Hydrogen from Next-generation Electrolyzers of Water

U.S. DEPARTMENT OF ENERGY

Hydrogen's Big Shot : Where we are and where we are going

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Date: 4/27/22

EESI Briefing

H2@Scale

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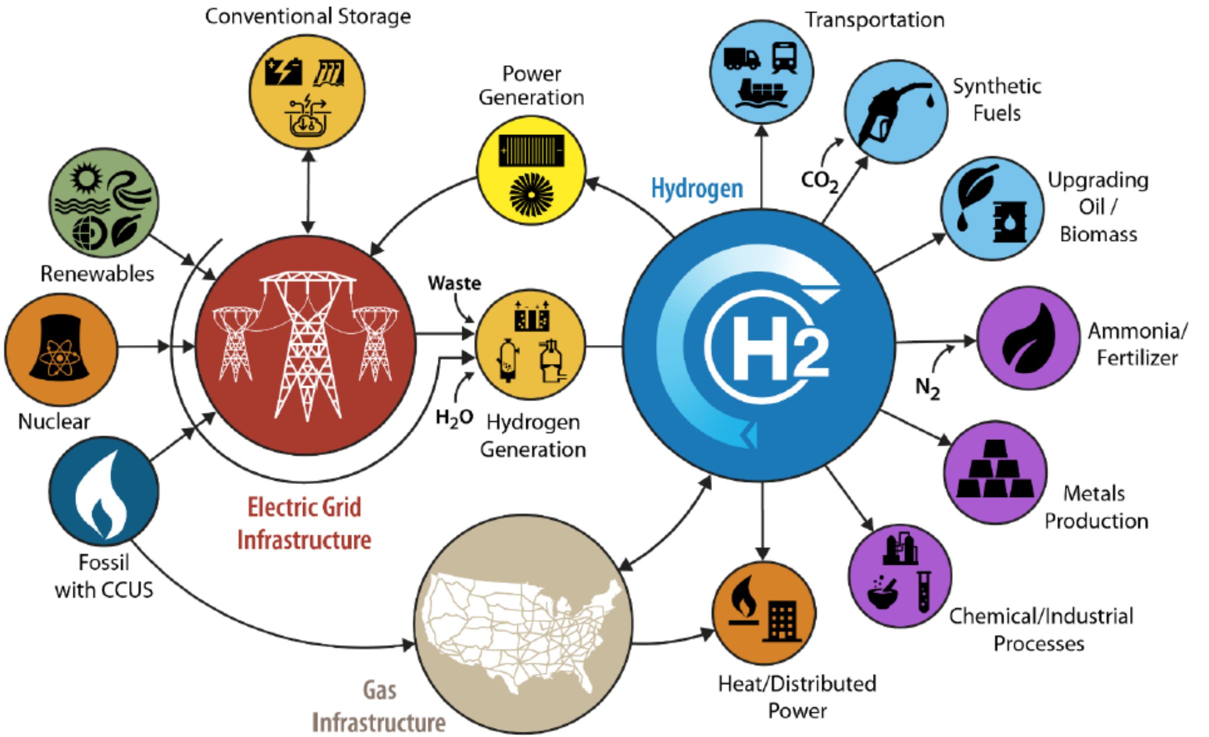

Illustrative example, not comprehensive

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

H2@Scale

- Attributes
  - Cross-sectoral and temporal energy impact
  - Clean, efficient end use
- Benefits
  - Economic factors (jobs, GDP)
  - Enhanced Security (energy, manufacturing)
  - Environmental Benefits (air, water)
    - GHG
    - Local criteria pollutants

Getting <u>all</u> these benefits in a single energy system significantly enhances value proposition.

