U.S. DEPARTMENT OF ENERGY

Hydrogen Program
2022 Annual Merit Review and
Peer Evaluation Meeting

Hydrogen Shot – Industry/Lab Collaboration and Innovation Panels

June 7, 2022

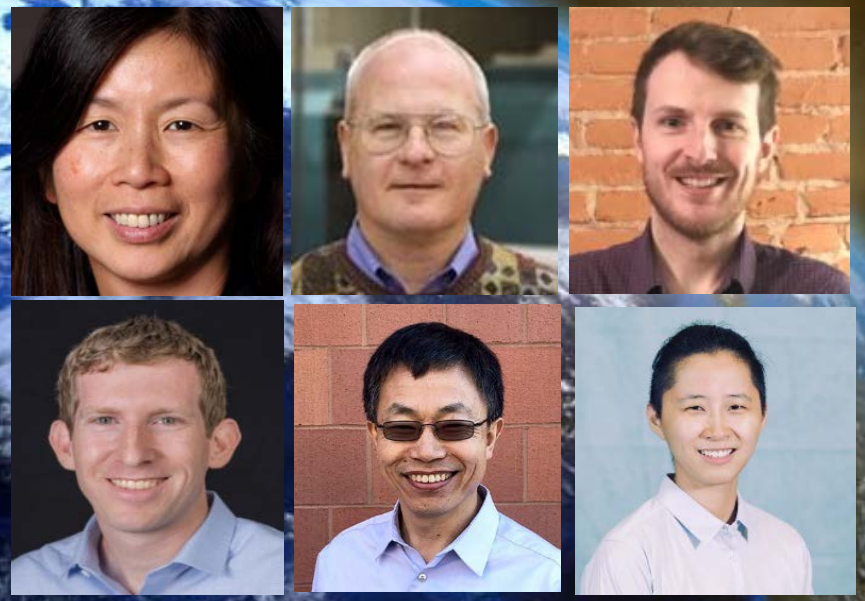
DOE Hydrogen Shot Industry & Lab Panels

PROGRAM		
***PANEL 1* - 12:00 PM ET**	***PANEL 2* - 12:20 PM ET**	***PANEL 3* - 12:40 PM ET**
HydroGEN Consortium Partnerships	***Integrated Systems Collaborations***	***Low-Temperature Electrolyzers***
Huyen Dinh *Senior Scientist, NREL* **Mike Tucker** *Staff Scientist, LBNL* **Scott Swartz** *CTO, Nexceris* **Yushan Yan** *CEO, Versogen* **Andrew Park** *R&D Principal Engineer, The Chemours Co.* **Yingying Chen** *Research Scientist, W. L. Gore & Associates*	**Richard Boardman** *Directorate Research Fellow, INL* **Olga Marina** *Chief Scientist, PNNL* **Harry Abernathy** *Senior Scientist, NETL* **Rita Baranwal** *CTO, Westinghouse* **Christy Verbofsky** *CRADA Project Manager, Westinghouse* **Colleen Wright,** *VP of Corporate Strategy, Constellation* **Noah Meeks,** *Principal Research Engineer, Southern Co.*	**Bryan Pivovar** *Senior Research Fellow, NREL* **Debbie Myers** *Senior Scientist, ANL* **Kathy Ayers** *VP for R&D, Nel Hydrogen* **Corky Mittelsteadt** *VP for Electrolyzer Technology Plug Power*

Moderator
Eric Miller
DOE-EERE-HFTO

June 7th, 2022

PANEL 1: HydroGEN Partnerships



Huyen Dinh
Senior Scientist, NREL

Mike Tucker
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Scott Swartz
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Yushan Yan
CEO, Versogen

Andrew Park, *R&D*
Principal Engineer, The Chemours Co.

Yingying Chen, *Research Scientist,*
W. L. Gore & Associates

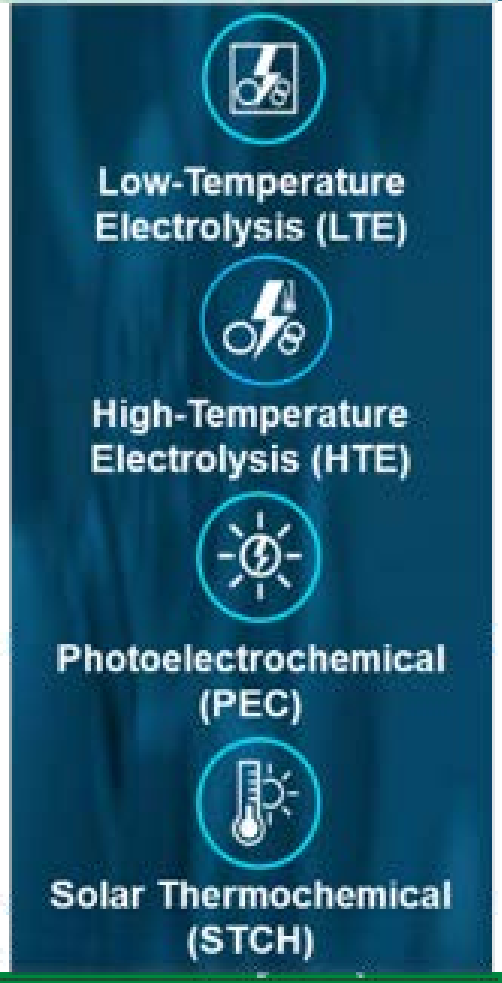
HydroGEN is Advancing Hydrogen Shot

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



National Lab Consortium Team

NREL National Renewable Energy Laboratory; Berkeley Lab; Idaho National Laboratory; Sandia National Laboratories; Lawrence Livermore National Laboratory

H_2 Production target of $1/kg

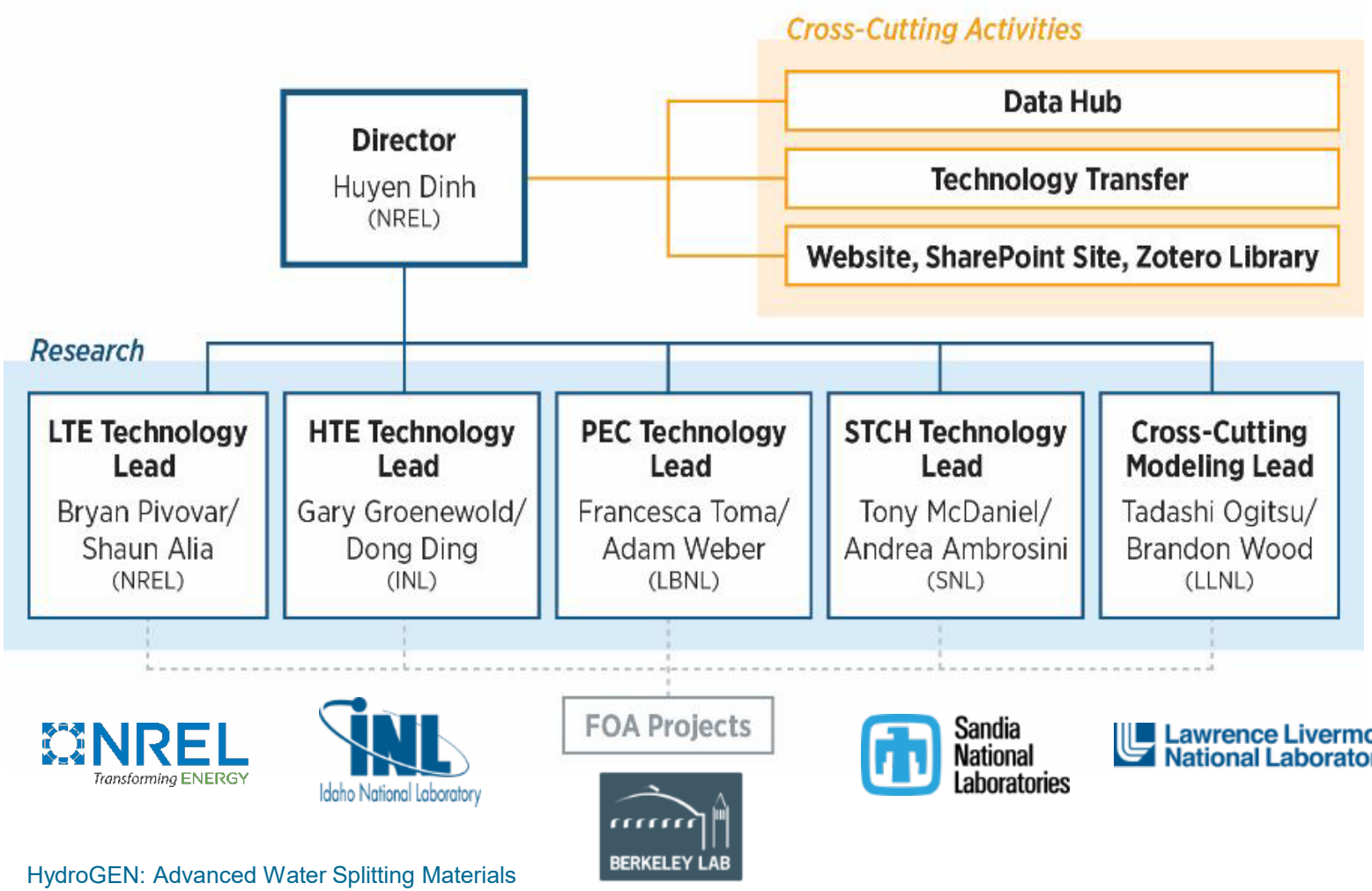
Hydrogen

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

HydroGEN 2.0 Collaboration

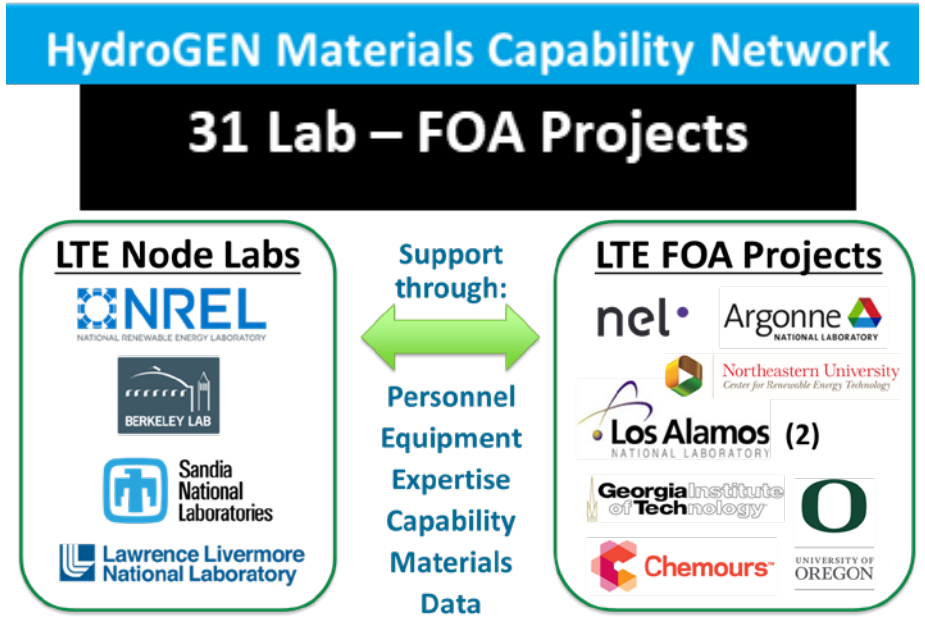
HydroGEN 2.0:

