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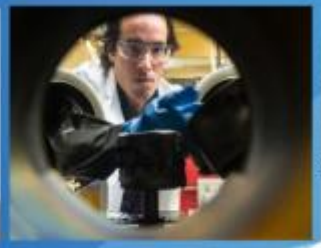
1977 – 2017


H2@Scale Resource and Market Analysis

Hydrogen and Fuel Cell Technical Advisory Committee Meeting

Washington, D.C.

Mark Ruth

May 4, 2017

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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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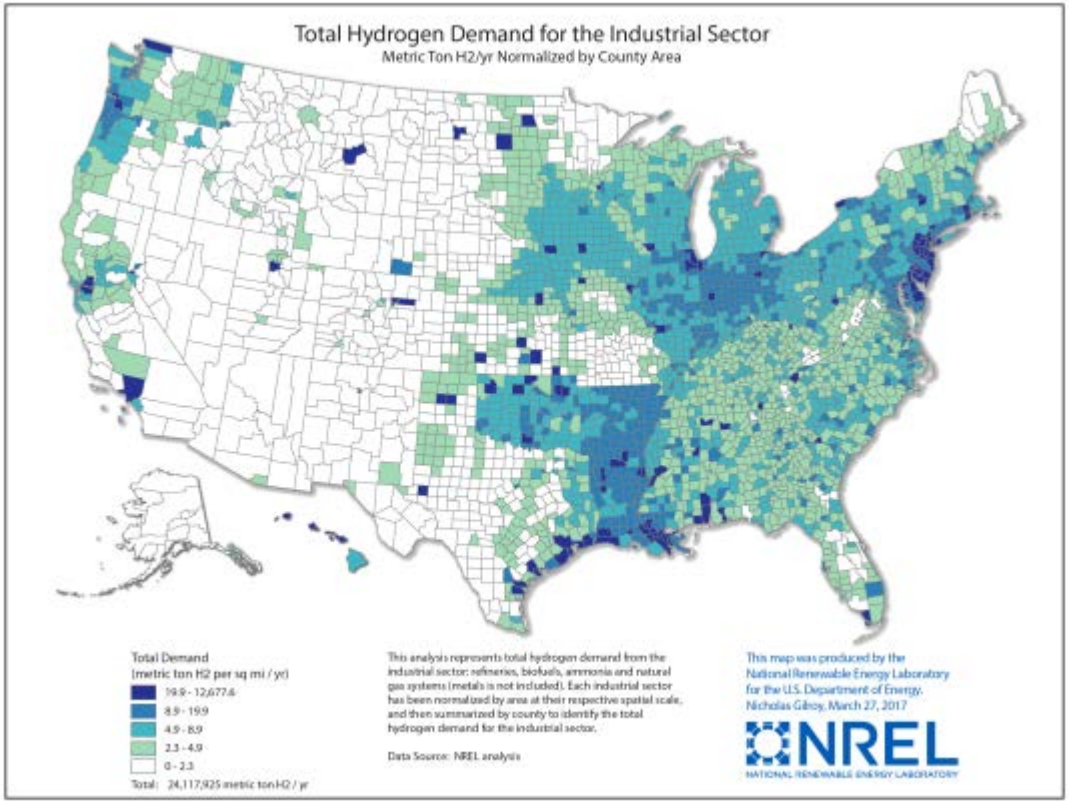
Initial Analysis: U.S. Hydrogen Demand Potential



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

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

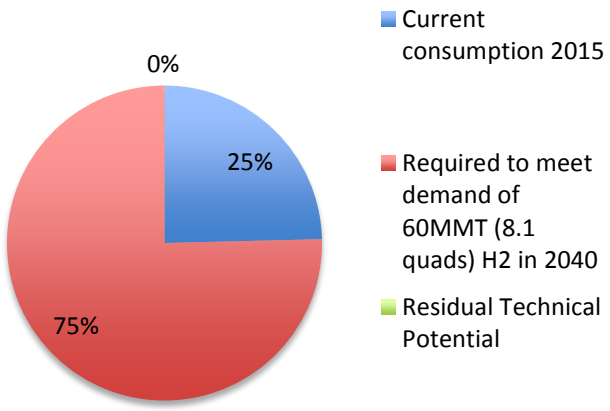
Light duty vehicle calculation basis: 190,000,000 light-duty FCEVs from http://www.nap.edu/catalog/18264/transitions-to-alternative-vehicles-and-fuels

