Opportunities for Hydrogen to Green Industry

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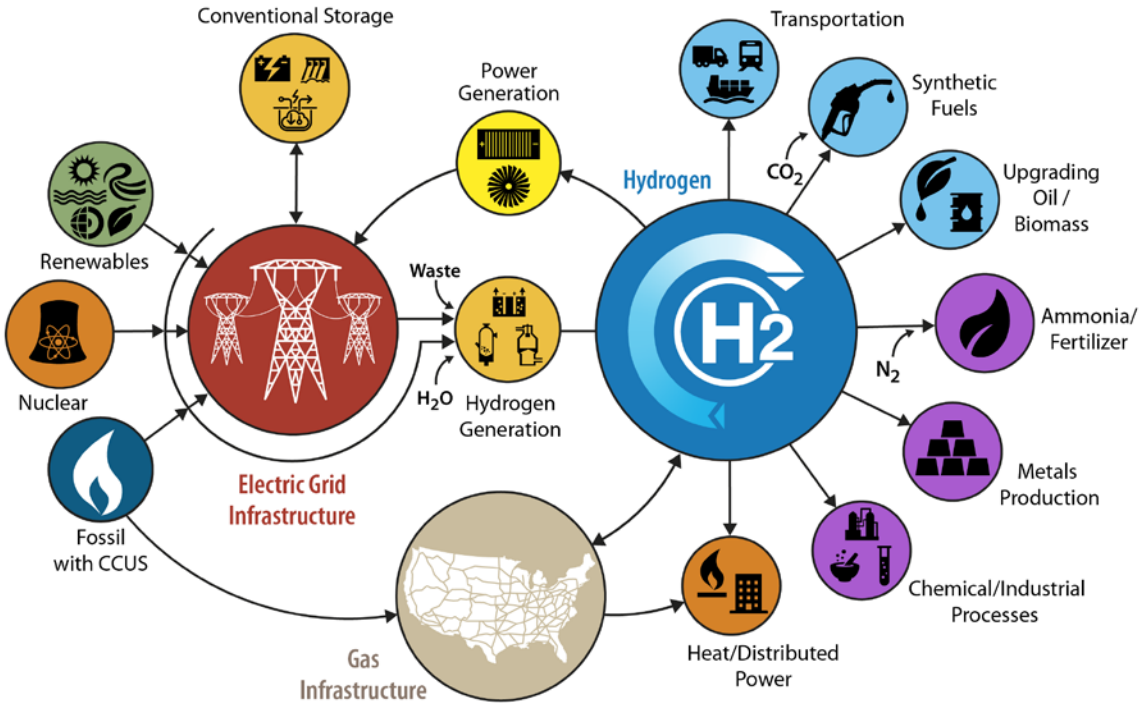
NREL/PR-6A20-79011

