U.S. DEPARTMENT OF
ENERGY

Office of
ENERGY EFFICIENCY &
RENEWABLE ENERGY

Hydrogen and Fuel Cell Perspectives

Dr. Sunita Satyapal, Director, Hydrogen and Fuel Cell Technologies Office and DOE Hydrogen Program Coordinator, U.S. Department of Energy

December 6, 2021

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

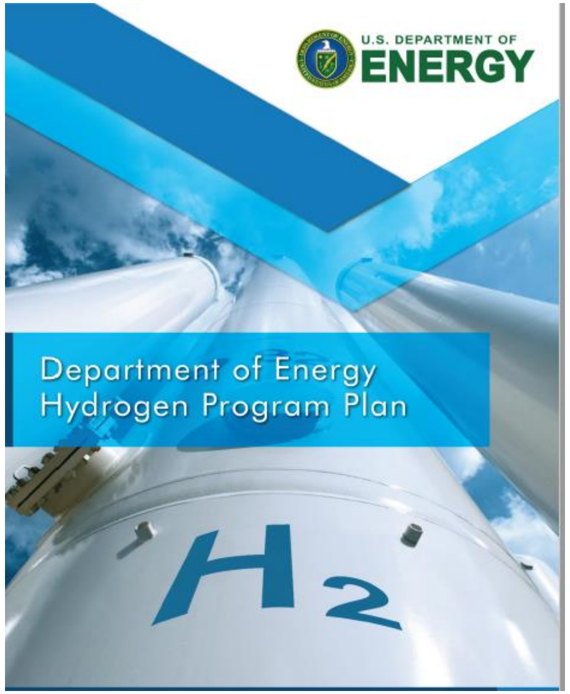
- H. Luccock


Collaboration
Diversity, Equity, Inclusion

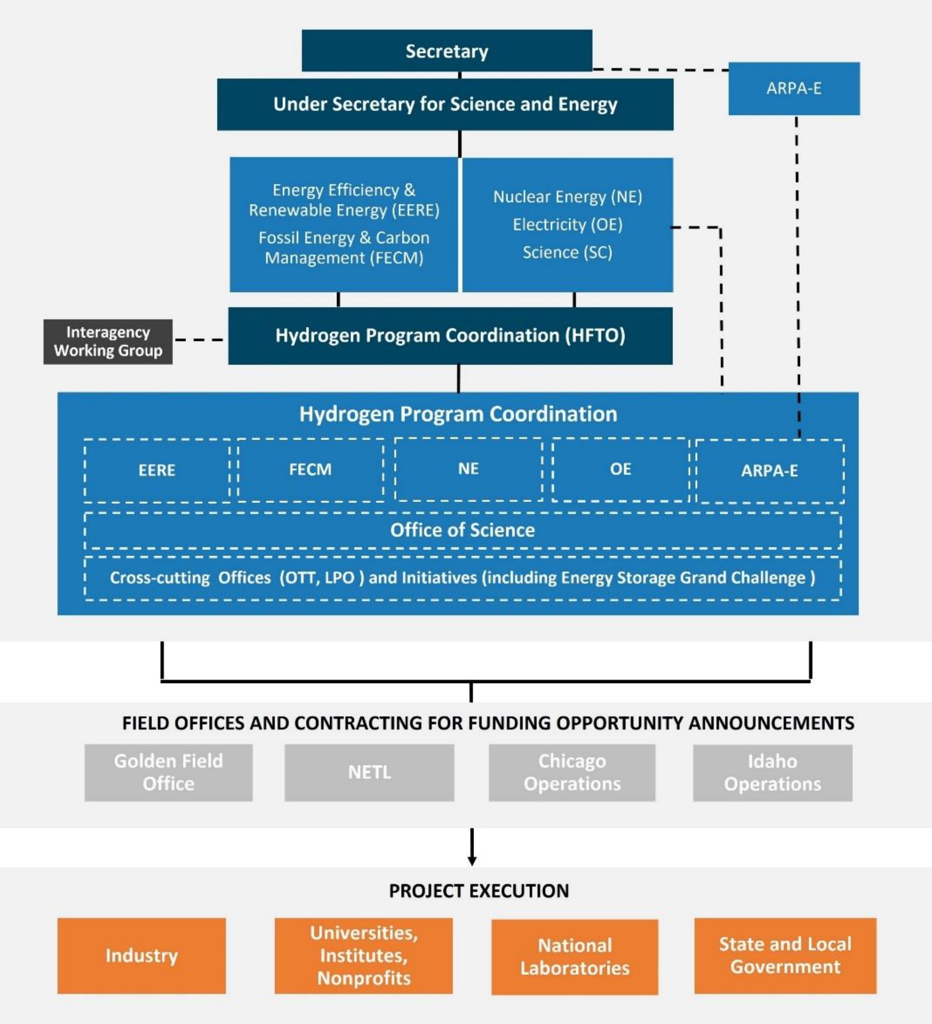
The U.S. DOE Hydrogen Program

Key DOE Hydrogen Authorizations in Energy Policy Act (2005, 2020) and Infrastructure Investment and Jobs Act (2021)

