NREL
Transforming ENERGY

H2@Scale: Opportunities for Hydrogen Production to Benefit Variable Renewables

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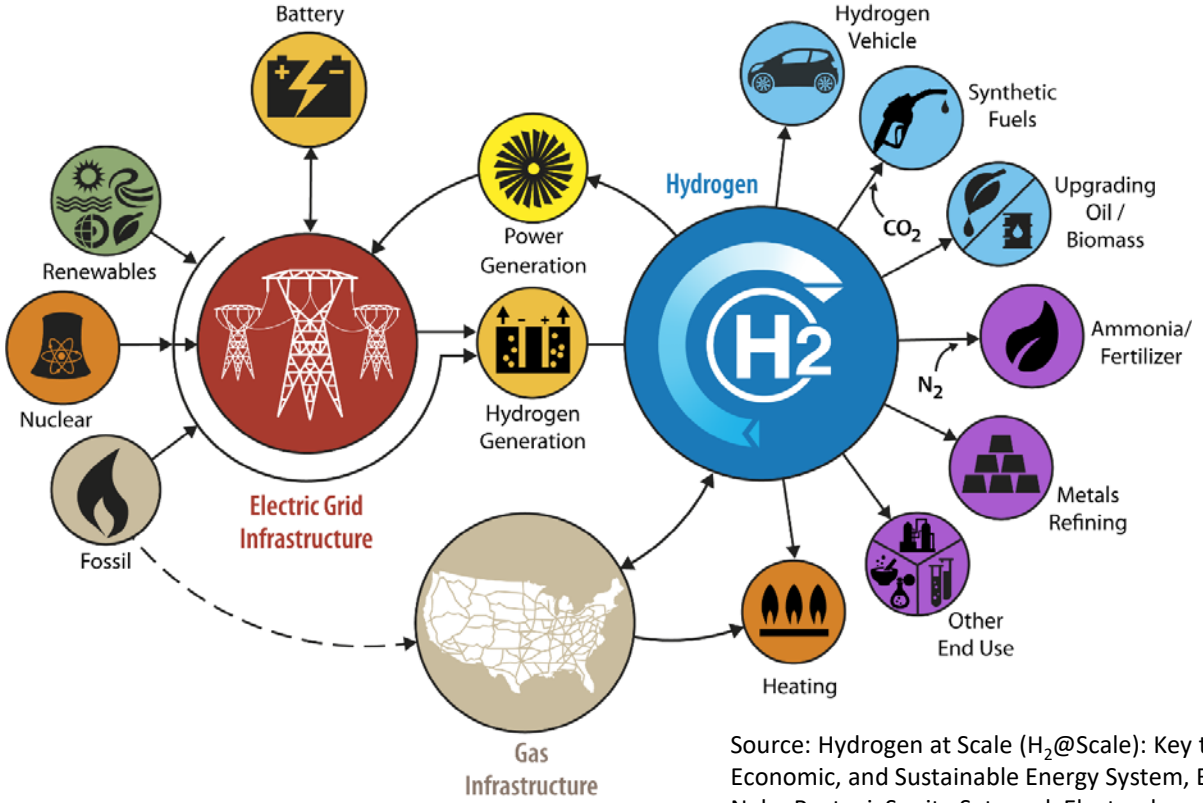
September 24, 2019

H2@Scale Concept

Hydrogen has the potential to be an energy interface that complements electricity and natural gas systems

