U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

Hydrogen and Fuel Cell Technologies Office: Hydrogen Production Overview

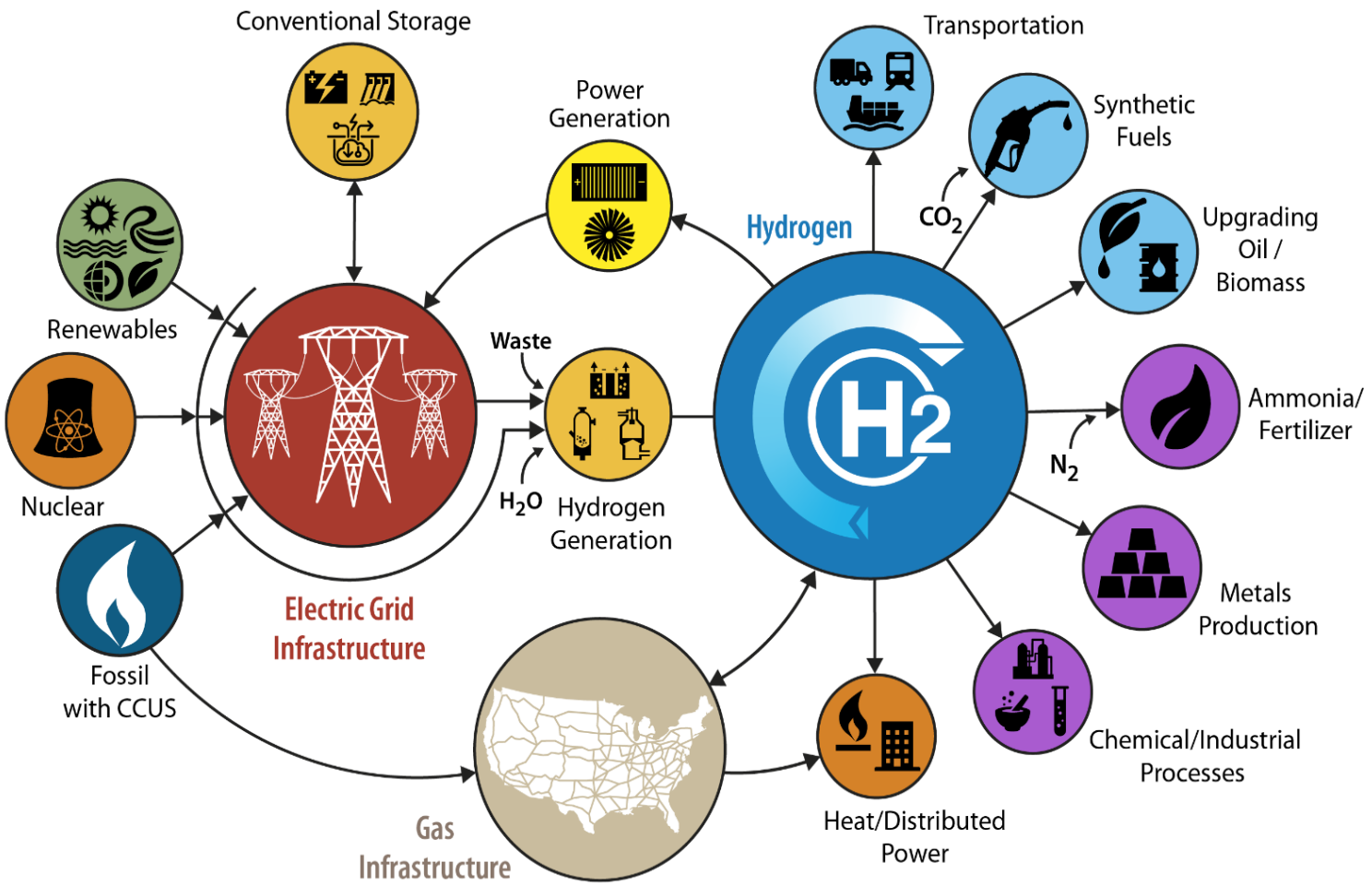
Katie Randolph

Hydrogen and Fuel Cell Technologies Office

3rd Annual HydroGEN Advanced Water Splitting Technology Pathways Benchmarking and Protocols Workshop

