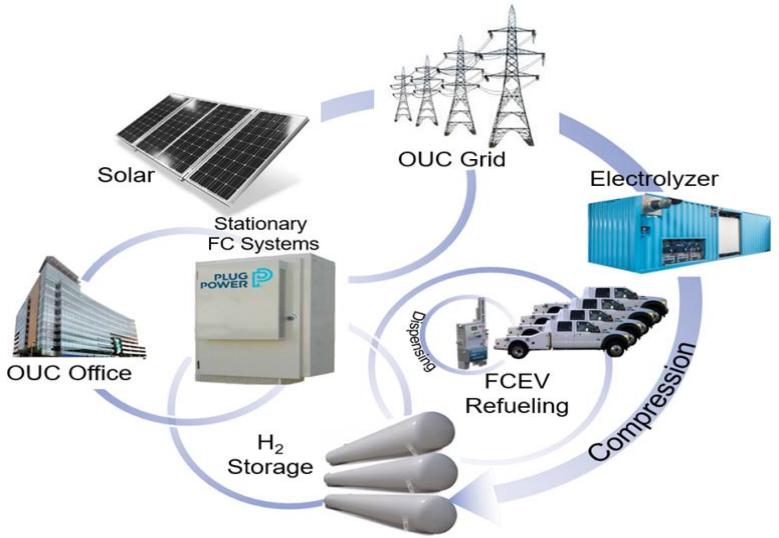
Goals:

- Minimize H_2 cost through multiple generation sources
- Co-locate H_2 end uses (stationary power & vehicle fueling)
- 5-year Plan for Port of Houston focused on H_2

Key Accomplishments:

- Site plans completed and undergoing final engineering
- Collected 1 year of load data from U. Texas Advanced Computing Center - modeled with H_2 and FC power
- Preliminary Port of Houston model with supply & demand hubs

Plug Power - Integrated H_2 Production & Consumption for Improved Utility Function in FL (TA030)



Goals:

- Develop grid-integrated H_2 assets to allow renewable penetration
- Develop H_2 end uses (stationary & vehicle fueling)

Key Accomplishments:

- Sizing of the storage system to meet H_2 delivery demands, including vehicular and stationary FC applications
- Site design, dynamic power simulations, & TEA underway

Technology Acceleration: Integrated Clean Energy Systems

Integration of Baseload Nuclear Energy with H_2 Production

Exelon – Demo of Electrolyzer Operation at a Nuclear Plant (TA028)

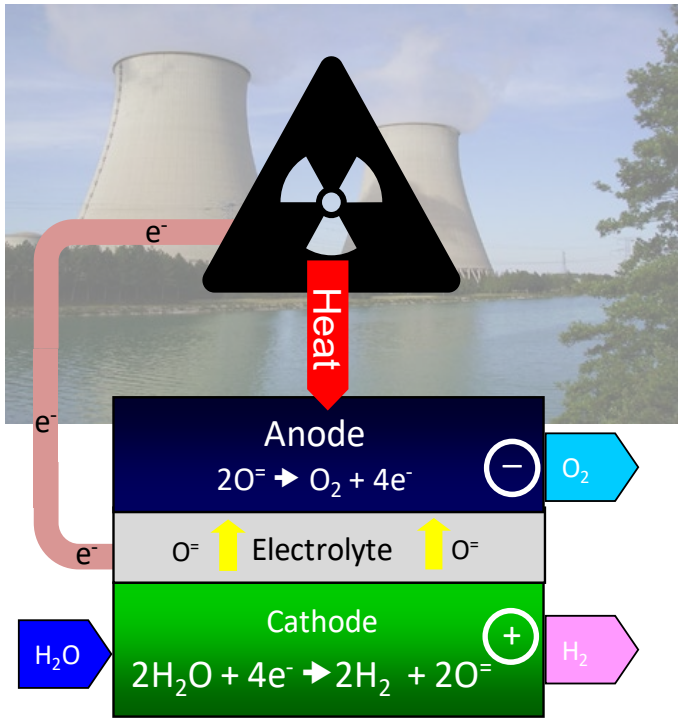
Goals:

- Install 1.2MW PEM electrolyzer at a nuclear power plant
- Provide low-cost supply of in-house H_2 used for cooling
- Simulate scaled-up operation of a larger electrolyzer in nuclear power markets

Key Accomplishments:

- Nine Mile Point (NY) selected as site
- Initial engineering design underway
- Completed acceptance testing of Nel electrolyzer – over 500 hours & degradation <0.1% (NREL)
- Conducted initial market demand for various sites (ANL)

FuelCell Energy – Solid Oxide Electrolysis System Demonstration (poster-TA039)



Key Accomplishments:
New project just underway

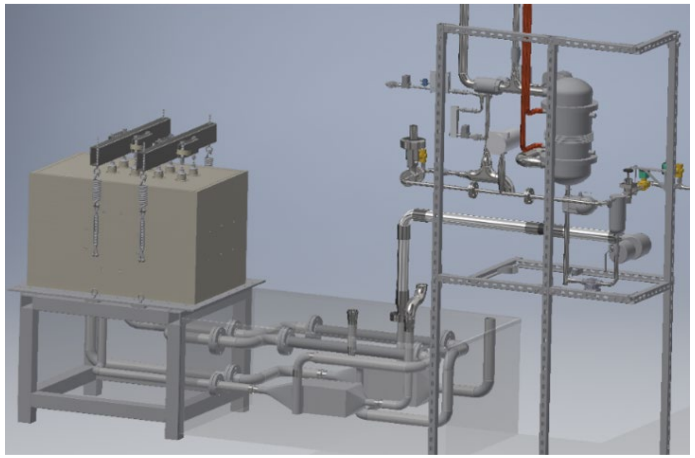
Goals:

- Integrate high temperature 250kW solid oxide electrolyzer (SOEC) with nuclear plant emulator
- Validate high efficiency & low-cost H_2 production from SOEC using electricity & waste heat from nuclear plant
- Increase operating flexibility & profitability by switching between power & H_2 generation

Technology Acceleration: Integrated Clean Energy Systems

High Temperature Electrolyzer Development and Testing

INL - High Temperature Electrolysis Test Stand (TA018)



50kW test stand integrated w/nuclear power plant emulator

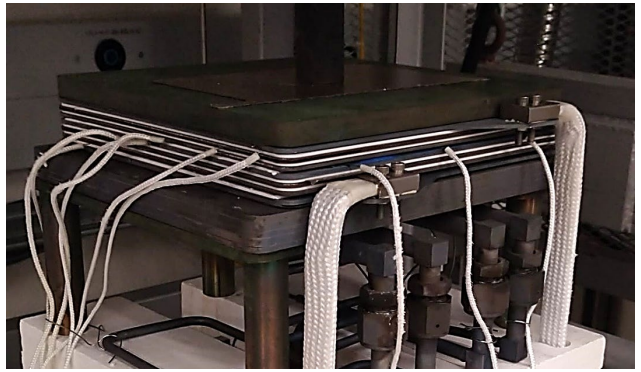
Goals:

- Accelerate U.S. Solid Oxide Electrolyzer Competitiveness
- Independently validate stack performance
- Provide nuclear simulated integration/testing

Key Accomplishments:

- Validating commercial stack performance from Bloom, Nexceris, OxEon, FuelCell Energy, Haldor Topsoe (2 tested, 3 lined up)
- >4,000 hours testing on 25 kW stack; <0.5% degradation/1,000 hrs
- Great integration across EERE (H2NEW, HydroGEN), Fossil & Nuclear Energy Offices

PNNL - Electrolyzer Stack Development & Manufacturing (TA043)



Goal:

Work w/ industry to solve cost & degradation issues through MEA development, modeling, post-mortem analysis, AST development & manufacturing

