ENERGY earthshots U.S. DEPARTMENT OF ENERGY | Hydrogen

Current Status of (Low Temperature) Electrolyzer Technology and Needs for Successful Widespread Commercialization and Meeting Hydrogen Shot Targets

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Hydrogen Shot Summit

The 2020's – The Decade of Hydrogen

Hydrogen Council

CLIMATE CH2AMPION: HYDROGEN IS THE MISSING PIECE OF THE ENERGY PUZZLE

HYDROGEN COST TO FALL SHARPLY AND SOONER THAN EXPECTED

HYDROGEN DEPLOYMENT ACCELERATING WITH MORE THAN $300 BILLION IN PROJECT PIPELINE

> *Potential Impacts from Hydrogen Council Roadmap Study. By 2050:*
> - *$2.5 trillion in global revenues*
> - *30 million jobs*
> - *400 million cars, 15-20 million trucks*
> - *18% of total global energy demand*

https://hydrogencouncil.com/en/

Live news

The global race to develop 'green' hydrogen

Issued on: 31/03/2021 - 05:52 Modified: 31/03/2021 - 05:50

Hydrogen-powered fuel cells could solve the key problem with battery electric vehicles – the long recharge times – as filling up a tank with hydrogen takes just a bit longer than putting in petrol. GEORGES GOBET AFP/File

4 min

Paris (AFP)

It's seen as the missing link in the race for carbon-neutrality: "green" hydrogen produced without fossil fuel energy is a popular buzzword in competing press releases and investment plans across the globe.

https://www.france24.com/en/live-news/20210331-the-global-race-to-develop-green-hydrogen

Politics

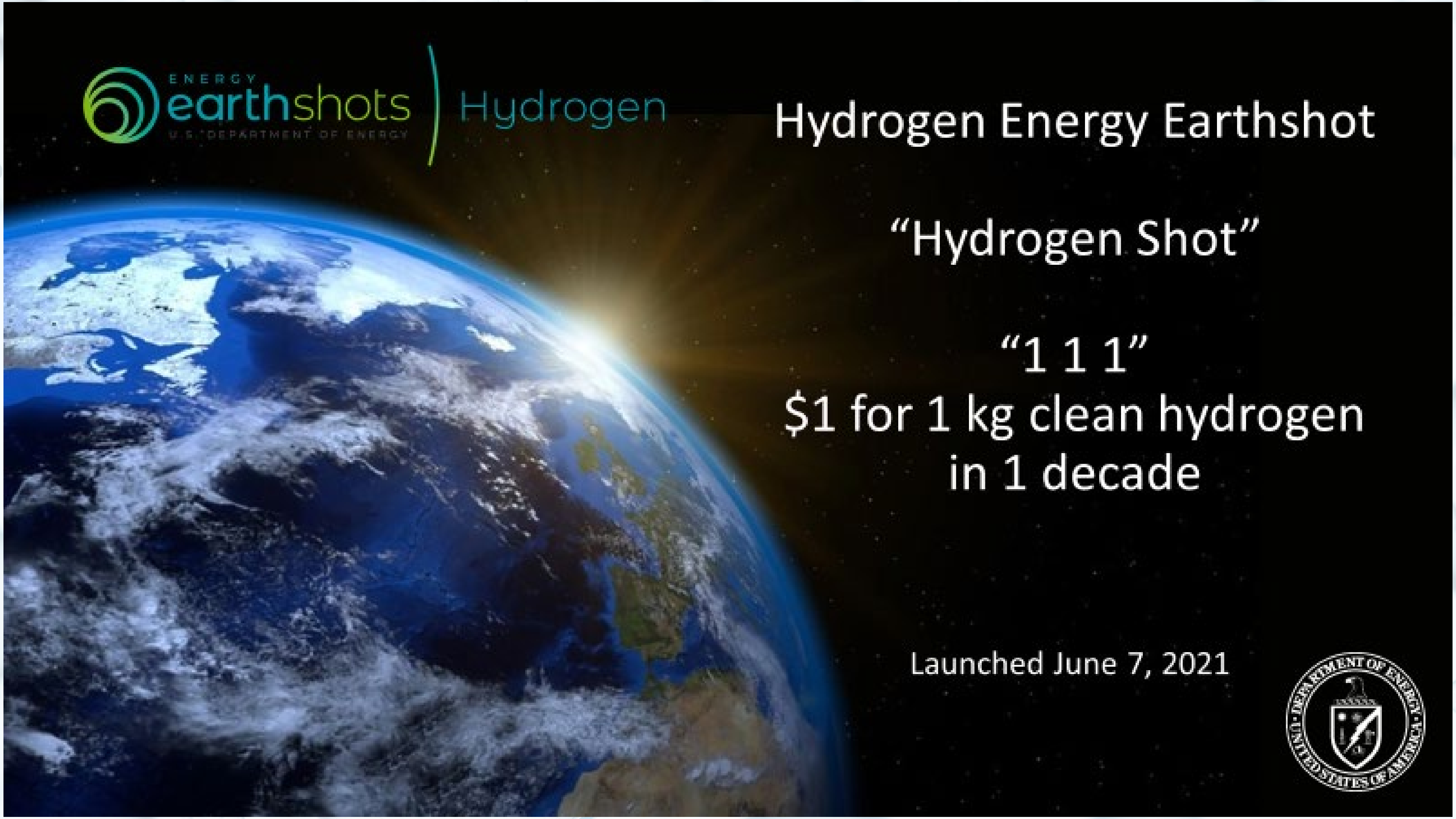
Hydrogen Is 'Jump Ball' in Global Clean-Energy Race, Kerry Says

