NREL
Transforming ENERGY

Hydrogen Considerations for the United States

World Hydrogen Leaders Forum

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Mark Ruth

Serviceable Consumption Potential

Serviceable Consumption Potential of hydrogen market by 2050 is >10X.

Other applications are possible based on technology and policy growth as well as smaller applications

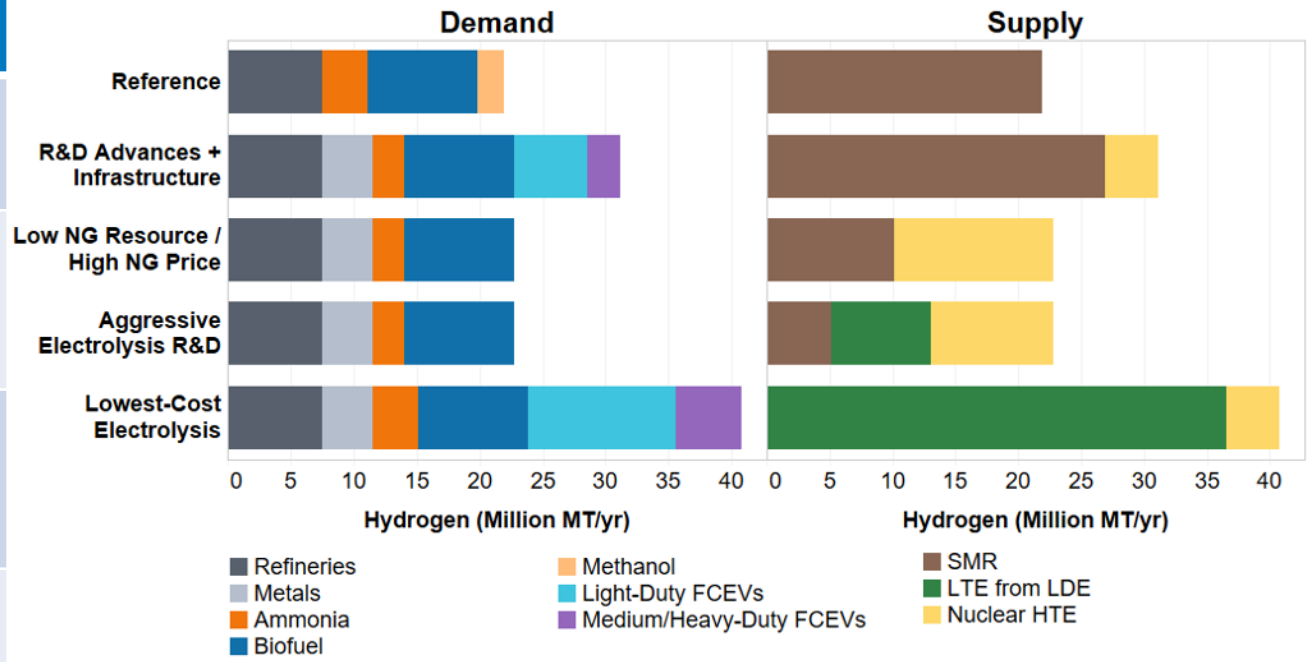
Application	Serviceable Consumption Potential (MMT/yr)	2015 Market for On-Purpose H2 (MMT/yr)
Refineries and the chemical processing industry (CPI) [a]	7	6
Metals	12	0
Ammonia	4	3
Biofuels	9	0
Synthetic hydrocarbons	14	1
Natural gas supplementation	16	0
Seasonal energy storage for the electricity grid	15	0
Industry and Storage Subtotal	**77**	**10**
Light-duty fuel cell electric vehicles (FCEVs)	21	0
Medium- & Heavy-Duty FCEVs	8	0
Transportation Fuel Subtotal	**29**	**0**
Total	**106**	**10**

Definition: The Serviceable Consumption Potential is the estimated market size constrained by the services for which society currently uses energy, real-world geography, system performance, and by optimistic market shares but not by economic calculations.