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

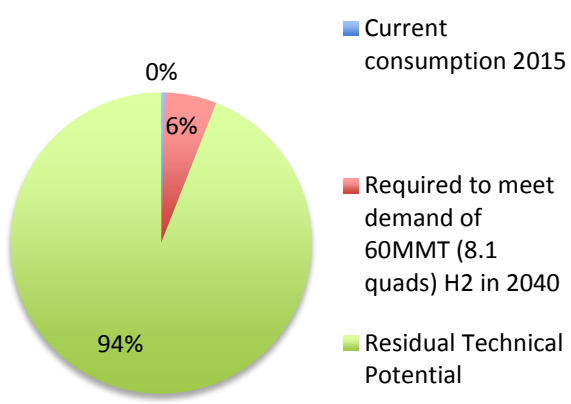
Initial Analysis: Resource Availability for Hydrogen

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

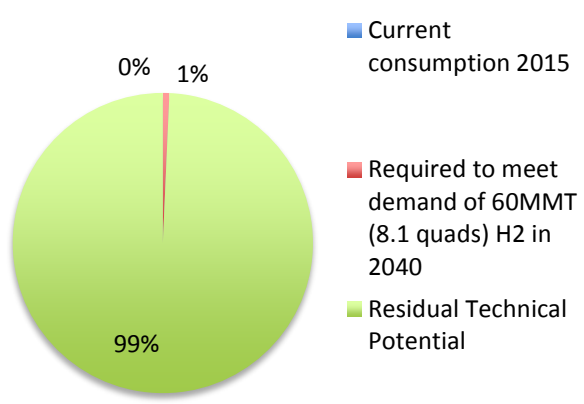
Biomass Technical Potential (quads/yr)



Wind Technical Potential (quads/yr)

