Photo by Dennis Schroeder, NREL 46840

Clean Hydrogen Production R&D

Huyen N. Dinh (She/Her/Hers)

Plenary Session: From the Classroom to the **Lab** to the Boardroom

ASES Solar 2023, CU Boulder

August 11, 2023

NREL at a Glance

3,343 workforce, including:

- 2,482 regular/limited term
- 485 contingent workers
- 183 postdoctoral researchers
- 125 graduate students
- 68 undergraduate students

—as of 12/31/2022

World-class research expertise in:

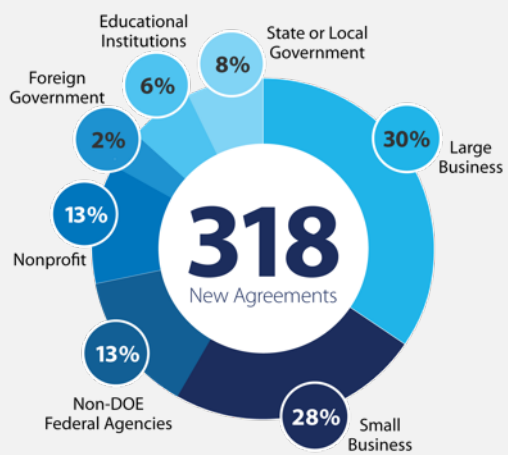
- Renewable Power
- Energy Efficiency
- Sustainable Transportation
- Energy Systems Integration

Partnerships with:

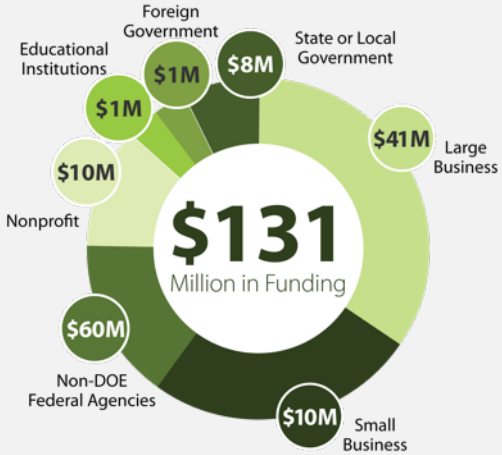
- Industry
- Academia
- Government

3 campuses operate as living laboratories

More Than 1,000 Active Partnerships in FY 2022



Agreements by Business Type



Funding by Business Type

Integrated Energy Pathways

Electrons to Molecules

Circular Economy for Energy Materials

NREL's Vision:

A Clean Energy Future for the World

Three critical research areas respond to today's energy challenges and provide tomorrow's solutions

Huyen Dinh

- Current roles at NREL (~16 years)
  - Manager of the Electrosynthesis, Fuel Storage science and Engineering (EFSS&E) Group
  - Director of HydroGEN EMN (https://h2awsm.org/)
  - Electrons to Molecules (E2M) lead for MCCS directorate
  - Distinguished Member of the Research Staff (DMRS)
- Worked at 3 different fuel cell start up companies
- Postdoctoral research at Los Alamos National Lab
- Ph.D. in Electrochemistry


Fuel cell vehicle

- Co-lead of the Asian Employee Resource Group at NREL
- Member of the Women's Network Employee Resource Group at NREL
- Member of the MCCS DEIA Committee

