



# 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



Photo by Werner Slocum, NREL 71582

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



# Mentoring & Career Development



Organized ECS lunch with esteemed Prof. Sossina Haile



Introduced postdocs to people at ECS networking event

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

# 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<sub>2</sub> hubs
  - \$1B for electrolysis RD&D
  - \$0.5B for clean H<sub>2</sub> 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 Holton/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



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<sub>2</sub> in the US

Economic potential: 2x to 4x more

Agriculture

Industry

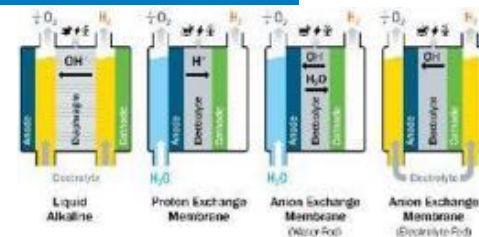
Buildings

'Hydrogen at Scale (H<sub>2</sub>@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.

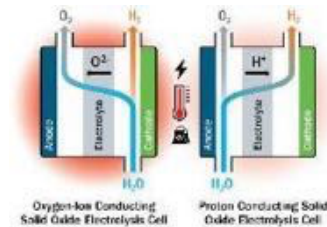
# R&D on Advanced Production Technologies

**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

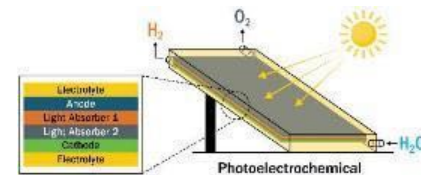
- **Near-term:** focus on electrolysis (water splitting with electricity and nuclear)
  - Accelerate **research on advanced water-splitting** technologies – take advantage of today’s renewable and nuclear power
  - Achieve \$100/kW electrolyzer stack goal in just 5 years through **H2NEW** consortium
  - 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<sub>2</sub> production
  - Incubate and support promising technology development through **HydroGEN** consortium



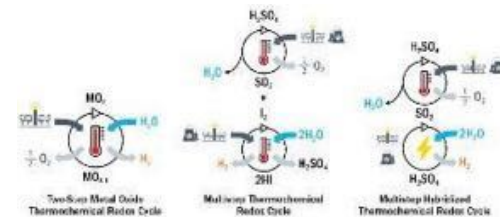
LTE



HTE



PEC



STCH



# HydroGEN Materials R&D Feeds to H2NEW Materials Integration

## H<sub>2</sub>NEW

U.S. DEPARTMENT OF ENERGY



## H<sub>2</sub>NEW

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)**



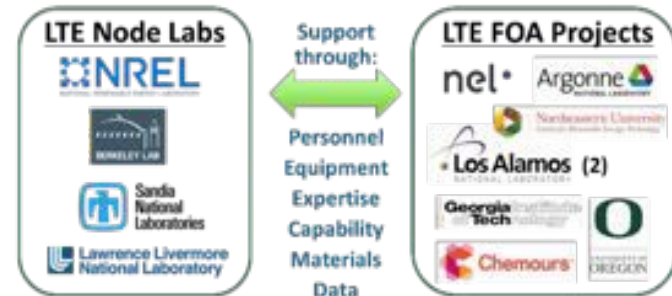
# HydroGEN Lab R&D + Lab Capability Support