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

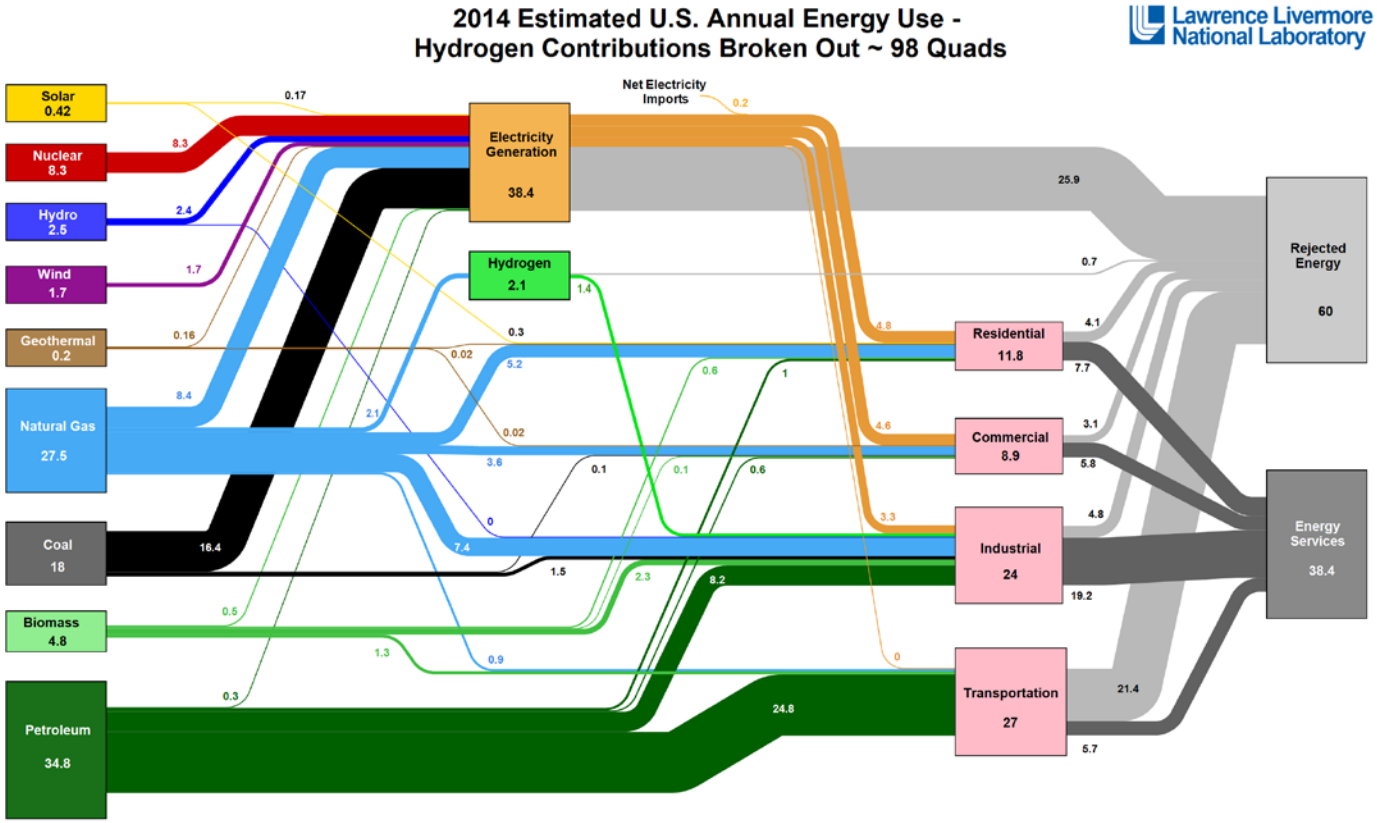
H2@Scale

DOE initiative focusing on hydrogen as an energy intermediate.

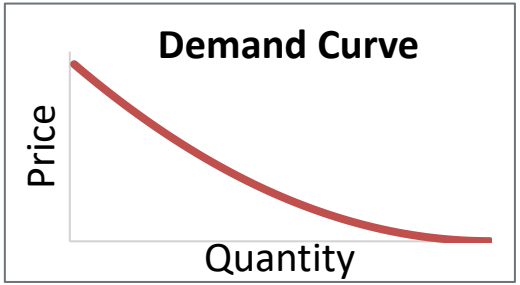


https://www.energy.gov/eere/fuelcells/h2scale

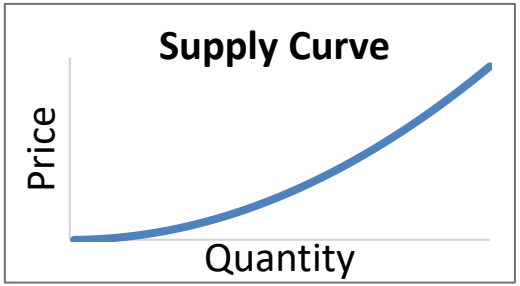
Hydrogen in Today's Energy System: 10 MMT / yr



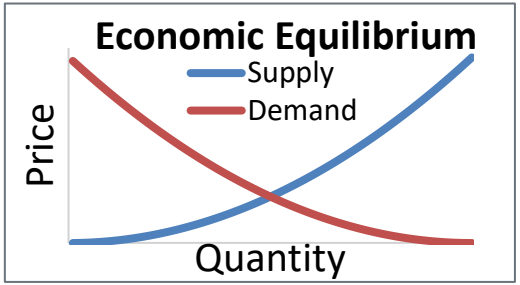
Economic Potential Methodology: Market Equilibrium



Demand Curve: how much are consumers willing and able to pay for a good?



Supply Curve: threshold prices showing how much are producers willing and able to produce at each?



Economic Equilibrium: Quantity where demand price is equal to the supply price**.**

- No excess supply or demand.
- Market pushes price and quantity to equilibrium.

