
H₂

@Scale:

Energy system-wide
benefits of increased
H₂ implementation

Concept Overview & Preliminary Analysis

May 23, 2017

November 2016 Workshop Report available at
<http://www.nrel.gov/docs/fy17osti/68244.pdf>

H2@Scale webinar available at
<http://energy.gov/eere/fuelcells/downloads/h2-scale-potential-opportunity-webinar>



Energy System Challenges

- **Evolving multi-sector requirements**

- Transportation
- Industrial
- Electricity

U.S. uses 3700 TWh electricity and 7.2 billion barrels oil annually

Air pollution causes 200,000 premature deaths annually in the U.S.

Over 6 million Americans work in the energy sector

How do we supply all these services in the most beneficial manner?

U.S. oil Imports in 2016 > \$100 billion

Electricity Use: AEO 2016

Oil Use: <https://www.eia.gov/tools/faqs/faq.php?id=33&t=6>

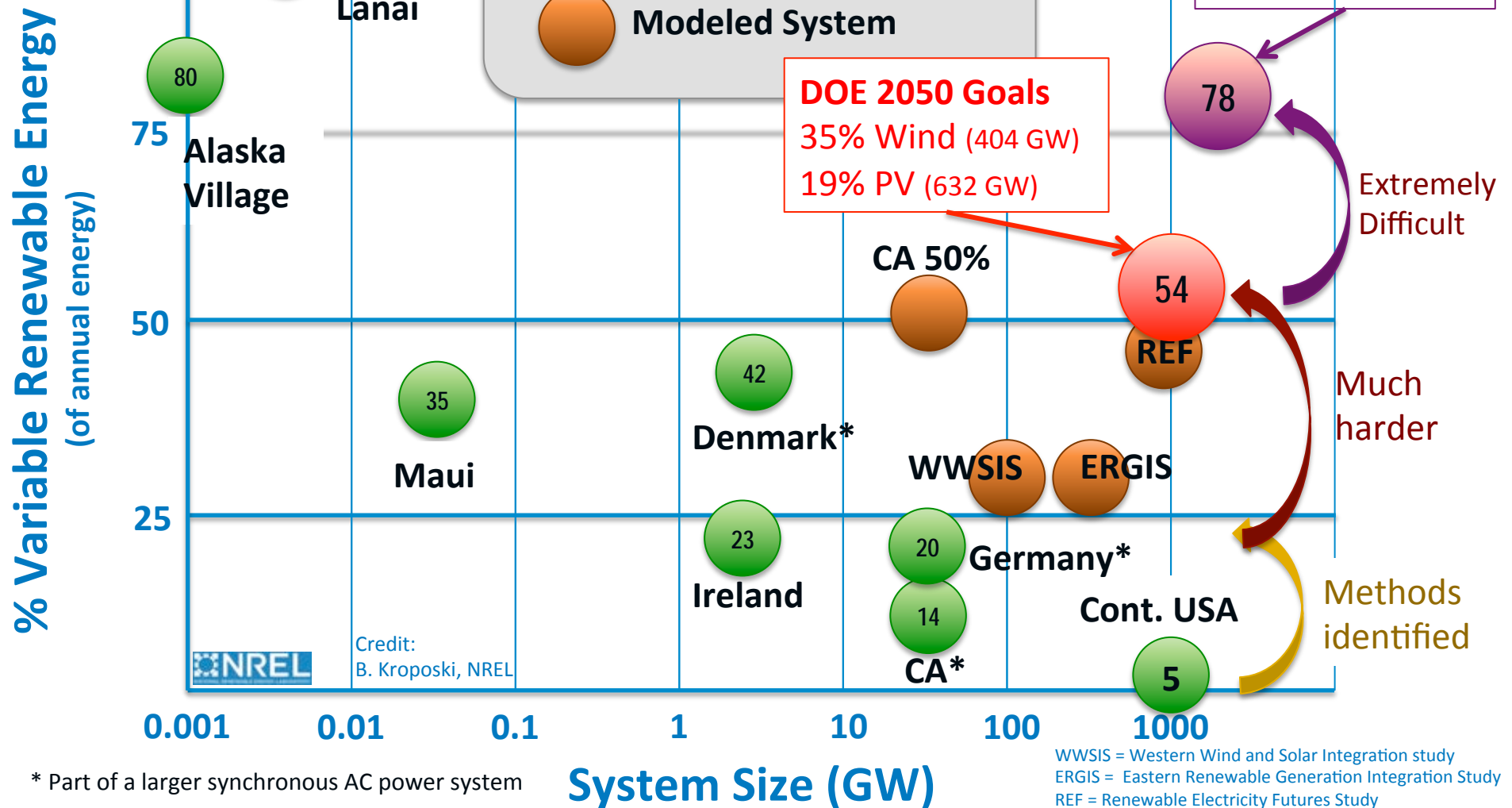
Oil import costs: <https://www.census.gov/foreign-trade/statistics/historical/petr.txt>