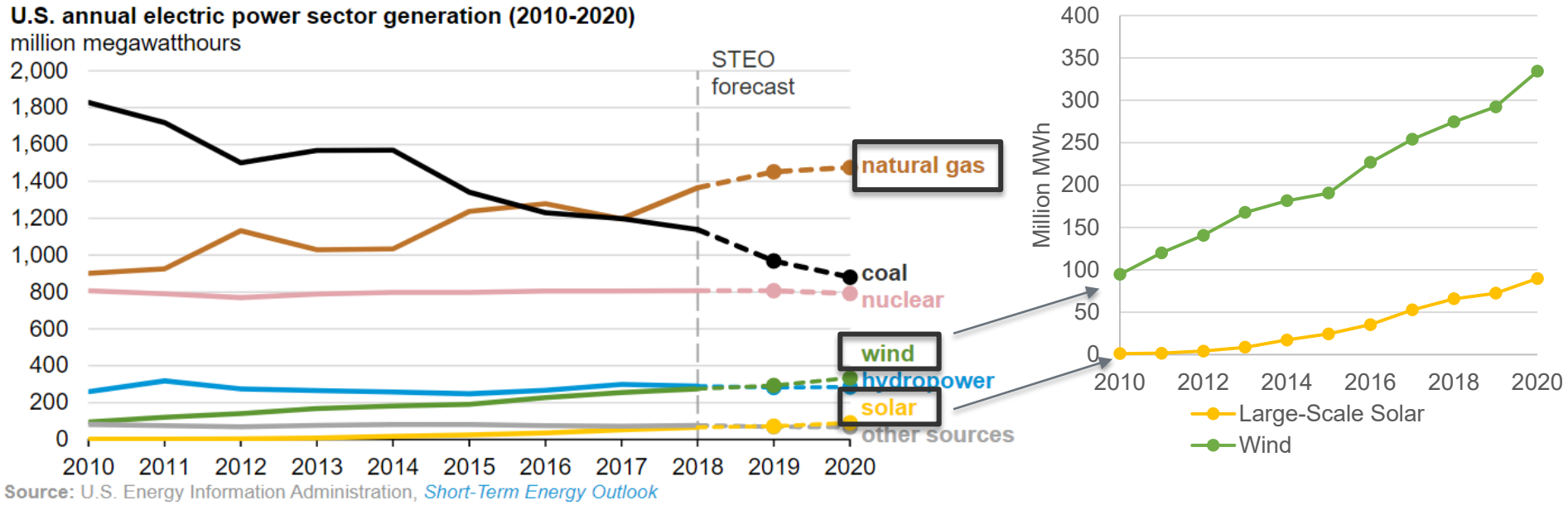


*Illustrative example, not comprehensive

Source: 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

The Electricity Mix is Changing

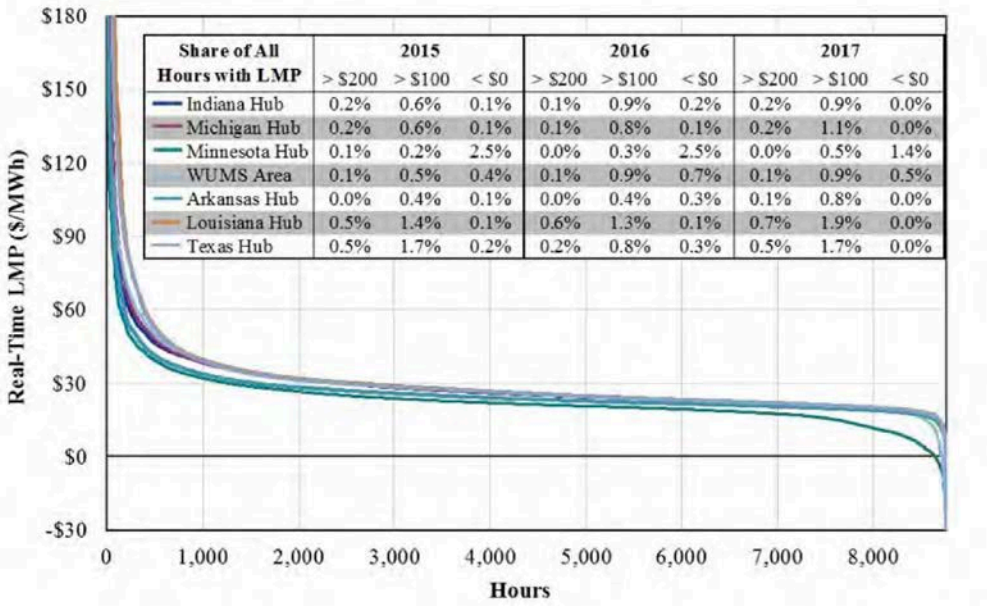
Projected growth in renewable and gas-fired generation



Source: U.S. Energy Information Administration, *Short-Term Energy Outlook*

Thus Prices are Changing

Figure A2: Real-Time Energy Price-Duration Curve
2017



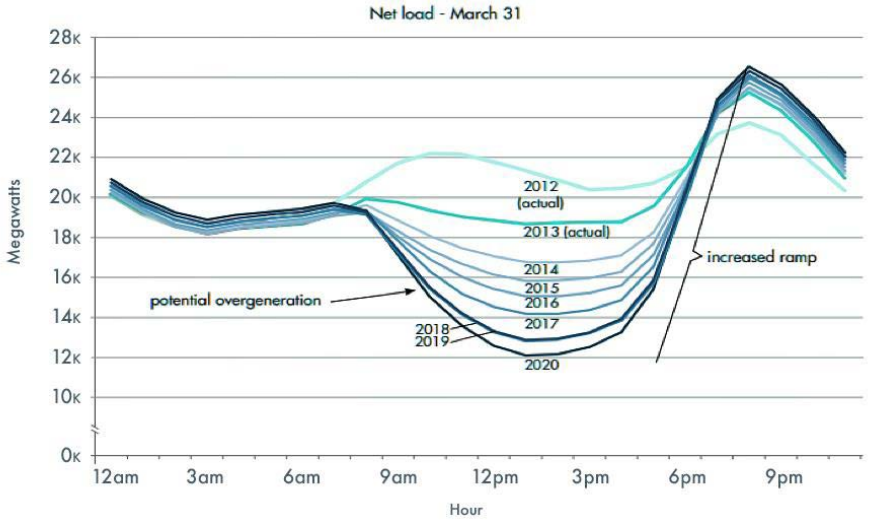
Share of All Hours with LMP	2015			2016			2017		
	> $200	> $100	< $0	> $200	> $100	< $0	> $200	> $100	< $0
Indiana Hub	0.2%	0.6%	0.1%	0.1%	0.9%	0.2%	0.2%	0.9%	0.0%
Michigan Hub	0.2%	0.6%	0.1%	0.1%	0.8%	0.1%	0.2%	1.1%	0.0%
Minnesota Hub	0.1%	0.2%	2.5%	0.0%	0.3%	2.5%	0.0%	0.5%	1.4%
WUMS Area	0.1%	0.5%	0.4%	0.1%	0.9%	0.7%	0.1%	0.9%	0.5%
Arkansas Hub	0.0%	0.4%	0.1%	0.0%	0.4%	0.3%	0.1%	0.8%	0.0%
Louisiana Hub	0.5%	1.4%	0.1%	0.6%	1.3%	0.1%	0.7%	1.9%	0.0%
Texas Hub	0.5%	1.7%	0.2%	0.2%	0.8%	0.3%	0.5%	1.7%	0.0%