March 1, 2021

H2@Scale: Enabling affordable, reliable, clean, and secure energy



- Hydrogen can address specific applications across sectors that are hard to decarbonize
- Today: 10MMT H_2 in the U.S.
- Economic Potential: 2 to 4x more

Strategies

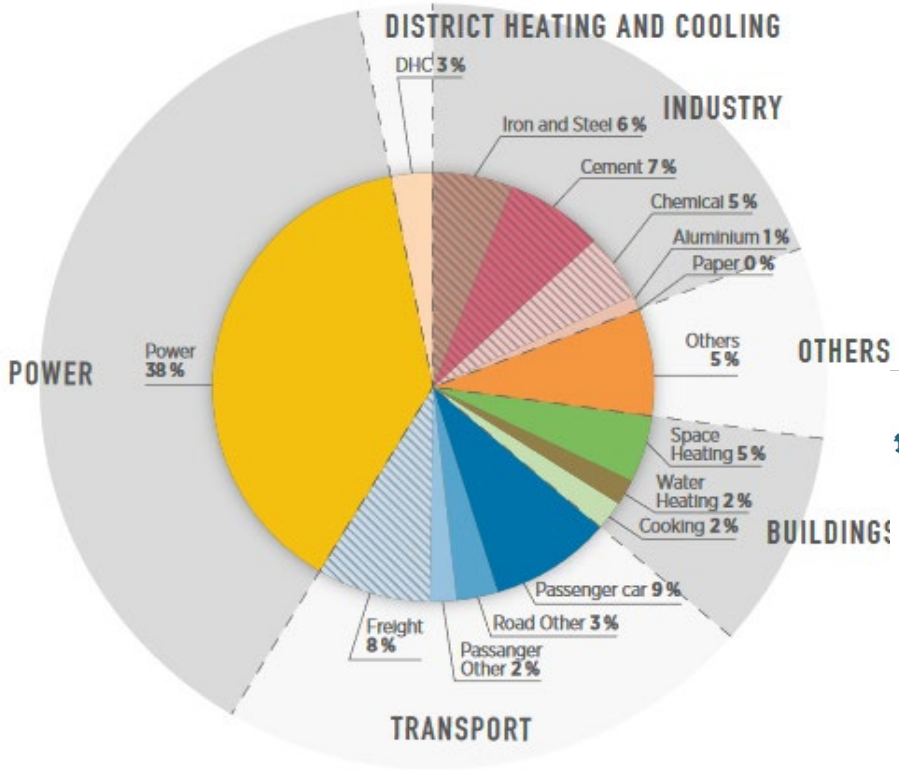
- Scale up technologies in key sectors
- Continue R&D to reduce cost and improve performance, reliability
- Address enablers: harmonization of codes, standards, safety, global supply chain, workforce development, sustainable markets

Source: U.S. DOE Hydrogen and Fuel Cell Technologies Office, https://www.energy.gov/eere/fuelcells/h2scale

Global Interest, Drivers and Energy Related Carbon Emissions by Sector

Drivers include:

- Emissions reduction
- Energy security
- Economic growth
- Resiliency
- Energy efficiency
- Innovation potential
- Environmental benefits