Energy Sector Jobs: https://energy.gov/sites/prod/files/2017/01/f34/2017%20US%20Energy%20and%20Jobs%20Report_0.pdf

Air pollution deaths: Fabio Caiazzo, Akshay Ashok, Ian A. Waitz, Steve H.L. Yim, Steven R.H. Barrett, Air pollution and early deaths in the United States. Part I: Quantifying the impact of major sectors in 2005, *Atmospheric Environment*, Volume 79, November 2013, Pages 198-208

Where is the Grid Headed? How Will It Get There?

Note: % VRE in 2015



* Part of a larger synchronous AC power system

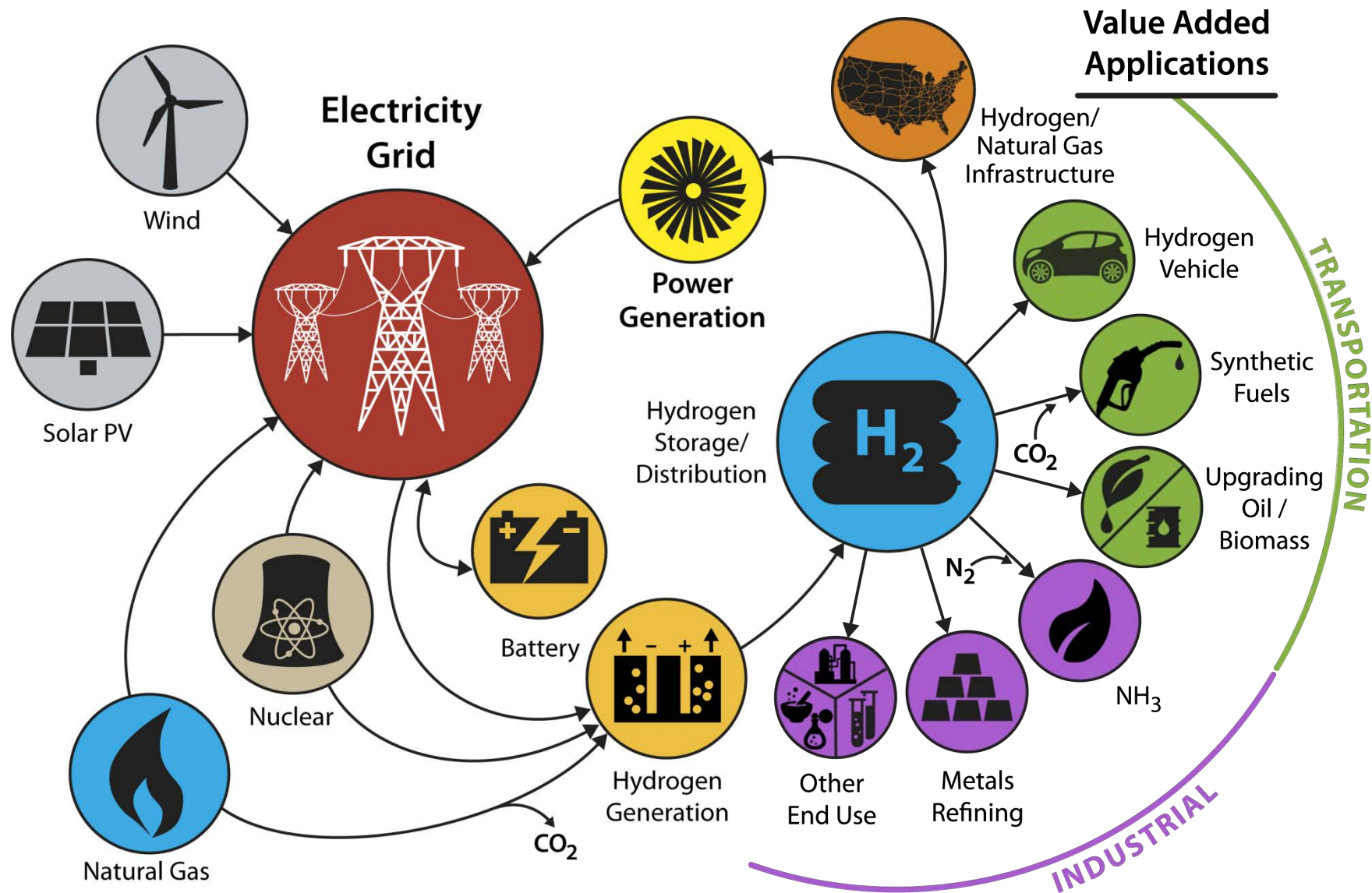
**"If you can't solve a problem,
enlarge it"**



