# U.S. DOE Hydrogen Production Program & LAWE Meeting

**Dr. Sunita Satyapal (Director) & Dr. Ned Stetson (Program Manager),**
**Hydrogen and Fuel Cell Technologies Office**

Liquid Alkaline Electrolysis Experts Meeting, January 26-27, 2022

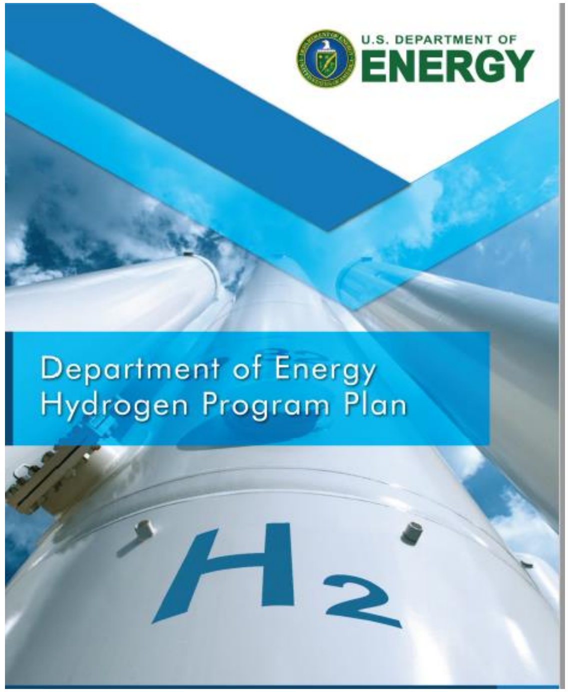




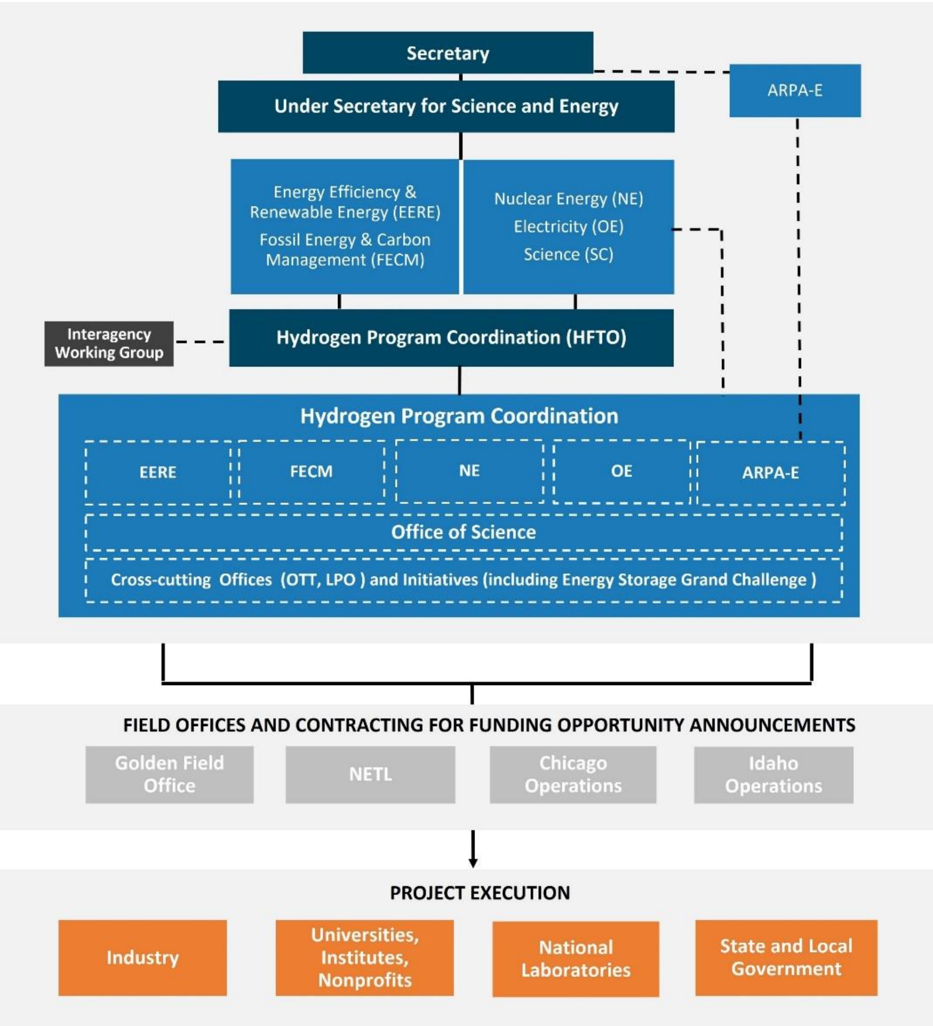
# The U.S. DOE Hydrogen Program

## 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*

# Snapshot of Hydrogen and Fuel Cells in the U.S.

## Deployment Examples
June 2021 Snapshot