Methodology described in Schwartz, Robert A. *Micro Markets A Market Structure Approach to Microeconomic Analysis*. Wiley Finance. Chichester: Wiley, 2010.

Hydrogen Applications and Threshold Prices

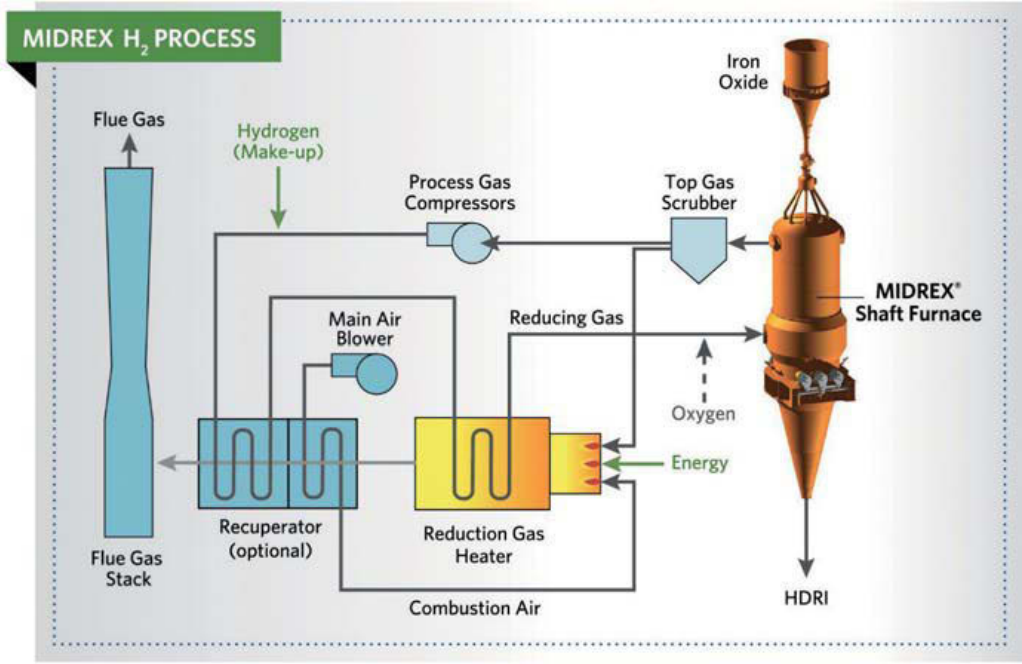
Potential hydrogen demands are based on potential market sizes. Threshold prices are estimates of hydrogen prices necessary to replace incumbent technologies.

Application	Hydrogen Threshold Price-1 ($/kg)	Demand at Threshold Price-1 (MMT/yr)	Hydrogen Threshold Price-2 ($/kg)	Additional Demand at Threshold Price-2 (MMT/yr)
Refineries and the chemical processing industry (CPI) [a]	High	7.5	----	----
Metals	$1.70	4.0	$1.40	12
Ammonia	High	2.5	$2.00	1.1
Biofuels	High	8.7	----	----
Synthetic hydrocarbons	$1.73	6.0	$0.00	8.0
Natural gas supplementation	$1.40	16	----	----
Seasonal energy storage for the electricity grid	$1.10	14	$0.26	0.8
Light-duty fuel cell electric vehicles (FCEVs)	$2.20	12	----	----
Medium- & Heavy-Duty FCEVs	$2.20	5.2	----	----

Hydrogen threshold prices and demands for scenarios using the EIA's Low Oil and Gas Resource Scenario. Other scenarios have different threshold prices and quantities.

Potential Hydrogen Markets: Metals Refining (Steel)

- Status:
  - 81 MMT_{steel}/yr produced in the U.S. project to grow to 120 MMT_{steel}/yr by 2050
  - Blast furnaces: 430 kg_{coke} / MT_{iron}
  - Direct reduced iron optimally uses hydrogen/CO blends, with 30 kg_{H2} /$MT_{hot\ iron}$
    - Can use up to 100% hydrogen (100 kg_{H2}/$MT_{hot\ iron}$)
- Serviceable Consumption Potential:
  - 12 MMT/yr_{H2} based on 120 MMT_{steel}/yr at 100 kg_{H2}/$MT_{hot\ iron}$
- Threshold Price for Economic Potential:
  - 4 MMT_{H2}/yr for market at positive ROI: \$1.70/kg_{H2} based on converting all U.S. production to optimal hydrogen/CO ratio of 30 kg_{H2} /$MT_{hot\ iron}$
    - Increase threshold price in "R&D Advances Scenario" to \$2.50/kg_{H2} based on maintaining domestic production while reducing associated emissions
  - 12 MMT_{H2}/yr: \$0.80/kg_{H2} for positive ROI competing with natural gas heat (i.e., using 100% hydrogen – 100 kg_{H2}/$MT_{hot\ iron}$