Five Economic Potential Scenarios

The economic potential of hydrogen demand in the U.S. is 2-4X current annual consumption based on our market-equilibrium analysis

Scenario	Insights
Reference	Growing markets for refining, ammonia, and biofuels met with low-cost NG
R&D Advances + Infrastructure	Higher penetrations of FCEV + drivers for metals, SMR dominates production due to low cost NG but have some nuclear HTE
Low NG Resource / High NG Price	High NG price increases cost of hydrogen for same quantity and limits FCEV penetration but more nuclear HTE
Aggressive Electrolysis R&D	Some LTE penetration at $200/kW capital cost with grid value.
Lowest-Cost Electrolysis	Low-cost electrolyzers with high grid value reduce hydrogen cost and can enable additional H_2 applications

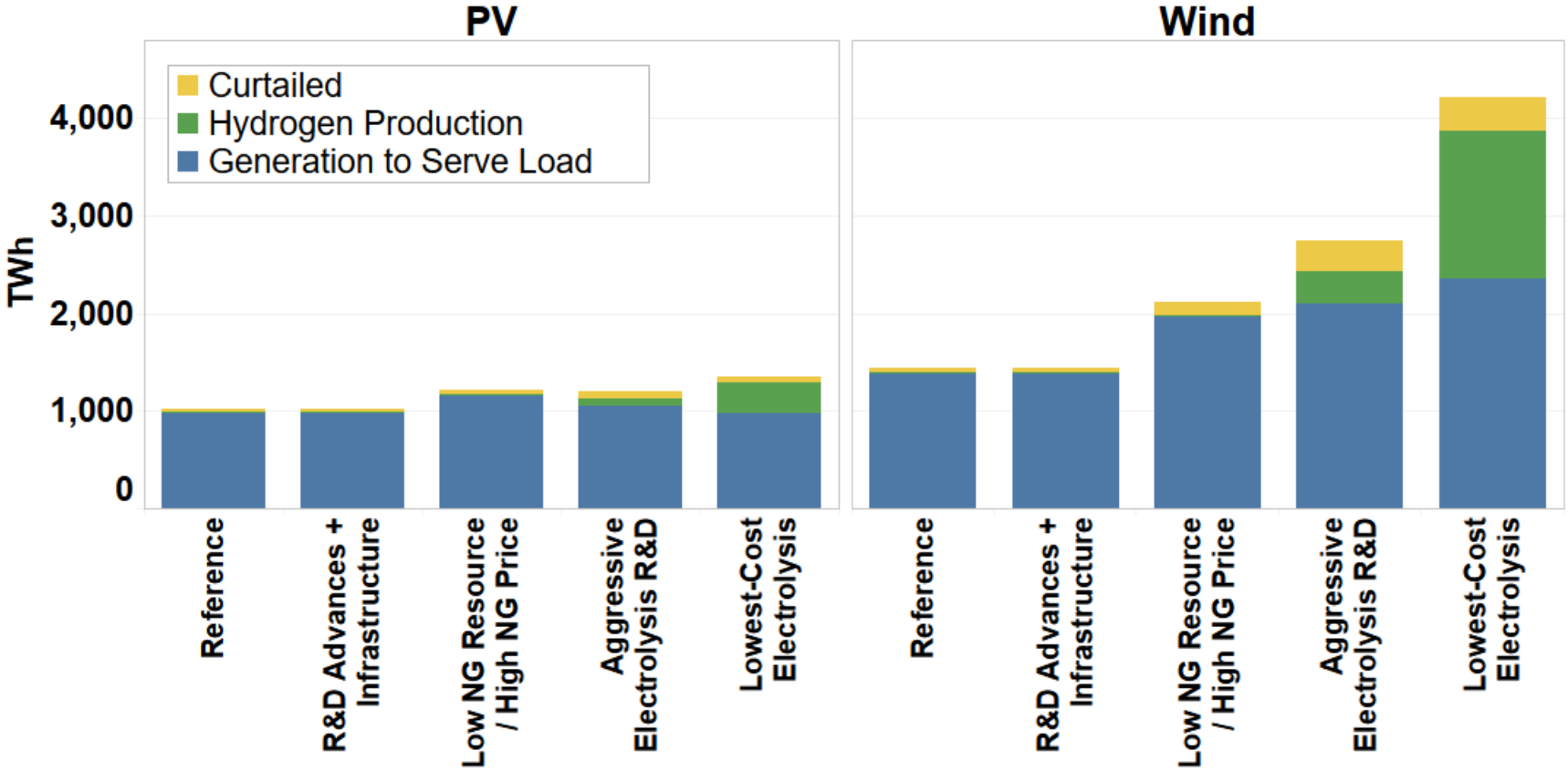


FCEV: Fuel-cell electric vehicles
SMR: Steam methane reforming
NG: Natural gas
LTE: Low-temperature electrolysis
LDE: Low-cost, dispatch-constrained electricity
HTE: High-temperature electrolysis

