H2@Scale: Opportunities for Hydrogen as an Energy Carrier

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The National Renewable Energy Laboratory

Mission: NREL advances the science and engineering of energy efficiency, sustainable transportation, and renewable power technologies and provides the knowledge to integrate and optimize energy systems.

Example Technology Areas:

- Approximately 2,200 employees, postdoctoral researchers, interns, visiting professionals, and subcontractors
- 327-acre campus in Golden & 305-acre National Wind Technology Center 13 miles north
- 63 R&D 100 awards. More than 1000 scientific and technical materials published annually

www.nrel.gov/about

Partnering with Business for Competitive Advantage

Nearly **820** active partnerships with industry, academia, and government

In **2018** NREL had:

272 new **partnership agreements**

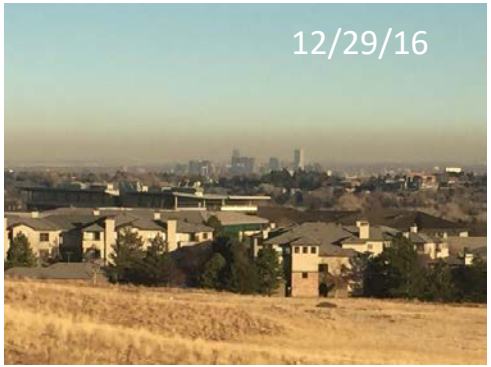
$70.0 million value of new **partnership agreements**

69 **unique** new **partners**

528 **unique** active **partners**

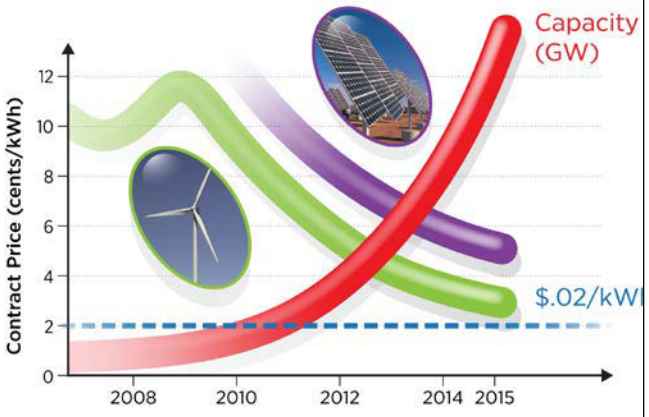
Relevant Megatrends

- Increased global focus on emissions, increased policy regulations (market impact)
- Low, cost intermittent renewable electrons
- Decentralization