Source: Steel Times International

Potential Hydrogen Markets: Biofuels

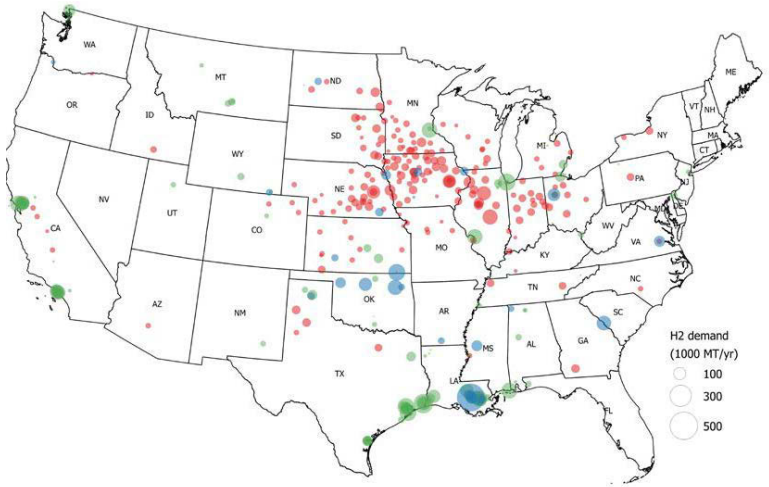
- Opportunity:
  - 50% of total jet fuel demand in 2050 (38.6 billion gal/yr AEO Reference)
  - 1.8 billion gal/yr is from fats, oils, & greases (FOGs)
  - 17.5 billion gal/yr based on catalytic fast pyrolysis of biomass
- Serviceable Consumption Potential:
  - FOGs require 76 g H_2/gal → 0.1 MMT/yr
  - Catalytic fast pyrolysis requires 490 g H_2/gal → 8.6 MMT/yr*
  - Total: 8.7 MMT H_2/yr
- Threshold Price: High because of non-hydrogen price drivers → $3.00/$kg_{H2}$

Source: http://yelloblu.com/blog/biofuels-part-three-biomass-future-fuels

* Designs have hydrogen produced from non-condensibles in the process. We assume those can go to higher value products. Further analysis is needed

Potential Hydrogen Markets: Synthetic Hydrocarbons

- Methanol
  - Methanol: Current capacity 9.4 MMT methanol/yr and EIA projects 34.9 MMT methanol/yr by 2030
  - Producing additional 25.5 MMT methanol/yr would require 44 MMT/yr CO_2 (equal to annual ethanol plants production)*
  - Serviceable consumption potential of 6 MMT H_2/yr to convert 44 MMT/yr CO_2 to methanol
  - Threshold price: \$1.73/kg H_2 for methanol price equivalent to NG-sourced methanol (\$0.5/kg methanol)
- Methanol-to-Gasoline (MTG) **
  - 56 MMT CO_2/yr from SMR and ammonia production could be used to produce MTG
  - Serviceable consumption potential of 8.0 MMT H_2/yr to convert that 56 MMT/yr CO_2 to methanol (no additional H_2 needed for MTG)
  - That 56 MMT CO_2/yr would need concentrating thus not in economic potential (i.e., H_2 price point is too low for any of our scenarios so shows up as \$0/kg H_2 in demand curves)
- Total serviceable consumption potential: 14.0 MMT H_2/yr



