U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

2021 AMR Plenary Session

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Director, U.S. Department of Energy Hydrogen and Fuel Cell Technologies Office

June 7, 2021

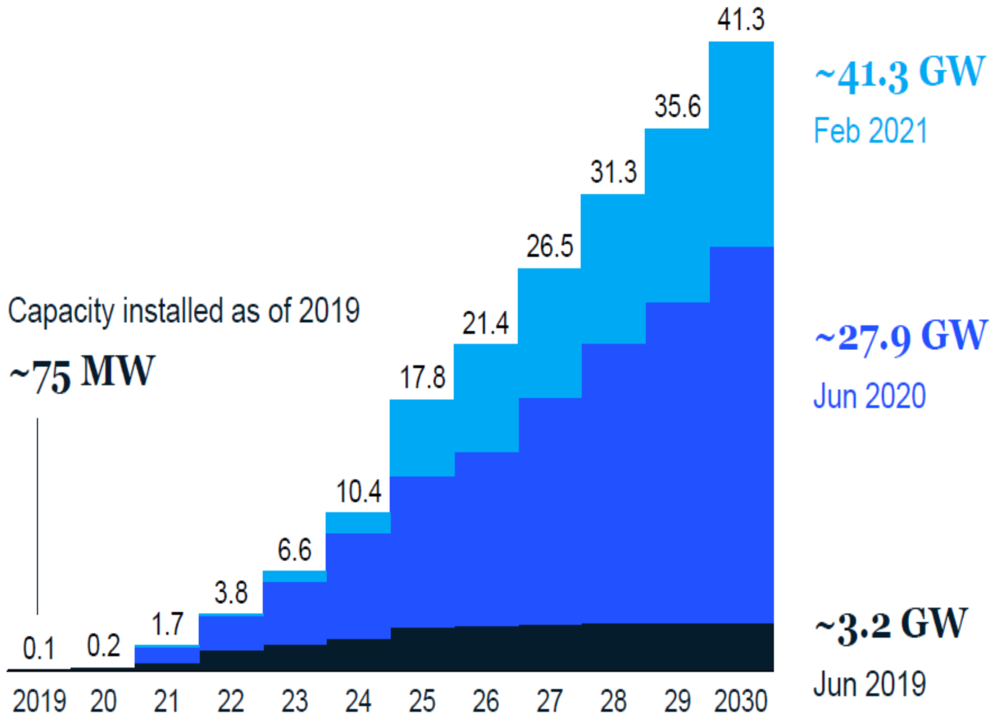




Recent Increased Interest in Hydrogen: Global Drivers

- ✓ **Low-cost renewables** are now available
- ✓ **Countries see clean H_2 can help meet climate goals**
  - Hard to decarbonize sectors
  - Energy storage
  - Import/export opportunities

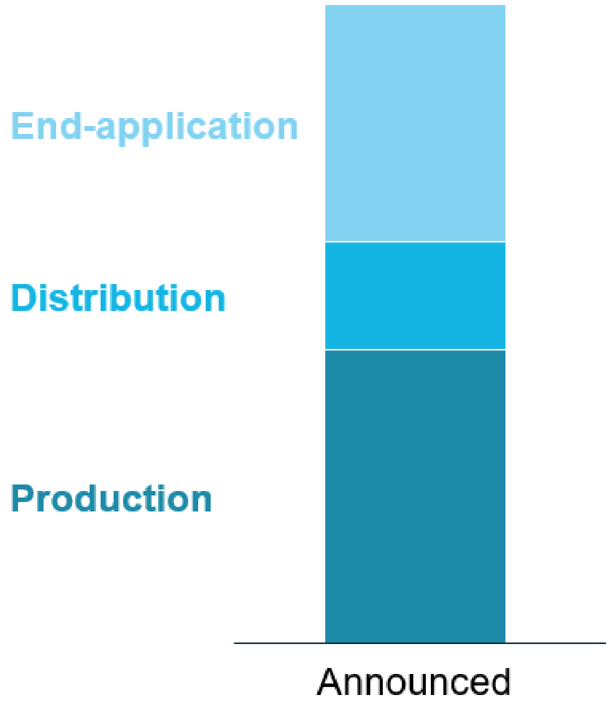
200-fold electrolyzer growth by 2030
Over 40 GW planned



1. For projects without known deployment timeline capacity additions were interpolated between known milestones

Source: McKinsey Hydrogen Project database

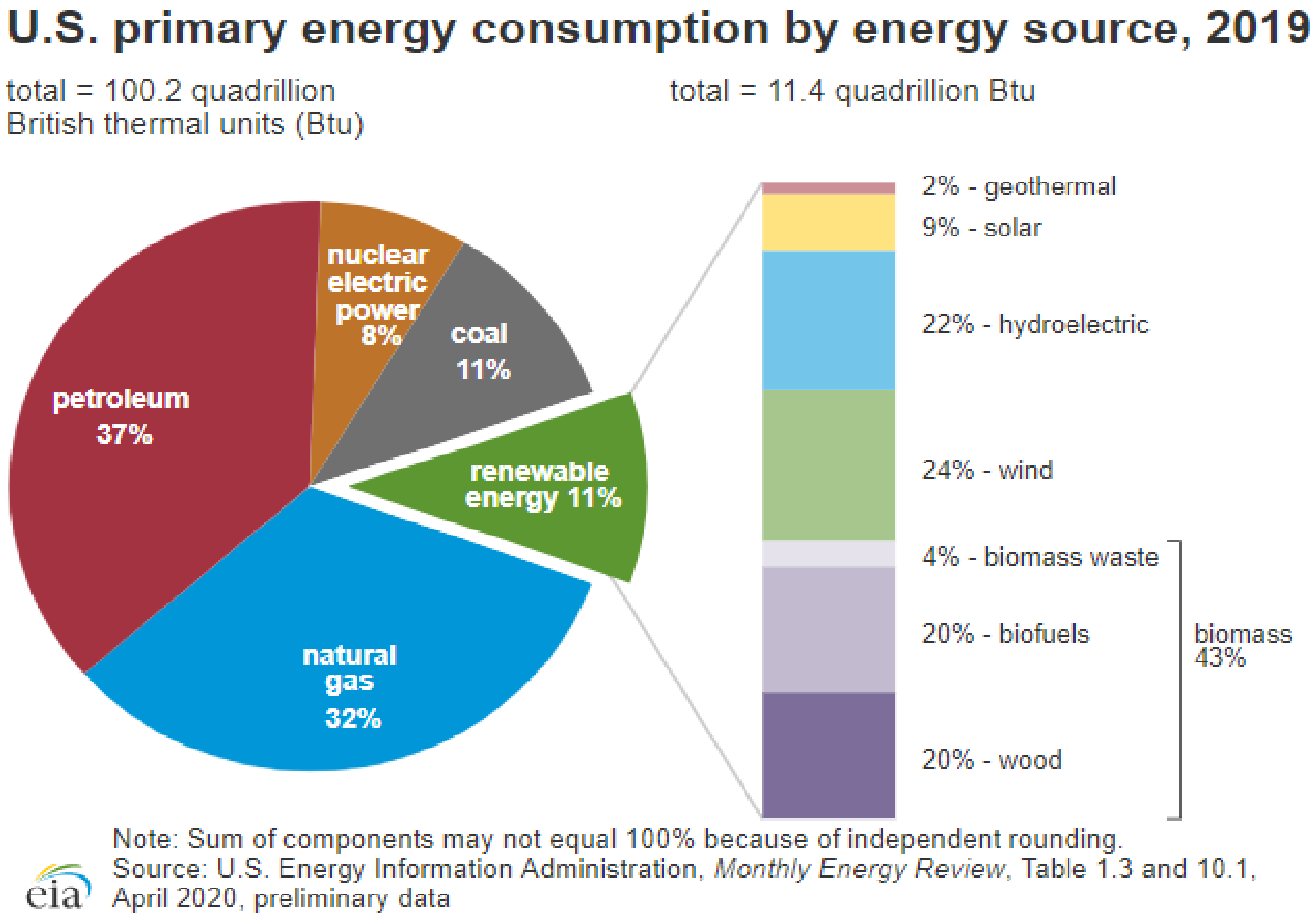
$80B Global Government Funding. 6X More with Private Sector through 2025



Source: McKinsey, H2 Council, Spring 2021

Studies show potential for 10 to 25% global GHG reduction using clean hydrogen. $2.5T Revenue. 30M Jobs.

U.S. Energy Landscape and Key Goals



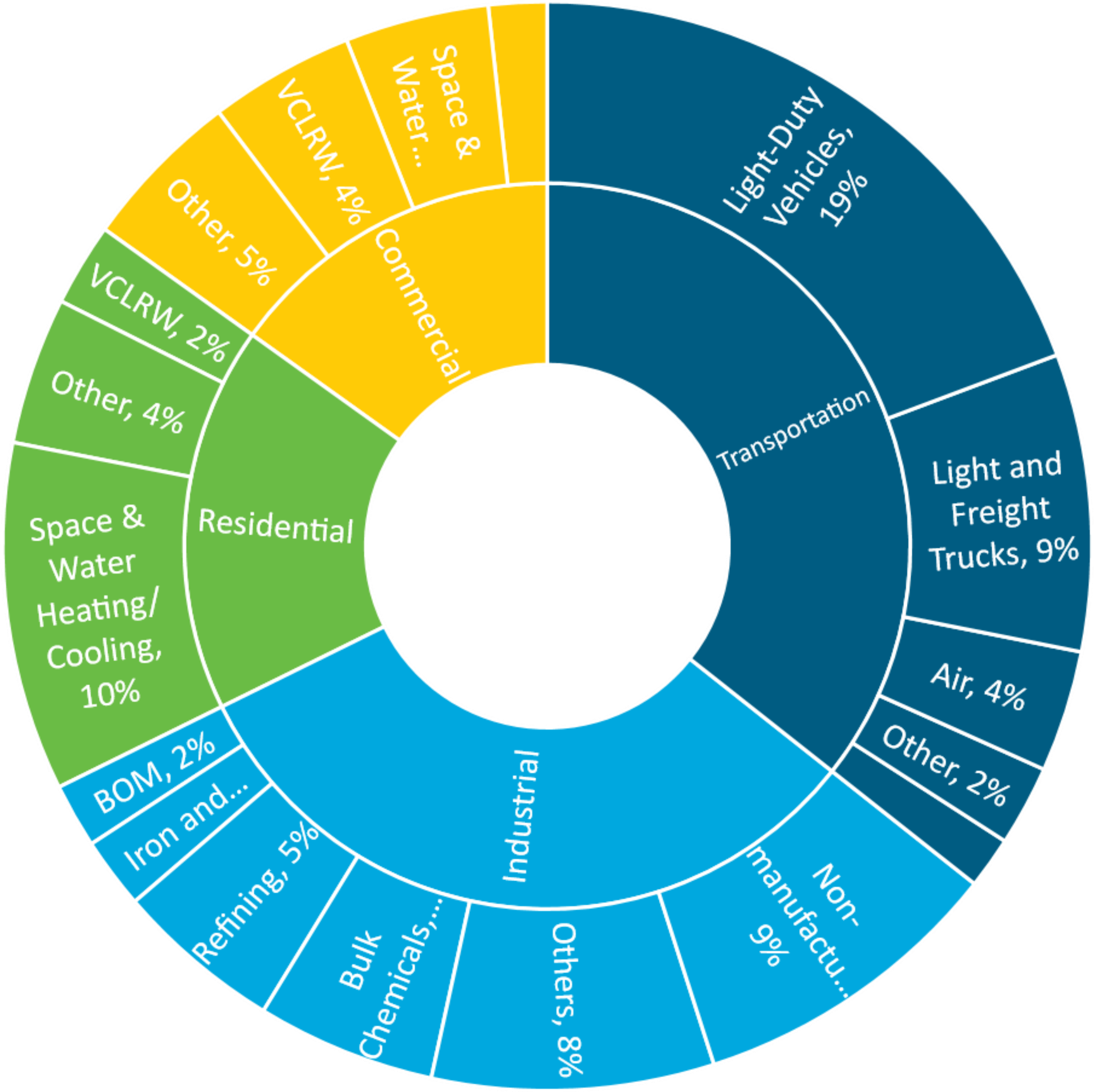
Administration Goals include:

- **100% carbon-pollution-free electric sector by 2035**
- **Net zero emissions economy by 2050**

Priorities: Ensure benefits to all Americans, focus on jobs, EJ40: 40% of benefits in disadvantaged communities

EJ: Environmental Justice

U.S. Energy Related Carbon Dioxide Emissions by Sector

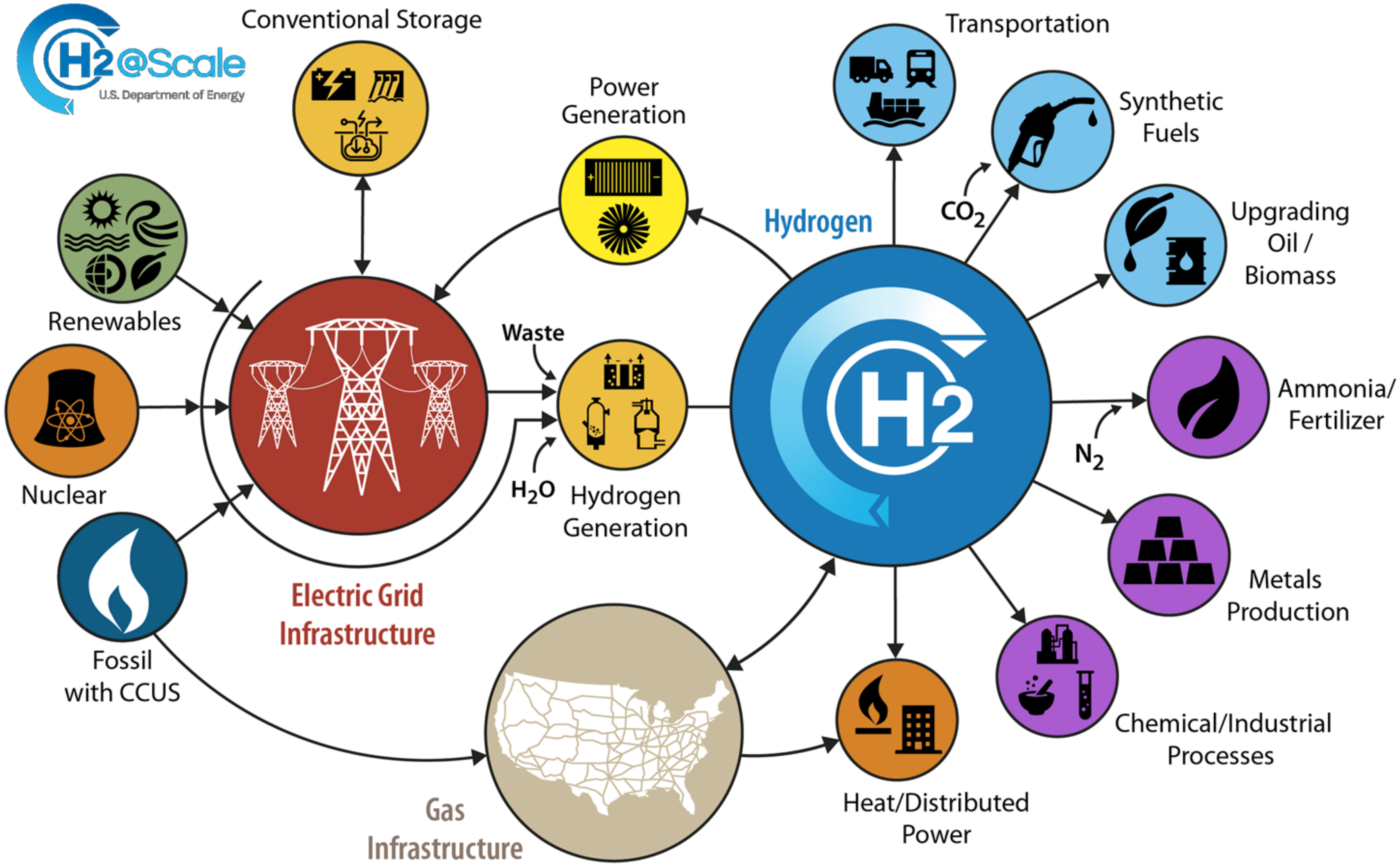


Need to address all sectors with portfolio approach

Hydrogen can provide benefits particularly in hard to decarbonize sectors: industry, heavy duty transport, energy storage, etc.

Source: M. Koleva, DOE HFTO, NREL, adapted from EPA, [Sources of Greenhouse Gas Emissions | Greenhouse Gas (GHG) Emissions | US EPA]

H2@Scale Opportunities: Deep Decarbonization, Economic Growth, Jobs



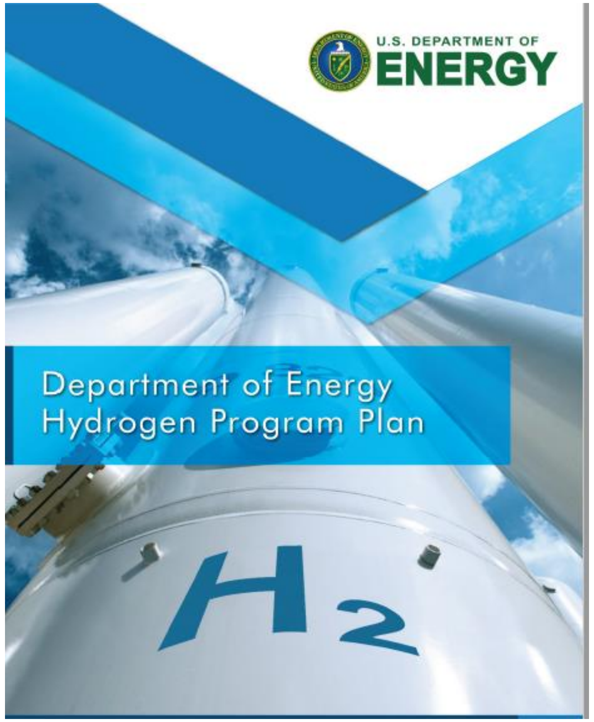
Potential

- 10 MMT of H_2/yr produced today with scenarios for ~5X growth
- 10 MMT H_2 would ~ double today's solar or wind deployment
- Industry study shows potential for $140B in revenue, 700K jobs, 16% GHG reduction. Analysis underway, including on export potential.