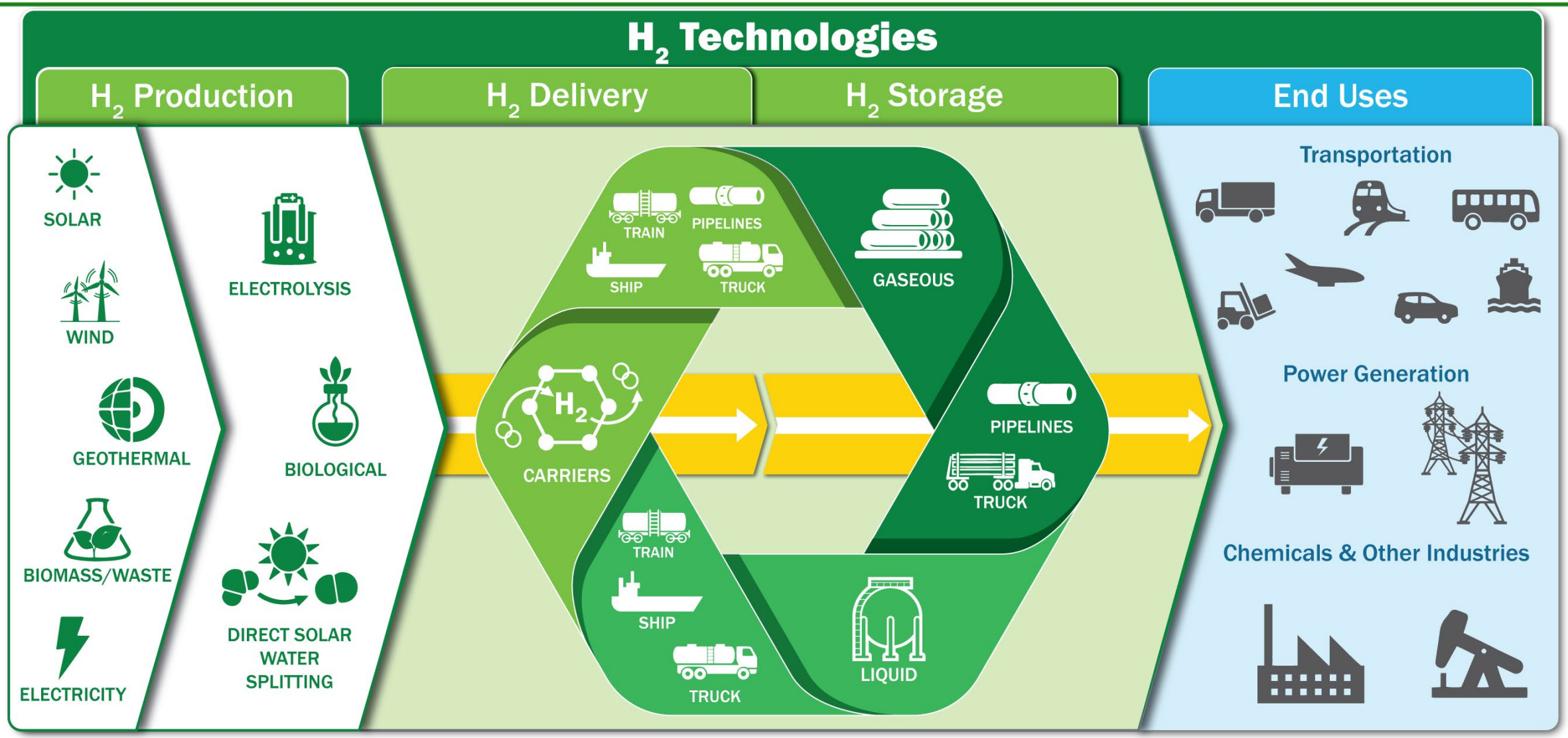


Sectors today with no economically scalable option for deep emission reductions

Hydrogen Roadmaps and Plans Developing Worldwide

Source: IRENA, 2017a from: https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2018/Sep/IRENA_Hydrogen_from_renewable_power_2018.pdf