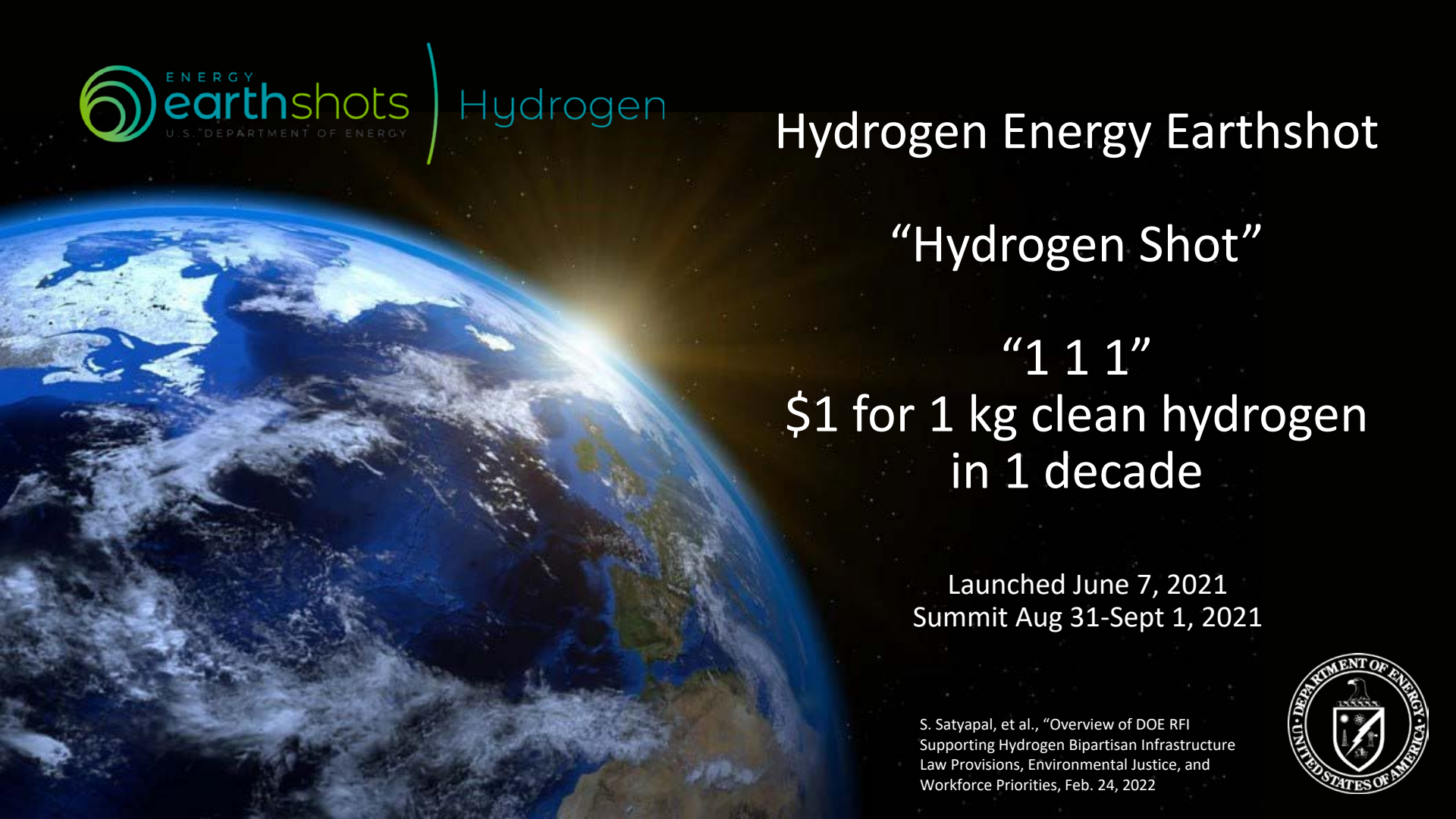
Mentoring & Career Development

Intentionally invite women and early career researchers to chair sessions and as invited speakers at conference symposium that I organize

Organized ECS lunch with esteemed Prof. Sossina Haile

Introduced postdocs to people at ECS networking event

What is the hydrogen energy earthshot goal?