By Jennifer A Dlouhy and Will Wade
March 2, 2021, 9:38 AM MST

- Climate envoy touts oil-industry opportunity at CERAWeek
- Says tensions with China won't block aggressive climate action

https://www.bloomberg.com/news/articles/2021-03-02/hydrogen-is-jump-ball-in-global-clean-energy-race-kerry-says

Now is the time for hydrogen and the "global race" is on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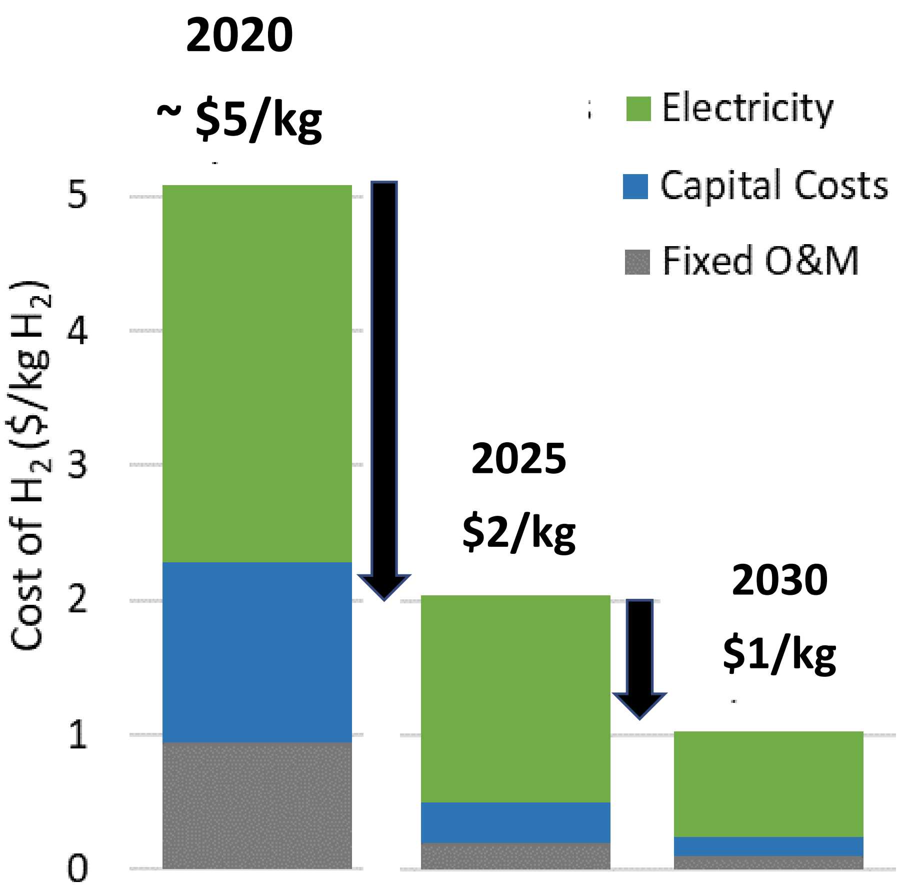
Hydrogen
Hydrogen Energy Earthshot
"Hydrogen Shot"
"1 1 1"
$1 for 1 kg clean hydrogen
in 1 decade
Launched June 7, 2021
DEPARTMENT OF ENERGY
UNITED STATES OF AMERICA