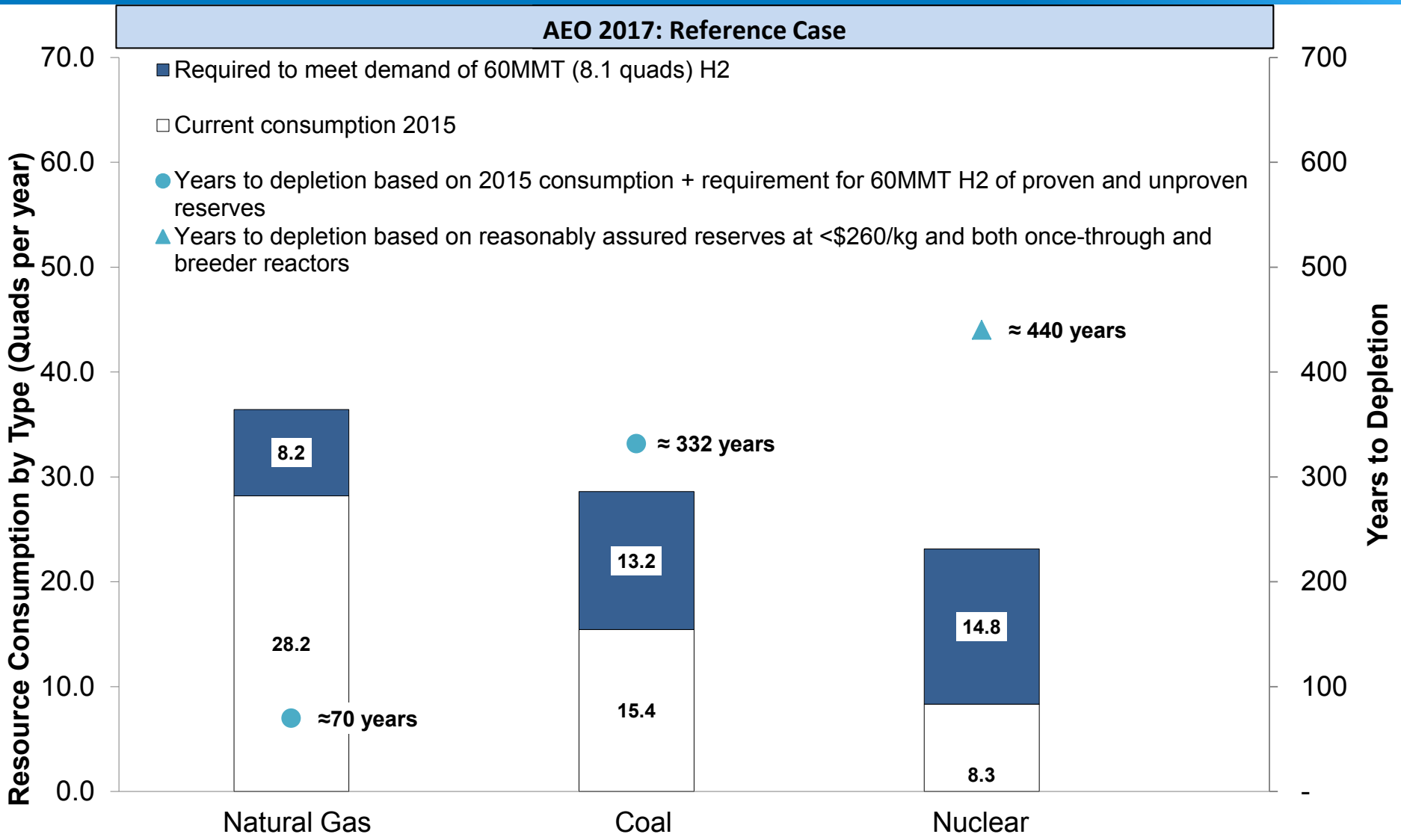


Solar Technical Potential (quads/yr)



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

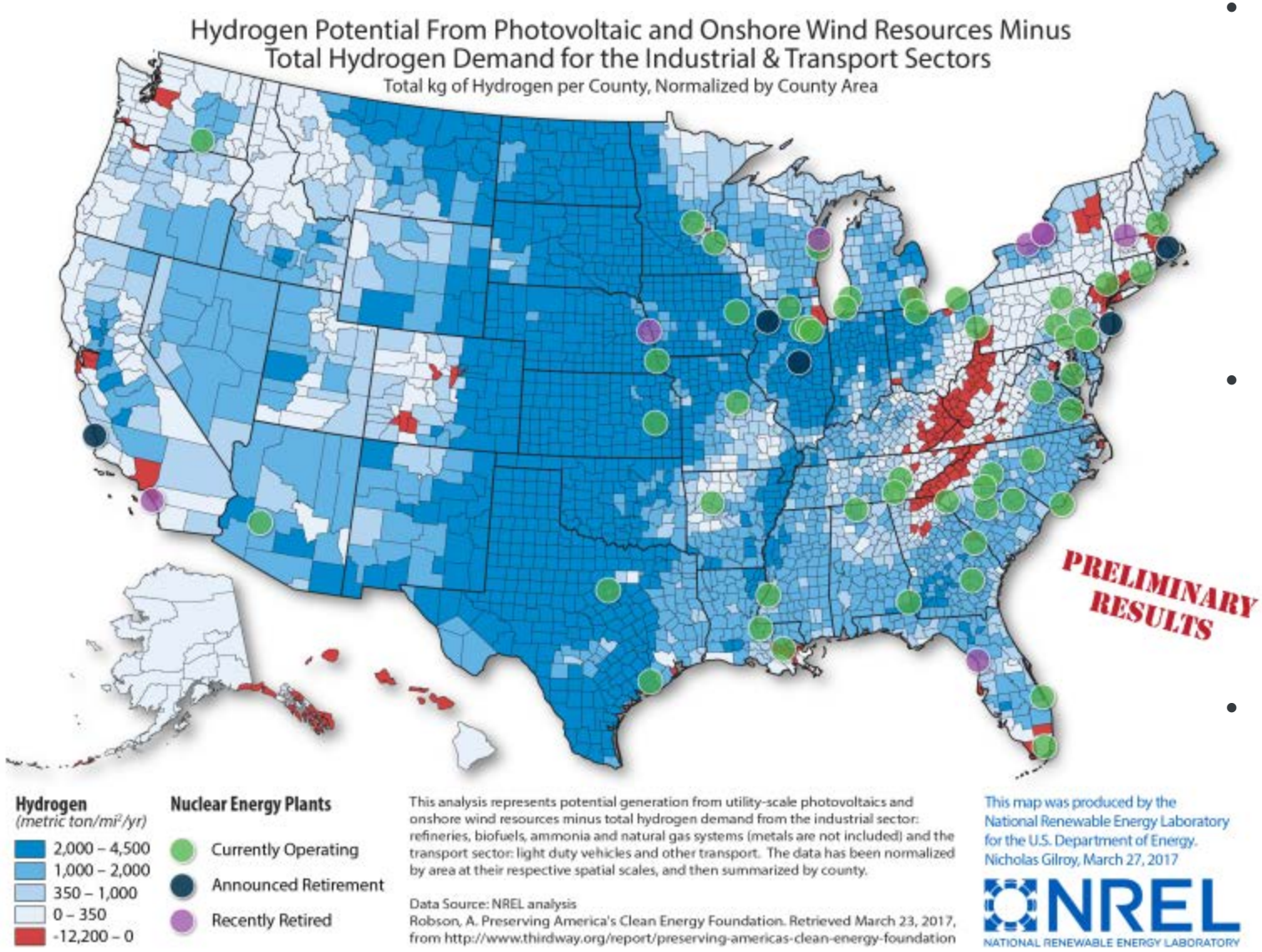
~14% of U.S. natural gas consumption in 2016

