Current Status and Future Focus of HTE Manufacturing

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ENERGY earthshots U.S. DEPARTMENT OF ENERGY | Hydrogen

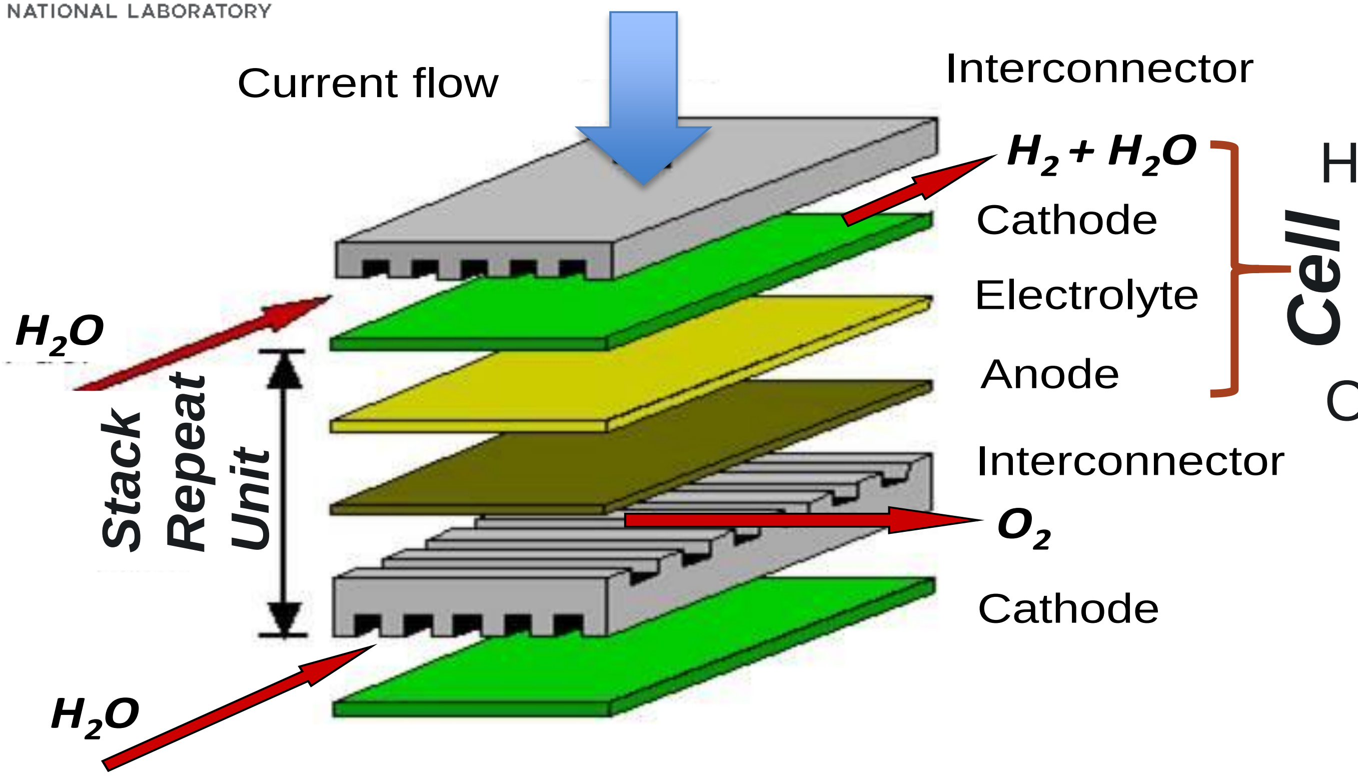
Hydrogen Energy Earthshot

“Hydrogen Shot”

“1 1 1”
$1 for 1 kg clean hydrogen in 1 decade

Launched June 7, 2021

Solid Oxide Electrolysis Cell (SOEC): Mature Technology with Low-Cost Materials



$H_2O + 2e^- \rightarrow H_2 + O^{2-}$

$O^{2-} \rightarrow \frac{1}{2} O_2 + 2e^-$

Single Cell

Stack of cells

- Electrolyte: Y or Sc stabilized zirconium oxide
- Hydrogen electrode: Ni – zirconium oxide composite
- Oxygen electrode: oxides – $LSCoO_3$, $La(Sr)Fe(Co)O_3$, nickelates
- Interconnect: Fe (stainless steel) with protective coatings against oxidation and Cr volatilization
- Low-cost materials (no Pt, Ir)