Improving the economics of H2@Scale

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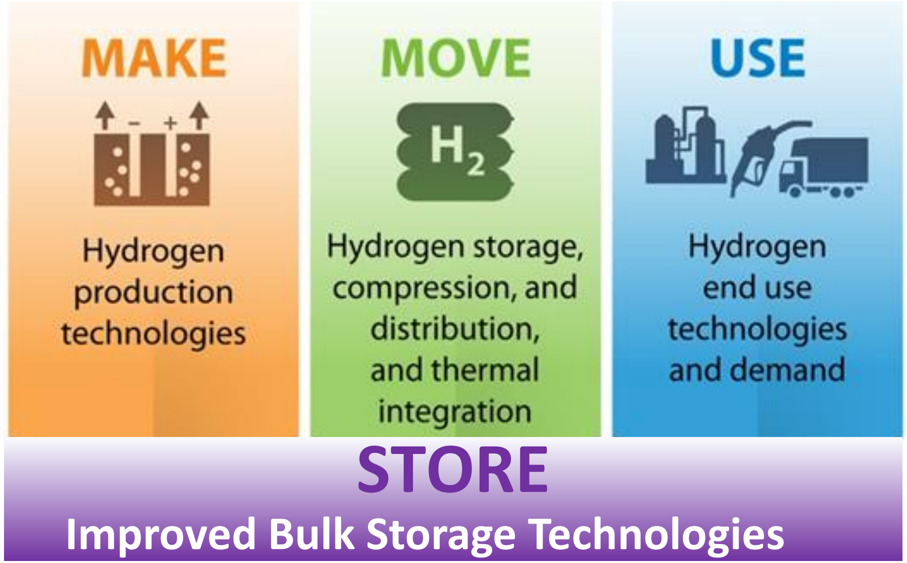
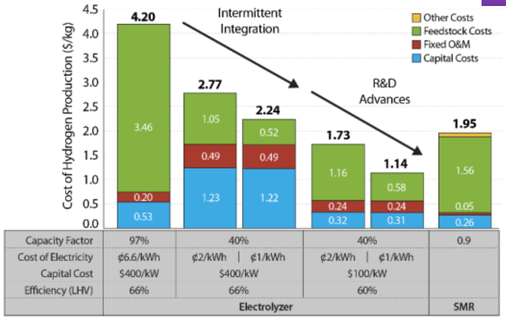
Early-stage research is required to evolve and de-risk the technologies.

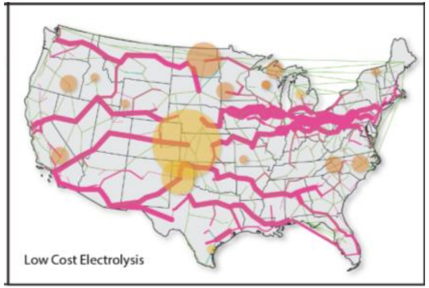


Preliminary

Use	Potential MMT/yr
Refineries & CPI	8
Metals	12
Ammonia	4
Synthetic Chemicals	14
Biofuels	1
Natural Gas	10
Light Duty Vehicles	57
Other Transport	17
Electricity Storage	28
Total	**151**