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



- 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*

~85% of current U.S. electricity demand

*2015 consumption. Source: EIA AEO 2016

In-Depth Analysis

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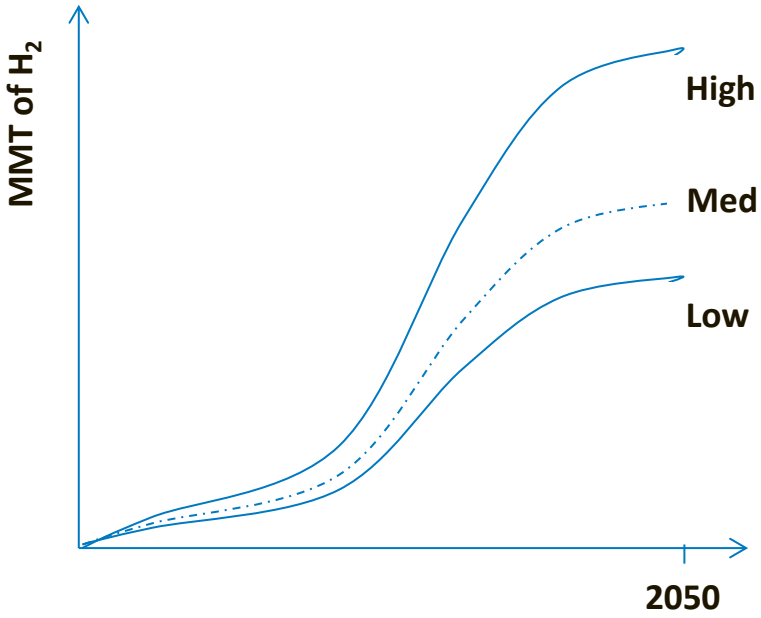
In-Depth: Price Requirements & Supply Options (Underway)

