Hydrogen Production and Hydrogen Shot

Options for producing low-carbon hydrogen at scale

Huyen N. Dinh
Director of HydroGEN, NREL

MIT Energy Initiative Spring Symposium
Hydrogen's role in a decarbonized energy system: How to enable it
May 10, 2022

2020's Decade of Hydrogen

H2NEW
L.S. DEPARTMENT OF ENERGY

Hydrogen Council

CLIMATE CH2AMPION: HYDROGEN IS THE MISSING PIECE OF THE ENERGY PUZZLE

HYDROGEN COST TO FALL SHARPLY AND SOONER THAN EXPECTED

HYDROGEN DEPLOYMENT ACCELERATING WITH MORE THAN $300 BILLION IN PROJECT PIPELINE

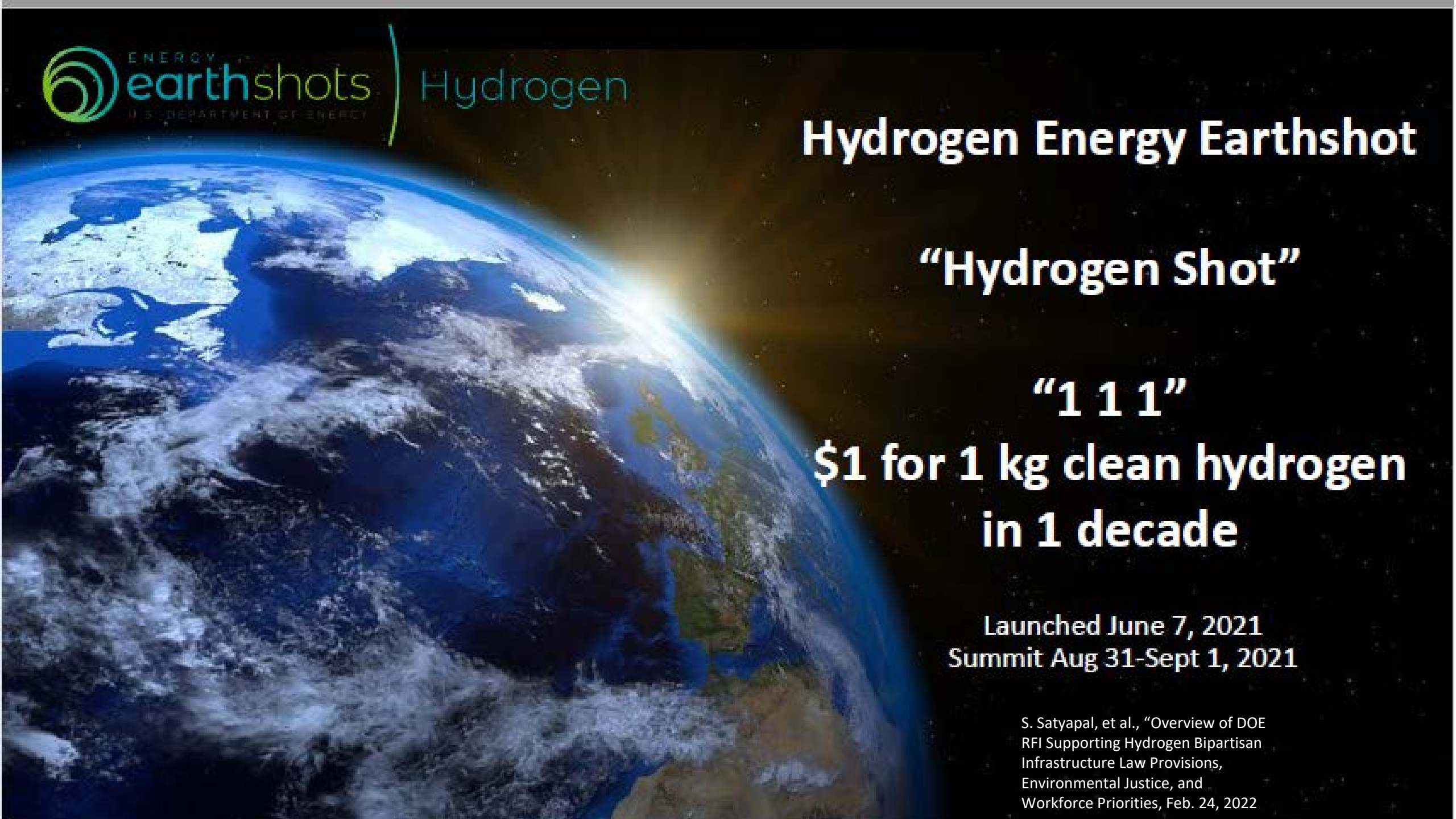
> *Potential Impacts from Hydrogen Council Roadmap Study. By 2050:*
> - *$2.5 trillion in global revenues*
> - *30 million jobs*
> - *400 million cars, 15-20 million trucks*
> - *18% of total global energy demand*

