



H2@Scale Resource and Market Analysis

Hydrogen and Fuel Cell Technical Advisory Committee Meeting

Washington, D.C.

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Acknowledgements

- NREL: Lori Bird, Wesley Cole, Elizabeth Connelly, Josh Eichman, Nicholas Gilroy, Bryan Pivovar, Keith Wipke
- ANL: Jeongwoo Han, Amgad Elgowainy
- LBNL: Max Wei
- PNNL: Karen Studarus

Analysis Objectives

- Improve fidelity of H2@Scale value proposition
 - Provide results that are supported by in-depth analysis and can be used to
- Quantify potential impacts
 - Resource use
 - Emissions
 - Economic
- Identify regional opportunities and challenges
- Perform by a multilab team with support from DOE's Fuel Cell Technologies Office (FCTO) and DOE's Nuclear Energy Office

Overview of Analysis Effort

Initial (Complete)

- Potential demand
- Supply resources
- Impact potential (limited)
- Infrastructure Issues

In-depth (FY17)

- H₂ price requirements
- Supply options and costs
- Scenarios
- Impact potential
- Stage-gate review

Additional analysis needs

- Additional scenarios
- Economic inertia
- Economic externalities
- Spatial issues

Initial Analysis

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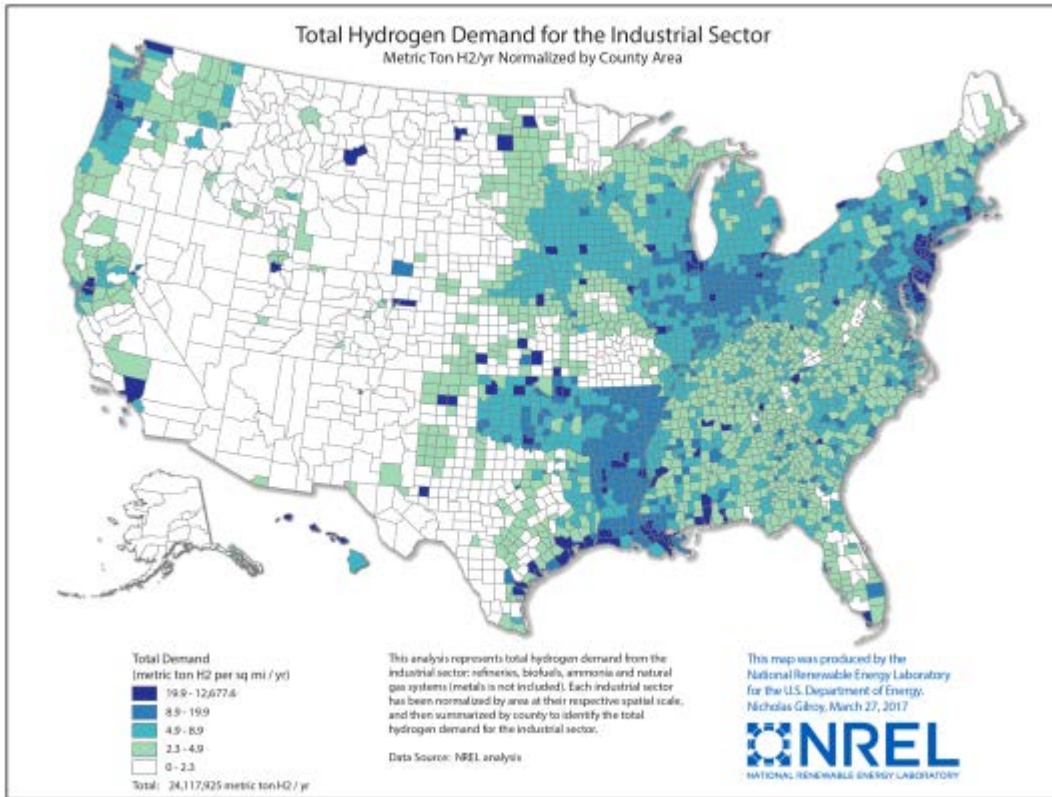
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Initial Analysis: U.S. Hydrogen Demand Potential