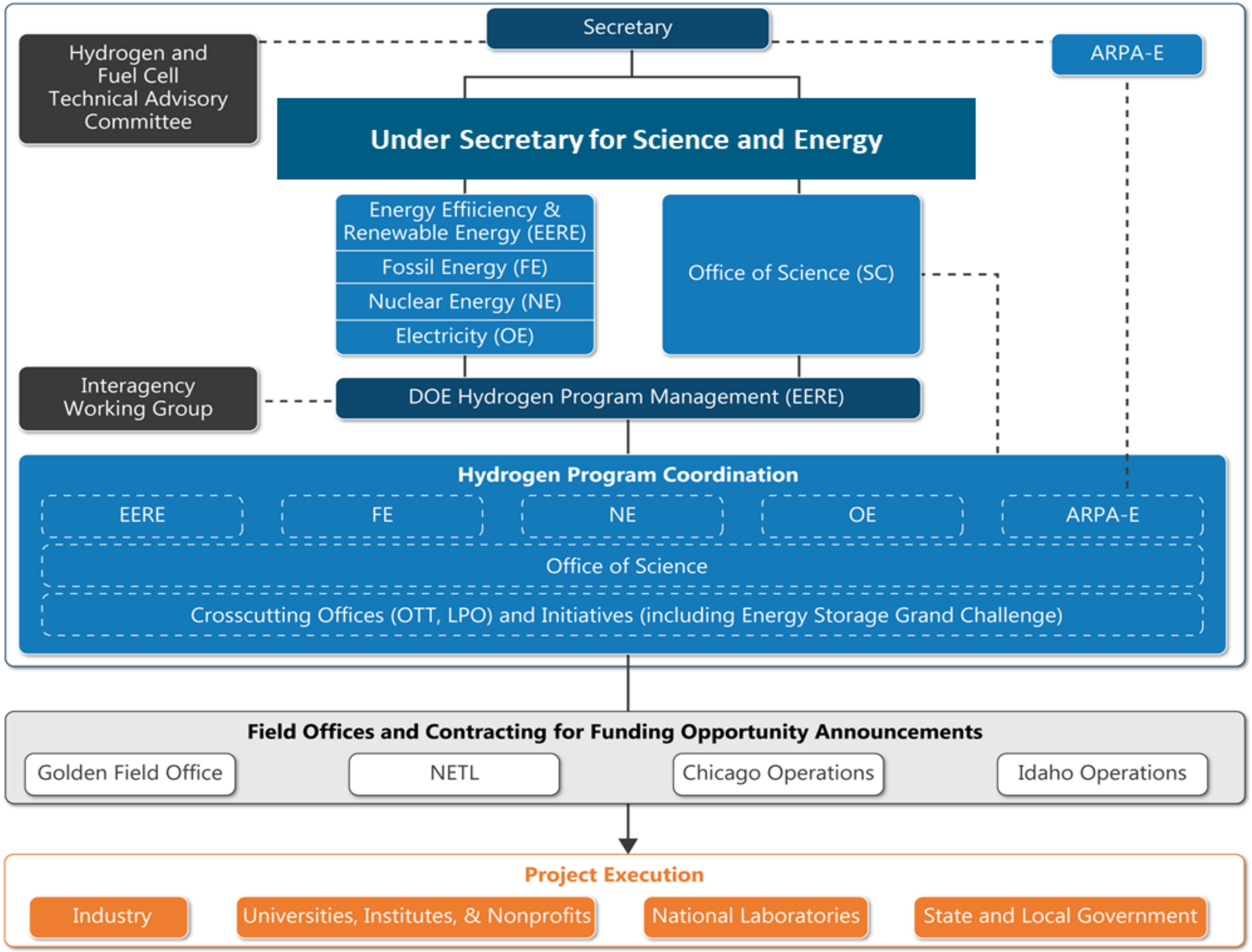
The U.S. DOE Hydrogen Program Released November 2020

The Energy Policy Act (2005) Title VIII and Energy Policy Act of 2020 provide key authorization

Hydrogen is one part of a broad portfolio of activities



www.hydrogen.energy.gov



Comprehensive DOE Strategy Across the Hydrogen Value Chain

NEAR-TERM → **LONGER-TERM**

Production
- Gasification of coal, biomass, and waste with carbon capture, utilization, and storage
- Advanced fossil and biomass reforming/conversion
- Electrolysis (low-temperature, high-temperature)
- Advanced biological/microbial conversion
- Advanced thermo/photoelectro-chemical H_2O splitting

Delivery
- Distribution from on-site production
- Tube trailers (gaseous H_2)
- Cryogenic trucks (liquid H_2)
- Chemical H_2 carriers
- Widespread pipeline transmission and distribution

Storage
- Pressurized tanks (gaseous H_2)
- Cryogenic vessels (liquid H_2)
- Geologic H_2 storage (e.g., caverns, depleted oil/gas reservoirs)
- Cryo-compressed
- Chemical H_2 carriers
- Materials-based H_2 storage

Conversion
- Turbine combustion
- Fuel cells
- Advanced combustion
- Next generation fuel cells
- Fuel cell/combustion hybrids
- Reversible fuel cells

Applications
- Fuel refining
- Space applications
- Portable power
- Blending in natural gas pipelines
- Distributed stationary power
- Transportation
- Distributed CHP
- Industrial and chemical processes
- Defense, security, and logistics applications
- Utility systems
- Integrated energy systems

Hydrogen Program Objectives

Examples of Key DOE Hydrogen Program Targets

DOE targets are application-specific and developed with stakeholder input to enable competitiveness with incumbent and emerging technologies. These targets guide the R&D community and inform the Program's portfolio of activities. Examples include:

- $2/kg for hydrogen production and $2/kg for delivery and dispensing for transportation applications
- $1/kg hydrogen for industrial and stationary power generation applications
- Fuel cell system cost of $80/kW with 25,000-hour durability for long-haul heavy-duty trucks
- On-board vehicular hydrogen storage at $8/kWh, 2.2 kWh/kg, and 1.7kWh/l
- Electrolyzer capital cost of $300/kW, 80,000 hour durability, and 65% system efficiency
- Fuel cell system cost of $900/kW and 40,000 hour durability for fuel-flexible stationary high-temperature fuel cells

Priorities

1. **Low cost, clean hydrogen production: $2/kg by 2025, $1/kg by 2030**
2. **Low cost, efficient, safe hydrogen delivery and storage**
3. **End use applications to achieve scale and sustainability, enable emissions reduction and address environmental justice priorities**

Enablers: Workforce development, safety, codes, standards, analysis

The Hydrogen and Fuel Cell Technologies Office (HFTO)

Mission	Research, development and demonstration (RD&D) of hydrogen and fuel cell technologies that can advance	• **Clean Energy and Emissions Reduction Across Sectors** • **Job Creation and a Sustainable and Equitable Energy Future**

Key RD&D Sub-Programs

Fuel Cells

- Cost, durability, efficiency
- Components (catalysts, electrodes) & systems
- Focus on heavy duty applications (trucks, marine, data centers, rail, air, etc.)

Hydrogen

- Hydrogen production, infrastructure/delivery, storage (for transport and stationary storage)
- Cost, efficiency, reliability & availability

Systems Development & Integration

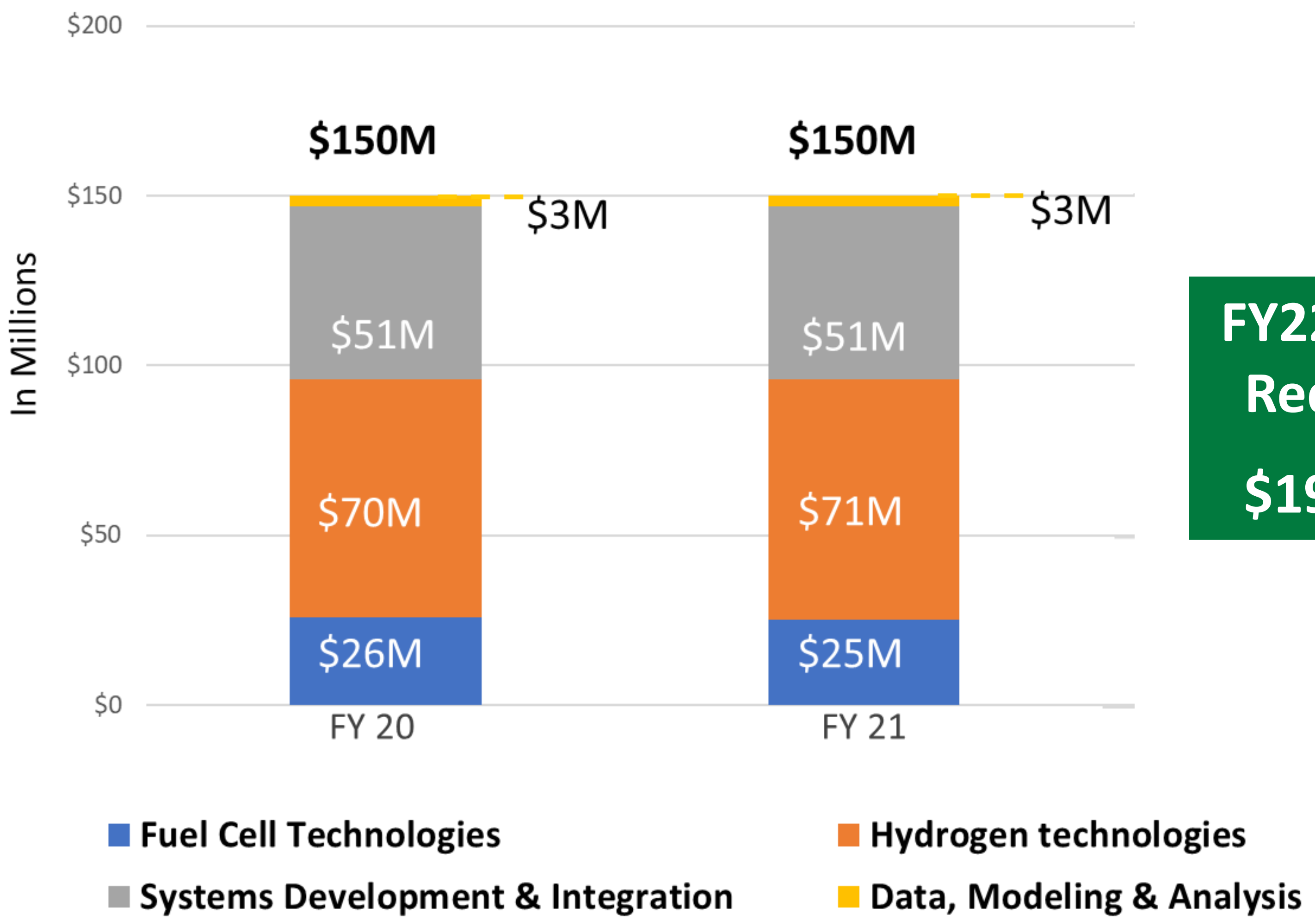
- Hybrid, grid integrated systems, energy storage
- Safety, codes & standards
- Technology acceleration
- Workforce development

Data, Modeling, Analysis: Assess pathways, impacts; set targets, guide RD&D

Enabling

H2@Scale℠
U.S. Department of Energy

Funding for Hydrogen and Fuel Cell Technologies Office (HFTO)



FY22 HFTO Request:

$197.5M

HFTO has funded over 190 companies, 109 universities, and 16 National Labs across 40 States over the last decade

Program Enabled Accomplishments

Innovation

1,100 Patents

in hydrogen and fuel cell technologies through HFTO funding from Labs, Industry and Academia

35% from National Labs

Technology-to-Market

30 Technologies Commercialized

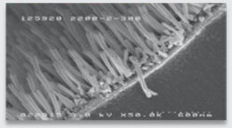
By private industry

65 With Potential to Enter Market

in the next 3-5 years

Examples of Technologies Enabled

Fuel Cell Catalysts



Catalyst and Supports for PEM Fuel Cells
3M

Hydrogen Tube Trailers

Hydrogen Tube Trailers
Hexagon Lincoln

Forklifts

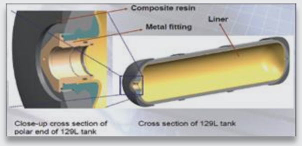
Class-1, -2, and -3 Forklifts
Plug Power (GenDrive FCs)

Electrolyzers

Electrolyzer System
Proton Series

PEM Electrolyzer System
Giner

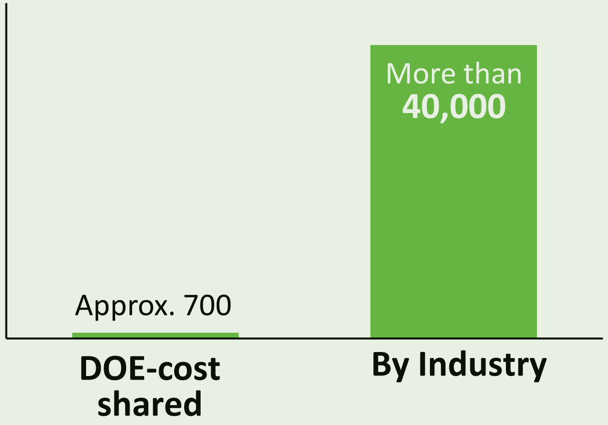
Hydrogen Tanks



Optimized 129L Tank
Quantum Technologies

Market Uptake

Hydrogen fuel cell forklifts in the U.S.



American-made small-scale hydrogen refueler

- Exported to Japan
- Uses electrolysis

HFTO Comprehensive Strategy

R&D

Focused Consortia with labs, industry, universities

Core Team: National Labs

FOA

University & Non-Profit | Industry | National Lab

HyMARC — Hydrogen Materials Advanced Research Consortium

HydroGEN — Advanced Water Splitting Materials

ElectroCat — Electrocatalysis Consortium

New: $100M/5yrs

H2NEW — U.S. DEPARTMENT OF ENERGY

FCT — U.S. DEPARTMENT OF ENERGY

MILLION MILE FUEL CELL TRUCK

2016 — 2018 — 2020

D&D

Trucks, GSE

Infrastructure

CO_2+H_2

Renewables to H_2

Data Center

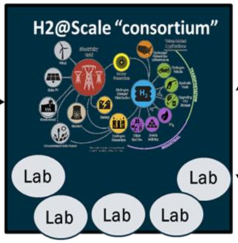
Nuclear to H_2

Ammonia (ARPA-E)

New: Super Truck FOA and more…

Enablers

Government Funding



CRADAs

SPPs

Comprehensive analysis, tools and models to accelerate progress

Safety, codes, standards, workforce development

Systems integration and validation

H2EDGE — Hydrogen Education for a Decarbonized Global Economy

H-Mat — Hydrogen Materials Compatibility Consortium

Center for Hydrogen Safety — Connecting a Global Community

HyBlend — U.S. DEPARTMENT OF ENERGY

Key 2030 Targets

Clean Hydrogen
- $1/kg production
- $2/kg delivery
- $9/kWh storage

Electrolyzers
- $150/kW
- 73% efficiency
- 80Khr durability

Fuel Cells
- $80/kW
- 25Khr durability

Enable EJ40 Priorities, DEI

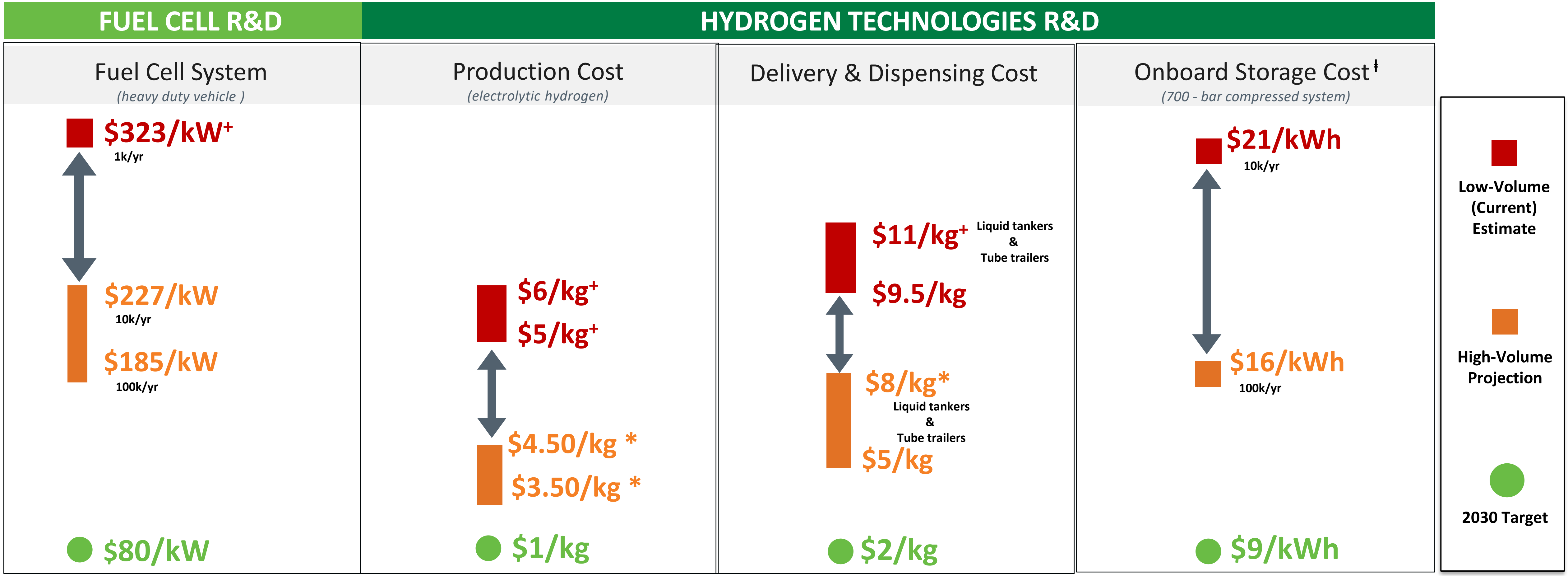
Deployment in collaboration with Loan Program Office

Examples shown, not exhaustive. Over 190 companies, 109 universities, 16 national labs in the last decade; CRADAs are Cooperative Research And Development Agreements

Research and Development

Technology Targets Guide HFTO R&D Activities

Key Goals: Reduce the cost of fuel cells and hydrogen production, delivery, storage, and meet performance and durability requirements – guided by applications specific targets



†Based on 275 kW Heavy Duty Fuel Cell System Cost Analysis (2021), adjusted to reflect cost of system that meets 25,000 hours durability

ǂ 5 to 7 cents/kWh, 90% capacity factor at $1500/kW
*5 to 7 cents/kWh, 90% capacity factor at $460/kW

†For range: Delivery and dispensing at today's (2020) stations with capacity ~450 kg/day
*For range: Delivery and dispensing at today's (2020) stations with capacity 450-1,000 kg/day at high volume manufacturing

ǂ Storage costs based on 2019 storage cost record

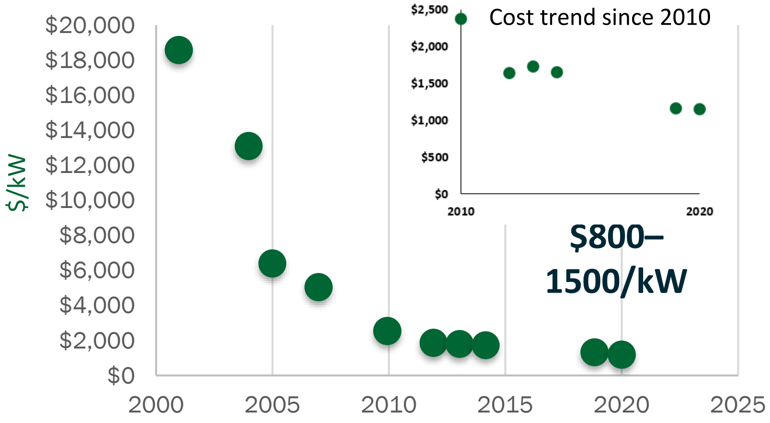
All costs based on $2016

Note: Graph is not at scale. For illustrative purposes only

Program-funded Progress But More Work is Needed

Hydrogen Production
(PEM electrolyzer- low volume)

Cut cost by 90% since 2005

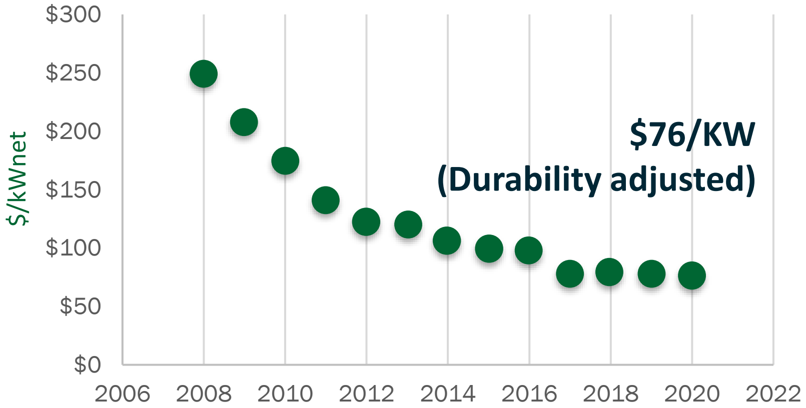


Note: 2010 to 2018-zero/limited HFTO funding on electrolysis
PEM: Polymer Electrolyte Membrane