- Early-Stage Materials R&D Projects



HydroGEN 1.0:

- Lab capabilities and experts support projects



Community Approach to Benchmarking and Protocol Development

Goal: Develop best practices in materials characterization and benchmarking: Critical to accelerate materials discovery and development

Best Practices in Materials Characterization

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

- **4 Annual AWS community-wide benchmarking workshop**
- **Developed high-level roadmaps by AWS technology**
- **Disseminated information to AWS community**
- **Strong community engagement and participation, nationally and internationally**

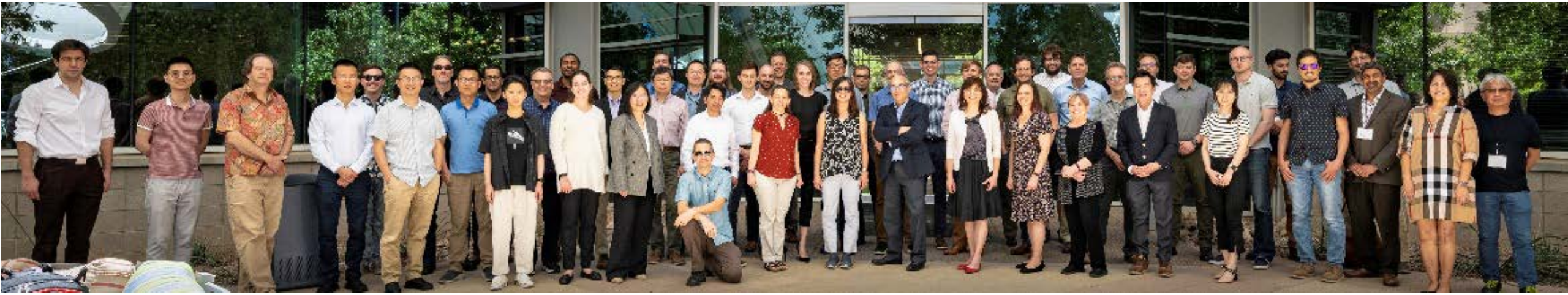
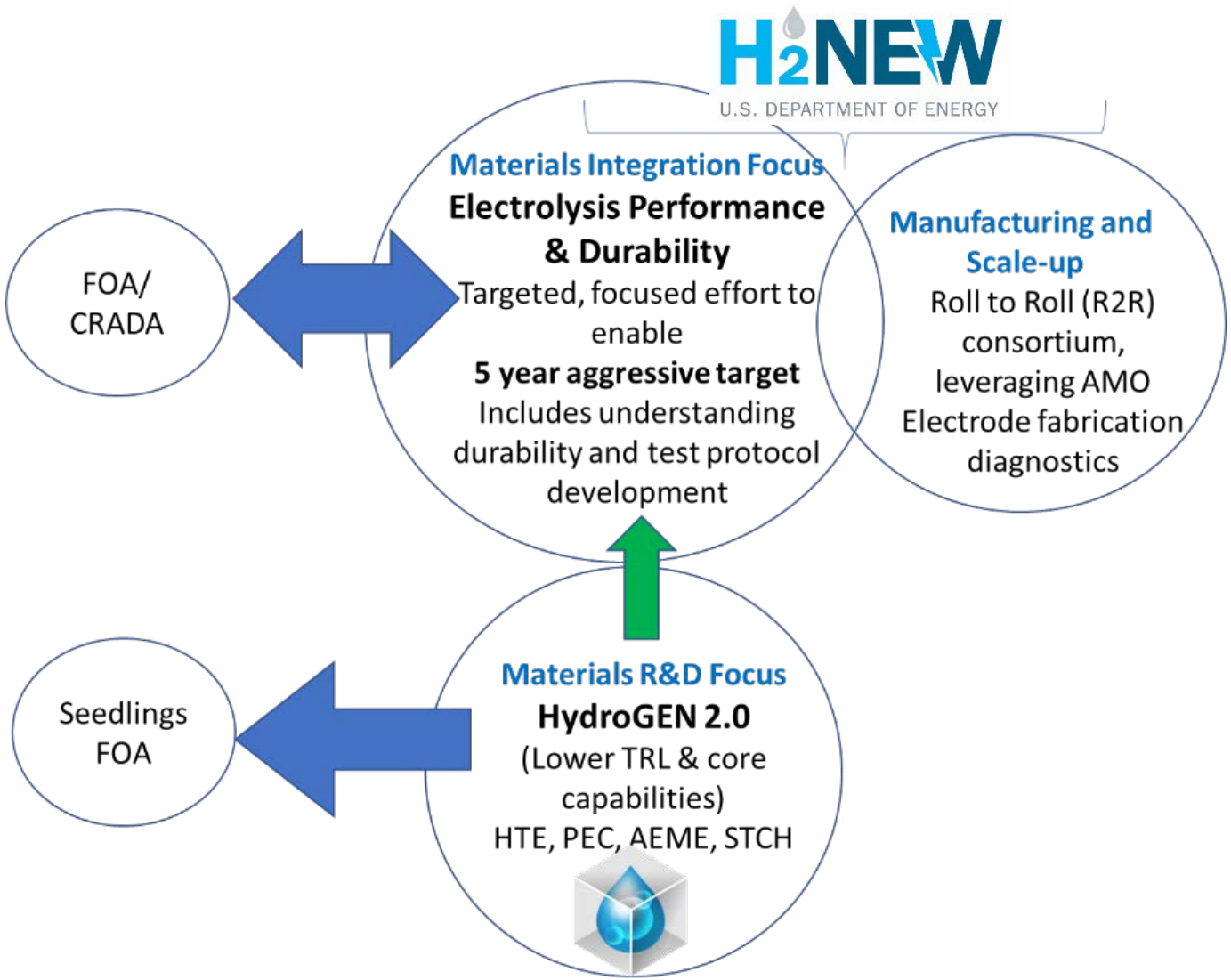


photo credit: Tadashi Ogitsu; 2022; Group picture at the 4th Advanced Water Splitting Technology Pathways Benchmarking and Protocols Workshop, May 2022

HydroGEN Materials R&D Feeds to H2NEW Component Integration



H2NEW Consortium

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

includes HydroGEN 1.0 legacy

HydroGEN 2.0 Focus

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

Nexceris Perspectives

Scott Swartz
Founder and CTO
Nexceris, LLC

About Nexceris

Nexceris, LLC

- Founded in 1994, privately held, located in Lewis Center, Ohio.
- 25+ years of experience in the solid oxide fuel cell and electrolysis space.
- Vertically integrated manufacturer of solid oxide materials, cells, coatings and stacks.
- Other products include sensors, catalysts, batteries, and solid oxide cell materials.

Proven solid oxide technology provider and stack manufacturer with state-of-the-art high temperature electrolysis technology.

NEXCERIS
where energy meets environment

Nexceris' Long History with National Labs

National Lab Interactions

- First government project with PNNL in 1996 (ONR).
- First SOFC project with LBNL in 1997 (EERE).
- Multiple collaborations with PNNL, NETL, ORNL and Argonne on SOFC materials in the 2000's and 2010's.
- Ongoing collaboration with PNNL on battery technology development.
- Current collaboration with NETL on SOFC/turbine hybrid power systems.
- Collaborating with LBNL and INL under ongoing EERE sponsored high-temperature electrolysis projects.

Argonne NATIONAL LABORATORY

BERKELEY LAB
LAWRENCE BERKELEY NATIONAL LABORATORY

Pacific Northwest NATIONAL LABORATORY

OAK RIDGE National Laboratory

INL Idaho National Laboratory
70 YEARS OF SCIENCE & INNOVATION

NETL NATIONAL ENERGY TECHNOLOGY LABORATORY

Versogen Perspectives

Yushan Yan,
CEO
Versogen

Yushan Yan, Ph.D.
Cheif Executive Officer and Co-Founder

Yushan is a leading electrochemical engineer, inventor, educator and entrepreneur with a Ph.D. in Chemical Engineering. He has worked in both industry and academia, and his 20+ U.S. patents have contributed to multiple startups, including Versogen and NanoH2O. He serves as the Henry B. du Pont Chair in Chemical and Biomolecular Engineering at the University of Delaware, where Versogen's research and development efforts began. His research has focused on developing AEMs and AEM fuel cells and electrolyzers for twenty years. His recognitions include Fellow of the Electrochemical Society, National Academy of Inventors, and American Association for the Advancement of Science, and recipient of the Electrochemical Society's Energy Technology Division Research Award.

Sharon Perl, Ph.D., MBA
Director of Membrane Production

Sharon has both the knowledge and experience in process development and scale-up of chemistry related products. Her deep understanding of organic chemistry, together with her extensive industrial knowledge in process optimization and scale up from bench to commercialization aid to scale-up Versogen membrane and Ionomer production. She has managed small and large teams. She earned a Ph.D. in Chemistry from the Technion – Israel institute of technology and an MBA from Derby University.

Balsu Laksmanan, Ph.D.
Chief Technology Officer

Balsu has over 20 years of leadership experience in hydrogen and fuel cell technology, business development, and commercialization. As CTO, he leads the efforts to design, build and commercialize the Anion Exchange Membrane (AEM) electrolyzer. Previously, he developed a 100kW scale Proton Exchange Membrane (PEM) electrolyzer stack at Ohmium, and led the stack and system design effort for Gen3 fuel cell system (FCS) at GM. Balsu is an inventor on over 45 U.S. patents and has co-authored many peer-reviewed publications. He earned a Ph.D. in Chemical Engineering and a B.T. in Chemical and Electrochemical Engineering.

Our Team

Versogen brings expertise in anion exchange membrane chemistry, production, and scaleup. We are a tight-knit team of scientists, engineers, inventors, and entrepreneurs who push the boundaries in science to discover new insights. Our organic, multidisciplinary, and cohesive team shares a vision to become the global leader in leveraging the sustainability and versatility of hydrogen to achieve a carbon-neutral society. Our team's capabilities are augmented by consultants in polymer scaleup, process design, controls engineering, and membrane production, as well as by the expertise of our toll coating partner.

Versogen™
The Hydrogen Generation.