Images by Haldor Topsoe

HTE Achieve Very High Electrical Efficiencies; Energy is Provided by Heat

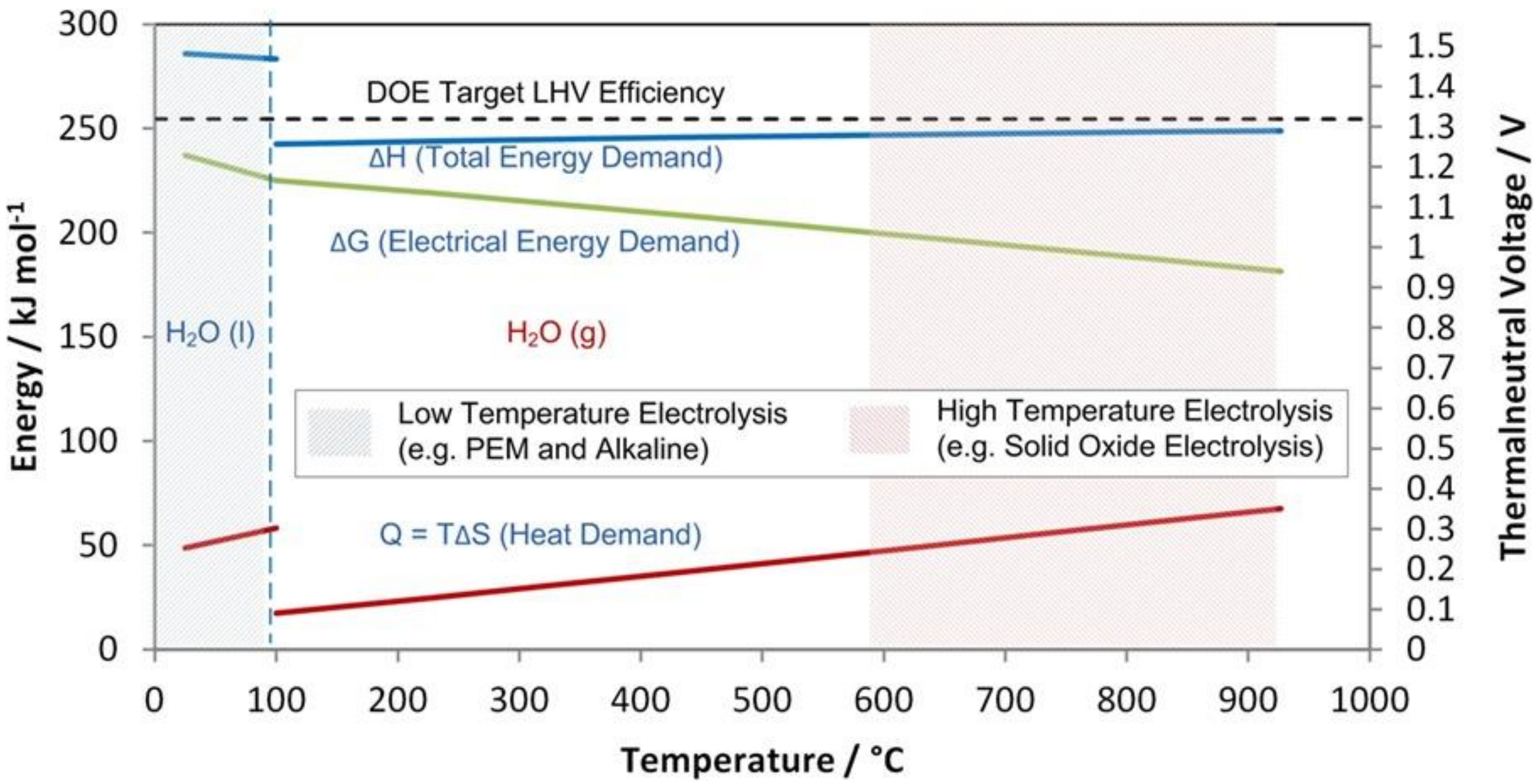


Figure source: DOI 10.1002/fuce.201600185)

Thermodynamic advantage:

- > 95% stack electrical efficiency
- Thermal integration opportunities with process heat sources
- Low operating voltage, 1.28V
- Pressurization

Scaleup and Demonstration Projects Started

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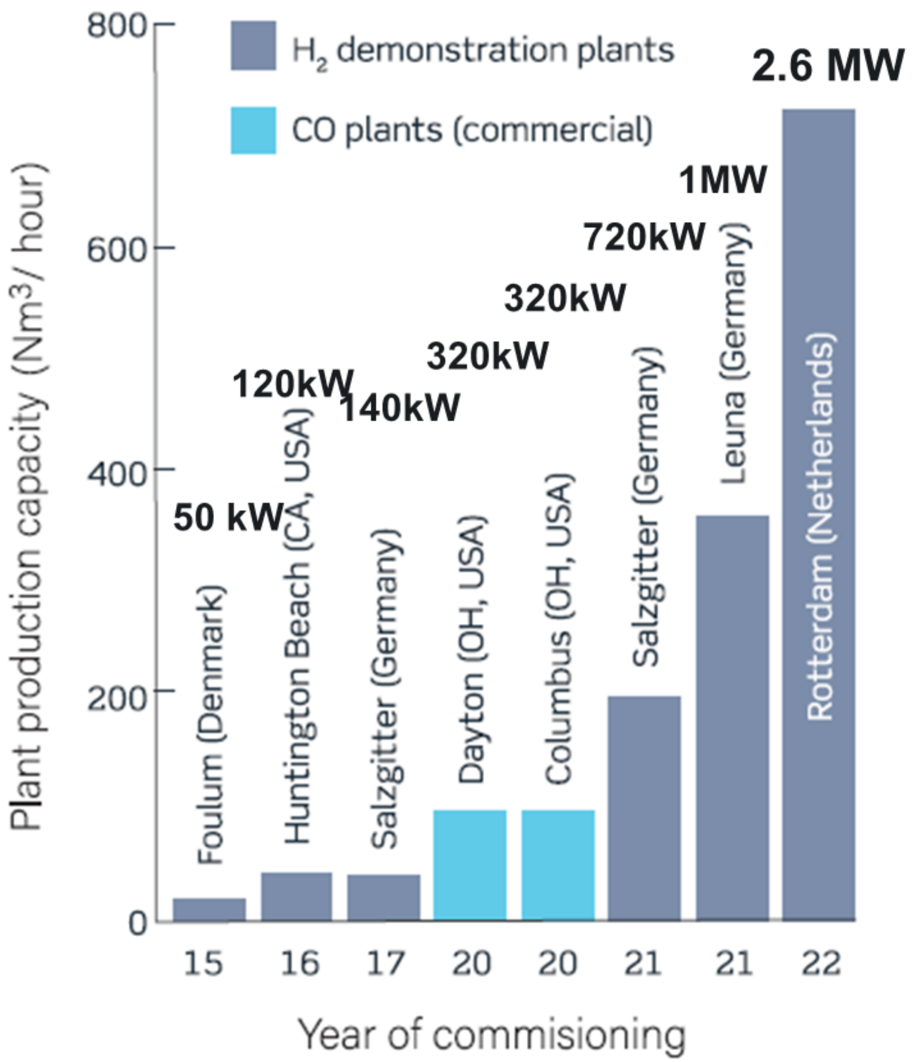
Demo Projects