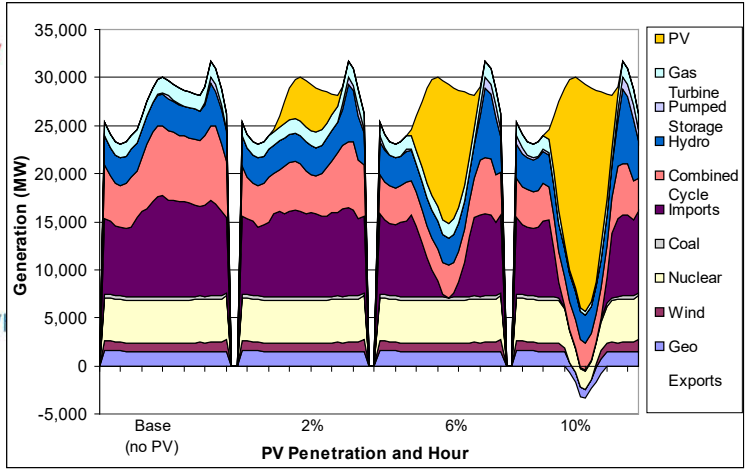


Downtown Denver from NREL's Energy System Integration Facility

Credit: Bryan Pivovar

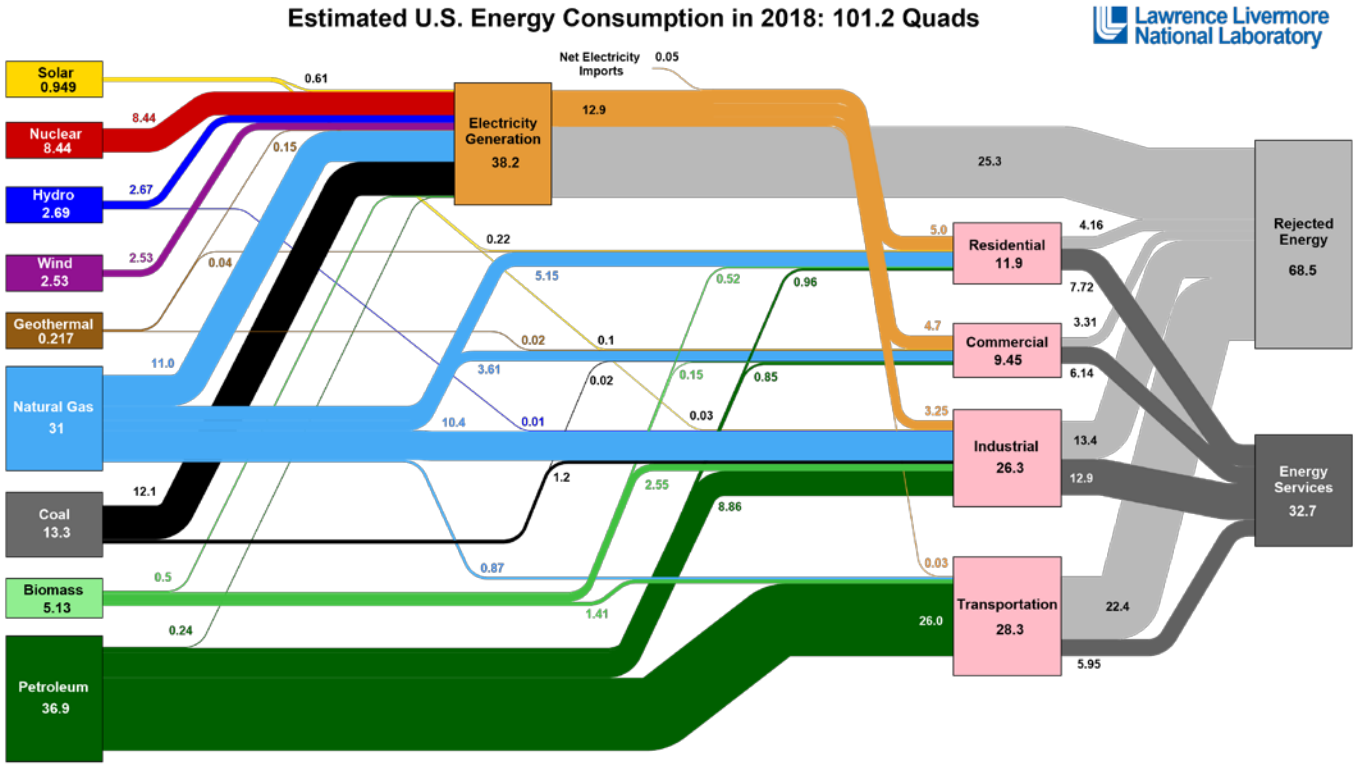


Source: (Arun Majumdar) 1. DOE EERE Sunshot Q1'15 Report, 2. DOE EERE Wind Report, 2015