https://hydrogencouncil.com/en/

https://www.france24.com/en/live-news/20210331-the-global-race-to-develop-green-hydrogen

https://www.bloomberg.com/news/articles/2021-03-02/hydrogen-is-jump-ball-in-global-clean-energy-race-kerry-says

Now is the time for hydrogen and the "global race" is on


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
S. Satyapal, et al., "Overview of DOE RFI Supporting Hydrogen Bipartisan Infrastructure Law Provisions, Environmental Justice, and Workforce Priorities, Feb. 24, 2022

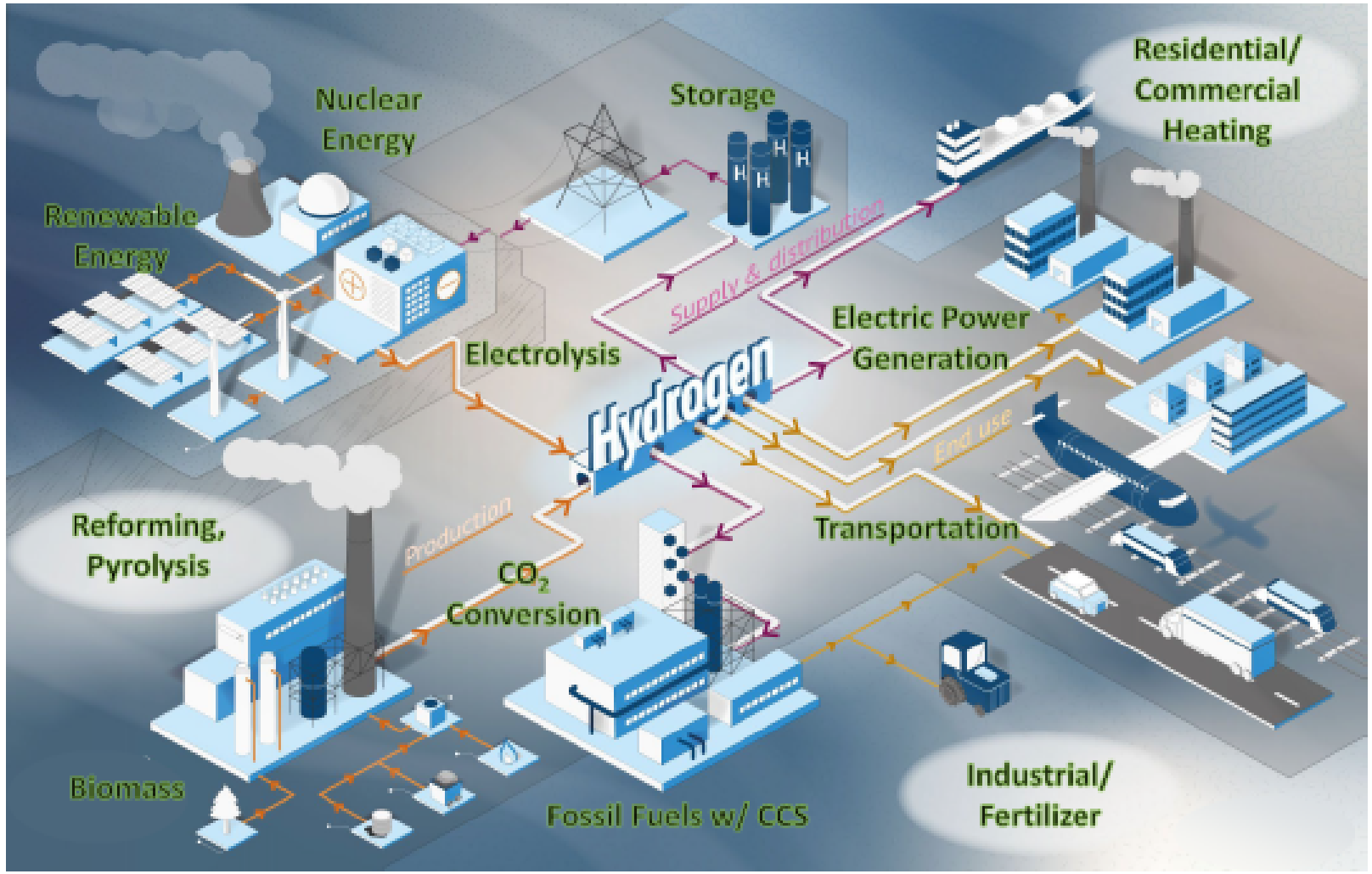
Bipartisan Infrastructure Law – Hydrogen Highlights