Adopted from Hauch et al., Science 370, eaba6118 (2020)

120 kW$_{DC}$ reversible SOFC energy storage system demonstrated at Boeing Huntington Beach connected to the Southern California Edison grid.

https://onlinelibrary.wiley.com/doi/full/10.1002/fuce.201600185

Sunfire achieves major milestone with second generation SOEC

250 kW HTE module successfully tested in May 2021 by Sunfire; 2.6 MW planned for 2022

https://fuelcellsworks.com/news/sunfire-successfully-tests-the-worlds-largest-high-temperature-electrolysis-module/

Bloom Energy's manufacturing facilities are capable of producing 500 MW of electrolyzers; GW within a year

https://www.bloomenergy.com/news/bloom-energy-unveils-electrolyzer/

March 4, 2021

Haldor Topsoe to build large-scale SOEC electrolyzer manufacturing facility to meet customer needs for green hydrogen production

Production capacity of 500 MW/year, expandable to 5 GW; operational by 2023

https://blog.topsoe.com/haldor-topsoe-to-build-large-scale-soec-electrolyzer-manufacturing-facility-to-meet-customer-needs-for-green-hydrogen-production

From Materials Discovery to Stack Demonstration

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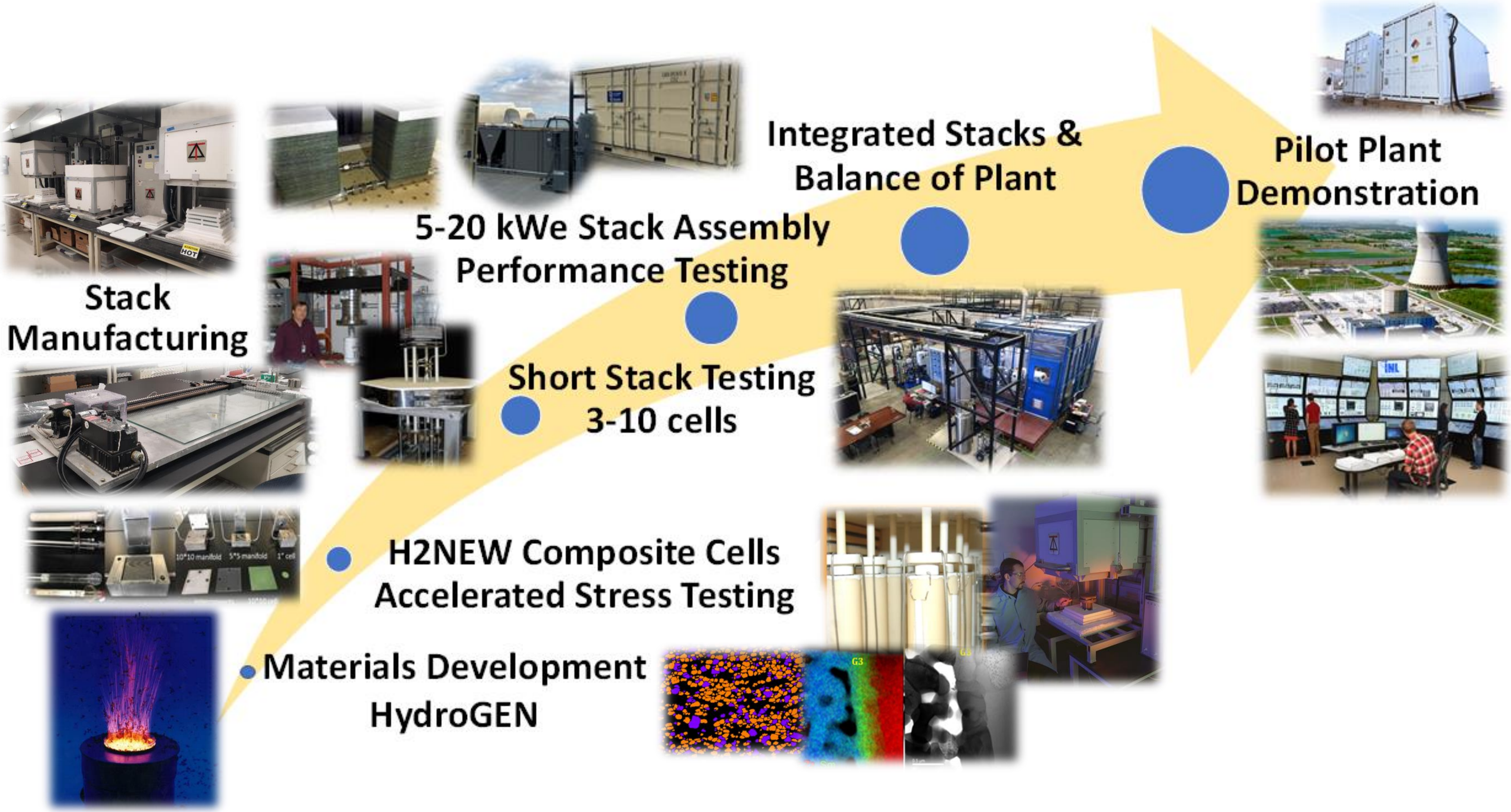