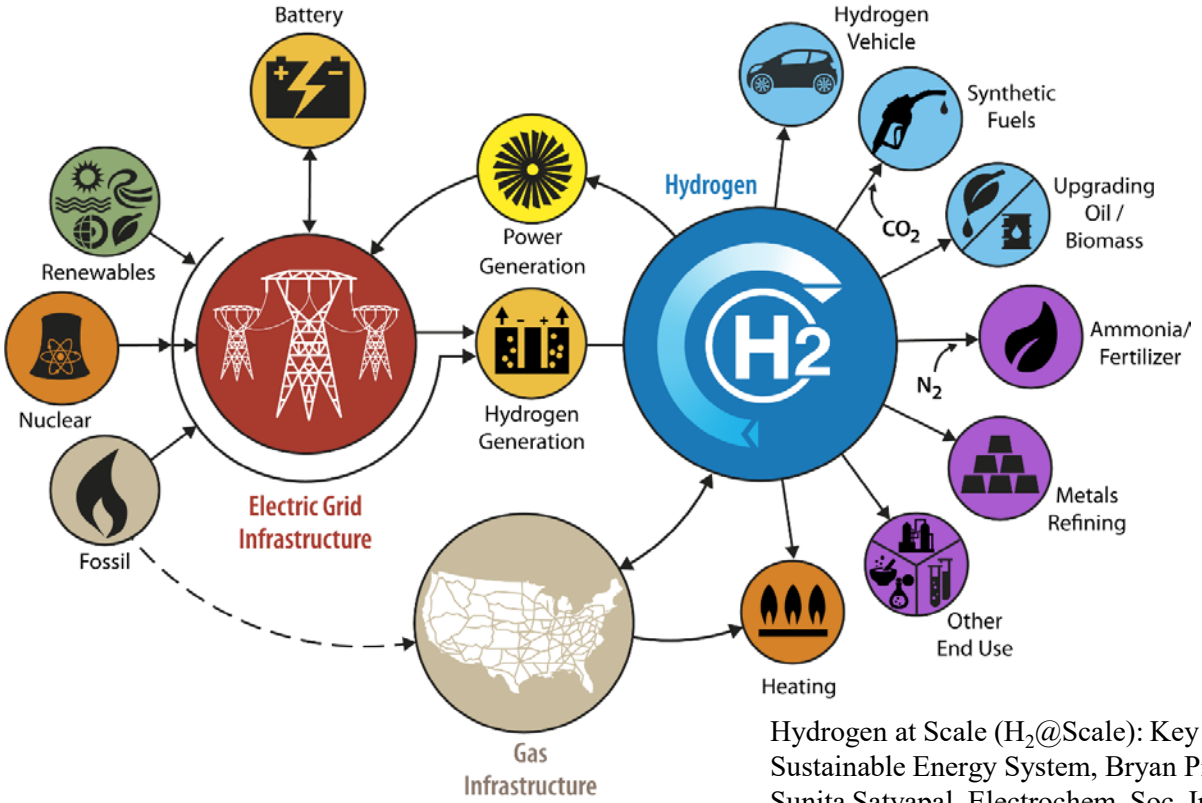


Denholm et al. 2008

Current Energy Needs



H2@Scale Concept



*Illustrative example, not comprehensive

Hydrogen at Scale (H_2@Scale): Key to a Clean, Economic, and Sustainable Energy System, Bryan Pivovar, Neha Rustagi, Sunita Satyapal, Electrochem. Soc. Interface Spring 2018 27(1): 47-52; doi:10.1149/2.F04181if

H_2 is different and changing fast

H_2 Council*

– Launched in January 2017 its members include leading companies with over $10 billion in investments along the hydrogen value chain, including transportation, industry, and energy exploration, production, and distribution.