Hydrogen is one part of a broad portfolio of activities



www.hydrogen.energy.gov



Priorities

1. **Low cost, clean hydrogen**
2. **Low cost, efficient, safe hydrogen delivery and storage**
3. **Enable end use applications at scale for impact**

Workforce development, safety, codes, standards, and Environmental Justice priorities

Example of DOE Hydrogen Program Collaboration

EERE Hydrogen

Feedstocks:
- Renewables and Water

Technologies:
- Electrolysis—Low- and High-Temperature
- Advanced Water Splitting—Solar/High-Temp Thermochemical, Photoelectrochemical
- Biological Approaches

FE Hydrogen

Feedstocks:
- Fossil Fuels—Coal* and Natural Gas

*Waste coal, other waste

Technologies:
- Gasification, Reforming, Pyrolysis
- Advanced Approaches—Co-firing and Modular Systems
- Natural Gas to Solid Carbon plus Hydrogen

Areas of Collaboration

Reversible Fuel Cells, Biomass, Municipal Solid Waste, Plastics

Polygeneration including Co-Gasification with Biomass

High-Temperature Electrolysis, System Integration

NE Hydrogen

Feedstocks:
- Nuclear Fuels and Water

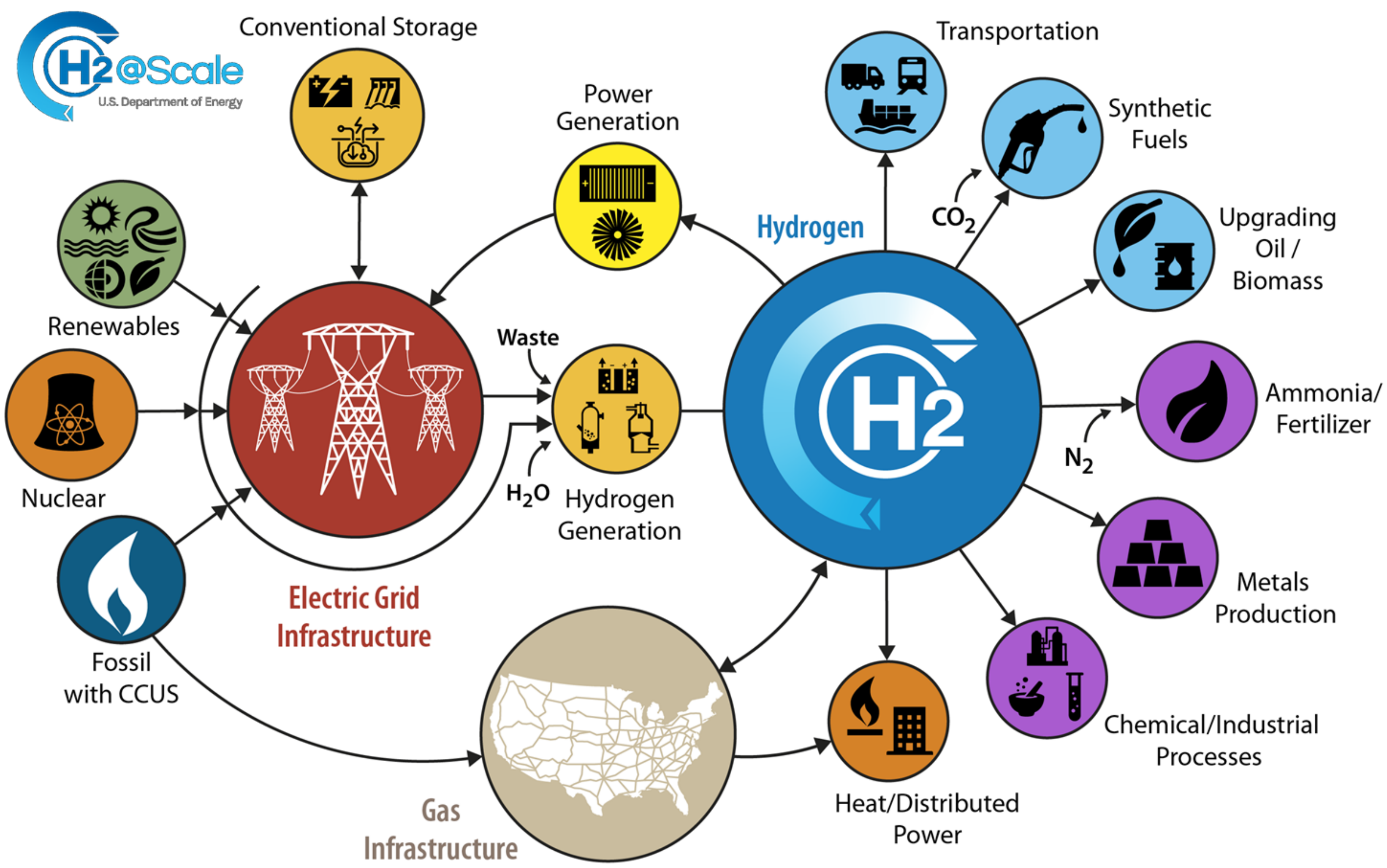
Technologies:
- Risk Assessment & Licensing, Thermal Delivery
- Advanced Nuclear Reactors
- System Integration and Controls - LWRs and Advanced Reactors