Decreasing cost of H_2 production





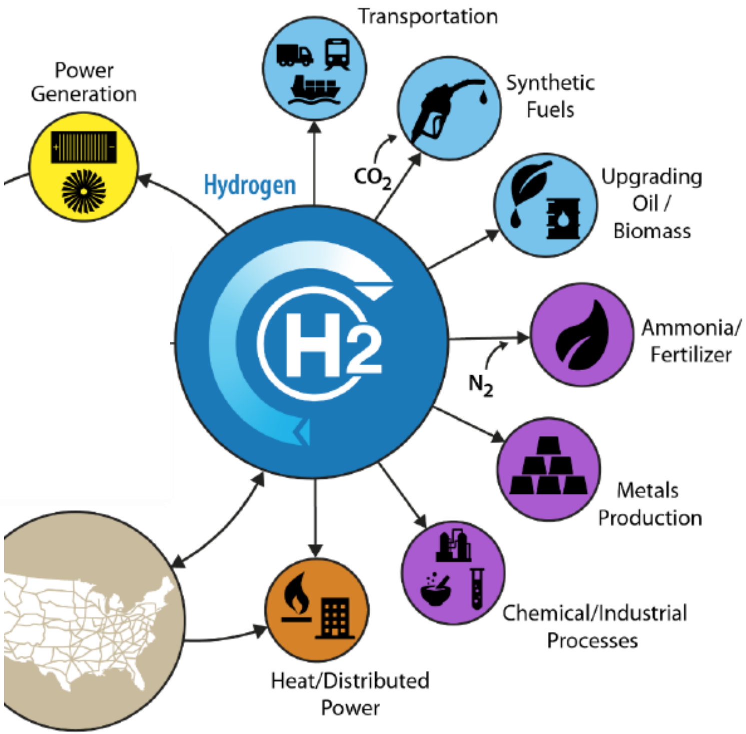
Optimizing H_2 storage and distribution

Leveraging of national laboratories' early-stage R&D capabilities needed to develop affordable technologies for production, delivery, and end use applications.

https://www.hydrogen.energy.gov/pdfs/review18/tv045_ruth_2018_o.pdf

Use

Use



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https://www.nrel.gov/docs/fy21osti/77610.pdf

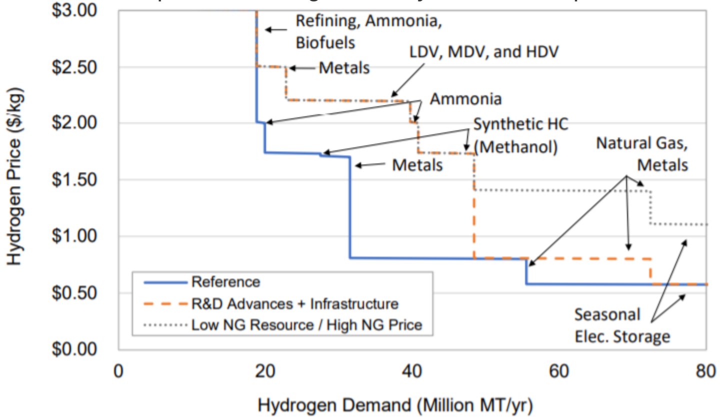


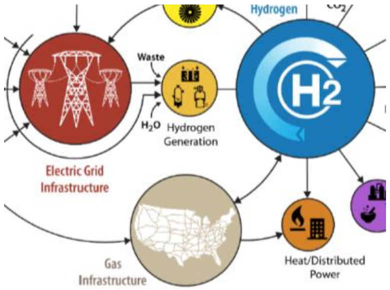
Figure 24. Aggregated demand curves for H2@Scale scenarios

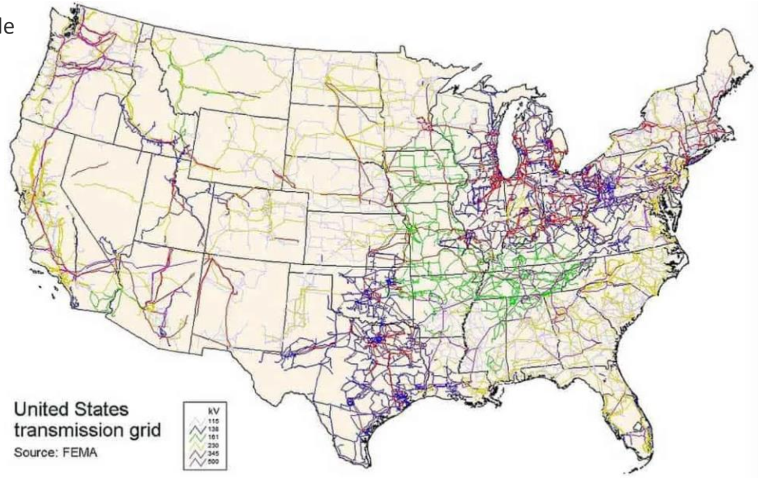
- Transportation and Industry are strongest economic sectors (also difficult to decarbonize)
- Difficult or impossible to fully electrify
- Many of the processes are or could be electrochemical
- R&D needs are significant
  - Fuel Cells (M2FCT), NH3, Steel, burners/turbines