The Hydrogen Technologies Program

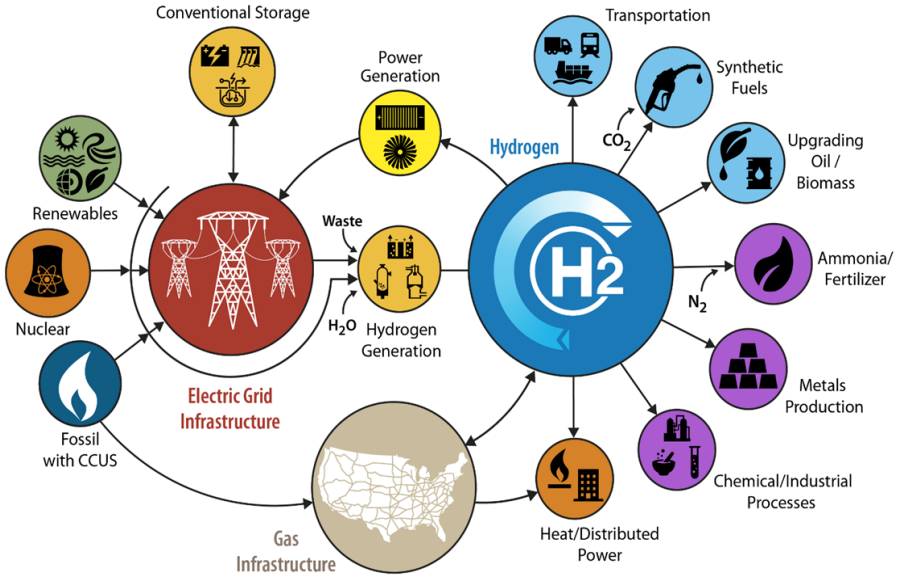


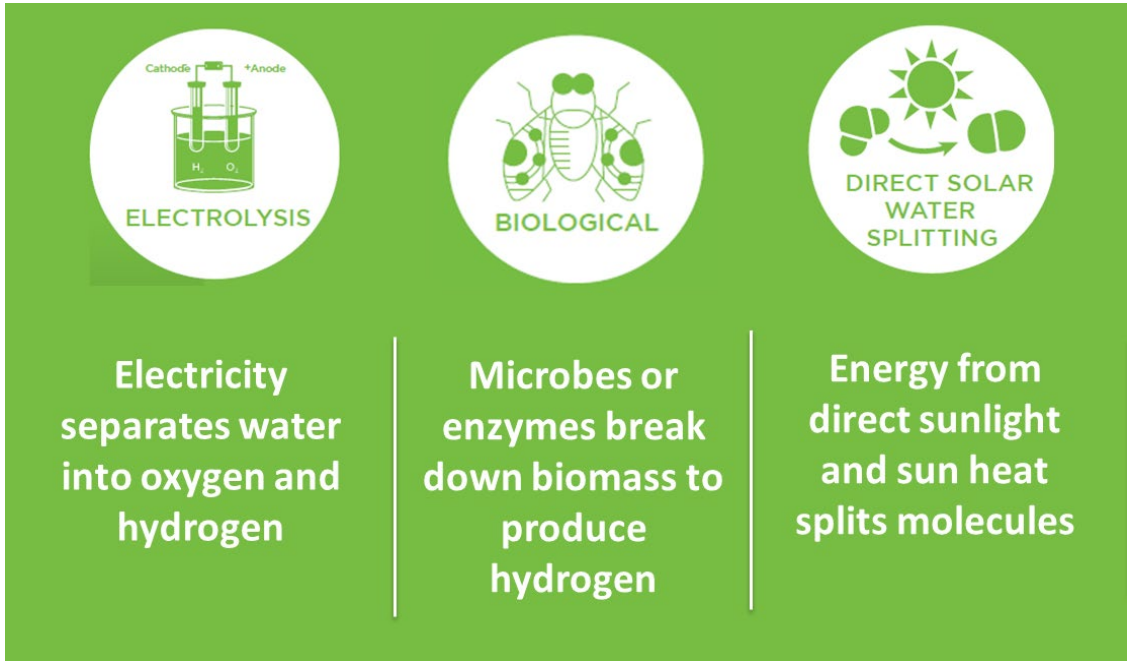
From producing hydrogen from feedstocks through delivering it to the end-use application

Enabling sustainable, low cost and efficient H_2 production

Strategic R&D Priorities

	Near-term 2025	Mid-term 2030	Long-term 2040
Hydrogen Production	• Affordable, efficient and durable **multi-MW-scale electrolyzers** • **Innovative approaches to H_2 production**, beyond electrolysis		





A Multi-layered Approach to AWS Technology Development

Advanced Manufacturing (TRL 6-7) – R&D on manufacturing processes and techniques suitable for high-volume manufacture of mega-watt scale electrolyzers and electrolyzer components

Advanced Components (TRL 4-5) – R&D on integration of materials into components (e.g., catalysts into MEA) and components into systems (e.g., cells into stacks), developing an understanding of mechanisms and addressing performance barriers for PEM LTE and O^{2-} conducting HTE

Advanced Materials (TRL 1-3) – Foundational R&D on materials with improved performance and durability for water splitting technologies, including low and high-temperature electrolysis and direct thermochemical and photoelectrochemical technologies.