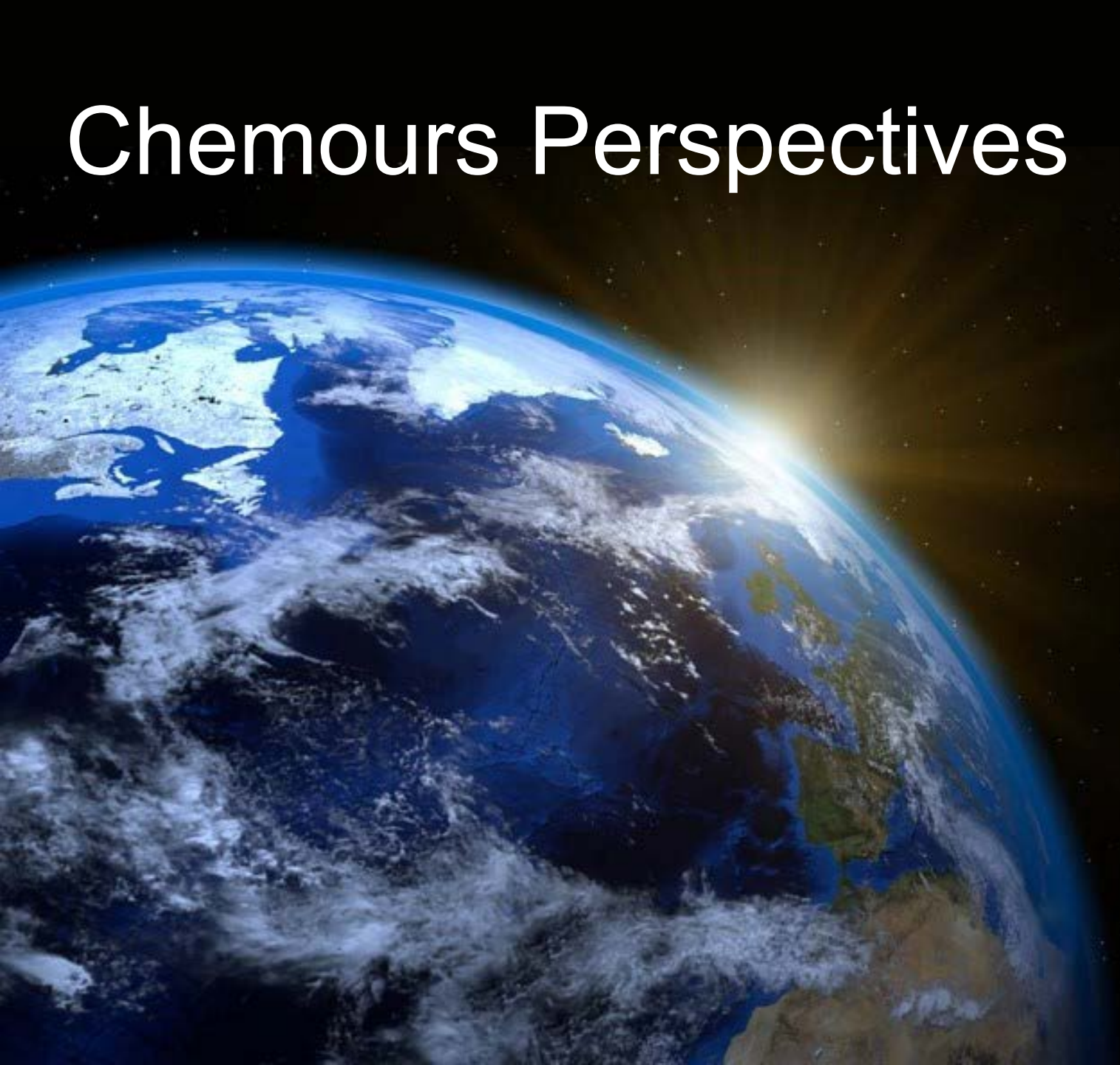
- Mission
  - Producing green hydrogen at scale-reliably and affordably
- Products
  - AEM
  - AEM electrolyzer stacks
- Experienced leadership team
- Versogen by numbers
  - $5.6M Seed
  - $14.5M Series A
  - 18 employees, growing to 30 by the end of 2022
  - 60+ customers
  - ~$1M AEM sales

Interactions with the Labs

Versogen™
The Hydrogen Generation.

- AEM materials to HydroGEN and other programs
- NREL Industry Growth Forum
- NREL Shell Game Changer (GCxN)
- …

Chemours Perspectives

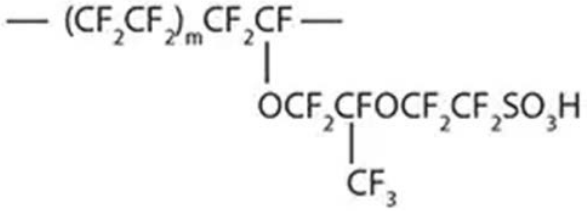


Andrew Park
Principal Engineer
The Chemours Co.

The Chemours Company: An Introduction

Industry Leader in safe production and manufacture of performance chemicals, combining leading products, applications expertise, and market-shaping chemistry

Nafion™



Chemours is **backward integrated** in the manufacture of Nafion™ membranes and dispersions.

Chemours has the **polymer capacity** to manufacture Nafion™ membranes in large scale.

Raw Materials → **Monomers** → **Polymer Resins** → **Nafion™ Membranes and Dispersions**

- Chemours has >50 years' experience in the commercial manufacture of Nafion™ ion exchange materials
- Chemours has established a Global Venture Team solely focused on the development of materials used in the Hydrogen Economy, enabling our customers to achieve their business objectives.
- Multiple new product development programs in progress for membranes and dispersions in hydrogen applications

Industry and Lab Collaboration: Next Generation PEMWE Membranes

- ***Goal:*** Increase voltage efficiency of hydrogen production via water electrolysis with advanced, low resistance membranes. *And do it fast.*
- ***Problem:*** Low resistance (thin) membranes invite gas crossover, durability concerns that require advanced diagnostics to evaluate.
- ***Solution:*** Collaborate with national labs to build capabilities to evaluate next gen membranes

