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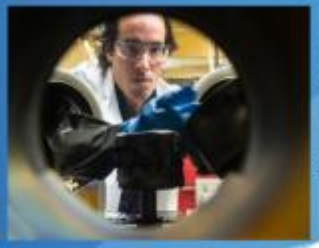


H2@Scale Resource and Market Analysis

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Washington, D.C.
May 5, 2017

NREL/PR-6A20-68429

NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

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)

- H_2 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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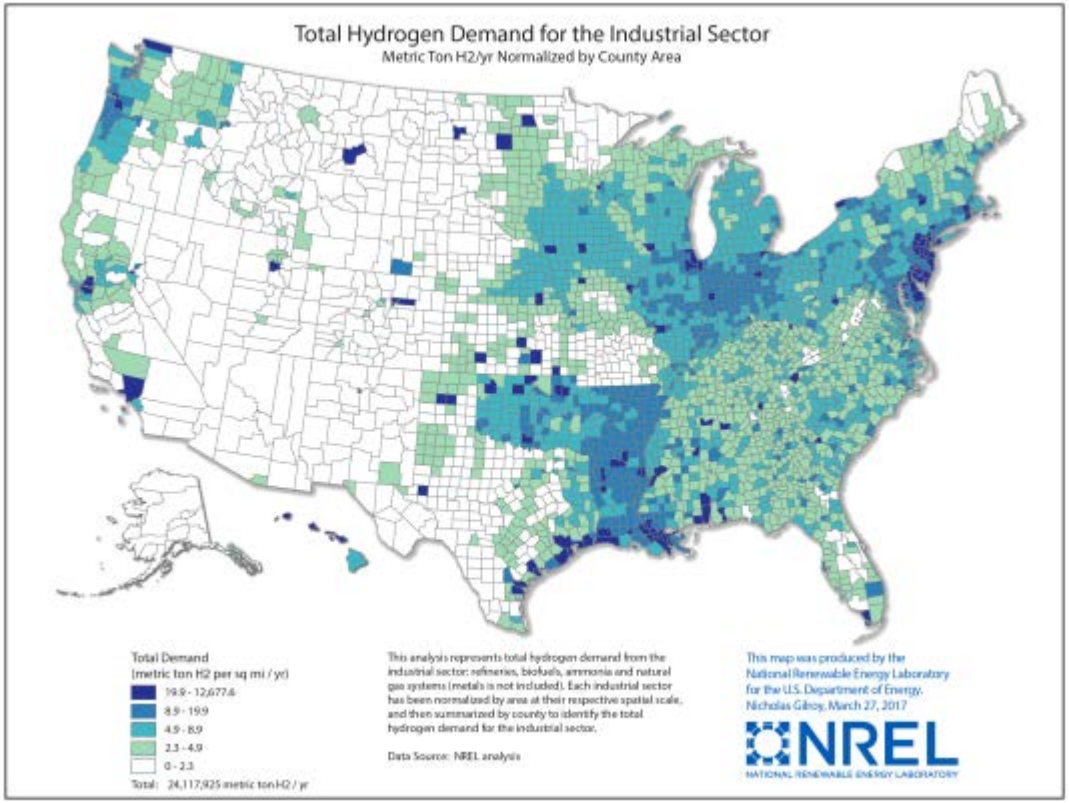
Initial Analysis: U.S. Hydrogen Demand Potential



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**

Total market potential:

60 MMT/yr

Preliminary Results

Current U.S. market: ≈ 10 MMT/yr

Global H_2 production revenue: 6% CAGR, 2009-2016[1]

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

* Current potential used due to lack of consistent future projections

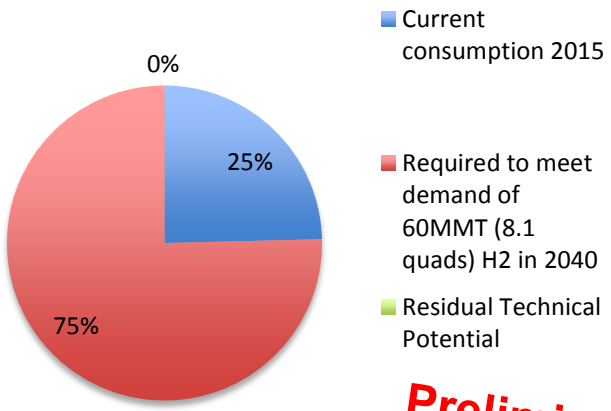
Light duty vehicle calculation basis: 190,000,000 light-duty FCEVs from http://www.nap.edu/catalog/18264/transitions-to-alternative-vehicles-and-fuels