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

Increase Market Size of and Available Electricity from Variable Generation

H2@Scale has the potential to increase the total market size of wind and solar photovoltaic (PV) generation

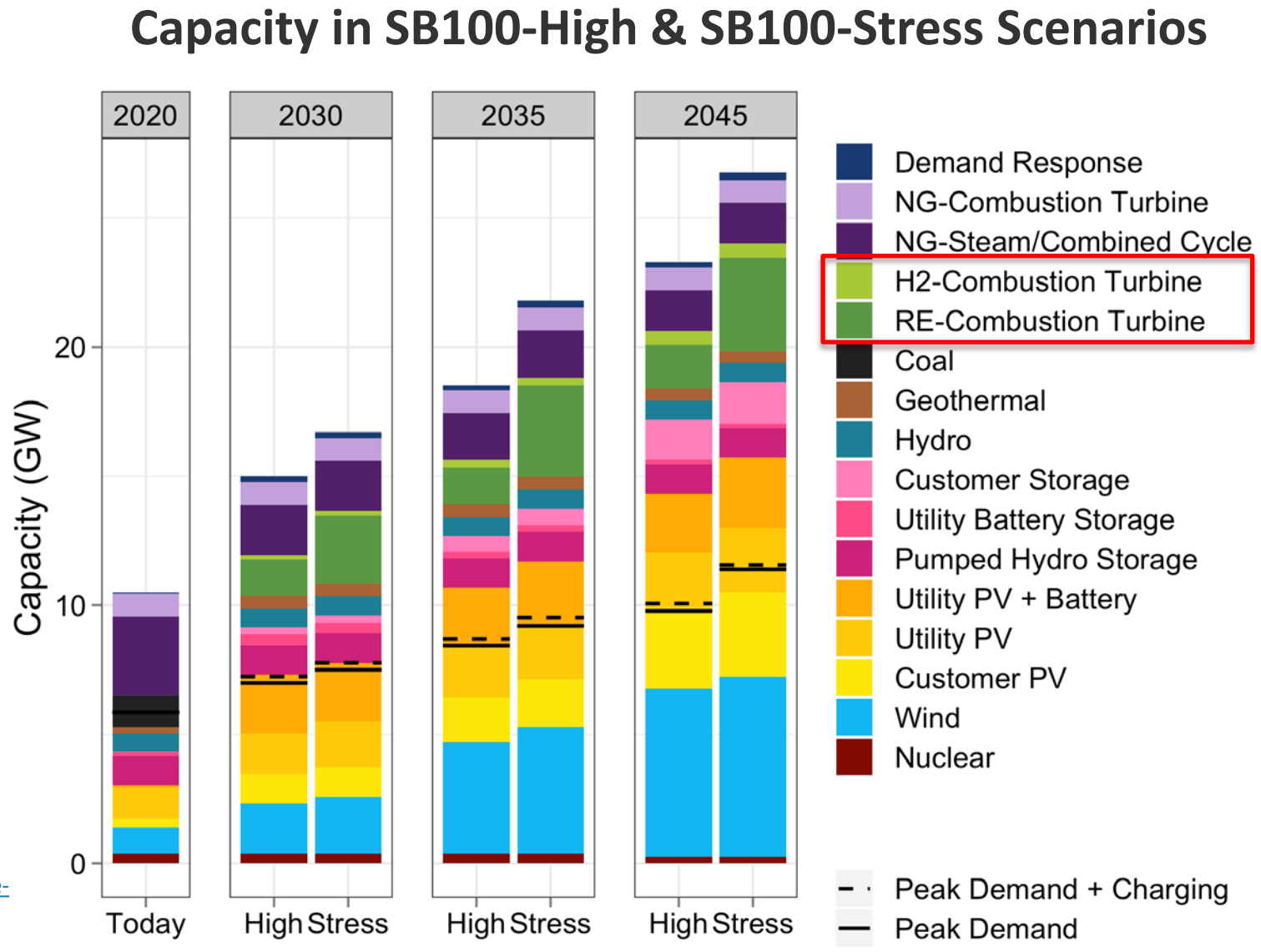


Source: https://www.nrel.gov/docs/fy21osti/77610.pdf

Estimates are based on national scenarios with minimal resolution into regional constraints. Increased resolution will likely impact the most competitive source of energy supply