> ***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*

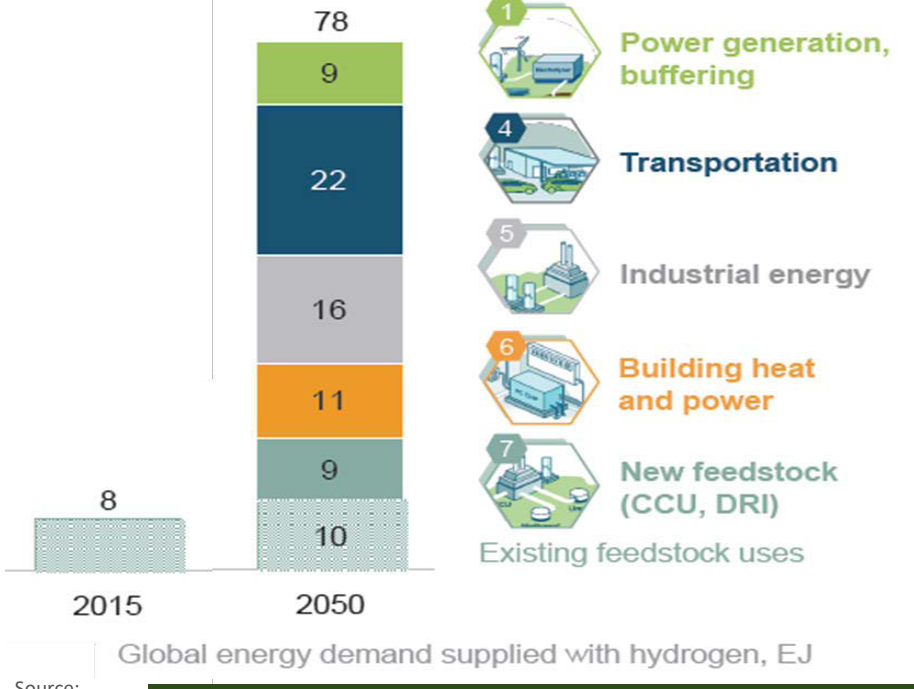
13 members (Jan 2017).

32 steering members and 20 supporting members (Nov 2018).

*Steering members shown, additional supporting members www.hydrogencouncil.com

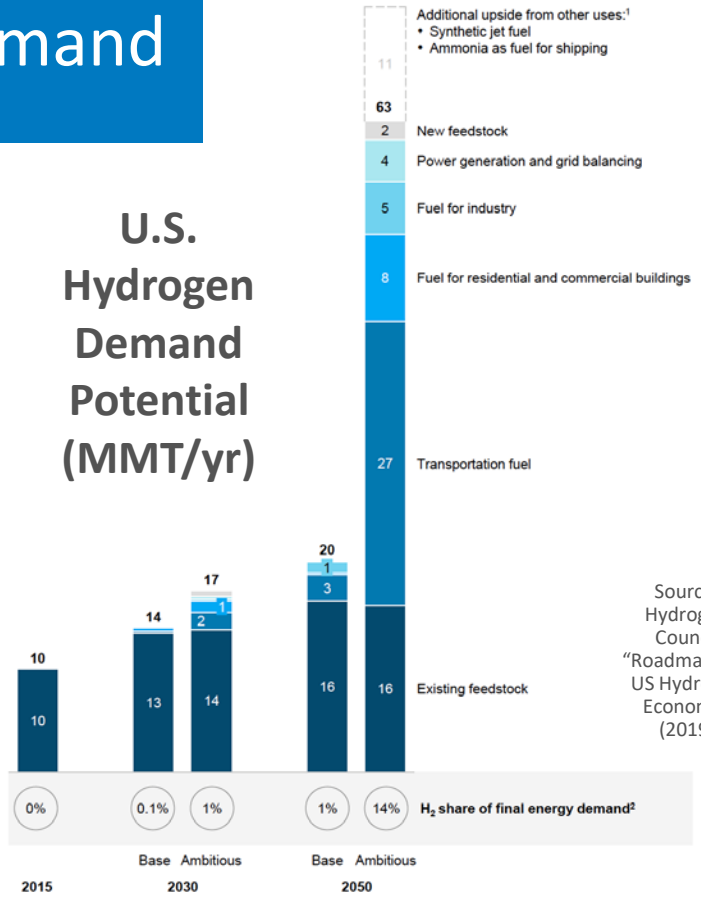
Potential Growth in Hydrogen Demand

Global Hydrogen Demand Potential (EJ)



Source: Hydrogen Council "Hydrogen Scaling Up"

U.S. Hydrogen Demand Potential (MMT/yr)