## HydroGEN 2.0: Lab R&D Early-Stage Materials R&D Projects



## HydroGEN 1.0: Lab Support Lab capabilities + experts support projects

### HydroGEN Materials Capability Network 31 Lab – FOA Projects



# National Laboratory Collaboration is Critical for Success



Hydrogen from Next-generation Electrolyzers of Water

U.S. DEPARTMENT OF ENERGY

## Hydrogen Production



Advanced Water Splitting Materials

## Hydrogen Production



## BioH<sub>2</sub>

## Hydrogen Production



## Hydrogen Storage



MILLION MILE FUEL CELL TRUCK

U.S. DEPARTMENT OF ENERGY

## Fuel Cells



# 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**

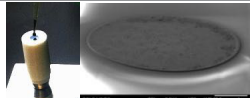


Hydrogen  
Penetration into  
Heavy-Duty  
Transportation  
Sector

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

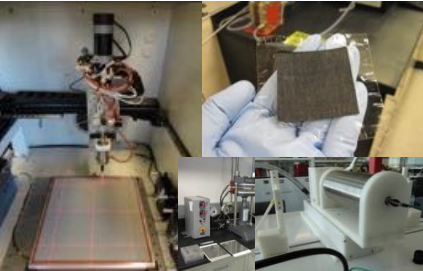
 <p><b>Electrochemical Characterization:</b> RDE &amp; RRDE stations for Mass &amp; Specific Activity, ECA, ORR; FOCMB, Seiras</p>	 <p><b>Roll-to-roll manufacturing:</b> Micro-gravure coating, Slot die coating</p>	 <p><b>Manufacturing Lab</b> QC Diagnostic Development, Areal characterization, Roll-to-roll demonstration</p>
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**Material Synthesis:**  
Catalyst & Membrane Development