Crosscutting R&D Offices: Office of Science (SC) and ARPA-E

Fundamental Science and Advanced Innovative Concepts

Foundational research and innovation; user facilities and tools, materials and chemical processes (e.g., catalysis, separations), artificial intelligence/machine learning, databases and validation, high risk-high impact R&D, and other crosscutting activities

H2@Scale: Enabler for Deep Decarbonization across Sectors and Jobs



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

U.S. Snapshot

- 10 MMT of H_2/yr produced today with scenarios for 2-5X growth.
- +10 MMT H_2 would ~ double today's solar or wind deployment
- Potential for 700K jobs, $140B by 2030

ENERGY earthshots U.S. DEPARTMENT OF ENERGY | Hydrogen

Hydrogen Energy Earthshot

“Hydrogen Shot”

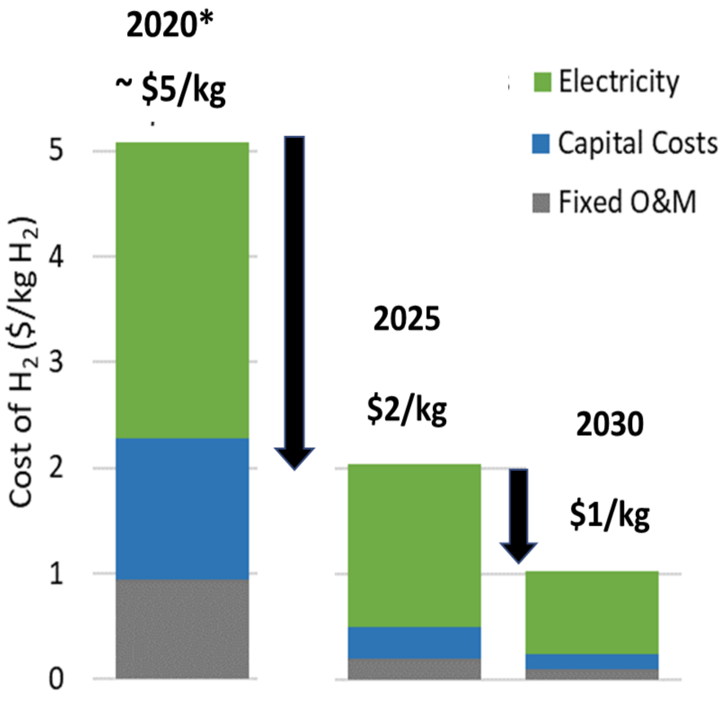
“1 1 1”

$1 for 1 kg clean hydrogen in 1 decade

Launched June 7, 2021
Summit Aug 31-Sept 1, 2021

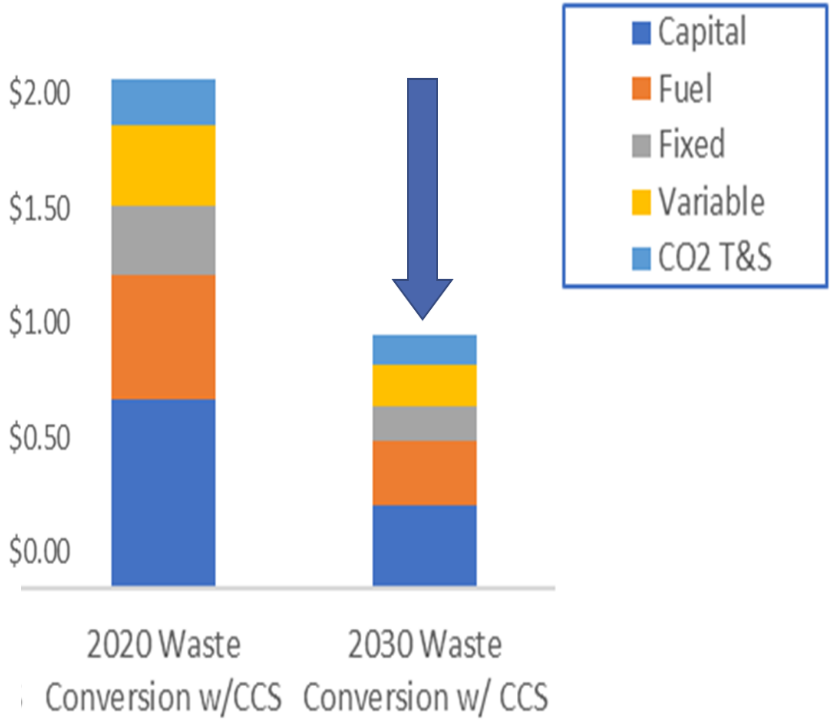
All pathways with potential for "1 1 1" being assessed