**>500MW**
Backup Power

**>40,000**
Forklifts

**>172 MW**
PEM* Electrolyzers

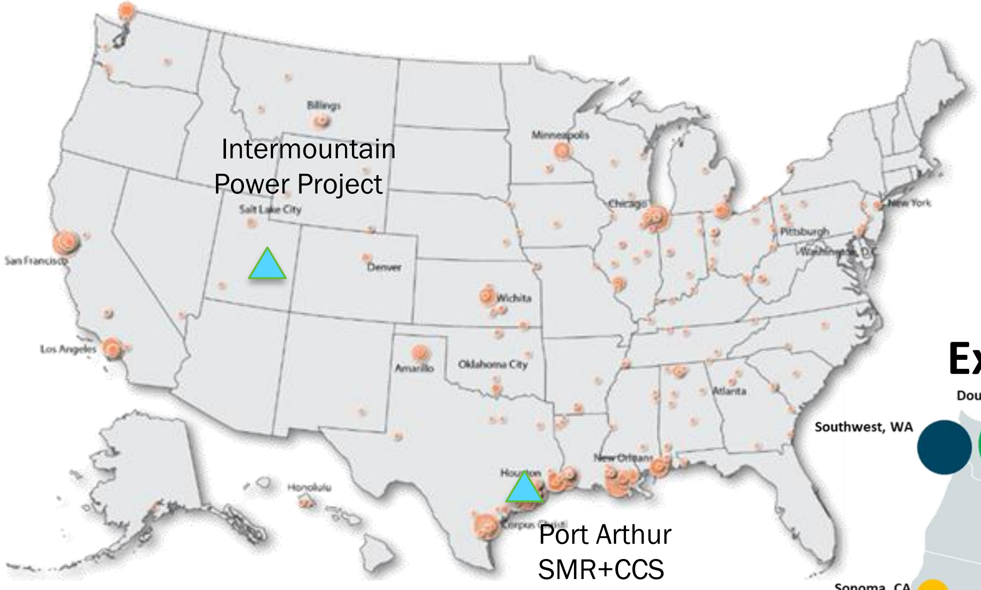
**>60**
Fuel Cell Buses

**>45**
$H_2$ Retail Stations

**>12,000**
Fuel Cell Cars

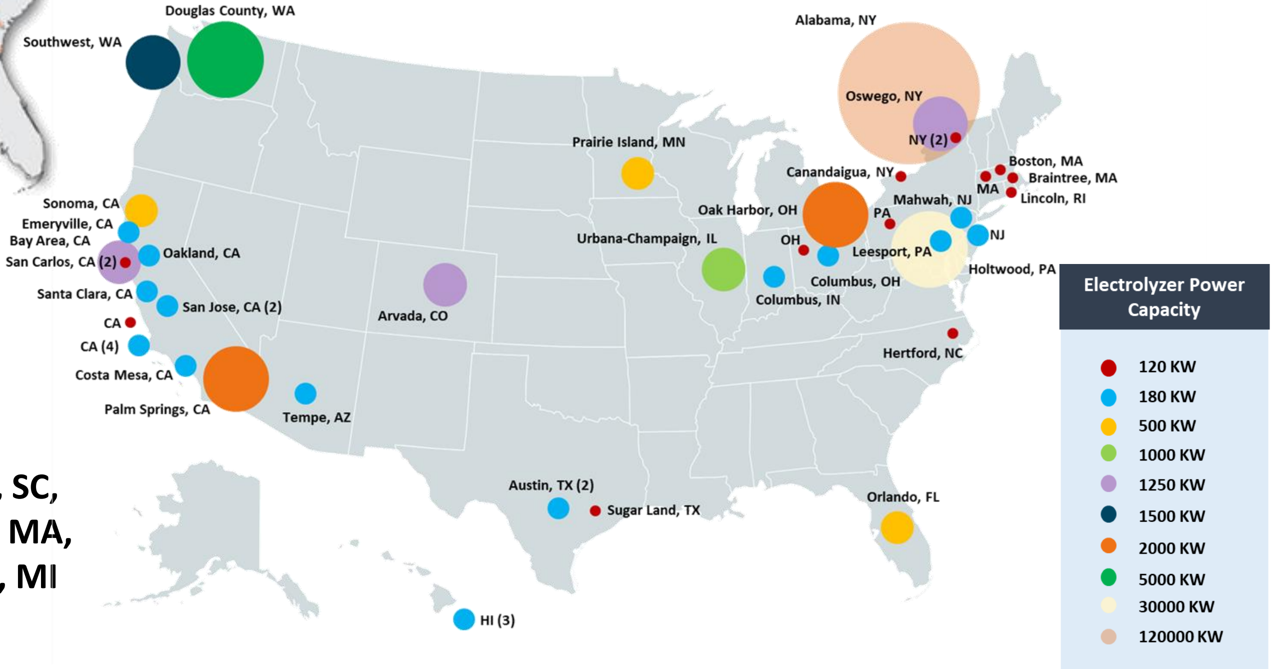
* Polymer electrolyte membrane

## Examples of Hydrogen Production Locations




- 10 million metric tons (MMT) $H_2$/yr
- Over 1,600 miles of $H_2$ pipelines
- World's largest $H_2$ storage cavern