Total market potential:
60 MMT/yr

Use	Market potential (million metric tonne H ₂ / year)
Industrial Use	
Refineries & CPI [§]	8*
Metals	5
Ammonia	5
Natural Gas	7
Biofuels	4
Light Duty Vehicles	28
Other Transport	3
Total	60

Current U.S. market: ≈ 10 MMT/yr

Global H₂ production revenue:
6% CAGR, 2009-2016¹

[§] CPI: Chemical Processing Industry not including metals, biofuels, or ammonia

* Current potential used due to lack of consistent future projections

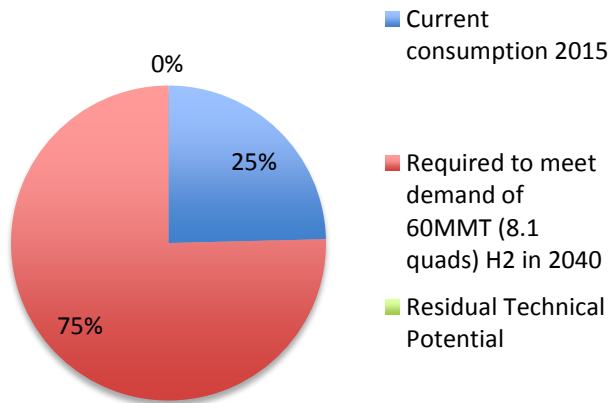
Light duty vehicle calculation basis: 190,000,000 light-duty FCEVs from <http://www.nap.edu/catalog/18264/transitions-to-alternative-vehicles-and-fuels>

1. Global hydrogen Generation Market by Merchant & Captive Type, Distributed & Centralized Generation, Application & Technology- Trends & Forecasts (2011-2016)

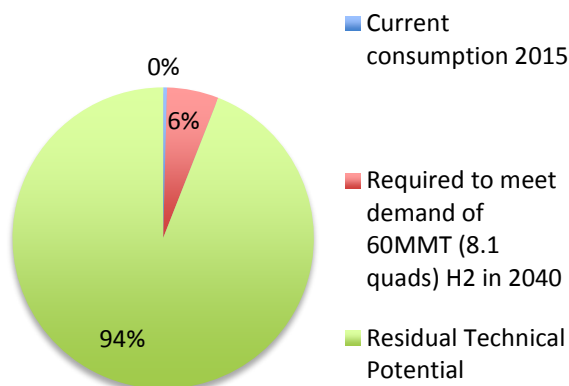
Initial Analysis: Resource Availability for Hydrogen

	EIA 2015 current consumption (quads/yr)	Required to meet demand of 60 MMT (8.1 quads) / yr H ₂ in 2040 (quads/yr)	Technical Potential (quads/yr)
Solid Biomass	4.7	15	20
Wind Electrolysis	0.7	9	170
Solar Electrolysis	0.1	9	1,364

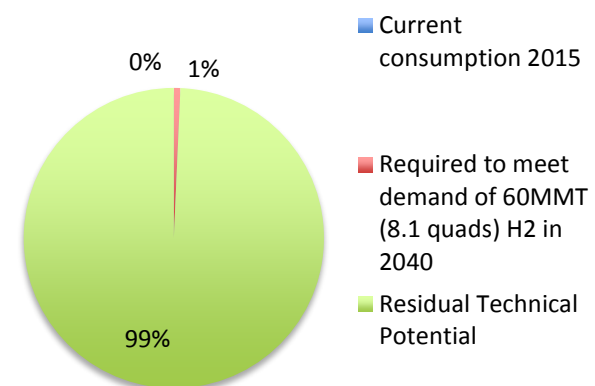
Biomass Technical Potential (quads/yr)