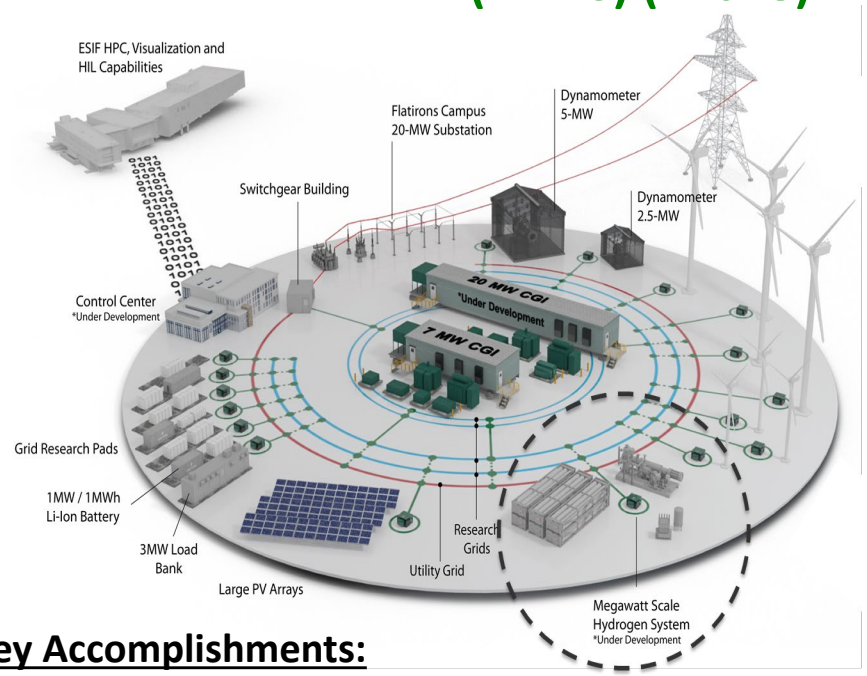
Key Accomplishments:

- Developed process to produce 300 cm^2 SOEC cells
- Established stack repeat unit fabrication process
- Applied protective coating to metal interconnects to prevent corrosion and CR poisoning

Technology Acceleration: Integrated Clean Energy Systems

Enabling & Demonstrating Integrated Hydrogen Energy Systems

NREL – Advanced Research on Integrated Energy Systems (ARIES) (TA048)



Goals:

- Integrate 1.25MW PEM electrolyzer, 600 kg H_2 storage & 1MW fuel cell
- Provide platform for RD&D in grid integration, energy storage, NG blending & scaling H_2 systems

Key Accomplishments:

- Overall site layout & safety reviews complete
- Most key pieces of equipment have been ordered
- Systems integration (controllable grid interface, thermal, water, gas, electrical) underway

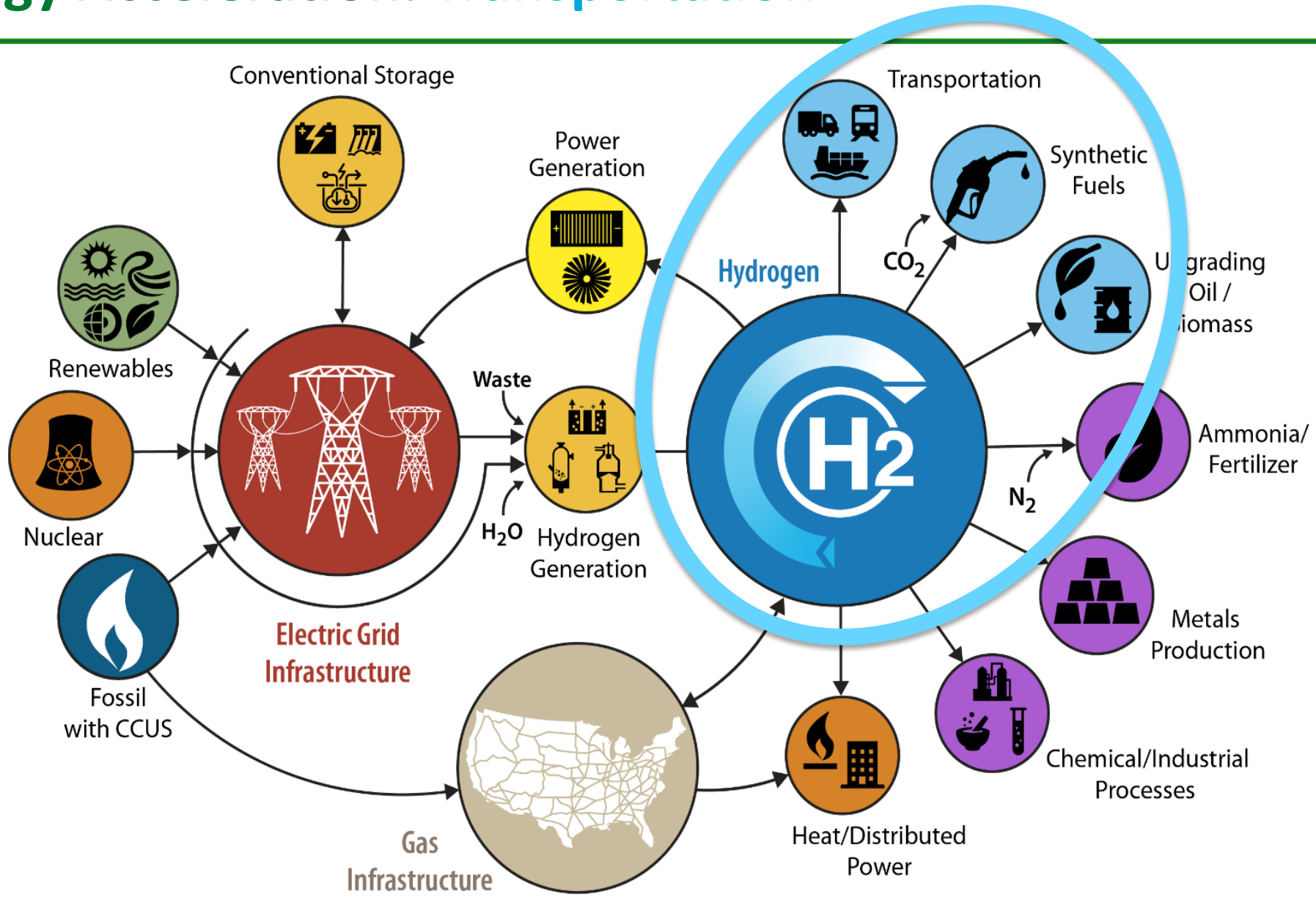
Caterpillar – Demonstration of H_2 Fuel Cell at a Data Center (poster - TA044)

Goals:

- Install 1.5MW stationary fuel cell at a Microsoft data center in Washington state
- 48 hours of LH_2 onsite
- Increase confidence and comfort in H_2 & fuel cells for IT industry (document requirements and identify gaps)

Key Accomplishments:
New project just underway

Technology Acceleration: Transportation



Technology Acceleration: Transportation (Medium / Heavy-Duty)

Focused on M/HD Trucks with Demanding Drive Cycles & Range Requirements

CTE – Fuel Cell Hybrid Electric Delivery Van (TA01)

Goal:

Demonstrate hybrid electric delivery vans with fuel cell range extenders (75 to >125 mile range)

Key Accomplishments:

- 5 trucks built and undergoing testing
- 10 more trucks in assembly – to be completed by summer 2021
- Trucks to operate in disadvantaged community in CA

NREL – Fuel Cell Electric Bus Evaluations (TA013)

Goal:

Validate fuel cell electric bus performance & cost using real-world data

Key Accomplishments:

- Tracked 38 buses; 12 surpassed 25,000 hours & 1 over 32,000 hours
- ~9 mpdge (~2x greater than CNG or diesel); ~300 mile range (37.5 kg H_2)
- Status report: https://www.nrel.gov/docs/fy21osti/75583.pdf

SuperTruck III Funding Opportunity Announcement

- **Develop & demonstrate medium/heavy-duty electric trucks including H_2 fuel cells**
- **Up to $100M over 4 years; Released on April 15th (funded jointly by HFTO and VTO)**