Pathways to Reduce the Cost of Electrolytic H_2

Cost Reduction of Clean Electrolytic H_2



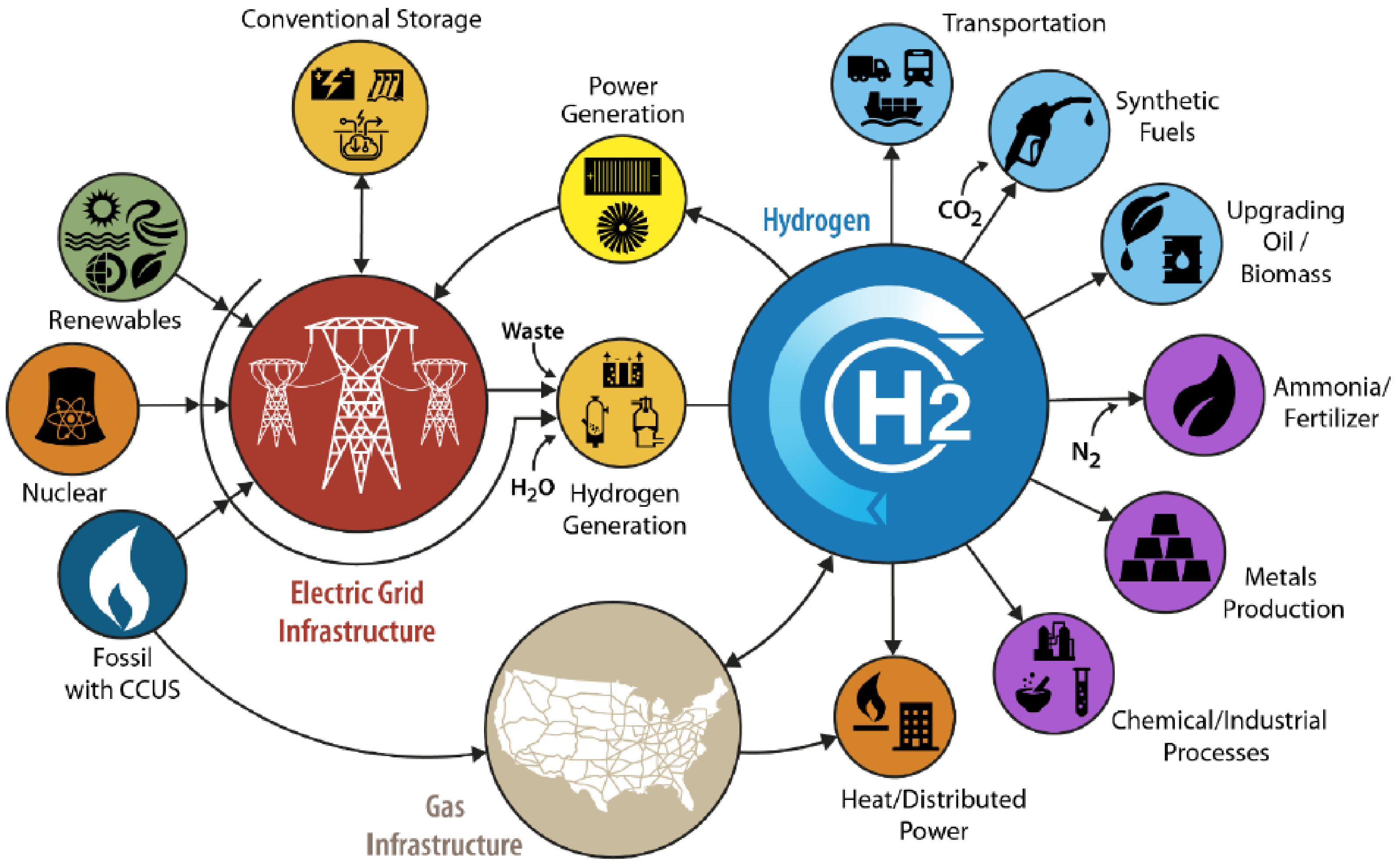
Key enablers for lower cost electrolytic H_2:

- **Low-cost electricity**
- **High electrical efficiency**
- **Low-cost capital expense**
- **Increased durability/lifetime**
- **Low-cost manufacturing processes**
- **Manufacturing at MW-scale**

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

Electrolysis Connection to H2@Scale



Illustrative example, not comprehensive

https://www.energy.gov/eere/fuelcells/h2-scale

- Making, storing, moving and using H_2 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.

Electrolyzers by Type

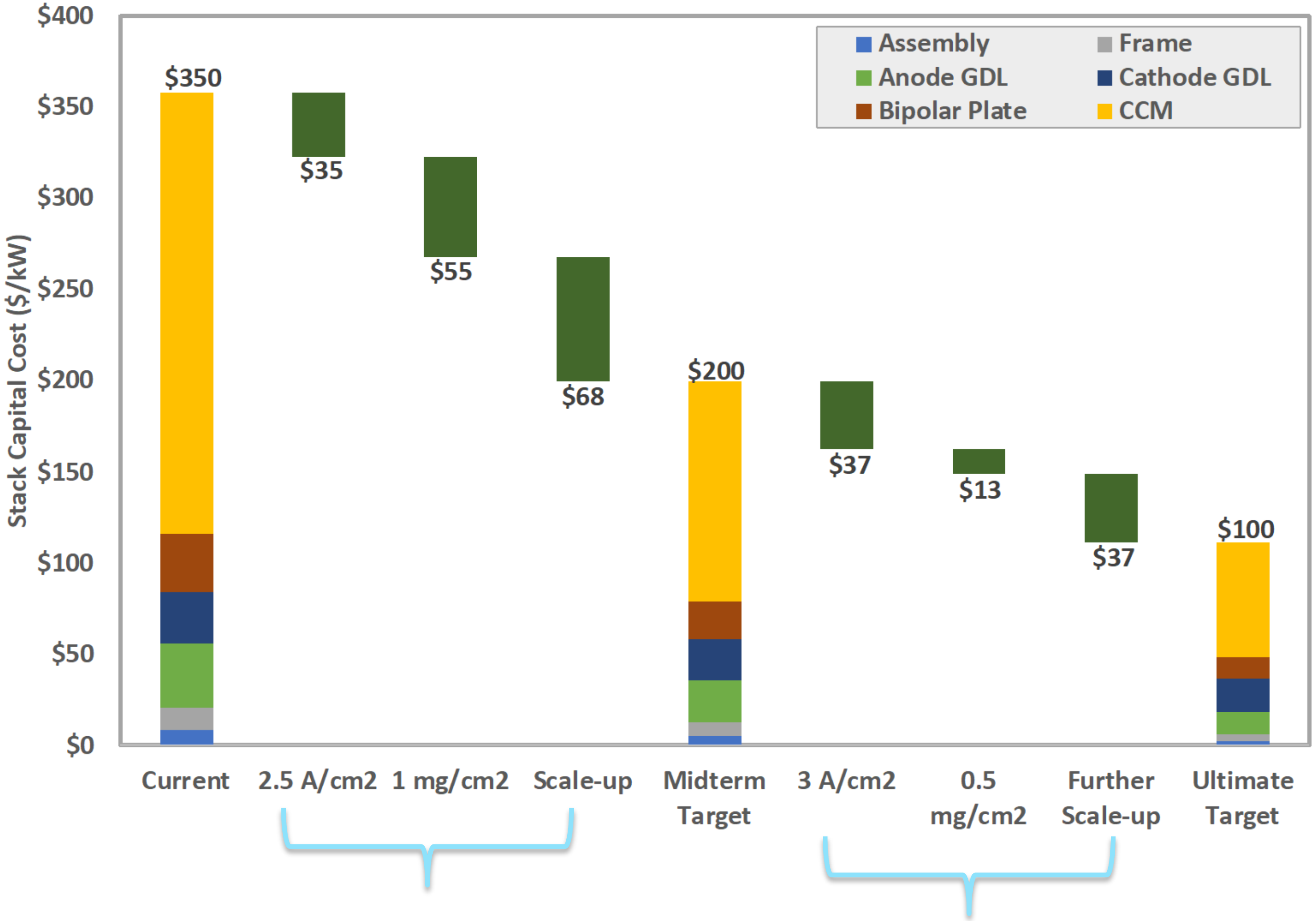
Type	Pros	Cons
Alkaline	Well established, lower capital cost, more materials choices at high pH, high manufacturing readiness, can leverage established supply chains, demonstrated in larger capacity	Corrosive liquid electrolyte used, higher ohmic drop, lack of differential pressure operation, shunt currents, 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°C) (Alkaline, Polymer Electrolyte Membrane)

