NREL
NATIONAL RENEWABLE ENERGY LABORATORY



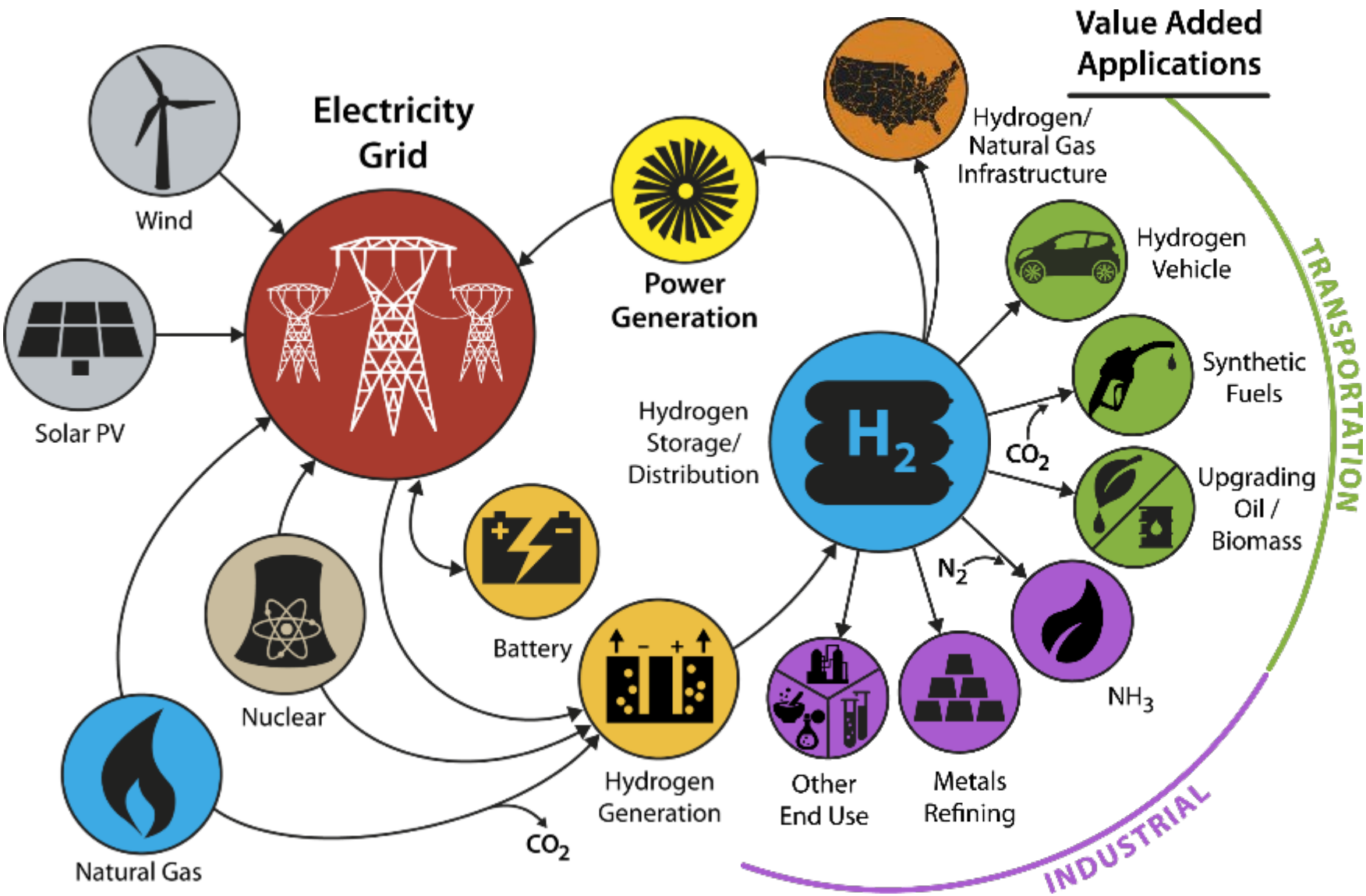


Hydrogen potential demand and renewable resources

Adapted from Mark Ruth's AMR presentation

UC Riverside Renewable Natural Gas Meeting
May 17, 2017

Conceptual H2@Scale Energy System*

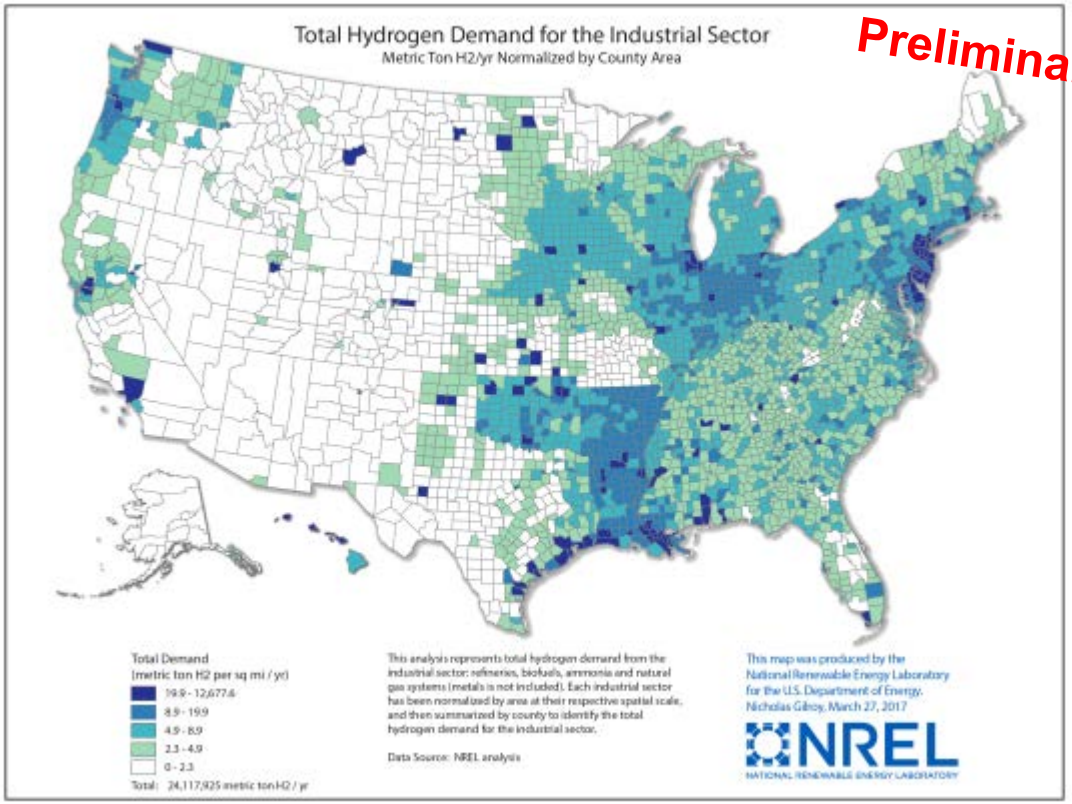


*Illustrative example, not comprehensive

H_2 Fun Facts

- **Are you surprised that H_2:**
  - Has 10 million metric tons of domestic production (gasoline, fertilizer)
  - This is 2% of US energy and is approximately equal to solar and wind combined.