Need ~ 80% cost reduction to $250-$300/kW

Fuel Cells
(Automotive PEM fuel cell system- 100K/yr)

Cut cost by 70% since 2008

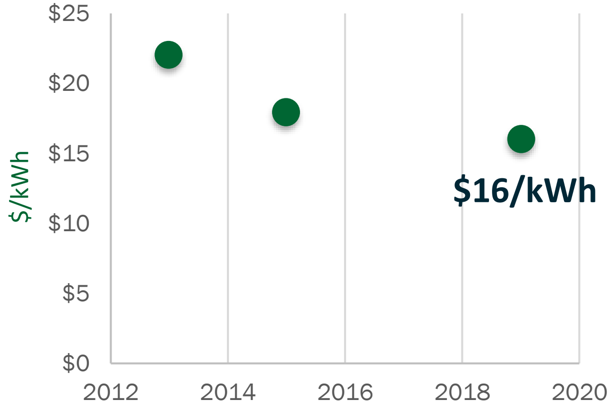


Note: At 100k systems/year

Need 60% cost reduction to $80/kW for HD Trucks

Hydrogen Storage
(Carbon fiber 700 bar tanks- 100K/yr)

Cut cost by 30% since 2013



Note: At 100k units/year

Need 50% cost reduction to $8/kWh

Million Mile Fuel Cell Truck Consortium (M2FCT)

MILLION MILE FUEL CELL TRUCK
U.S. DEPARTMENT OF ENERGY

"Team-of-teams" approach that allows for rapid feedback, idea development, and information exchange, resulting in an effort that is more than the sum of its parts

HD MEA Projects

Carnegie Mellon University, GM, NIKOLA

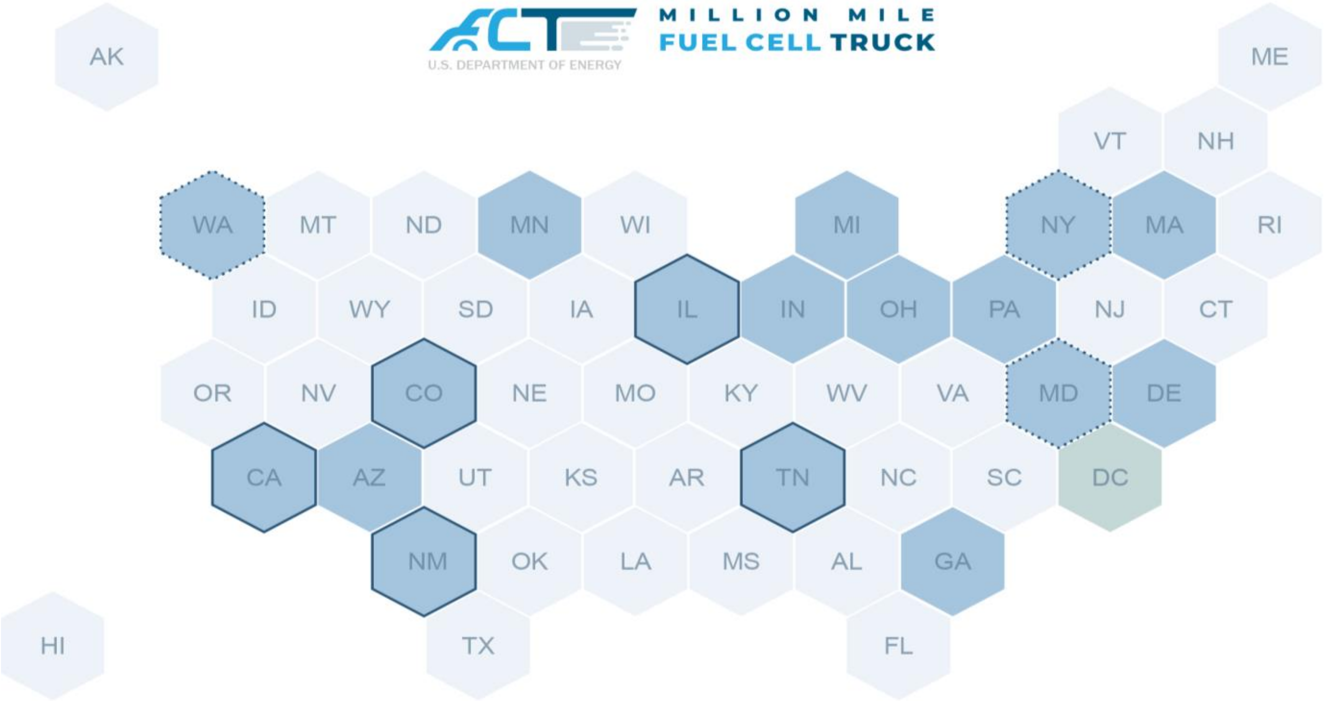
HD Membrane Projects

University of Tennessee, Lubrizol, 3M, NIKOLA

HD Stack Projects

Cummins, PLUG POWER

To add FOA bipolar plate and air management projects in FY21



Primary Labs
- LBNL
- LANL
- ANL
- NREL
- ORNL

Partners Labs
- PNNL
- BNL
- NIST

Partners Academia
- Cornell
- Carneige Mellon Univ.
- Colorado School of Mines
- GeorgiaTech
- Northeastern
- University of Tennessee

Partners Industry
- 3M Company
- Akron Polymer Products
- Ballard
- Chemours
- Cummins
- General Motors
- Kodak
- Lubrizol
- Nikola Motors
- Pajarito Powder
- Plug Power

Main Laboratories

- Los Alamos National Laboratory
- Berkeley Lab
- Oak Ridge National Laboratory
- NREL – National Renewable Energy Laboratory
- Argonne National Laboratory

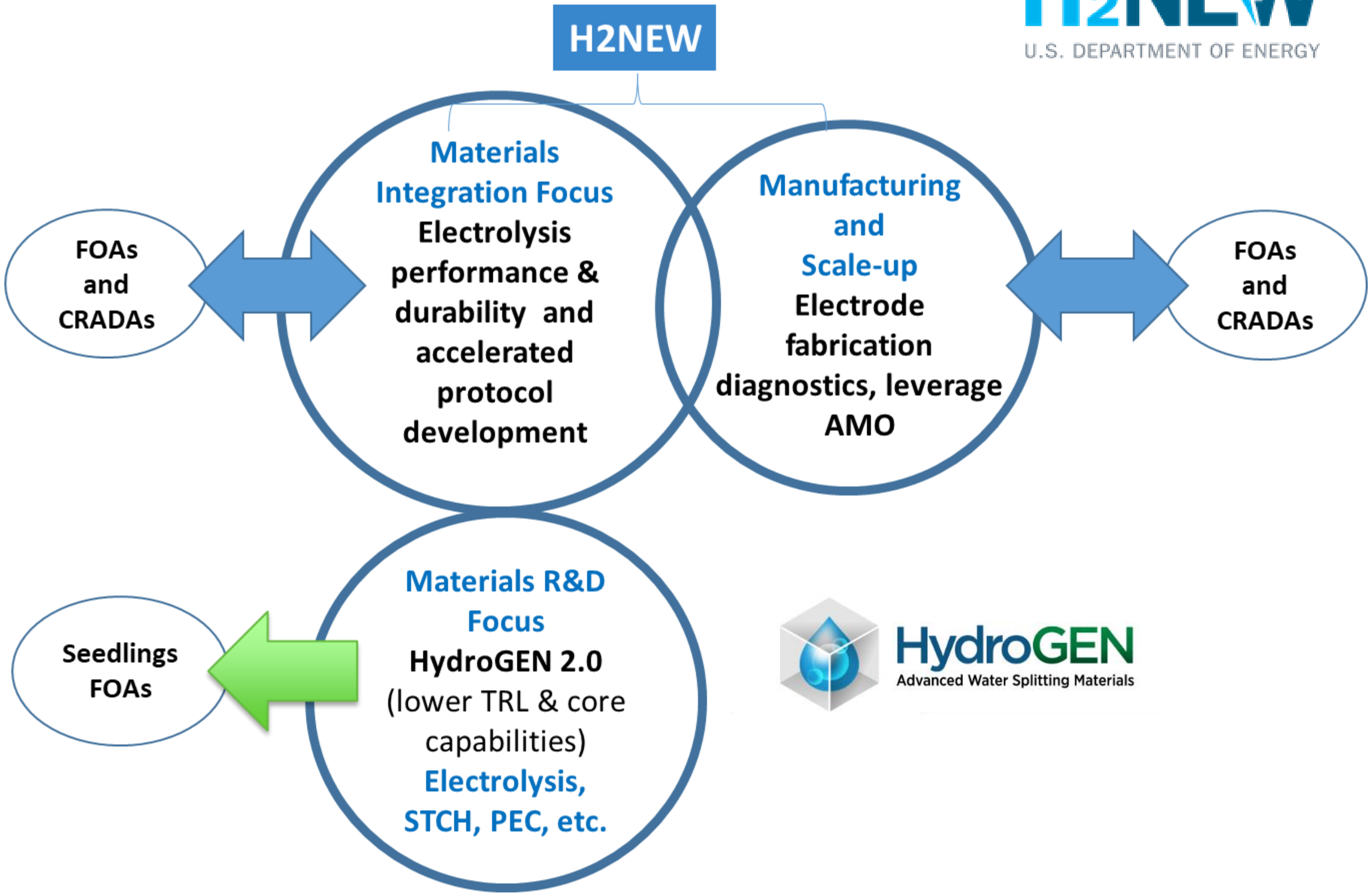
Affiliate Laboratories

- Pacific Northwest National Laboratory
- Brookhaven National Laboratory
- NIST – National Institute of Standards and Technology

H2NEW Consortium to Accelerate Progress in Electrolyzers

H2 from the Next-generation of Electrolyzers of Water

H2NEW
U.S. DEPARTMENT OF ENERGY



HydroGEN
Advanced Water Splitting Materials

National Lab Consortium Team

NREL National Renewable Energy Laboratory
INL Idaho National Laboratory
Argonne National Laboratory
Berkeley Lab
Pacific Northwest National Laboratory
Los Alamos National Laboratory
Lawrence Livermore National Laboratory
Oak Ridge National Laboratory
NETL National Energy Technology Laboratory

Clear, well-defined stack metrics

Electrolyzer Stack Goals by 2025		
	LTE PEM	**HTE**
Capital Cost	\$100/kW	\$100/kW
Elect. Efficiency (LHV)	70% at 3 A/cm^2	98% at 1.5 A/cm^2
Lifetime	80,000 hr	60,000 hr

Demonstration and Deployment

Snapshot of Hydrogen and Fuel Cell Applications in the U.S.

Examples of Applications Deployed

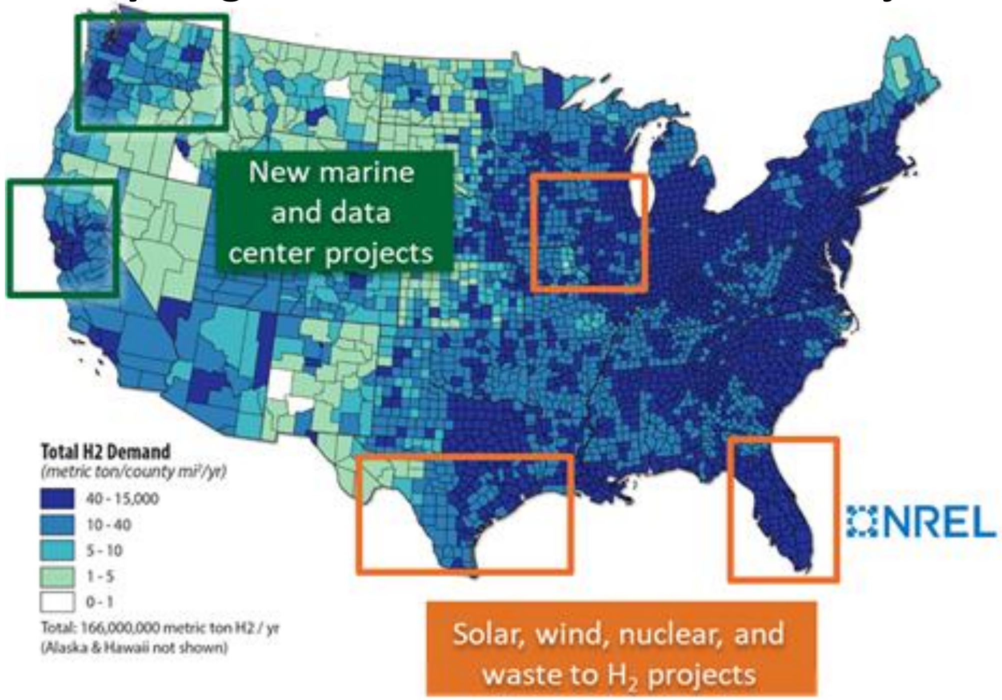
- **>500MW** Backup Power
- **>40,000** Forklifts
- **>172 MW** PEM* Electrolyzers
- **>60** Fuel Cell Buses
- **>45** H_2 Retail Stations
- **~10,000** Fuel Cell Cars

*Polymer electrolyte membrane

Major Hydrogen Production Sites

- 10 million metric tons produced annually
- More than 1,600 miles of H_2 pipeline
- World's largest H_2 storage cavern

Hydrogen Demand and H2@Scale Projects



Hydrogen Stations Plans Across States

California	Northeast	HI, OH, SC, NY, CT, MA, CO, UT, TX, MI
200 Stations Planned California Fuel Cell Partnership Goal	12 – 20 Stations Planned	And Others

H2@Scale Projects to Demonstrate Technology and Train Future Workforce

Different regions, hydrogen sources, end uses & educational opportunities

H_2 for Marine Application

California

1st-of-its-kind maritime H_2 refueling on floating barge - up to ½ ton H_2 /day

H_2 from Renewables

Texas

Integrates wind, solar, RNG from waste with onsite electrolysis and multiple end-uses

H_2 for Data Center

Washington

Integrates a 1.5MW fuel cell with a data center to provide reliable and resilient power

H_2 for Steel Production

Missouri

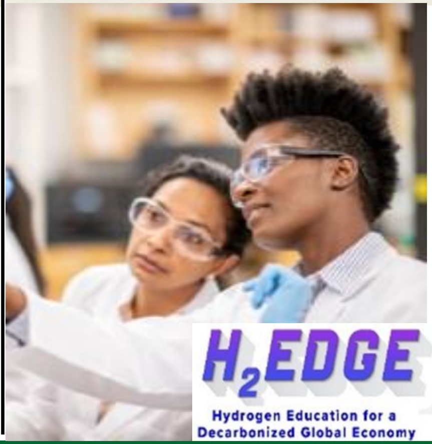
Reduction of 30% in energy and 40% emissions vs. conventional processes

H_2 from Nuclear

New York

Demonstrates a MW electrolyzer with a nuclear plant (collaboration with Nuclear Office)

Workforce Development

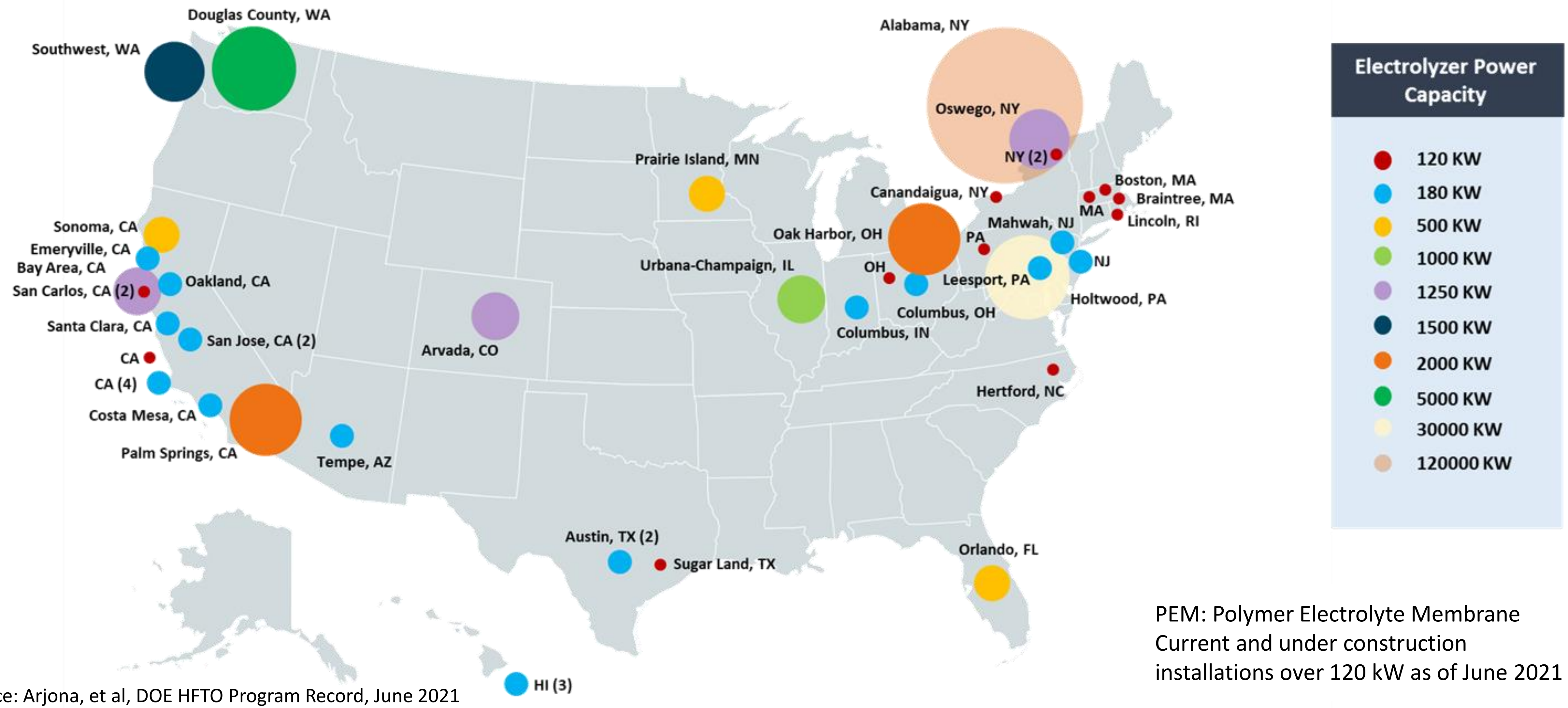


Multi-state

A Training, education and recruiting program to build skills needed in the H_2 industry

Snapshot of PEM Electrolyzer Locations and Capacity

Operational and Under Construction: 172 MW Capacity



PEM: Polymer Electrolyte Membrane
Current and under construction installations over 120 kW as of June 2021

Source: Arjona, et al, DOE HFTO Program Record, June 2021

Financing to Enable Deployment at Scale

$40 Billion in Available Debt Capital

LPO offers project financing across energy sectors through three distinct loan programs.