Wind Technical Potential (quads/yr)

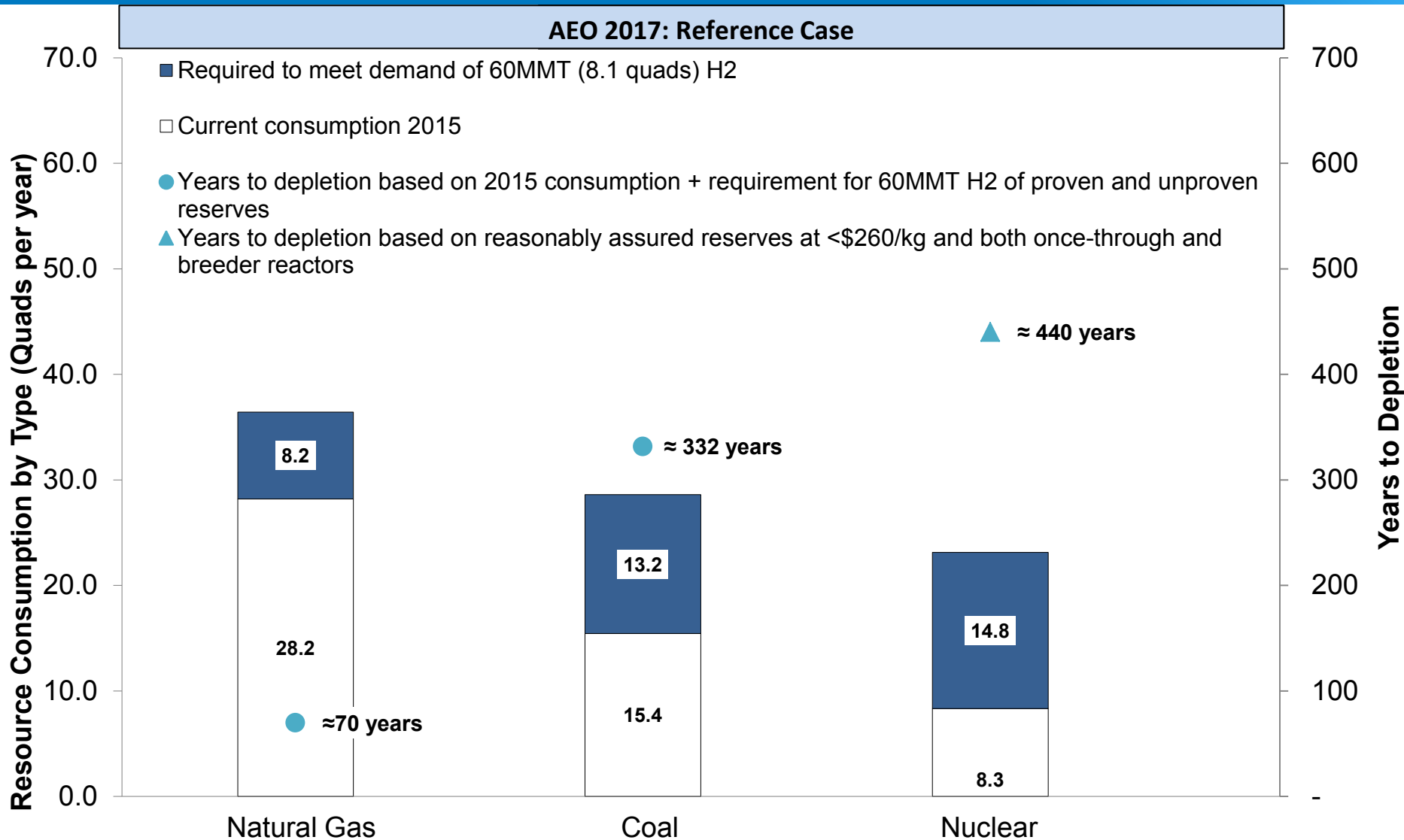


Solar Technical Potential (quads/yr)



Technical potential for wind and solar are much greater than potential demand. Biomass potential equals demand.