High Temperature (>500°C) (Solid Oxide)

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

Stack Costs (PEM analysis from H2NEW)



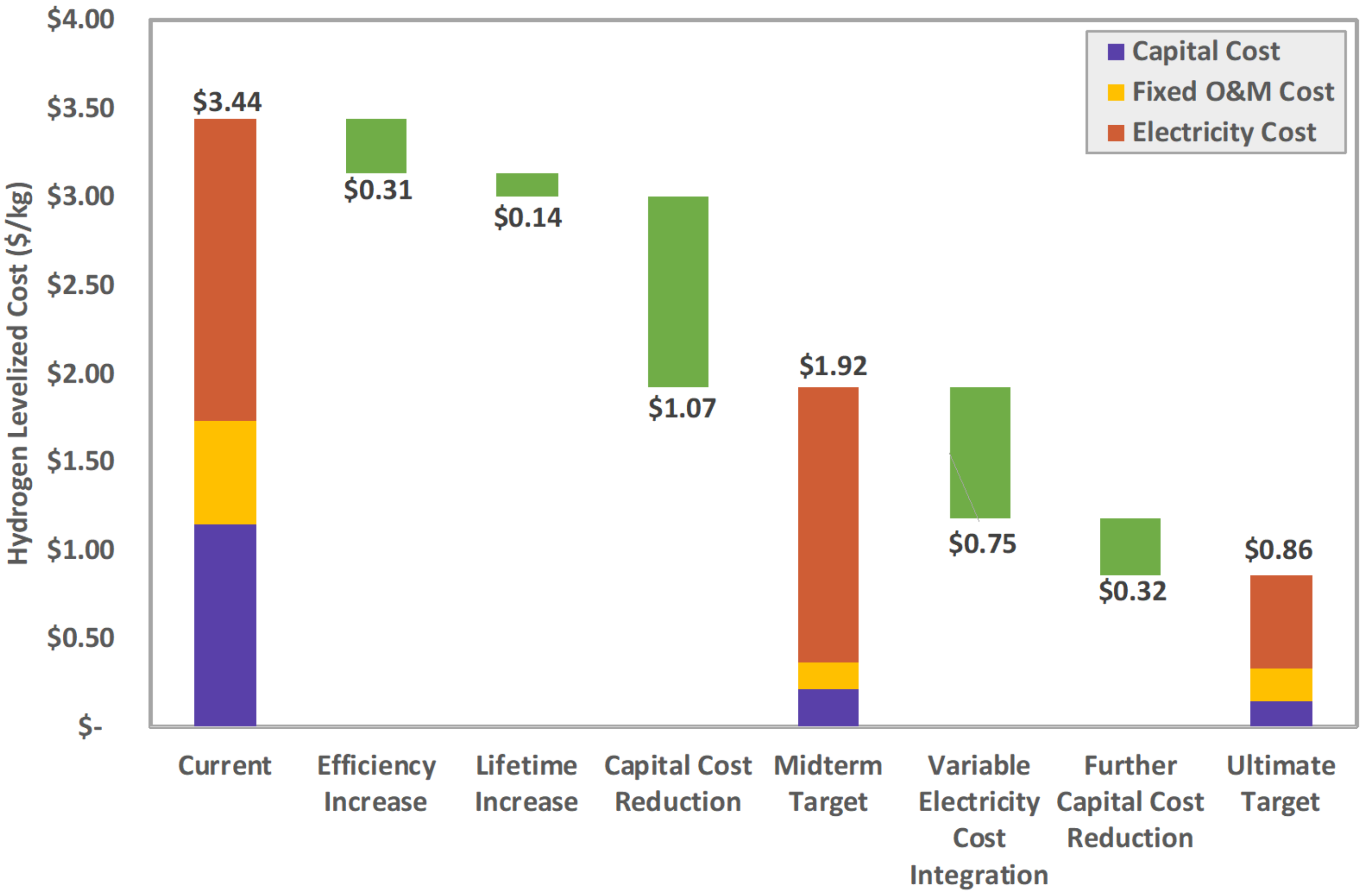
Stack Targets	Status	2023	2025
Cell (A/cm^2@1.9V)	2.0	2.5	3.0
Efficiency (%)	66	68	70
Lifetime (khr)	60	70	80
Degradation (mV/khr)	3.2	2.75	2.25
Capital Cost ($/kW)	350	200	100
PGM loading (mg/cm^2)	3	1	0.5

These 3 areas

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

Are the strongest levers for addressing stack costs.