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

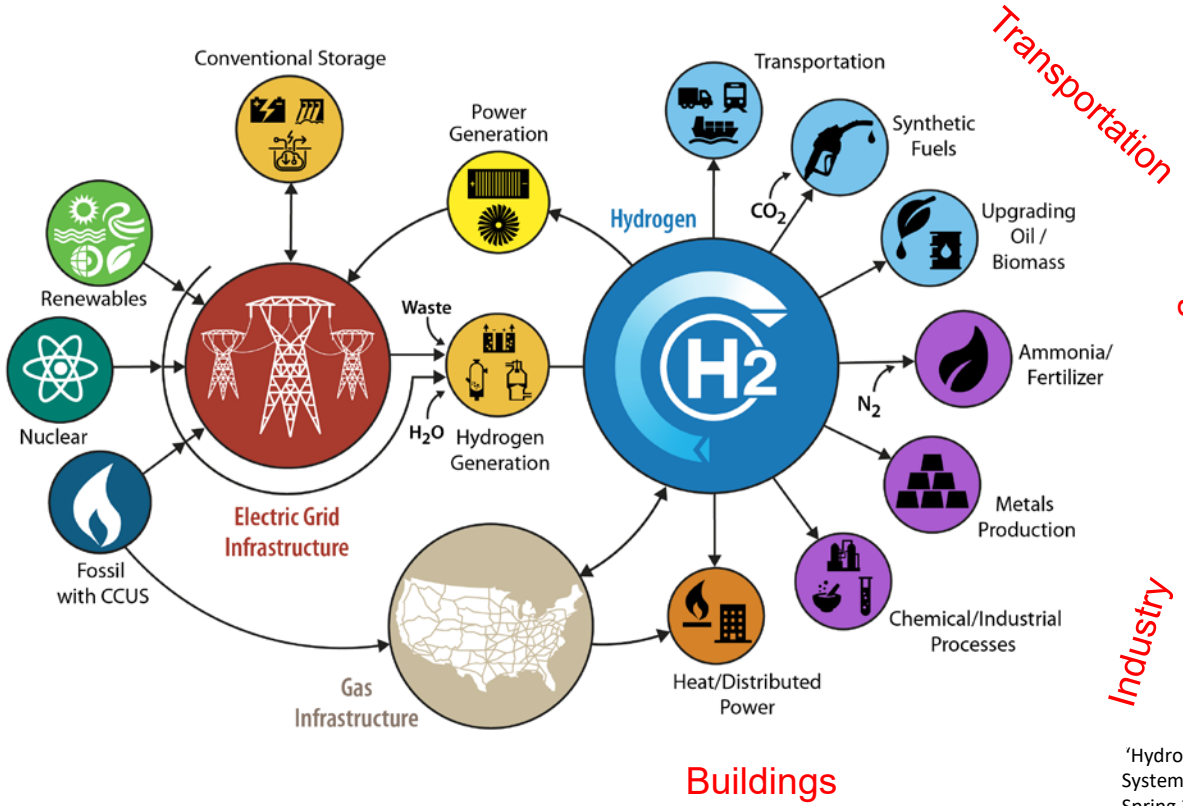
Bipartisan Infrastructure Law – Hydrogen Highlights

- **Covers $9.5B** for clean hydrogen:
  - $8B for at least 6-10 regional clean H_2 hubs
  - $1B for electrolysis RD&D
  - $0.5B for clean H_2 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

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



Source: DOE Hydrogen and Fuel Cell Technologies Office, https://energy.gov/eere/fuelcells/h2-scale

Transportation and Beyond

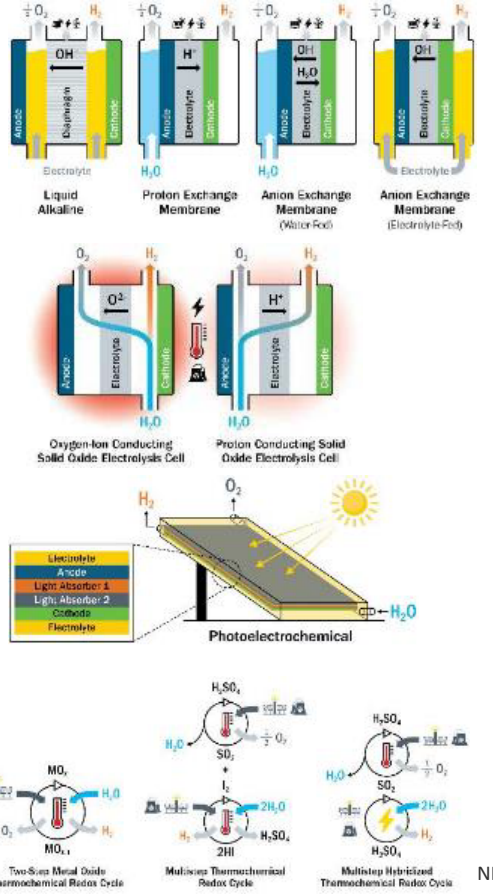
- Large-scale, low-cost hydrogen from diverse domestic resources enables an economically competitive and environmentally beneficial future energy system across sectors
- Hydrogen can address specific applications that are hard to decarbonize
- Today: 10 MMT H_2 in the US
- Economic potential: 2x to 4x more

'Hydrogen at Scale (H_2@Scale): Key to a Clean, Economic, and Sustainable Energy System," Bryan Pivovar, Neha Rustagi, Sunita Satyapal, *Electrochem. Soc. Interface* Spring 2018 27(1): 47-52; doi:10.1149/2.F04181if.