Hydrogen is Often Identified as a Carbon-Free Energy Source for Dispatchable Power Generation

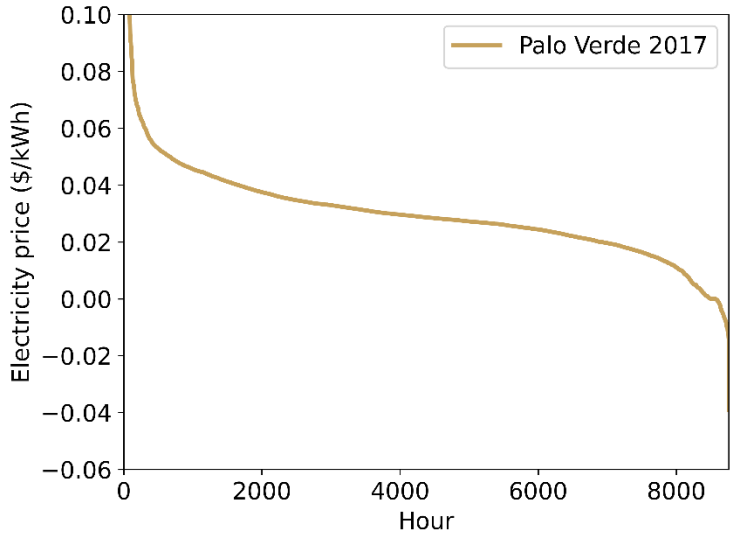
The LA100 study identified options to achieve 100% renewable energy by 2045. Findings include hydrogen to provide electricity when other storage options are depleted.

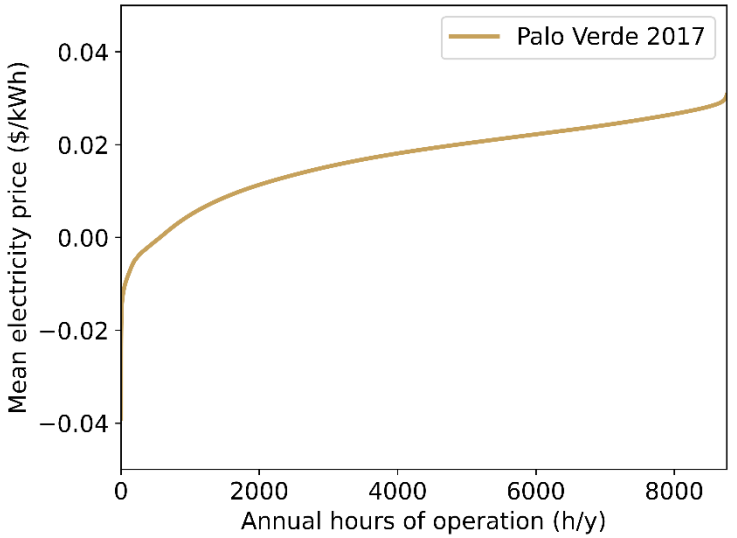


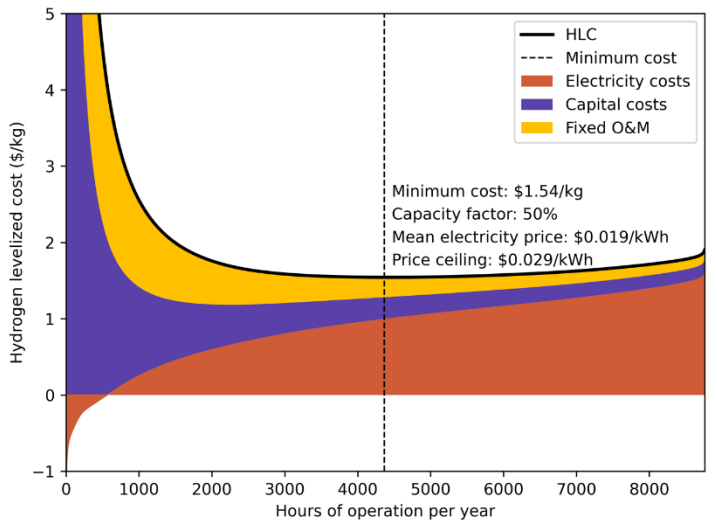
More available at: https://maps-dev.nrel.gov/la100/key-findings/topics/renewable-energy-pathways#renewable-energy-pathways-assumptions