Includes Clean Hydrogen

Program	Sector
TITLE 17 Innovative Energy Loan Guarantees	**Advanced Fossil Energy** $8.5 Billion Available
	Advanced Nuclear Energy $10.9 Billion Available
	Renewable Energy & Efficient Energy Up to $4.5 Billion Available
ATVM Direct Loans	**Advanced Technology Vehicle Manufacturing** $17.7 Billion Available
TELGP Partial Loan Guarantees	**Tribal Energy Projects** Up to $2 Billion Available

Jigar Shah joins DOE as LPO Director

For more information: lpo@hq.doe.gov or Monique.Fridell@hq.doe.gov

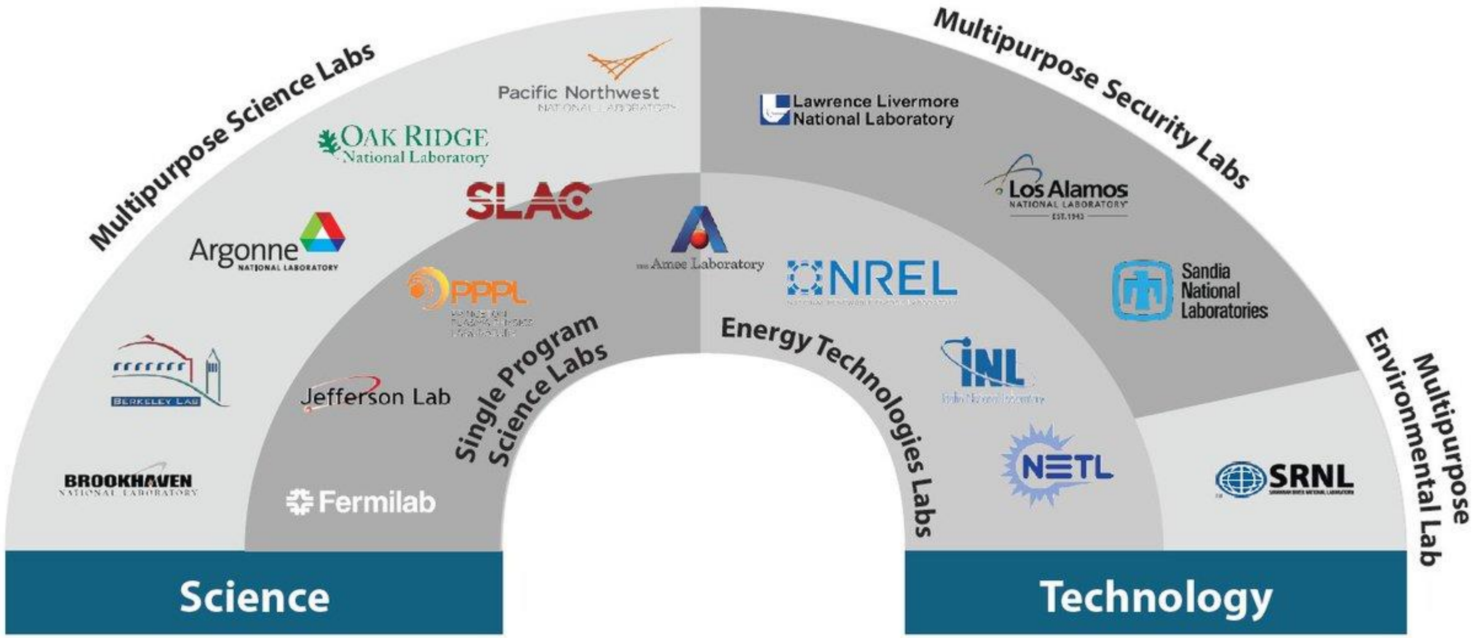
Enabling Activities

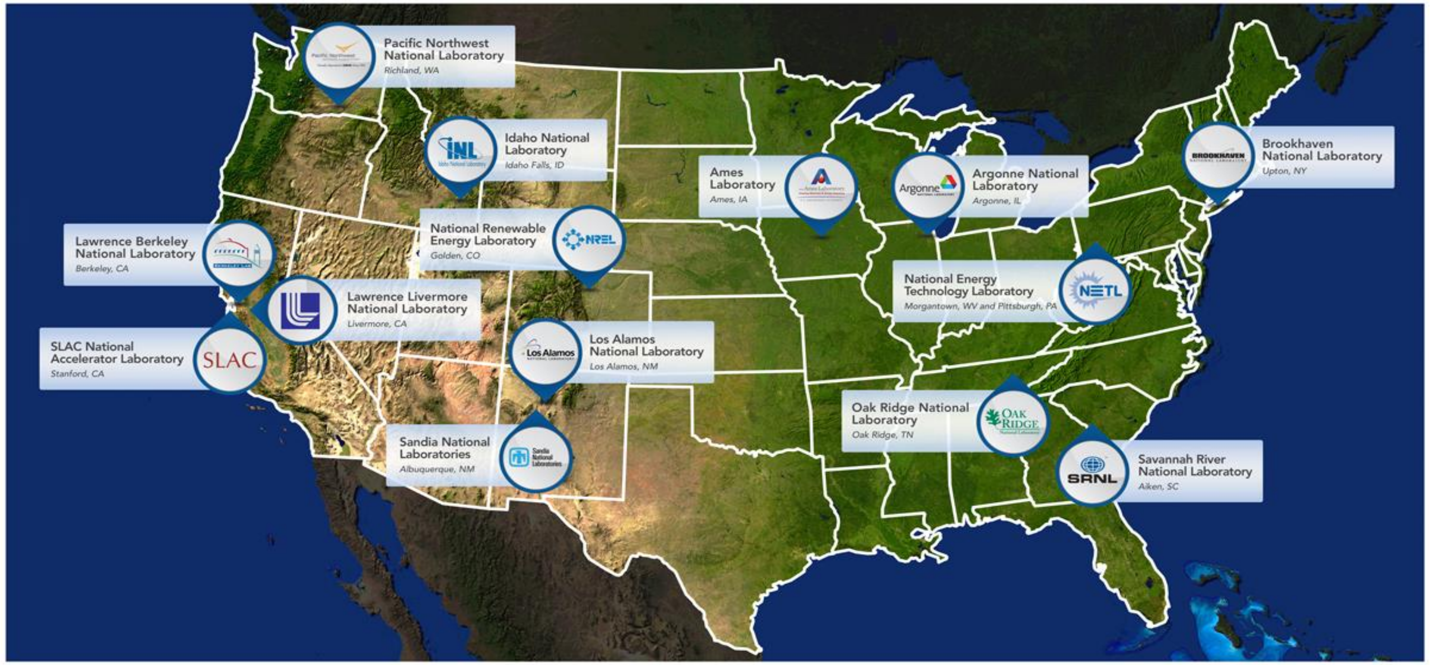
DOE National Laboratories

HFTO has activities at 14 National Laboratories across the portfolio

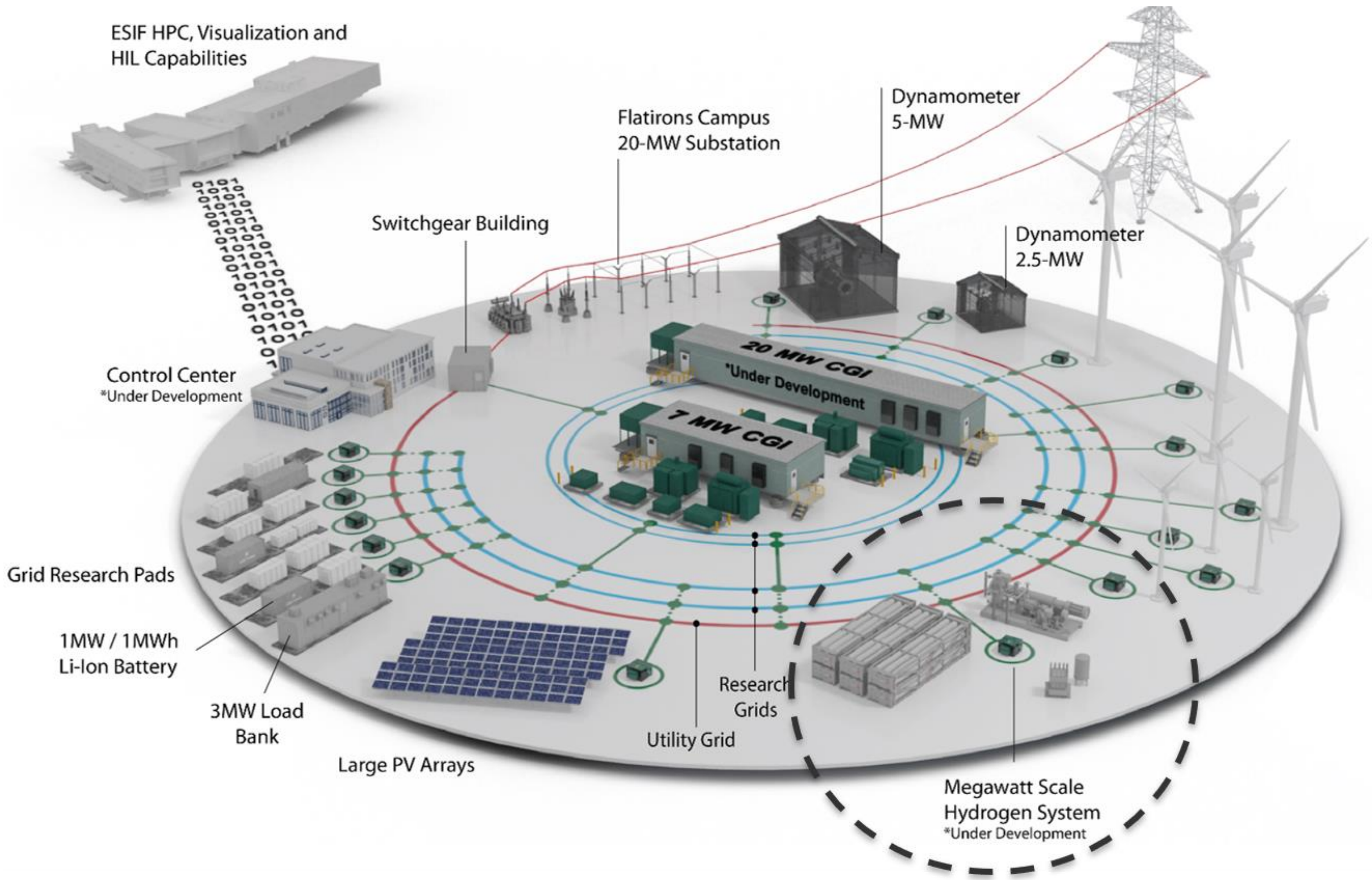
DOE National Laboratories across energy, science, and security:

- Support RD&D
- Offer User Facilities and science resources
- Help to de-risk technology adoption, accelerating progress.



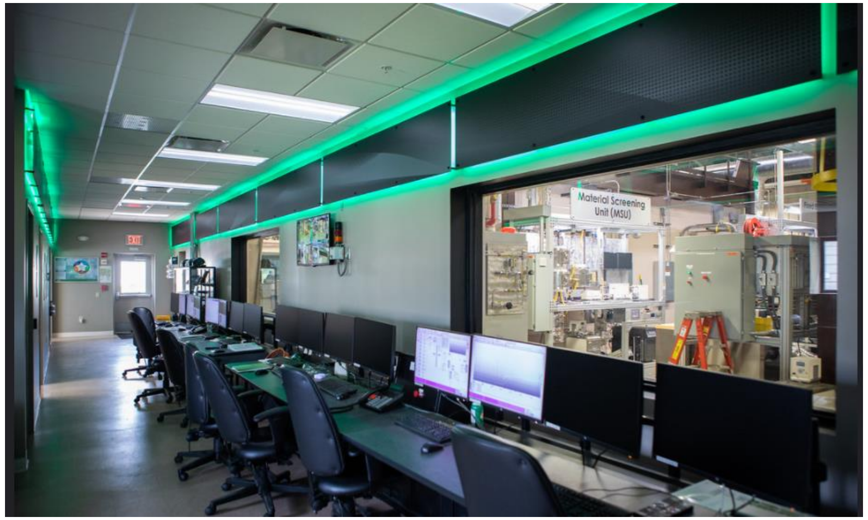


Enablers: Platforms for Integration, Validation, and De-risking Deployments



ARIES: Advanced Research on Integrated Energy Systems expansion (NREL) and collaboration with other labs

High Temperature Electrolysis Facility (INL)



REACT: Reaction chemistry facility includes microwave reaction methods for hydrogen production (NETL)

Hot off the Press: CRADA Call Released Today at AMR – June 7, 2021

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 govt, universities, and more

Topics

1) Integrated Hydrogen Energy System Testing & Validation
2) Applied Risk Assessment and Modeling for H2@Scale Applications
3) Next-Generation Sensor Technologies

Proposals due July 19, 2021

CRADAs are Cooperative Research And Development Agreements

*Pending Appropriations

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

HyBlend and H-Mat Consortia – Opportunities Available

To assess and enhance compatibility of key materials with hydrogen, and to accelerate the use of hydrogen in multiple applications (including in natural gas blending)

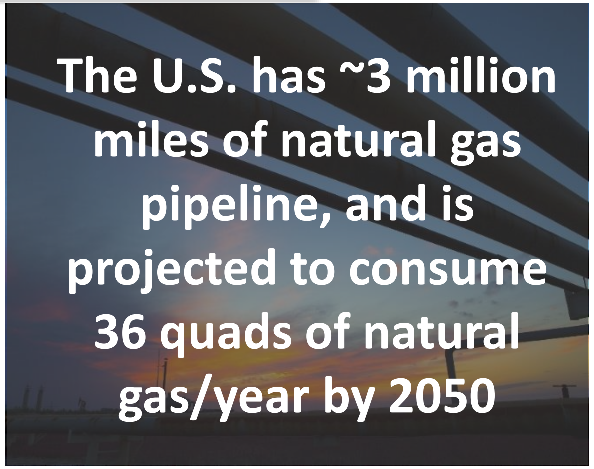
H-Mat Hydrogen Materials Compatibility Consortium SM

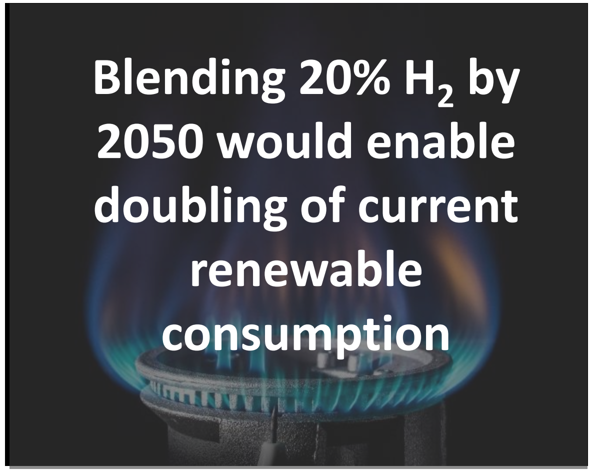
National lab consortium to assess and improve performance and reliability of materials in hydrogen, reduce costs, and inform codes & standards.

HyBlend U.S. DEPARTMENT OF ENERGY

Pipeline materials compatibility R&D, technoeconomic analysis, and life cycle analysis to assess the feasibility of hydrogen blending in the US natural gas pipeline infrastructure.

Over 40 partners





Labs | Sandia National Laboratories, PNNL, SRNL, Oak Ridge National Laboratory, Argonne National Laboratory

Labs | NREL National Renewable Energy Laboratory, Sandia National Laboratories, PNNL, Oak Ridge National Laboratory, Argonne National Laboratory, NETL

Enabler: Center for Hydrogen Safety

Global Center for Hydrogen Safety established to share best practices, training resources and information

High Priority:
Lessons learned and best practices on safety

Encourage membership (industry, govt, universities, labs) to join CHS

CENTER FOR Hydrogen SAFETY 水素安全センター

Connecting a Global Community

www.aiche.org/CHS

IPHE

Hydrogen Council

AIChE

Pacific Northwest NATIONAL LABORATORY

hySafe

Over 60 partners: government, industry, universities and more

Access to >110 countries, 60,000 members

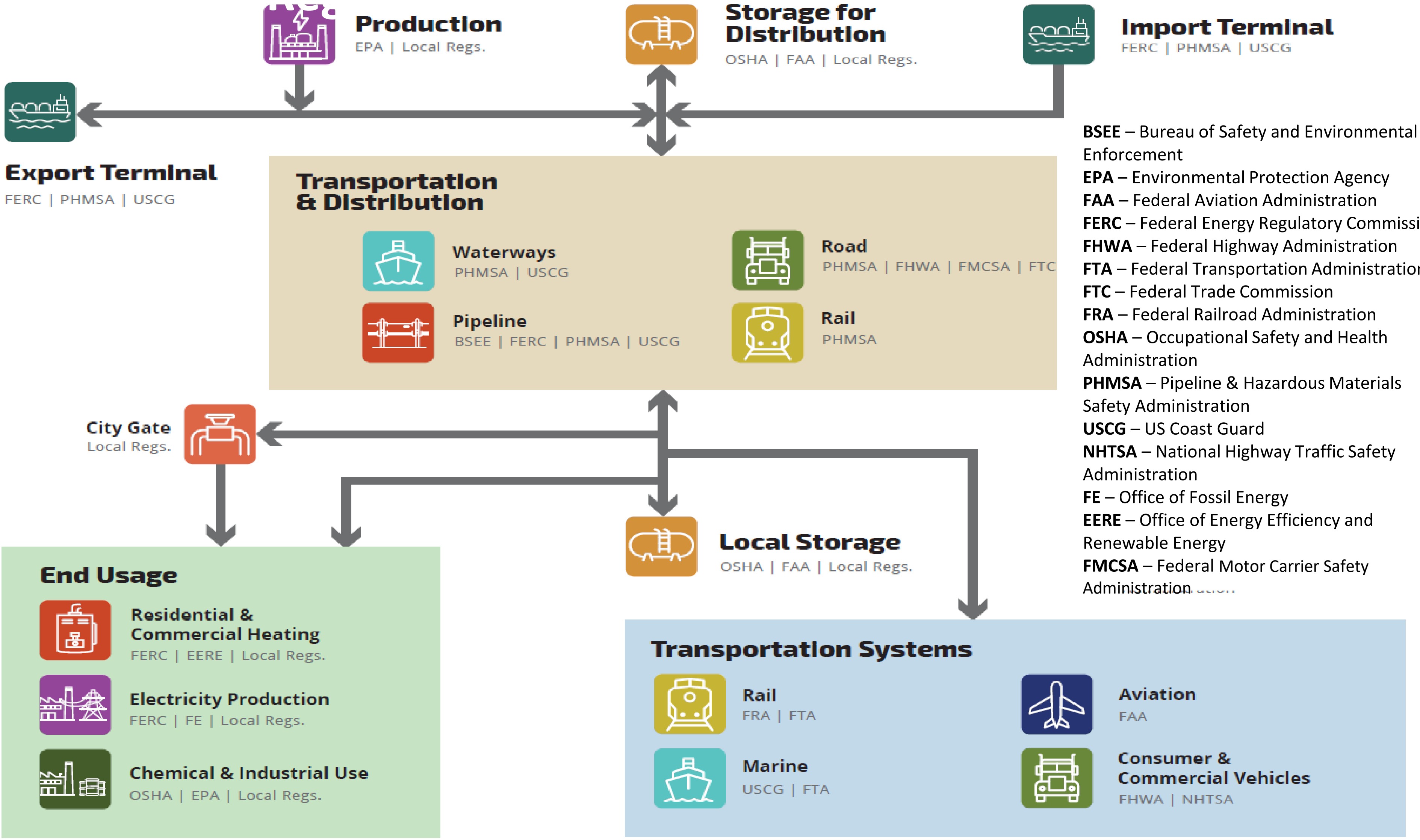
CENTER FOR Hydrogen SAFETY

Connecting a Global Community

HYDROGEN Safety Panel

HYDROGEN Emergency Response Training Resources

Enabler: Developed Federal Regulatory Map & Identified Gaps



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

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**

Final Report Available:
energy.sandia.gov/wp-content/uploads/2021/03/H2-Regulatory-Map-Report_SAND2021-2955.pdf

Interagency Working Group on Hydrogen and Fuel Cell Technologies

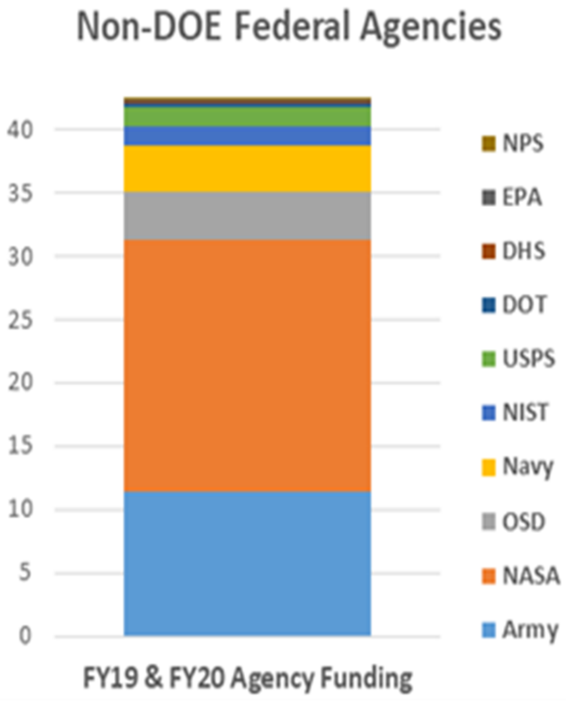
Go to Interagency Session of AMR on Thursday to Learn More!