H_2 from Electrolysis



- Reduce electricity cost, improve efficiency and utilization
- Reduce capital cost >80%; operating & maintenance cost >90%

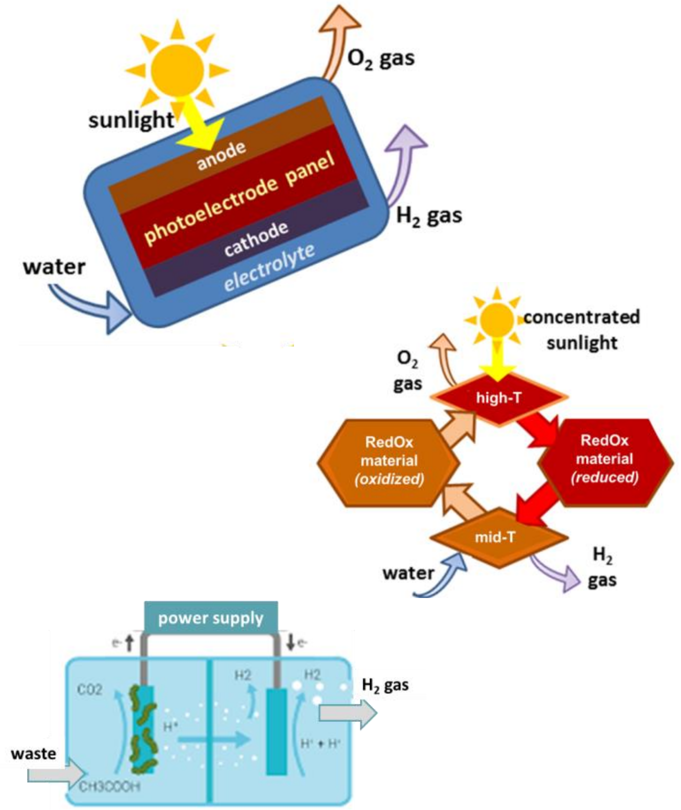
H_2 from Waste Conversion + CCS



* Waste coal, plastics, biomass residuals, municipal solid waste (MSW), and biogas

- Reforming, pyrolysis, air separation, catalysts, CCS, upstream emissions

Advanced Pathways

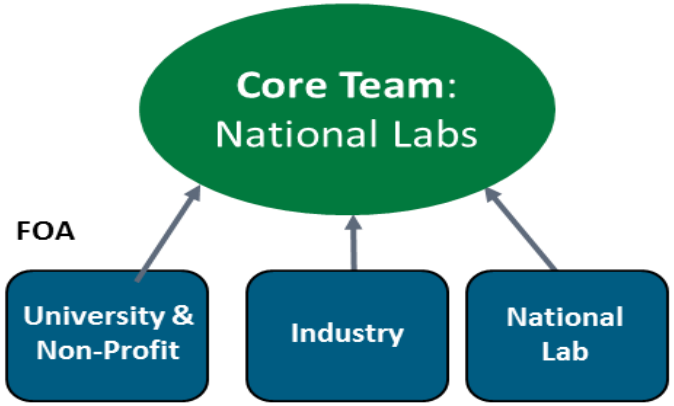


- Photelectrochemical (PEC), thermochemical, biological, etc.

*2020 Baseline: PEM (Polymer Electrolyte Membrane) low volume capital cost ~$1,500/kW, electricity at $50/MWh. Pathways to targets include capital cost < $300/kW by 2025, < $150/kW by 2030 (at scale). Assumes $50/MWh in 2020, $30/MWh in 2025, $20/MWh in 2030

Examples of Collaboration and Opportunities

Consortia:



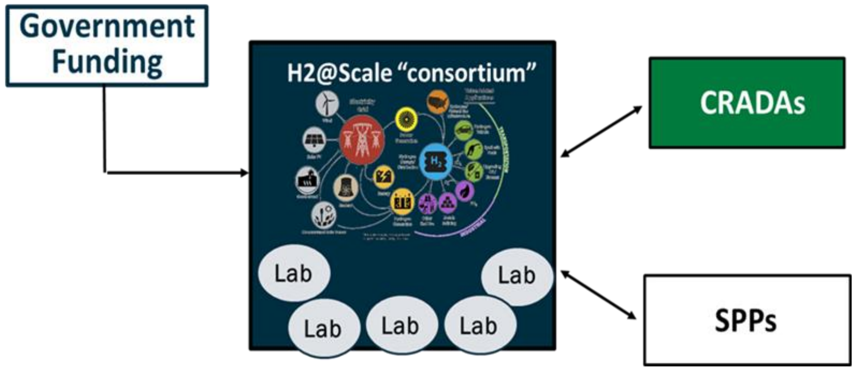
- H2NEW and Million Mile Fuel Cell Truck Consortia will enable low cost electrolyzers and fuel cell trucks
- FECM FOA includes EERE language to collaborate with H-Mat and H2NEW consortia

SC User Facilities

- Strong collaboration between SC User facilities and H_2-related consortia have resulted in over 70 joint publications in high-impact, peer reviewed journals.