Initial Analysis: Nuclear & Fossil Resources for Hydrogen



Hydrogen production from grid electricity can be supplemented by diverse domestic resources to meet aggressive growth in demand

Initial Analysis: GHG Emissions, Petroleum Use, and NG Use Reductions

Use	MMT / yr	GHG Reduction (million metric ton CO ₂ /yr)	Petroleum Reduction (bbl/yr)	NG Reduction (mmBtu/yr)
Refineries	8	87	900,000	1,332,000,000
Metals	5	78		365,000,000
Ammonia	5	54	500,000	833,000,000
Natural Gas System	7	63	700,000	923,000,000
Biofuels [§]	4	28	77,500,000	-26,000,000*
Light Duty Vehicles	28	469	1,017,600,000	629,000,000
Other Transport	3	50	113,400,000	51,000,000
Total	60	830 Million MT	1.2 Billion bbl	4.1 Quads

~16% of U.S. energy-related emissions in 2016

~17% of U.S. petroleum consumption in 2016 – potential savings of over \$50 billion

~14% of U.S. natural gas consumption in 2016

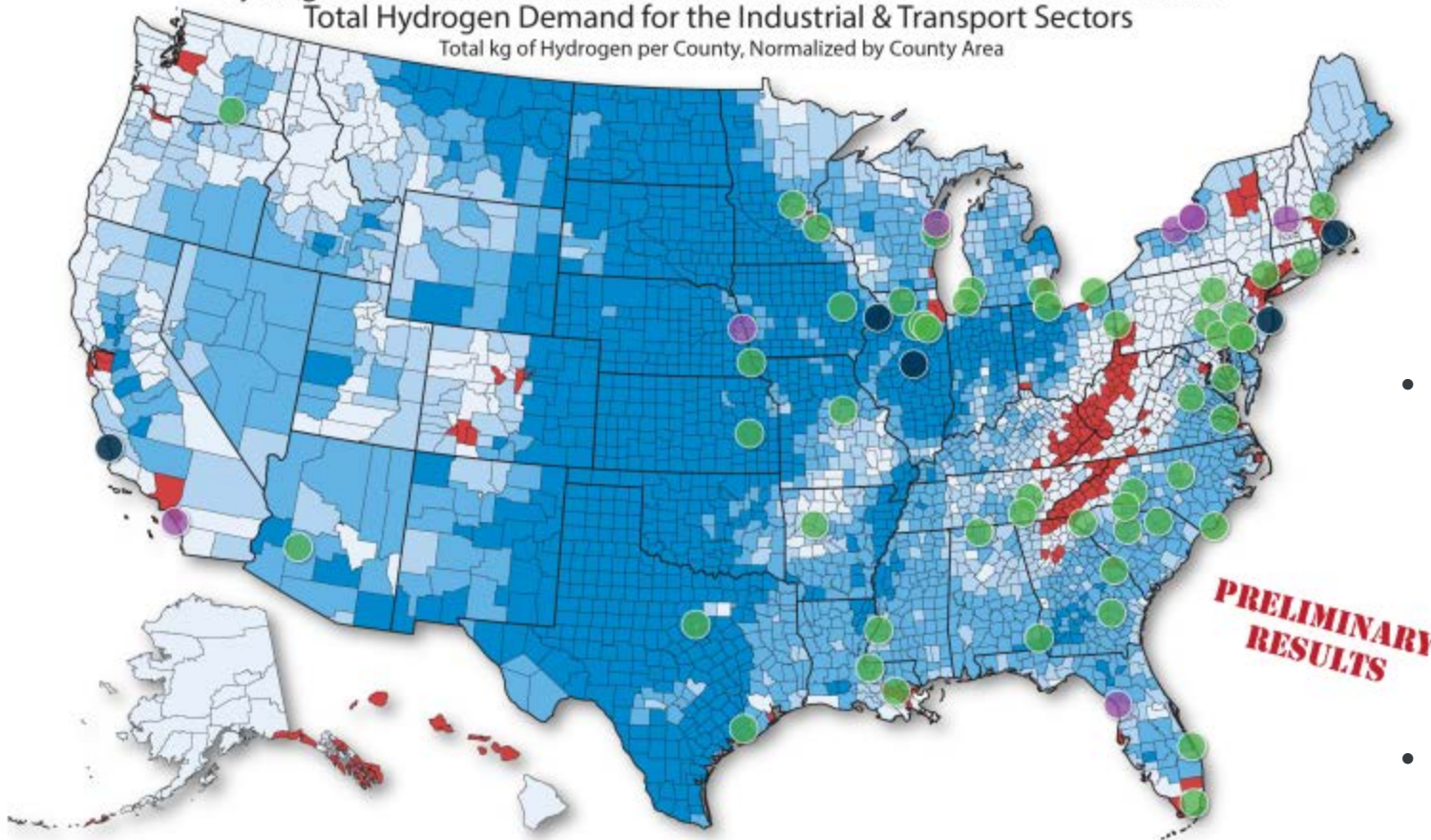
Hydrogen alone has the potential to reduce emissions and fossil use by ≈15%. The ability to enable higher penetrations of renewable energy can further reduce emissions and fossil use.