Partners	Activity
DOE, NIST	Update of the national standards for H2 metering (Handbook 44)
DOE, Navy	Unmanned Underwater Vehicles (UUVs) at NUWC
DOE, USPS	FC Lift Truck Deployment and Hydrogen Infrastructure
DOE, Air Force, NPS	Fuel Cell Vehicle and H2 Demonstration in Hawaii
DOE, Navy	Hydrogen as Grid Frequency Management Tool

Example: H2Rescue Truck
DOE, DOD, FEMA

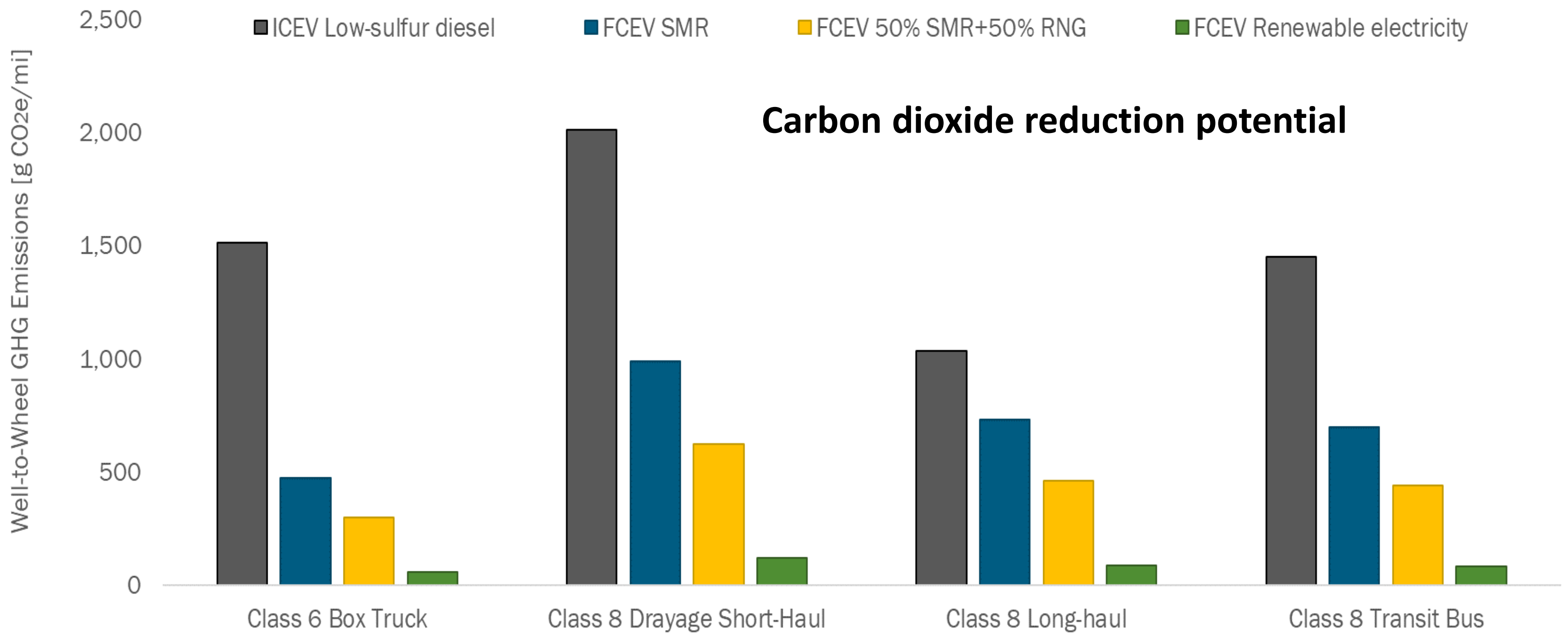
POC: Pete Devlin, HFTO, EERE

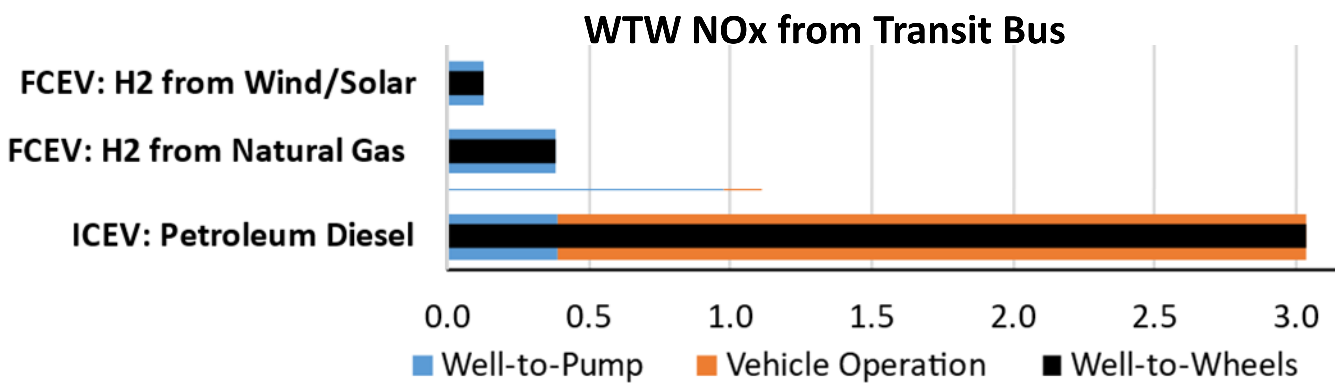
~$43M in Hydrogen and Fuel Cells Funding



IWG members share RD&D information on their programs and collaborate through joint projects

Enabler: Analysis Guides Portfolio, Decision Making, and Impact





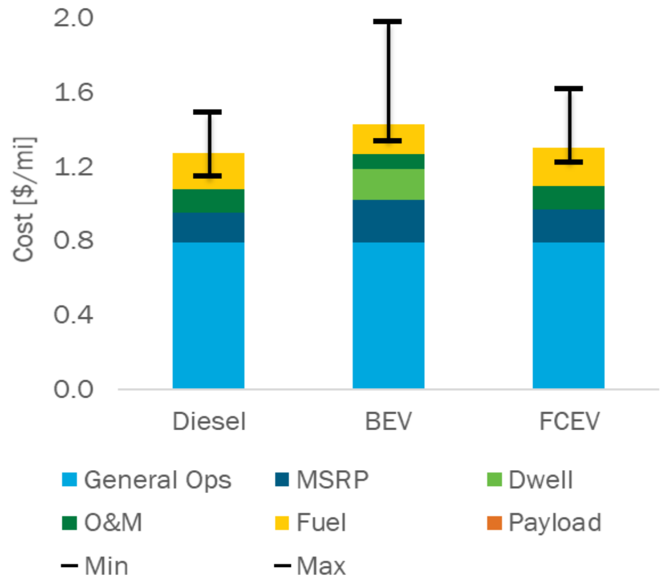
Source: Elgowainy, et. al. (ANL), 2021

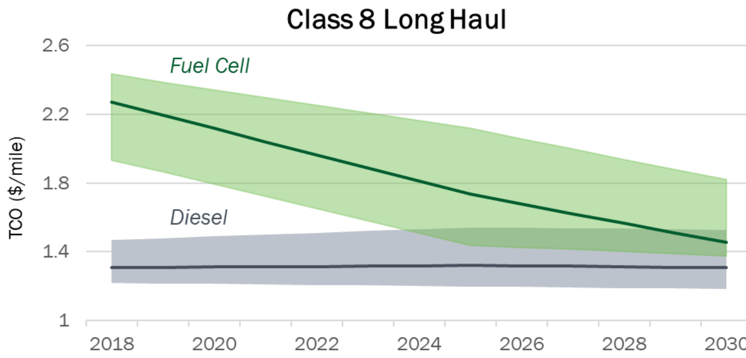
Preliminary analysis

TCO Analysis

Class 8 (500-mile)

- Multi-shift operations
- 150,000 mi/yr
- 6.7 years life

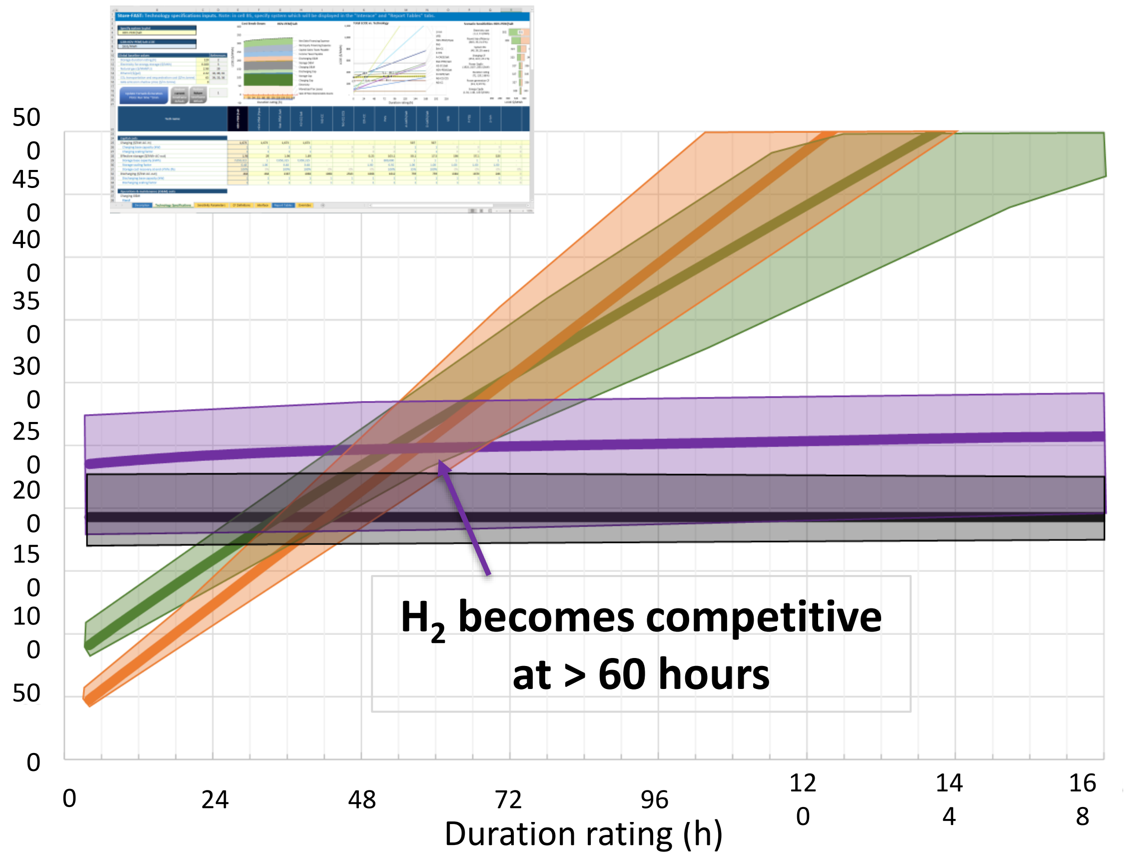




Source: Hunter, et al, NREL, 2021

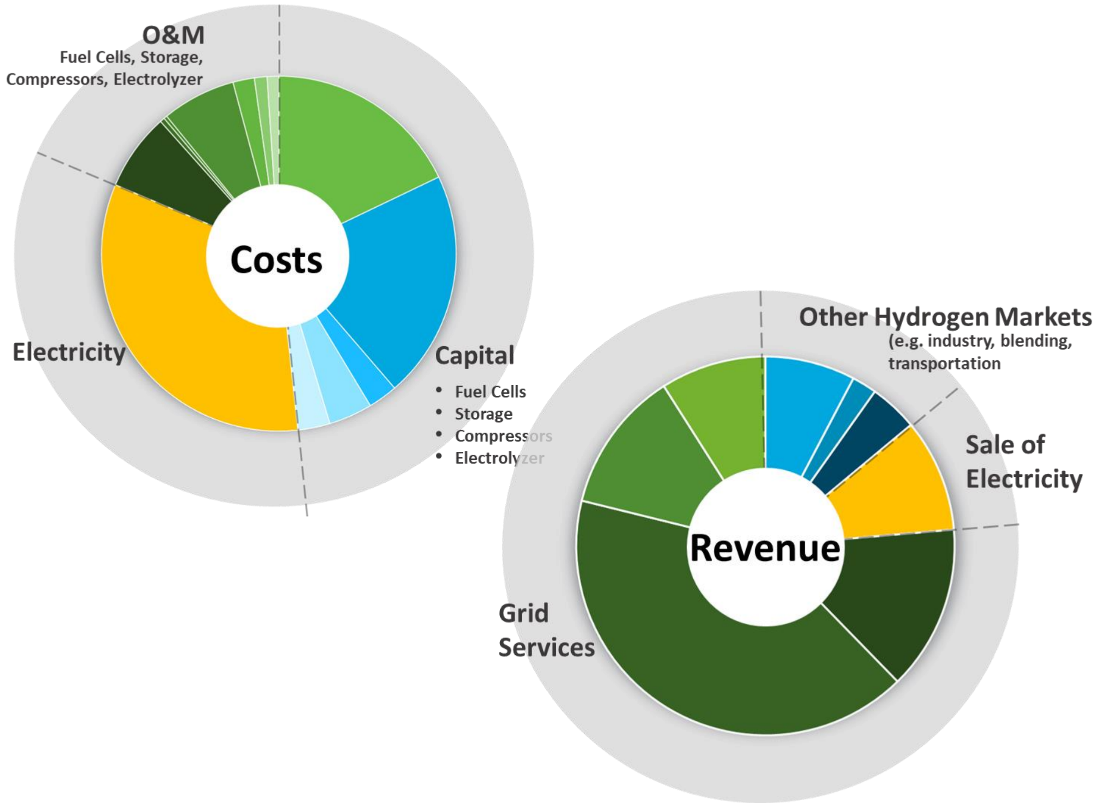
New Tools Developed: Long Duration Energy Storage & Value Proposition Tool

Newly released StoreFAST model assesses cost of long duration energy storage



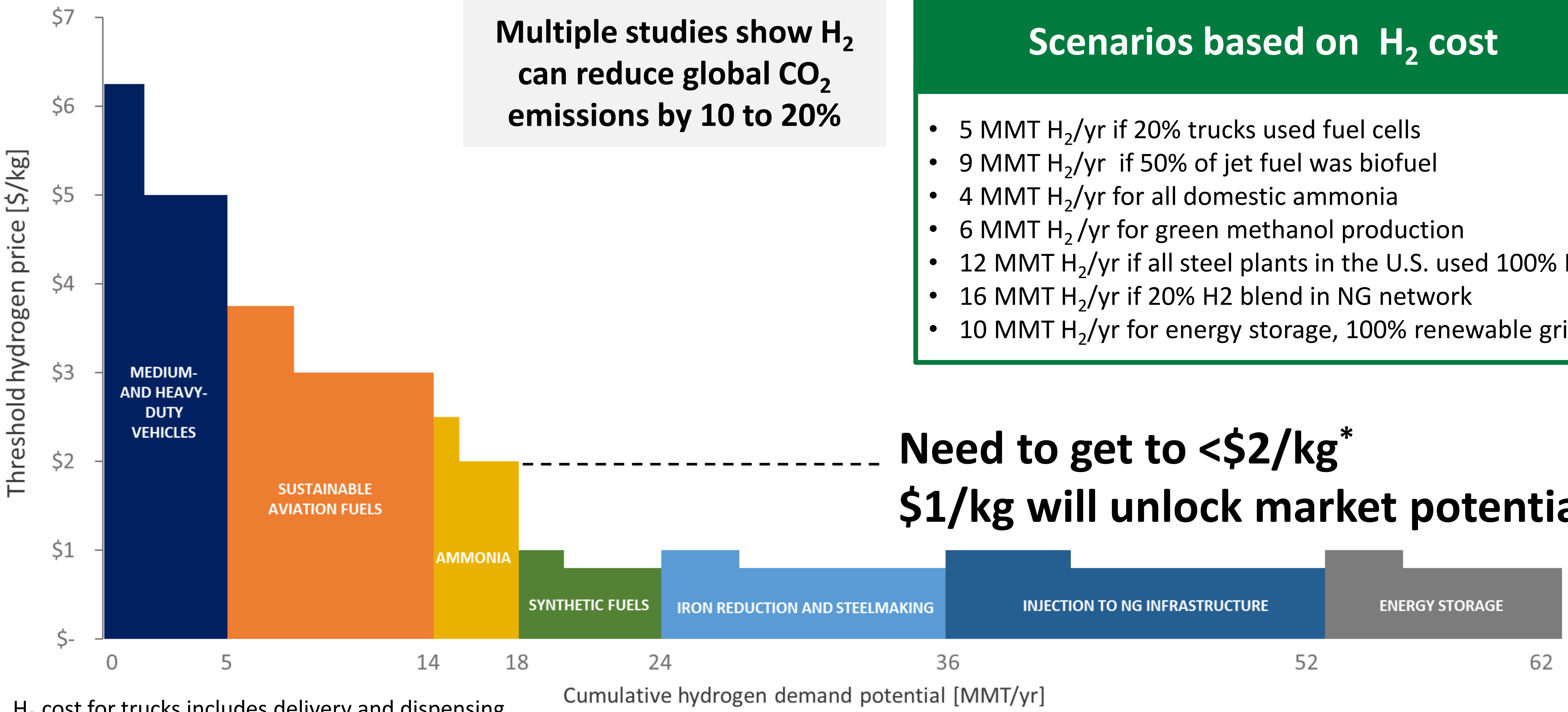
Available at: https://www.nrel.gov/storage/storefast.html (NREL)

New tool to assess cost and revenue potential of grid-integrated hydrogen energy storage systems



Co-funded by HFTO and OE, now in beta testing at: https://eset.pnnl.gov (PNNL)

Analysis Determines Market Potential Scenarios



Multiple studies show H_2 can reduce global CO_2 emissions by 10 to 20%

Scenarios based on H_2 cost

- 5 MMT H_2/yr if 20% trucks used fuel cells
- 9 MMT H_2/yr if 50% of jet fuel was biofuel
- 4 MMT H_2/yr for all domestic ammonia
- 6 MMT H_2 /yr for green methanol production
- 12 MMT H_2/yr if all steel plants in the U.S. used 100% H_2
- 16 MMT H_2/yr if 20% H2 blend in NG network
- 10 MMT H_2/yr for energy storage, 100% renewable grid

Need to get to <$2/kg*
$1/kg will unlock market potential

H_2 cost for trucks includes delivery and dispensing

* H_2 could compete at $1 to $2/kg higher cost with a carbon price

Results based on preliminary analysis

Hydrogen Energy Earthshot

“Hydrogen Shot”

Launched June 7, 2021

President Biden and Energy Secretary Granholm at Climate Summit

"…I've asked the Secretary of Energy to speed the development of critical technologies to tackle the climate crisis. No single technology is the answer on its own because every sector requires innovation to meet this moment."