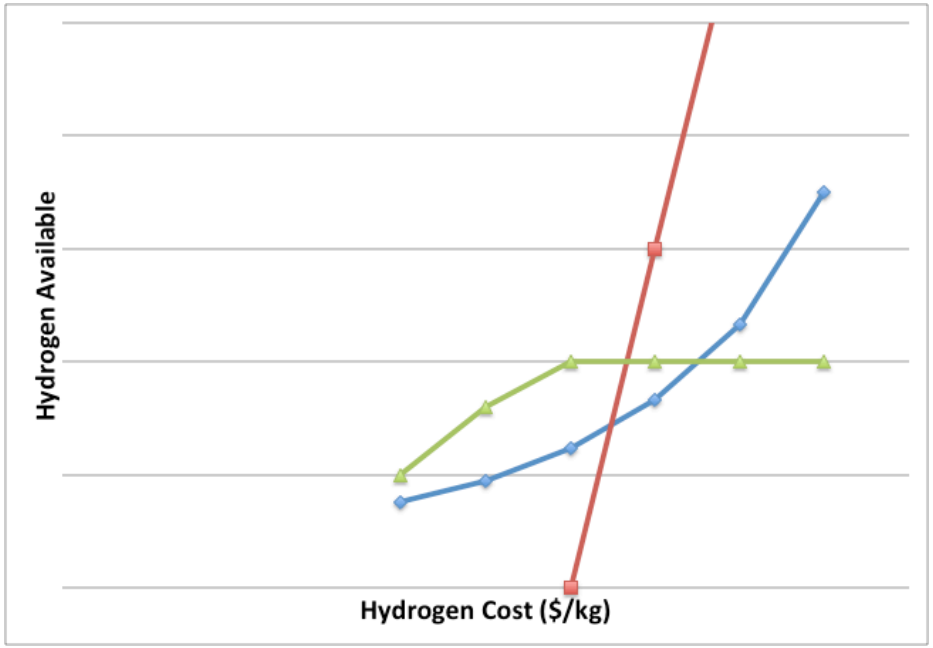
Price requirements and demand curves



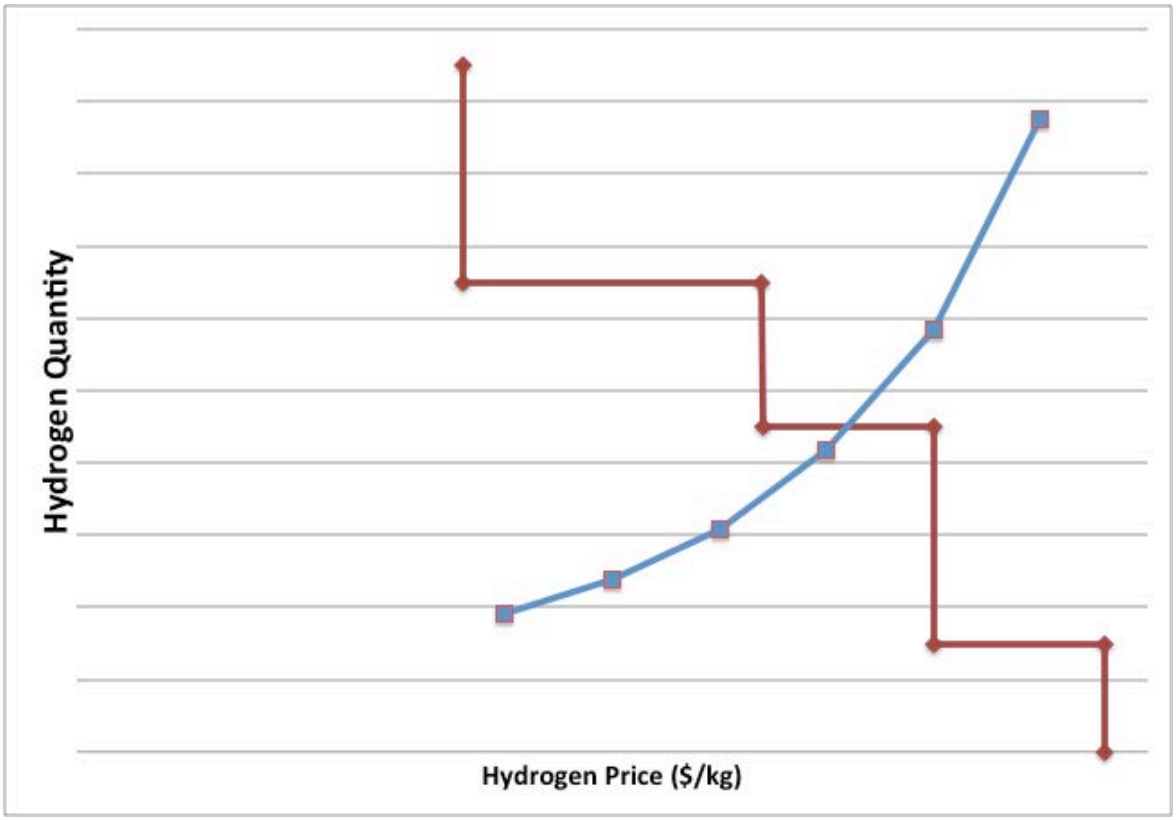
- Bottom-up demand estimates
- Technical, inertia, and resource constraints
- Includes demand aggregation to avoid double counting