President Dwight D. Eisenhower

Source: https://www.whitehouse.gov/sites/whitehouse.gov/files/images/first-family/34_dwight_d_eisenhower%5B1%5D.jpg

Conceptual H₂ at Scale Energy System*



*Illustrative example, not comprehensive

H2@Scale Vision

- **Attributes**

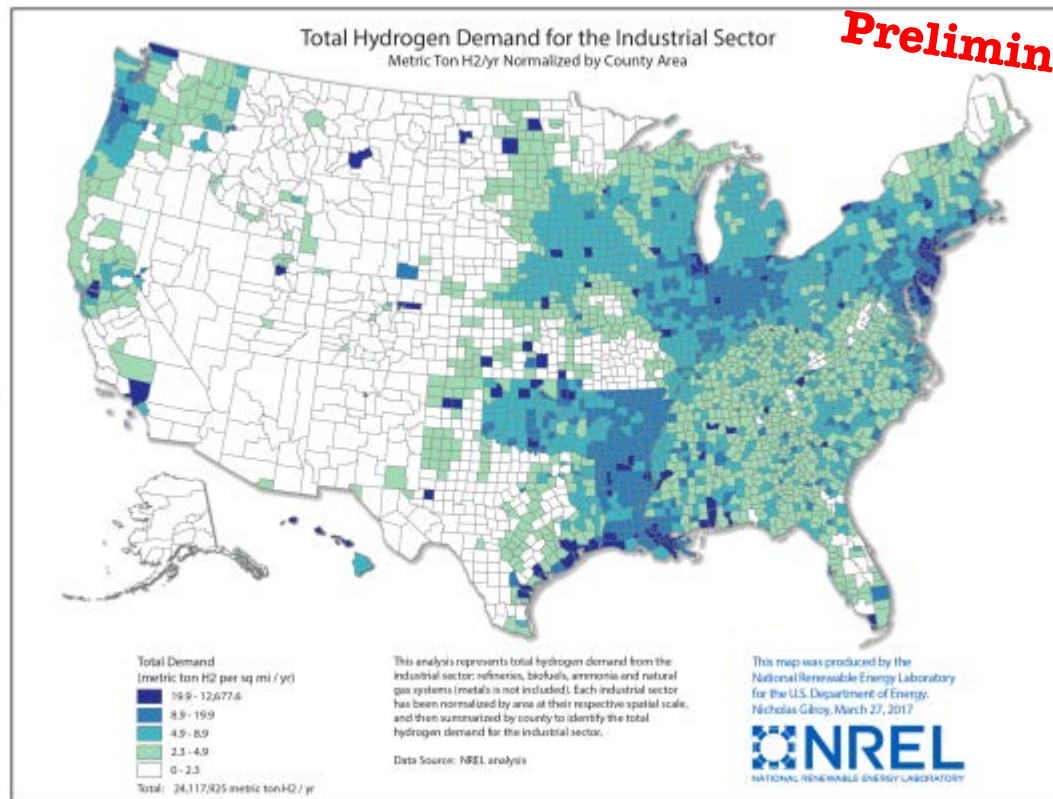
- Large-scale, clean, energy-carrying intermediate for use across energy sectors
- Increased penetration of variable renewable power and nuclear generation
- Improved economics of thermal power generation (nuclear, CSP, geothermal) through hybridization
- Increased H2 from methane (carbon capture/use potential)