## Examples of PEM Electrolyzer Installations

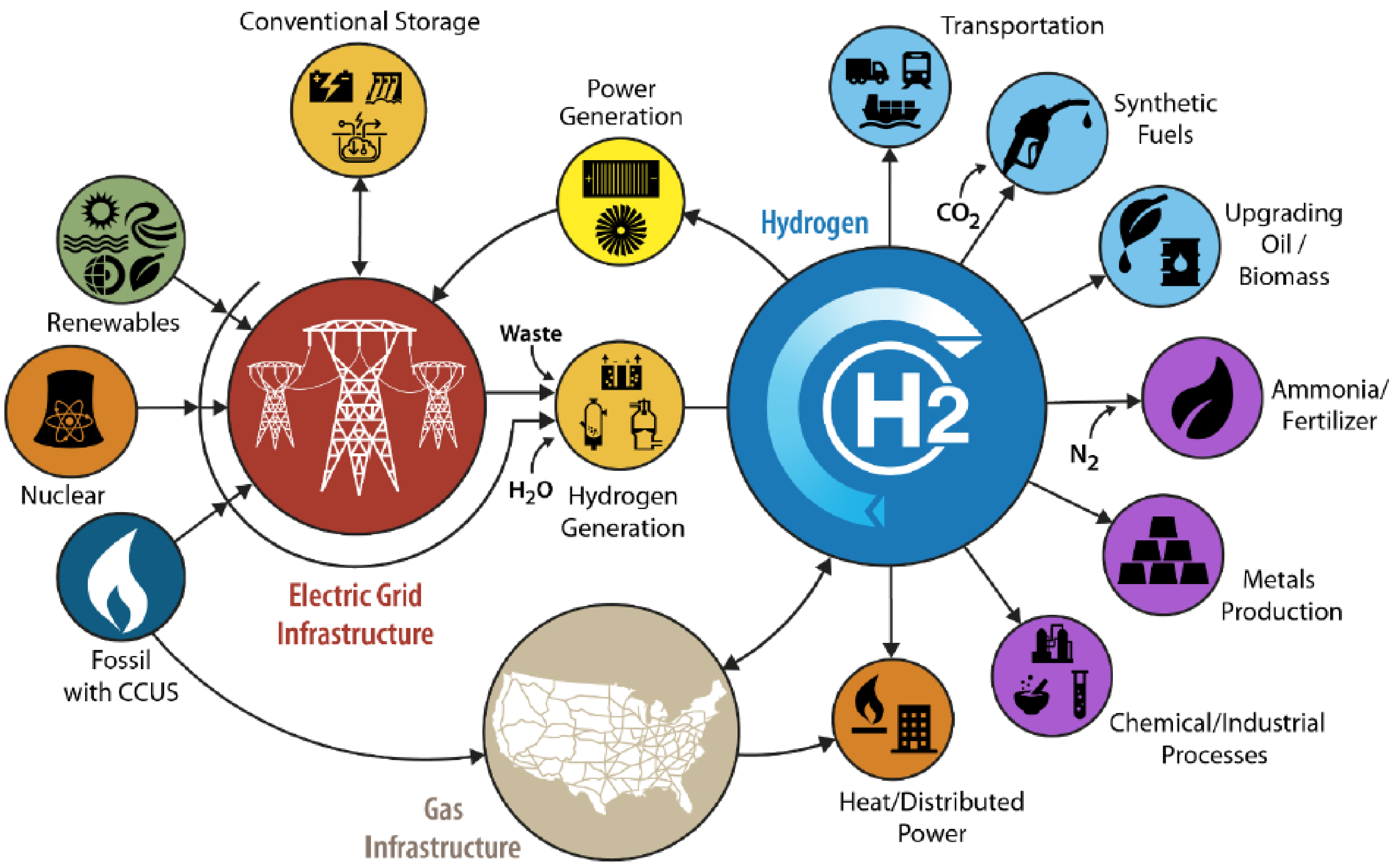



Current and under construction installations over 120 kW as of Jun. 2021
** Source: Arjona, et al, DOE HFTO Program Record, June 2021*

## Examples of Hydrogen Station Plans

| California | Northeast | AZ, HI, OH, SC, NJ, NY, CT, MA, CO, UT, TX, MI |
|---|---|---|
| 200 Stations Planned California Fuel Cell Partnership Goal | 12 – 20 Stations Planned | And more |