- **Covers $9.5B** for clean hydrogen:
  - $8B for at least four regional clean hydrogen hubs
  - $1B for electrolysis research, development and demonstration
  - $500M for clean hydrogen technology manufacturing and recycling R&D
- Aligns with Hydrogen Shot priorities by directing work to reduce the cost of clean hydrogen to $2 per kilogram by 2026
- Requires developing a National Hydrogen Strategy and Roadmap

President Biden Signs the Bipartisan Infrastructure Bill into law on November 15, 2021. Photo Credit: Kenny Holston/Getty Images

S. Satyapal, et al., "Overview of DOE RFI Supporting Hydrogen Bipartisan Infrastructure Law Provisions, Environmental Justice, and Workforce Priorities, Feb. 24, 2022

Hubs Enable Multiple Feedstocks and End Uses



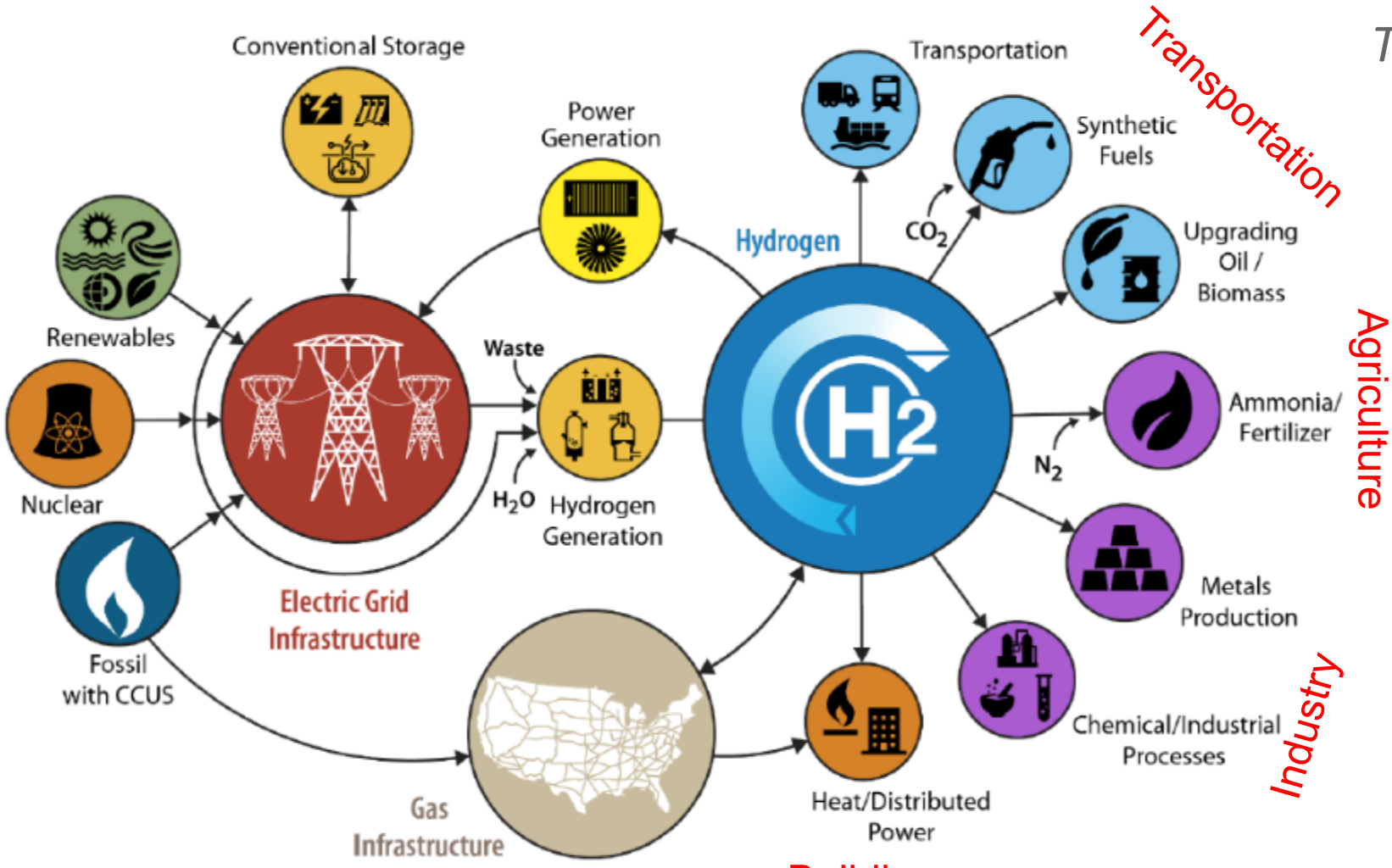
H_2 Ecosystem: Potential for different clean H_2 production methods, end uses, and necessary infrastructure all in close proximity

Additional Key Items beyond H_2 Technology:

- Environmental Justice
- Community Engagement
- Job Creation
- Workforce Development
- Labor Standards
- Diversity, Equity, Inclusion
- Commercial Sustainability
- U.S. Manufacturing

S. Satyapal, et al., "Overview of DOE RFI Supporting Hydrogen Bipartisan Infrastructure Law Provisions, Environmental Justice, and Workforce Priorities, Feb. 24, 2022

H2@Scale: Enabling Affordable, Reliable, Clean and Secure energy



Illustrative example, not comprehensive
https://www.energy.gov/eere/fuelcells/h2-scale

Transportation and Beyond

Large-scale, low-cost hydrogen from diverse domestic resources enables an economically competitive and environmentally beneficial future energy system across sectors

Hydrogen can address specific applications that are hard to decarbonize

Today: 10 MMT H_2 in the US

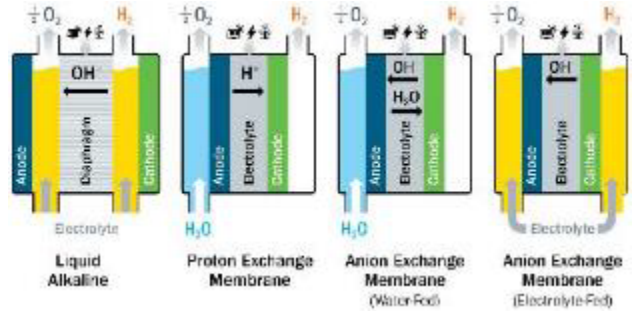
Economic potential: 2x to 4x more

Timeframe is short, competition intense, coordinated effort critical for domestic competitiveness.