Industry-led R&D projects competitively selected through Funding Opportunity Announcements, coordinated with H2NEW

H2NEW National Laboratory-led research consortium on advance component development for low and high-temperature electrolysis

HydroGEN National Laboratory-led research consortium on advance materials development for water splitting technologies

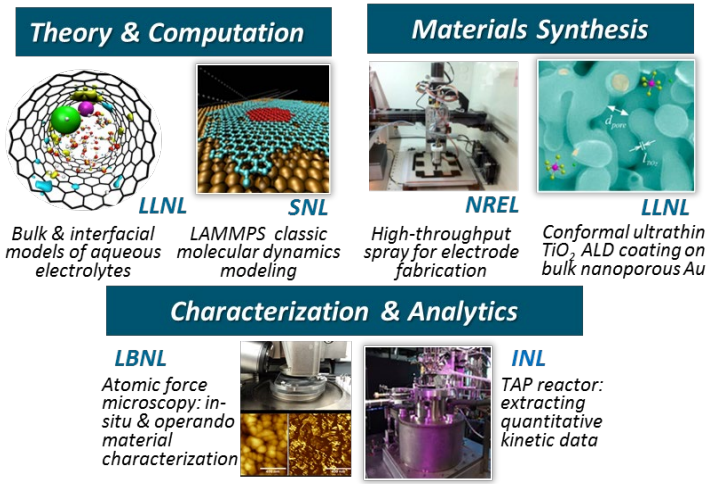
Approach flows from ***foundational materials-development*** across multiple technologies to ***advanced integrated component development*** to ***advanced system manufacturing processes***

HydroGEN Advanced Water Splitting (AWS) Materials Consortium

HydroGEN
Advanced Water Splitting Materials

Accelerating AWS Materials R&D to Enable <$2/kg H_2

- Leveraging & streamlining access to world-class capabilities & expertise
- Providing a robust, secure, searchable, & sharable Data Hub
- Developing universal standards & best practices for benchmarking & reporting
- Fostering cross-cutting innovation



Innovative Consortia Model Connecting AWS Community and Enhancing R&D

- 5 Core Labs with >80 capabilities & expertise in electrolysis, PEC, & STCH
- Supporting 32 projects awarded through FOAs
- Aiding development of > 35 AWS test protocols
- Addressing R&D gaps through collaborative Lab-led research efforts

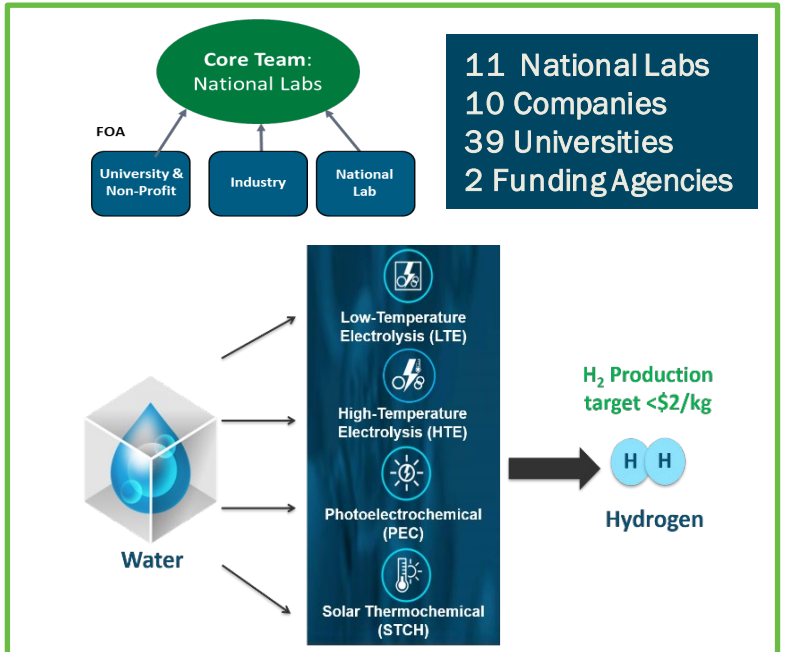
HydroGEN 2.0 Focus Areas

LTE: Enable high efficiency, durable AEMWE without supporting electrolytes

HTE: Identify electronic leakage mechanisms in p-SOEC for higher cell performance at lower temperatures

STCH: Develop global understanding of material structure & composition required to achieve high yield performance

PEC: Scale-up & improved durability through corrosion mitigation & ~neutral pH operation



Key Technical Accomplishments

- Achieved 70% PEM electrolyzer cell efficiency while improving durability & reducing cost
- Scaled up baseline cell by 8X w/ 9% STH efficiency & 100 h stability integrated pv-PEC system
- Discovered new STCH compounds with H_2 production capacities > SOA at lower temperatures
- Demonstrated a metal-supported o-SOEC cell with dramatically improved stability