Los Alamos NATIONAL LABORATORY

Siddharth Komini Babu, Kaustubh Khedekar, Rod Borup

Ex-situ crossover screening
Additive mobility

NREL Transforming ENERGY

Jake Wrubel, Guido Bender

Operando MEA testing
Durability

BERKELEY LAB

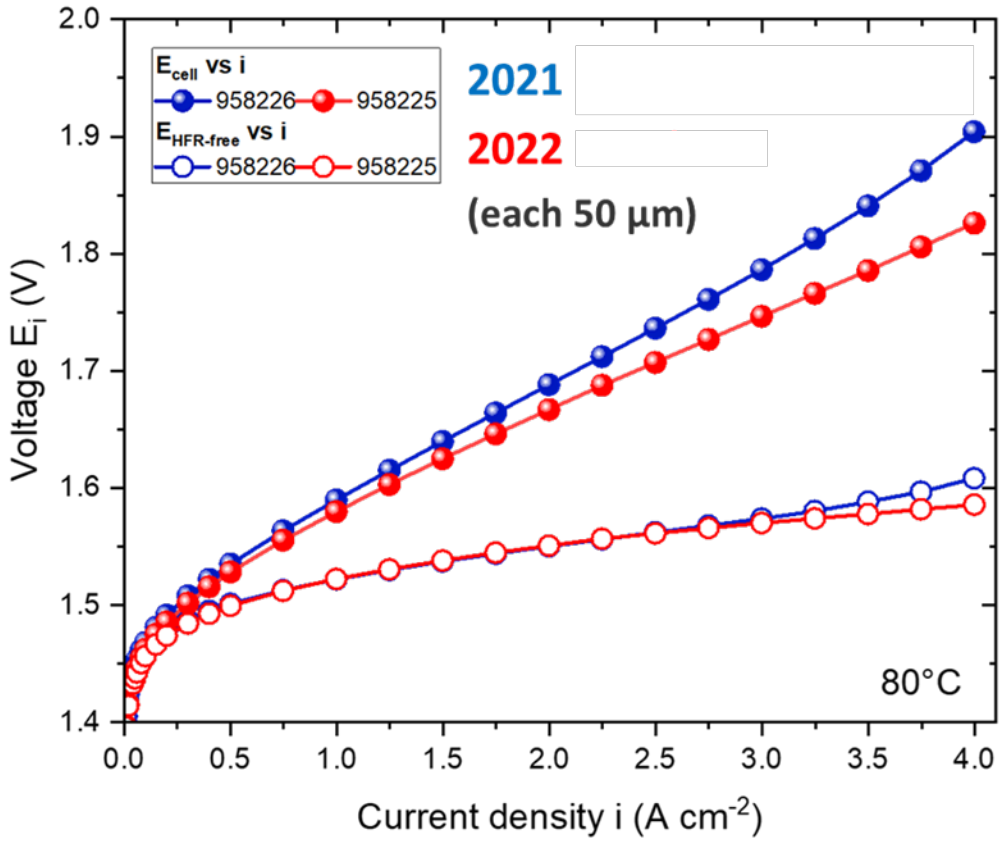
Arthur Dizon

Modeling

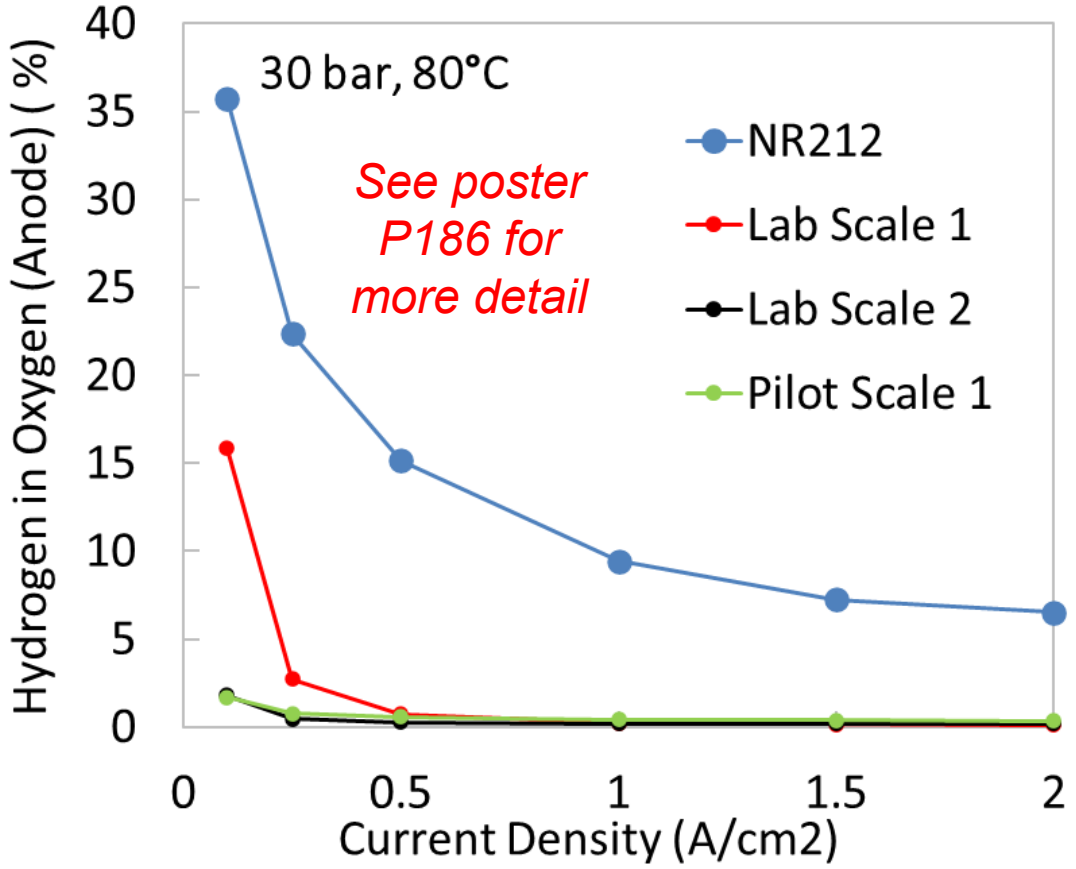
Nafion™

Chemours™

Pilot Scale Membrane Performance and H_2 Crossover Mitigation



High performance membranes improve overall efficiency

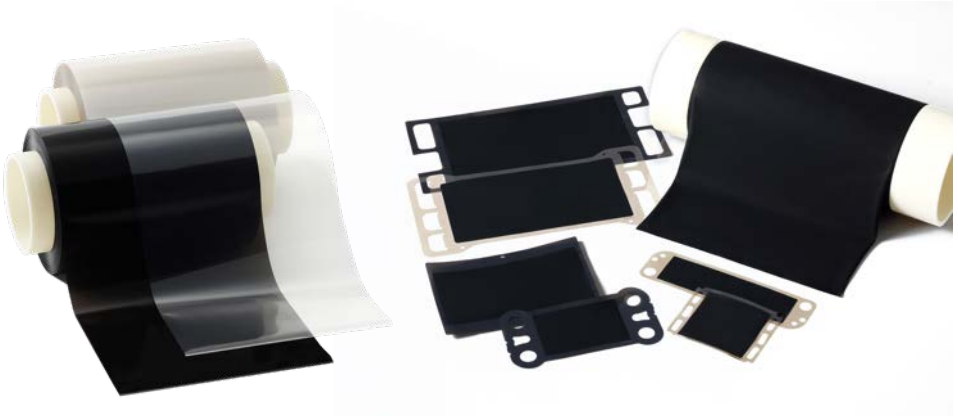


Low effective gas crossover at high differential pressure

W. L. Gore Perspectives

Yingying Chen
Research Scientist,
W. L. Gore & Associates

>25 years of Gore Fuel Cell history



we have produced **millions square meters** of PEM and MEA…

…to enable more than **40,000** fuel cell vehicles developed in more than **100** different models…

…reducing more than **150,000** metric tons of CO2 emissions.

PEM Development for Water Electrolysis

Gore Capabilities	**ePTFE Reinforced** Composite Membrane Technology	+	**High** Capacity **Strong** Brand **Secure** Supply Chain	+	**Large** Portfolio **Predictive** Model
Benefit to Customer	Low Total cost of Ownership (TCO)	+	High Performing System		• Low component cost • Fast H^+ transport • Low H_2 permeance • Long life • …

Creating Value for a Cleaner Environment

- Collaborating with NREL under TSA (Technical Service Agreement), with parametric experimental design, utilizing NREL's water electrolysis test capabilities and protocols, enabling us to understand PEM properties and performance in water electrolysis cells
- Participated in HydroGen Benchmarking workshop, supporting the development of PEM water electrolysis testing protocols

Gore's PEM development for water electrolysis

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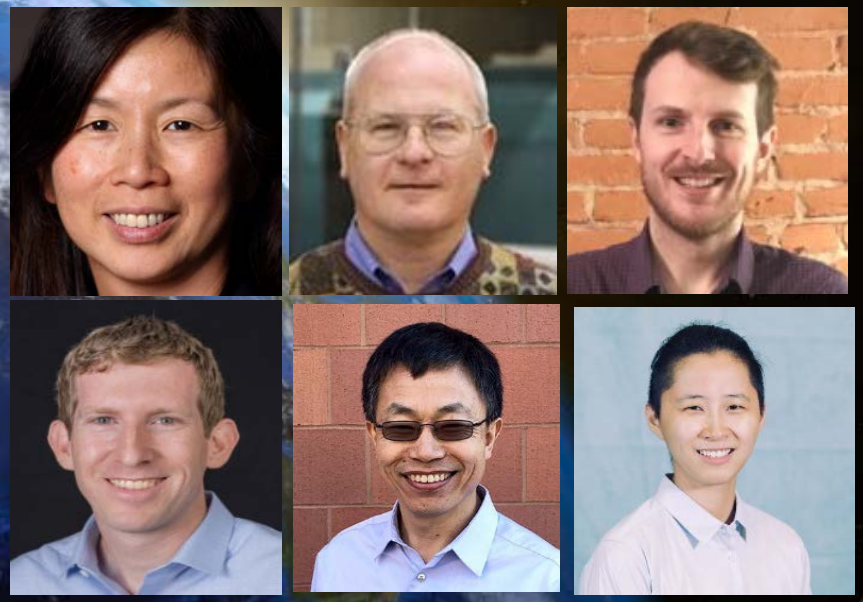
Thanks to Our Panelists!



PANEL 2: Integrated Systems Collaborations

Richard Boardman
Directorate Research Fellow, INL

Olga Marina
Chief Scientist, PNNL

Harry Abernathy
Senior Scientist, NETL

Rita Baranwal
CTO, Westinghouse Electric Co.

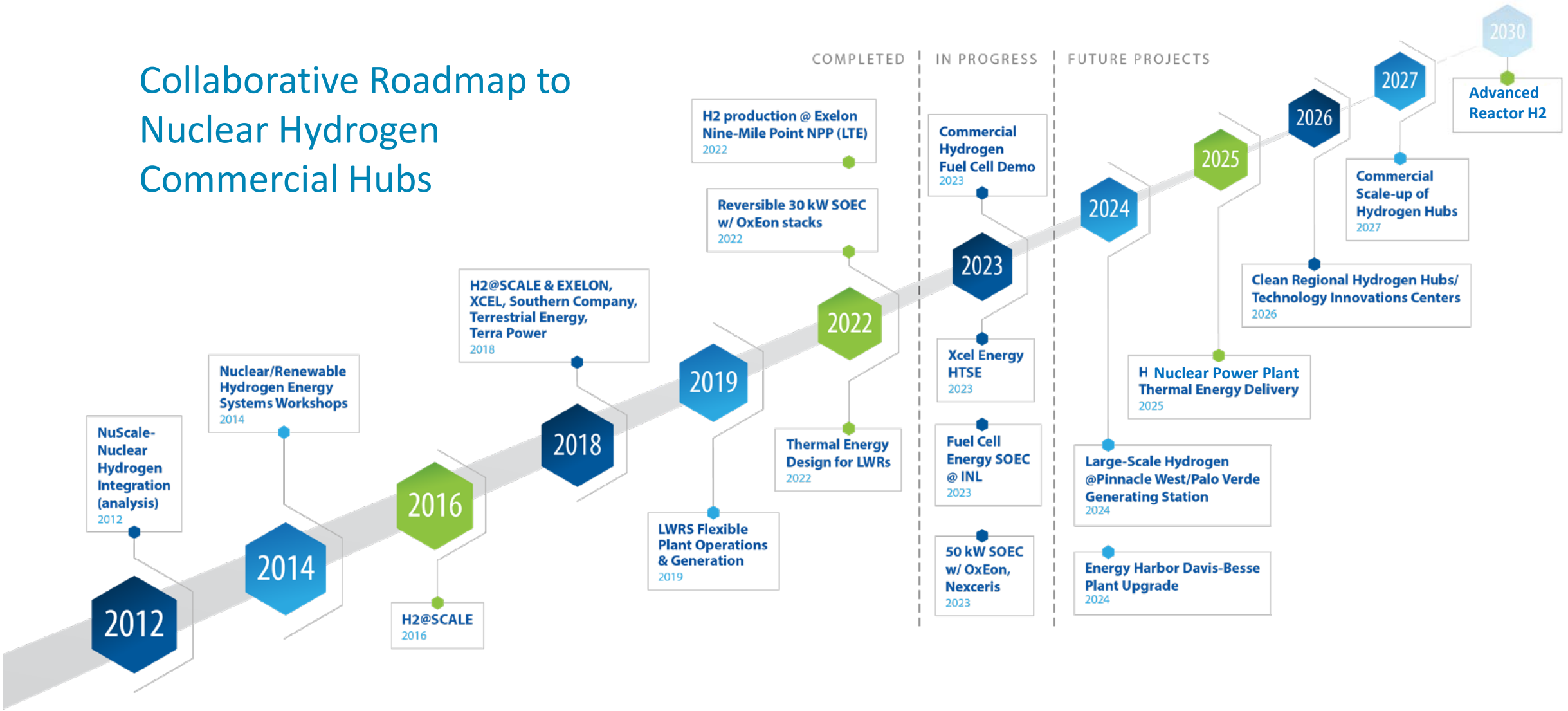
Christy Verbofsky, *CRADA Project Manager, Westinghouse Electric Co.*

Colleen Wright,
VP of Corporate Strategy, Constellation

Noah Meeks, *Principal Research Engineer, Southern Co.*

Hydrogen Shot – Industry/Lab Collaboration and Innovations

Collaborative Roadmap to Nuclear Hydrogen Commercial Hubs



Constellation: Who We Are

Constellation is the #1 zero-carbon energy provider in the U.S with 90% carbon-free output, backed by more than 32,000 MW of generating capacity.

