Hydrogen and Renewables: Technical and Economic Potential

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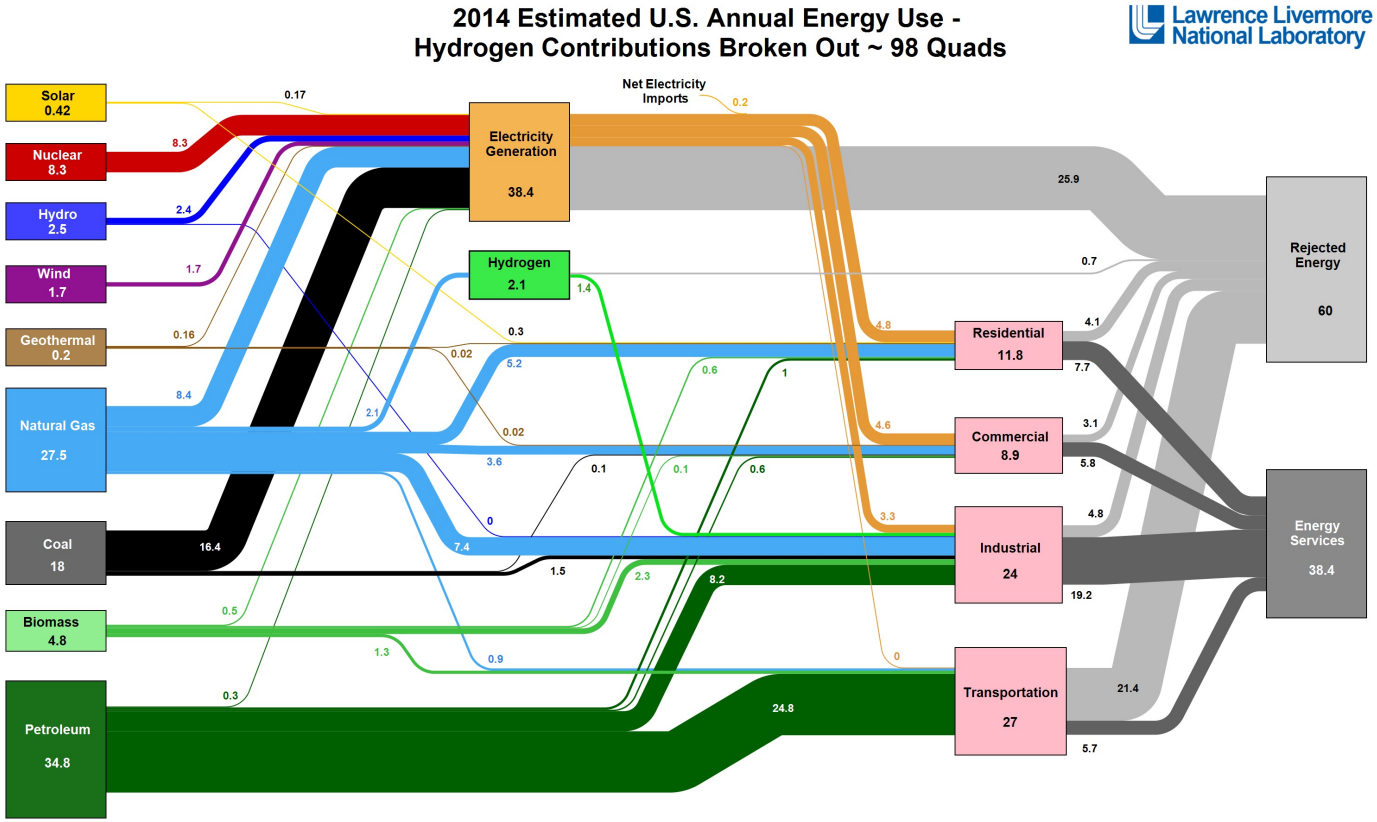
Report available at: https://www.nrel.gov/docs/fy21osti/77610.pdf
Detailed demand report available at: https://greet.es.anl.gov/publication-us_future_h2