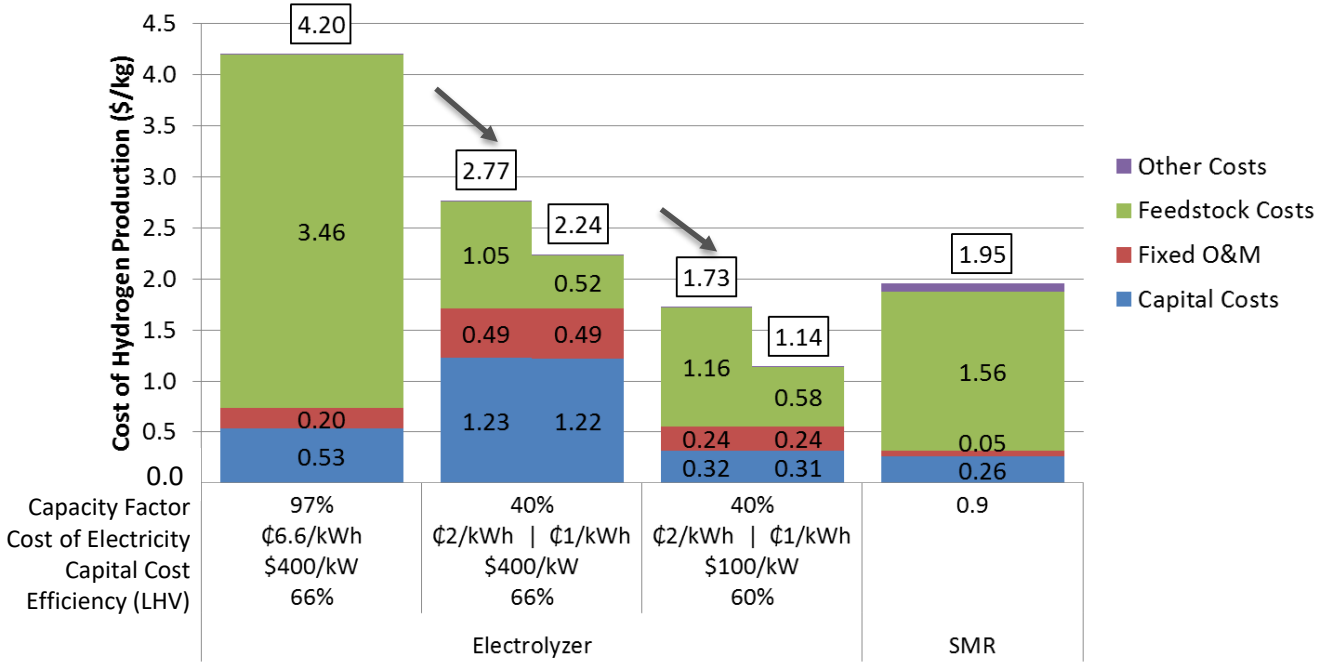


Source: Hydrogen Council "Roadmap to a US Hydrogen Economy" (2019)