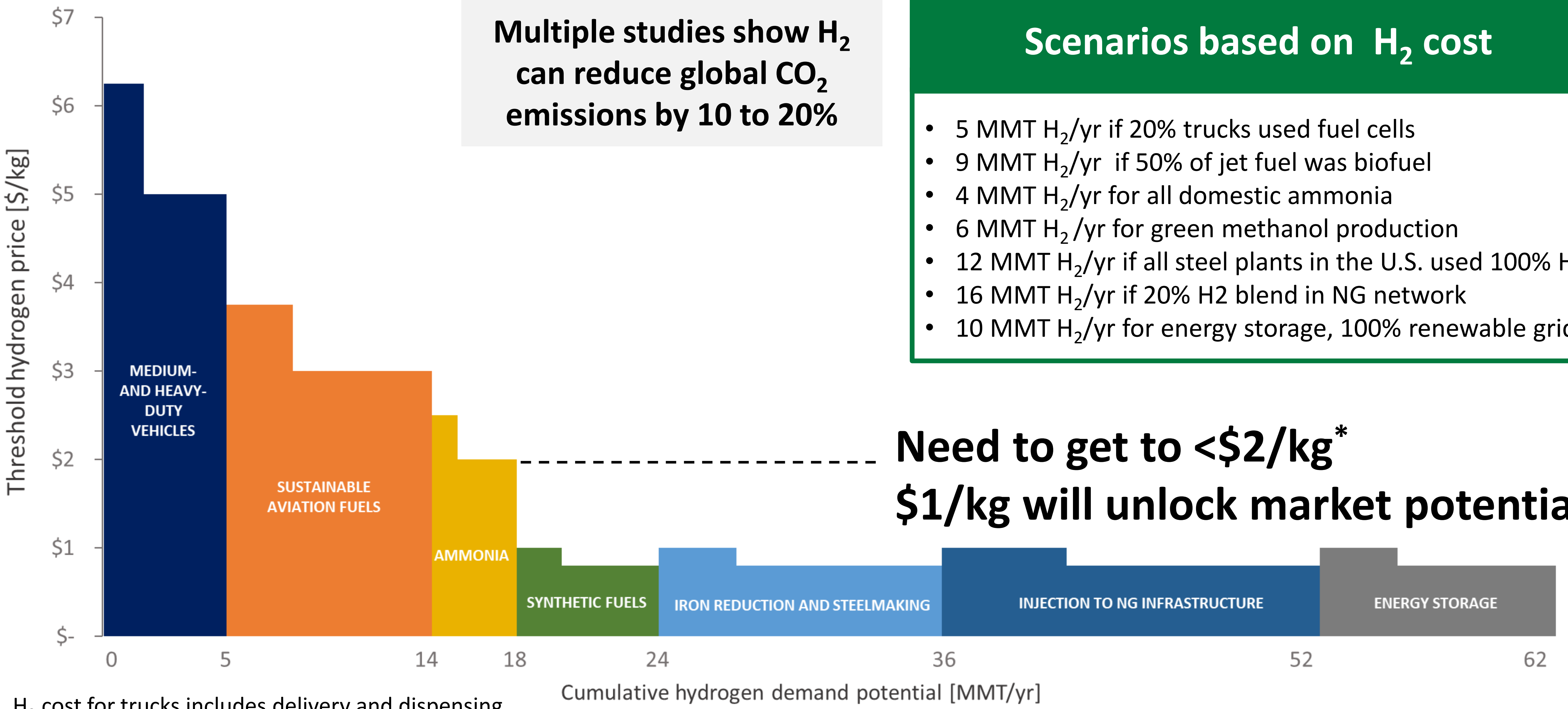
# Electrolysis within H2@Scale




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

- Making, storing, moving and using H2 more efficiently are the main H2@Scale pillars and all are needed.
- Making H2 is the inherently obvious, first step to spur the wide-ranging benefits of the H2@Scale vision.
- Electrolysis has most competitive economics and balances increasing renewable generation challenges.
- Timeframe is short, competition intense, coordinated effort critical for domestic competitiveness.

# Analysis Determines Market Potential Scenarios




**Multiple studies show $H_2$ can reduce global $CO_2$ emissions by 10 to 20%**

## Scenarios based on $H_2$ cost

- 5 MMT $H_2$/yr if 20% trucks used fuel cells
- 9 MMT $H_2$/yr if 50% of jet fuel was biofuel
- 4 MMT $H_2$/yr for all domestic ammonia
- 6 MMT $H_2$ /yr for green methanol production
- 12 MMT $H_2$/yr if all steel plants in the U.S. used 100% $H_2$
- 16 MMT $H_2$/yr if 20% H2 blend in NG network
- 10 MMT $H_2$/yr for energy storage, 100% renewable grid

**Need to get to <$2/kg***

**$1/kg will unlock market potential**

$H_2$ cost for trucks includes delivery and dispensing

* $H_2$ could compete at $1 to $2/kg higher cost with a carbon price

Results based on preliminary analysis

# President Biden and Energy Secretary Granholm at Climate Summit

"…I've asked the Secretary of Energy to speed the development of critical technologies to tackle the climate crisis. No single technology is the answer on its own because every sector requires innovation to meet this moment."

***President Joseph R. Biden***
*April 23, 2021*

Launch of Hydrogen Energy Earthshot
First of the Energy Earthshots
June 7, 2021
at DOE Hydrogen Program Annual Merit Review

***Secretary Jennifer Granholm***
*June 7, 2021*

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

# 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, demonstration, commercialization, and deployment
  - $500M for clean hydrogen technology manufacturing and recycling R&D

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

- **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**

# Clean Hydrogen Electrolysis Program – continued

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(e) FOCUS.—The program shall focus on research relating to, and the development, demonstration, and deployment of—

(1) low-temperature electrolyzers, including liquid-alkaline electrolyzers, membrane-based electrolyzers, and other advanced electrolyzers, capable of converting intermittent sources of electric power to clean hydrogen with enhanced efficiency and durability;

(2) high-temperature electrolyzers that combine electricity and heat to improve the efficiency of clean hydrogen production;

(3) advanced reversible fuel cells that combine the functionality of an electrolyzer and a fuel cell;

(4) new highly active, selective, and durable electrolyzer catalysts and electro-catalysts that—