CRADAs:

- **Over 25 CRADA projects with private sector** aligned with H2@scale vision and focus areas



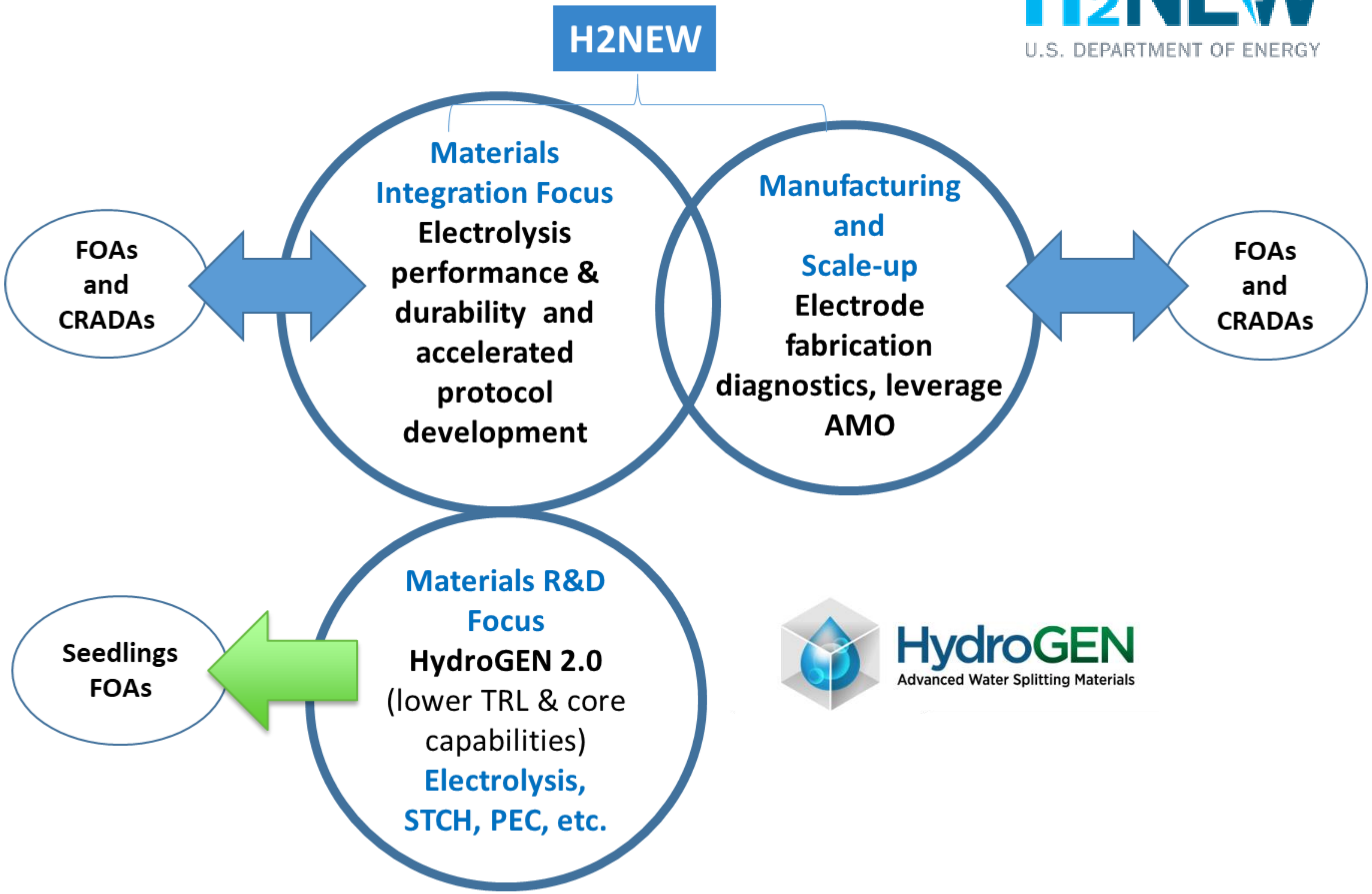
CRADA = Cooperative Research and Development Agreement
SPP- Strategic Partnership Project ('Work for Others')

Other Mechanisms Fostering Collaboration

- Annual Merit Review includes ARPA-E, EERE, FECM, NE, SC other agencies
- Job rotations, Joint FOAs including recent NE-HFTO FOA
- Joint planning activities, including workshops and roundtables
- Under Secretary Science and Energy Tech Team (SETT)