President Joseph R. Biden
April 23, 2021

Launch of Hydrogen Energy Earthshot
First of the Energy Earthshots
June 7, 2021
at DOE Hydrogen Program AMR

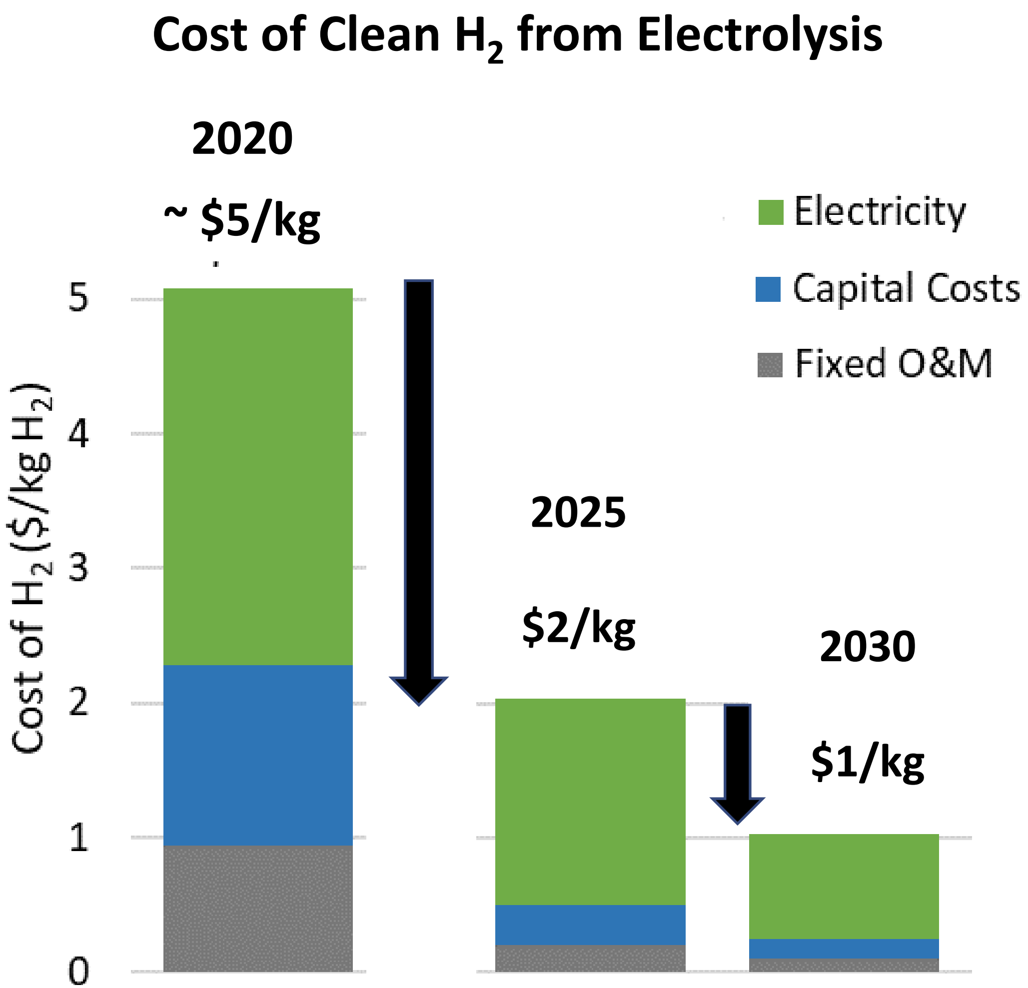
Secretary Jennifer Granholm
June 7, 2021

1 for 1 in 1

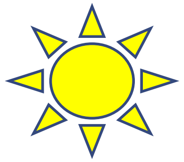
$1 — 1 kg H_2 — 1 decade

Is Hydrogen Shot Achievable? How can we get there?

ENERGY earthshots U.S. DEPARTMENT OF ENERGY | Hydrogen



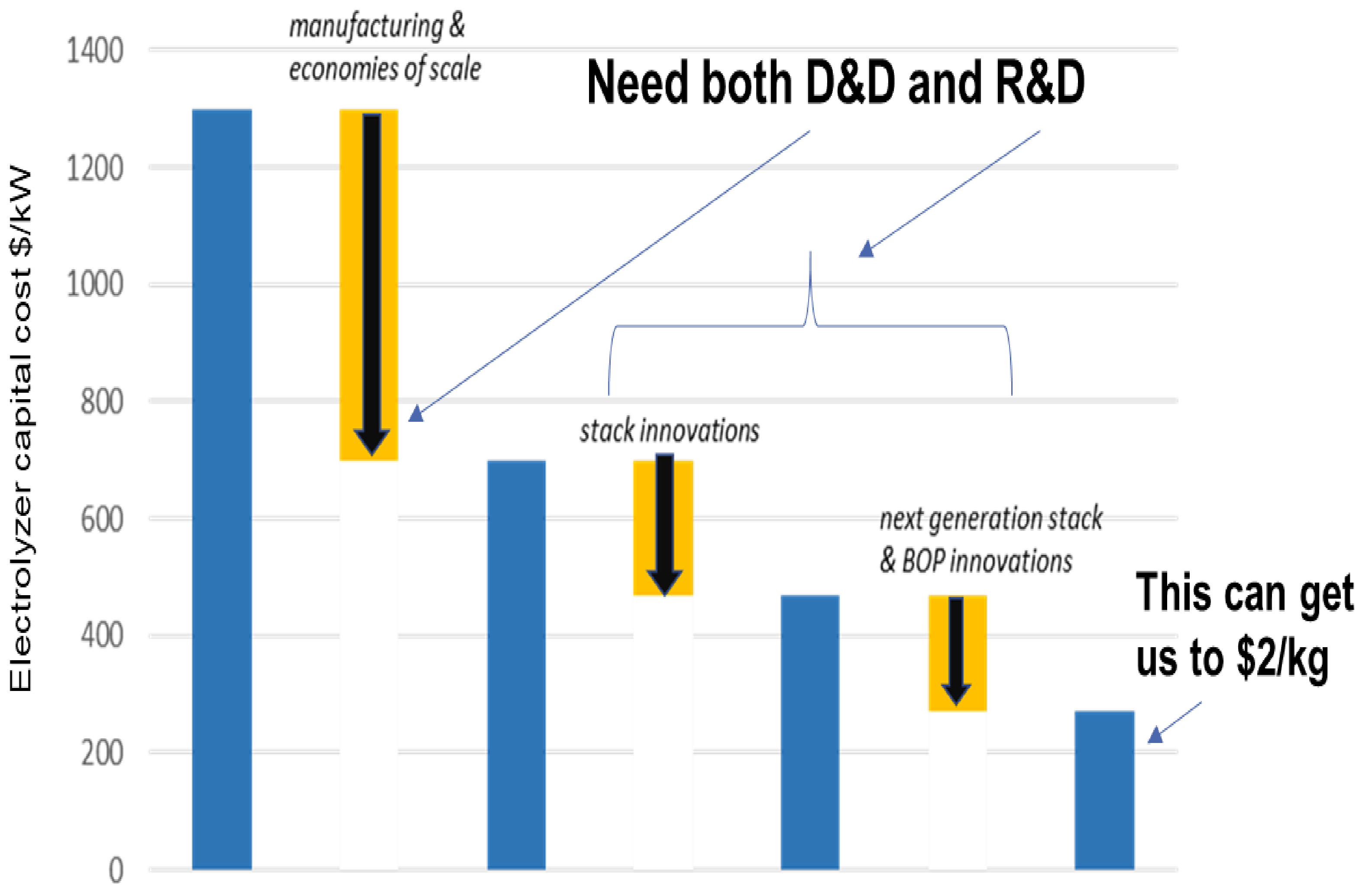
- Reduce electricity cost from >$50/MWh to
  - $30/MWh (2025)
  - $20/MWh (2030)



- Reduce capital cost >80%
- Reduce operating & maintenance cost >90%

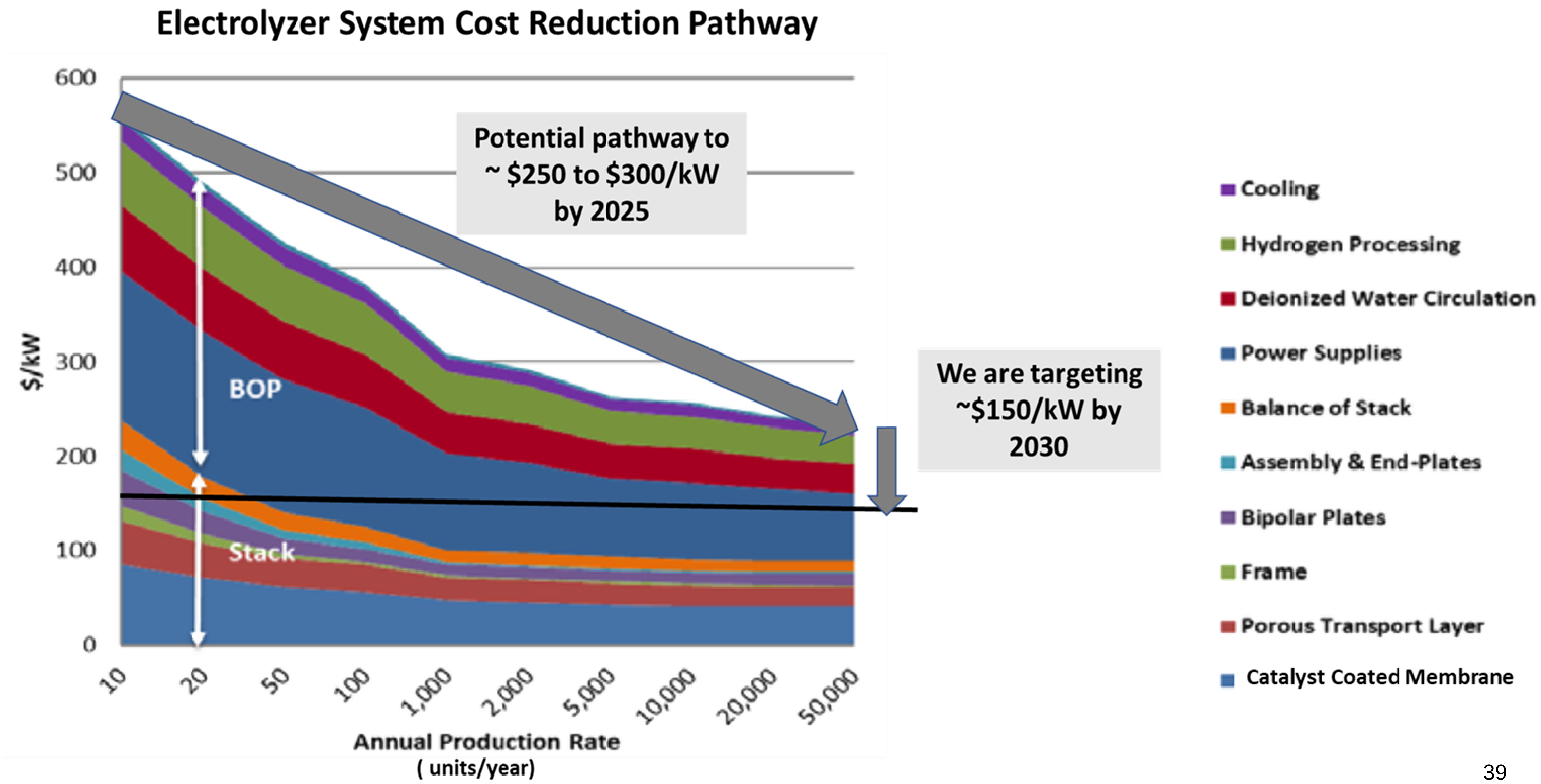
2020 Baseline: PEM low volume capital cost ~$1,500/kW, electricity at $50/MWh. Need less than $300/kW by 2025, less than $150/kW by 2030 (at scale)

Scenario to Reduce Electrolyzer Cost



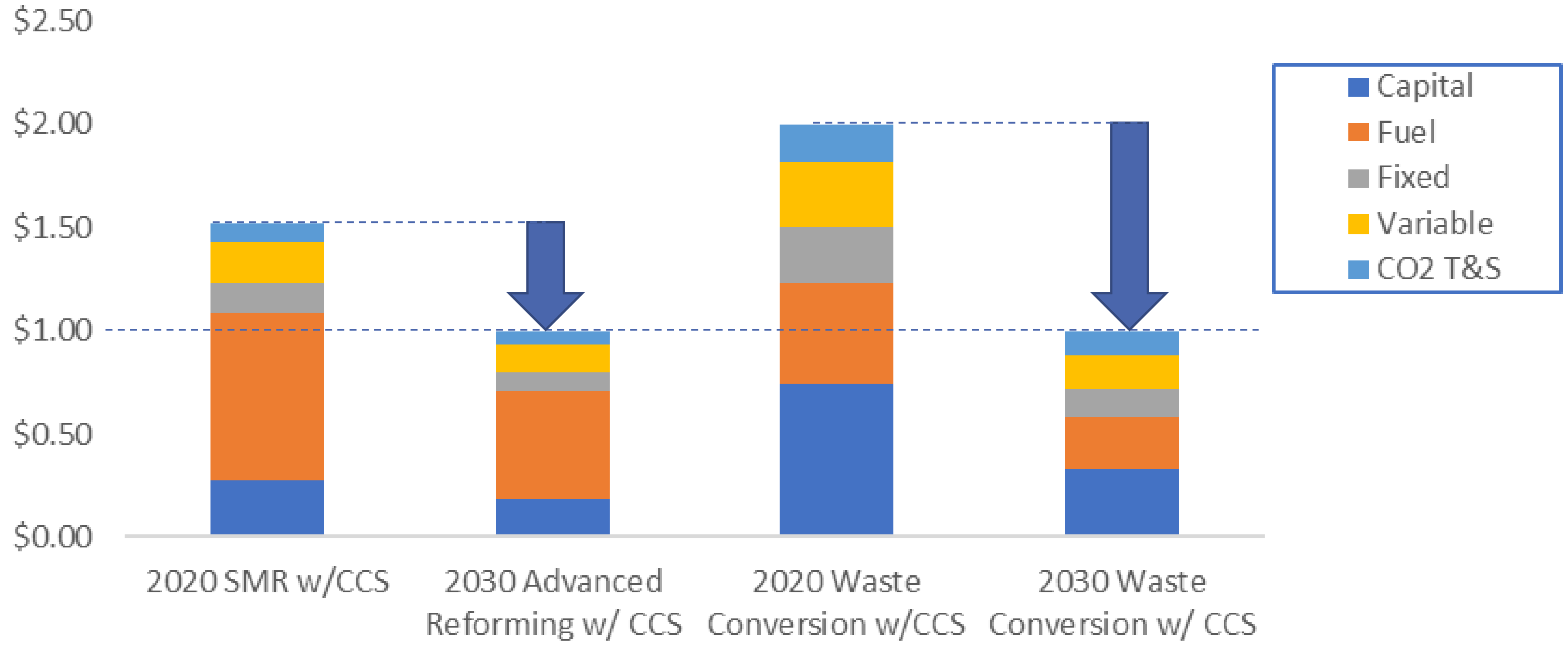
- Increase manufacturing volume (multi-GW)
- Reduce capital cost <$300/kW by 2025, ~150/kW by 2030
- Increase efficiency (73%), durability (80Khr), utilization (>50%)

Potential pathways exist for $2/kg but $1/kg is very challenging



Scenarios to use reforming and thermal conversion for Hydrogen Production

Cost reduction pathways for reforming natural/biogas and conversion of wastes to hydrogen



Advanced Technology R&D, Science and Innovation

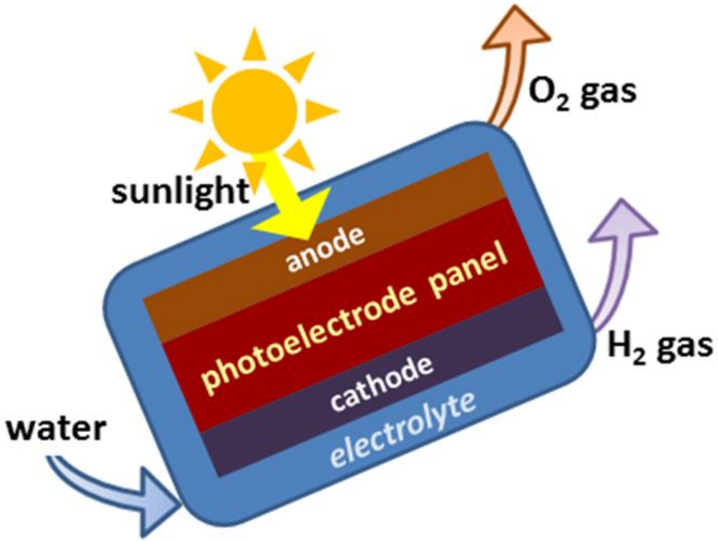
- Alternate conversion approaches for reforming and waste conversion needed for process intensification and optimization
- Improvements to air separation, catalyst, carbon capture, are key areas to reduce cost and eliminate emissions

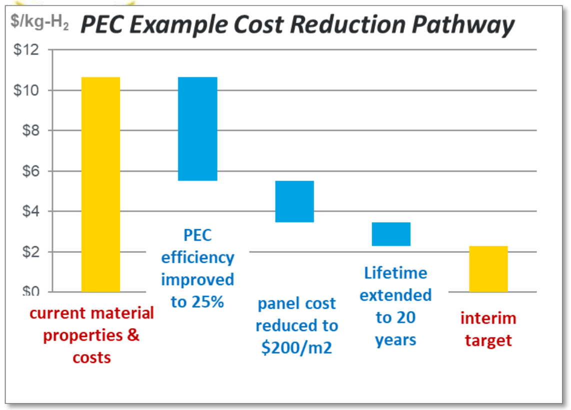
* Waste coal, plastics, biomass residuals, MSW, and biogas

Includes advanced pathways

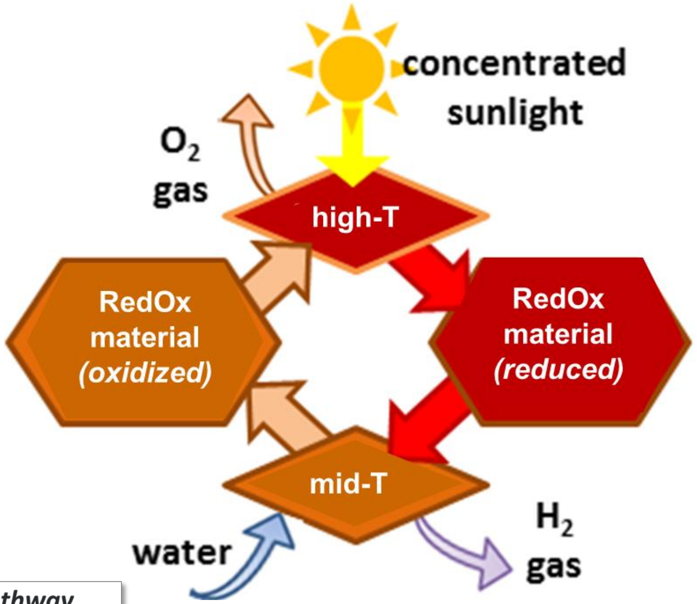
Continued R&D needed to improve efficiency, durability, and cost of these high-risk/high-reward approaches