Operates in 48 States & DC

215 TWh
1600 Bcf
Customer Load Served

Scalable national platform of approximately **2 million customers** served, offering a diversity of innovative products and services, including ¾ of Fortune 100 companies

Power Supply Mix	TWh
Nuclear	176
Conventional	20
Owned Renewable	7
Contracted Renewable	7
Purchased Power	73

13,000 Employees

Constellation is soon to be a **Fortune 200** Company

C&I Market Share Ranking **#1**

Goal of providing 100% of business customers with custom GHG data by end of 2022

Nine Mile Point Nuclear Power Plant Demonstration

- **Demonstrate hydrogen production using behind the meter power offtake from a nuclear power plant on-site**
- **Develop monitoring and controls procedures for scaleup to large commercial-scale hydrogen plants**
- **Produce hydrogen for captive use to supply nuclear power plant's own consumption**

NREL and INL support the demonstration project

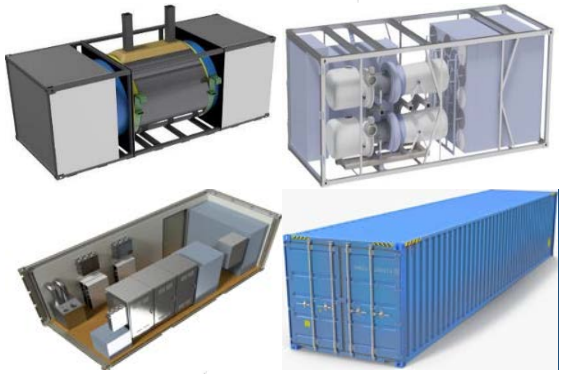
Constellation

Westinghouse: A leader in nuclear technology and power

Current Activities & Interests

- Westinghouse Initiative in Hydrogen
- Light-Water Reactor Concepts of Operations for Tightly Coupled Hydrogen Plants
- CRADA with INL
- Development of Advanced Reactors: Hydrogen Production

eVinci™ Micro-Reactor



Southern Company - Hydrogen R&D Program

Hydrogen is the next evolution of the utility business model.

- Decarbonize entire energy economy, building on baseload, cost-effective primary energy
- Enhance resiliency at all scales
- Provide long-term, carbon-free energy within the regulatory compact.

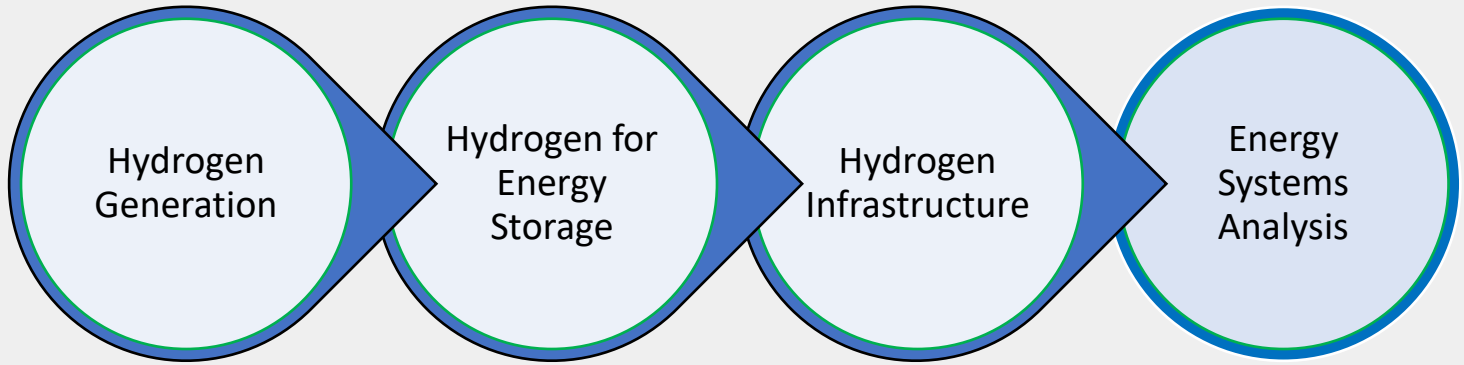
LCRI LOW-CARBON RESOURCES INITIATIVE

Hydrogen Council

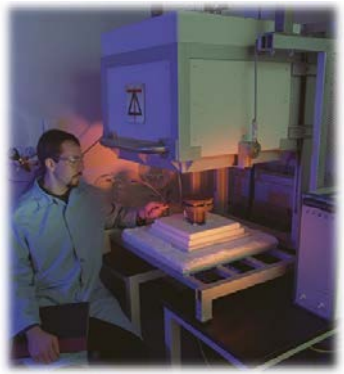
FCHEA Fuel Cell & Hydrogen Energy Association

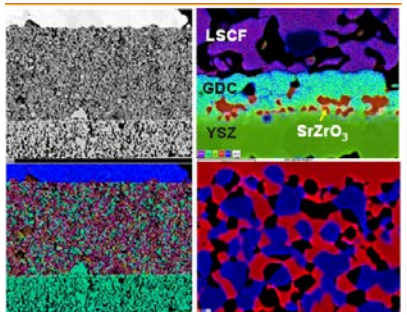
C H2 FC Clean Hydrogen Future Coalition

Hydrogen R&D Portfolio



Hydrogen Shot – Industry/Lab Collaboration and Innovations

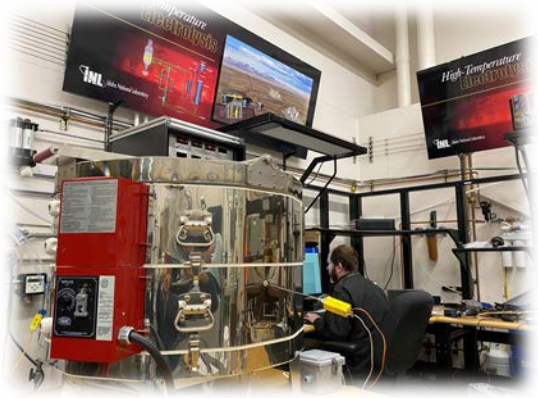




SOC Fuel Cells and Electrolysis Research & Development

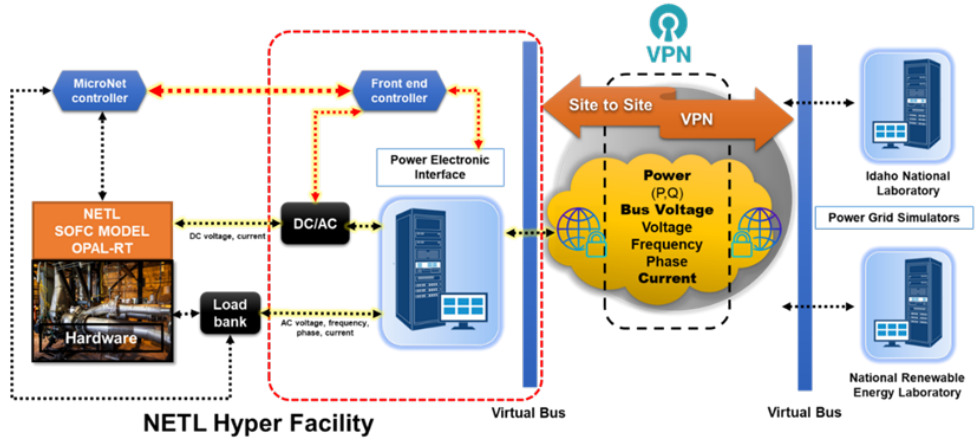
Commercial Stack & Module Performance

Interfacing Fuel Cells & Electrolyzers with the Grid



Stack Testing

Coupling electrolysis to nuclear reactors



Cyber/Physical Integrated Fuel Cell Power Systems

Hydrogen Shot – Industry/Lab Collaboration and Innovations

Inform

Analyze & Optimize

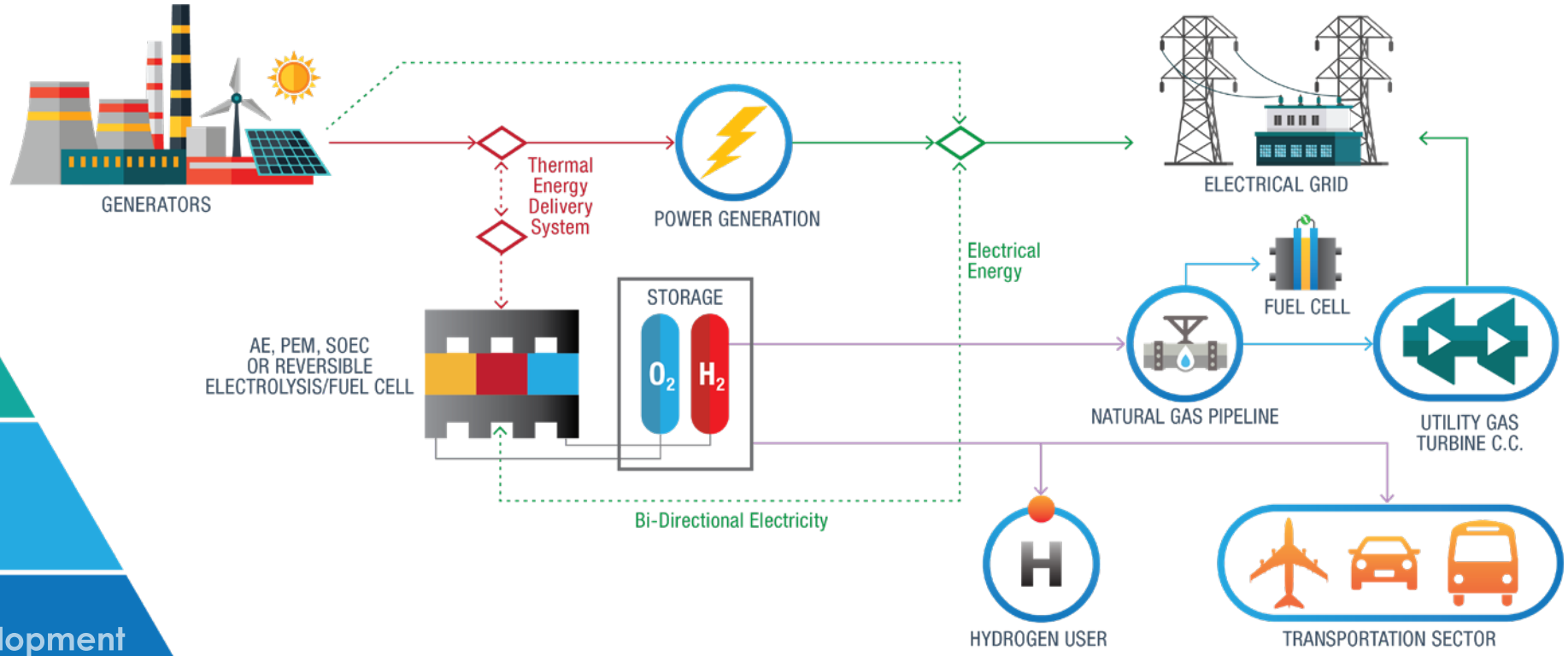
Project Demonstrations

Systems Integrations & Interfaces

Cell Design & Performance Optimization

Materials Research & Development

Nuclear Hydrogen: Path to $1/kg/Hydrogen



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U.S. DEPARTMENT OF ENERGY

Thanks to Our Panelists!