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

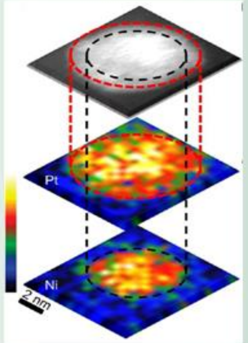
Electrolyzer Stack Goals by 2025

	LTE PEM	HTE
Capital Cost	\$100/kW	\$100/kW
Elect. Efficiency (LHV)	70% at 3 A/cm²	98% at 1.5 A/cm²
Lifetime	80,000 hr	60,000 hr

Example: Advanced Durable Fuel Cell Electrocatalysts

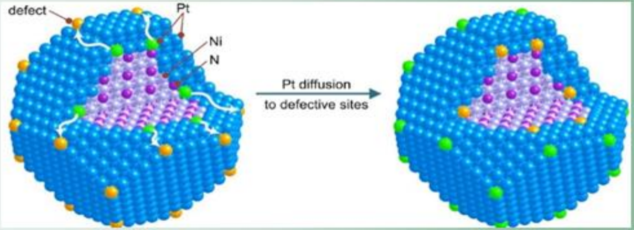
SC-BES Basic Science

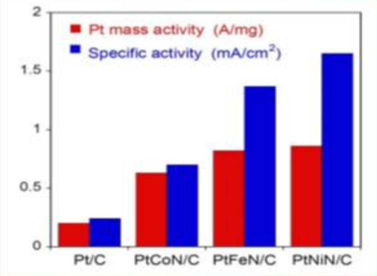
Principle and method of nitride-stabilized Pt-shell catalyst



Discovery that nitrogen doped in transition metal cores greatly increases the activity and stability of Pt shell catalysts.

DFT calculations to rationalize the origin of enhanced performance



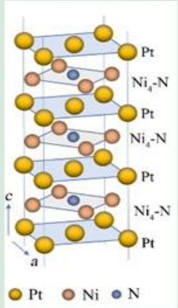


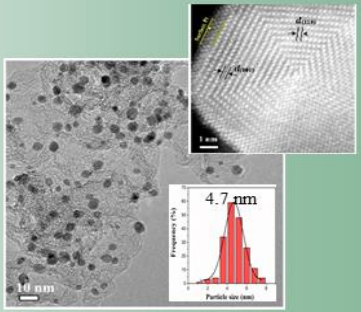
Identification of the best composition & system

EERE HFTO Applied R&D

Core-shell electrocatalysts with high activity and durability

Nitrogen-doped intermetallic structure to further improve the activity and stability



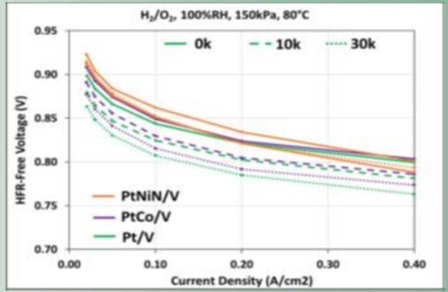


DOE Technology Commercialization Fund project: scale synthesis from mg to grams to enable device studies

Toward Commercialization

Performance and durability in subsystem membrane electrode assemblies, licensing, manufacture method

Collaboration with Toyota North America Inc. for further development & deployment



GM

Excellent fuel cell durability 30k cycles with GM

BROOKHAVEN NATIONAL LABORATORY

DOE Research Areas to Enable H_2 Progress

	Production	Delivery	Storage	Conversion	Application
	EERE FE NE ARPA-E SC	EERE FE ARPA-E SC	EERE FE ARPA-E SC	EERE FE NE ARPA-E SC	EERE FE NE ARPA-E OE
Near Term	• Thermal/catalytic reforming of waste coal, natural gas, biomass & waste feedstocks (with CCUS) • Electrolysis of water (low- and high-temperature)	• H_2 distribution from on-site production • Tube trailers (gaseous H_2) • Cryogenic trucks (liquid H_2) • Blending in natural gas pipelines	• Pressurized tanks (gaseous H_2) • Cryogenic vessels (liquid H_2) • Geological H_2 storage	• Blending in turbine/advanced combustion • 100% fired simple cycle turbines • Fuel cells for transportation and stationary power	• Energy storage • Stationary power, CHP, Polygen • Transportation Industrial and chemical products (trucks, marine, rail, steel, ammonia, etc.)
Long Term	• Advanced biological/ microbial conversion of diverse feedstocks • Direct solar photo-electrochemical and thermochemical water splitting	• Delivery through chemical H_2 carriers • Widespread pipeline transmission and distribution	• Storage in chemical H_2 carriers • Cryo-compressed H_2 storage • Materials-based H_2 storage	• Next-generation fuel cells (including liquid fuel cells) • Reversible fuel cells • Fuel cell / combustion hybrids • 100% H_2 combined cycle turbines	• Integrated energy systems • Defense, security and logistics applications