  - Has over 1000 miles of pipelines in the US
  - Has been used in over 1000 fuel cell vehicles with several million miles of vehicle travel
  - Has fueling stations for vehicles open to the public in the US today

Technical Potential for H_2 Demand



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

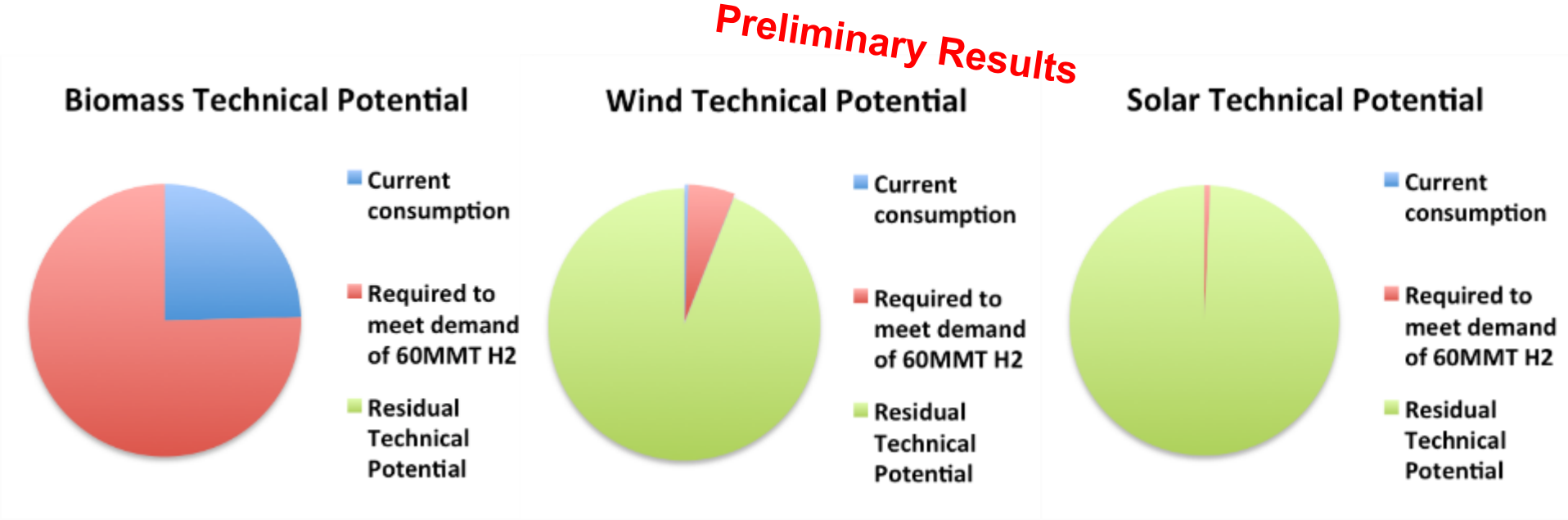
Light duty vehicle calculation basis: 190,000,000 light-duty FCEVs from http://www.nap.edu/catalog/18264/transitions-to-alternative-vehicles-and-fuels