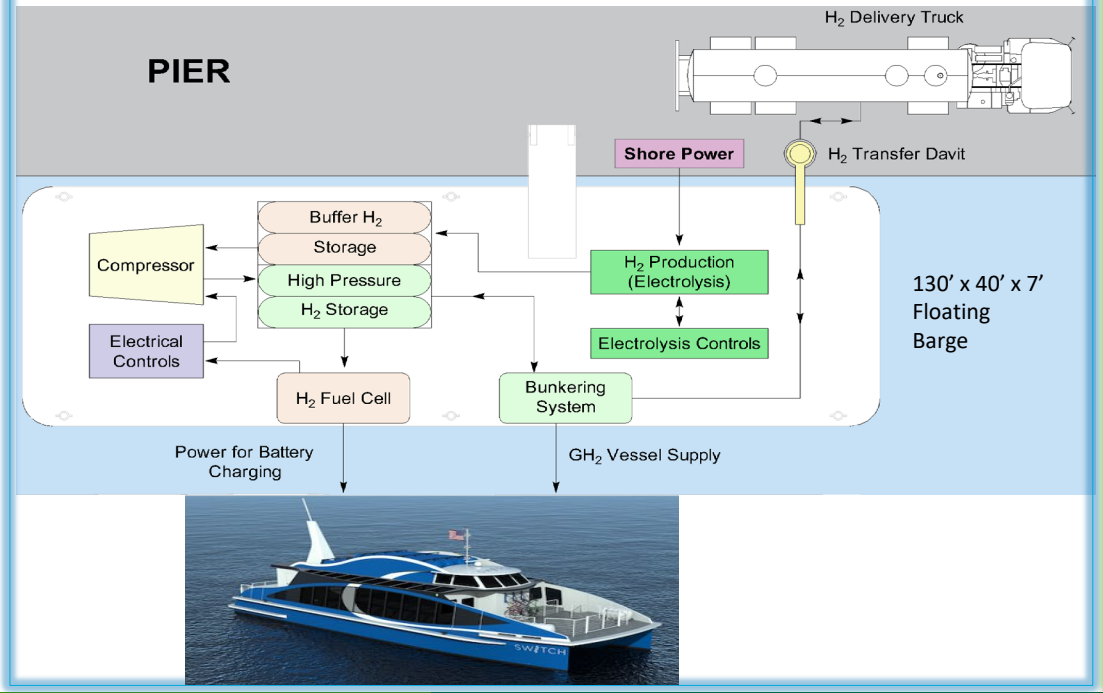
Technology Acceleration: Transportation (Maritime)

H_2 Can Reduce GHGs & Still Meet Maritime Performance Requirements

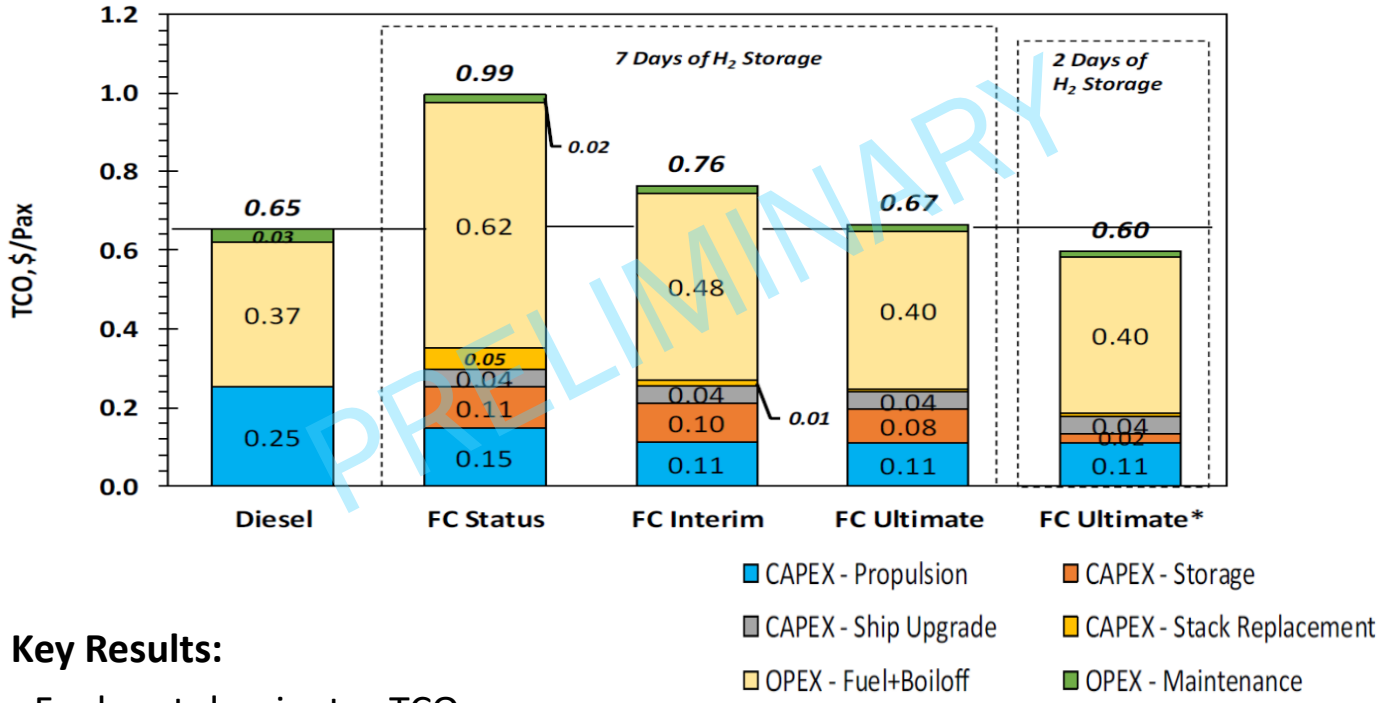
Hornblower – Marine Hydrogen Demonstration (poster - TA045)

Goal:

First of its kind maritime H_2 refueling infrastructure on water (530 kg H_2 /day) - onboard a barge at the San Francisco Waterfront



ANL - Total Cost of Ownership Analysis for Ferries (TA034)



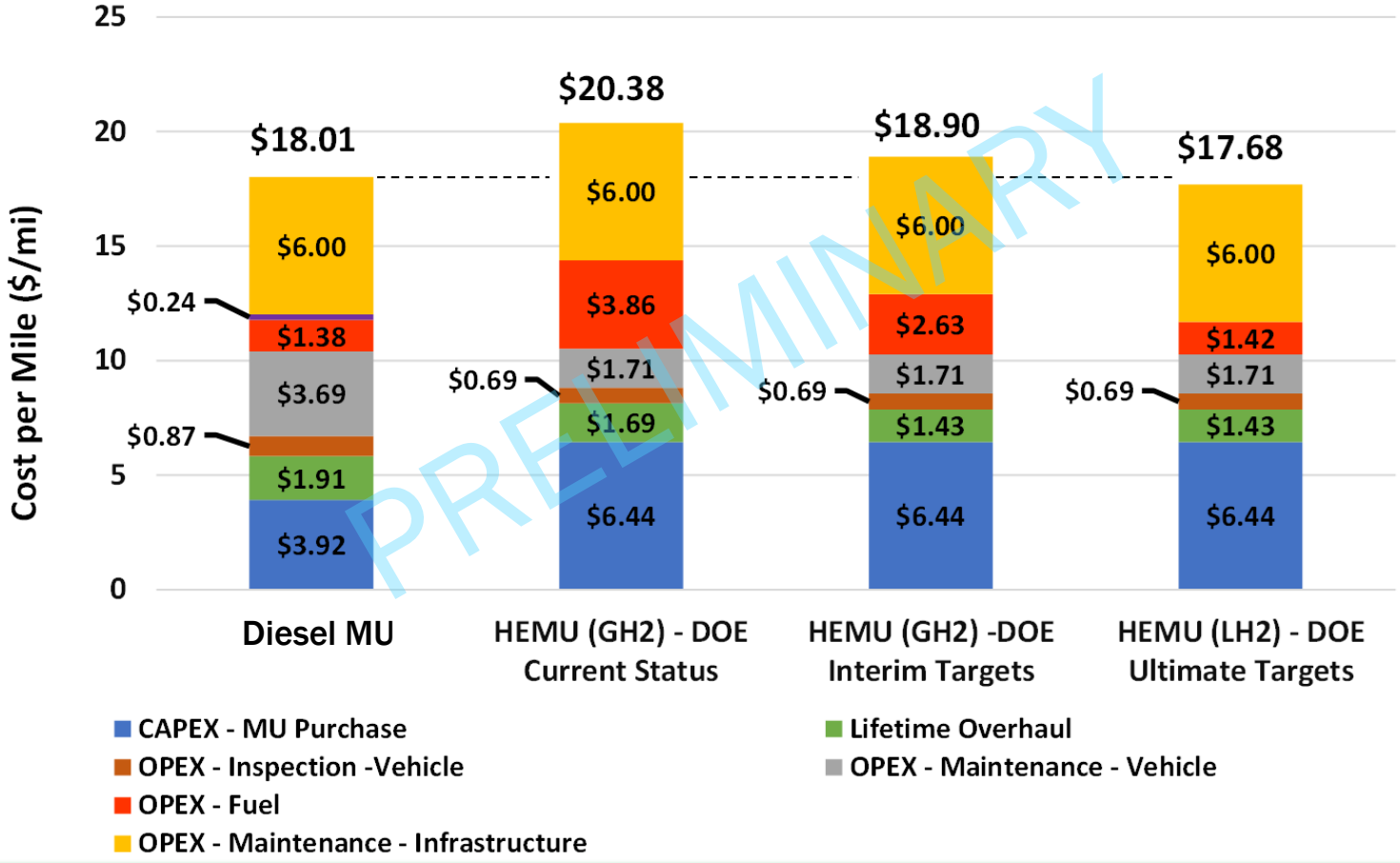
Key Results:

- Fuel cost dominates TCO
- H_2 fuel cell ferries likely to be cost competitive at fuel cell cost of $60/kW & LH_2 bunkered cost of $4.00/kg$H_2$ (Ultimate)
- Reducing onboard storage can yield lower TCO than diesel

Technology Acceleration: Transportation (Rail)

H_2 and Fuel Cells Offer Big Potential for Rail Applications

ANL - Total Cost of Ownership Analysis for Passenger Rail (TA034)



Key Results:

H_2 Electric Multiple Unit (HEMU) locomotives likely to be cost competitive at fuel cell cost of $60/kW & LH_2 cost of $3.50/kg (Ultimate)

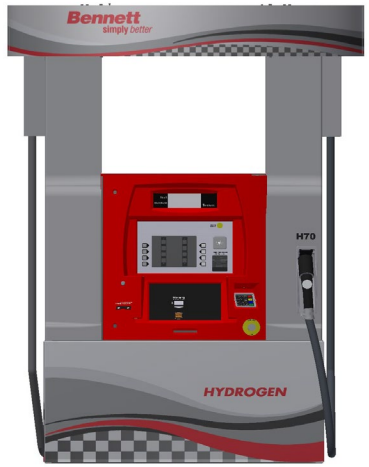
CEC - H_2 Switcher Locomotive

Technical advisor for CEC's FC-powered switcher locomotive demo project

Technology Acceleration: Transportation (Fueling)

Fueling Infrastructure Critical for Heavy-Duty Applications

Electricore - High Pressure / Flow Rate Dispenser & Nozzle for HD Vehicles (TA049)



Goals:

- Develop dispenser & nozzle (receptacle, hose, breakaway) for HD vehicles
- 100 kg in 10 mins at 70 MPa
- Demonstrate system at NREL

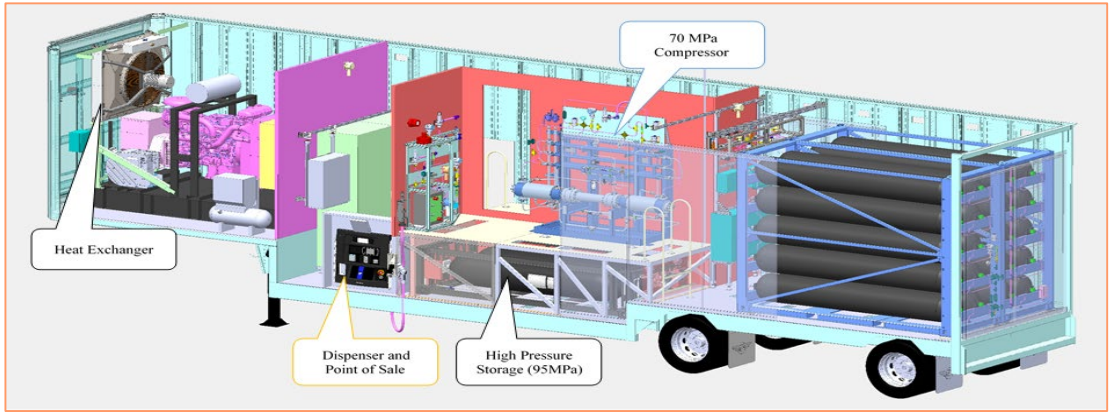
Key Accomplishments:

- Completed industry survey (27 organizations) to determine specifications
- Initial design work completed including component selection, CFD and FMEA analysis
- Partnered with WEH & Bennett

Electricore – Advanced H_2 Mobile Fueler (TA017)

Goal:

Develop a mobile fueler capable of fueling 20-40 vehicles / day (70MPa, T40, 3-5 min fill, 200 kg H_2)



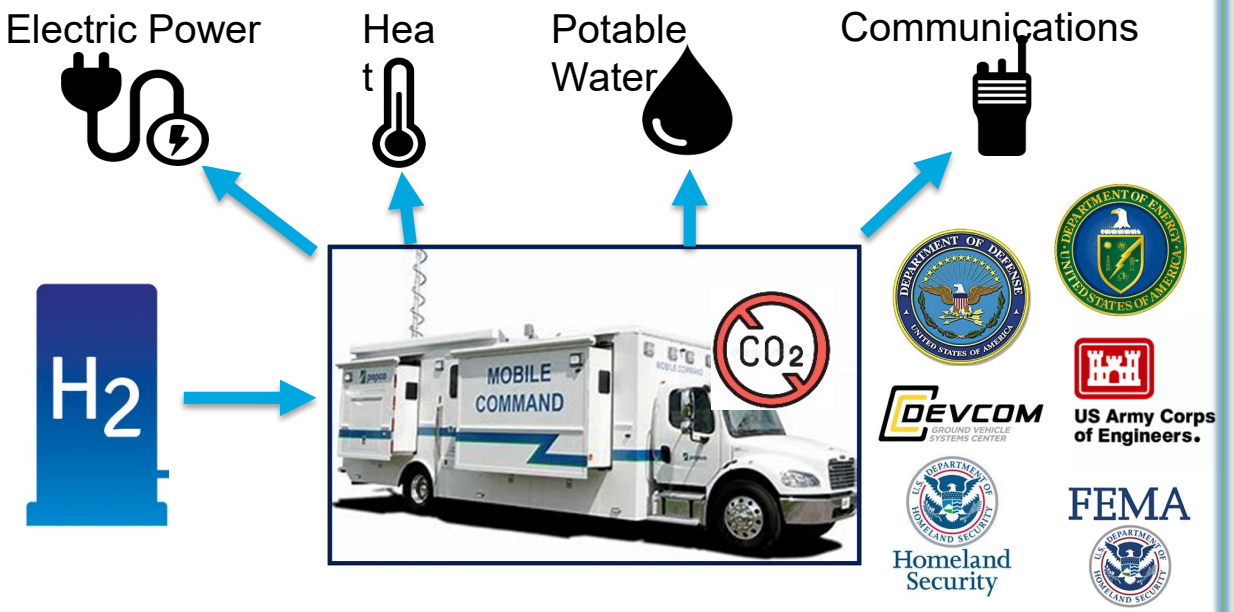
Key Accomplishments:

Design, assembly, and initial testing complete; available soon for public fueling in Ontario, CA

Technology Acceleration: Transportation (New Uses)

HFTO Continues to Pursue New End Use Applications for H_2

H2Rescue



Goal:

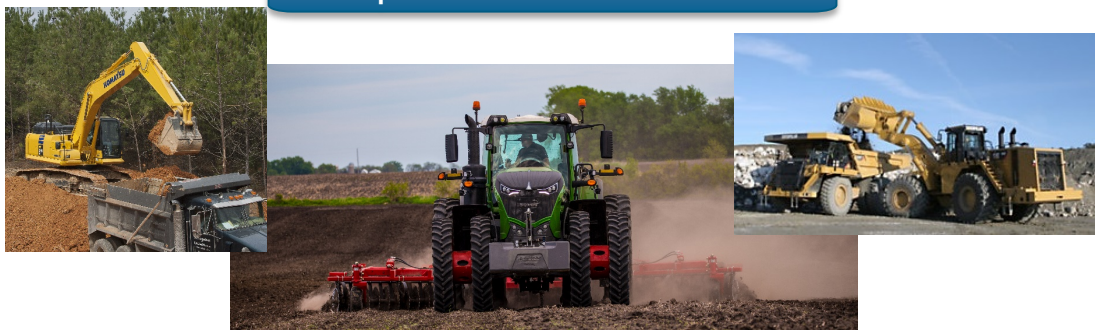
Develop & demonstrate disaster relief truck to provide victim aid, communication support, exportable power & potable water