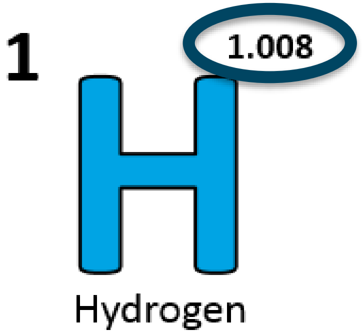
Opportunities for Engagement

Energy Earthshots – U.S. Department of Energy | Hydrogen

DOE Annual Merit Review and Peer Evaluation Meeting June 6 -9, 2022

Hydrogen and Fuel Cells Day October 8

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



INCREASE YOUR H_2IQ

Join Monthly H2IQ Hour Webinars

Download H2IQ For Free

Visit H2tools.Org For Hydrogen Safety And Lessons Learned

https://h2tools.org/

Center for Hydrogen Safety – Connecting a Global Community

www.aiche.org/CHS

Sign up to receive hydrogen and fuel cell updates

www.energy.gov/eere/fuelcells/fuel-cell-technologies-office-newsletter

Learn more at: energy.gov/eere/fuelcells AND www.hydrogen.energy.gov

Main Hydrogen Sections of the Bipartisan Infrastructure Law

- SEC. 40313. CLEAN HYDROGEN RESEARCH AND DEVELOPMENT PROGRAM
- SEC. 813. REGIONAL CLEAN HYDROGEN HUBS
  - $8,000,000,000 for the period of fiscal years 2022 through 2026
- SEC. 814. NATIONAL CLEAN HYDROGEN STRATEGY AND ROADMAP
- SEC. 815. CLEAN HYDROGEN MANUFACTURING AND RECYCLING
  - $500,000,000 for the period of fiscal years 2022 through 2026
- SEC. 816. CLEAN HYDROGEN ELECTROLYSIS PROGRAM
  - $1,000,000,000 for the period of fiscal years 2022 through 2026
- SEC. 822. CLEAN HYDROGEN PRODUCTION QUALIFICATIONS

Tune in to DOE Webinar Dec 8, 2021

Thank you

Dr. Sunita Satyapal
Director, Hydrogen and Fuel Cell Technologies Office
Coordinator, DOE Hydrogen Program
Sunita.Satyapal@ee.doe.gov
U.S. Department of Energy

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

Priority Research Opportunities to Advance Foundational Science for Carbon-Neutral Hydrogen Technologies

Discover and Control Materials and Chemical Processes to Revolutionize Electrolysis Systems

- How do we co-design multiple components that work together to enable stable, efficient electrolysis for the carbon-free production of hydrogen from water?

Manipulate Hydrogen Interactions to Harness the Full Potential of Hydrogen as an Energy Carrier

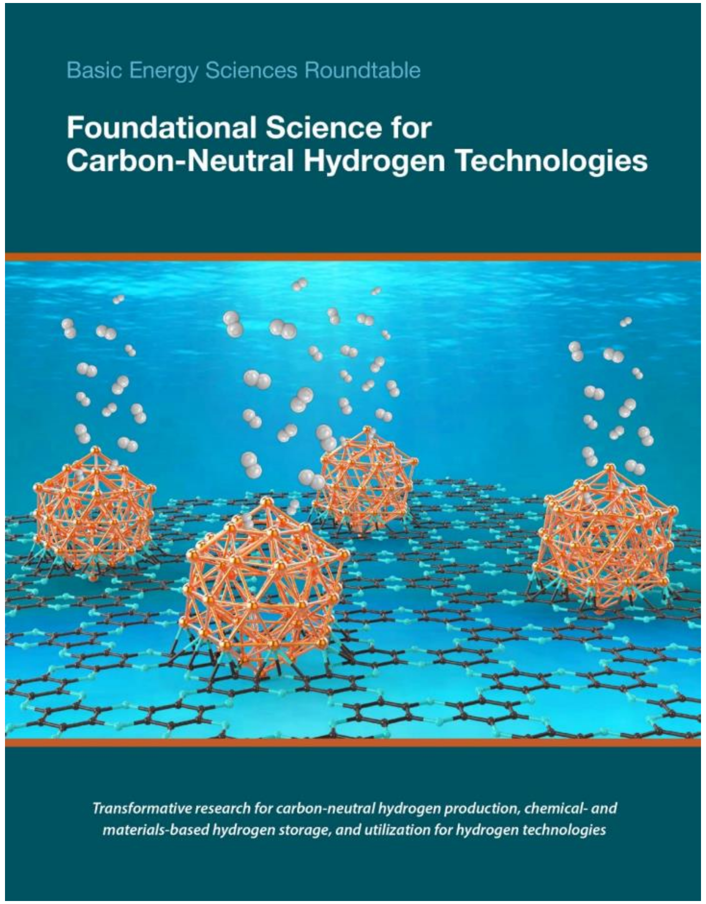
- How do we acquire fundamental insights across the entire range of energies to allow selective tuning of hydrogen interactions with molecules and materials?