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

Utilization of Renewable Resources

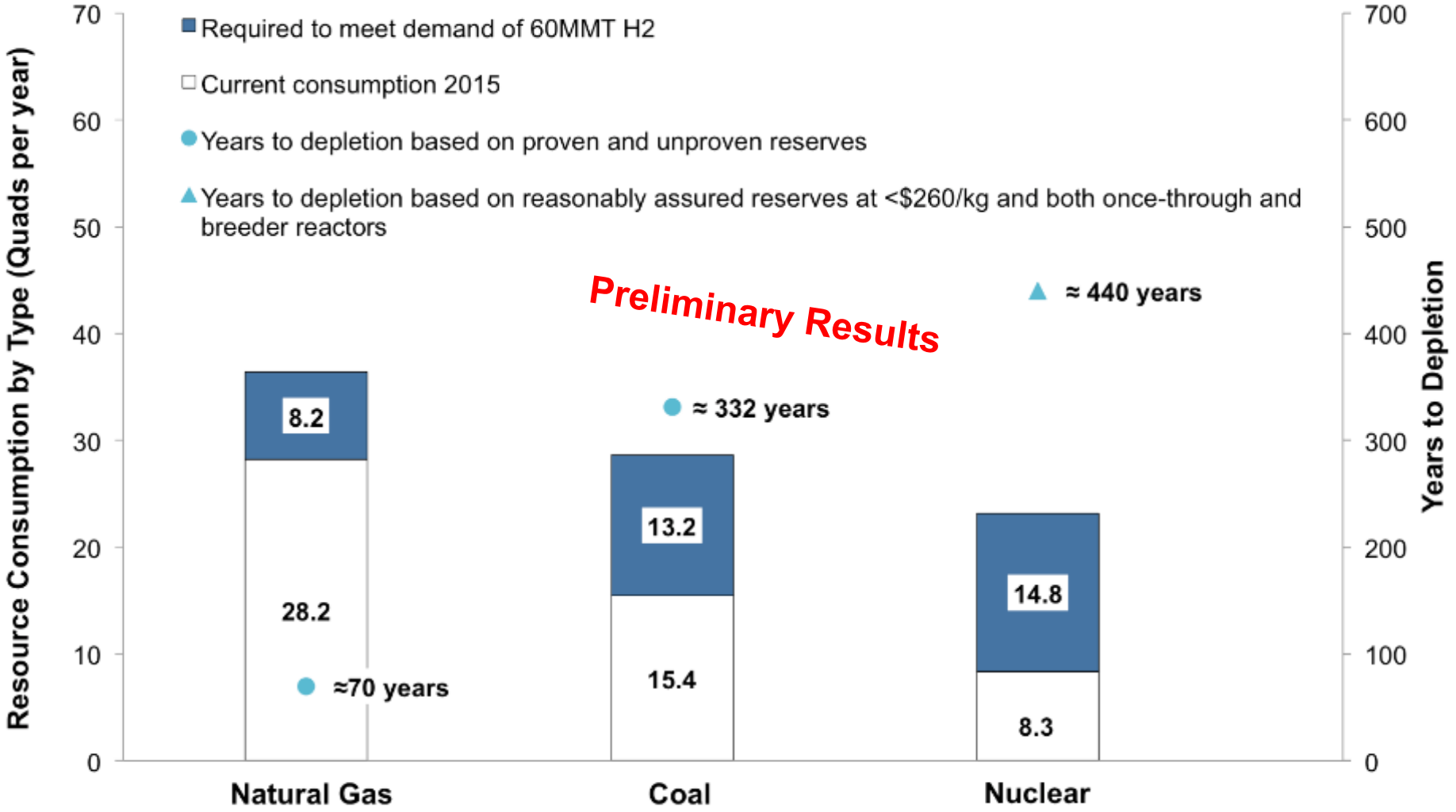
	EIA 2015 current consumption (quads/yr)	Required to meet demand of 60 MMT / yr (quads/yr)	Technical Potential (quads/yr)
Solid Biomass	4.7	15	20
Wind Electrolysis	0.7	9	170
Solar Electrolysis	0.1	9	1,364

Preliminary Results



Total demand including hydrogen is satisfied by ≈6% of wind, <1% of solar, and ≈100% of biomass technical potential

Utilization of Fossil & Nuclear Resources



Hydrogen can be produced from diverse domestic resources to meet aggressive growth in demand

Potential Impacts on Emissions and Resources

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	0	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 fertilizer production

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

Estimate of Impacts on 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?