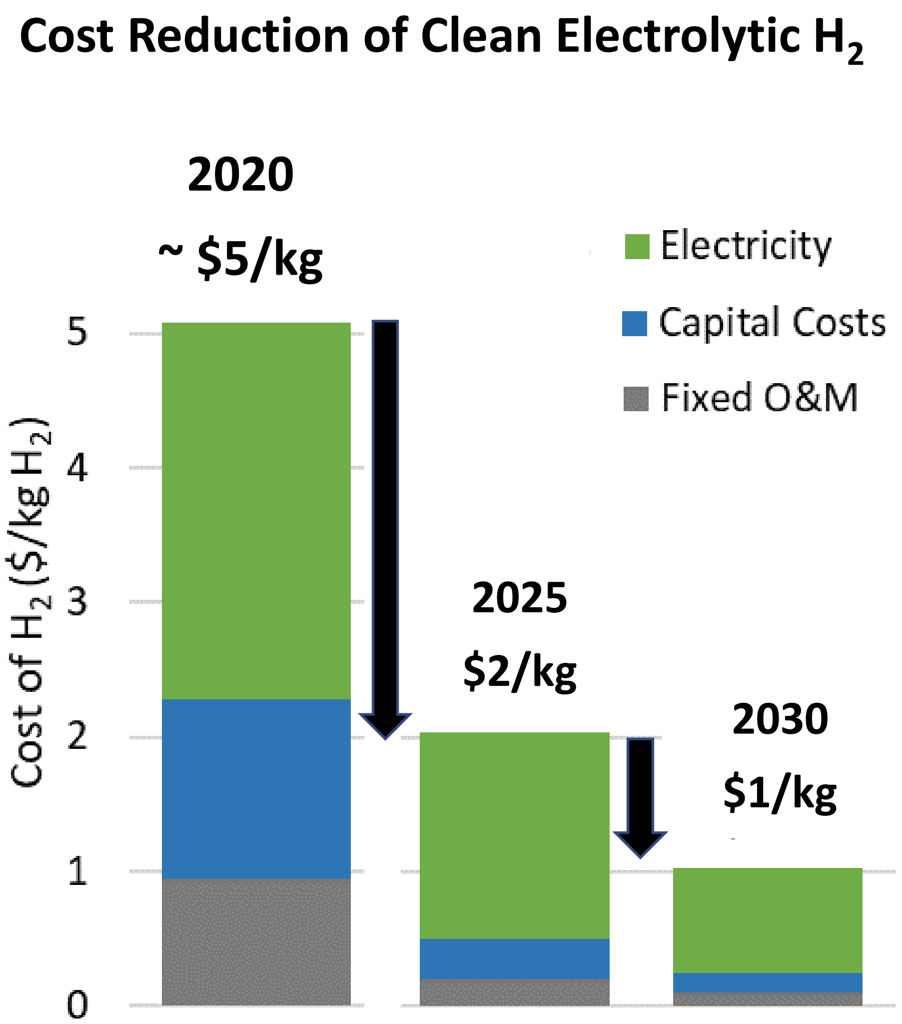
(A) greatly reduce or eliminate the need for platinum group metals; and

(B) enable electrolysis of complex mixtures with impurities, including seawater;

(5) modular electrolyzers for distributed energy systems and the bulk-power system (as defined in section 215(a) of the Federal Power Act (16 U.S.C. 824o(a)));

https://www.energy.gov/sites/default/files/2021-12/h2iq-12082021.pdf

# Pathways to Reduce the Cost of 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

# HFTO's Multi-layered Approach to Electrolyzer Development

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

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

**Advanced Components (TRL 4-5) –** RD&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

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

**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.

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

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

U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

# Connecting H2NEW Activities to Liquid Alkaline Technology

**Dr. Bryan Pivovar, Director of H2NEW, National Renewable Energy Laboratory**

Advanced Liquid Alkaline Water Electrolysis Experts Meeting

January 26, 2022

# Electrolyzers by Type

| Type | Pros | Cons |
|---|---|---|
| **Alkaline** | Well established, lower capital cost, more materials choices at high pH, high manufacturing readiness, can leverage established supply chains, demonstrated in larger capacity | Corrosive liquid electrolyte used, higher ohmic drop, lack of differential pressure operation, shunt currents, limited intermittency capabilities, efficiency |
| **Polymer Electrolyte Membrane** | Low ohmic losses/high power density operation, differential pressure operation, DI water only operation, leverages PEM fuel cell development and supply chain, load following capability | Requires expensive materials (Ti, Ir, Pt, perfluorinated polymers), lower manufacturing and technology readiness, efficiency |
| **Solid Oxide** | High efficiency, low-cost materials, integration with continuous high temperature electricity sources (e.g., nuclear energy), leverages SOFC development and supply chain, differential pressure operation | High temperature materials challenges, limited intermittency capabilities, thermal integration, lower manufacturing and technology readiness, steam conversion and separation challenges |

**Low Temperature (0 - 200$^{o}$C)**

**High Temperature (>500$^{o}$C)**

Badgett, Ruth and Pivovar, “Economic considerations for hydrogen production with a focus on polymer electrolyte membrane electrolysis,” accepted 2021.