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

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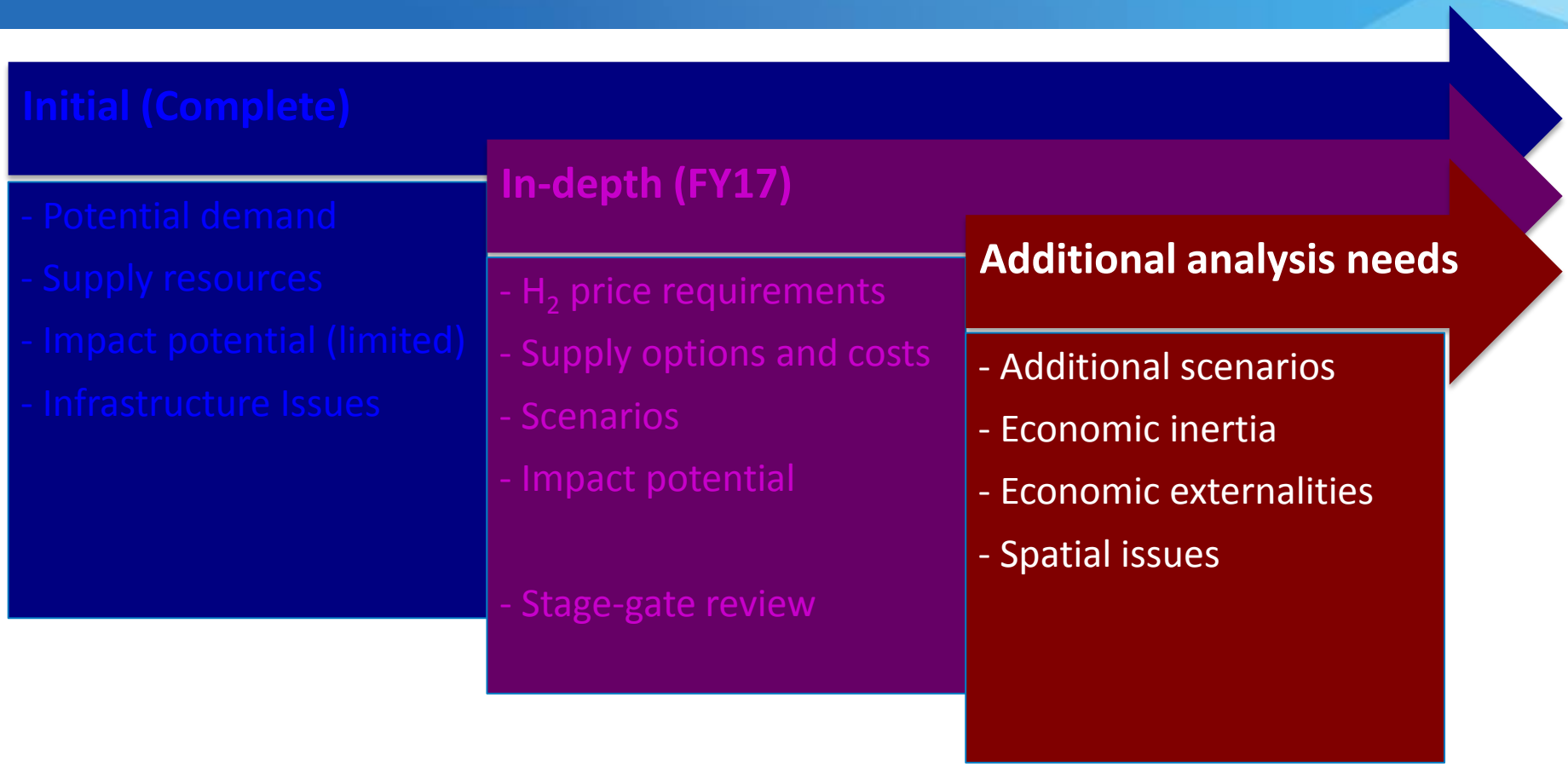

- FY18 efforts based on feedback from stage-gate review
- Potential opportunities
  - Additional demands or supply options
  - Improved understanding of economic inertia
  - Impact on macro-economics and feedback loops
  - Regional and spatial issues

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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