Achieving Hydrogen Levelized Cost (HLC) Targets

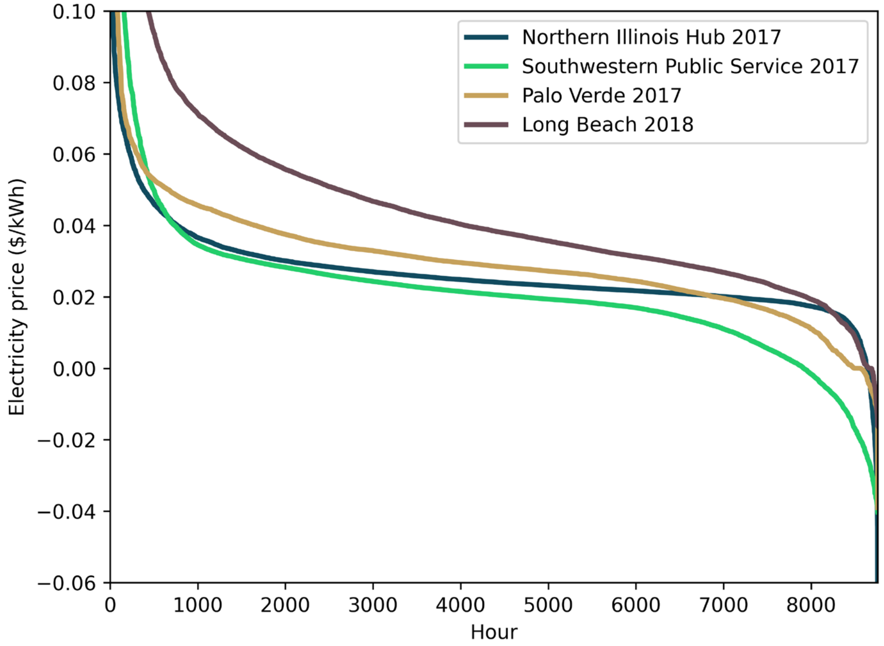


Select pathway to $2/kg and $1/kg identified.

Much of HLC gains possible through greatly decreasing capital costs and enabling lower cost electricity through variable operation.

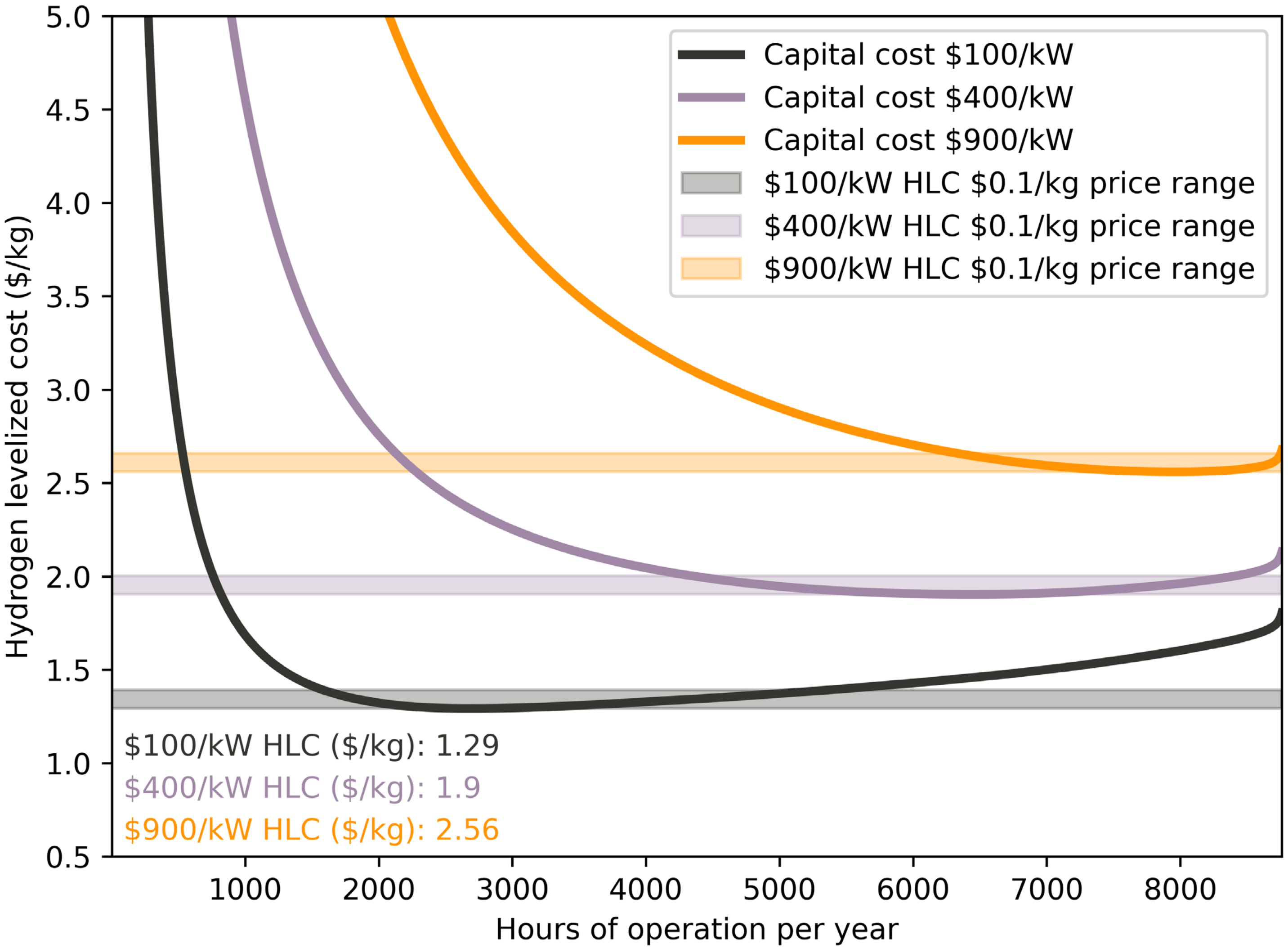
These advances can’t come with compromised durability or efficiency, so all three areas are linked.