PANEL 3: Low-Temperature Electrolyzers

Bryan Pivovar
Senior Research Fellow, NREL

Debbie Myers
Senior Scientist, ANL

Kathy Ayers
VP for R&D, Nel Hydrogen

Corky Mittlesteadt
VP for Electrolyzer Tech, Plug Power

H2NEW
U.S. DEPARTMENT OF ENERGY

H2NEW : H2 from Next-generation Electrolyzers of Water

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

- Launched October 1, 2020
- To date, 75% PEM, 25% SOFC
- Minimum of $50M over 5 years

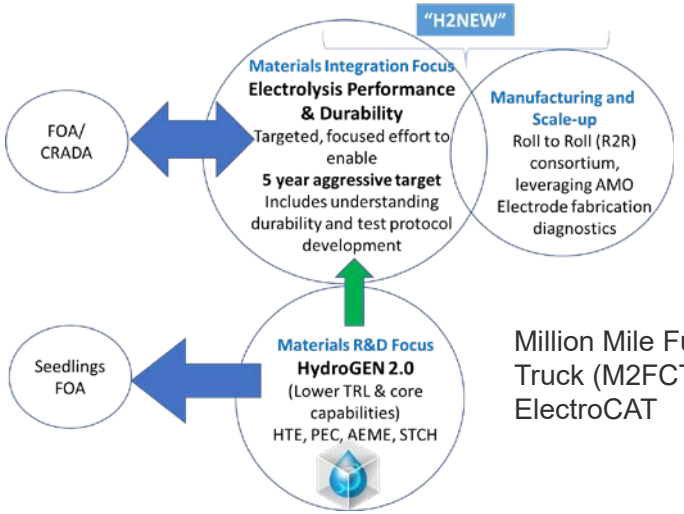
Initial Lab Consortium Team

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
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/cm^2	98% at 1.5 A/cm^2
Lifetime	80,000 hr	60,000 hr

Connection to DOE Consortia



Million Mile Fuel Cell Truck (M2FCT) ElectroCAT

External Engagement

LTE Strategic Advisory Board Members

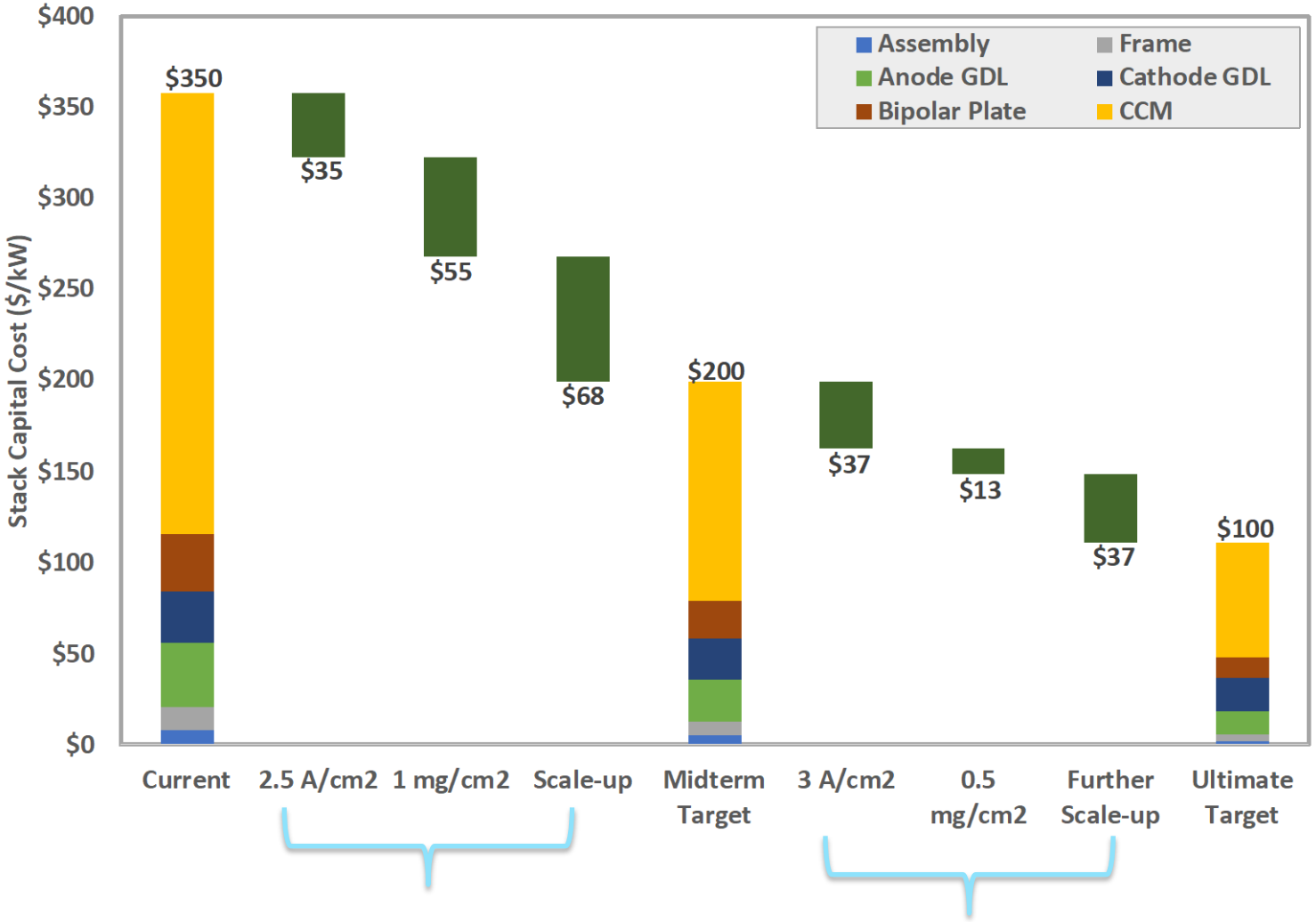
Kathy Ayers, VP R&D, Nel Hydrogen
Cortney Mittelsteadt, VP Electrolyzer Technology, Plug Power
Andy Steinbach, Specialist Materials Science, 3M
Jack Brouwer, Professor, U.C. Irvine
Mark Mathias, Consultant retired (GM)

- IEA, ASTWG, materials suppliers
- Need to expand further engagement with industry and academia

Durability/lifetime has been primary focus of H2NEW

- Limited fundamental knowledge of degradation mechanisms, inhibits AST development.
- 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.
- Cost, performance, durability tradeoffs.

Relevance: Stack Costs (PEM)



Stack Targets	Status	2023	2025
Cell (A/cm²@1.9V)	2.0	2.5	3.0
Efficiency (%)	66	68	70
Lifetime (khr)	60	70	80
Degradation (mV/khr)	3.2	2.75	2.25
Capital Cost ($/kW)	350	200	100
PGM loading (mg/cm²)	3	1	0.5

These 3 areas

1. Increased efficiency/current density
2. Decreased PGM loading
3. Scale-up

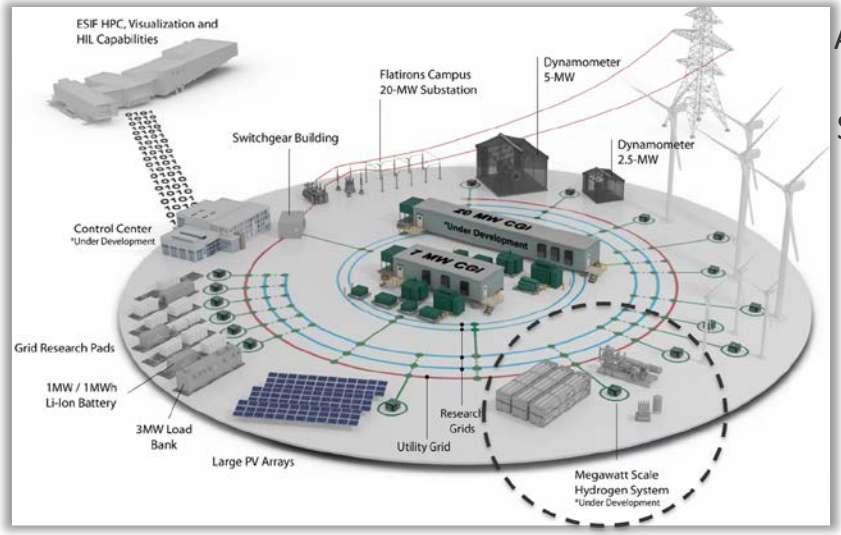
Are the strongest levers for addressing stack costs.

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

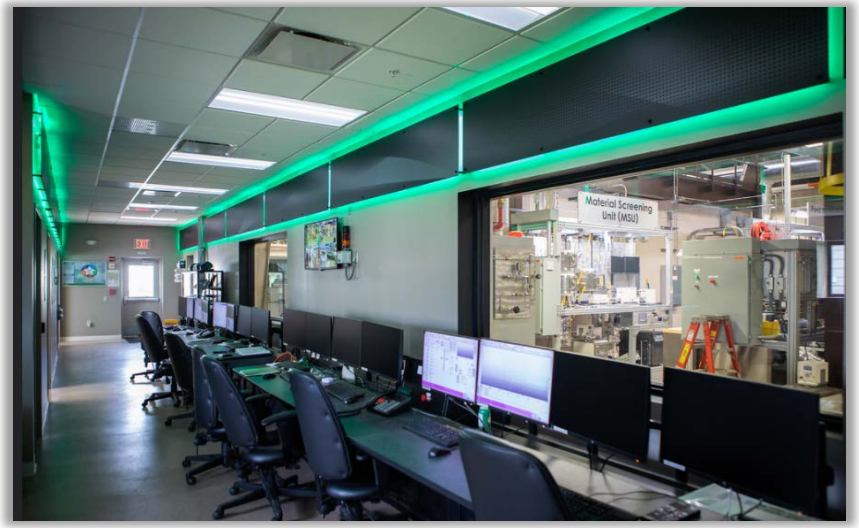
Lab Platforms for Integration, Validation, and De-risking Deployments

Low Temperature Electrolysis Facility (NREL)

High Temperature Electrolysis Facility (INL)



ARIES: Advanced Research on Integrated Energy Systems expansion (NREL) ***and collaboration with other labs***



REACT: Reaction chemistry facility including hydrogen production (NETL)