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

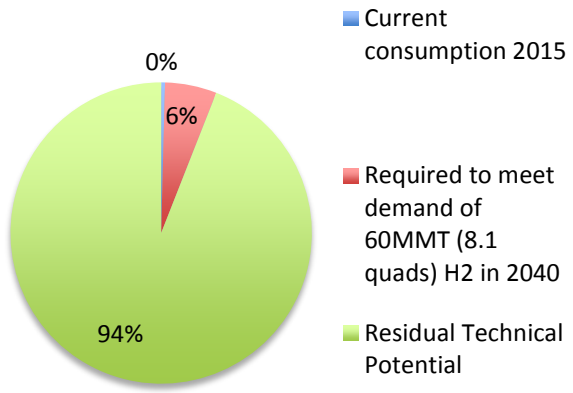
Initial Analysis: Resource Availability for Hydrogen

	EIA 2015 current consumption (quads/yr)	Required to meet demand of 60 MMT (8.1 quads) / yr H_2 (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

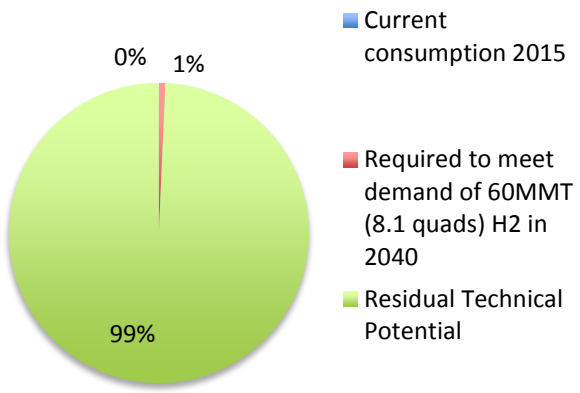
Biomass Technical Potential (quads/yr)



Wind Technical Potential (quads/yr)



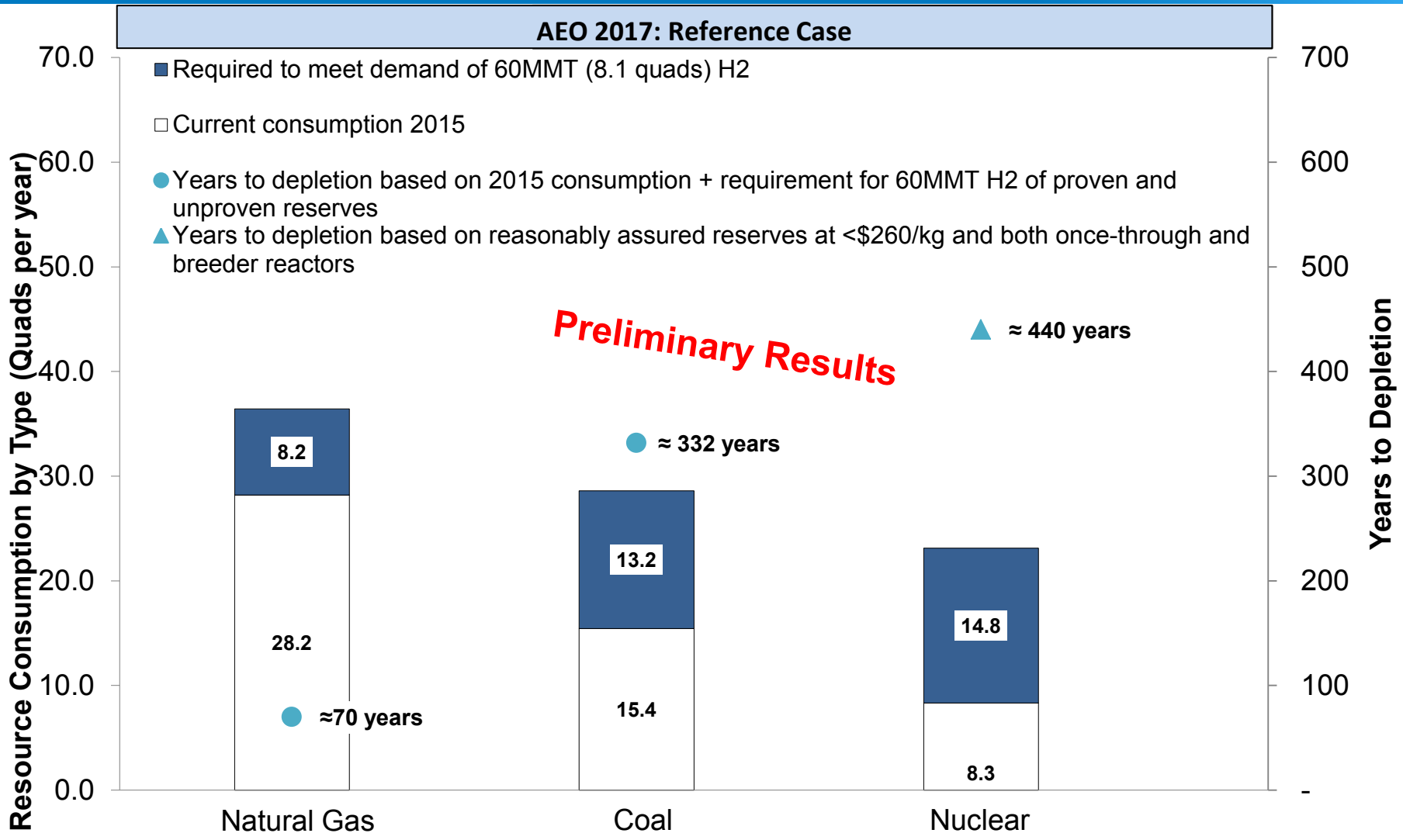
Solar Technical Potential (quads/yr)