Wholesale Electricity Cost Curves



Curves at low capital costs are:

- Lower cost
- Flatter
- Optimum at lower capacity factor



H2A Future Central case. 51.3 kWh/kg system efficiency. Capital costs are total system purchase cost. Palo Verde LMPs.

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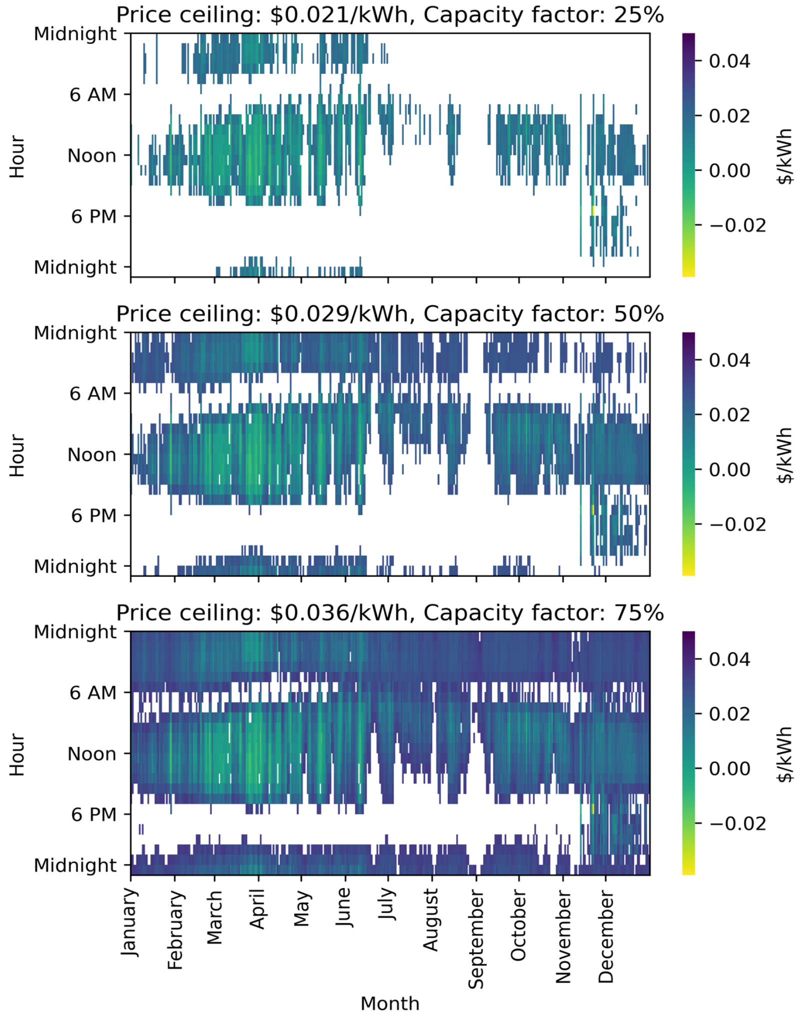
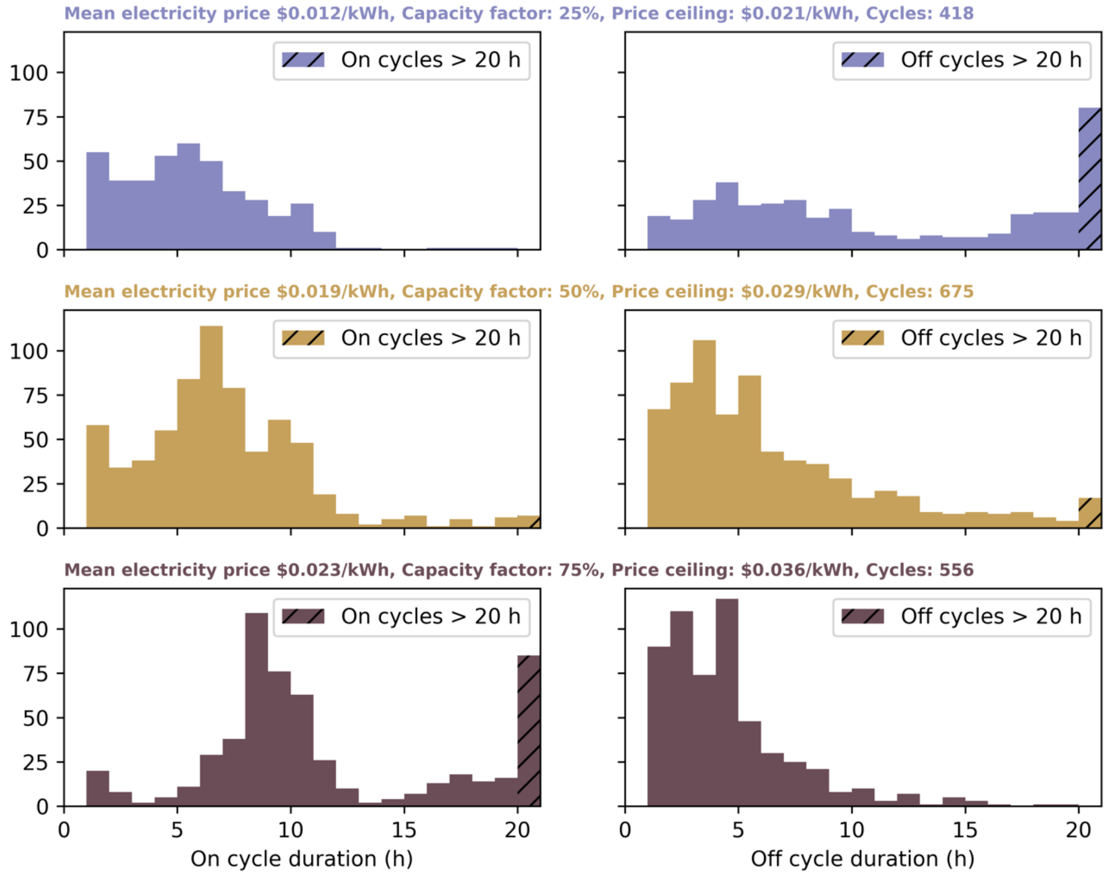
Badgett, A., M. Ruth, B. Pivovar. "Economic Considerations for Hydrogen Production with a Focus on Polymer Electrolyte Membrane Electrolysis" Submitted as a chapter in Hydrogen Production by Water Electrolysis. Ed. Tom Smolinka. accepted, 2021.