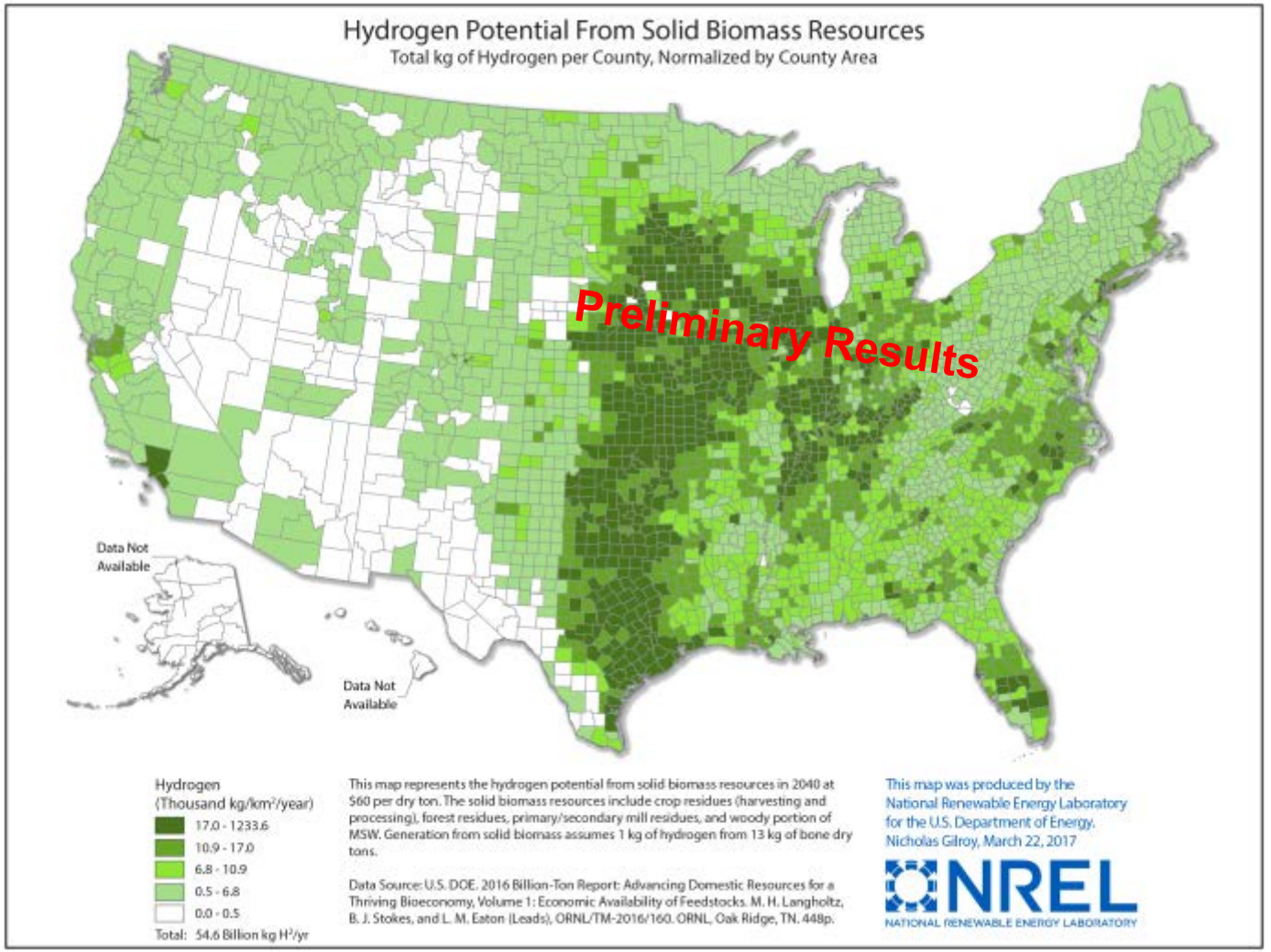
U.S. Electricity Consumption = Approximately 3,900 TWh per year*