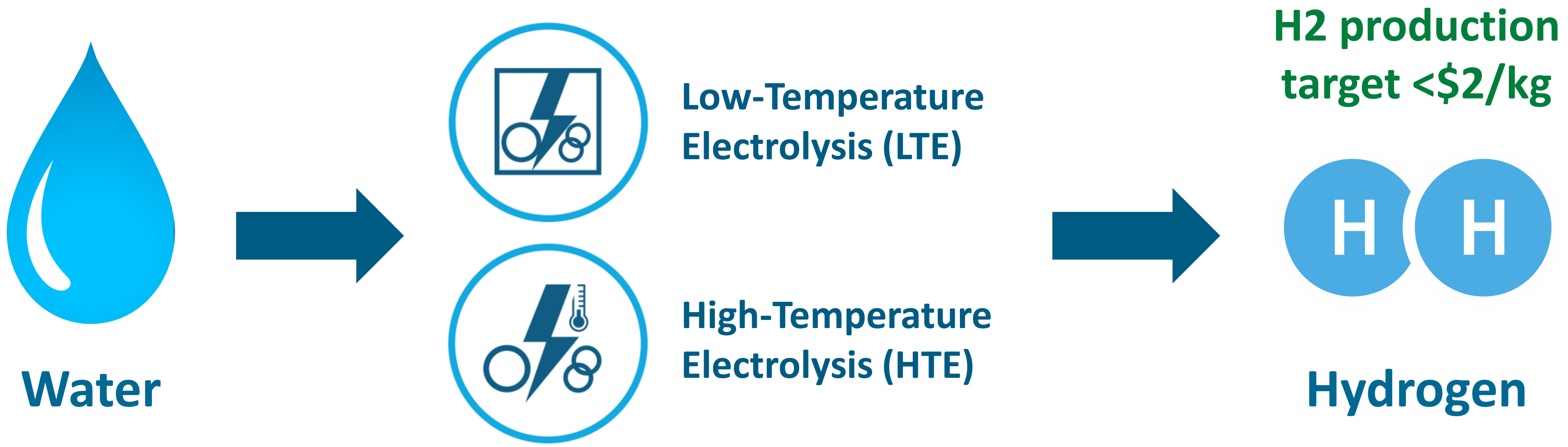
# Liquid Alkaline Water Electrolyzers

- Have not been the major domestic emphasis
- Received limited RD&D funding
- Have growing domestic (industrial) interest
- Have R&D needs to become/improve competitiveness
- Have a significant domestic basis from which to leverage
  - PEM electrolysis
  - Alkaline membrane electrolysis
  - Significant National Lab and Academic assets

- Purpose of this meeting is to start filling in these gaps

# Liquid Alkaline Water Electrolysis Parallels to PEM/SOEC in H2NEW

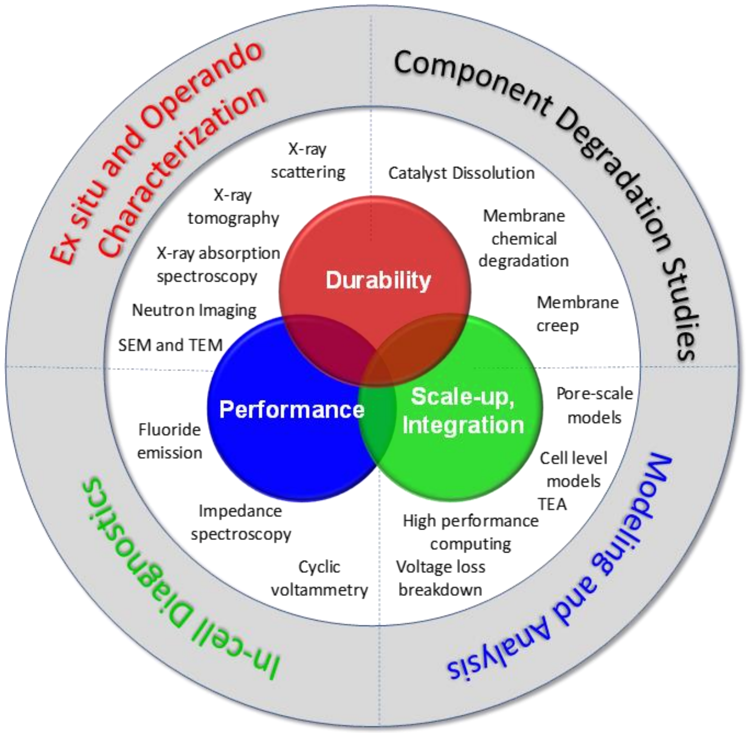
Goal: H2NEW will address components, materials integration, and manufacturing R&D to enable manufacturable electrolyzers that meet required cost, durability, and performance targets, simultaneously, in order to enable \$2/kg hydrogen.