R&D on Advanced Production Technologies

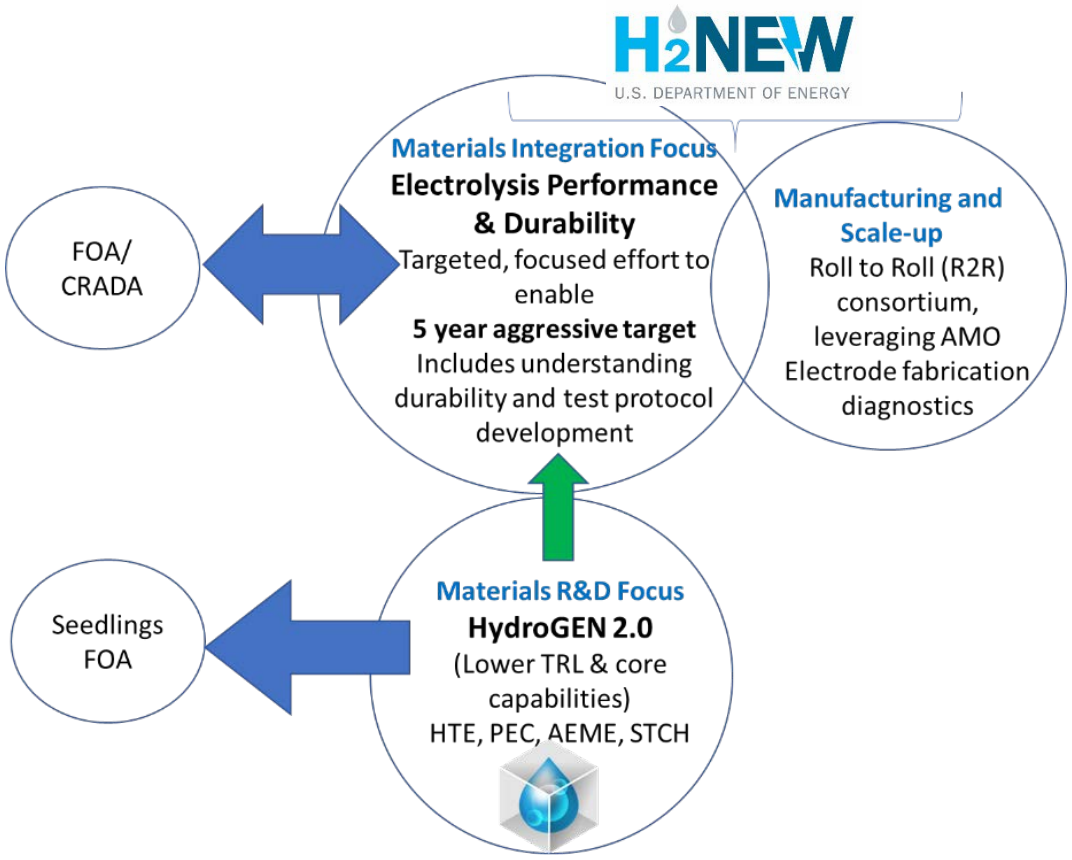
Challenge: Wind and solar took ~40 years to be cost competitive… we need to do that for green hydrogen production in the next 5-10 years

- **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



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.***

HydroGEN Materials R&D Feeds to H2NEW Materials Integration



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

- Polymer electrolyte membrane (PEM) electrolysis
- Oxygen-conducting solid oxide electrolysis (SOEC)
- Liquid alkaline electrolysis