Preliminary Results

~85% of current U.S. electricity demand

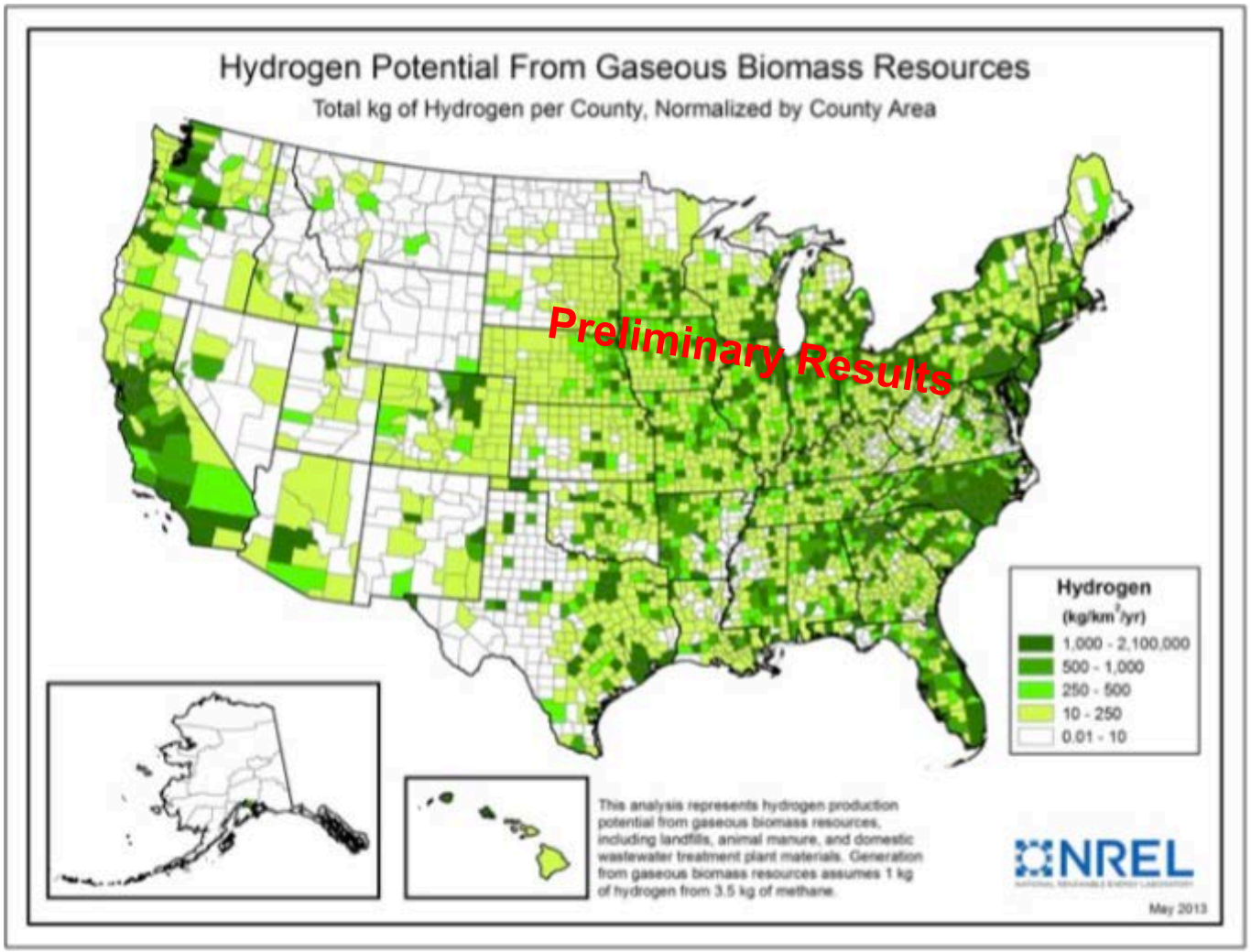
*2015 consumption. Source: EIA AEO 2016

Resource Locations: Solid Biomass



Based on Billion Ton Study (approximately 1.1 billion metric tonnes available)