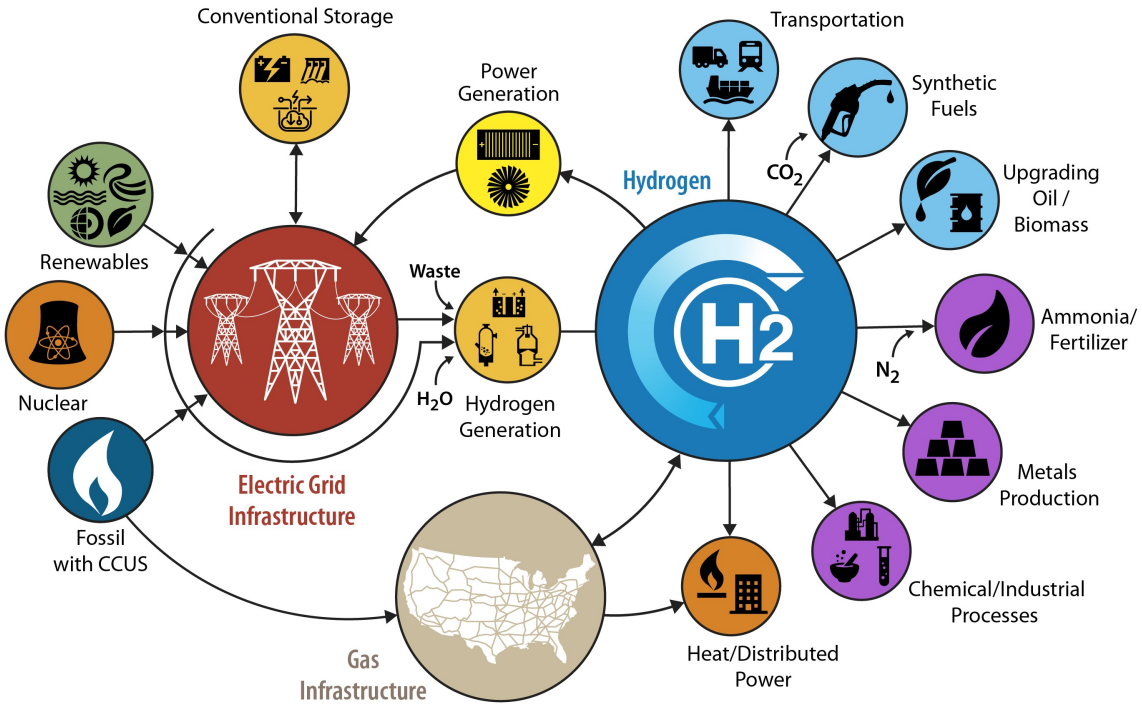
Hydrogen in Today's Energy System: 10 MMT / yr



Source: LLNL September 2015. Data is based on DOE/EIA-0035(2015-03) and Annual Energy Outlook DOE/EIA-0383(2014). If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. Distributed electricity represents only retail electricity sales and does not include self-generation. EIA reports consumption of renewable resources (i.e., hydro, wind, geothermal and solar) for electricity in BTU-equivalent values by assuming a typical fossil fuel plant "heat rate". The efficiency of electricity production is calculated as the total retail electricity delivered divided by the primary energy input into electricity generation. End use efficiency is estimated as 65% for the residential sector, 65% for the commercial sector, 80% for the industrial sector, and 21% for the transportation sector. Totals may not equal sum of components due to independent rounding. LLNL-MI-676987