*Negative values represent increase in use due to natural gas use for hydrogen production

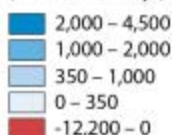
§ 12% of the benefits of hydrogenated biofuels are credited to hydrogen and reported here

Initial Analysis: Where Resources are Sufficient

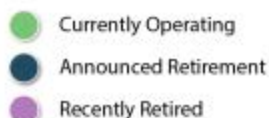
Hydrogen Potential From Photovoltaic and Onshore Wind Resources Minus
Total Hydrogen Demand for the Industrial & Transport Sectors
Total kg of Hydrogen per County, Normalized by County Area



Hydrogen
(metric ton/m²/yr)



Nuclear Energy Plants



This analysis represents potential generation from utility-scale photovoltaics and onshore wind resources minus total hydrogen demand from the industrial sector: refineries, biofuels, ammonia and natural gas systems (metals are not included) and the transport sector: light duty vehicles and other transport. The data has been normalized by area at their respective spatial scales, and then summarized by county.

Data Source: NREL analysis
Robson, A. Preserving America's Clean Energy Foundation. Retrieved March 23, 2017, from <http://www.thirdway.org/report/preserving-americas-clean-energy-foundation>

This map was produced by the
National Renewable Energy Laboratory
for the U.S. Department of Energy.
Nicholas Gilroy, March 27, 2017



- PV and wind resources exceed industrial + transportation demand (not including metals) in **counties colored blue**
- Industrial + transportation demand is greater than resources **only in counties colored red**
- Nuclear production could provide the necessary additional generation

How much electricity would H2@Scale require?

$$60\text{B kg H}_2 \text{ per year} \times 55 \text{ kWh per kilogram} = 3,300 \text{ TWh per year}$$



How does that compare with our current electricity use?

$$\text{U.S. Electricity Consumption} = \text{Approximately } 3,900 \text{ TWh per year}^*$$