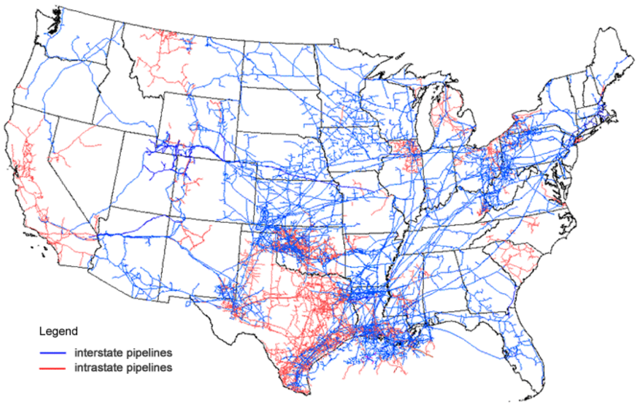
Move/Store

Energy Transmission Infrastructure

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

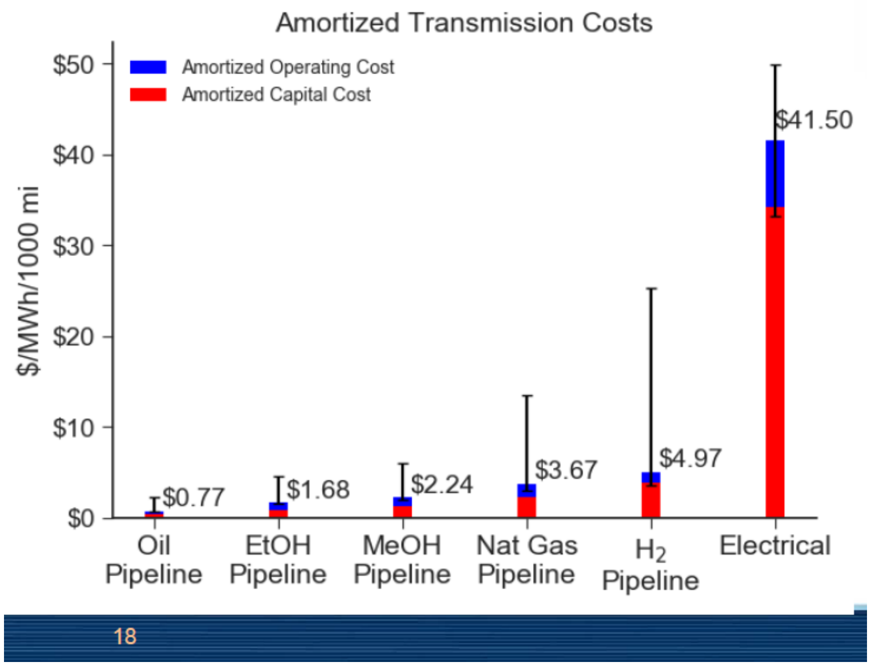






- Hydrogen has a very limited infrastructure (due to scale and selective use).
  - Current H2 prices dominated by storage and distribution (LDV CA)
- Electricity and natural gas have extensive infrastructural investments.
- Similar maps, much different energy/cost, permitting challenges
- Hydrogen pipeline analogous to natural gas