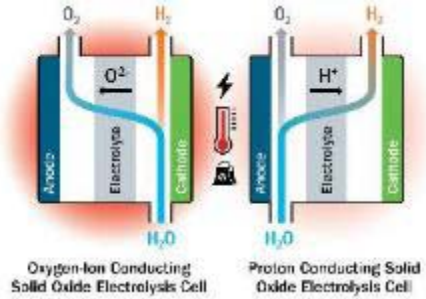
R&D on Advanced Production Technologies

Challenge: Wind and solar took ~40 years to be cost competitive… we need to do that for green hydrogen production in the next 5-10 years

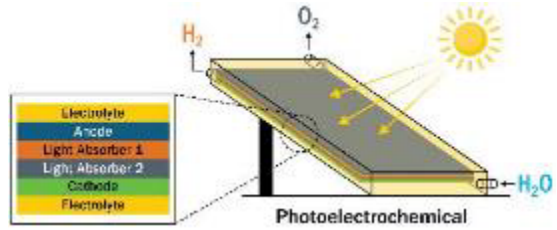
- **Near-term:** focus on electrolysis (water splitting with electricity and nuclear)
  - Accelerate **research on advanced water-splitting** technologies – take advantage of today's renewable and nuclear power
  - Achieve $100/kW electrolyzer stack goal in just 5 years through **H2NEW** consortium
  - Include research on both **LTE** (**PEM, liquid alkaline), and HTE (solid oxide) electrolyzer** technologies
  - **Research urgency:** Need order of magnitude increase in effort on electrolysis to accelerate development to meet near-term cost goals *(NOTE: new $1B BIL activity now enables this)*
- **Longer-term:** Use solar energy or heat to more directly to split water
  - Photoelectrochemical (PEC) and solar thermochemical (STCH) H_2 production
  - Incubate and support promising technology development through **HydroGEN** consortium