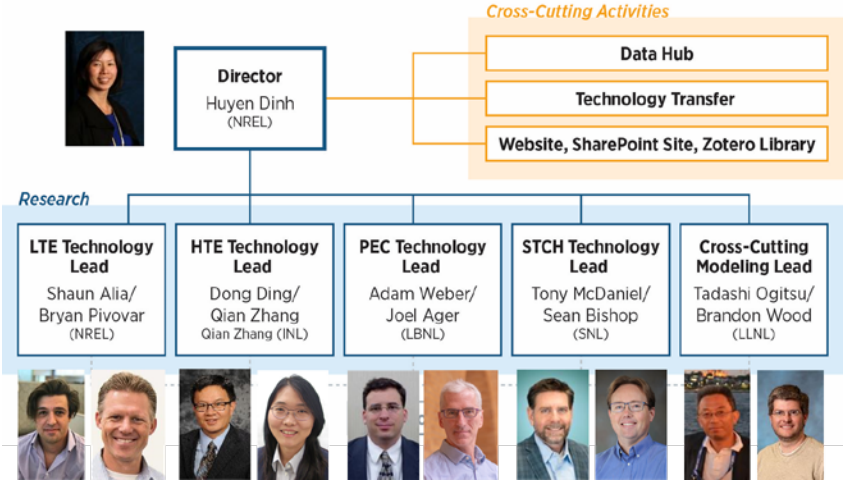
HydroGEN 2.0 (lower TRL AWS)

- Alkaline exchange membrane (AEM) electrolysis
- Metal-supported SOEC (MS-SOEC)
- Proton-conducting SOEC (p-SOEC)
- Photoelectrochemical (PEC)
- Solar thermochemical (STCH)

HydroGEN Lab R&D + Lab Capability Support

HydroGEN 2.0: Lab R&D

Early-Stage Materials R&D Projects



NREL Transforming ENERGY · INL Idaho National Laboratory · Berkeley Lab · Sandia National Laboratories · Lawrence Livermore National Laboratory

HydroGEN 1.0: Lab Support

Lab capabilities + experts support projects

HydroGEN Materials Capability Network

31 Lab – FOA Projects

LTE Node Labs

NREL · Berkeley Lab · Sandia National Laboratories · Lawrence Livermore National Laboratory

Support through:

Personnel
Equipment
Expertise
Capability
Materials
Data

LTE FOA Projects

nel · Argonne National Laboratory · Northeastern University Center for Renewable Energy Technology · Los Alamos (2) National Laboratory · Georgia Institute of Technology · Chemours · University of Oregon

National Laboratory Collaboration is Critical for Success

NREL Research Spans MAKE/MOVE/STORE/USE

Make

R&D on Advanced Production Technologies

Move

Infrastructure Research & Large Scale Demonstration and Deployment

Store

Hydrogen Storage Materials and Systems Research

Use

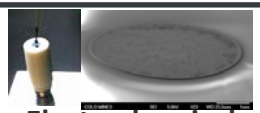
Hydrogen Penetration into Heavy-Duty Transportation Sector

Expanding Green Hydrogen Into New End-Use Cases

NREL's HFCT Program Strategy is on Accelerating Progress & Impact

Energy justice and American jobs are considerations that underly all these efforts.

Hydrogen Core Competencies – From Powders to Power: FC & LTE



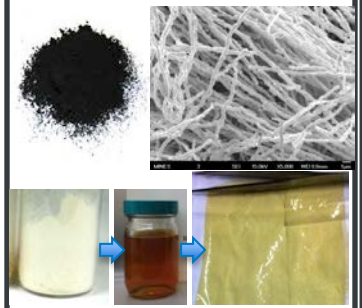
Electrochemical Characterization:
RDE & RRDE stations for Mass & Specific Activity, ECA, ORR; EQCMB, Seiras

Roll-to-roll manufacturing:
Micro-gravure coating, Slot die coating

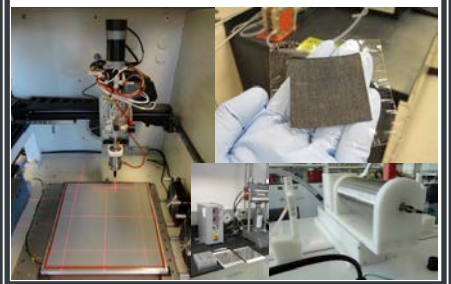
Manufacturing Lab
QC Diagnostic Development, Areal characterization, Roll-to-roll demonstration

Powders → Power

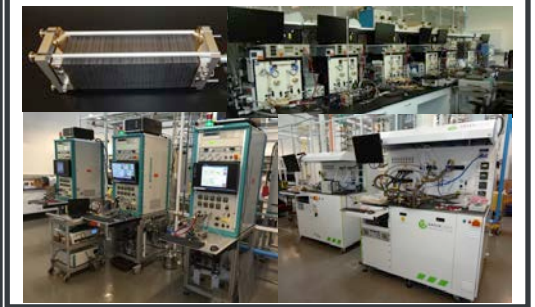
Material Synthesis:
Catalyst & Membrane Development