Photoelectrochemical solar water splitting (PEC)



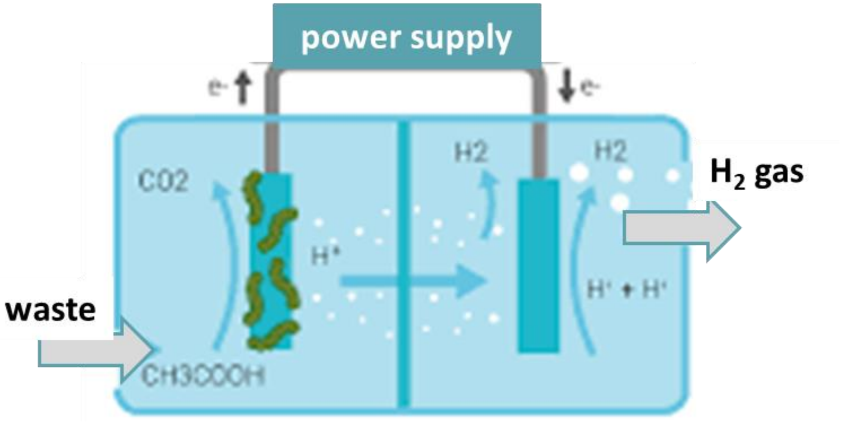


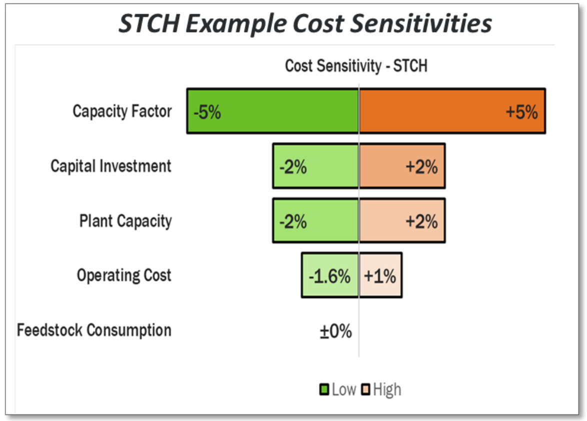
Thermochemical solar water splitting



More work required to assess system cost and pathways to goals. Planned for Hydrogen Shot Summit

Microbial electrolysis of waste streams





Request for Information (RFI) released – Due July 7, 2021

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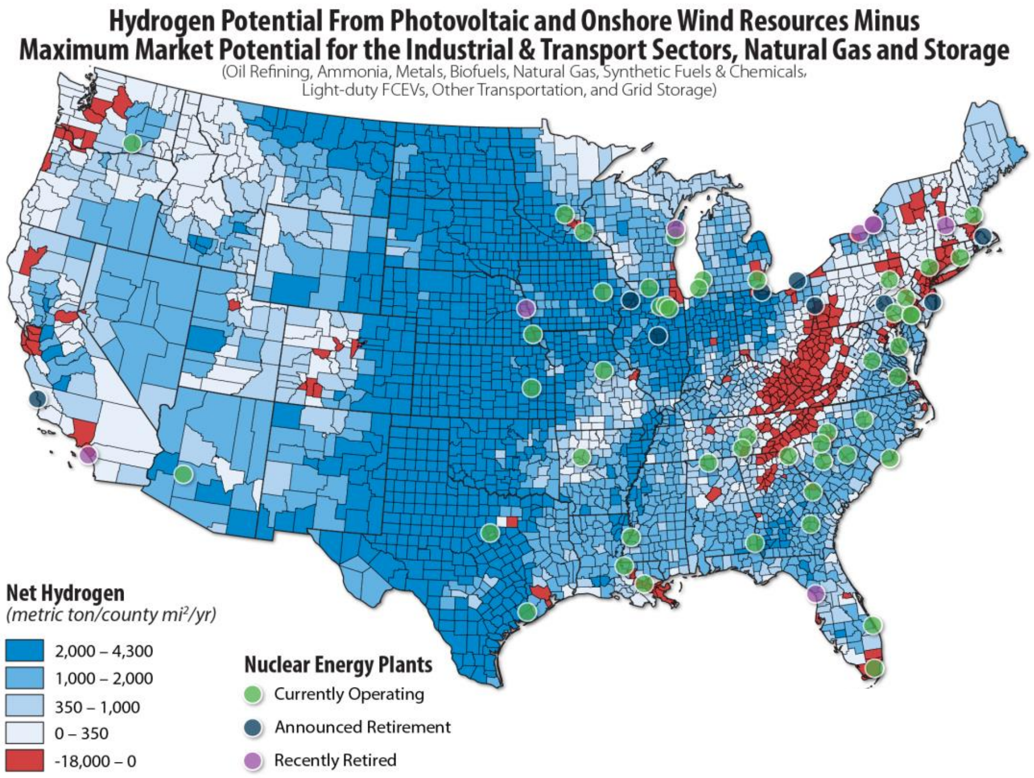
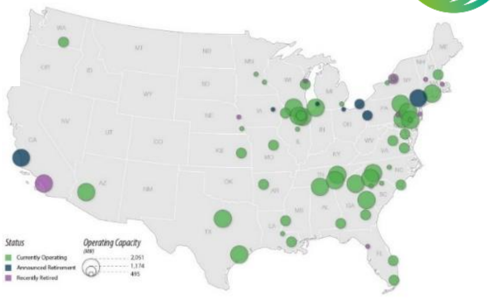
Renewables



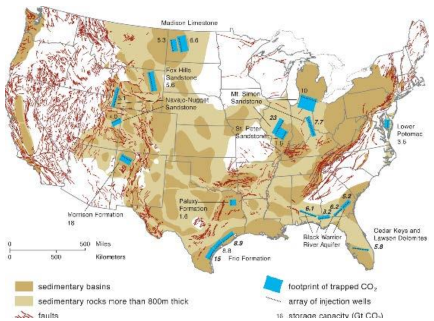
Red: Regions where projected industrial & transportation demand exceeds local supply.

Nuclear



Natural Gas (SMR)

CCS



- Production, Resources, Infrastructure
- End Users, Cost, Value Proposition
- Co-location potential
- Emissions Reduction Potential
- DEI, Jobs, EJ
- Science & Innovation Needs and Challenges

DEI: Diversity, Equity and Inclusion
EJ: Environmental Justice

Hydrogen Shot Stakeholder Engagement and Next Steps

Stakeholder Engagement Planned

Industry, National Labs, Universities, Regional Coalitions, Labor Groups, Associations, Supply Chains, Federal and State Agencies, SBIRs/STTRs, Technology Commercialization Fund, Investors, International, Codes & Standards, Workforce Development and EJ Communities, and more

Timeline

- Announce Hydrogen Shot and RFI – June 7
- RFI Responses Due – July 7
- Office of Science Round Table- August
- Hydrogen Shot Summit – Fall
- Regional Analysis Preliminary Results – Fall
- Follow on Event – Oct 8: Hydrogen and Fuel Cell Day
- Stay tuned for more details

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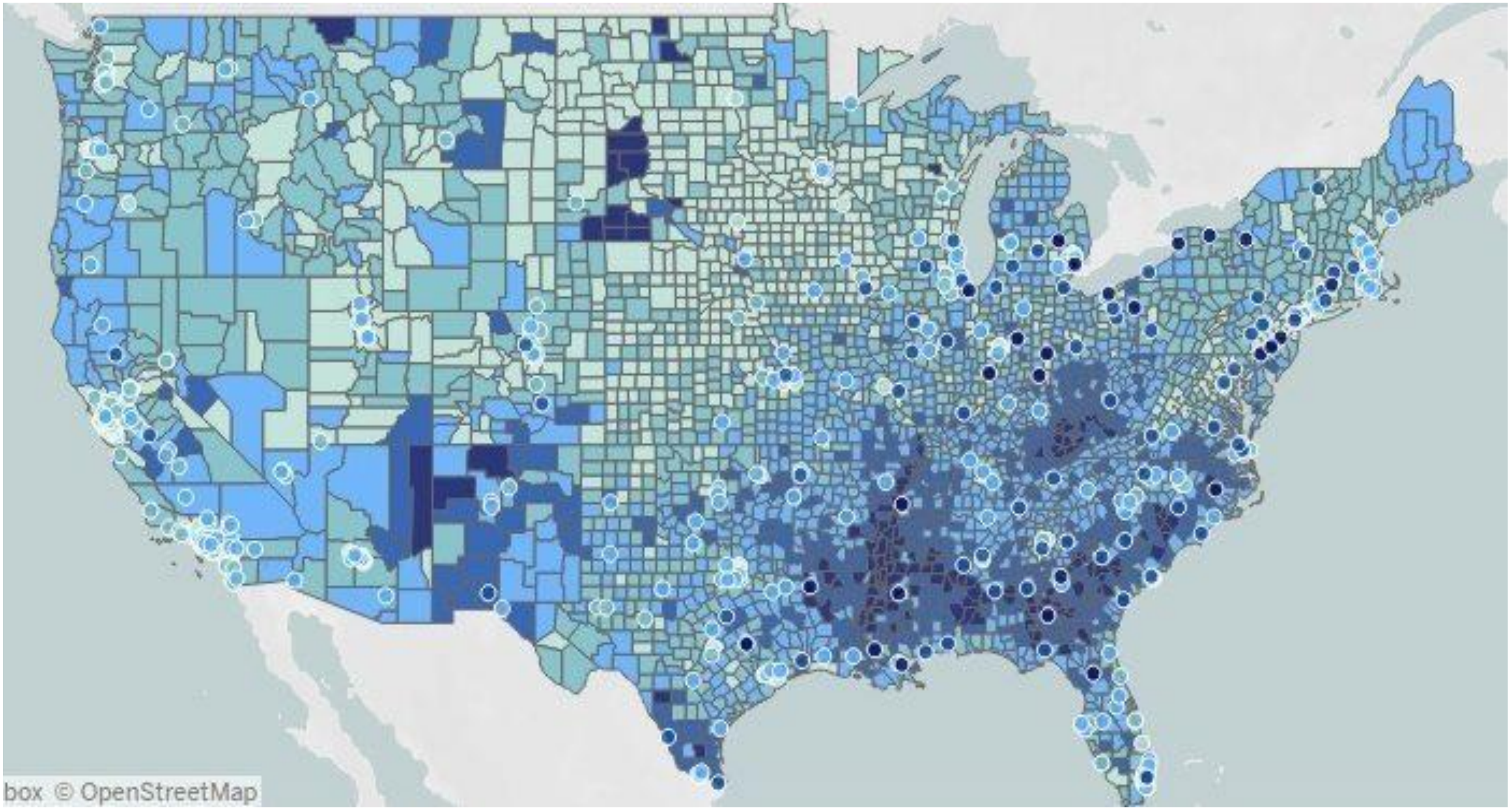
hydrogen.energy.gov


Collaboration
Diversity, Equity, Inclusion

We Aim to Demonstrate Benefits in Underserved Communities



The map references communities identified on the Index of Deep Disadvantage

FOAs, Lab Calls, CRADA Calls will encourage broader engagement, demonstrating benefits, including DEI (minorities, gender equity, etc.)

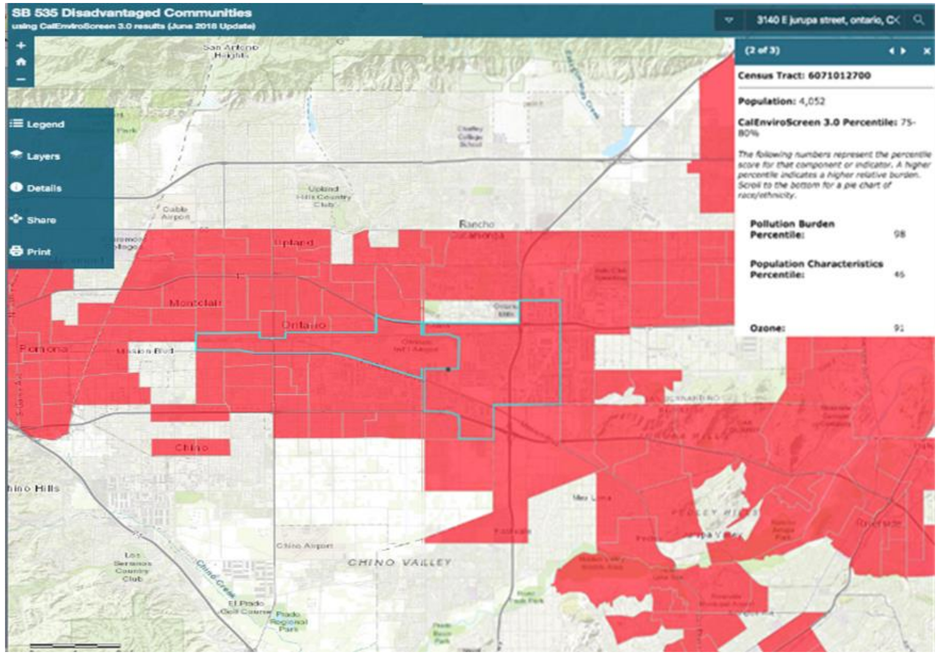
New index ranks America's 100 most disadvantaged communities | University of Michigan News (umich.edu)

FOA: Funding Opportunity Announcement
CRADA: Cooperative Research and Development Agreement
DEI: Diversity, Equity and Inclusion

Highlighting Project in Disadvantaged Community: CTE and UPS

HFTO project with CTE for 15 UPS Fuel Cell Delivery Vans

Co-funded by CA state agencies and industry



Ontario, CA, Census Tracts: 6071012700 and 6071001600
CalEnviroScreen 3.0 Percentile scores: 75-80% and 95-100%

Goal: Demonstrate hybrid electric delivery vans with fuel cell range extenders (up to 125-mile range)

Key Accomplishments:

- 5 trucks built, undergoing testing, 10 more in assembly
- Trucks to operate in disadvantaged community in CA

Project impact per year: savings of

- 285 metric tons of CO_{2e}
- 280,000 grams of criteria pollutants
- 56,000 gallons of diesel

Could enable 8.8 million gallons savings per year if 1% of California's 253,000 Class 3-8 urban work trucks adopt

Announced Today: HFTO, NNSA, LANL Collaboration to Engage with HBCU Students

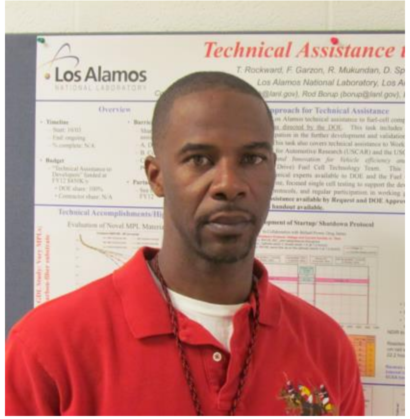
Leveraging LANL's MSIPP Program and Focusing on Building a Diverse Hydrogen and Fuel Cell Workforce Pipeline

National Nuclear Security Administration

Program will:

- **Focus on Historically Black Colleges and Universities (HBCUs)**
- **Help transition HBCU students to careers in hydrogen and fuel cells**
- **Leverage Minority Serving Institution Partnership Program (MSIPP) at LANL**

MSIPP Program and Success Stories:



LANL's Tommy Rockward leads the LANL's MSIPP

- **LANL hosted approximately 100 students**
- **~ 40 involved in LANL Fuel Cell research**

David Alexander IV

Tuskegee University

André Spears

Southern University and A&M College

Stefan Williams

Morehouse College

Workforce Development Supported by HFTO

A partnership between the U. of Tennessee and ORNL to Develop a National Model for Workforce Development in Energy Related Disciplines

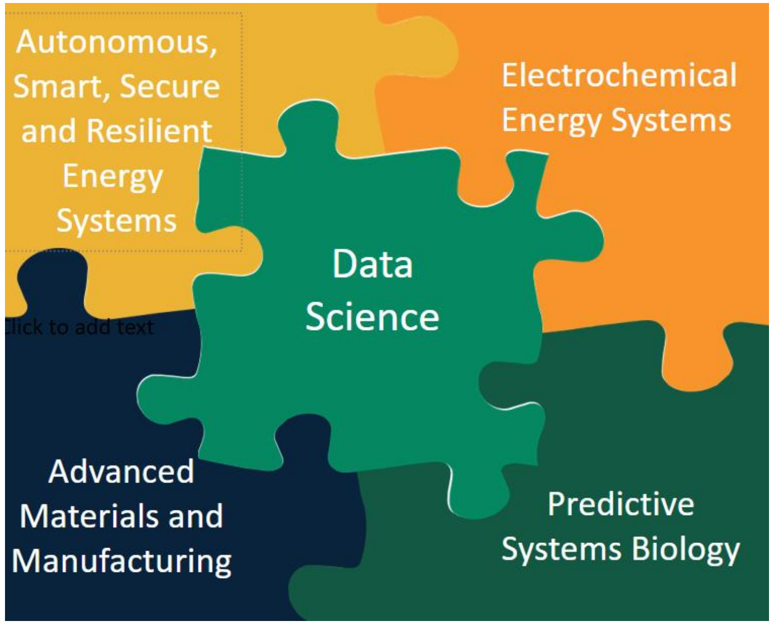
As art of a $20M EERE award, with $2.6M support from HFTO, the project will:

- Develop a **national model for research and workforce development** from the technician to graduate level
- Expand and **enhance Interdisciplinary** R&D for workforce development

Call for students or postdocs to apply for Fellowship* in partnership with UT-ORNL Workforce Development Program, encouraging DEI

Contact: ORI@tennessee.edu

*Rose Fellowship established 2019 in honor of Bob Rose, founder of US Fuel Cell Council



THE UNIVERSITY OF TENNESSEE
Oak Ridge Innovation Institute

International Early Career Network through IPHE

- **Established by IPHE's Education & Outreach (E&O) Working Group** to promote international H_2 and fuel cell awareness and launch a platform for the next generation of H_2 and fuel cell leaders
- **Open to students, post-docs and early career** professionals

Stephanie Azubike
Chair

Learn more: iphe.net/early-career-chapter

Membership form: https://forms.gle/gUnWyV7gU4QqoHLm7

Priya Buddhavarapu
Co-Chair

IPHE

#HydrogenNow

#FuelCellsNow

FOLLOW US

@The_IPHE

IPHE

iphe.net

IPHE

Global Collaboration

Examples of International Collaborations

- International Energy Agency
- Clean Energy Ministerial
- Hydrogen Energy Ministerial
- Mission Innovation
  - Hydrogen
  - Shipping

Engagement with Europe's FCH-JU:
- PRESLHY – liquid hydrogen R&D
- PRHYDE – protocol for heavy duty refueling

The International Partnership for Hydrogen and Fuel Cells in the Economy

Enabling the global adoption of hydrogen and fuel cells in the economy

www.iphe.net

Regulations, Codes, Standards, Safety and Education & Outreach Working Groups

RCS&S Compendium

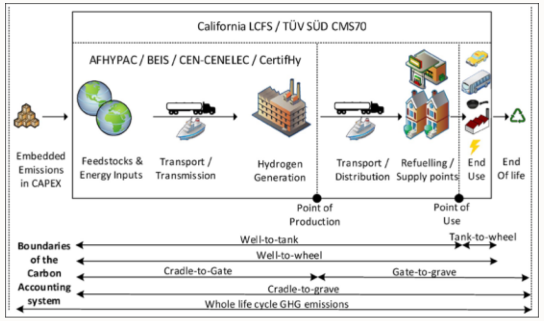
Hydrogen Infrastructure						Hydrogen for Mobility/Tr	
Hydrogen injection at transmission level	Hydrogen injection at distribution level	Methanation and injection of Methane (SNG) via methanation from hydrogen at transmission / distribution level	H2 refilling station (HRS)		Maritime Infra	Mobility infra (tunnel, bridge, underground parking...)	Heavy Duty vehicles
Legal framework: permissions and restrictions (and Ownership constraints (unbundling))	Legal framework: permissions and restrictions (and Ownership constraints (unbundling))	Legal framework: permissions and restrictions (and Ownership constraints (unbundling))	Land use plan (zone prohibition)		Off-shore refueling	Restrictions & Incentives	Type approval & Individual vehicle registration - Process
Permission to connect/ inject	Permission to connect/ inject	Permission to connect/inject	(LH2) Permitting requirements/ process	(GH2) Permitting requirements/ process	On-shore refueling		Restrictions & Incentives
			(LH2) Safety	(GH2) Safety			