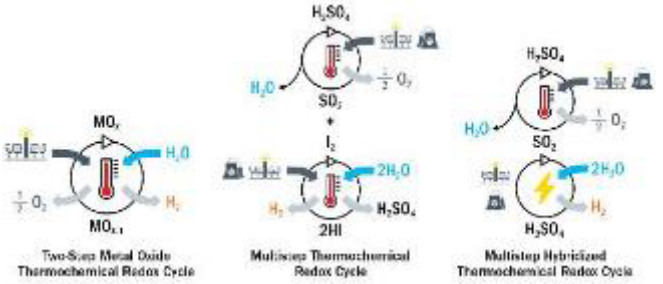
LTE



HTE



PEC

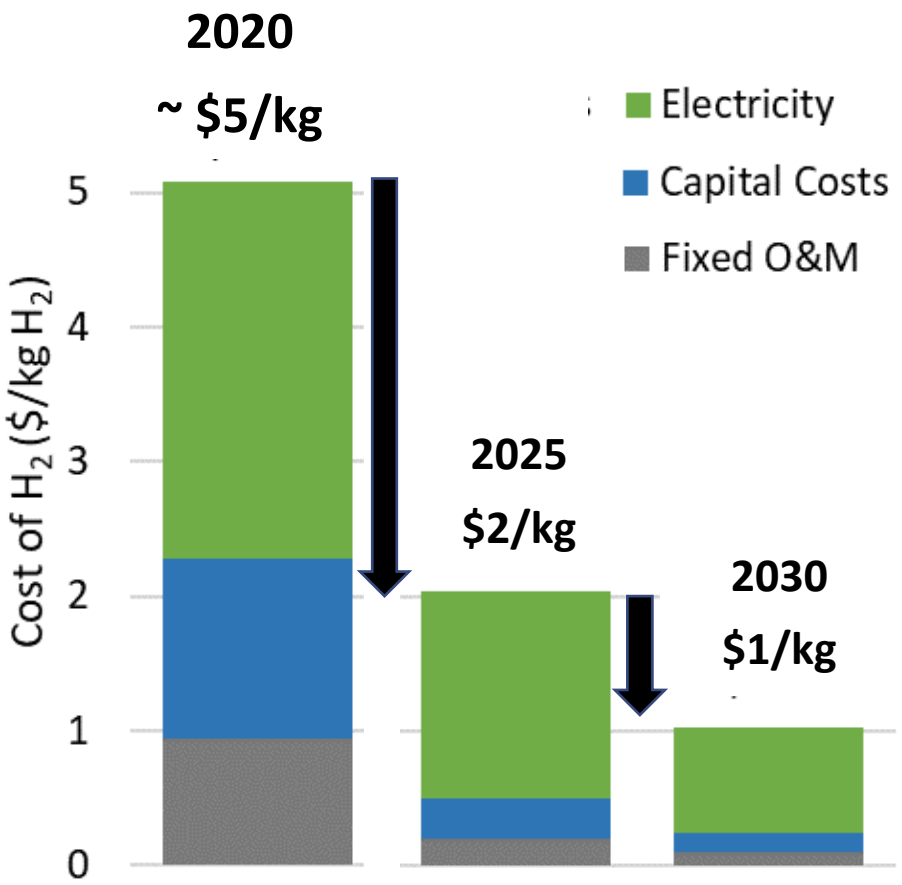


STCH

S. Alia, D. Ding, A. McDaniel, F. M. Toma, H.N. Dinh, "**How to Make Clean Hydrogen AWSM:** ***The Advanced Water Splitting Materials Consortium" ECS Interface, 30(4) Winter 2021.***

Pathways to Reduce the Cost of Electrolytic H_2

Cost Reduction of Clean Electrolytic H_2



Key enablers for lower cost electrolytic H_2:

- **Low-cost electricity, variable operation**
- **High electrical efficiency**
- **Low-cost capital expense**
- **Increased durability/lifetime**
- **Low-cost manufacturing processes**
- **Manufacturing at MW-scale**
- **Increased power density**

Electrolyzer goals for 2025	Unit	PEM	SOEC
Higher electrical efficiency	% (LHV)	≥ 70	≥ 98
Lower stack costs	$/kW	≤ 100	≤ 100
Increased durability	hours	80,000	60,000
Lower system CAPEX	$/kW	≤ 250	≤ 300