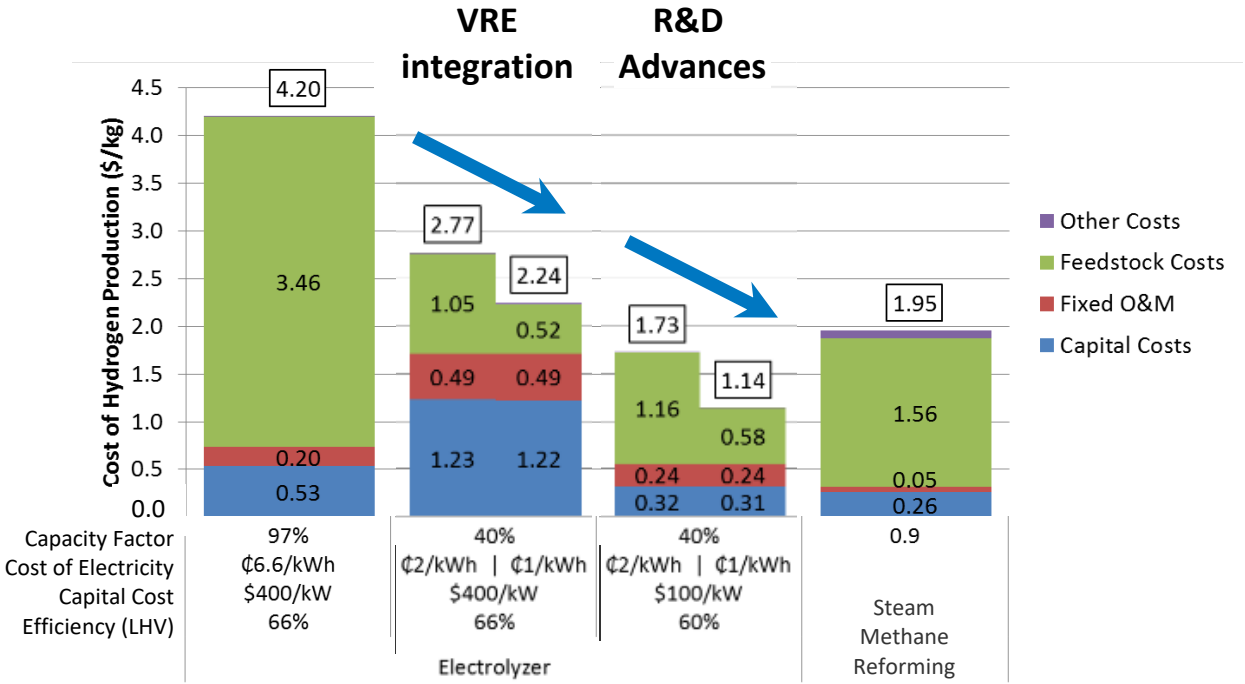
H2@Scale

DOE initiative focusing on hydrogen as an energy intermediate.



https://www.energy.gov/eere/fuelcells/h2scale

Low-Cost, Variable Electricity Could Be Source for Low-Cost Hydrogen



Low-temperature electrolysis could produce hydrogen using low-cost, dispatch-constrained electricity.

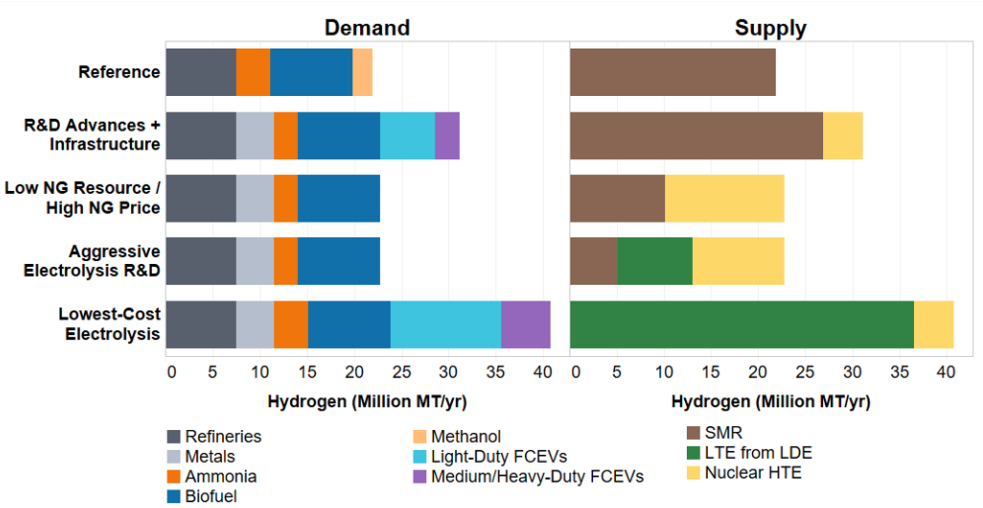
Economic Potential: Limitations and Caveats