Key Accomplishments:

- Developed vehicle design specifications w/ DOE-VTO, Army GVSC, DHS S&T (and FEMA) & Army Corps of Engineers

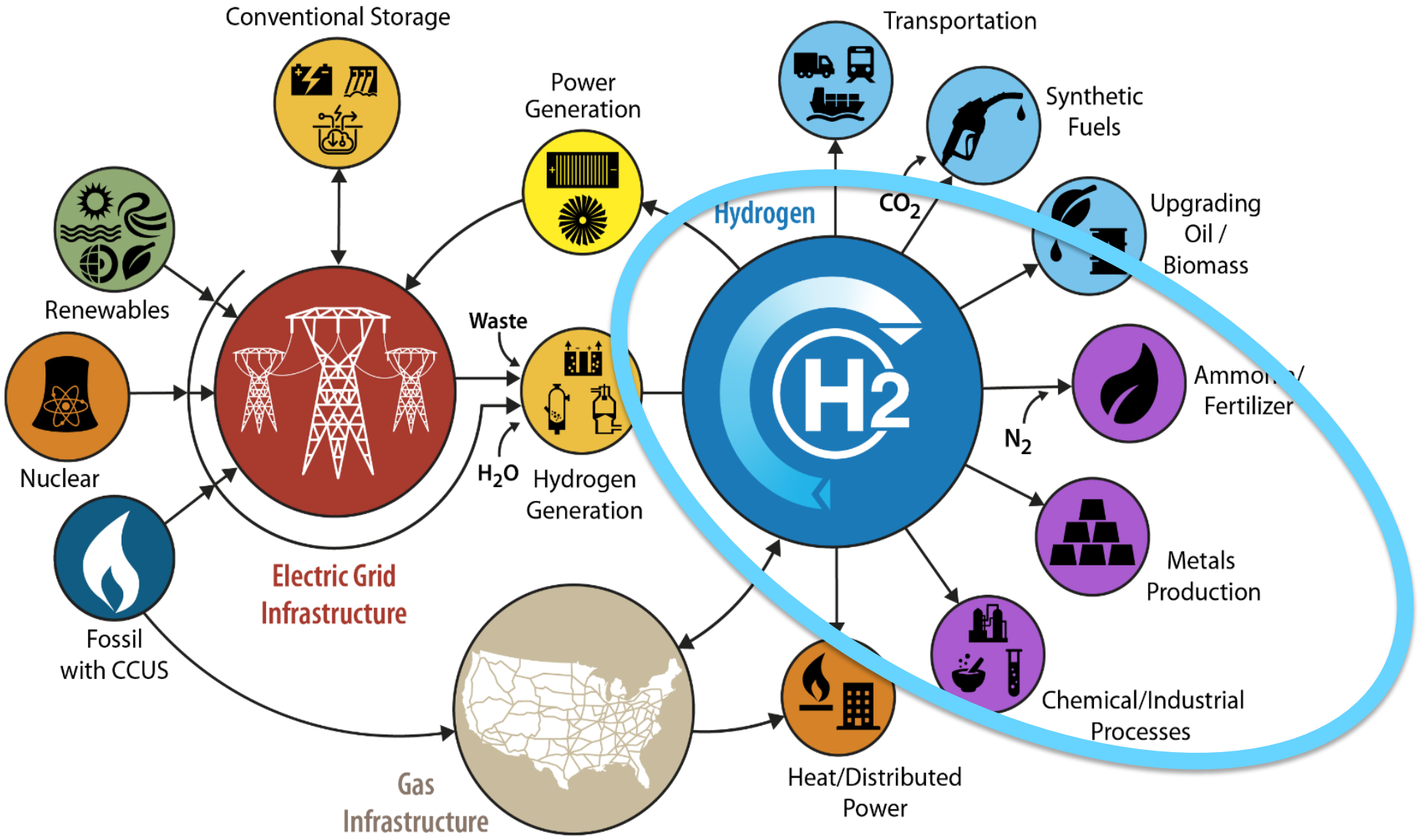
H_2 HD Off-Road Equipment Workshop

Save the Date
September 22nd – 24th



- Heavy-Duty Fuel Cell Truck Workshop, July 2018
  https://www.energy.gov/eere/fuelcells/fuel-cell-truck-powertrain-rd-activities-and-target-review-workshop-h2-scale-end-use
- H2@Rail Workshop, March 2019
  https://www.energy.gov/eere/fuelcells/h2ports-workshop
- H2@Ports Workshop, September 2019
  https://www.energy.gov/eere/fuelcells/h2ports-workshop
- H2@Airports Workshop, November 2020
  https://www.energy.gov/eere/fuelcells/h2airports-workshop

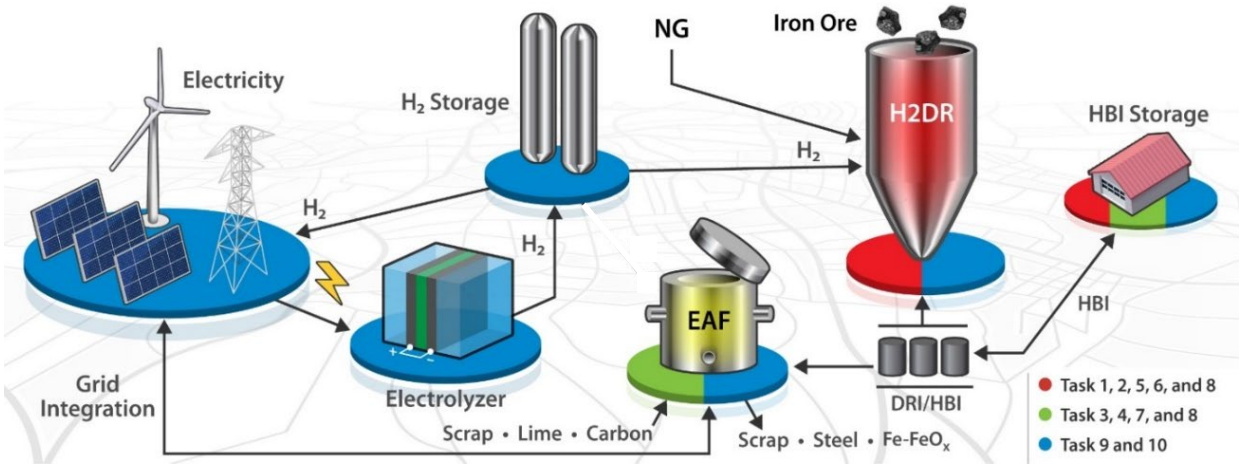
Technology Acceleration: Industrial & Chemical Processes



Technology Acceleration: Industrial & Chemical Processes (Steel)

Decarbonizing Iron/Steel Production with Hydrogen (HySteel) – new projects

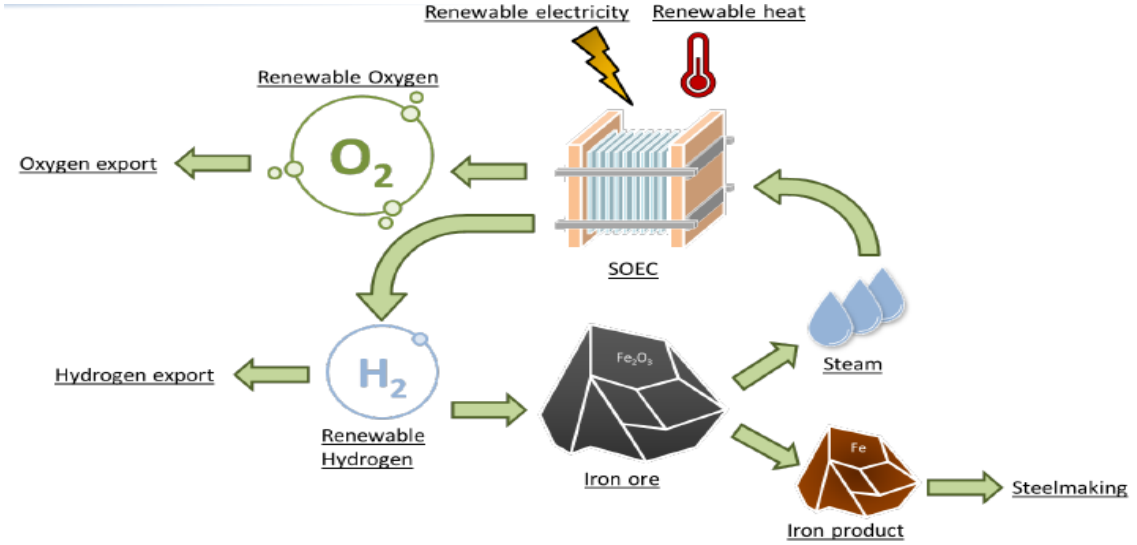
Missouri U. of S&T - Grid Interactive Steelmaking with H_2 (GISH) (poster TA053)