Elucidate the Structure, Evolution, and Chemistry of Complex Interfaces for Energy and Atom Efficiency

- How can co-existing and evolving interfaces be tailored at multiple length scales to achieve energy-efficient, selective processes and enable carbon-neutral hydrogen technologies?

Understand and Limit Degradation Processes to Enhance the Durability of Hydrogen Systems

- How do we identify and understand the complex mechanisms of degradation to obtain foundational knowledge that enables the predictive design of robust hydrogen systems?



Roundtable Brochure published on BES website on Hydrogen Day (10-08-2021); Brochure & Technology Status Document available at: https://science.osti.gov/bes/Community-Resources/Reports

Example: H2NEW Consortium

Summary: H2NEW LTE

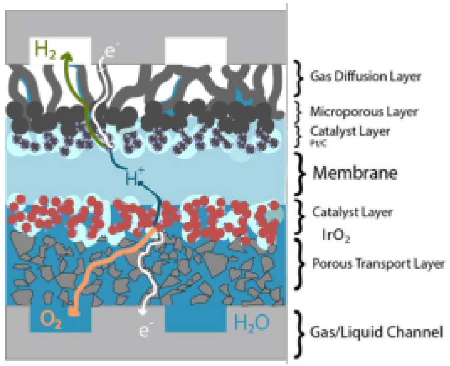
H2NEW
U.S. DEPARTMENT OF ENERGY

Task 1: Durability: Fundamental Understanding to ASTs to Mitigation

Degradation and Accelerated Stress Test (ASTs)
- ✓Probing of single stressor degradation pathways
- ✓Rainbow stack for durability demo established for correlating with AST
- ✓AST Working Group Established

Operando cell and ex situ component studies
- ✓Operando neutron diffraction cell commissioned
- ✓Discretionary funding allocated to operando tomography
- ✓Identical location microscopy and on-line ICMPS demonstrated for studying degradation

Mitigation Strategies
- ✓To be informed by degradation and AST



Stack Targets	Status	2023	2025
Cell (A/cm²@1.9V)	2.0	2.5	3.0
Efficiency (%)	66	68	70
Lifetime (khr)	60	70	80
Degradation (mV/khr)	3.2	2.75	2.25
Capital Cost ($/kW)	350	200	100
PGM loading (mg/cm²)	4	1	0.5

Task 2: Performance: Structure-Property Relations to Optimized Performance

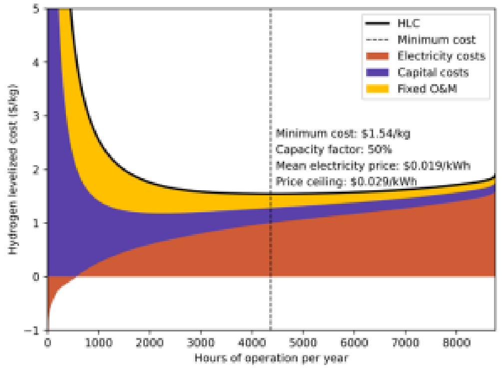
Baseline MEA
- ✓Crosstask team established common MEA, testing and prep
- ✓Identified and sourced PTL

Cell Modeling
- ✓Identified parameter space and experimental matrix that support the model needs of the consortium with regards to in-situ, ex-situ, and in-operando experiments

Task 3: Component processing to Scale-up to Systems Analysis

Inks, catalyst layers, porous transport layers
- ✓Study of PTL structure property relations initiated
- ✓Identified and sourced PTL
- ✓Feasibility of PTL fabrication via 3-D printing and tape casting demonstrated
- ✓Concentrated ink baselining between 3 labs

TEA, Systems Analysis
- ✓Performance, manufacturing, and system analysis is underway and tools are being developed and implemented
- ✓Identified Operating Strategy that Minimizes Cost for Several Electrolyzer Costs Identified and sourced PTL
- ✓Initial Input to Stack Performance Targets
- ✓Cell to system level performance model



H2NEW: Hydrogen from Next generation Electrolyzers of Water 48

Source: DOE Hydrogen Program AMR, 2021, Pivovar, Boardman, et al, H2NEW presentation

Example of HFTO Collaboration with NNSA, LANL, and HBCU Students

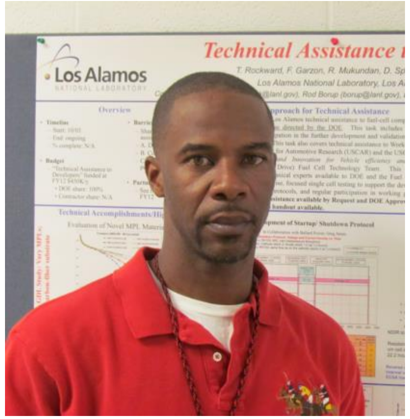
Leveraging LANL's MSIPP Program and Focusing on Building a Diverse Hydrogen and Fuel Cell Workforce Pipeline

NNSA
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