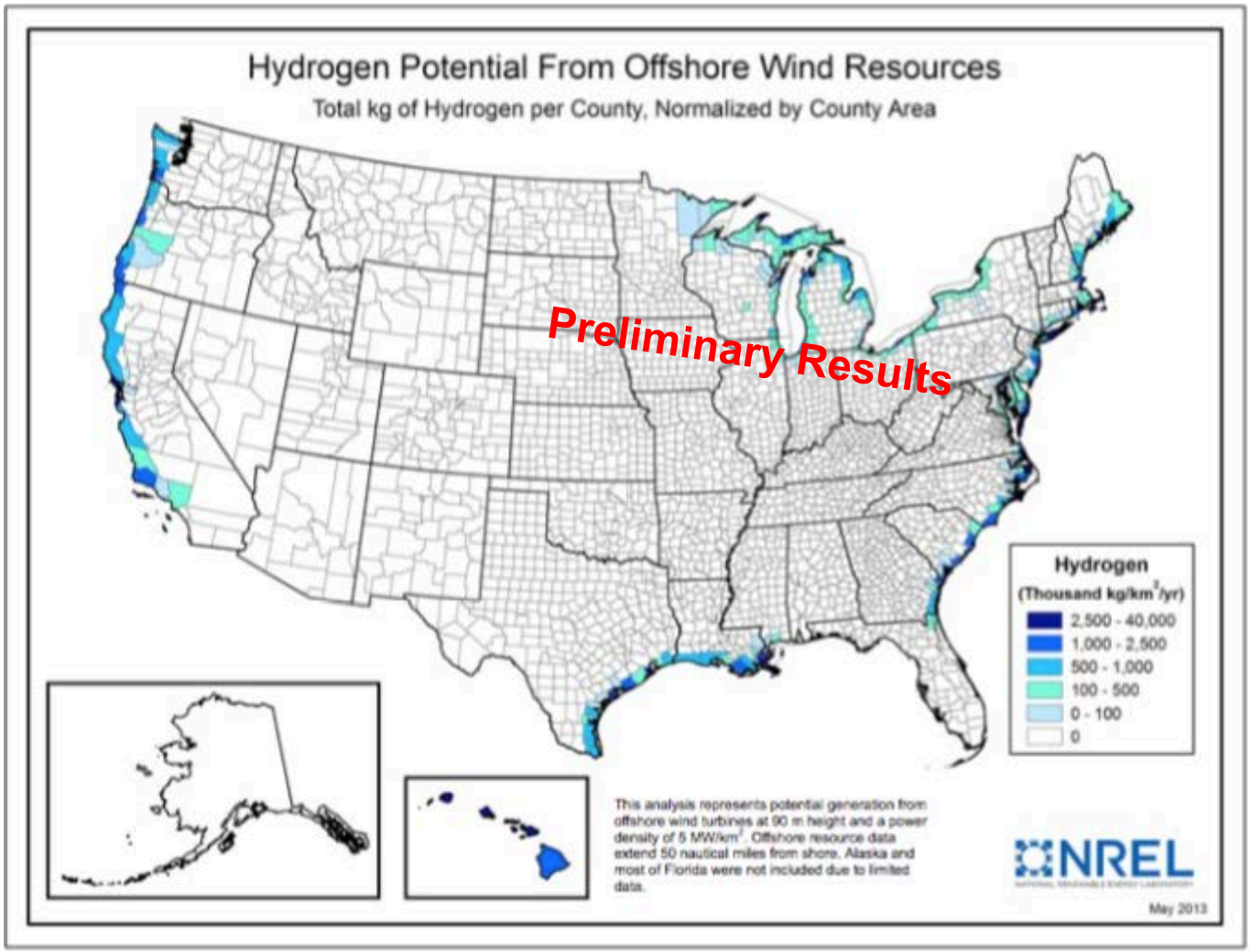
Resource Locations: Biogas



Map from Melaina (2013)