H2NEW Consortium: H2 from the Next-generation of Electrolyzers of Water

H2NEW
U.S. DEPARTMENT OF ENERGY

The emphasis is not on new materials but addressing components, materials integration, and manufacturing R&D

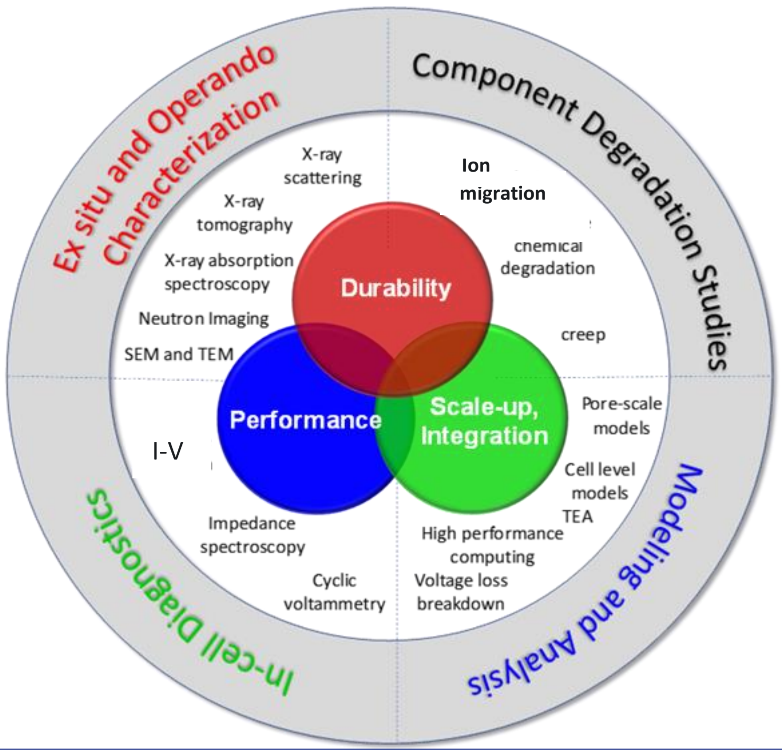
- Actual cells and environments
- Real world conditions
- Consistent testing and accurate comparison

National Lab Consortium Team

NREL – National Renewable Energy Laboratory; INL – Idaho National Laboratory; Pacific Northwest National Laboratory; Argonne National Laboratory; Berkeley Lab; Los Alamos National Laboratory; Lawrence Livermore National Laboratory; Oak Ridge National Laboratory; NETL – National Energy Technology Laboratory

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

Makes use of a 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 including under real operating modes
- Lack of understanding on how to effectively accelerate degradation processes.
- Develop and validate methods to accelerate identified degradation processes to evaluate durability in 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.