https://www.hydrogen.energy.gov/pdfs/review21/plenary7_stetson_2021_o.pdf

H2NEW : H2 from Next-generation Electrolyzers of Water

H2NEW
U.S. DEPARTMENT OF ENERGY

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

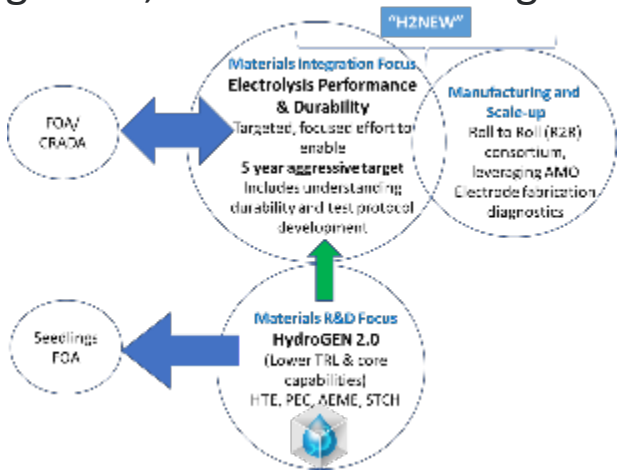
National Lab Consortium Team

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

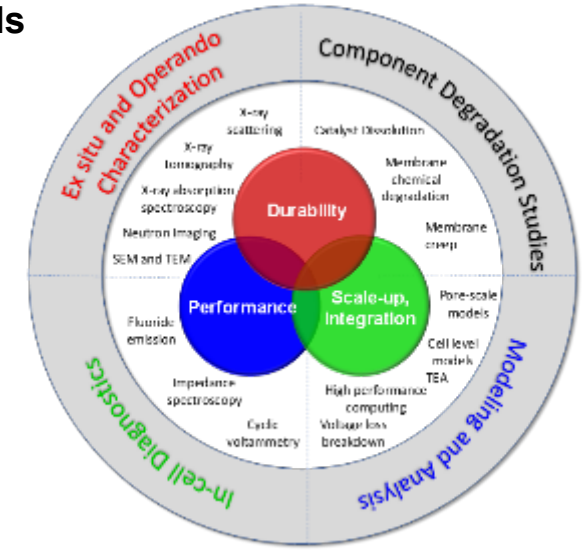
Clear, well-defined stack metrics to guide efforts.

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.

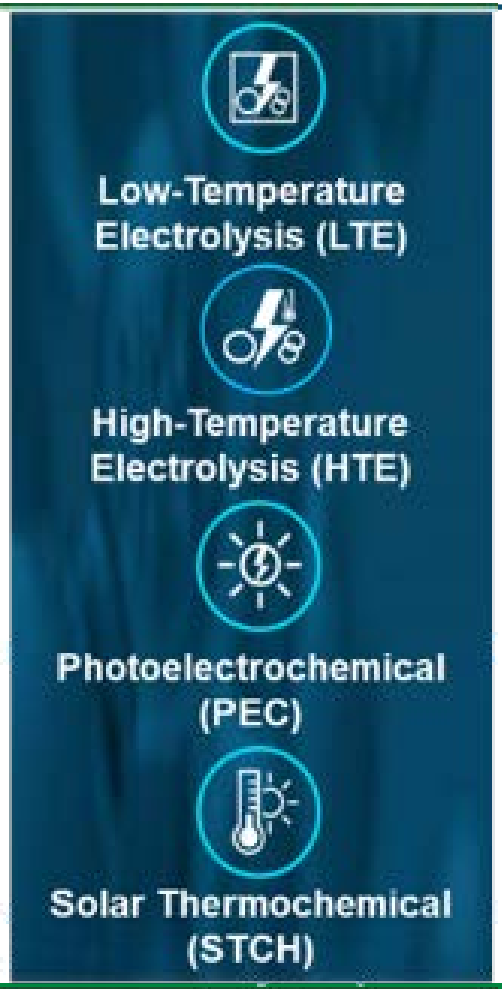
HydroGEN is advancing Hydrogen Shot

Website: https://www.h2awsm.org/

Goal: Accelerating R&D of innovative advance water splitting (AWS) materials and technologies for clean, sustainable and low-cost hydrogen production.

Challenges
- Cost
- Efficiency
- Durability

Water



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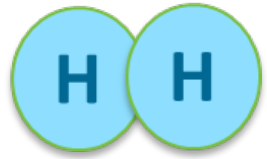
Sandia National Laboratories
Lawrence Livermore National Laboratory

H_2 Production target <$2/kg



Hydrogen

HydroGEN is advancing Hydrogen Shot goals by fostering cross-cutting innovation using theory-guided applied materials R&D to accelerate the time-to-market and advance all emerging water-splitting pathways to enable clean, low cost, and sustainable low-cost hydrogen production