Source: Potomac Economics 2017 State of the Market Report for the MISO Electricity Market – Analytic Appendix (June 2018)

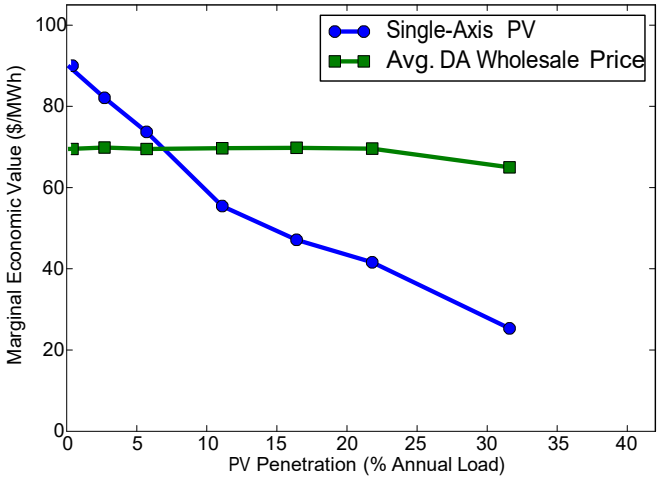
- Hours with energy at very low and very high prices are increasing
- Other revenue streams (e.g., capacity, services) are becoming more critical
- Wind and solar power purchase agreements (PPAs) are key opportunities

Low-Cost, Dispatch-Constrained Electricity (LDE)

As renewable penetration increases, ramp rates and transients become larger concerns



Economic value of VRE generation decreases with increasing penetration, potentially limiting penetration of VRE generation

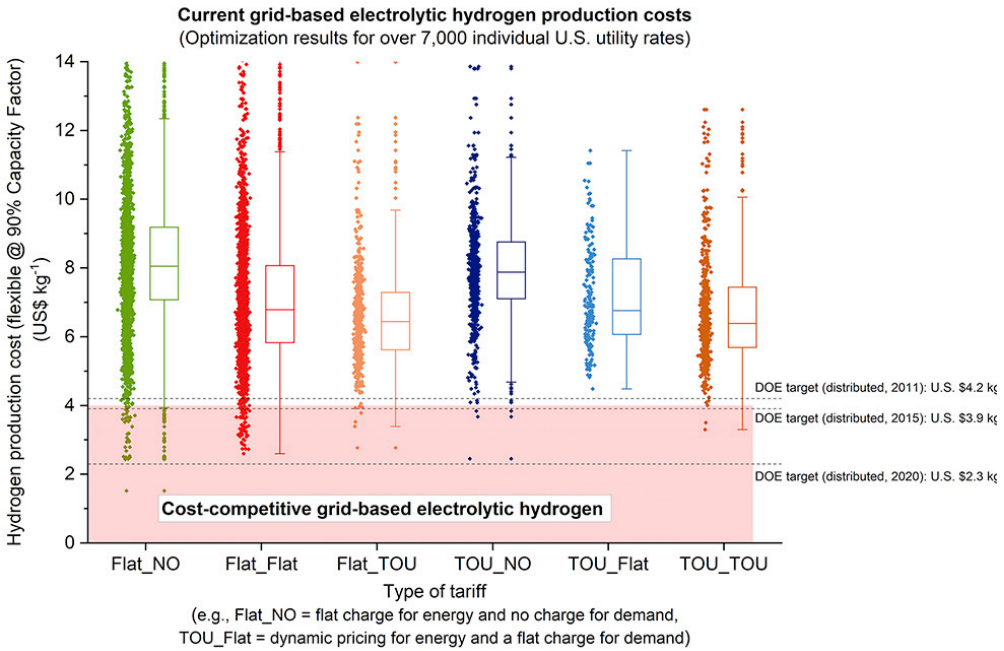


Changes in the Economic Value of Variable Generation at High Penetration Levels: A Pilot Case Study of California Andrew Mills and Ryan Wiser, June 2012, http://eetd.lbl.gov/EA/EMP

Current Opportunities

- Some locations already have tariffs that are sufficient for electrolyzers today[1]