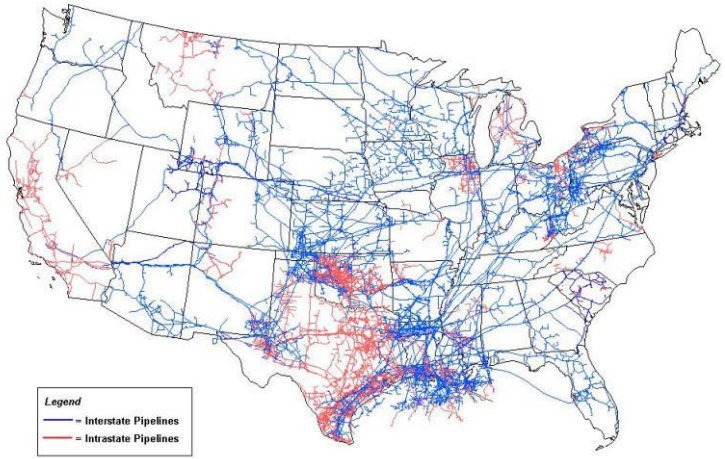
Source: Supekar and Skerlos, ES&T (2014)

* 3:1 H_2:CO_2 molar ratio and 79% CO_2 selectivity
** Other chemicals and products are possible and could be considered with further analysis

Potential Hydrogen Markets: Natural Gas Supplementation

- Serviceable Consumption Potential:
  - 20% (volume) assumed to not have significant impact on technologies that utilize natural gas
  - 16 MMT_{H2}/yr
- Threshold Price:
  - Energy value on a higher heating value (HHV) basis
  - \$0.80/kg_{H2} for AEO reference case (\$5.88/MMBtu)
  - \$1.40/kg_{H2} for AEO Low Oil & Gas Resource case (\$10.23/MMBtu)

U.S. Natural Gas Pipeline Network



Source: M. W. Melaina, O. Antonia, M. Penev. 2013. Blending Hydrogen into Natural Gas Pipeline Networks: A Review of Key Issues. NREL/TP-5600-51995. https://www.nrel.gov/docs/fy13osti/51995.pdf

Additional Potential Hydrogen Demands – Not Included in this Analysis

- Additional hydrocarbon opportunities
- High-temperature industrial heating applications
- Rail transport
- Marine transport (shipping, ferries)
- Material handling equipment
- Coal-to-Liquids
- Glassmaking
- Rocket fuel

Economic Potential: Limitations and Caveats

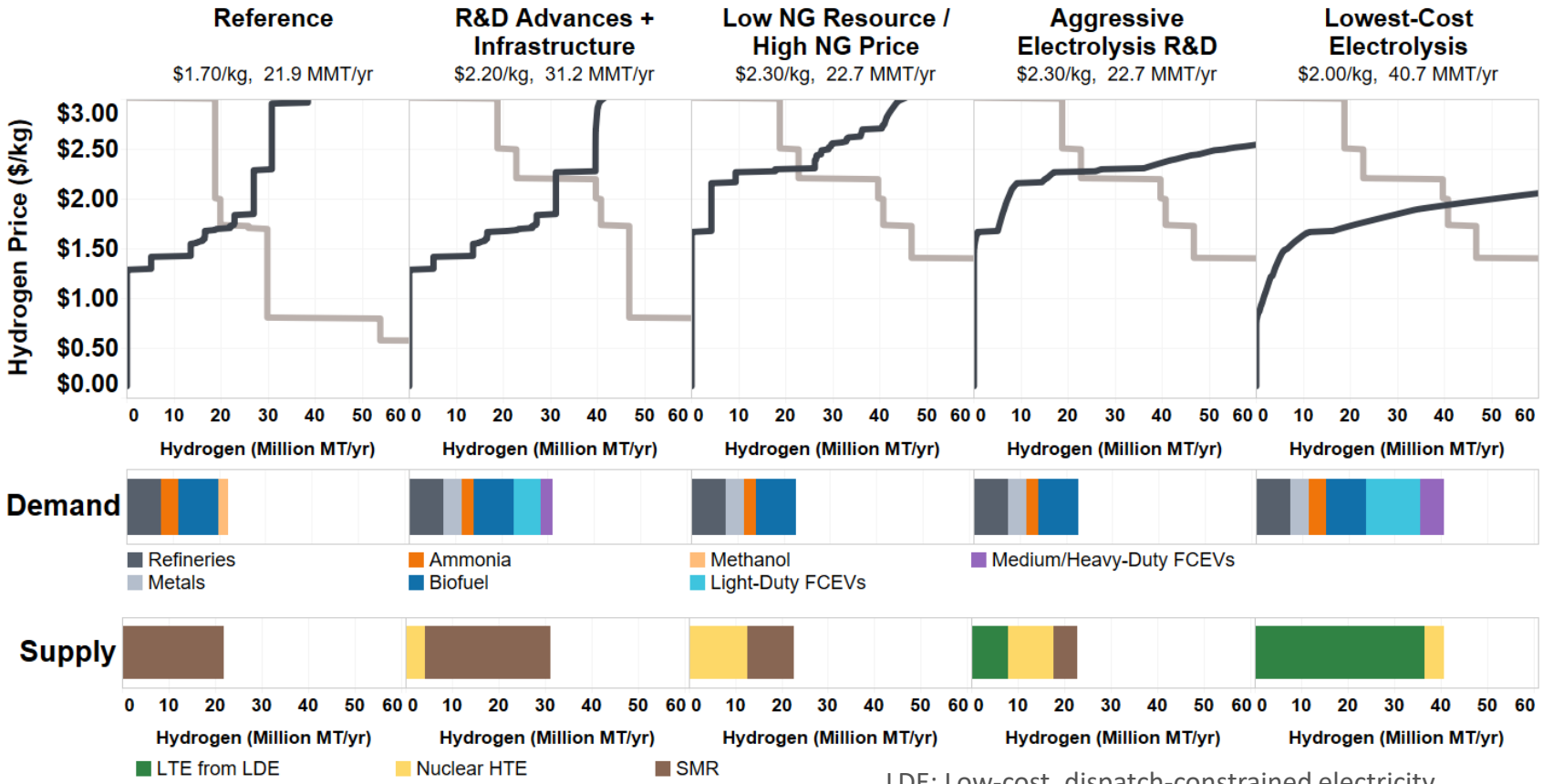
- Market equilibrium methodology and market size estimates in 2050
  - Transition issues such as stock turnover are not considered
- New policy drivers, such as emission policies, are not included either for hydrogen or the grid
- Technology and market performance involve many assumptions about adjacent 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