**~85% of current U.S.
electricity demand**

*2015 consumption. Source: EIA AEO 2016

In-Depth Analysis

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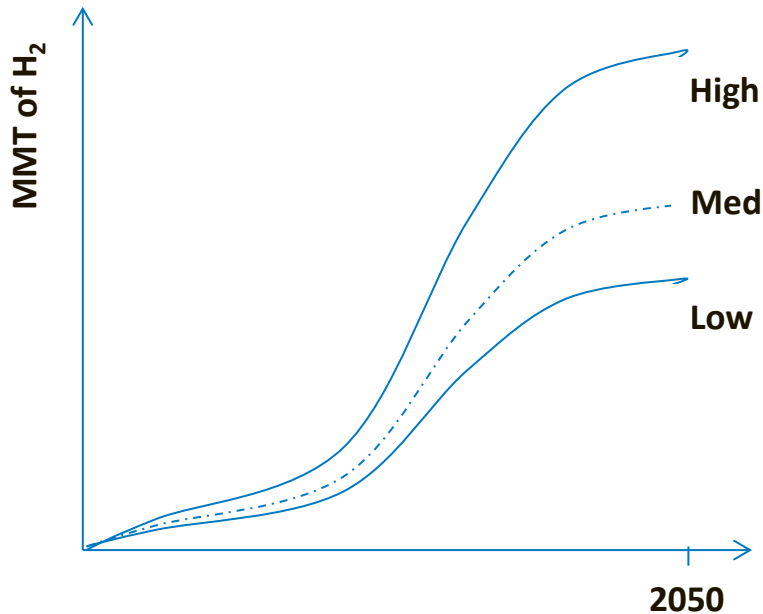
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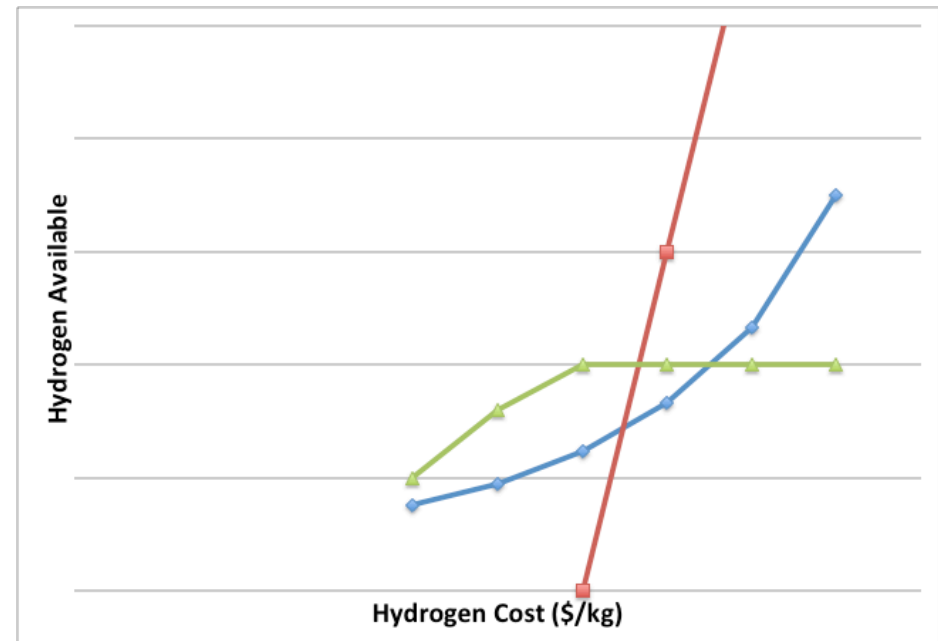
Price requirements and demand curves