MEA integration
Coating, Spraying, Painting, Electrospinning, Lamination, Hot Press Transfer, Edge protection

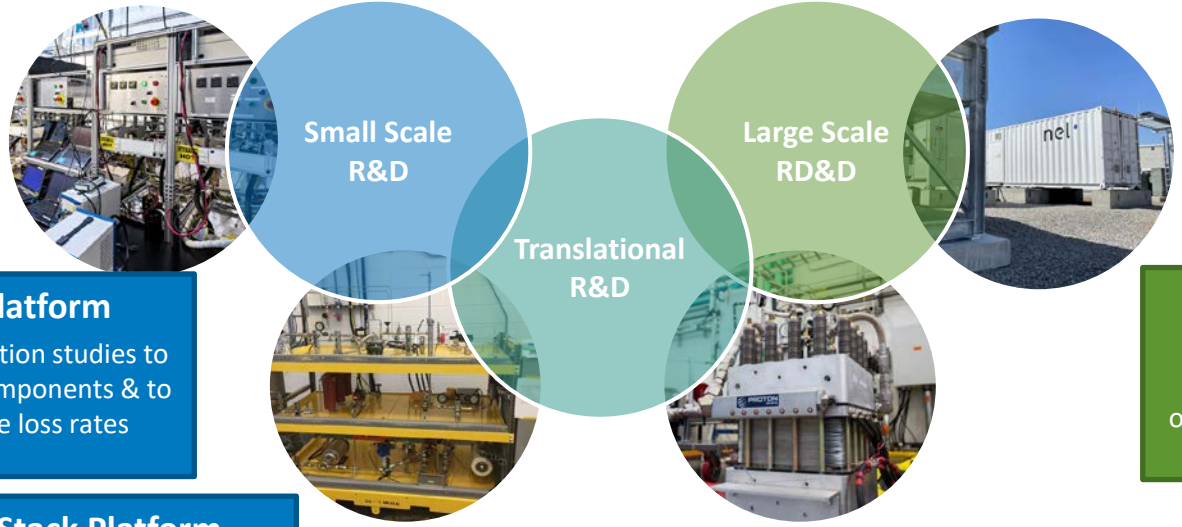


Performance Evaluation:
In-situ Diagnostics, PEMFC, AEMFC, Electrolyzer; Single Cell, Stacks, Spatial



Systems Integration in ESIF
… and soon Flatirons Campus

Growing Electrolyzer Capability at NREL
From Watts to Multi-MegaWatts



Single Cell Platform

Accelerated degradation studies to optimize material components & to determine voltage loss rates

Short Stack Platform

In-situ high–speed cell voltage, stack, and balance of plant (BOP) performance monitoring for continual intermittent operation

Full Stack Platform

Scaling electrolysis to characterize durability, response, and controls of multiple stacks

Full System Platform

Energy systems integration, durability, control & optimization with electrolysis, storage, and end uses