Economic Potential: Five National Scenarios

Scenario Name	Reference	R&D Advances + Infrastructure	Low NG Resource / High NG Price	Aggressive Electrolysis R&D	Lowest-Cost Electrolysis
Natural gas prices	Reference		Higher		
HTE costs	Current	Improvements			
LTE capital costs	Current	Current trajectory		Improvements	Optimistic assumptions
LDE market assumption	Available at retail price			Between retail and wholesale	Wholesale price
Distribution for FCEVs	Current	Cost targets met			
Metals demand	Market competition	Premium for hydrogen			

Key differences in scenarios: 1) natural gas price assumption, 2) distribution costs, 3) electrolyzer cost assumption, 4) electrolyzers' access to grid service markets, and 5) increased threshold price in metals industry

New Economic Potential Results



LDE: Low-cost, dispatch-constrained electricity

Summary of Key Conclusions

- **The economic potential of hydrogen demand in the U.S. is 2-4X current annual consumption**. **At those market sizes, hydrogen production is 4-17% of primary energy use.**
  - Range across 5 scenarios developed using a variety of economic and R&D success assumptions
  - Total U.S. petroleum use could decline by up to 15% below a scenario with a high renewable penetration on the grid
- **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 wind power generation by more than 60%** by monetizing additional low-cost, dispatch-constrained electricity
- Up to 60% of current **nuclear power plants could improve their profitability** by producing hydrogen.
- Scenarios show the potential for up to **20% reduction in U.S. CO_2e emissions over electricity grid improvements alone**. Higher reductions may be feasible given policy drivers and development of additional demand sectors.

Musings on Opportunities and Challenges for Hydrogen to Green High-Temperature Manufacturing

Combustion

- Higher flame temperature than methane
  - Emissions control
  - Redesign of boilers and direct heating
- Emissions' humidity
- Energy density – but carriers could improve opportunity

Molecular Properties

- Reducing agent (steel and fuels)
- Reactions R&D
- Potential opportunities for hybrid electrochemical processes

Energy Sector-Wide

- Potential to increase penetrations of variable renewable generation
- Where is the tipping point for H2@Scale?

Thank You

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The reports with details on this presentation are available at

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

https://greet.es.anl.gov/publication-us_future_h2

Additional information on H2@Scale can be found at:

https://www.hydrogen.energy.gov/pdfs/review18/h2000_pivovar_2018_o.pdf

http://energy.gov/eere/fuelcells/downloads/h2-scale-potential-opportunity-webinar

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