Impact of Electricity Costs on Operating Strategies



Locational Marginal Pricing (LMP) heatmaps can give insight into potential operating strategies



Lends insight into possible operating strategies

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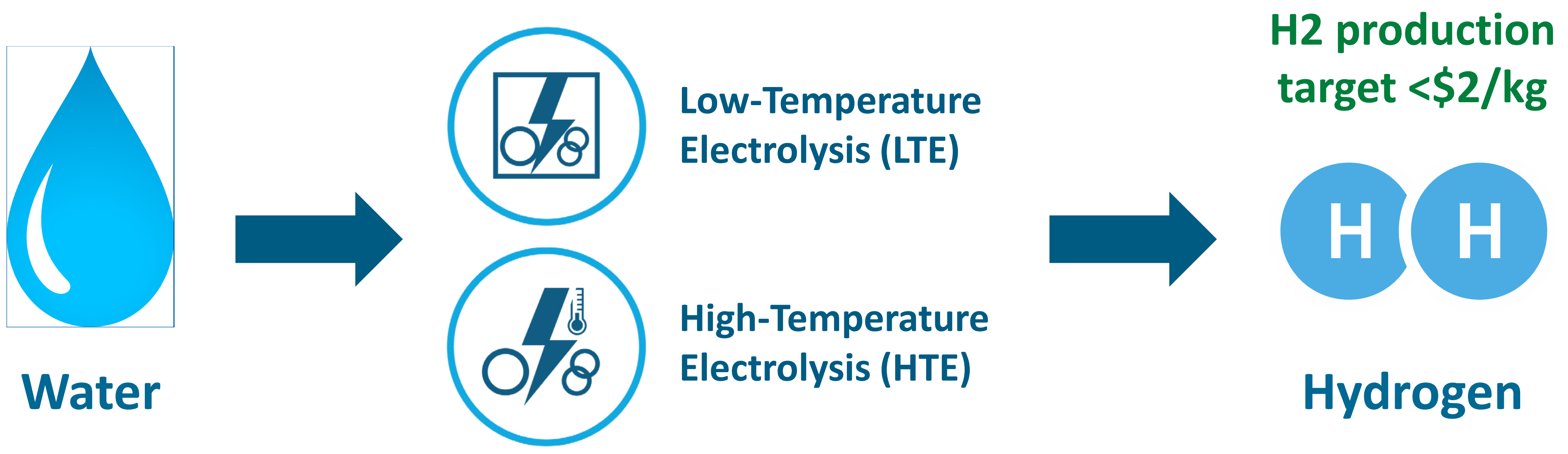
H2NEW Project Goals

By 2025, 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 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

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

A comprehensive, concerted effort focused on overcoming technical barriers to enable affordable & efficient electrolyzers to achieve <\$2/kg H_2 (2025)

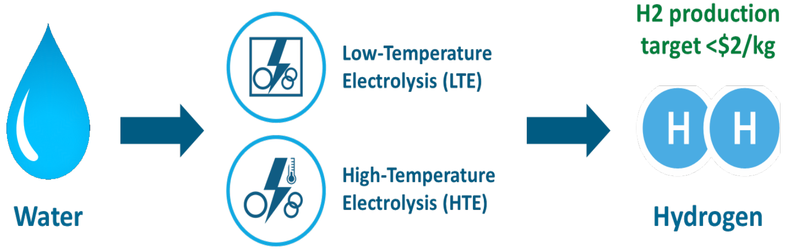
- Launched in Q1 FY2021
- Both low- and high-temperature electrolyzers
- ***Planned commitment of \$50M over 5 years***

National 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.