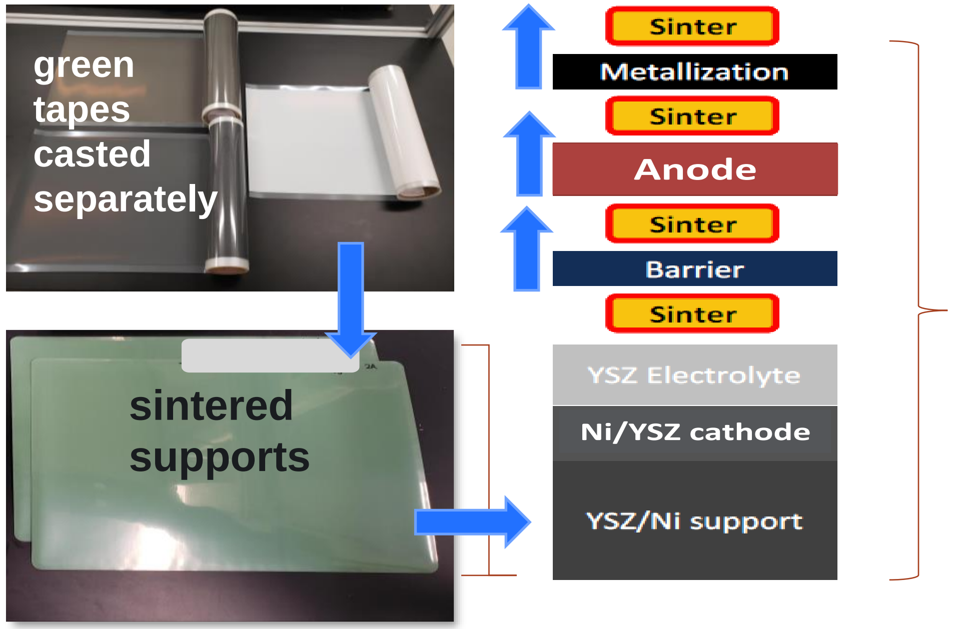
Benchmarking & Protocol Workshop

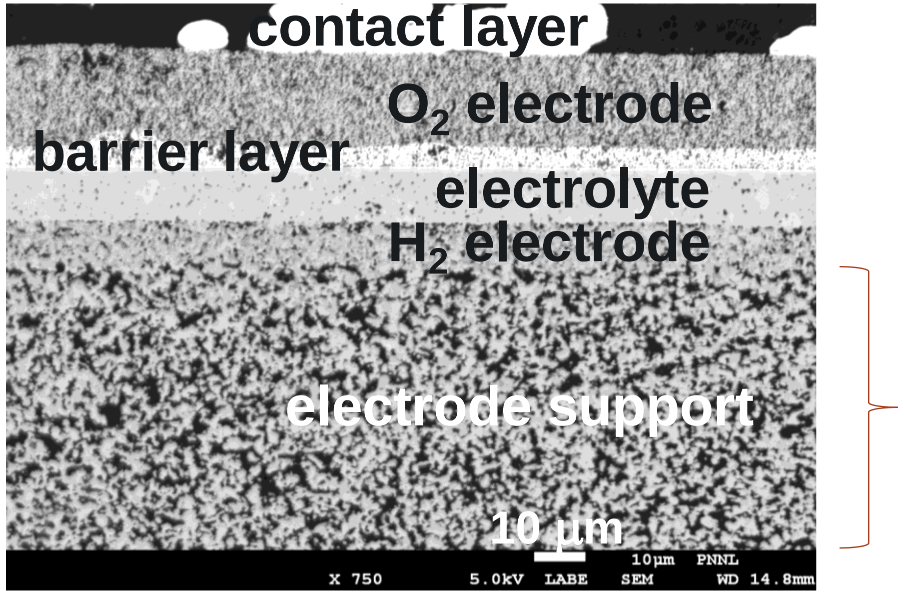
1st Workshop, 2018, ASU

- Protocol development for bench-scale, sub-scale and higher levels
- Effective comparison of results
- Define meaningful standards
- Develop a Round Robin verification plan
- Engage community and build consensus
- Understand needs of the community
- Leverage international efforts to increase harmony across the field

Cell Manufacturing: Planar Designs

Cell Fabrication Steps





Cell Configurations:
- Electrolyte-supported
- Electrode-supported
- Metal-supported

Low-cost manufacturing techniques:
- Ceramic tape fabrication and casting
- Screen-printing
- Spraying
- Thin film depositions
- Chemical infiltration and ex-solution for catalysts
- Laser cutting