Preliminary Results

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

Coal estimate based on demonstrated recoverable reserves

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

Preliminary Results

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

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

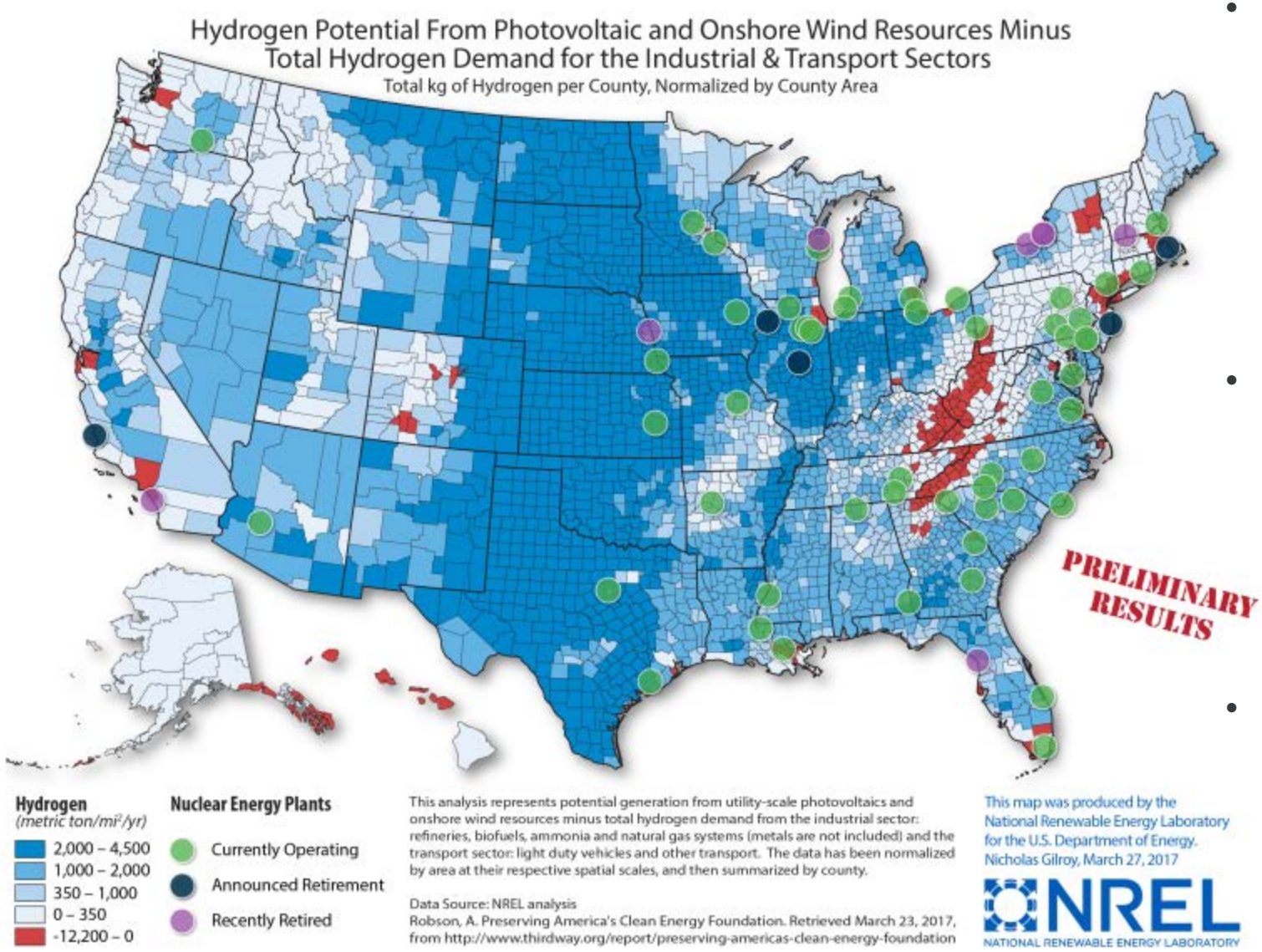
~14% of U.S. natural gas consumption in 2016