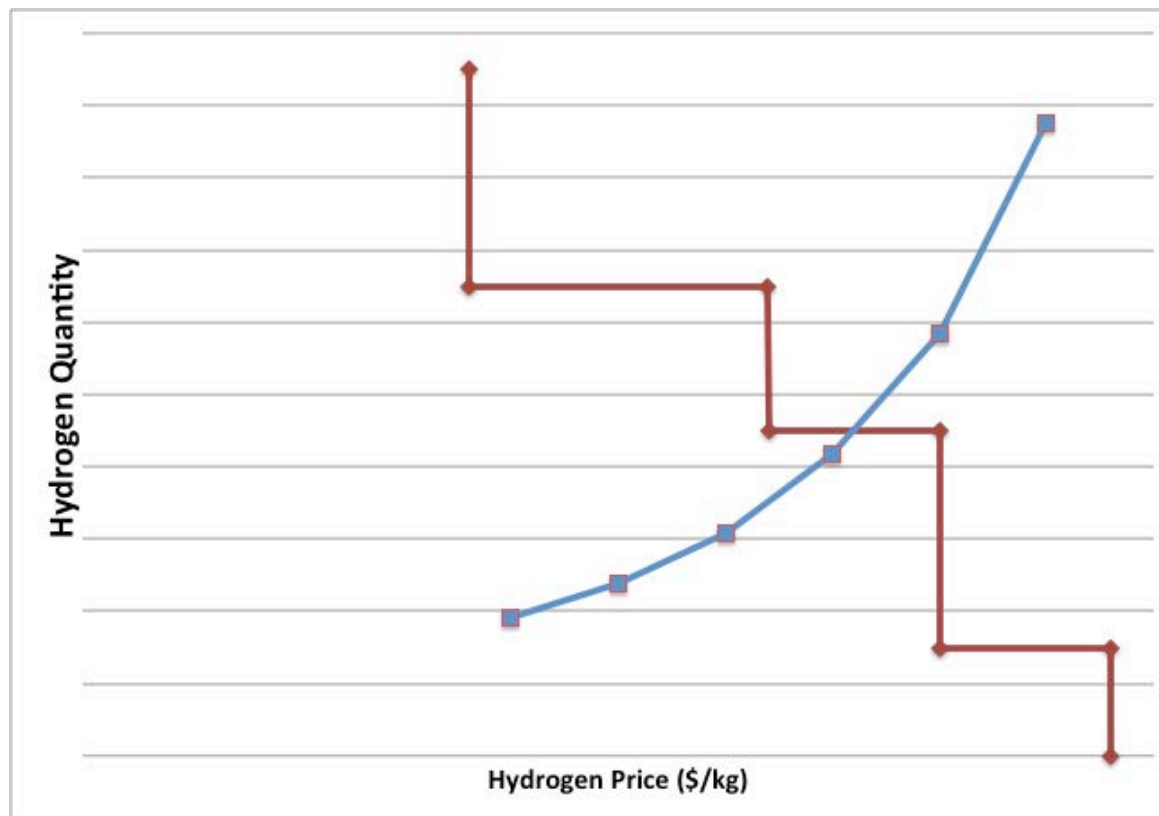
- Bottom-up demand estimates
- Technical, inertia, and resource constraints
- Includes demand aggregation to avoid double counting

Production cost estimates for several scenarios

- Steam methane reforming (StMR)
- Nuclear generation
- Otherwise curtailed electricity with high penetrations of variable renewable generators on the grid



In-Depth: Scenario Generation (Underway)



- Supply and demand curves can provide estimates of market size for many possible scenarios
 - Cross point identifies the amount of hydrogen generated and used as well as the hydrogen demand markets
- With that information we can estimate impacts