Key barriers:
- Fabrication time and cost
- QA/QC
- Stack durability

Stack Component Fabrication and Assembly

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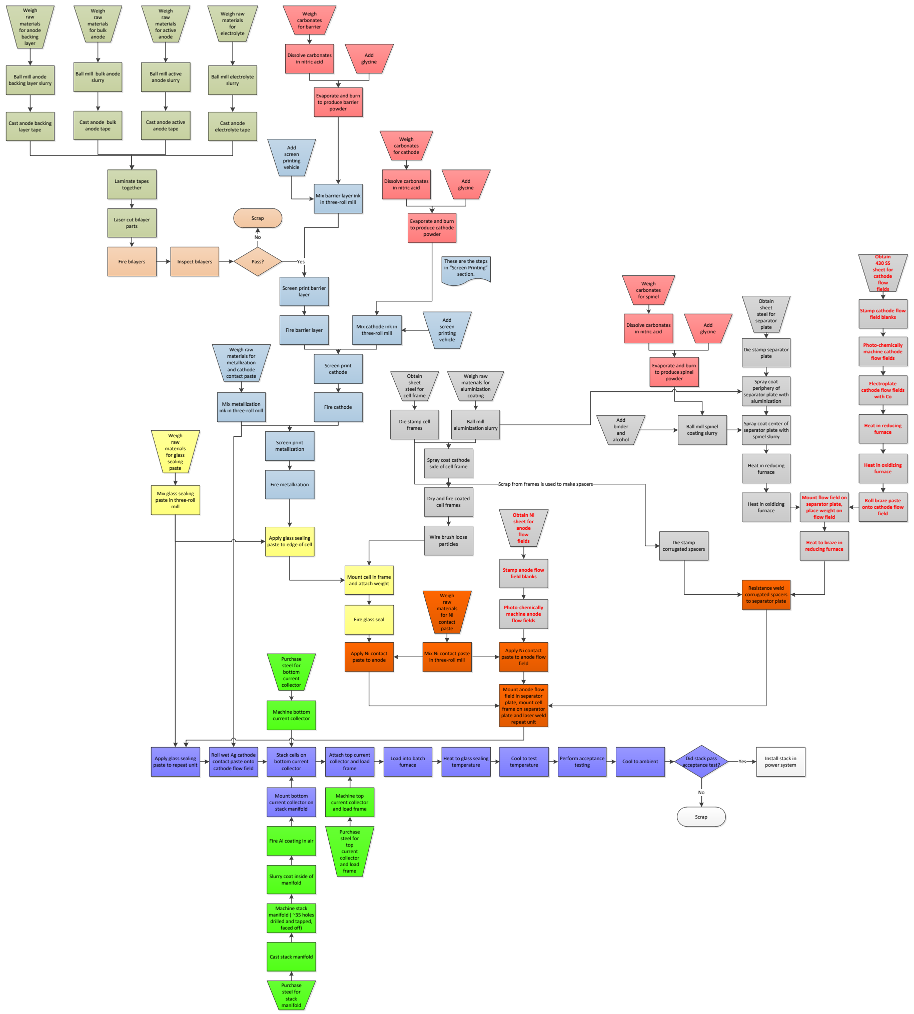
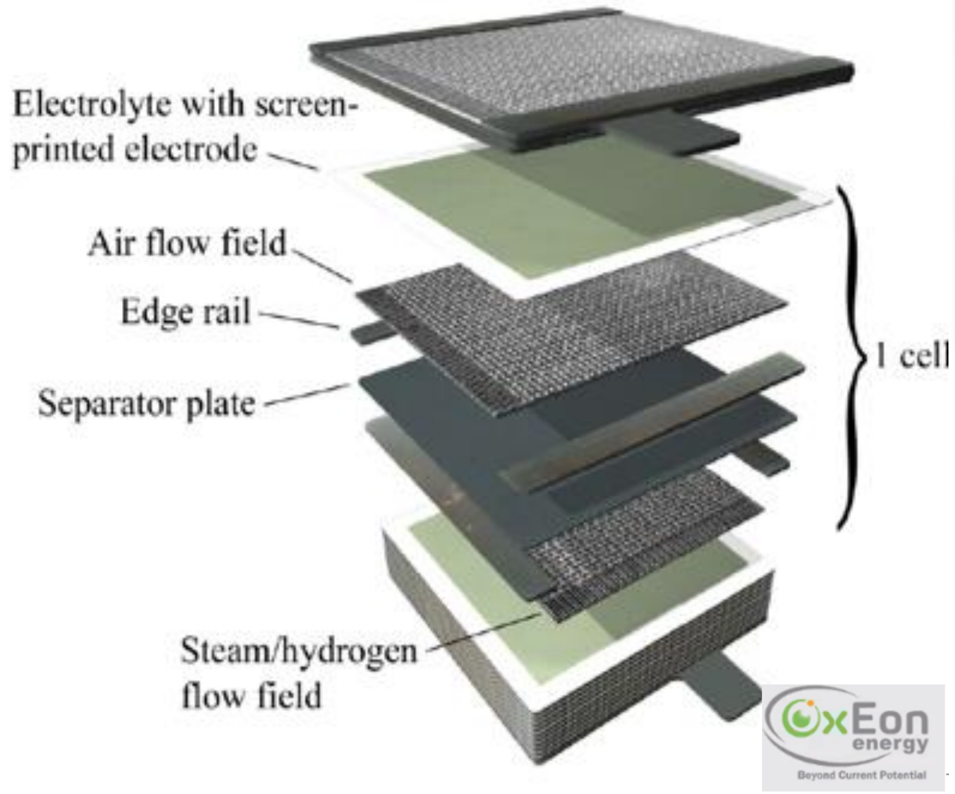


Chick et al, *Fuel Cells, 15 (2015) 49-60*

- Powders
- Tape Casting
- Sintering & Inspection
- Screen Printing
- Steel Parts & Coatings
- Cell-to-Frame Sealing
- Repeat Unit Fabrication
- Stack Assembly & Sealing
- Manifold & Current Collectors & Load Frame

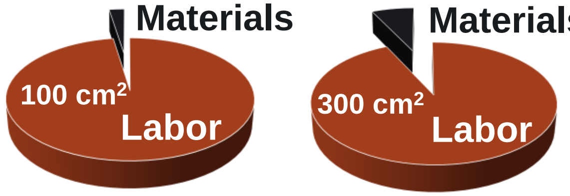
For competitive reasons manufacturers do not publish detailed manufacturing data. The costs analyses are black-box analyses, which do not give the exact information



- ❑ Interconnects (cut/machine, stamp)
- ❑ Apply protective coatings, fire, inspect
- ❑ Glass seal cells, mount, fire
- ❑ Fabricate and coat flow field parts, separator plates, spacers
- ❑ Weld frames and interconnects
- ❑ Stack fabrication
- ❑ Assembly

Identifying Pathways to <$100/kW HTE Stack Cost

Increasing cell size does not increase cost

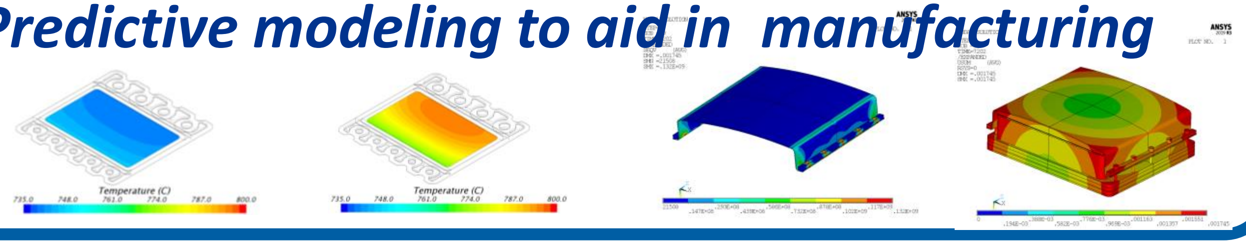


Advanced fabrication methods, robotics, automation, high volume manufacturing techniques