Biogas is not included in the resource calculation above

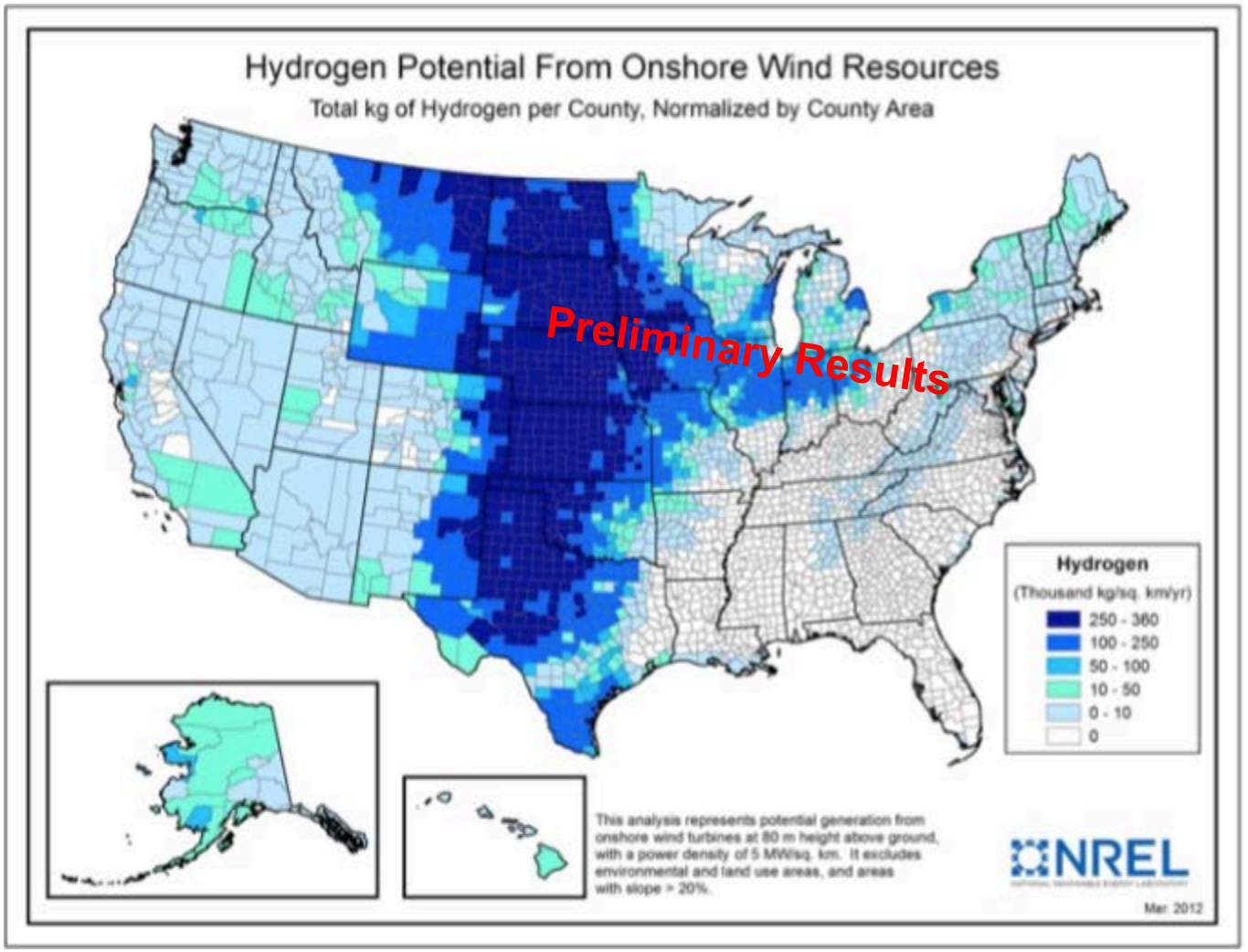
Resource Locations: Offshore Wind



Map from Melaina (2013)

Resource calculations include both on and offshore wind

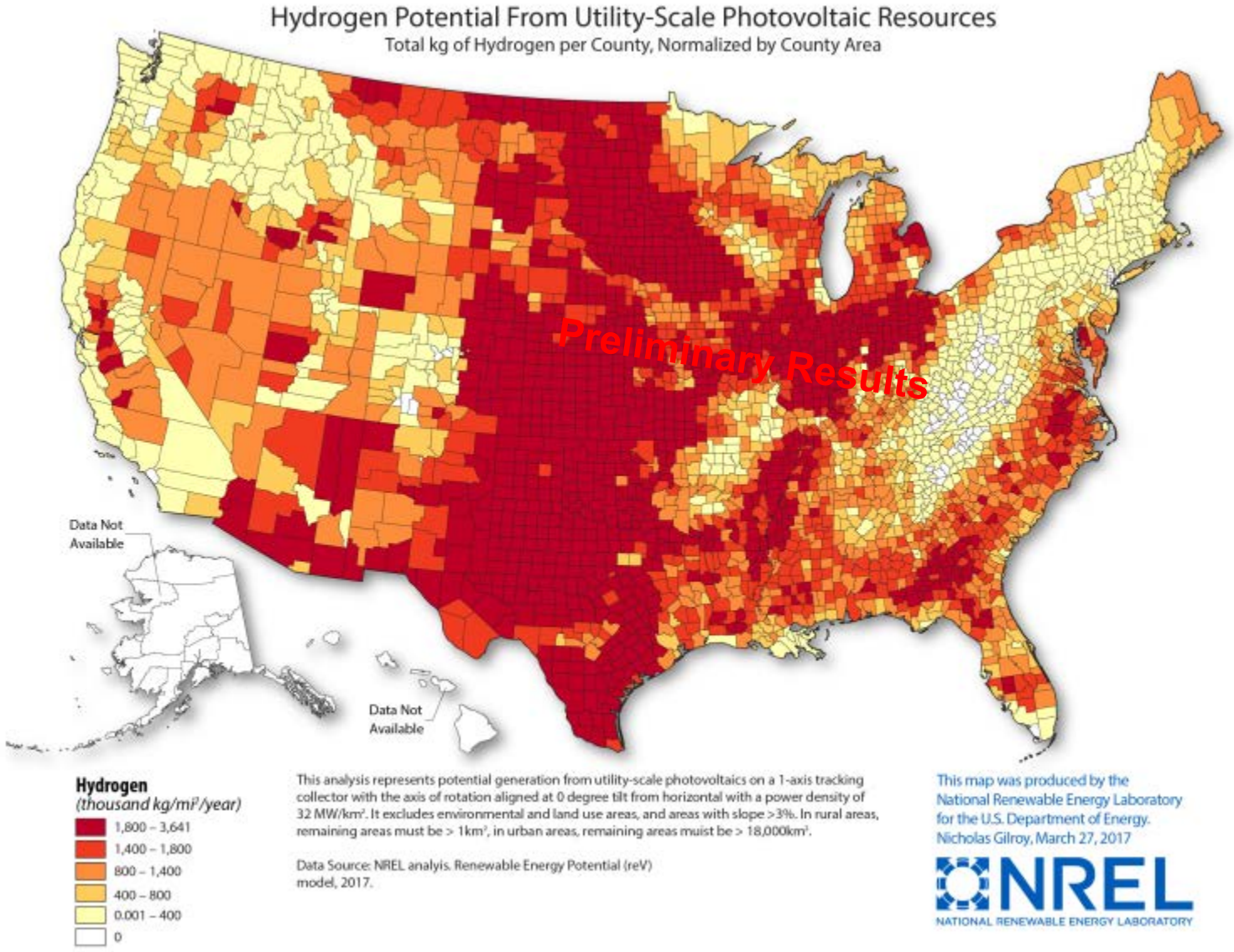
Resource Locations: Onshore Wind



Map from Melaina (2013)