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



- 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

Initial Analysis: Potential Impacts on Electric Grid

How much electricity would H2@Scale require?

60B kg H_2 per year **X 55 kWh** per kilogram **= 3,300 TWh** per year

How does that compare with our current electricity use?

U.S. Electricity Consumption **=** Approximately **3,900 TWh** per year*

Preliminary Results

~85% of current U.S. electricity demand

*2015 consumption. Source: EIA AEO 2016

In-Depth Analysis

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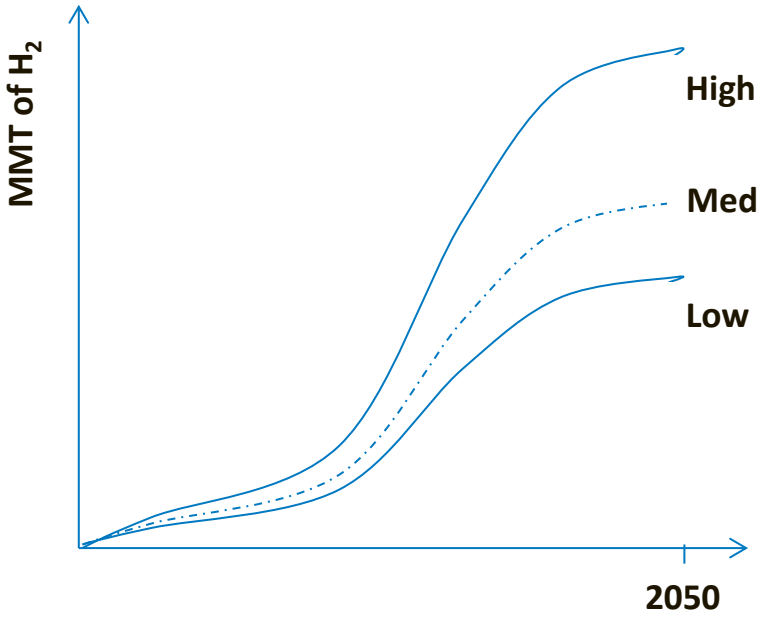
In-Depth: Price Requirements & Supply Options (Underway)