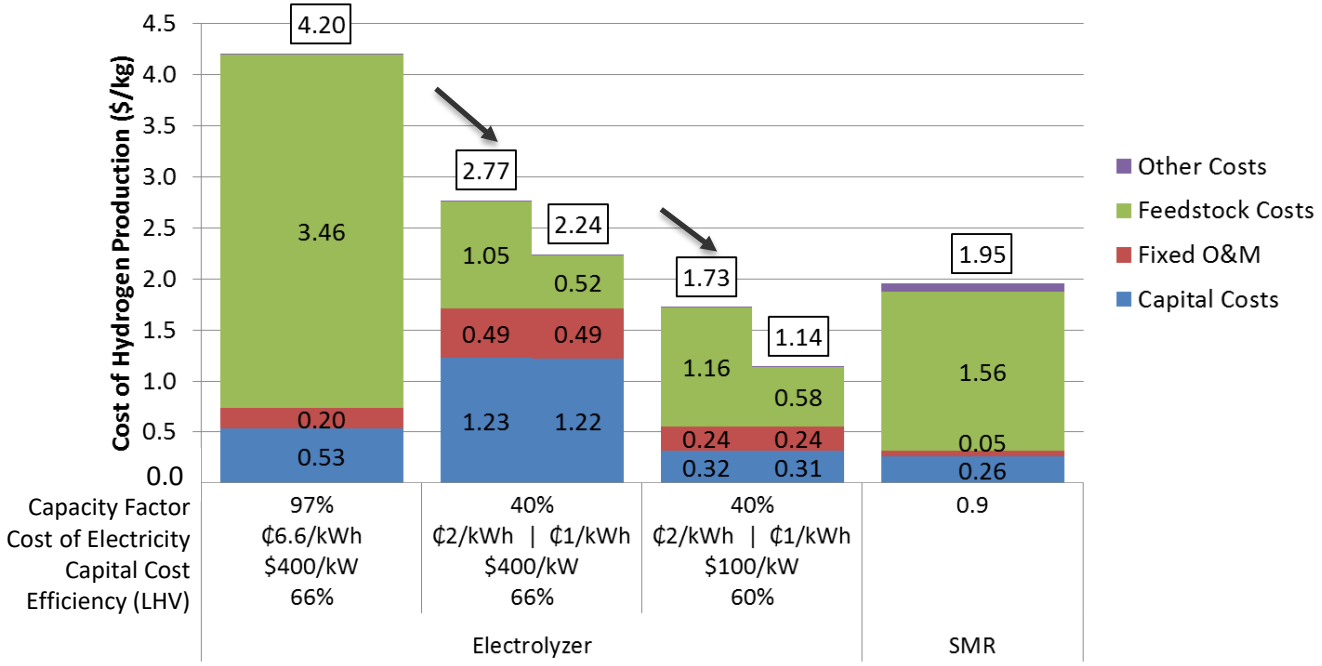
- Other locations may inherently have lower electricity prices, however prices may be more *volatile*



[1]Guerra, Omar J., Joshua Eichman, Jennifer Kurtz, and Bri-Mathias Hodge. 2019. "Cost Competitiveness of Electrolytic Hydrogen." *Joule*, July. https://doi.org/10.1016/j.joule.2019.07.006.

Potential Opportunity: Low Temperature Electrolysis

Potential Levelized Costs of H_2 Production



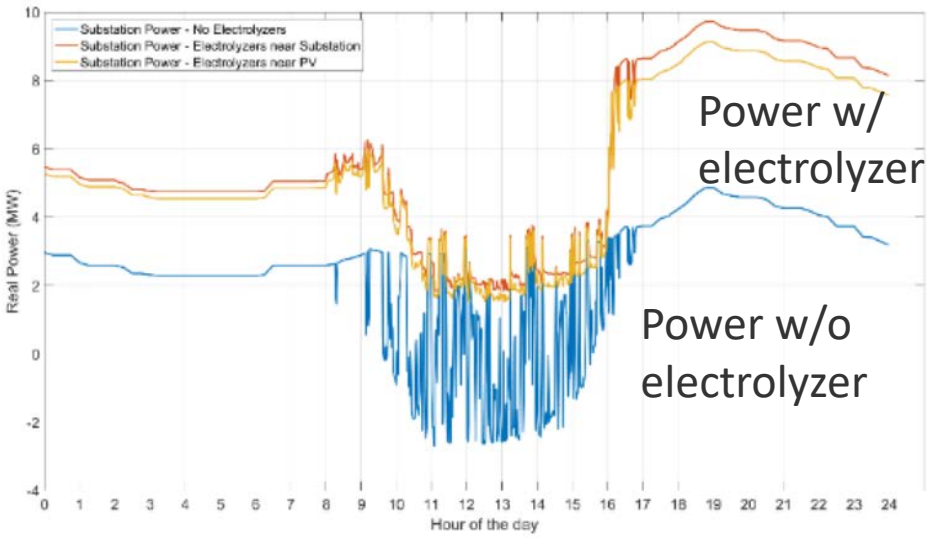
Source: Bryan Pivovar & Josh Eichman

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.

Potential Benefits to Renewable Generators

- Flexible electrolytic hydrogen production can
  - Utilize electricity during periods of oversupply on the grid
  - Reduce power spikes
- Assigning a price to excess energy provides additional revenue streams