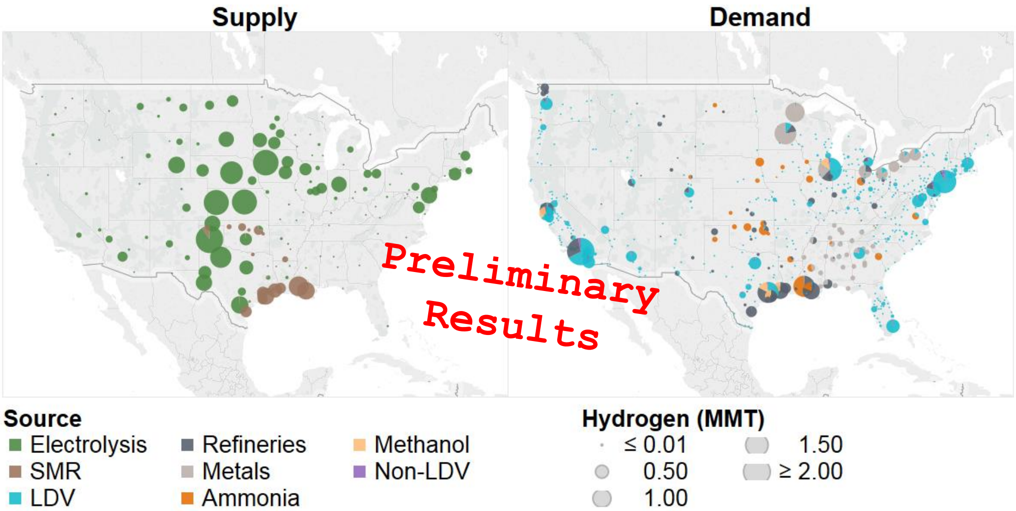
Natural gas as the nearest H2 parallel

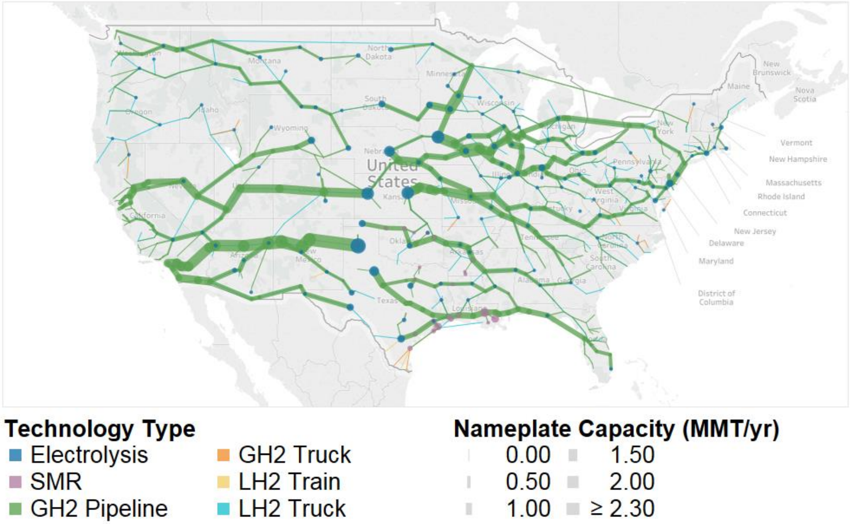


- Hydrogen perhaps ~30% move expensive to move than natural gas.
- ~1/3rd volumetric energy density, ~1/3rd viscosity.
- Additional materials compatibility limitations
- Particularly relevant at large scales and long distances

https://www.hydrogen.energy.gov/pdfs/review18/pd102_james_2018_p.pdf

Location of Generation vs. Demand





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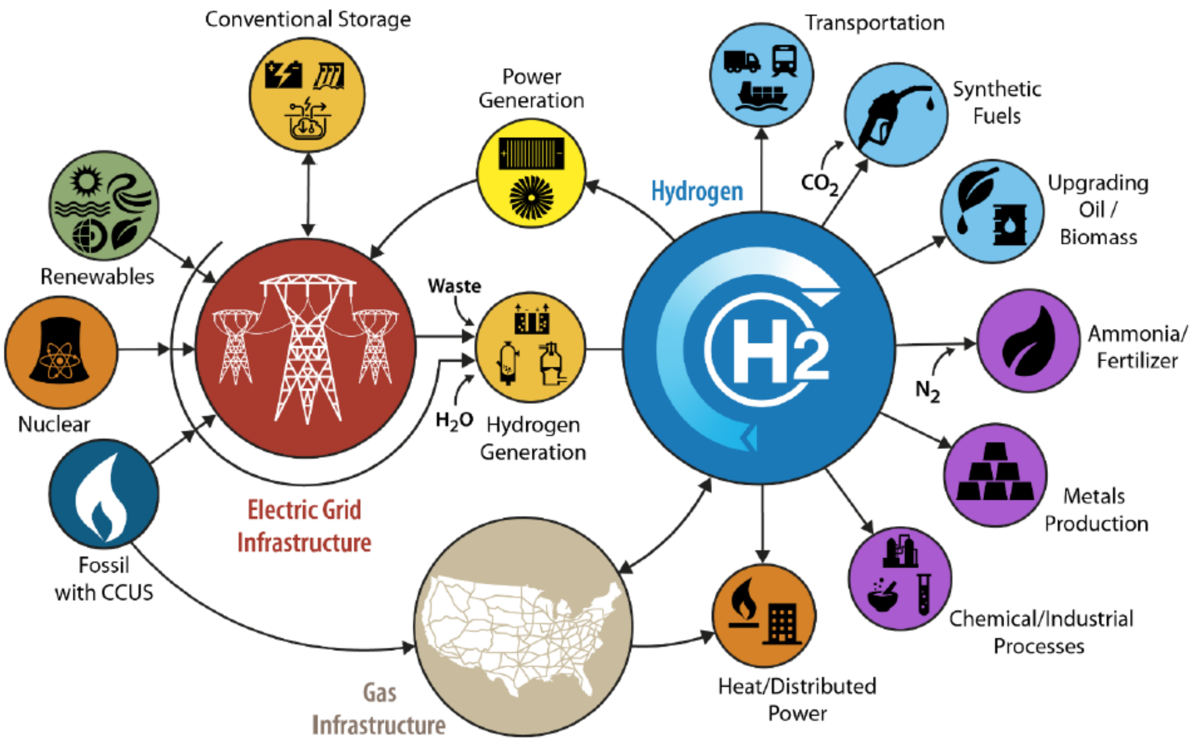
Select Store/Move Needs