NREL NATIONAL RENEWABLE ENERGY LABORATORY · Sandia National Laboratories · BERKELEY LAB · INL Idaho National Laboratory · Lawrence Livermore National Laboratory

H2NEW Consortium: H2 from the Next-generation of Electrolyzers of Water

A comprehensive, concerted effort focused on overcoming technical barriers to enable affordable, reliable & efficient electrolyzers to achieve <$2/kg H_2

- Launching in Q1 FY21
- Both low- and high-temperature electrolyzers
- $50M over 5 years

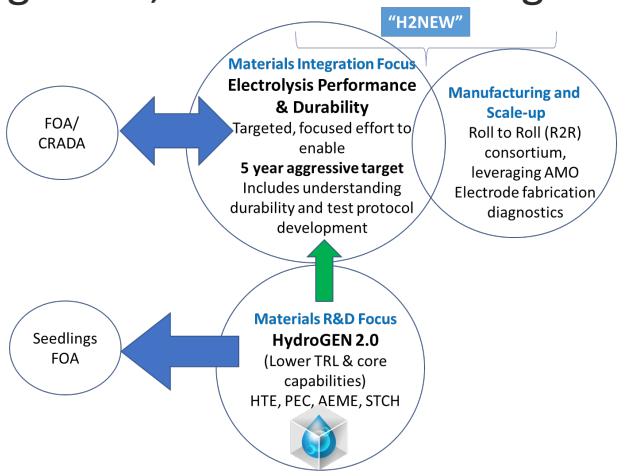
National Lab Consortium Team

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

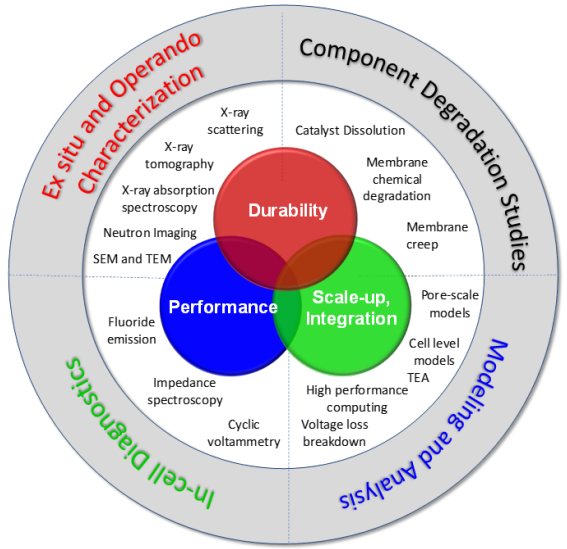
Clear, well-defined stack metrics to guide efforts.

Draft 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

The focus is not new materials but addressing components, materials integration, and manufacturing R&D



Utilize combination of world-class experimental, analytical, and modeling tools



Durability/lifetime is most critical, initial, primary focus of H2NEW

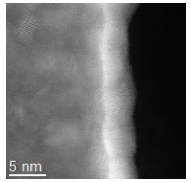
- Limited fundamental knowledge of degradation mechanisms.
- Lack of understanding on how to effectively accelerate degradation processes.
- Develop and validate methods and tests to accelerate identified degradation processes to be able to evaluate durability in a matter of weeks or months instead of years.
- National labs are ideal for this critical work due to existing capabilities and expertise combined with the ability to freely share research findings.

Enabling MW-Scale Manufacturing of Electrolyzers Critical to H_2@Scale

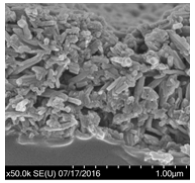
Advanced components, sub-systems, & systems for multi-MW-scale electrolyzers