H_2 Council: Opportunity for 6-10-fold increase by 2050

Potential Opportunity: Low Temperature Electrolysis

Potential Levelized Costs of H_2 Production

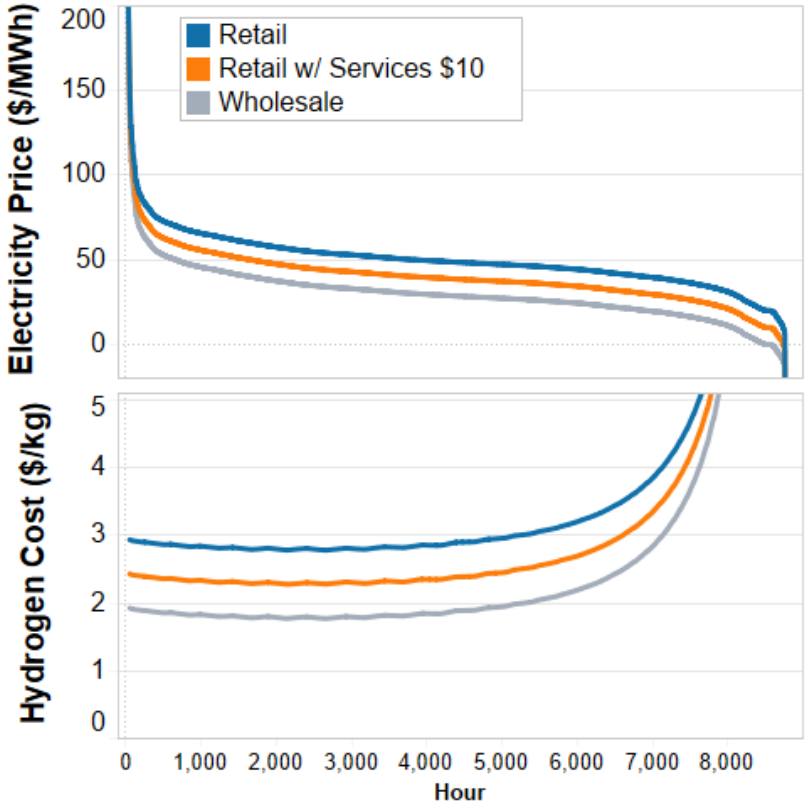


Source: Bryan Pivovar & Josh Eichman

Electrolytic H_2 has the potential to be cost competitive.

Availability of low-cost electricity can help enable low-cost H_2 production, even at low capacity factors.

Opportunity for Electrolytic Hydrogen Generation



Palo Verde 2017

- Electrolytic hydrogen could be cost-competitive if flexible, low-temperature electrolyzers can be purchased at $400/kW and markets are available

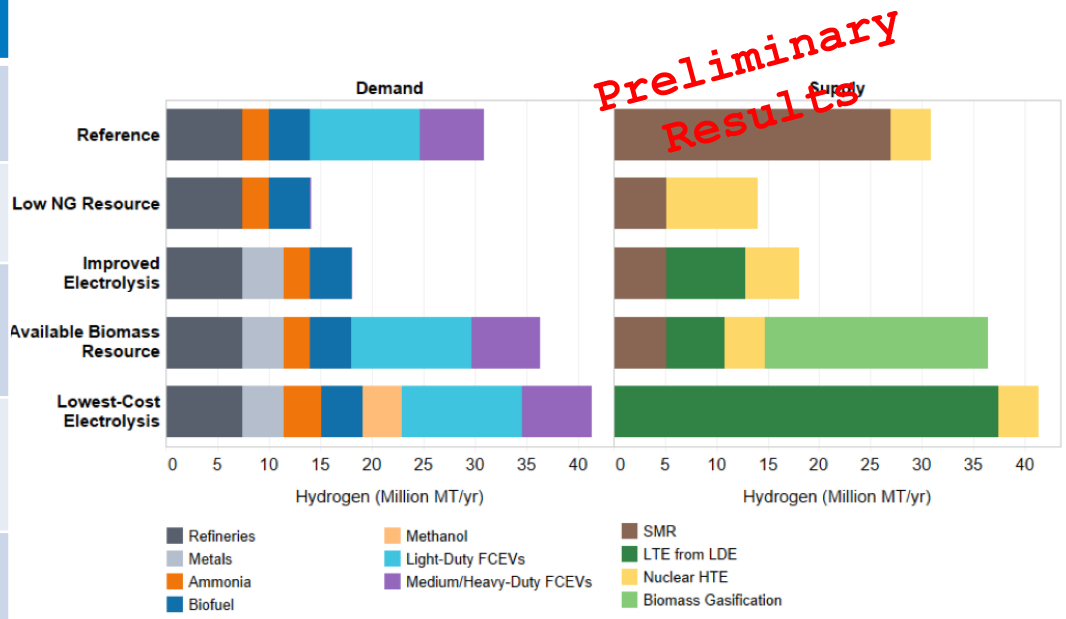
$400/kW electrolyzer purchase cost. Operating during lowest cost hours of the year

Economic Potential Analysis Results

The economic potential of hydrogen demand in the U.S. is 1.4-4X current annual consumption.