- Reports, workshops, safety sharing
- Assessing gaps
- Education, student engagement, compiling country info

Task Force to facilitate international trade of H_2

H_2 Production Analysis (H2PA)

- Developing a common analytical framework to determine emissions footprint for H_2
- Harmonizing approach across countries and pathways

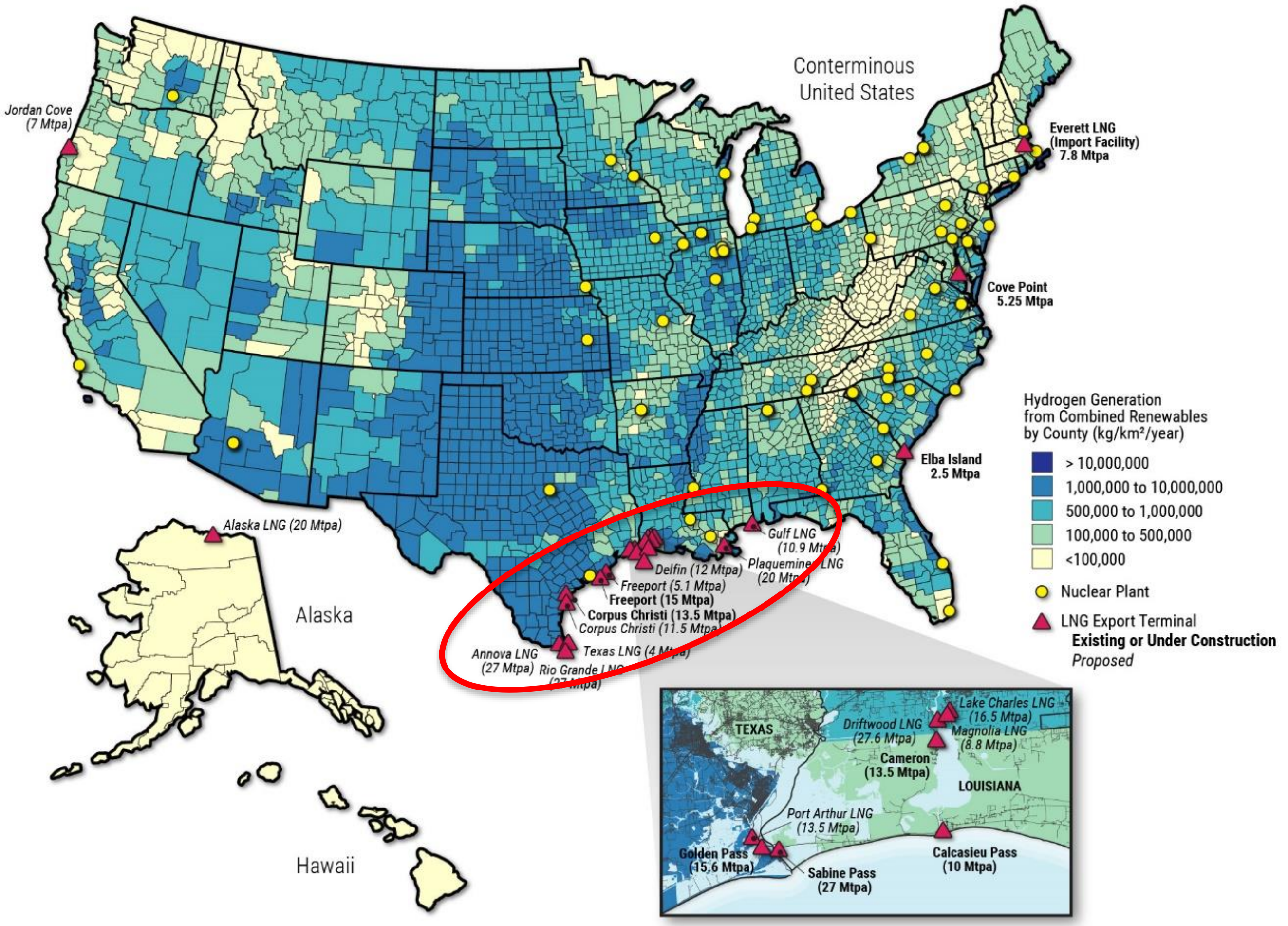


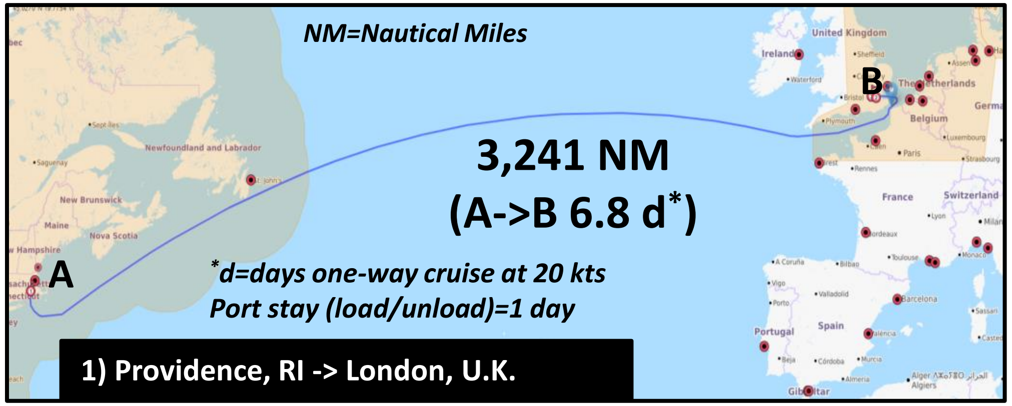
(Source: Abad et al., Energy policy 138 (2020) 111300)

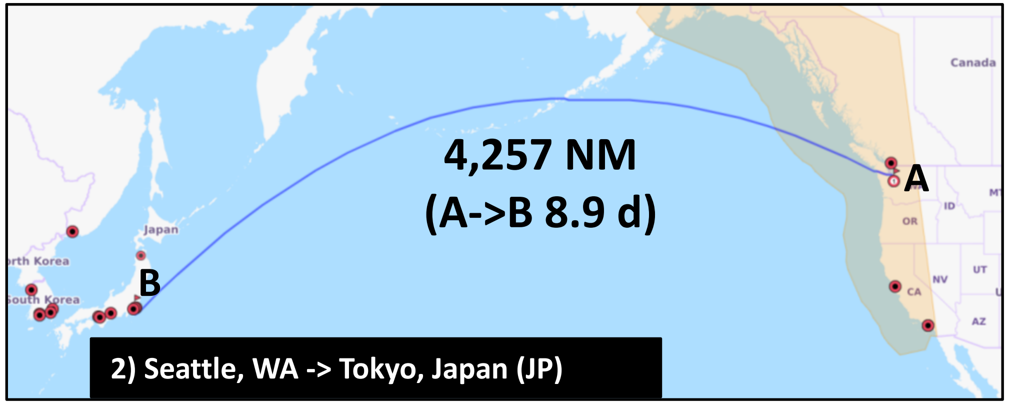
Potential for U.S. Hydrogen Exports: Analysis Underway

Argonne NATIONAL LABORATORY

NREL NATIONAL RENEWABLE ENERGY LABORATORY







Preliminary

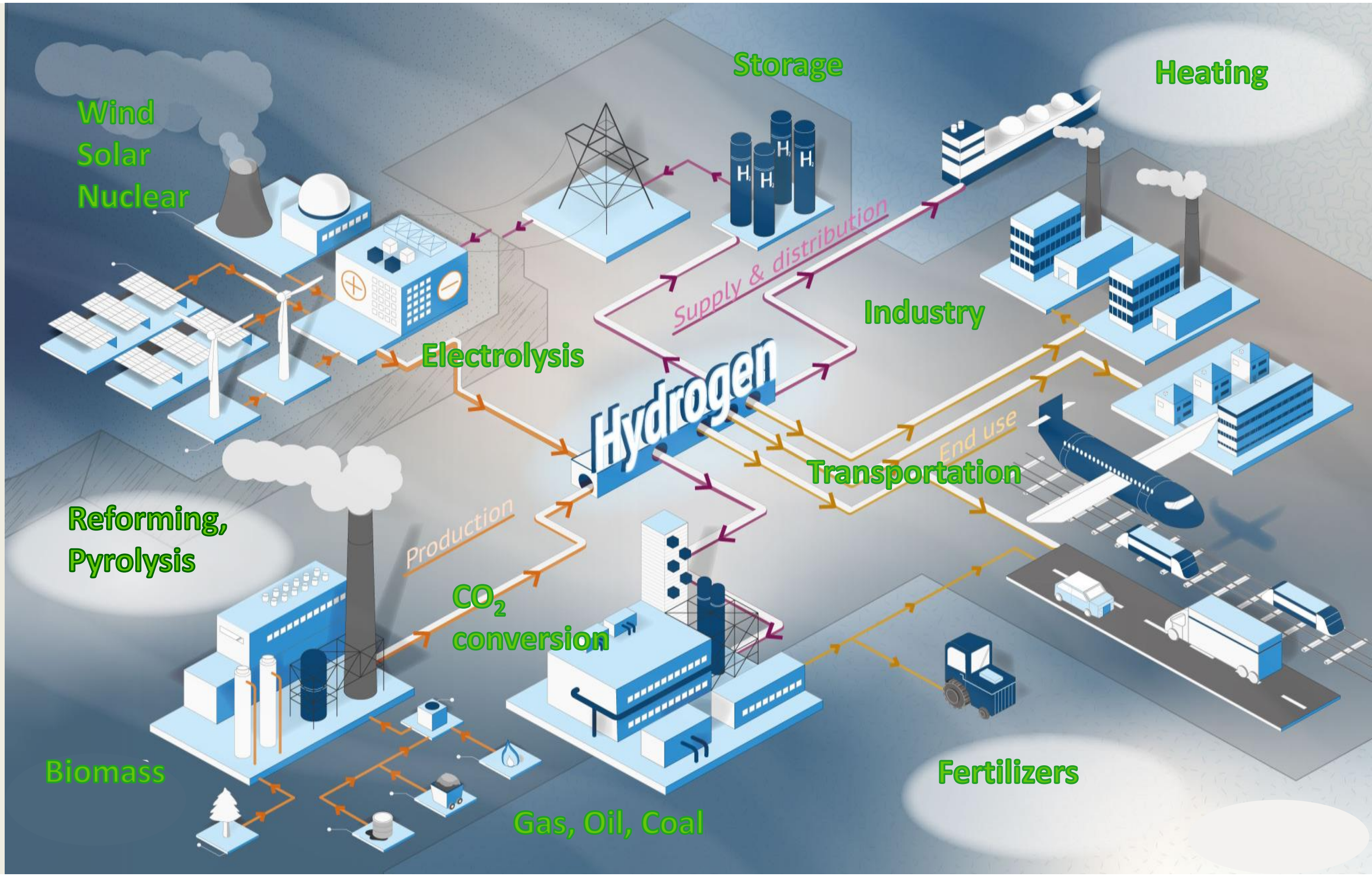
For more information, please see SA177 and ST001 presentations

US LNG Export terminals are concentrated in the Gulf Coast near substantial resources for renewable hydrogen supply

Preliminary estimates of the cost of hydrogen export via liquid tanker from the U.S. to Europe or Japan: ~$5-$6/kg

Summary: Strategy and Next Steps

1) **Accelerate R&D to reduce cost**
2) **De-risk demonstration and enable deployments**
3) **Strategic scale up**
   - **Clusters**: co-locate supply and demand (e.g., at ports) and enable infrastructure
   - **RFI feedback** and regional analysis will guide activities



Identify jobs, EJ, and workforce development opportunities (e.g., transition from fossil fuel to H_2, ports, etc.)

“No one can whistle a symphony. It takes a whole orchestra to play it.”

- H. Luccock

HFTO's Collaboration Network Acknowledgements

Focus on fostering technical excellence, accelerating progress, and environmental justice

Cross-Office work with Multiple DOE Offices

EERE: AMO, BETO, BTO, SA, SETO, WETO, WPTO, VTO; ARPA-E, FE, NE, SC

DOE Cross-Cutting Initiatives

Adv. Manufacturing, Adv. Transportation, AI/ML, Alt. Fuel, Cybersecurity, Critical Minerals, Decarbonization, ESGC, GMI, HPC, Space

DOE Hydrogen and Fuel Cell Technologies Office (HFTO)

Cross-Agency Collaborations & Coordination

Including DOD, DOT, DHS, EPA, NASA, NSF, NIST among others

International Collaborations

IEA, IPHE, CEM, HEM, MI, WEF, WEC, IRENA, FCH-JU, Bilaterals, etc.

14 National Labs

190 Companies

109 Universities

Regional and National Associations FCHEA, CaFCP, & more

Labor groups and EJ Community

Public-private partnerships 21 CTP, USDRIVE, etc.

The Team - Hydrogen and Fuel Cell Technologies Office

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Grigorii Soloveichik (ARPA-E)

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Fuel Cell Technologies Program Manager
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Zeric Hulvey
Vacancy

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Donna Ho
Greg Kleen
Dave Peterson

Systems Development & Integration
Pete Devlin
Michael Hahn
Brian Hunter
Vacancy (2)
Safety, Codes & Standards
Laura Hill

Thank You

Sunita Satyapal
Director
Sunita.Satyapal@ee.doe.gov

Save the Date

for next year's AMR
June 6 to 9, 2022
We hope in person!

INCREASE YOUR H2IQ
www.hydrogen.energy.gov

Looking for more info?
#H2IQ

www.energy.gov/fuelcells
www.hydrogen.energy.gov

Additional Information

www.energy.gov/fuelcells
www.hydrogen.energy.gov

Acknowledgements: Labs, Universities, and Industry

3M
Automated Dynamics
Advent Technologies, Inc.
Air Products and Chemicals
Army Corps of Engineers
Caterpillar, Inc.
Chemours Company FC, LLC
Center for Transportation and the Environment
Collaborative Composite Solutions Corporation
Cummins, Inc.
C-Zero, LLC
DOT National Highway Traffic Safety Administration
Electricore Inc.
Electric Power Research Institute, Inc.
Exelon Corporation
FedEx
Ford
Frontier Energy, Inc.
FuelCell Energy, Inc.
Gas Technology Institute
General Motors
Giner ELX / Plug Power
GLWN
Greenway Energy, LLC
Hexagon R & D LLC
Hornblower Yachts
Ivys, Inc.
Mercedes-Benz
National Institute of Standards and Technology
Ohio Fuel Cell Coalition
Pajarito Powder
Redox Power Systems, LLC
Proton Energy Systems Inc
Saint-Gobain Ceramics and Plastics, Inc.
Skyre, Inc.
Southwest Research Institute
Strategic Analysis Inc.
Treadstone
United Technologies Research Center
Lubrizol Corporation
Liox Power, Inc.
Hy-Performance Materials Testing, LLC
NASA
Nikola Motor Company
Ames Lab
Argonne National Lab
Brookhaven National Lab
Idaho National Lab
Lawrence Livermore National Lab
Los Alamos National Lab
National Energy Technology Lab
National Renewable Energy Lab
Oak Ridge National Lab
Pacific Northwest National Lab
Sandia National Laboratories
Savannah River National Lab
SLAC National Accelerator Lab
U.S. Naval Research Lab
Arizona State University
California Institute of Technology
Carnegie Mellon University
Clemson University
Colorado School of Mines
Drexel University
Georgia Institute of Technology
Indiana University Purdue University Indianapolis
James Madison University
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Massachusetts Institute of Technology
Missouri University of Science & Technology
Montana State University
Northeastern University
Oak Ridge Associated Universities
Oak Ridge Institute for Science & Education
Oregon State University
Penn State University
University of Michigan
Rice University
Rutgers University
The University of Alabama
The University of Toledo
University of Delaware
University of Hawaii
University of Illinois at Urbana-Champaign
University of Kansas
University of Kentucky
University of Oregon
University of South Carolina
University of Southern California
University of California, Irvine
University of California, San Diego
University of Colorado
University of Connecticut
University of Tennessee Space Institute
University of Texas at Austin
University of Virginia
Vanderbilt University
University of Tennessee-Knoxville
Washington State University
West Virginia University
Washington U (IIT)

Examples of funding recipients, not exhaustive

FY 21 DOE Funding Opportunity Announcements (FOAs) To Date

EERE	NE	FE

Hydrogen and Fuel Cell RD&D - $33.5M
SuperTruck: $5M
• Electrolysis
• H2 from biomass/waste
• Fuel cells for HD applications
• HD supply chain and refueling infrastructure
• Technoeconomic analyses
	Hydrogen Production & End Use Demonstration: $18M
	• Demonstration of nuclear-powered H2 production for end uses
	  • Chemical production
	  • Industrial manufacturing
		FE based Production, Storage, Transport, & Utilization of H2: $27.5M
		• Solid-oxide electrolysis, Advanced CO2 capture from H2 production, H2 combustion systems for gas turbines
		University Turbines Systems Research - Focus on H_2 Fuels: $6.4M
		• H2 combustion fundamentals and applications for gas turbines
		• H2-air rotating detonation engines

Office of Science	**"Open" Annual; Early Career Research Program; EPSCoR; Data Science and Critical Materials:** • Science related to H2 storage, catalysts, membranes/separations, bio-inspired, and solar H2 production.
ARPA-E	**OPEN2021 and Special Topic FOA** Next-generation stationary H2 storage technologies

HFTO Funding Opportunity Announcements (FOAs)

FY19	FY20	FY21
H2@Scale FOA	**H2@Scale New Markets FOA**	**Hydrogen and Fuel Cells R&D FOA**
Advanced H2 Storage & Infrastructure	Electrolyzer Manufacturing R&D	Fuel Cell R&D for Heavy-Duty Applications
Innovative concepts for hydrogen production & utilization	Advanced Carbon Fiber for Compressed H2 and Natural Gas Storage Tanks	Efficient and Innovative H2 Production
H2@Scale Pilot Integrated Systems	Fuel Cell R&D for Heavy-Duty Applications	High-flow Fueling Applications
	H2@Scale New Markets R&D—HySteel	Cost and Performance Analysis for Fuel Cells, H2 Production, and H2 Storage
Joint Truck FOA (VTO, HFTO, BETO)	H2@Scale New Markets Demonstrations	Joint SuperTruck FOA (VTO, HFTO)
Advanced storage for gaseous fuels	Training and Workforce Development for Emerging Hydrogen Technologies	FE based Production, Storage, Transport, & Utilization of H2 (FE w/ HFTO Collaboration
High throughput H2 fueling technologies for trucks	Nuclear to H2 Production Demonstrations (NE, HFTO)	University Turbines System Research – Focus on Hydrogen Fuels (FE)
Durable fuel cells with low PGM content applicable to trucks and similar applications	SOFC and Hybrid Electrolyzer Technology Development (FE w/HFTO Coordination)	Nuclear to H2 Production Demonstrations (NE, HFTO)