Advanced Components

Catalyst



Electrode

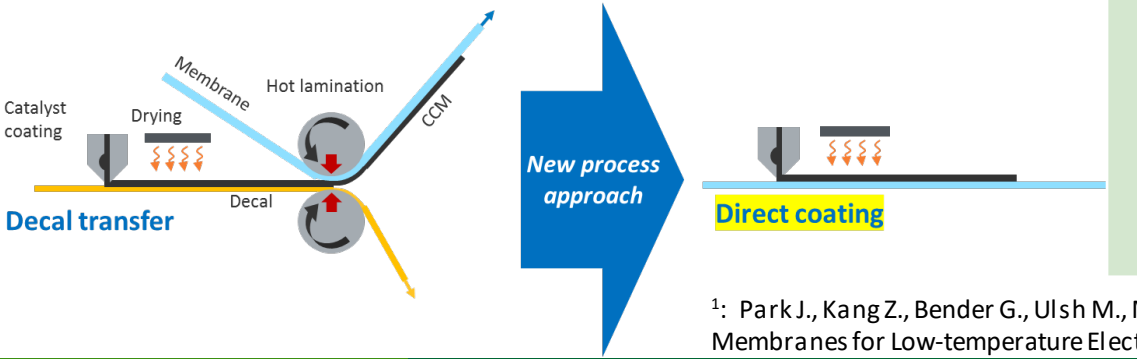


GW-Scale Manufacturing

MW-Scalable Electrolyzers

Courtesy of Plug Power Inc.

Manufacturing solutions for low cost, efficient, durable & reliable multi-MW scale deployments [1]



H2NEW
H2 from the Next-generation of Electrolyzers of Water

5 year, $10M/yr Multi-Lab Consortium

Objective: Overcome technical barriers & enable affordable, reliable & efficient low and high temperature electrolyzers at <$100/kW

FOAs

Addressing components, materials integration, & manufacturing R&D

LTE ($14M Effort - 3 New Projects)	**HTE ($10M Open FOA Topic)**
• **Plug Power**: Single-piece multi-functional integrated membrane anode assembly • **3M:** Advanced manufacturing technology enabling fabrication of SOA catalysts & electrodes • **Proton Energy:** Develop & optimize manufacturable PTL at >1000 cm^2	• Decrease part count, reduce processing steps, standardize processes & components • Develop real-time quality control metrology techniques • Manufacturing techniques targeting cost of $300/kW

[1]: Park J., Kang Z., Bender G., Ulsh M., Mauger S.A. "Roll-to-roll Production of Catalyst Coated Membranes for Low-temperature Electrolyzers." *Journal of Power Sources*, 479, 2020.

Benchmarking and Protocol Development for AWS Technologies

PI: Kathy Ayers, Proton OnSite (LTE)
Co-PIs: Ellen B. Stechel, ASU (STCH);
Olga Marina, PNNL (HTE);
CX Xiang, Caltech (PEC)
Consultant: Karl Gross

Goal: Development of best practices in materials characterization & benchmarking critical to accelerate materials discovery & development

Accomplishments:

- **2nd Annual AWS community-wide benchmarking workshop (ASU, Oct. 29–30, 2019)**
- **36 test protocols drafted and reviewed**
- **40 additional protocols in drafting process**
- **Relevant operational conditions were assessed for each of the water splitting technologies**
- **Engaged with new projects at March 2020 kickoff meeting and organized breakout meetings**
- **Quarterly newsletters disseminated to AWS community**

Development of best practices in materials characterization and benchmarking: critical to accelerate materials discovery and development

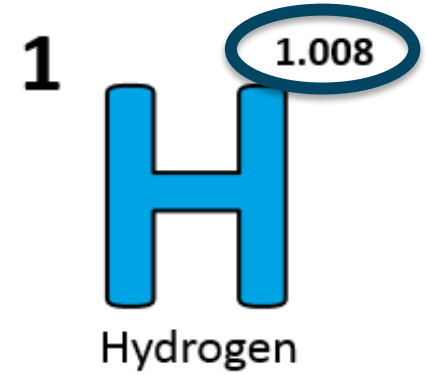
Resources and Events

Save the Date

June 8th week, 2021 Annual Merit Review and Peer Evaluation Meeting for the DOE Hydrogen and Fuel Cells Program

Oct 8 - Hydrogen and Fuel Cells Day

(Held on its very own atomic weight-day)



Resources

INCREASE YOUR H2IQ

Join Monthly
H2IQ Hour Webinars

Download
H2IQ For Free

energy.gov/eere/fuelcells/fuel-cell-technologies-office-webinars

energy.gov/eere/fuelcells/downloads/increase-your-h2iq-training-resource

Visit H2tools.Org For Hydrogen Safety And Lessons Learned
https://h2tools.org/

Learn more:

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

Thank You!

www. hydrogen.energy.gov