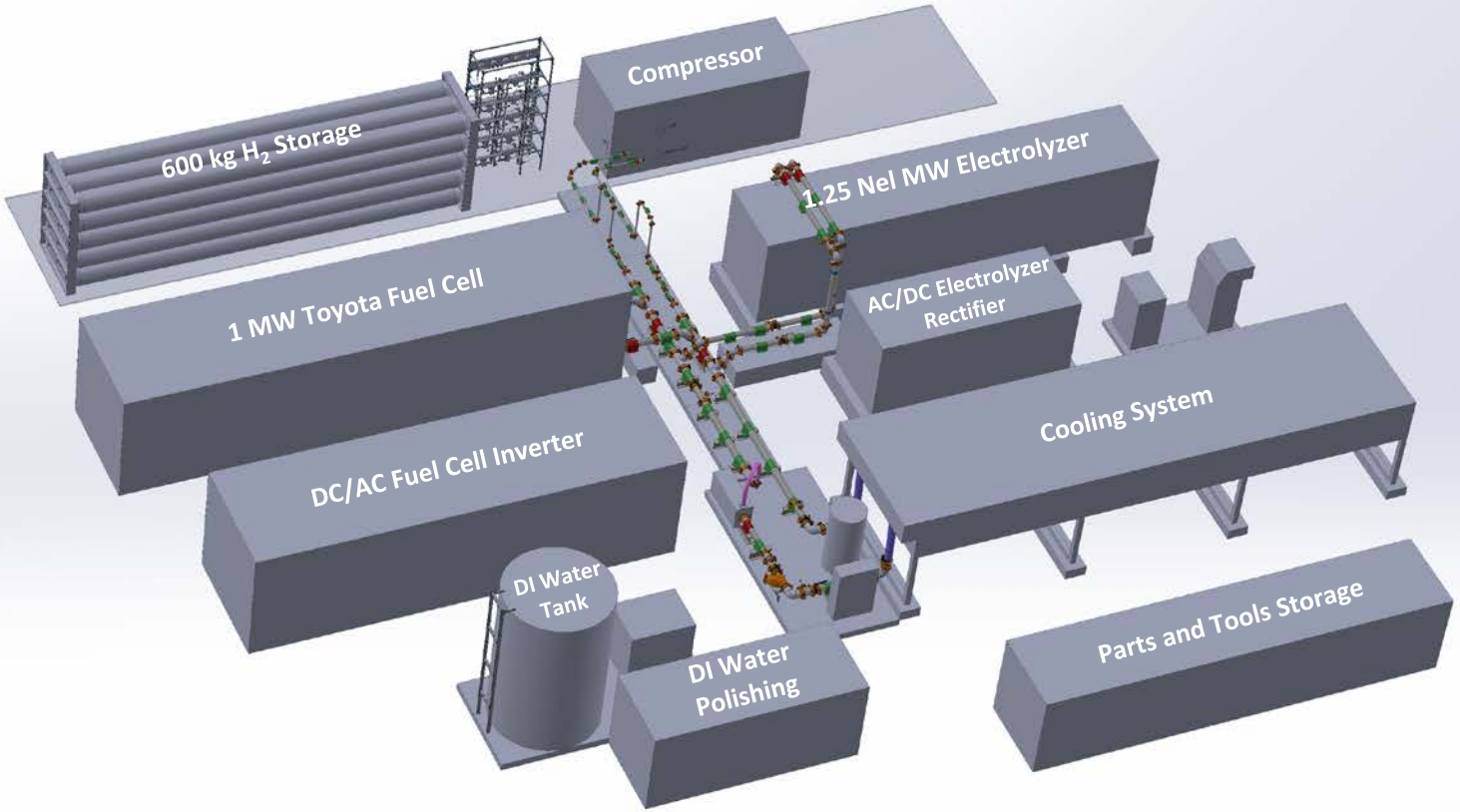
Experimental capabilities to accelerate advances from fundamental, single cell research to integrated systems research; with industry relevant scale and operation conditions

Images: NREL

The Role of Large-Scale Validation and Demonstration

- Prior to investment, investors, utilities, and other stakeholders need to **de-risk H_2 systems** through operating in real-life industrial environments
- Large-scale deployments (~100MW) need to be **de-risked** through smaller scale validation (1-5MW) with analysis to extrapolate to larger systems
- NREL's **Flatirons Campus** has this capability

3D Layout of Flatirons Campus Hydrogen System

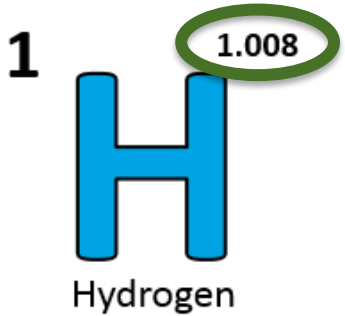


Recent View of Flatirons Campus H_2 System

When is Hydrogen & Fuel Cells Day?

Hydrogen and Fuel Cells Day
October 8

Held on hydrogen's very own atomic weight-day



Thank You

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NREL/PR-5900-87224

This work was authored by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by U.S. Department of Energy Office of Energy Efficiency and Renewable Energy Hydrogen and Fuel Cell Technologies Office. The views expressed in the article do not necessarily represent the views of the DOE or the U.S. Government. The U.S. Government retains and the publisher, by accepting the article for publication, acknowledges that the U.S. Government retains a nonexclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this work, or allow others to do so, for U.S. Government purposes.