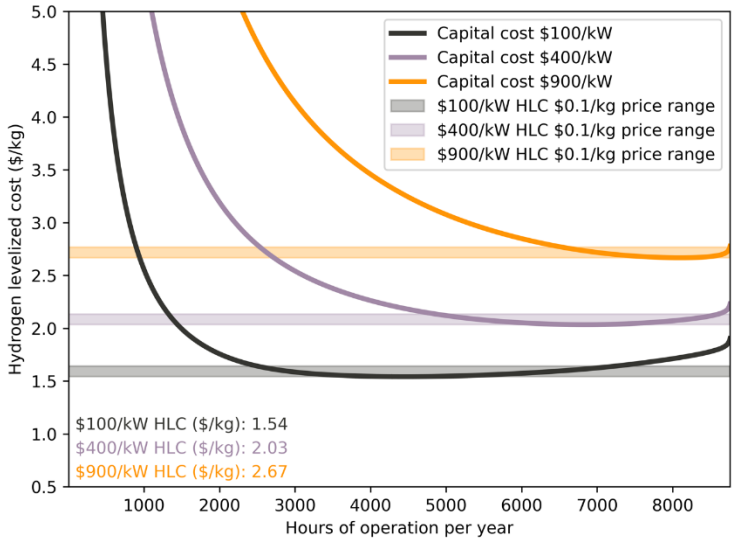
Optimizing Electrolyzer Operations to Minimize Hydrogen Levelized Cost

- Locational marginal prices are volatile
- Dispatchable loads (e.g., electrolyzers) can have low average electricity prices if they can choose to operate only during times with low-prices
- Reduced capacity factors result in tradeoffs between electricity cost and capital recovery
- Reducing capital costs reduces both hydrogen's levelized cost and the optimal capacity factor