https://www.hydrogen.energy.gov/pdfs/review19/ta015_hovsapian_2019_o.pdf

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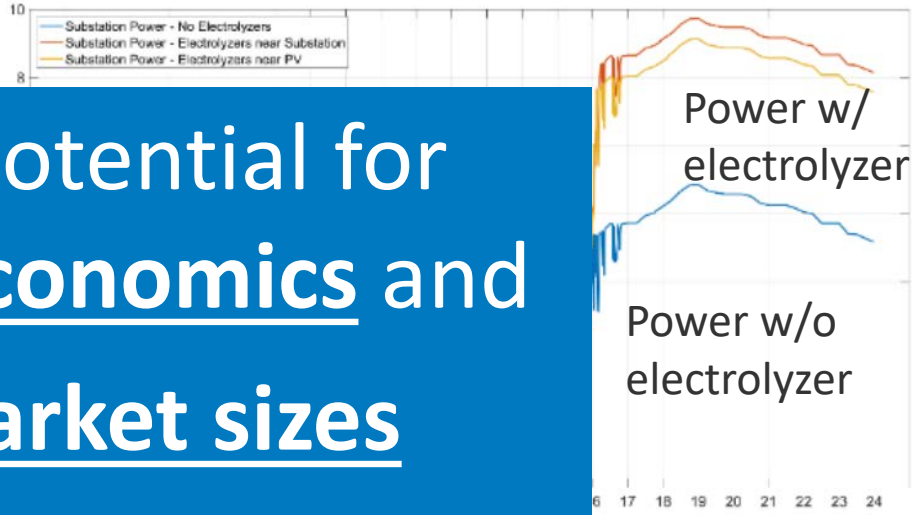
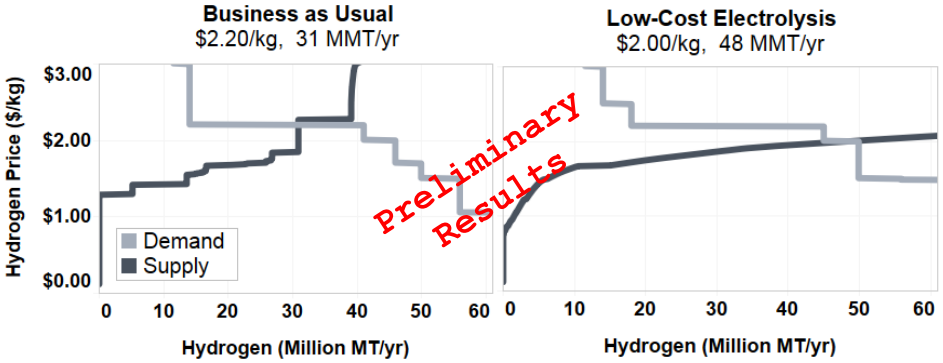


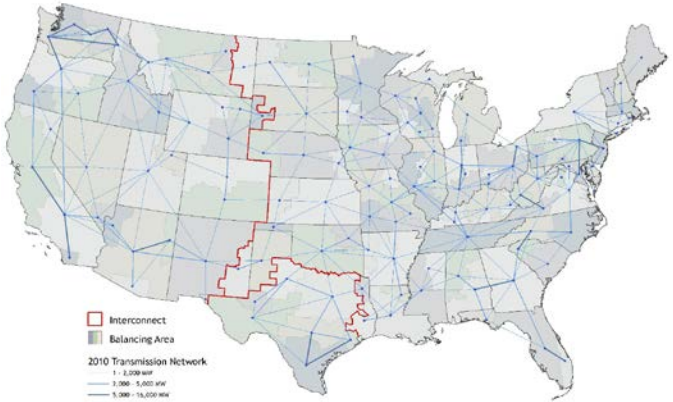
Leads to potential for **improved economics** and **larger market sizes**

https://www.hydrogen.energy.gov/pdfs/review19/ta015_hovsapian_2019_o.pdf

Quantifying the Potential Impact within H2@Scale

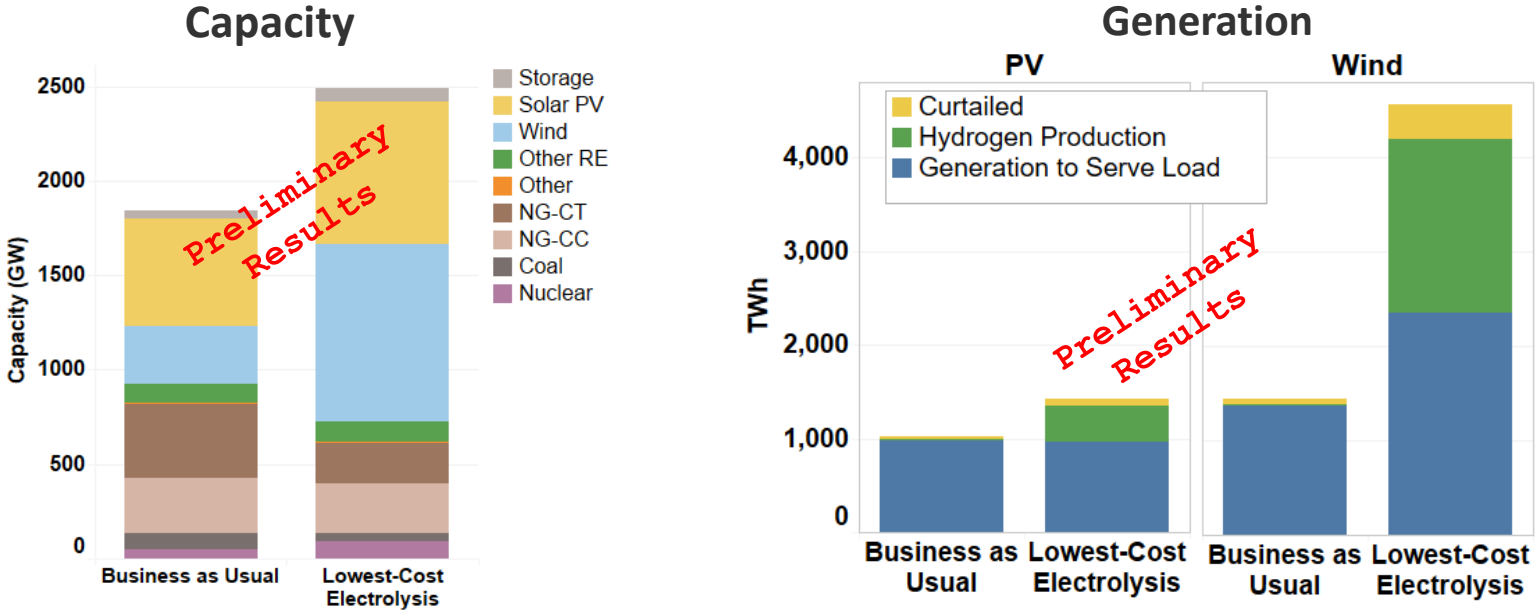
- Hydrogen markets estimated based on supply and demand curve methodology
- For LTE hydrogen, we used capacity expansion and production cost models to:
  - Assign a price to LDE from $0-35/MWh
  - Estimate the generator fleet
  - Estimate generation and available LDE for various price points