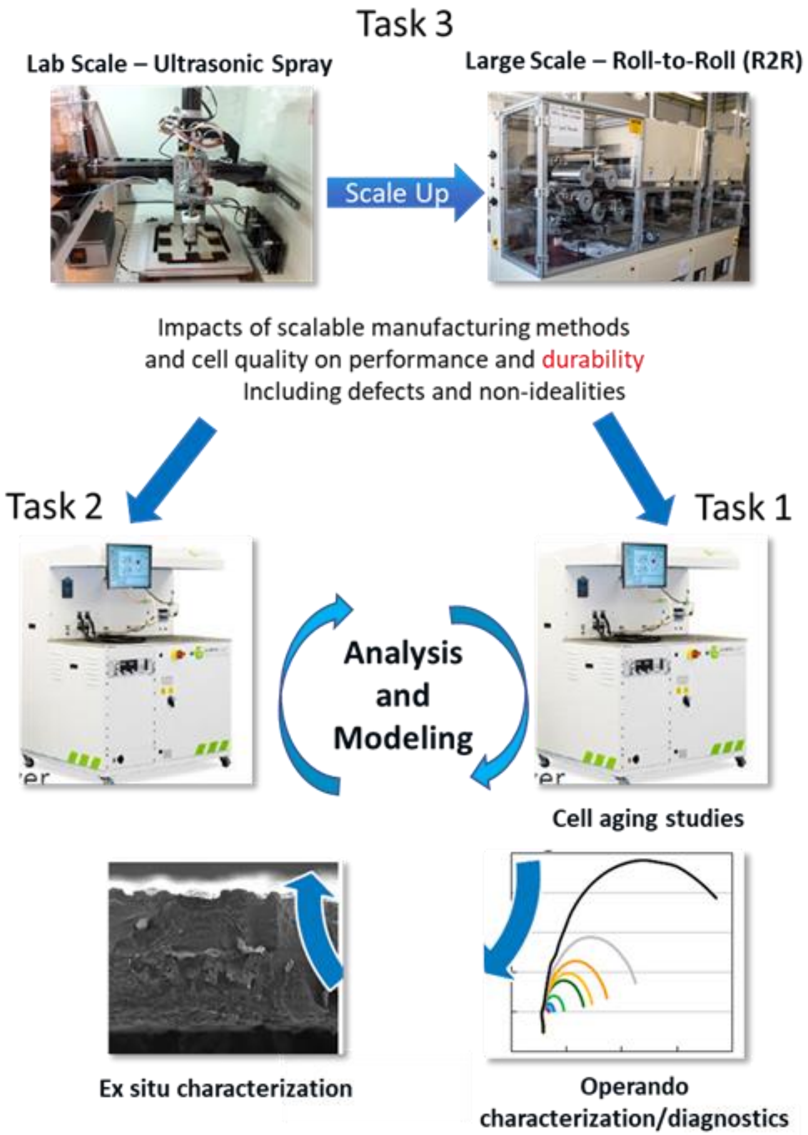

H2NEW (75% PEM, 25% SOEC) has a clear target of establishing and utilizing experimental, analytical, and modeling tools needed to provide the scientific understanding of electrolysis cell performance, cost, and durability tradeoffs of electrolysis systems under predicted future operating modes.

https://www.hydrogen.energy.gov/pdfs/review21/p196_pivovar_boardman_2021_o.pdf

# LAWE R&D needs similar to PEM R&D Approach of H2NEW



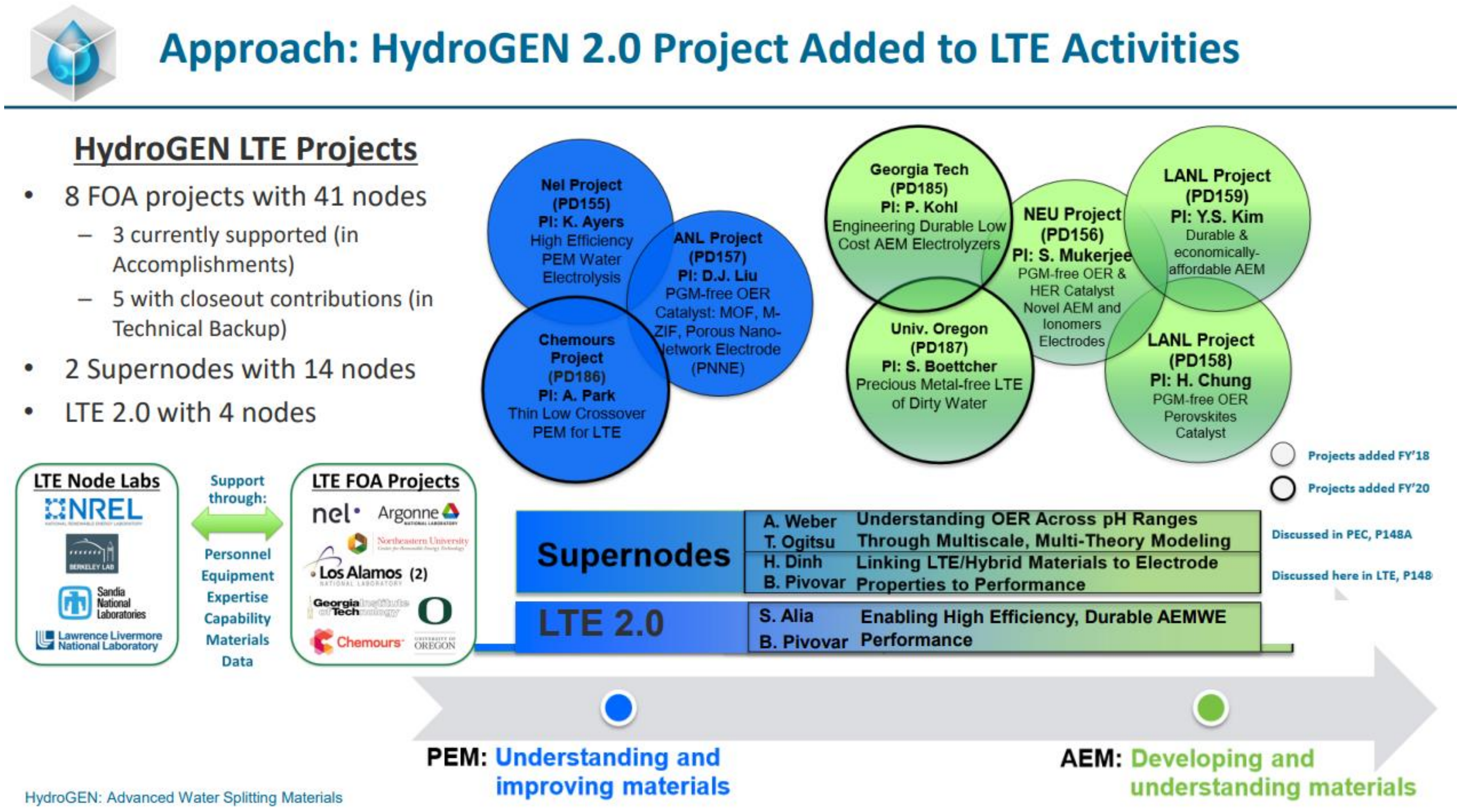

- Durability (Task 1, P196a)
  - Establish fundamental degradation mechanisms
  - Develop accelerated stress tests
  - Determine cost, performance, durability tradeoffs
  - Develop mitigation
- Performance (Task 2, P196b)
  - Benchmark performance
  - Novel diagnostic development and application
  - Cell level models and loss characterization
- Scale-up (Task 3, P196a)
  - Transition to mass manufacturing
  - Correlate processing with performance and durability
  - Guide efforts with systems and technoeconomic analysis (Task 3c, P196d)