Goals:

- 1 ton/week iron production using variable H_2/NG content; scaled to 5,000 ton/day
- Demonstrate grid integrated steel production system combining:
  - H_2-Direct-Reduction furnace for ironmaking
  - Electric melting for steelmaking

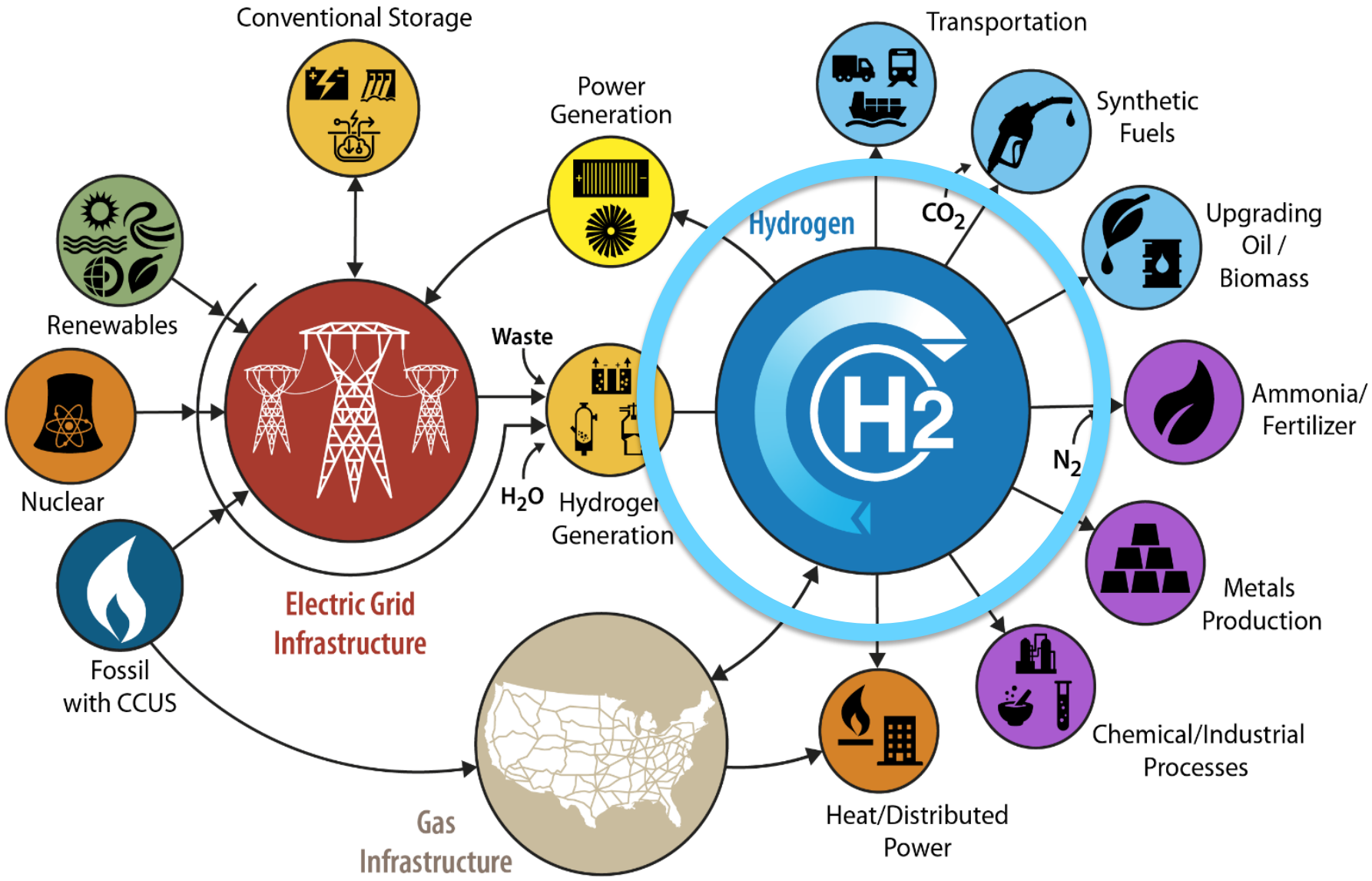
U. of California Irvine - H_2 SOEC integrated with Direct Reduced Iron (DRI) plants (poster TA052)



Goals:

- 1 ton/week equivalent H_2-Direct-Reduction pilot system, scale-up design for a 2Mton/year DRI product capacity
- Demonstrate a thermally & chemically integrated Solid Oxide Electrolyzer system with a DRI plant

Technology Acceleration: Enabling Activities



Technology Acceleration: Enabling Activities (Manufacturing)

Manufacturing is Key to Reduce Costs and Improve Durability at Large Volumes

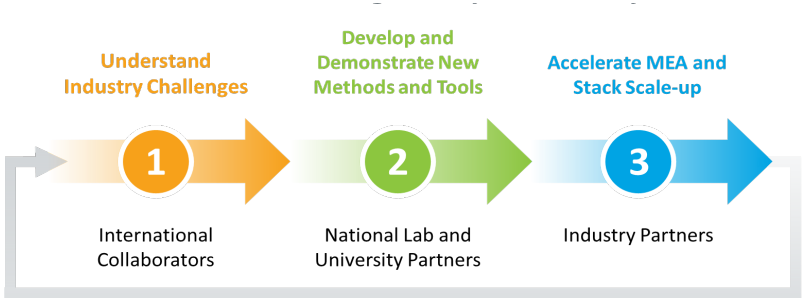
NREL - MEA Manufacturing R&D (TA001)

Goals:

- Develop quality inspection and defect threshold methods and understandings
- Focused on HD Fuel Cell and Low Temperature Electrolyzer (LTE) applications

Key Accomplishments:

- Validated membrane thickness imaging including impact of web speed
- Developed technique for reinforced & thick LTE membranes
- Developed thermal scanning for membrane thickness



International Meeting on Membrane Electrode Assembly Quality Control for Electrolysis and Fuel Cells (May 2021)

Goals:

- Review Prior Workshop Outcomes
- Add LTE MEA materials and compare to FC QC needs
- Prioritize QC needs for both FC and LTEs

Key Outcomes:

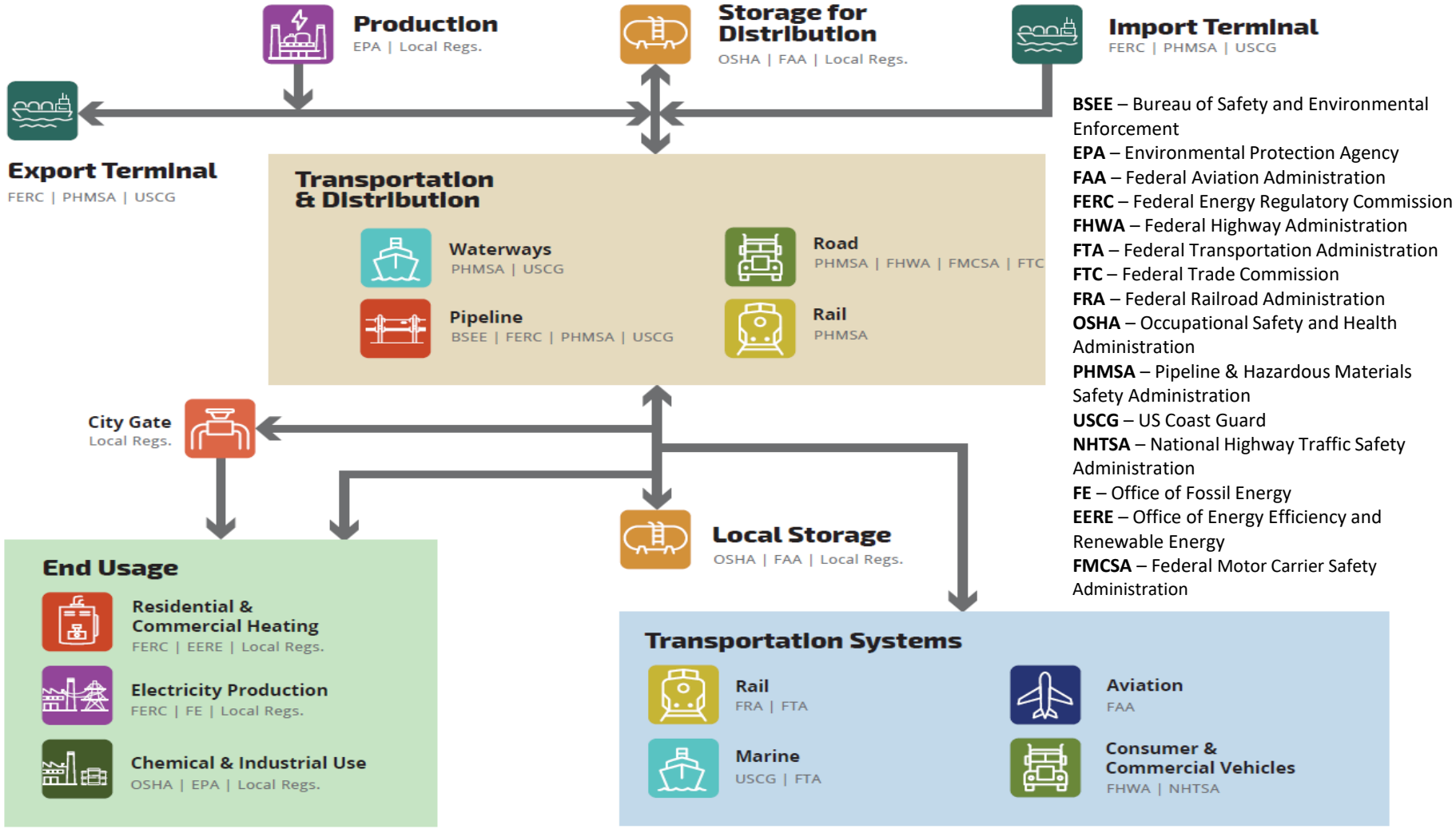
Preliminary findings show:

- FC industry expressed need to better understand features (material variations) vs. actual defects
- Electrolyzer industry expressed need to review failure modes to inform QC needs

Collaboration between U.S. (NREL - TA001), National Research Council-Canada and Frauhnhofer ISE in Germany

Technology Acceleration: Enabling Activities (Safety, Codes & Standards)

U.S. Federal Regulatory Map



BSEE – Bureau of Safety and Environmental Enforcement
EPA – Environmental Protection Agency
FAA – Federal Aviation Administration
FERC – Federal Energy Regulatory Commission
FHWA – Federal Highway Administration
FTA – Federal Transportation Administration
FTC – Federal Trade Commission
FRA – Federal Railroad Administration
OSHA – Occupational Safety and Health Administration
PHMSA – Pipeline & Hazardous Materials Safety Administration
USCG – US Coast Guard
NHTSA – National Highway Traffic Safety Administration
FE – Office of Fossil Energy
EERE – Office of Energy Efficiency and Renewable Energy
FMCSA – Federal Motor Carrier Safety Administration

Major Gaps Identified

- FERC for pipeline transmission, electricity production, and heating
- FHWA for bridges and tunnels
- FRA, USCG, and FAA for rail, maritime, and aviation use

Full report available soon at https://energy.sandia.gov/wp-content/uploads/2021/03/H2-Regulatory-Map-Report_SAND2021-2955.pdf

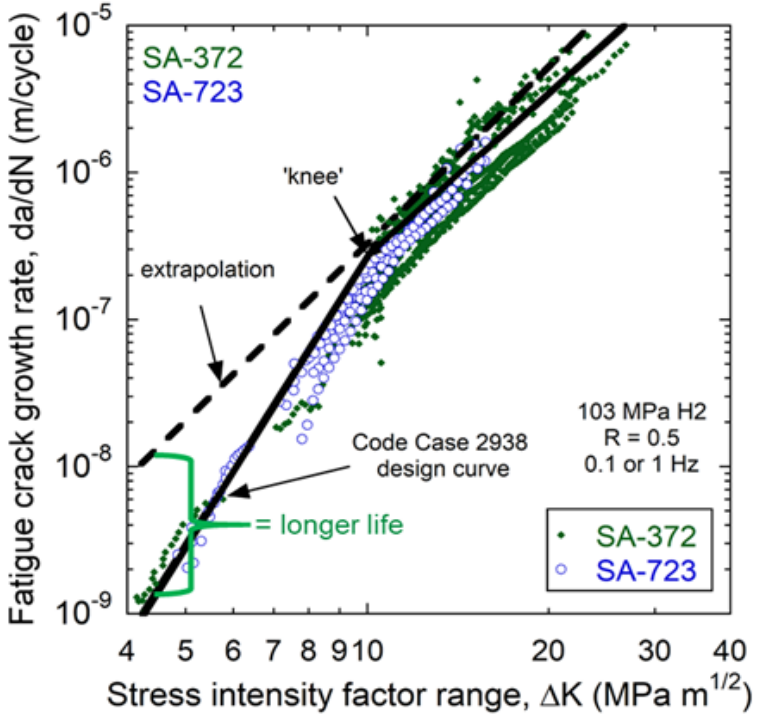
Technology Acceleration: Enabling Activities (Safety, Codes & Standards)

SCS - Enabling Codes & Standards

SNL - Materials Compatibility (SCS 005)

Goal:

Provide scientific basis for codes & standards surrounding materials compatibility



Key Accomplishments:

- ASME Code Case 2938 enabled up to 3X longer life for Type I & II tanks
- Demonstrated Modal Acoustic Emission & Eddy Current techniques for vessel inspection in effort to define cycle parameters

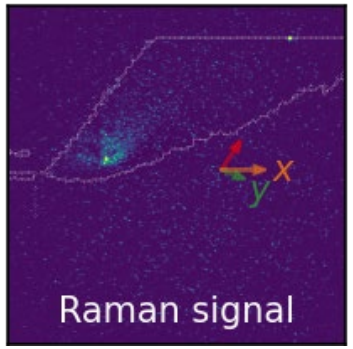
SNL - Hydrogen Behavior R&D (SCS 010)

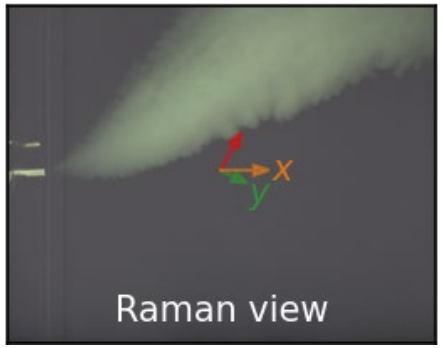
Goal:

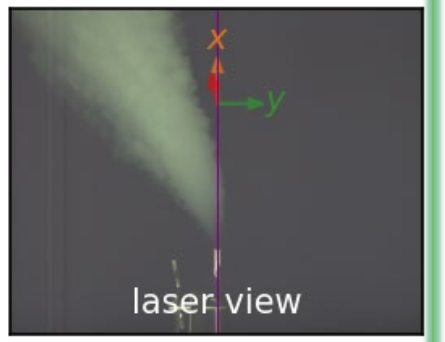
Identify ways to reduce siting burdens for LH_2 deployment through R&D to enable a 40% reduction in station footprint

Key Accomplishments:

- Developed proposed science-based LH_2 exposure distances tables for NFPA 2
- Field validation of cryogenic H_2 behavior:
  - Confirmed H_2 is concurrent with visible plume
  - Demonstrated minimal effect of humidity on H_2 plume







Technology Acceleration – Examples of International Collaboration

Lab-Level engagement with FCH-JU projects:

- **PRESLHY** – liquid hydrogen R&D
- **PRHYDE** – protocol for heavy duty refueling

PRESLHY

PRHYDE Protocol for heavy-duty Hydrogen refuelling

IPHE

International Partnership for Hydrogen and Fuel Cells in the Economy

- Co-Chair of IPHE RCSSWG and E&O WG
- Coordinating efforts to identify regulatory gaps and prioritize efforts

CENTER FOR Hydrogen SAFETY

Connecting a Global Community

- Strategic partnership with the Center for H_2 Safety
- Over 60 members & growing!