- **Market equilibrium methodology** and market size estimates in 2050
  - Transition issues such as stock turnover are not considered
- **New policy drivers, such as emission policies, are not included** either for hydrogen or the grid
- Technology and market performance involve many assumptions about adjacent technologies
  - In all but the non-reference scenario, the assumption is that R&D targets are met
- Demand analysis is limited to sectors that could be forecast for the foreseeable future
  - Hydrogen use to convert biomass based market size equal to 50% of aviation demand
  - Hydrogen for industrial heat is not included
  - Single hydrogen threshold price for fuel cell vehicle market estimates
- Estimates of delivery costs were standardized and without location specificity
- Potential long-term production technologies (e.g., photo-electrochemical) not included
- Economic feedback impacts are not considered
- Competing technologies (both for markets that use hydrogen and for resources to generate hydrogen) are addressed in a simplified manner only

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

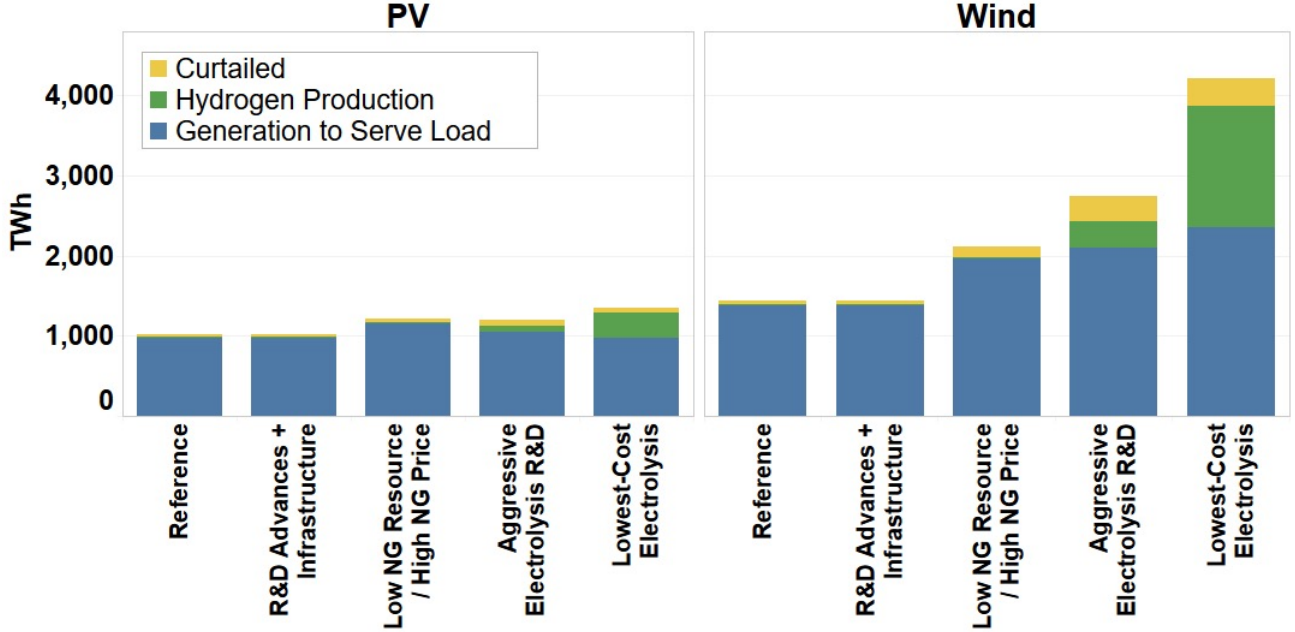


Incentives are needed for hydrogen to compete for long-duration storage / dispatchable electricity generation and for use to generate heat (in place of or supplementing natural gas)

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