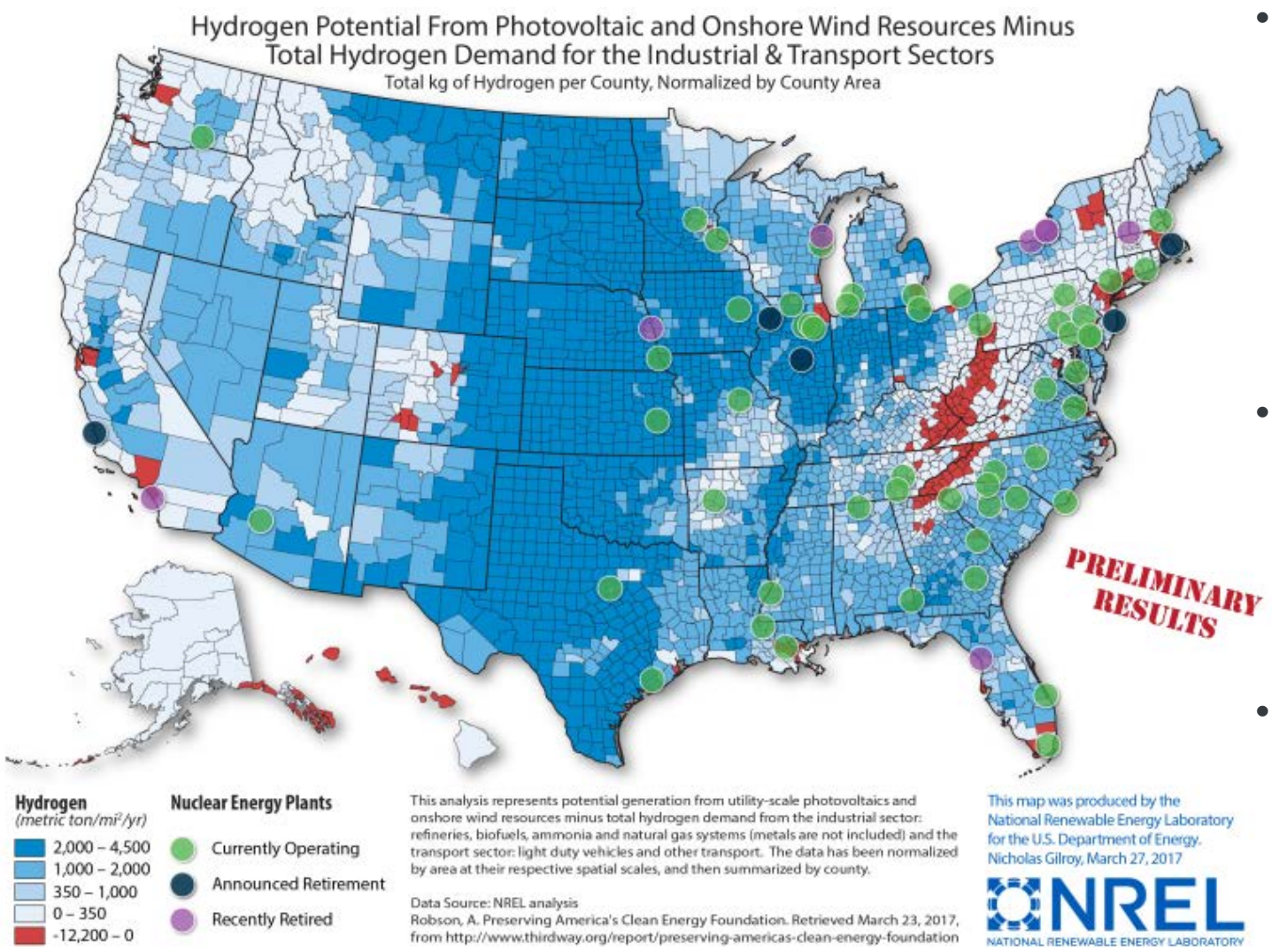
Resource calculations include both on and offshore wind

Resource Locations: PV



Total utility-scale PV (shown here) is 285,000 TWh/yr. An additional 820,000 TWh/yr rooftop PV and 116 of the total potential utility PV potential of 302,000 TWh/yr due to land area exclusions

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

Most counties have sufficient renewable resources. Those that do not have renewable or nuclear resources nearby.

Summary

- Technical potential demand = 60 MMT / yr
- Domestic resources are sufficient
- Using renewable electrolytic hydrogen would reduce emissions and fossil use by ≈15%
- Further reductions are likely when considering grid impacts
- Economic potential will be analyzed
- Future work includes barriers to market entry, regional and spatial issues, and economic feedback effects