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**

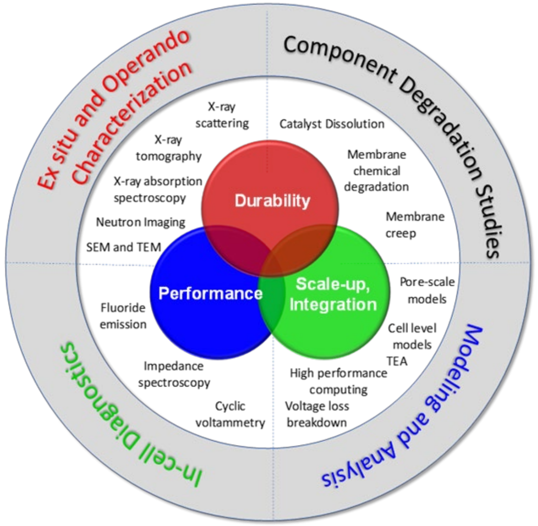


H2NEW focuses on higher TRL electrolyzer technologies:

- PEM for LTE
- Oxide ion conductors for HTE

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

Makes use of a combination of world-class experimental, analytical, and modeling tools

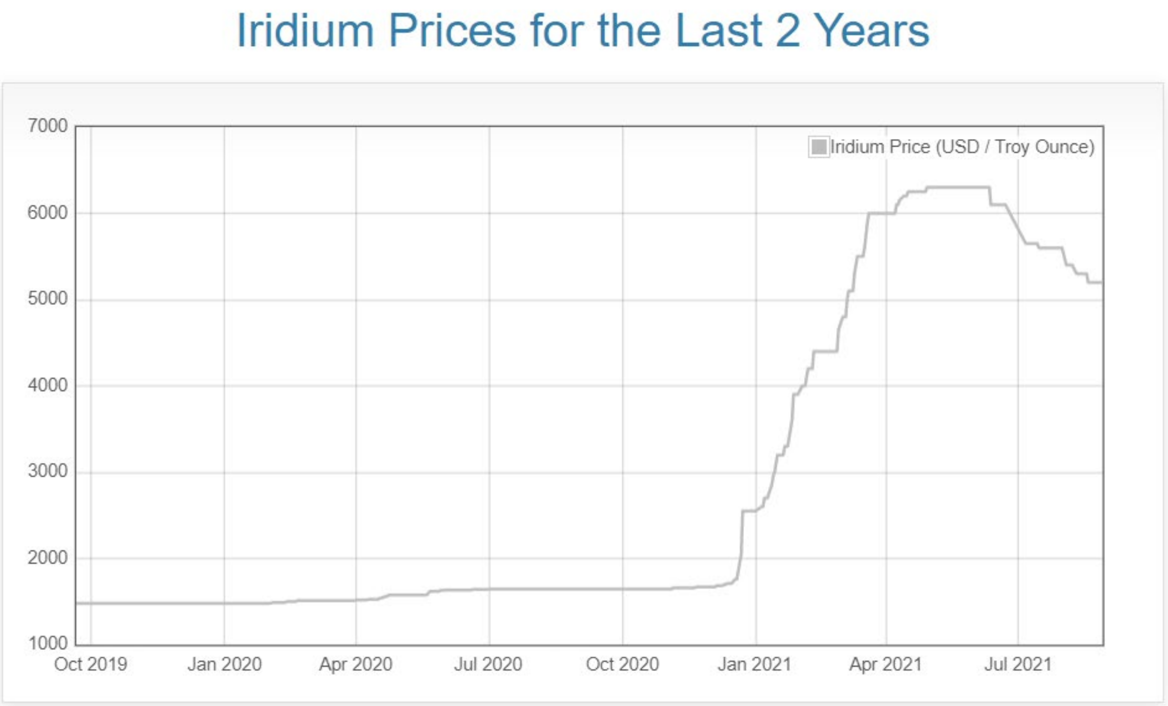


Durability/lifetime is most critical, initial, primary focus of H2NEW

- Limited fundamental knowledge of degradation mechanisms including under future 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.

Materials Needs for PEM

- Thrifting/replacing of Ir
  - Supports
  - Novel compositions/structures
  - Electrode fabrication impacts
- Improved membranes
  - Increased selectivity, thin membranes
  - Improved durability
  - Recombination layers
- Novel Porous Transport Layers (PTLs)
  - Materials
  - Morphology
  - Coatings



https://www.dailymetalprice.com/metalpricecharts.php?c=ir&u=oz&d=120

Alkaline Needs

- Traditional (Conc. KOH)
  - Intermittent operating capability
  - Operating pressure
  - Degradation mechanisms/ASTs
  - Performance/efficiency improvements

- AEM/hybrid (low conc/KOH-free systems)
  - Novel materials development
    - Stable polymers
    - Advanced catalysts
  - Performance dependence on electrolyte
  - Degradation mechanisms/ASTs