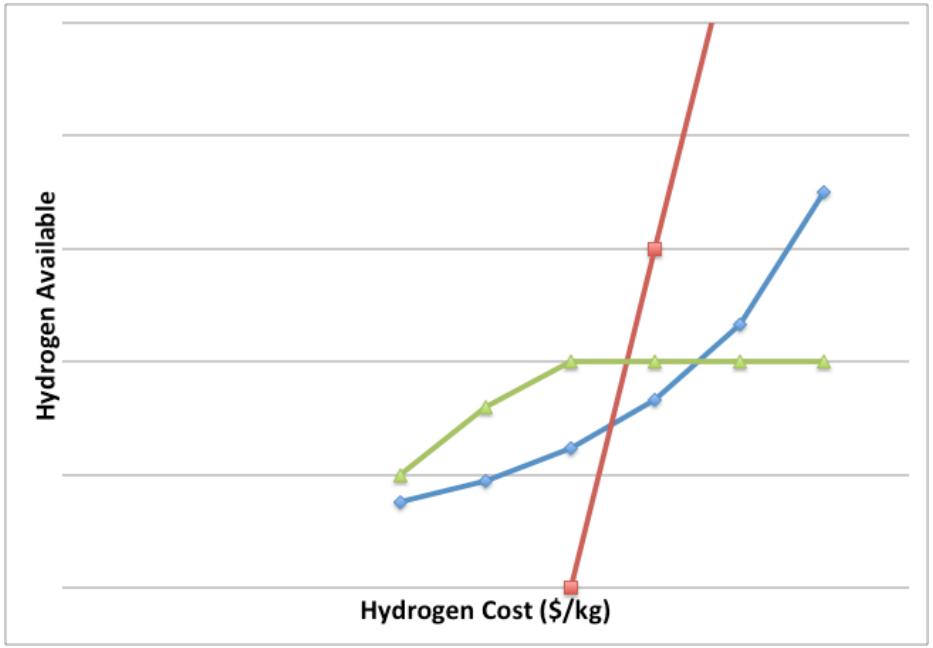
Price requirements and demand curves



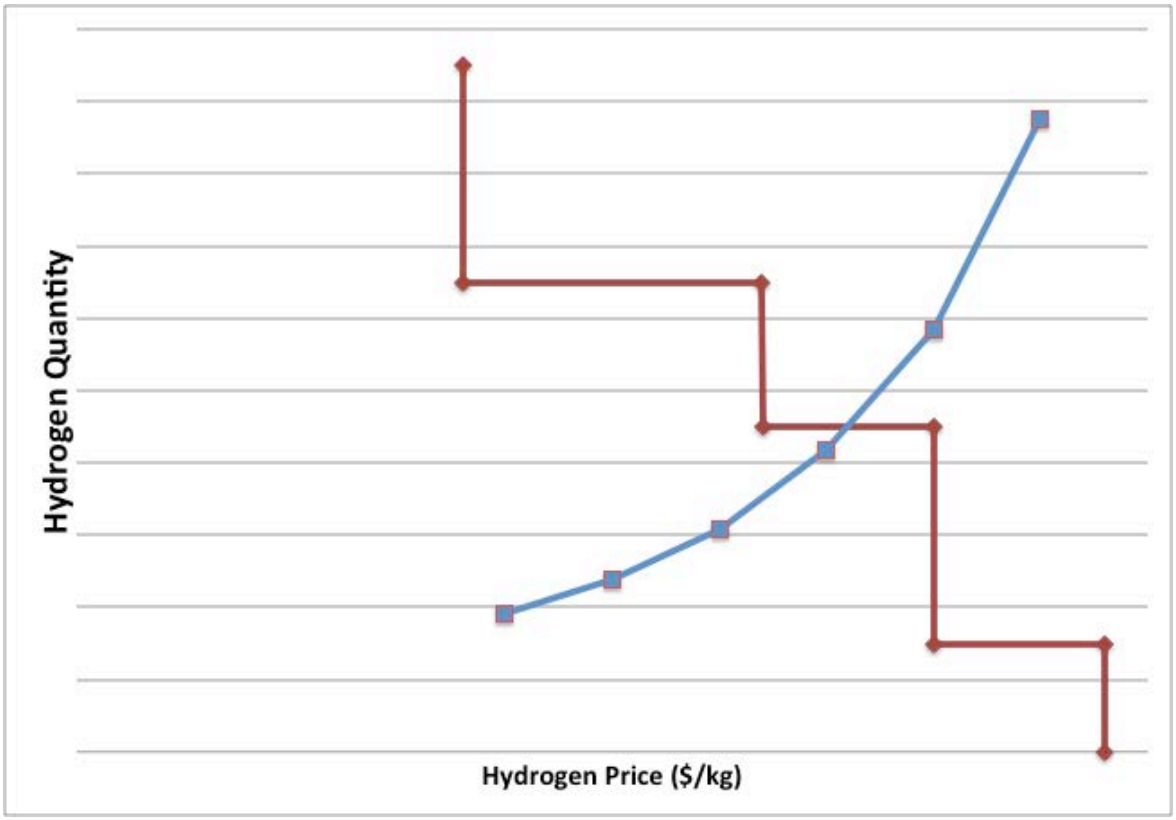
- Bottom-up demand estimates
- Technical, inertia, and resource constraints
- Includes demand aggregation to avoid double counting