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

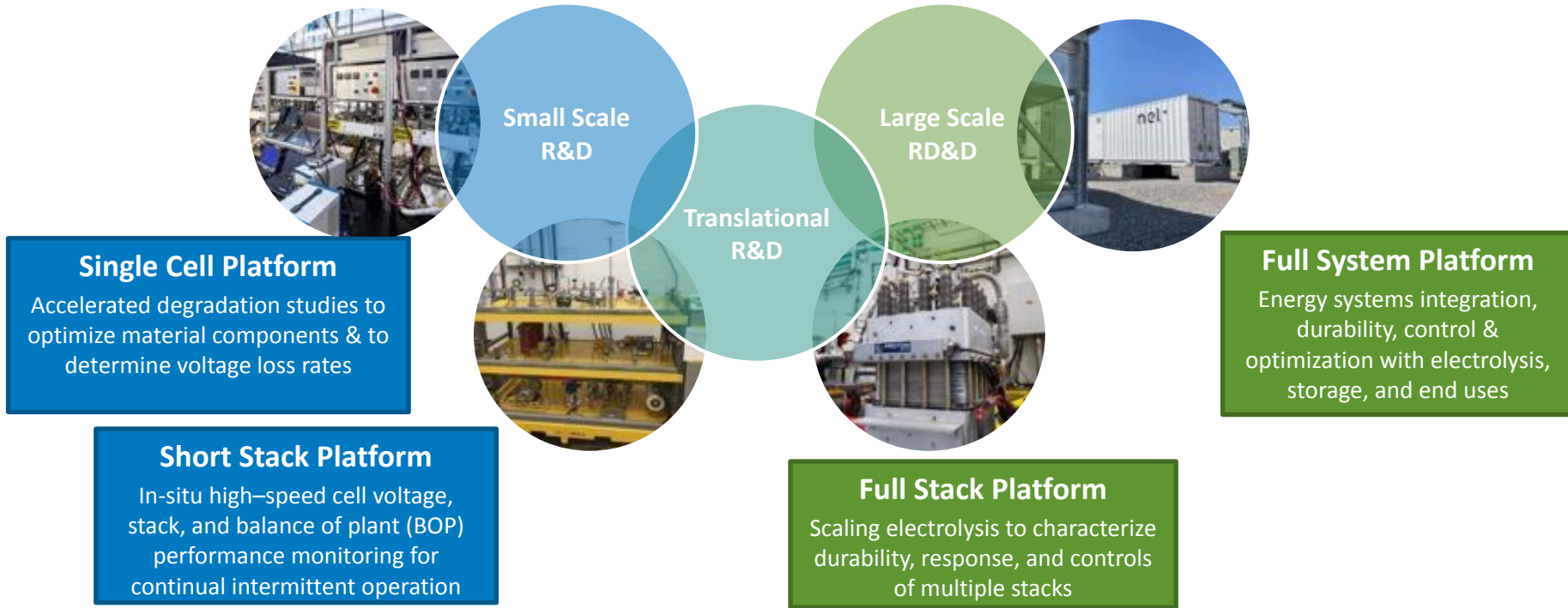


**Performance Evaluation:**  
In-situ Diagnostics, PEMFC, AEMFC, Electrolyzer; Single Cell, Stacks, Spatial



**Systems Integration in ESIF  
... and soon Flatirons Campus**

# Growing Electrolyzer Capability at NREL From Watts to Multi-MegaWatts



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

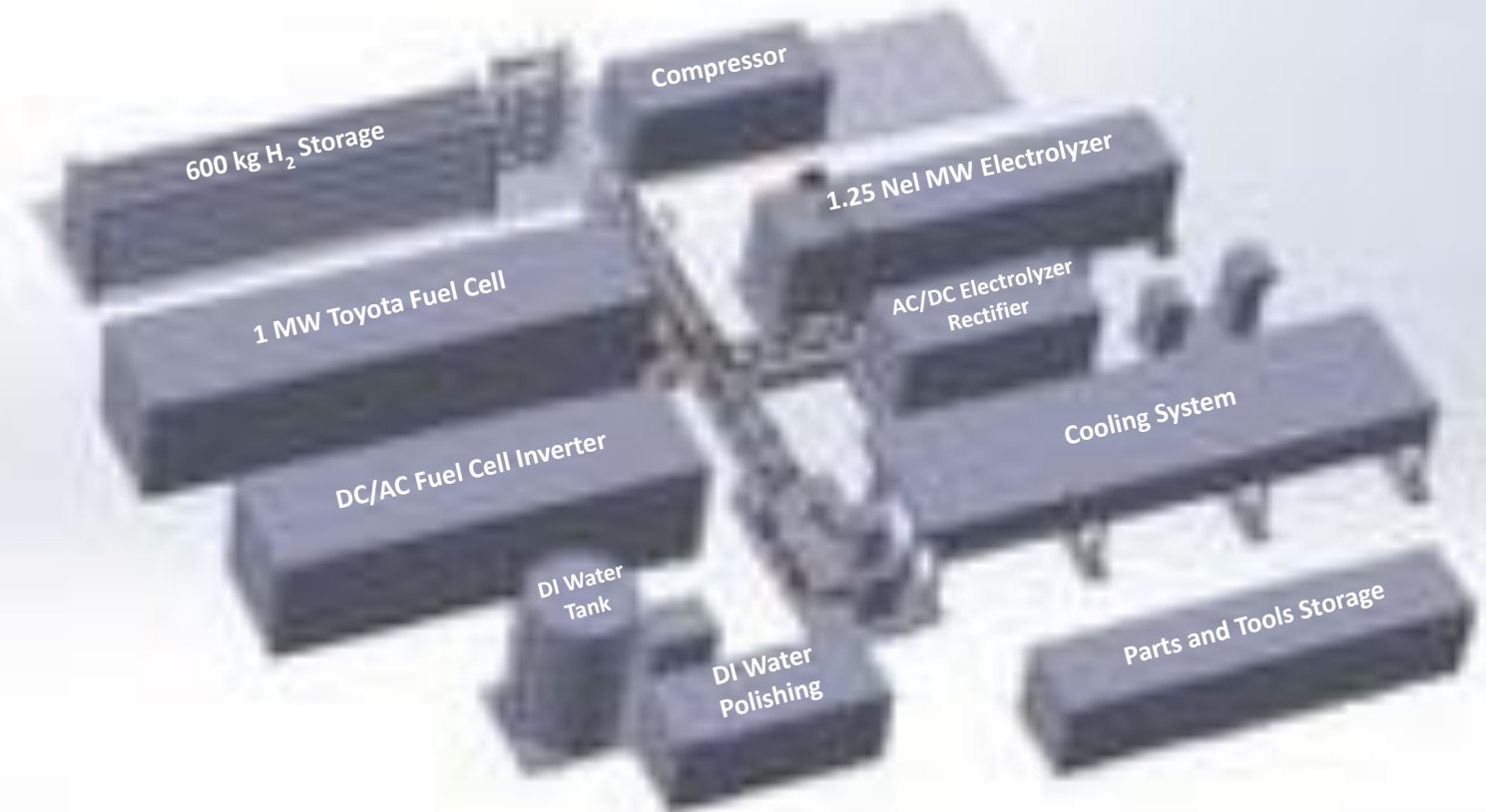


# The Role of Large-Scale Validation and Demonstration

- Prior to investment, investors, utilities, and other stakeholders need to **de-risk H<sub>2</sub> 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



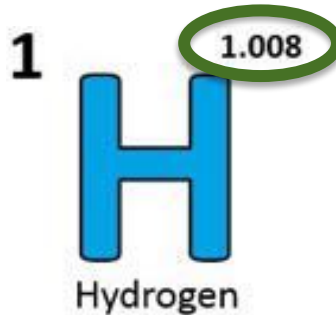
# Recent View of Flatirons Campus H<sub>2</sub> System



# 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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