Waste to BioHydrogen

Feedstock

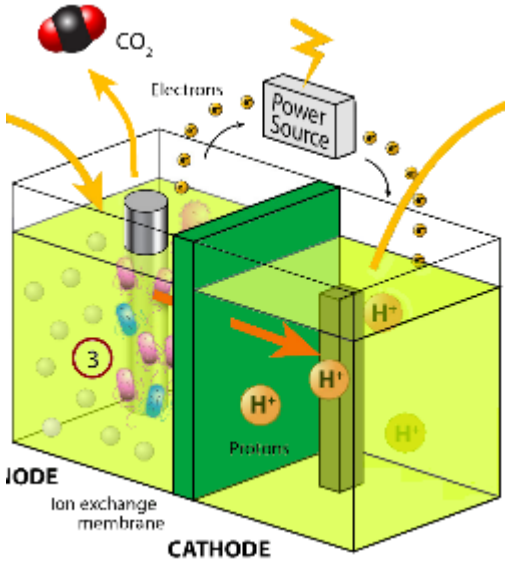
Agricultural Waste

Forest Residue

Aqueous Waste

Fermentation

Microbial electrolysis cell



H_2

Microbial Catalysts for H_2 Production

By Zina Deretsky, National Science Foundation (NSF), User:KVDP - http://images.dailytech.com/nimage/6590_large_biohydrogen_h.jpg, Public Domain, https://commons.wikimedia.org/w/index.php?curid=10095584

K. Chou, "**BioHydrogen (BioH2) Consortium to Advance Fermentative H_2 Production**" ***p179, HFTO AMR Presentation 2022.***

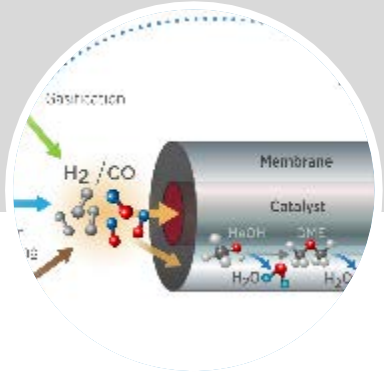
Carbon-negative Hydrogen

Definition: Hydrogen production (with or without carbon capture & storage) with net life-cycle GHG emissions resulting in a carbon intensity < zero

Team: Huyen Dinh, Gary Grim, Bob Baldwin

Feedstock

Biomass and waste carbon sources



Conversion

Thermochemical, biochemical, and hybrid technologies

Processing

Downstream processes for increasing product quality

Hydrogen

Emphasis on pathways for production of carbon-negative hydrogen

End Users

Industry and transportation

National Laboratory Collaboration is Critical for Success

Hydrogen Production

H2NEW: Hydrogen from Next-generation Electrolyzers of Water — U.S. DEPARTMENT OF ENERGY

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Argonne NATIONAL LABORATORY
BERKELEY LAB Bringing Science Solutions to the World
Lawrence Livermore National Laboratory
Los Alamos NATIONAL LABORATORY
NETL NATIONAL ENERGY TECHNOLOGY LABORATORY
OAK RIDGE National Laboratory
Pacific Northwest NATIONAL LABORATORY

Hydrogen Storage

HyMARC Hydrogen Materials Advanced Research Consortium

Sandia National Laboratories
NREL Transforming ENERGY
Pacific Northwest NATIONAL LABORATORY
Lawrence Livermore National Laboratory
BERKELEY LAB Bringing Science Solutions to the World

Hydrogen Production

HydroGEN Advanced Water Splitting Materials

NREL Transforming ENERGY
BERKELEY LAB Bringing Science Solutions to the World
Sandia National Laboratories
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INL Idaho National Laboratory

Fuel Cells

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

BERKELEY LAB Bringing Science Solutions to the World
Los Alamos NATIONAL LABORATORY
Argonne NATIONAL LABORATORY
NREL Transforming ENERGY
OAK RIDGE National Laboratory

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Eric Miller

Thank You

www.nrel.gov

Huyen.dinh@nrel.gov

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