- Bulk storage, liquefaction workshops
  - Subsurface, surface
  - Liquefaction, boil off, shipping, cryo
- Pipeline R&D
  - H2 only
  - HYBLEND
  - Conversion of existing NG infrastructure
- Compression (incl. electrochemical compression/separation)
- Hydrogen Storage Materials
- Dispensing (HD)

Make

H2NEW connection to H2@Scale



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

- 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.

Pathways to Reduce the Cost of Electrolytic H_2

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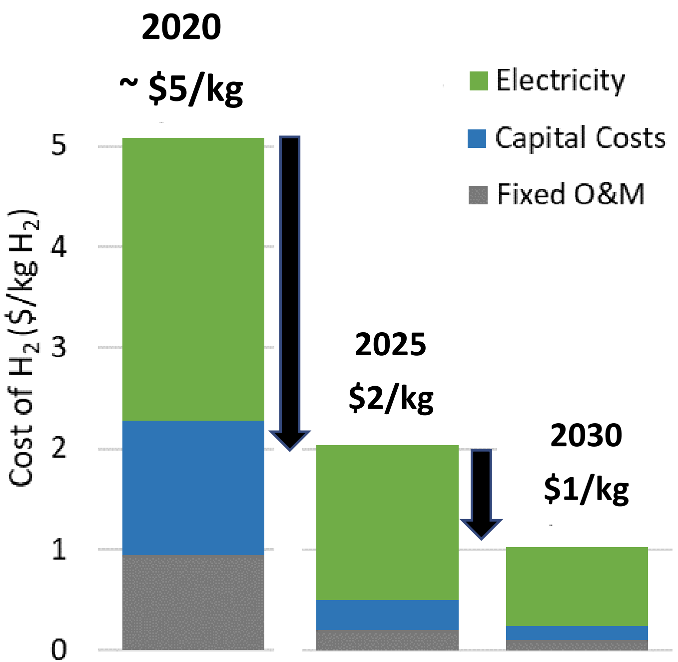
Cost Reduction of Clean Electrolytic H_2



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

Electrolyzers by Type

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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	Low Temperature (0 - 200ºC)
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	High Temperature (>500ºC)

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

H2NEW : H2 from Next-generation Electrolyzers of Water

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

- Launching in Q1 FY21
- Both low- and high-temperature electrolyzers
- \$50M over 5 years