Plug Power Perspectives

Corky Mittelsteadt

VP for Electrolyzer Technology

Karen Swider-Lyons

Principal Research Scientist

Plug Power

Plug: the green hydrogen ecosystem

25 years
of innovation

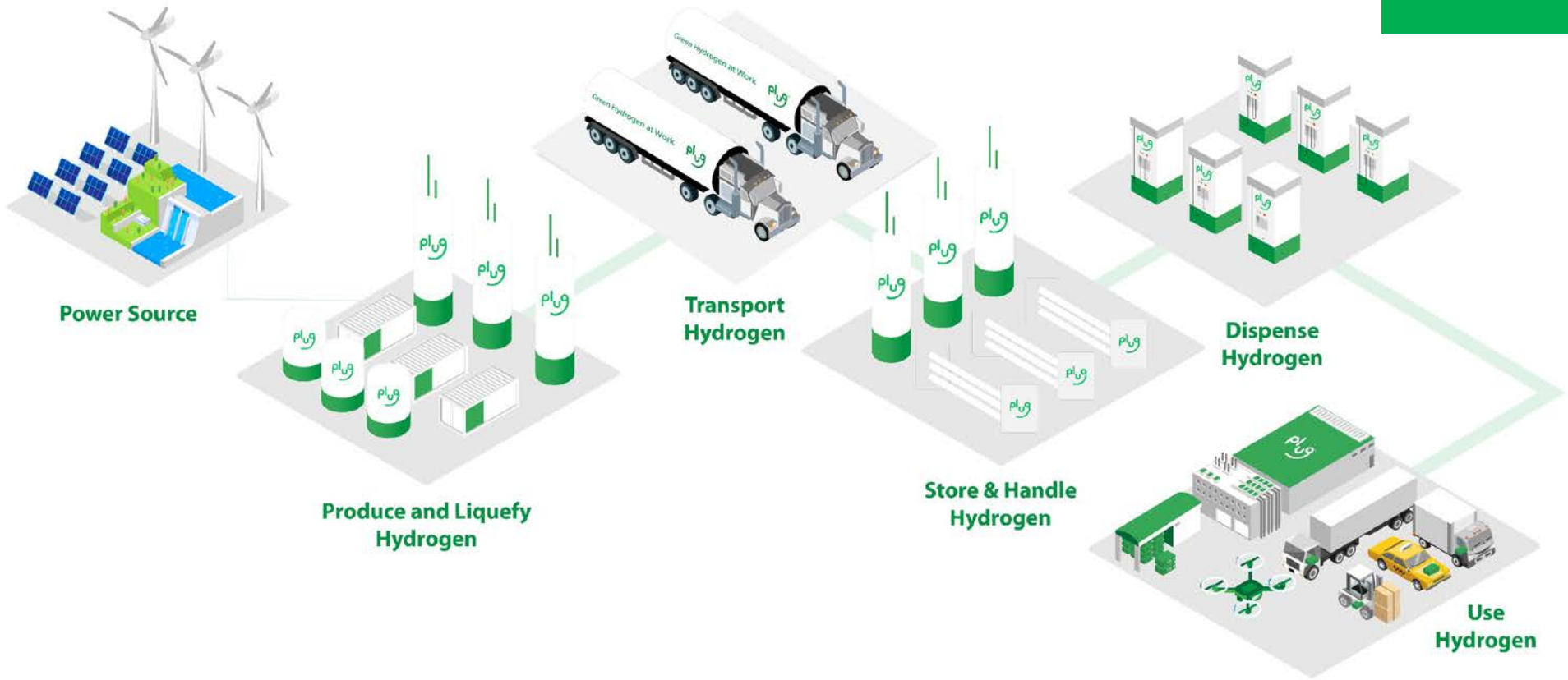
258
granted patents

40+ tons
of hydrogen
consumed daily

60,000+
systems in service

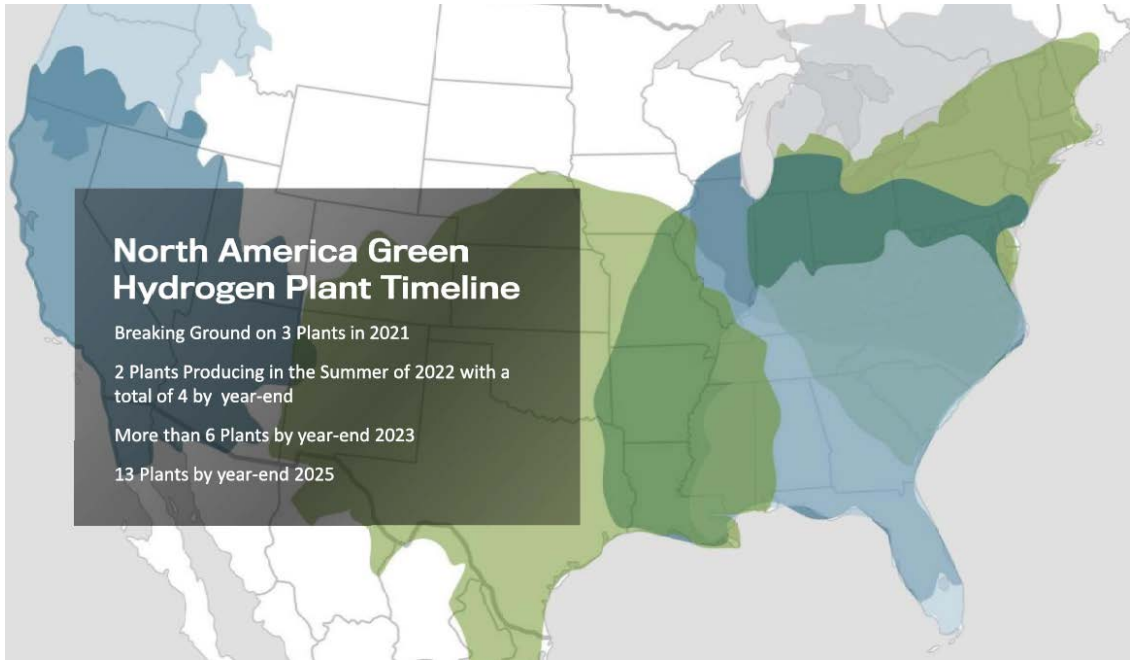
850+ million
hours of operation

2,800+
employees



10 MW facility in GA

Plug Power – Perspective on Green Hydrogen



- Connect RDD&D to Hydrogen Hubs
- Focus on near term technologies (high TRL and MRL) for near term wins
- Long-term tax incentives to sustain clean hydrogen infrastructure toward commercial sustainability

Plug Power on track for 500 metric tons of green hydrogen per day by 2025

- Direct coupling of PEM electrolysis to renewables
- >30,000 electrolysis systems to date

- 50,000 fuel cells presently in use
- Hydrogen liquification and transportation infrastructure
- 2,200 regular US employees (2800+ worldwide)
- Domestic manufacturing capability in NY (3 sites), MA, WA >Gigawatt capability

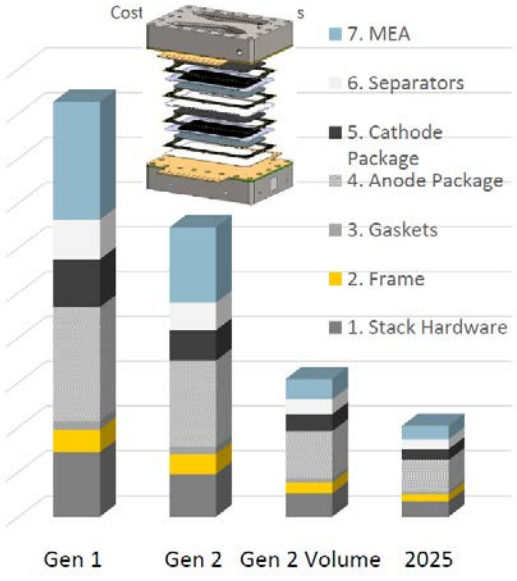
Need sustained support from US DOE to grow green hydrogen business

- Invest in cost reductions for materials and manufacturing
- Attract more manufacturers to the supply chain
- Large scale hydrogen storage development and demonstrations
- Convert natural gas infrastructure to hydrogen

Areas for National Labs Cooperation

Cell components needing cost reductions, durability and recycling research:

- Anode and cathode electrocatalysts
- Membranes
- Titanium (or suitable titanium replacement)
- End plates
- Porous transport layers (PTLs).
  - The prevention of hydrogen embrittlement in titanium
  - Stability of novel materials (not titanium) under the operating conditions of PTL
  - Creating an engineered design based on research on mass transport through the PTL



Balance of plant and supporting technologies:

- Power electronics
- **Wind/Solar integration, minimize power conditioning**
- Hydrogen dryers
- Hydrogen compression
- Water purification systems/pumps
- Improved rectifiers

Prognostics:

- Prognostics for membrane failures (impedance response)
- Prognostic for separator failure
- Prevention and prognostic for hydrogen embrittlement

Design barriers:

- Physics based models of mass transport across all the interfaces
- High voltage Operation
- Manufacturability of components
- Accurate quality control methods

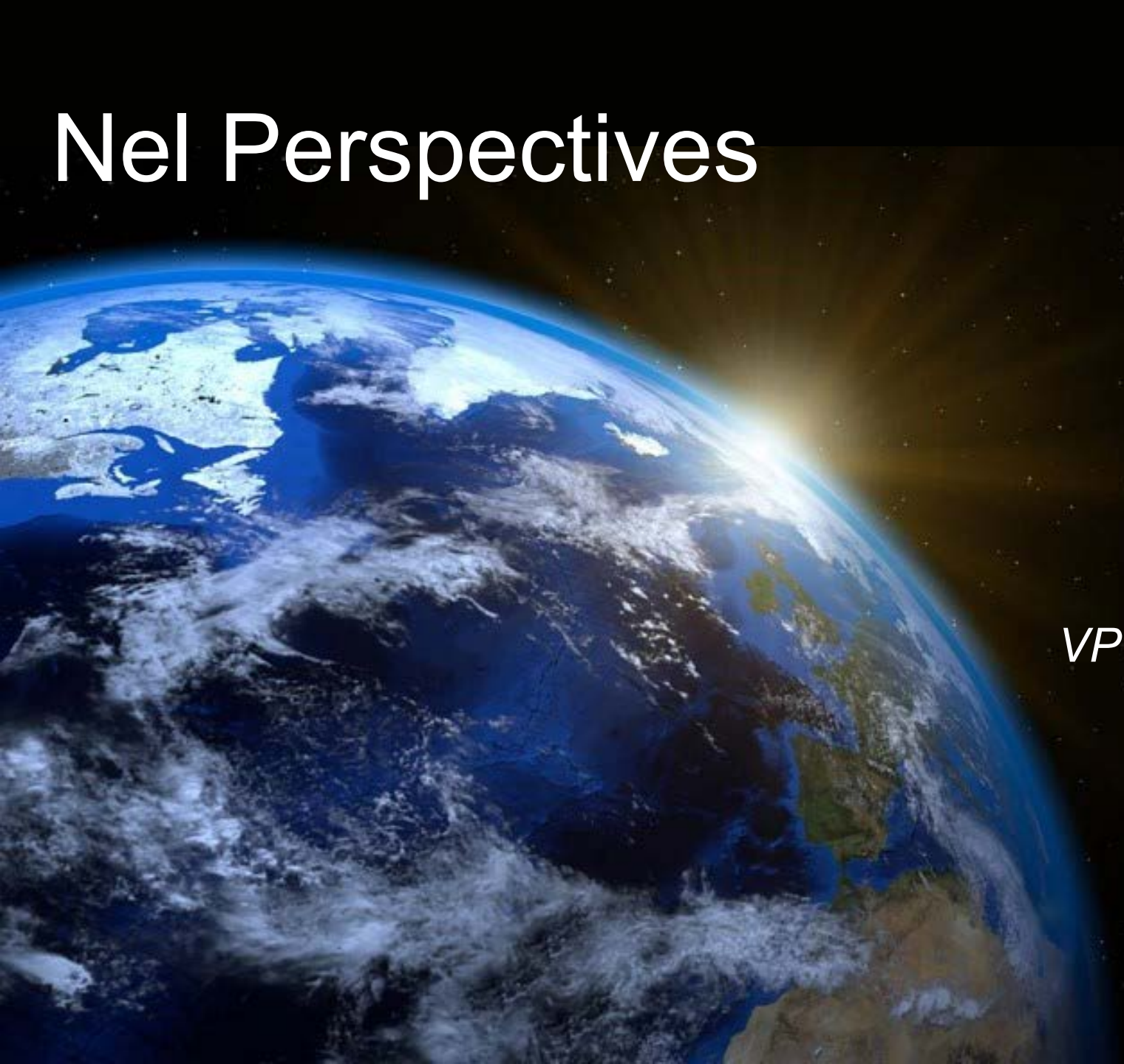
SAFETY

- Sensors
- Standards
- **Reviews and networking**

RECYCLING

- Iridium, carbon, PFSA, Balance of stack and BOP
- Design for recycling
- Techno economic analysis of recycling impact