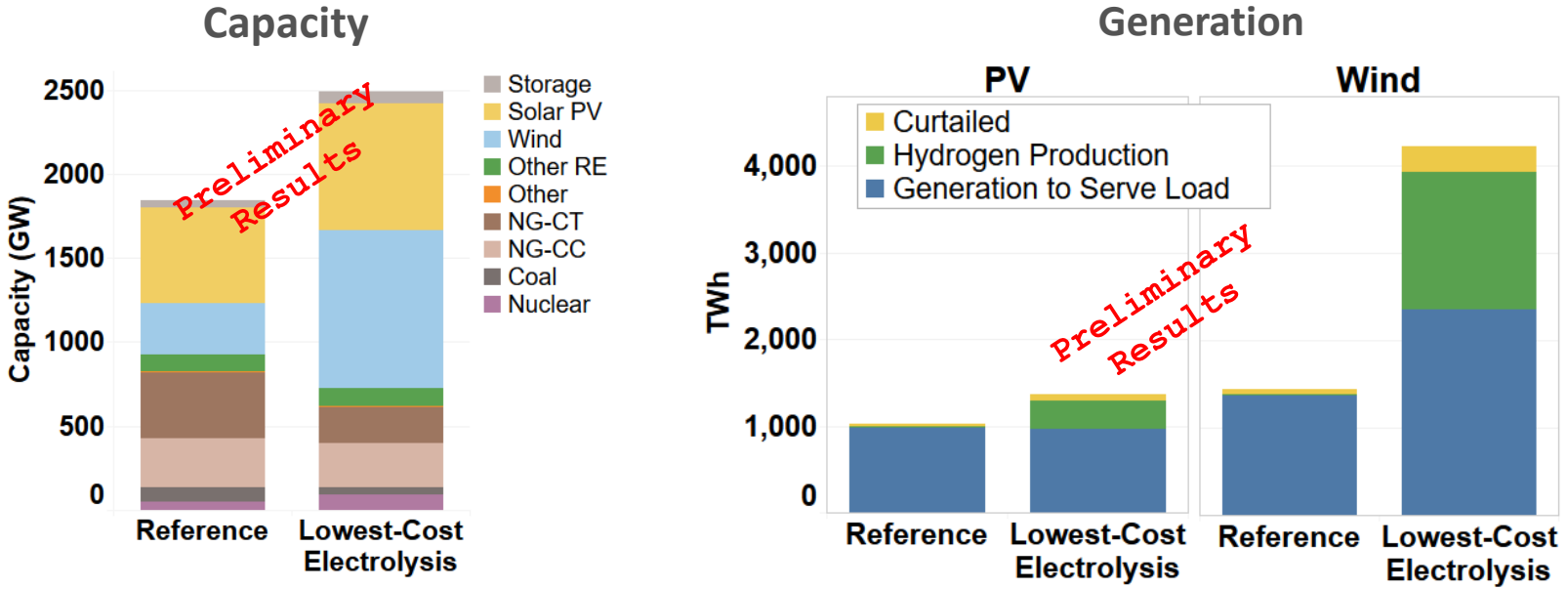
Scenario	Insights
Reference	Low-cost natural gas drives growth in H_2 markets with some nuclear participation*
Low NG Resources	Higher cost natural gas results in minimal growth in H_2 applications
Improved Electrolysis	Drivers for metals applications increase market. Some LTE penetration at $200/kW capital cost with grid value.
Available Biomass Resources	If the biomass is not used for higher value purposes, it could be a key resource
Lowest-Cost Electrolysis	$100/kW electrolyzers with high grid value can enable additional H2 applications

*~20% of U.S. nuclear generation is used for hydrogen production



Potential Impact of H2@Scale on Wind and Solar PV Markets

Hydrogen is a potential dispatchable load that can increase economic demand for variable electricity



- **Estimates are based on national scenarios with minimal resolution into regional constraints.**
- **Lowest-Cost Electrolysis assumes aggressive electrolyzer costs ($100/kW)**

Concluding Thoughts

- Energy requirements are getting more complex
- Hydrogen can play a large role in the future energy system
  - Energy carrier
  - Energy storage
  - Molecular properties
- RD&D is warranted across many aspects of the hydrogen value chain

Thank you

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NREL/PR-6A20-75399

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