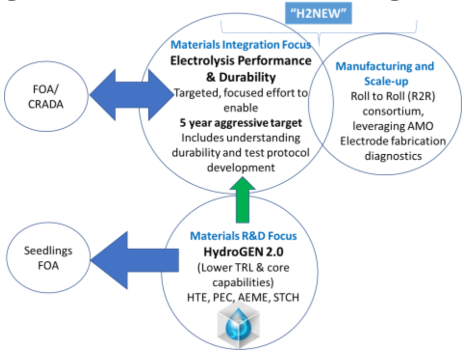
National Lab Consortium Team

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
NETL NATIONAL ENERGY TECHNOLOGY LABORATORY

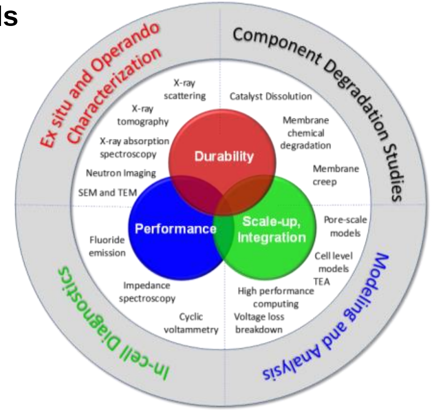
Clear, well-defined stack metrics to guide efforts.

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

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



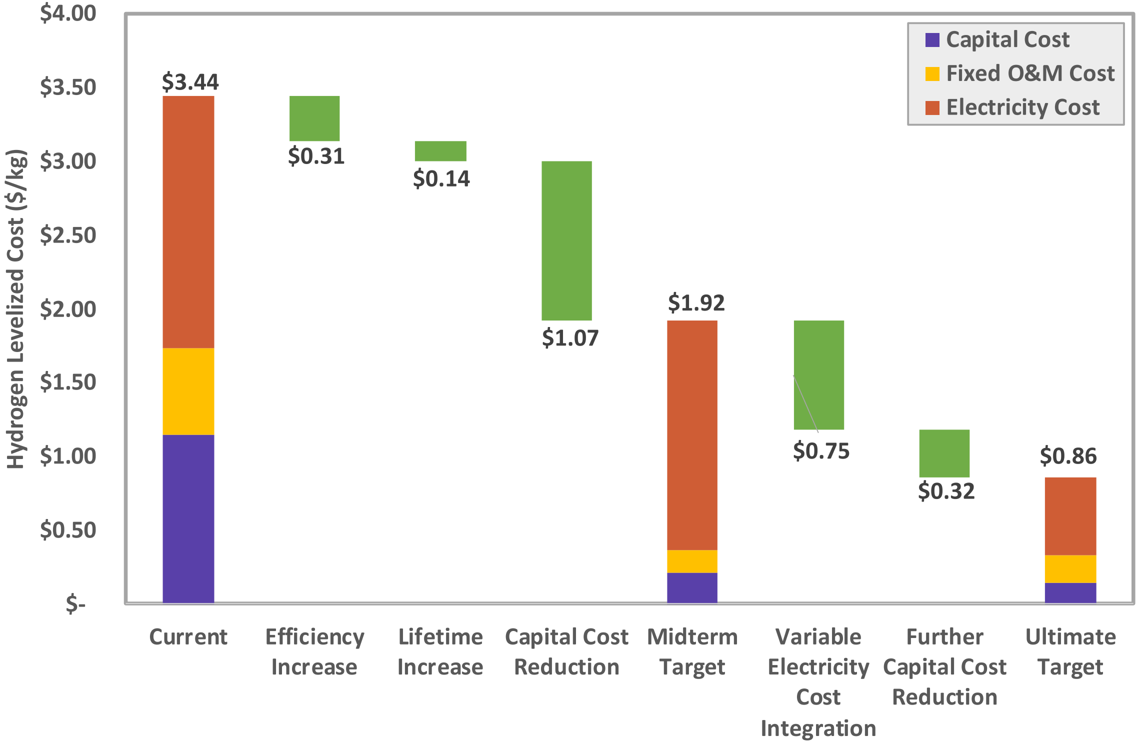
Utilize combination of world-class experimental, analytical, and modeling tools



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

- Limited fundamental knowledge of degradation mechanisms.
- Lack of understanding on how to effectively accelerate degradation processes.
- 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.
- National labs are ideal for this critical work due to existing capabilities and expertise combined with the ability to freely share research findings.

Relevance: Hydrogen Levelized Cost (PEM Centric)



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.