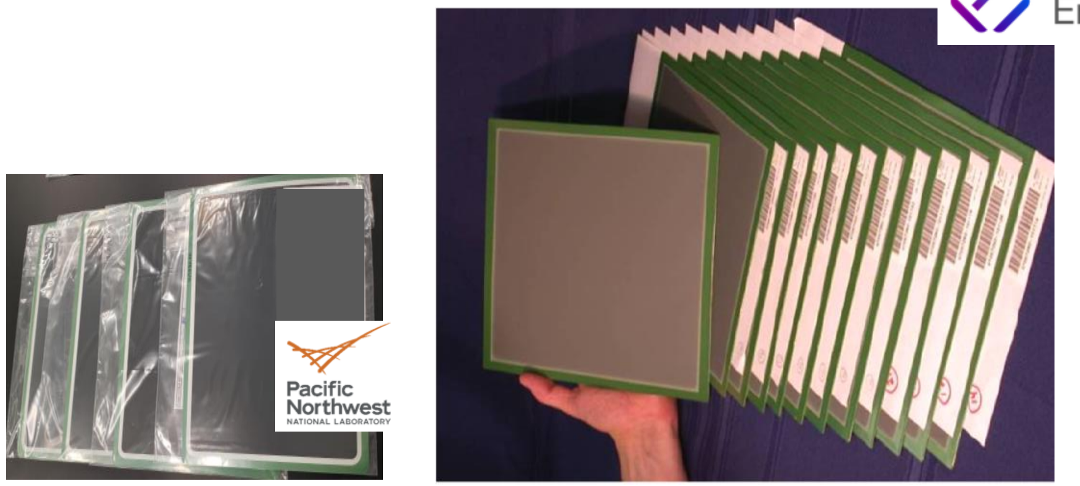
Performance and life improvement to reduce materials

Reduce production steps

Predictive modeling to aid in manufacturing



QA/QC improve parts yield



22x17 cm and 25x25 cm cells

Impact:

- Reduce number of all parts
- Reduced number of interfaces, thus minimize failures/degradations

Difficulty:

- Materials properties
- Equipment size
- Variability in materials sources, different materials purity