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

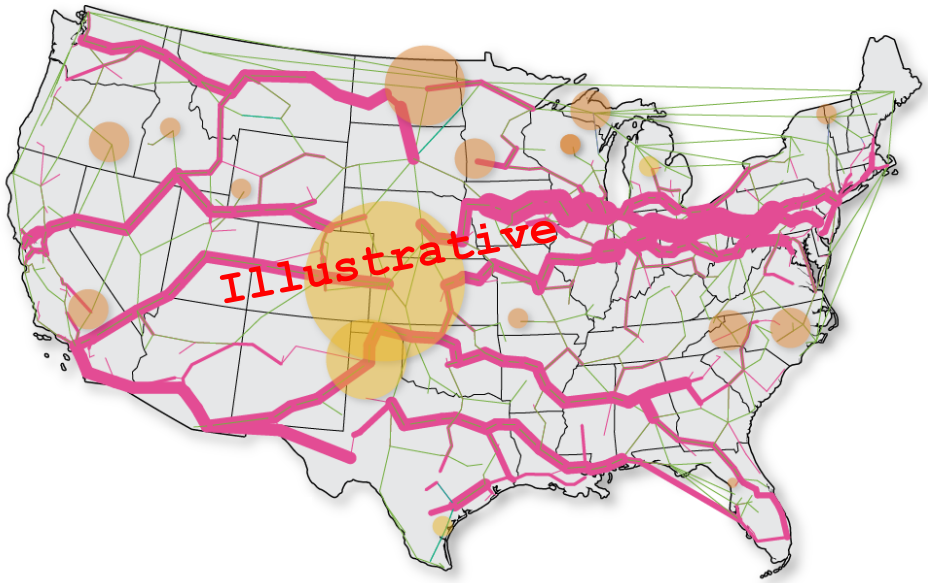


- **Estimates are based on national scenarios with minimal resolution into regional constraints.**
- **Lowest-Cost Electrolysis assumes aggressive electrolyzer costs ($100/kW)**

Future Uncertainties

- Will mechanisms exist to enable the use of LDE by electrolyzers?
  - Access to wholesale markets
  - Compensation for providing grid services
- What infrastructure will be required to connect supply with demand (e.g. transmission, storage)?

Illustrative transport and storage requirements



Thank You

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www.nrel.gov

Additional information on H2@Scale can be found at:

https://www.hydrogen.energy.gov/pdfs/review18/h2000_pivovar_2018_o.pdf
https://www.hydrogen.energy.gov/pdfs/review19/sa171_ruth_2019_o.pdf
http://energy.gov/eere/fuelcells/downloads/h2-scale-potential-opportunity-webinar