Building off Renewable Portfolio Standard Analysis

		EXISTING RPS		HIGH RE	
RENEWABLE ENERGY IN 2050		increased by ↑ 122 GW 296 TWh		increased by ↑ 331 GW 765 TWh	
COSTS	 ELECTRIC SYSTEM COSTS	range from -0.7% to 0.8%	equivalent to ±\$31 billion <small>estimates span +/- 0.5 CAGR-RE</small>	range from 0.6% to 4.5%	equivalent to \$23 billion - \$194 billion <small>estimates span 0.29-1.31 CAGR-RE</small>
	 ELECTRICITY PRICES	range from -2.4 cents/kWh to 1 cent/kWh		range from -1.9 cents/kWh to 4.2 cents/kWh	
BENEFITS	 SULFUR DIOXIDE	reduced by ↓ 6% 2.1 million <small>metric tons SO₂</small>		reduced by ↓ 29% 11.1 million <small>metric tons SO₂</small>	
	 NITROGEN OXIDES	reduced by ↓ 6% 2.5 million <small>metric tons NO_x</small>	equivalent to \$97 billion <small>(2.4¢/kWh-RE) estimates span \$48 billion - \$173 billion (1.7-4.2 CAGR-RE)</small>	reduced by ↓ 29% 12.8 million <small>metric tons NO_x</small>	equivalent to \$558 billion <small>(5.0¢/kWh-RE) estimates span \$307 billion - \$917 billion (2.7-8.1 CAGR-RE)</small>
	 PARTICULATE MATTER 2.5	reduced by ↓ 5% 0.3 million <small>metric tons PM_{2.5}</small>		reduced by ↓ 29% 1.8 million <small>metric tons PM_{2.5}</small>	
	 GREENHOUSE GAS EMISSIONS	reduced by ↓ 6% 4.7 billion <small>metric tons CO₂e</small>	equivalent to \$161 billion <small>(3.9¢/kWh-RE) estimates span \$37 billion - \$487 billion (1.9-17.8 CAGR-RE)</small>	reduced by ↓ 23% 18.1 billion <small>metric tons CO₂e</small>	equivalent to \$599 billion <small>(5.4¢/kWh-RE) estimates span \$132 billion - \$1,821 billion (1.7-16.1 CAGR-RE)</small>
	 WATER USE	reduced by ↓ 4% 3% <small>consumption withdrawal</small>		reduced by ↓ 18% 18% <small>consumption withdrawal</small>	
IMPACTS	 NATURAL GAS	reduced by ↓ 35 quads (3.3%)	equivalent to \$78 billion <small>impact: 1.5¢/kWh-RE</small>	reduced by ↓ 46 quads (4.3%)	equivalent to \$99 billion <small>impact: 0.9¢/kWh-RE</small>
	 RE JOB NEEDS	increase in ↑ 19% <small>RE-employment</small>	equivalent to 4.7 million <small>RE job-years</small>	increase in ↑ 47% <small>RE-employment</small>	equivalent to 11.5 million <small>RE job-years</small>

- Renewable (RE) and nuclear use offsets fossil fuel use leading to environmental benefits such as a reduction in air and water pollution and GHG emissions.
- Also monetary impacts such as the potential economic savings for companies and consumers and stimulation of job growth
- Overall, with existing RPS and high RE targets, benefits of investing in renewables exceeds the costs

[A Prospective Analysis of the Costs, Benefits, and Impacts of U.S. Renewable Portfolio Standards](http://www.nrel.gov/docs/fy17osti/67455.pdf)
NREL/TP-6A20-67455 <http://www.nrel.gov/docs/fy17osti/67455.pdf>

In-Depth: Stage-Gate Review

Planning for September 2017

Present

- Analysis results to external experts
- Roadmap and R&D plans

Review

- Analysis results and implications
- Plans in roadmap

Identify & Prioritize

- Future directions and needs for R&D & analysis

Plan

- Additional R&D & analysis efforts

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- FY18 efforts based on feedback from stage-gate review
- Potential opportunities
 - Additional demands or supply options
 - Improved understanding of economic inertia
 - Impact on macro-economics and feedback loops
 - Regional and spatial issues

Concluding Remarks

- Hydrogen demand of 60 MMT / yr is possible when transportation and industry are considered
- Resources are available to meet that demand
- Using renewable resources would reduce emissions and fossil use by over 15%
- Further impacts are possible when considering synergistic benefits
- Additional analysis is underway to improve understanding of potential markets and synergistic impacts
- Further analysis will be necessary to estimate impacts due to spatial characteristics, feedback effects in the economy, and inertia characteristics

Questions

- What key impacts would you like to see as the focus of our analysis?
- Are there non-policy impacts that we should consider? If so, which ones?
- What additional aspects would analysis be useful to address?

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