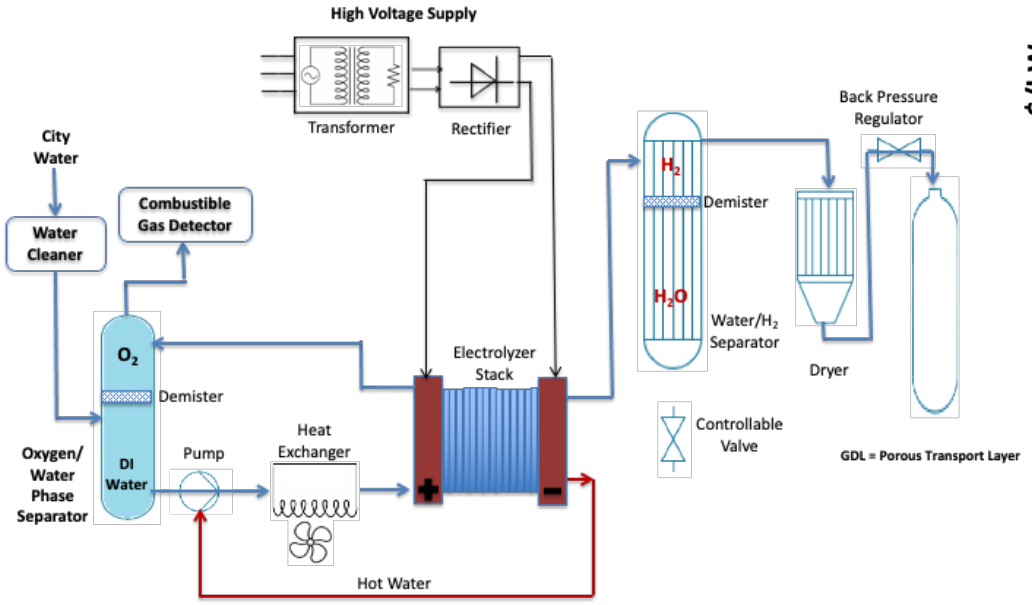


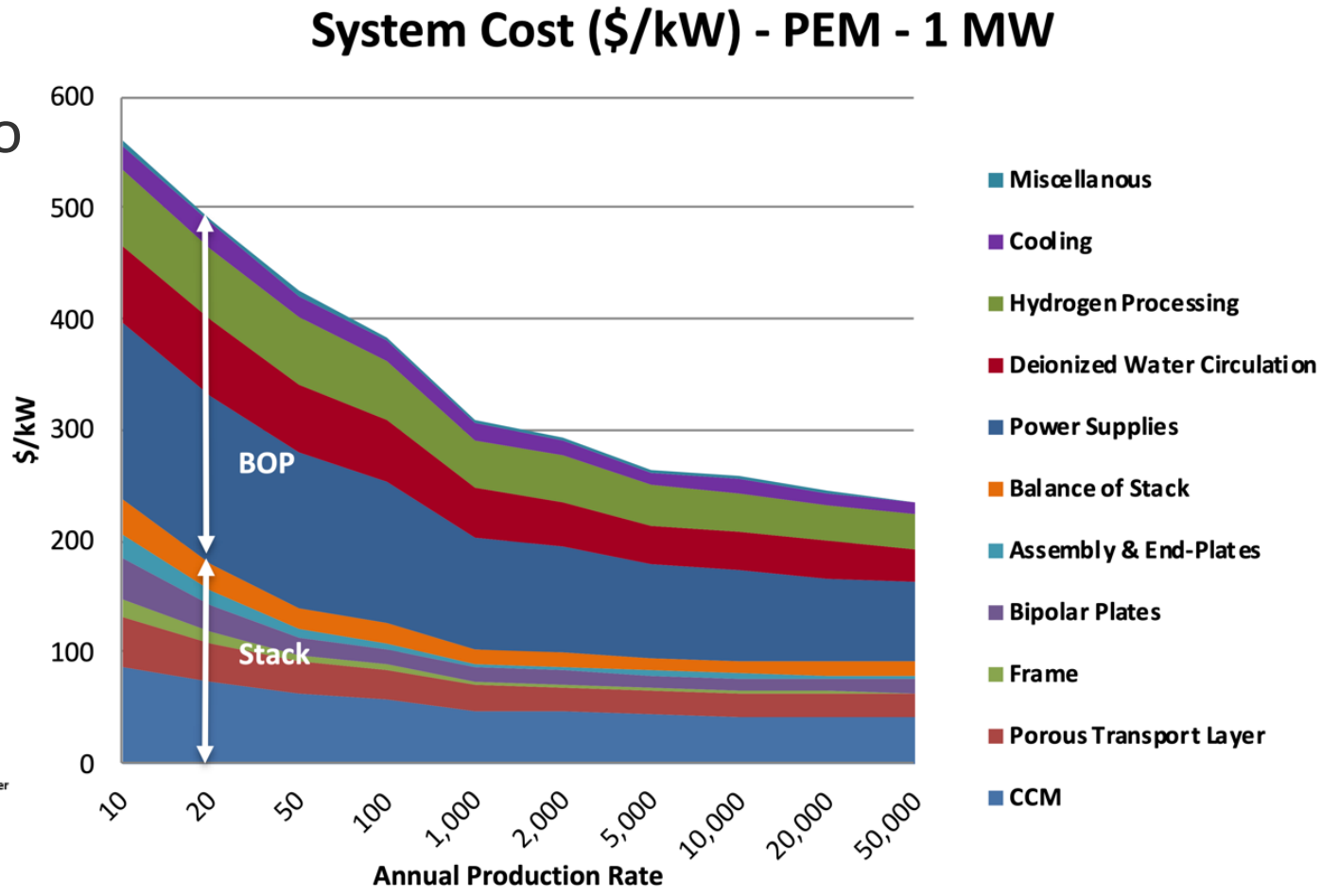


Source: Badgett, Alex, Mark Ruth, Bryan Pivovar. "Economic considerations for hydrogen production with a focus on polymer electrolyte membrane electrolysis" in *Electrochemical Power Sources: Fundamentals, Systems, and Applications: Hydrogen Production by Water Electrolysis*. Editors: Tom Smolinka and Jürgen Garche. 1st ed. Amsterdam, Elsevier, 2021. https://doi.org/10.1016/B978-0-12-819424-9.00005-7

Electrolyzer Manufacturing Cost Analysis to Inform R&D

Improving PEM electrolyzer manufacturing cost assessments to help prioritize R&D directions.





Source: https://www.nrel.gov/docs/fy19osti/72740.pdf

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