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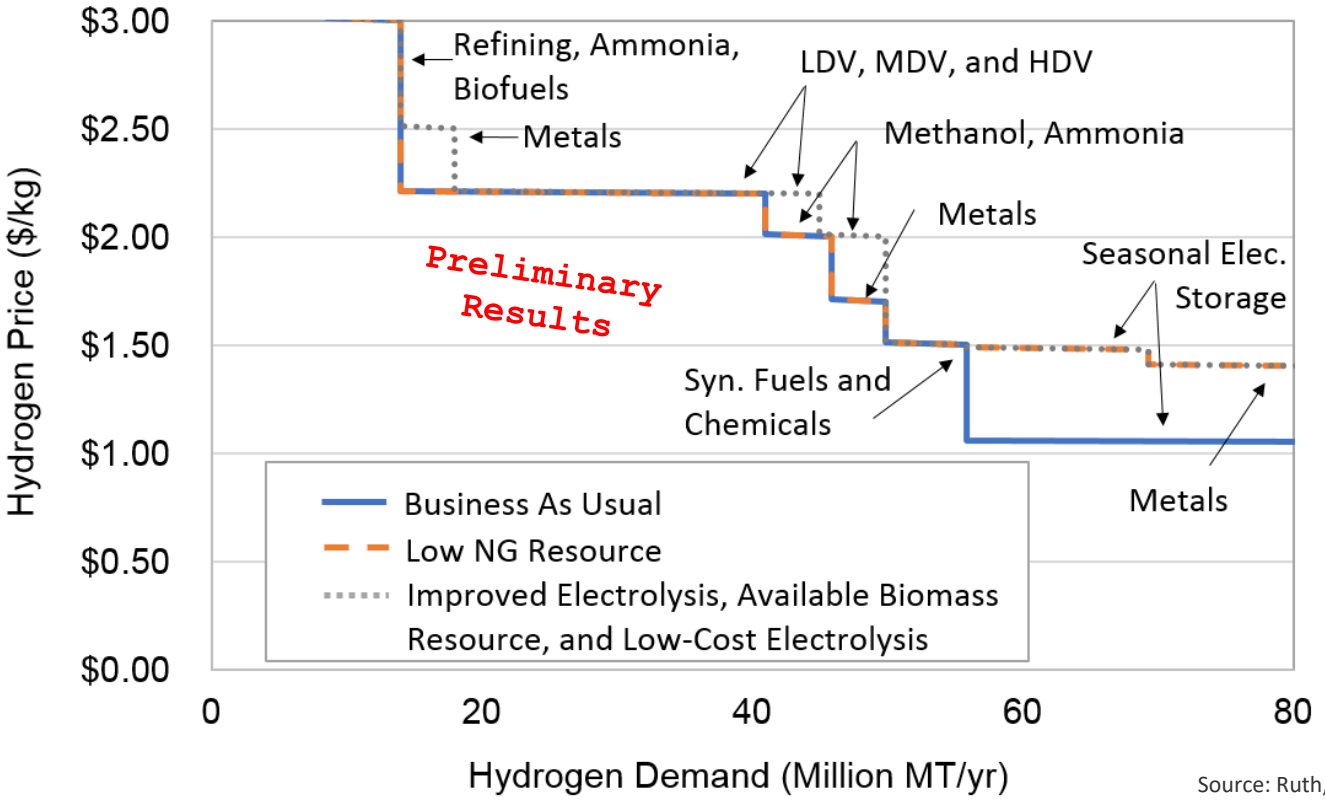
Supplemental Slides

Aggregated Demand Curves Across End Uses



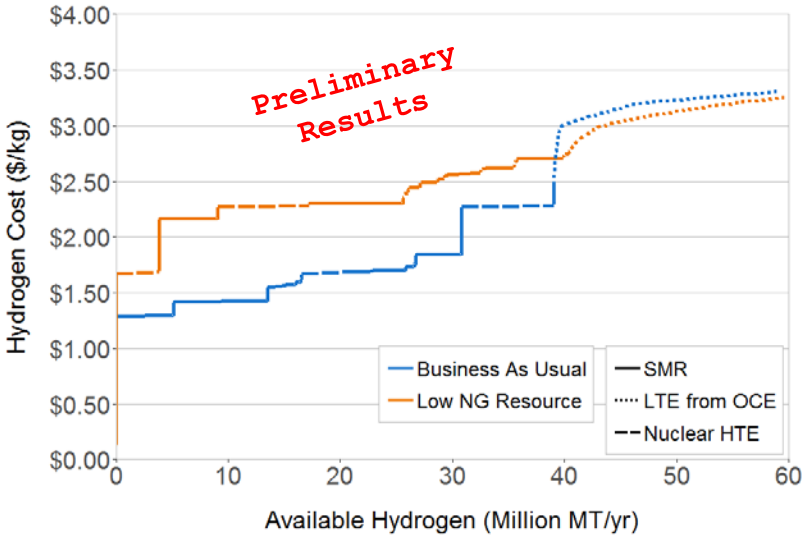
At lower prices, hydrogen is competitive in more markets. Prices must be very low to approach the maximum market potential.

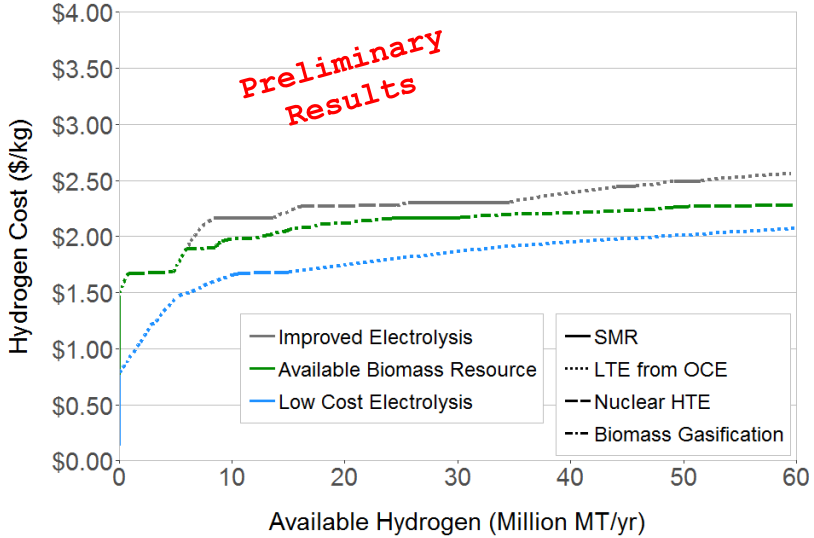
Source: Ruth, Mark, et al. "H2@Scale" 2019 Annual Merit Review. Crystal City, VA (April 30, 2019)