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

In-Depth: Impact Analysis

Building off Renewable Portfolio Standard Analysis

- 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
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

Additional Analysis Needs

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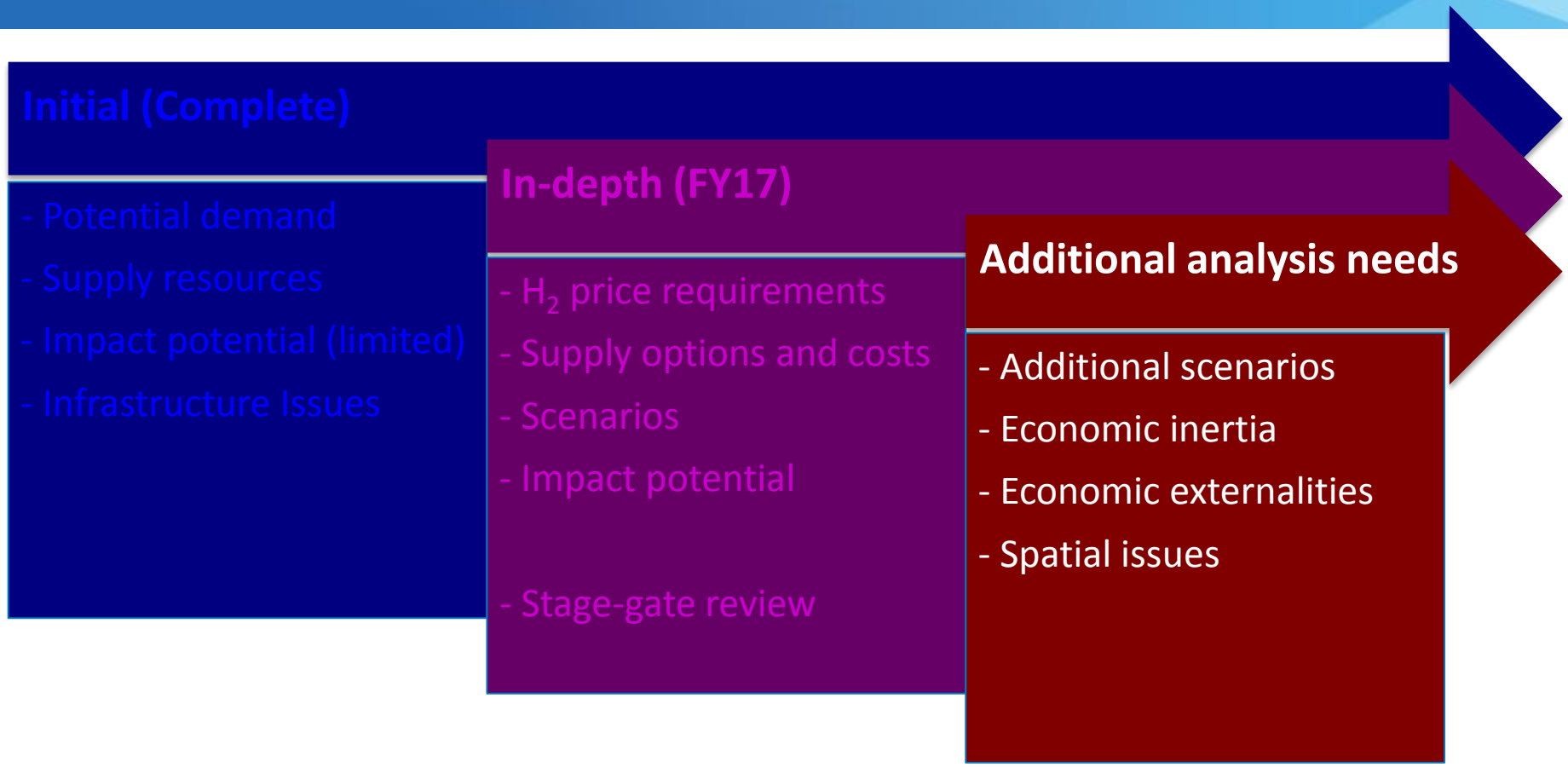

- FY18 efforts based on feedback from stage-gate review
- Potential opportunities
  - Additional demands or supply options
  - Improved understanding of economic inertia
  - Impact on macro-economics and feedback loops
  - Regional and spatial issues

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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