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

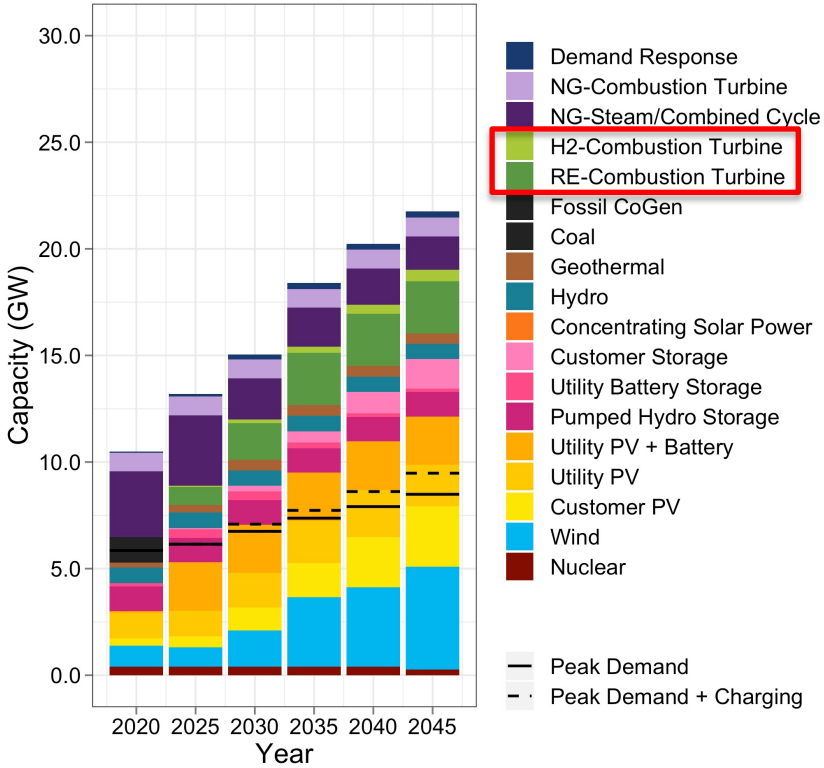
Estimates are based on national scenarios with minimal resolution into regional constraints. Increased resolution will likely impact the most competitive source of energy supply

100% Renewable Electricity Standards for Dispatchable Generation Requires Chemical Energy Storage

The LA100 project analyzed opportunities and challenges for decarbonizing electricity generation.

Optimally, 10% or more of generating capacity will be non-carbon emitting dispatchable generators.

More available at: https://maps-dev.nrel.gov/la100/#



Source: https://maps-dev.nrel.gov/la100/key-findings/scenarios/sb100/moderate#annual-generation-twh-2020-2045

Summary

- **The economic potential of hydrogen demand in the U.S. is 2.2-4.1X current annual consumption even without carbon policies**.
  - At those market sizes, hydrogen production is 4-17% of primary energy use.
- **An increased hydrogen market size can be realized even if low-cost LTE is not available as long as other hydrogen production options are available**
- **Grid-integrated electrolysis can increase renewable energy generation by more than 60%** by monetizing additional low-cost, dispatch-constrained electricity
- **Long-duration storage is critical for >90% decarbonization of the electric grid.** In many locations, hydrogen is the best option to provide that storage.