Aggregated Supply Curves Across Production Options

Based on estimates of levelized production cost/supply availability combinations for each production option

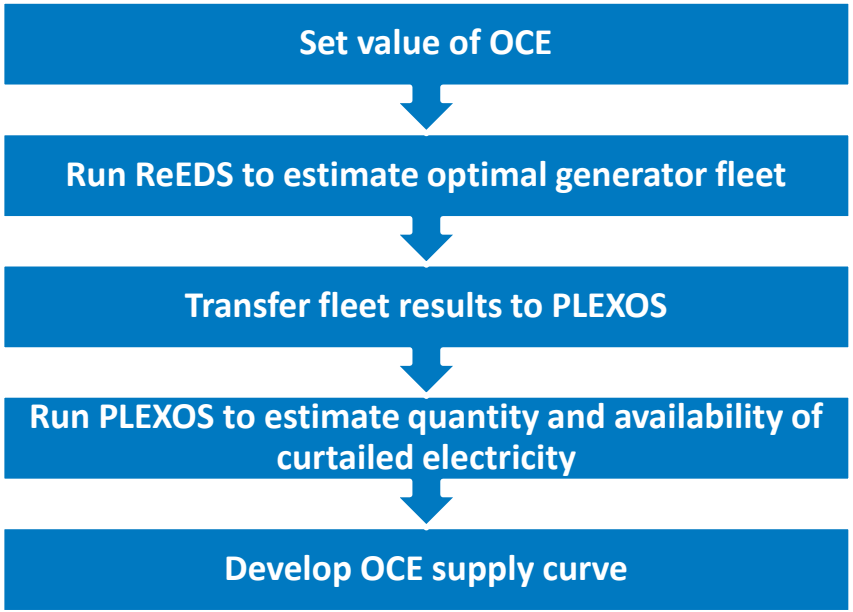
Alternative production options to SMR may be economic with R&D advances





Supply Curve Data: Low Temperature Electrolysis

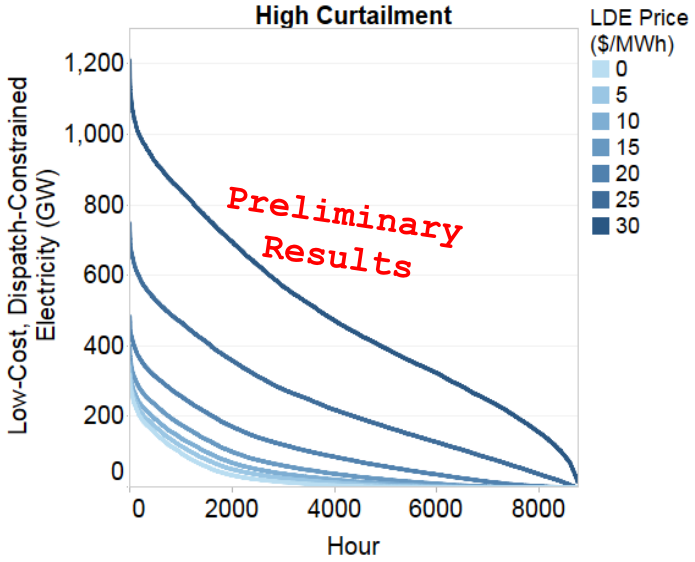
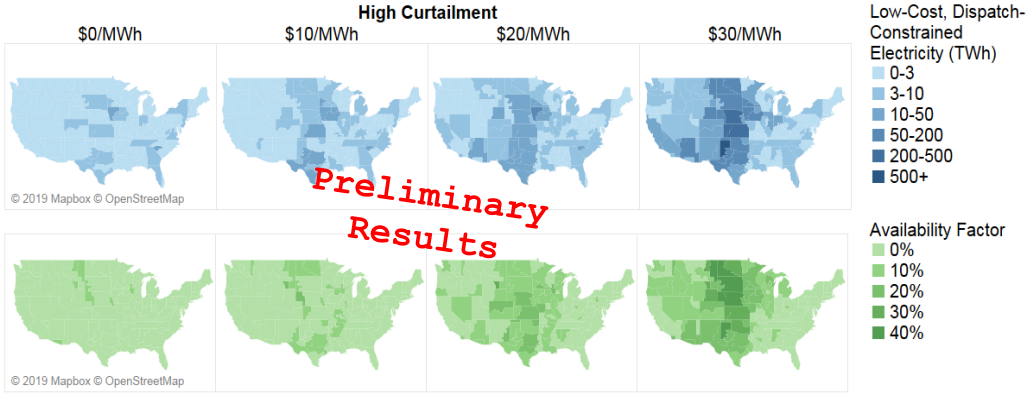
Developed a method to estimate the availability of otherwise curtailed electricity (OCE) and impacts if it has a value



- Assumed low temperature electrolysis is most cost effective using low cost, otherwise curtailed electricity (OCE)
- Used ReEDS Capacity Expansion model to estimate generation fleet and generation energy mixes for at various (OCE) prices

Quantification of LDE Cost and Availability

Novel analysis using capacity expansion (ReEDS) and production cost models (PLEXOS) to estimate the potentials quantity of LDE, including spatial and temporal characteristics



- **High levels of potential LDE, but availability varies over time and geography**
- **Demand for LDE may help increase market sizes of VRE generators**