Identifying Pathways to Reduce Hydrogen Cost to $1/kg H_2

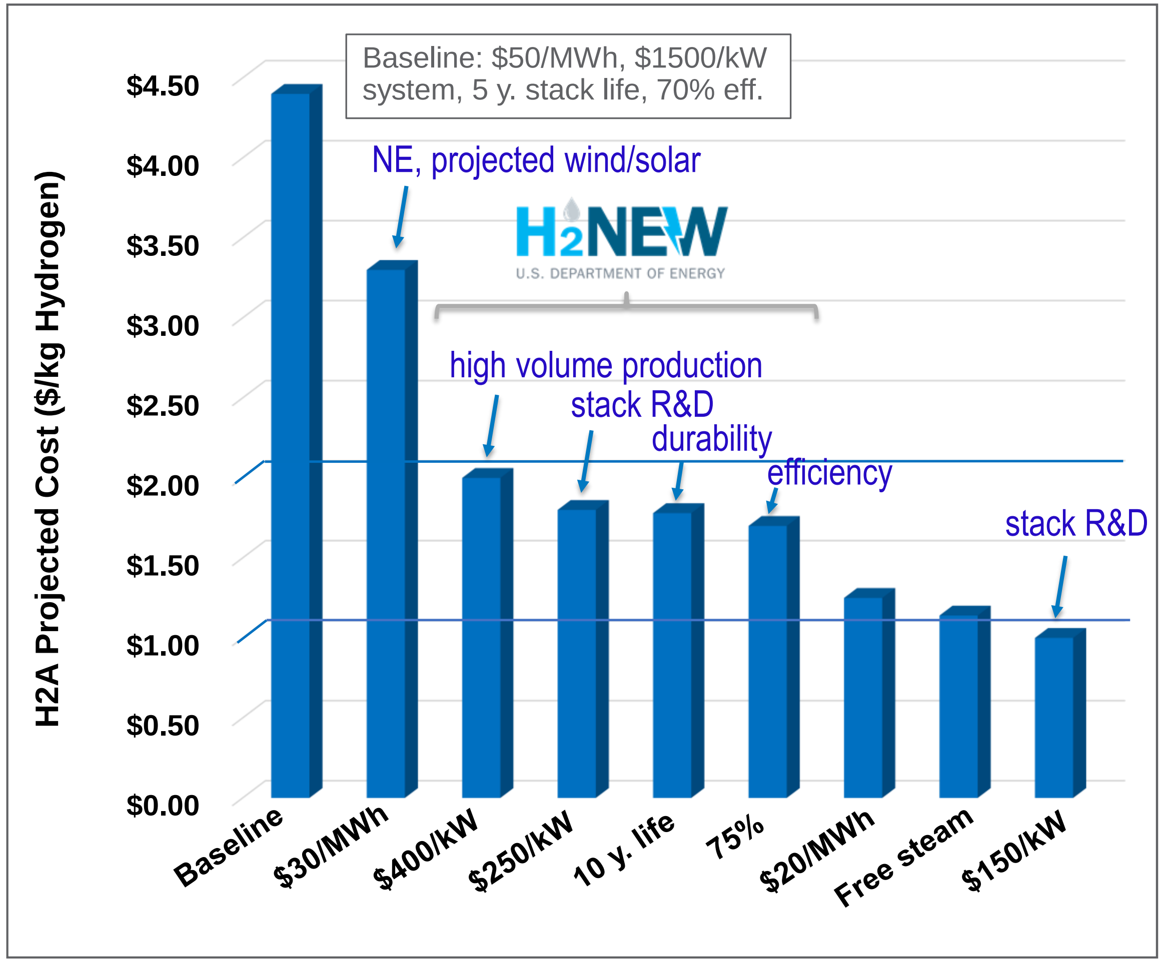
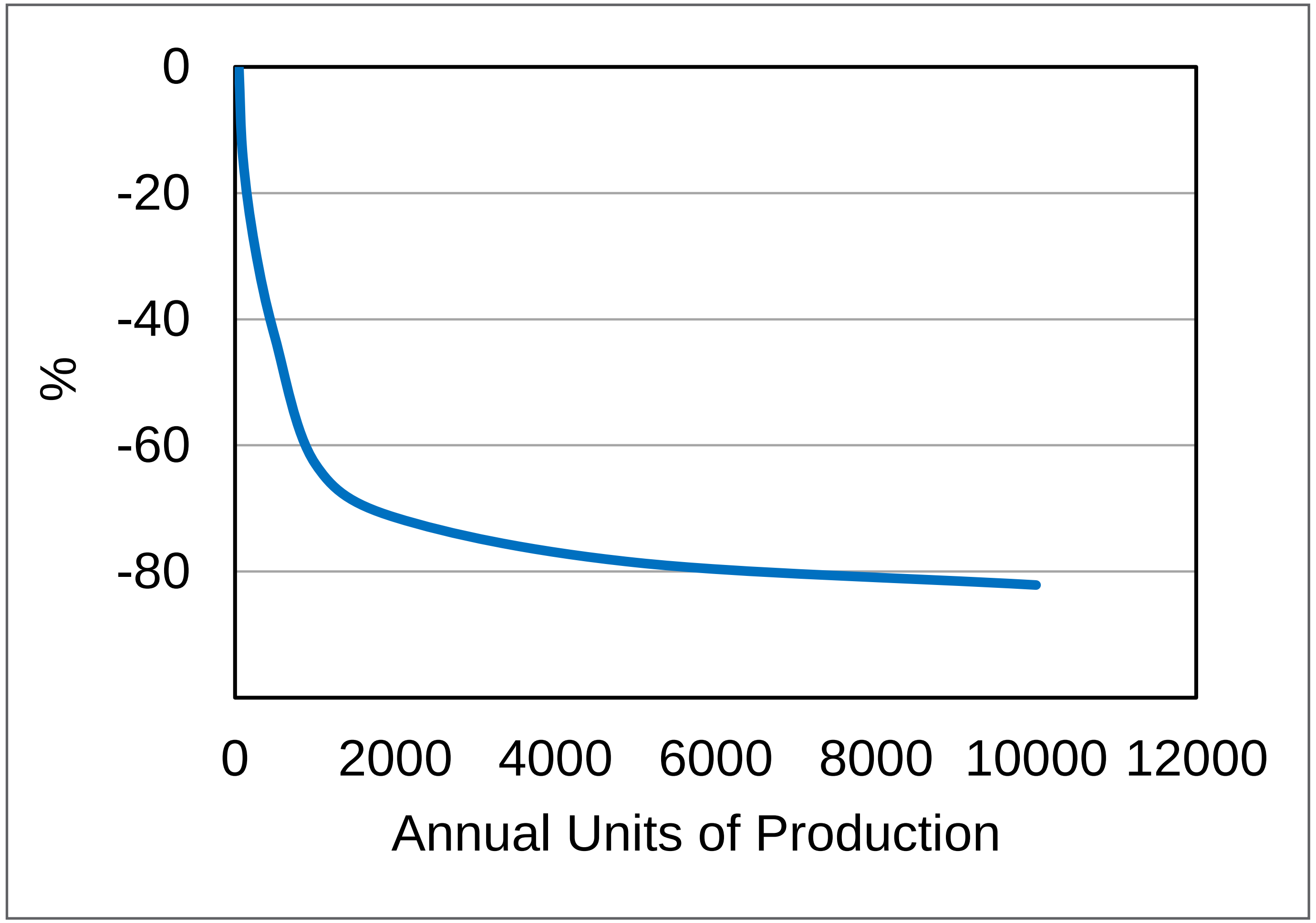


Figure source: PNNL (J. Holladay), 2021

Costs reduction for different levels of annual production



Adopted from Chick et al, Fuel Cells, 15 (2015) 49-60

Key enablers for lower cost electrolytic H_2

- Electricity price
- High electrical efficiency
- Thermal integration
- Manufacturing at scale
- Low-cost CAPEX
- Low-cost manufacturing methods