MISSION INNOVATION

accelerating the clean energy revolution

Shipping

- Shipping (maritime) collaboration w/ Denmark, Norway and others
- Focused on the entire value chain: ship, fuel production and port infrastructure
- Plan to engage in RD&D activities to develop, test, and accelerate the commercial readiness

Technology Acceleration Program: Collaboration Network

Fostering technical excellence, economic growth and environmental justice

Industry Engagement
Center for Hydrogen Safety
21st Century Truck Partnership
U.S. DRIVE
FCHEA

DOE H_2 Program Collaborations		
DOE AMO	DOE VTO	DOE WETO
DOE ARPA-E		

DOE Cross-Cutting Initiatives		
Energy Storage Grand Challenge	Cybersecurity	Advanced Manufacturing
Grid Modernization Initiative		

Cross-Agency Collaborations
DOT (NHTSA, FRA, FHWA, MARAD, FAA)
Army GVSC, DHS S&T, Army Corps of Engineers
NASA WSTF
IWG (15 government agencies including states)

U.S. Regional and International Collaborations							
Project Coordination across ~20 U.S. States	IPHE (RCSSWG)	FCH-JU	IA- HySafe	Mission Innovation - Shipping	Center for Hydrogen Safety	Bilateral Collaborations	National Research Council-Canada

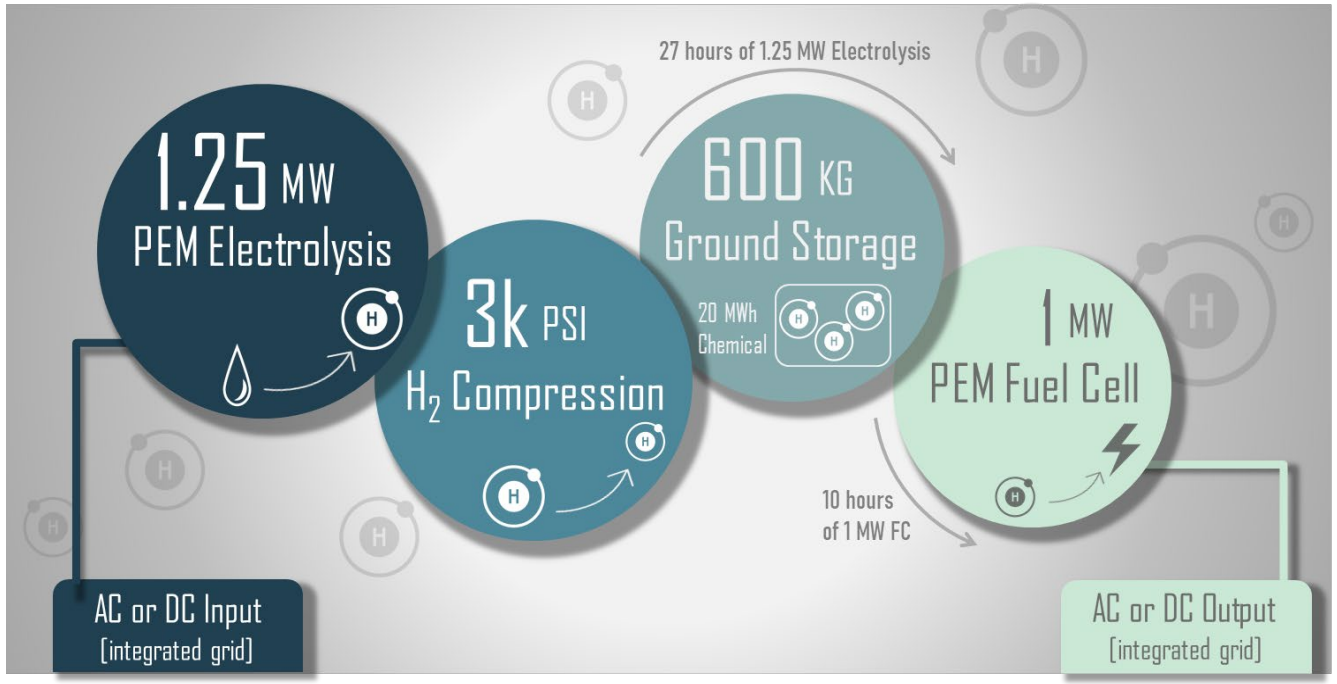
Technology Acceleration Program: Highlights and Milestones

FY2019	FY2020	FY2021	FY2022
Released DOE H_2 and Fuel Cell Targets for Long-Haul Class 8 Trucks	Kicked Off H_2 Working Group as part of the 21st Century Truck Partnership	Awarded World's first Large Scale Fuel Cell Powered Data Center (Caterpillar)	Focus on Integrated Offshore Wind to H_2 Demonstration
		Awarded World's First Renewable H_2 Production Refueling Barge (Hornblower)	Focus on Decarbonizing Steel & Ammonia through use of Green H_2
Launched the Center for Hydrogen Safety (AIChE & PNNL)	Kicked Off 2 Integrated Energy System Demonstration Projects Showcasing H2@Scale Concept (Plug Power & Frontier Energy)	Kicked off 2 HySteel projects to Demonstrate using H_2 to Decarbonize Iron & Steel Production (UCI and MS&T)	Continue Collaborating with NE on H_2 Production from Nuclear
H2@Ports Workshop in Collaboration with DOT MARAD	Kicked Off a First-of-a-Kind Dynamic H_2 Production Demonstration at a Nuclear Plant (Exelon)	Establishing an Integrated MW-scale H_2 Production, Storage and FC System at ARIES (NREL)	Select SuperTruck III Projects for M/HD H_2 Fuel Cell Trucks
		Released SuperTruck III FOA	Continued Collaboration and Alignment of 21CTP & U.S. DRIVE
H2@Rail Workshop in Collaboration with DOT-FRA	Setup National Validation Lab for Large High Temperature (HT) Electrolyzers (INL)	Initiated CRADA Project on High-Flow Fueling Protocol in Concert w/ International PRHYDE project (NREL)	Test 250kW Integrated HT Electrolysis System using Fully Emulated Nuclear Integrated Test Stand
Setback Distances for GH_2 Storage Reduced 50% as a result of Codes & Standards efforts	Performed Release of Cryogenic H_2 to support Reduced LH_2 Storage Separation Distances in NFPA 2 (SNL)	Validated 2 High Temp Electrolyzers from Industry – including a 25kW stack that Surpassed 4,000 hrs with <0.5% Degradation / 1,000 hrs (INL)	Utilize ARIES Capabilities to Advance Integration of H_2 Technologies in Future Energy Systems
		Kicked off H2EDGE Workforce Development Project (EPRI)	Collaboration with International Mission Innovation – Shipping (Maritime)
Released HyRAM 2.0 (H_2 Risk Assessment) (SNL)	Enabled ~3x Longer Life for Type I & II Storage Tanks through Testing to Enable ASME Code Case Revision (SNL)	Hosted International Workshop on Quality Control for Electrolysis & Fuel Cells w/ NRC (Canada) & Frauhnhofer ISE (Germany) (NREL)	Perform SCS Gap Assessment for Large Scale H_2 Applications
	H2@Airports Workshop	Released Federal Regulatory Map Report (SNL)	Utilize Bulk Cryogenic H_2 Behavior Validation Data to Enable Reduction of Separation Distances in NFPA 2

2021 H2@Scale CRADA Call – Supporting ARIES (Released Today!)

- Topic 1: H2@ARIES – Integrated Hydrogen Energy System Testing/Validation
- Topic 2: Applied Risk Assessment and Modeling for H2@Scale Applications
- Topic 3: Next-Generation Sensor Technologies (wide-area H_2 sensors)

https://www.nrel.gov/hydrogen/h2-at-scale-crada-call.html



Planned hydrogen system capabilities at NREL's Flatirons Campus

- Total funding up to $12M over 3 years*
- $500k - $2M per project (dependent on topic area)
- Up to 14 projects total
- 30% Cost share including 10% cash in
- National Lab leads w/ partners from industry, state & local gov, universities, etc.

Proposals due July 19, 2021

*Pending Appropriations

Technology Acceleration Team – THANKS!

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