Nel Perspectives



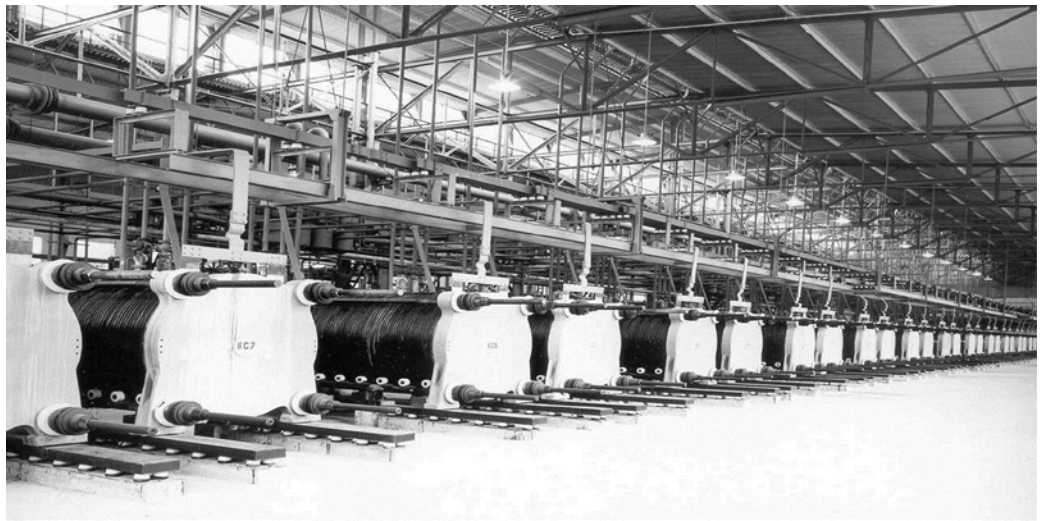
Kathy Ayers
VP for Research & Development
Nel Hydrogen

Nel Herøya plant

- Production of alkaline electrolyzers
  - Developed for industrial applications
  - 100 years of experience
  - Designed for low cost and efficiency
  - Demonstrated at 100+ MW

500 MW production line

- Scalable to 2 GW with additional lines



Nel PEM plant

CT employees: **125** (~15 open positions currently)

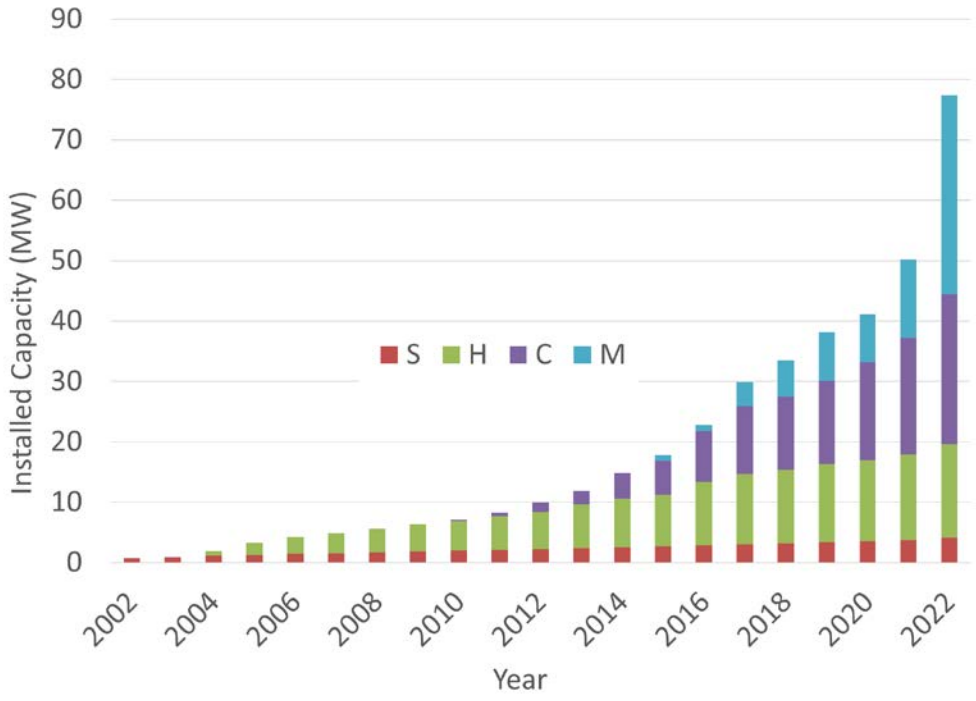
Systems delivered: **3,000+**

Production capacity: **>150 MW/year**

Established: **1996 (Acquired 2017)**

Unit	Year introduced	Capacity	# Fielded
G (lab)	1998 (disc. 2020)	<1 kW	>>1000
S	2000	4-7 kW	~800
H	2003	14-40 kW	~400
C	2010	60-180 kW	~160
M	2014 (single stack in 2020)	1-20 MW	>30 MW

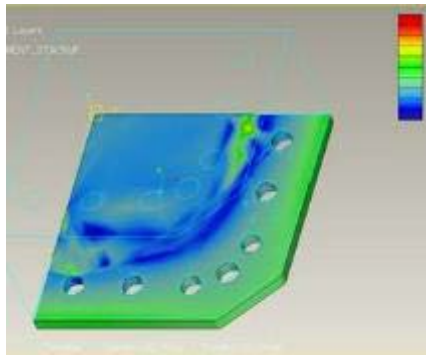
Total of >70 MW installed base (PEM only)

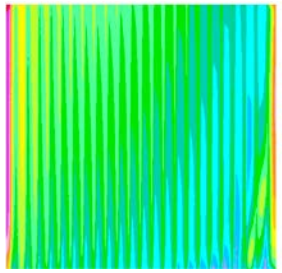


EXAMPLE OF 80% COMPONENT COST REDUCTION

Impact of Lab-industry collaboration

Fundamental R&D to Prototyping





Component modeling

Accelerated embrittlement

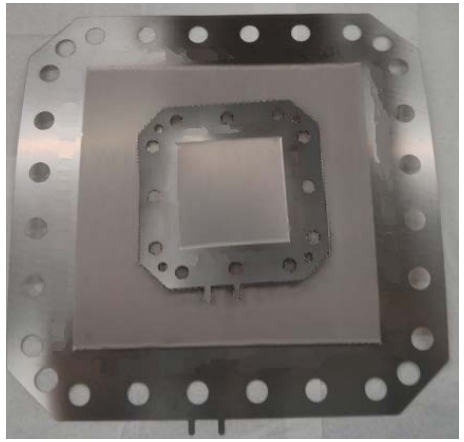
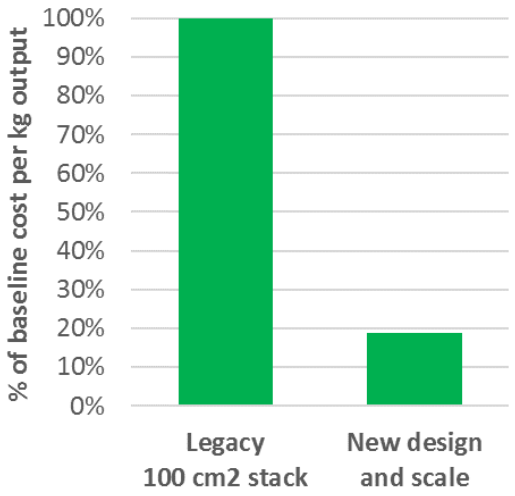
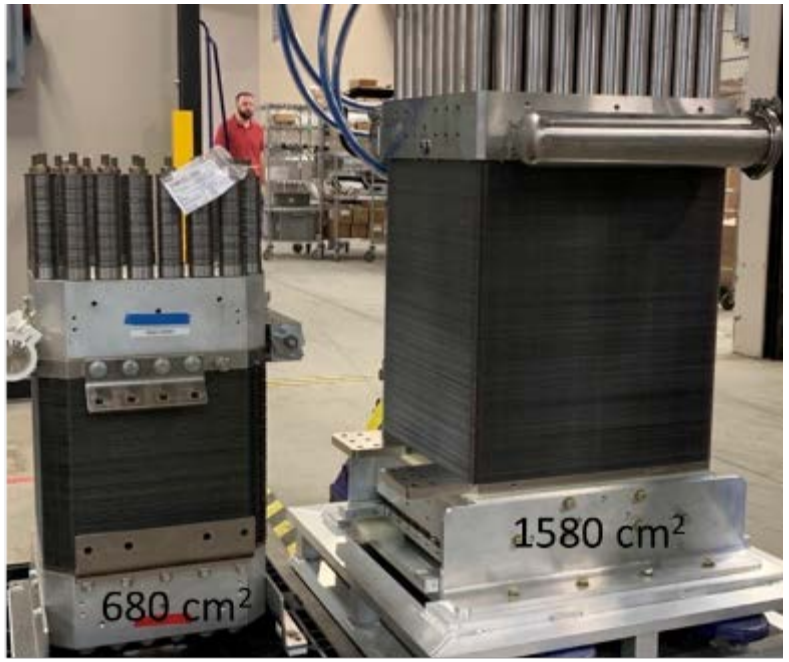


Plate manufacturing



Products from kW to MW scale

90 cm²



Nel scale up and commercialization:
MW stack based on same platform

nel

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Thanks to Our Panelists!




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Thank You!

https://www.energy.gov/eere/fuelcells/hydrogen-shot

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Hydrogen Program
2022 Annual Merit Review and Peer Evaluation Meeting

Join us for AMR Technical Sessions at 1:30 pm EDT

June 7, 2022