https://www.hydrogen.energy.gov/pdfs/review21/p196_pivovar_boardman_2021_o.pdf

# Relevant Materials Development Efforts in HydroGEN

- Advanced materials and components are needed and related materials have been pursued through the HydroGEN and HydroGEN 2.0 Consortia.
- Academic, Industrial and National Lab coordination




https://www.hydrogen.energy.gov/pdfs/review21/p148a_alia_2021_p.pdf

# Meeting Objectives

## Day 1 – Expert Presentations

Hear from experts on the challenges & opportunities for current & future liquid alkaline electrolyzer technologies

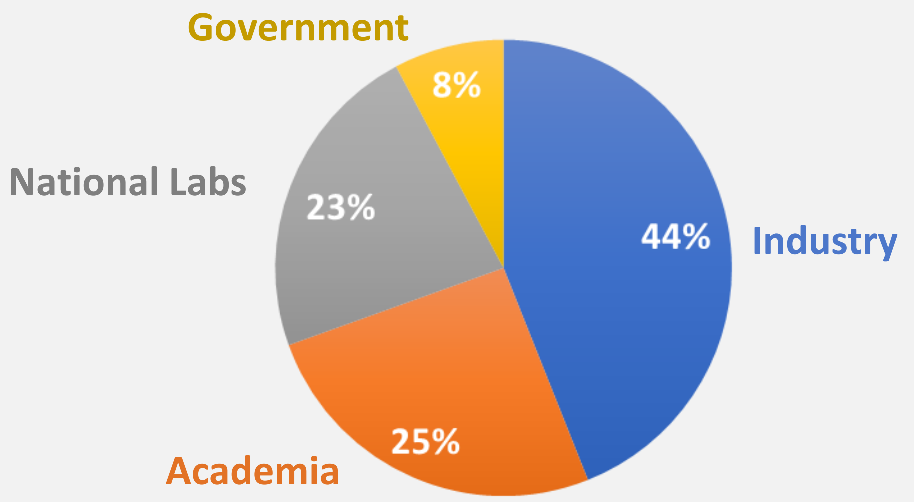
*Learn the current state of the field*

## Day 2 – Parallel Discussions

Discuss and prioritize the most promising & impactful RD&D opportunities for next-generation liquid alkaline electrolyzers

*Identify RD&D pathways to achieve $1/kg*

*Diverse stakeholders from industry, government, academia & the labs*




**Please feel free to use the Zoom *Q&A* feature to record your comments & questions during the meeting**

# Thank You for Joining Us!

*Special thanks to the Organizing Team...*

| *HFTO* | *NREL* |
| --- | --- |
| *Ned Stetson* | |
| *James Vickers* | *Bryan Pivovar* |
| *Dave Peterson* | *Sara Havig* |
| *McKenzie Hubert* | *Rebecca Martineau* |
| *Anne Marie Esposito* | *Jackie Petre* |
| *Nikkia McDonald* | *Ryan Ingwersen* |
| *Cassie Osvatics* | |

*And all Moderators & Scribes!*

| | |
| --- | --- |
| *Ahmed Farghaly* | *Julie Fornaciari* |
| *Alexey Serov* | *Jason Keonhag Lee* |
| *Andrew Tricker* | *Marcelo Carmo* |
| *Colin Gore* | *Mark Ruth* |
| *Debbie Myers* | *Plamen Atanassov* |
| *Elliot Padgett* | *Rangachary Mukundan* |
| *Eric Miller* | *Sandipkumar Maurya* |
| *Guido Bender* | *Shaun Alia* |
| *Haoran Yu* | *Tobias Schuler* |

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**www.energy.gov/fuelcells**

**www.hydrogen.energy.gov**

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

**h2new.energy.gov**

# Meeting Agenda* – Expert Presentations

| | | |
|---|---|---|
| 11:00 AM | Welcome, Context, & Overview of Workshop Goals | *DOE Hydrogen & Fuel Cell Technologies Office*<br>Bryan Pivovar, *National Renewable Energy Laboratory* |
| 11:30 AM | **Introduction to Liquid Alkaline Electrolysis** | **Marcelo Carmo, *Nel Hydrogen US*** |
| 12:15 PM | Cell & Stack Components (Interfaces & Corrosion Challenges) | Ed Revers, *De Nora* |
| 1:00 PM | System & Integration Challenges | Joe Poindexter, *Teledyne* |
| 1:30 PM | - Break - | |
| 2:00 PM | Cell-level Challenges | Steven Kloos, *AquaHydrex* |
| 2:45 PM | Accelerated Stress Test (AST) Development | Rangachary "Mukund" Mukundan, *Los Alamos National Laboratory* |
| 3:30 PM | Component & System Technoeconomic Analysis | Brian James, *Strategic Analysis* |
| 4:15 PM | - Wrap-up and Adjourn - | |

Moderators: Dave Peterson, *HFTO*
James Vickers, *HFTO*

**All times in Eastern Standard Time*