- **Benefits**

- Increased energy sector jobs (GDP impact)
- Manufacturing competitiveness (low energy costs)
- Enhanced energy security (reduced imports, system flexibility/resiliency)
- Enhanced national security (domestic production (metals), local resources)
- Improved air(water) quality via reduced emissions (criteria pollutants, GHGs)
- Decreased energy system water requirements.

Getting all these benefits in a single energy system significantly enhances value proposition.

H₂ Demand Technical 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>

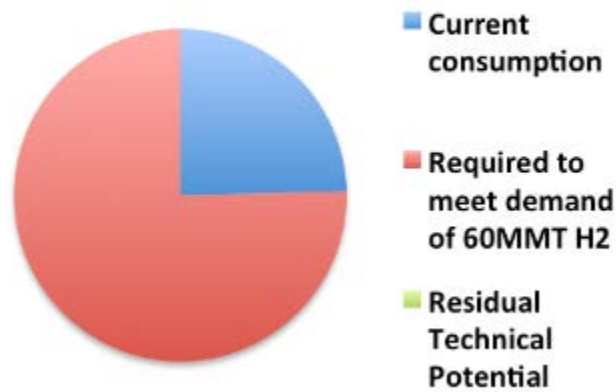
1. Global hydrogen Generation Market by Merchant & Captive Type, Distributed & Centralized Generation, Application & Technology- Trends & Forecasts (2011-2016)

Technical Potential Supply from Renewables

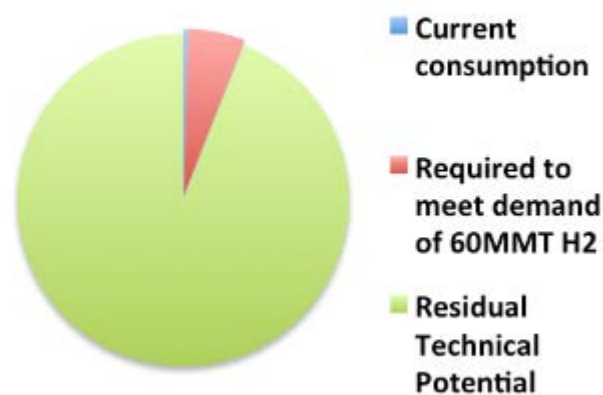
| | EIA 2015 current consumption (quads/yr) | Required to meet demand of 60 MMT / yr (quads/yr) | Technical Potential (quads/yr) |
|--------------------|---|---|--------------------------------|
| Solid Biomass | 4.7 | 15 | 20 |
| Wind Electrolysis | 0.7 | 9 | 170 |
| Solar Electrolysis | 0.1 | 9 | 1,364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

Preliminary Results

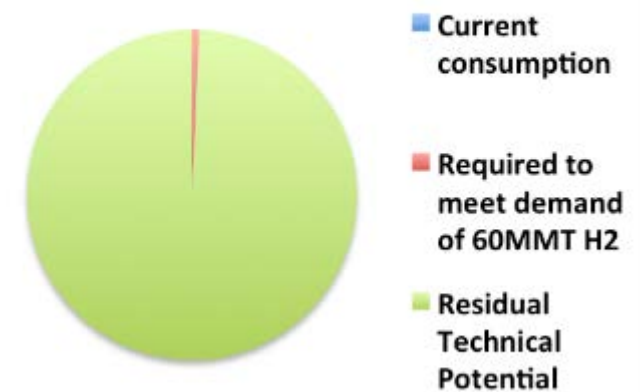
Biomass Technical Potential



Wind Technical Potential

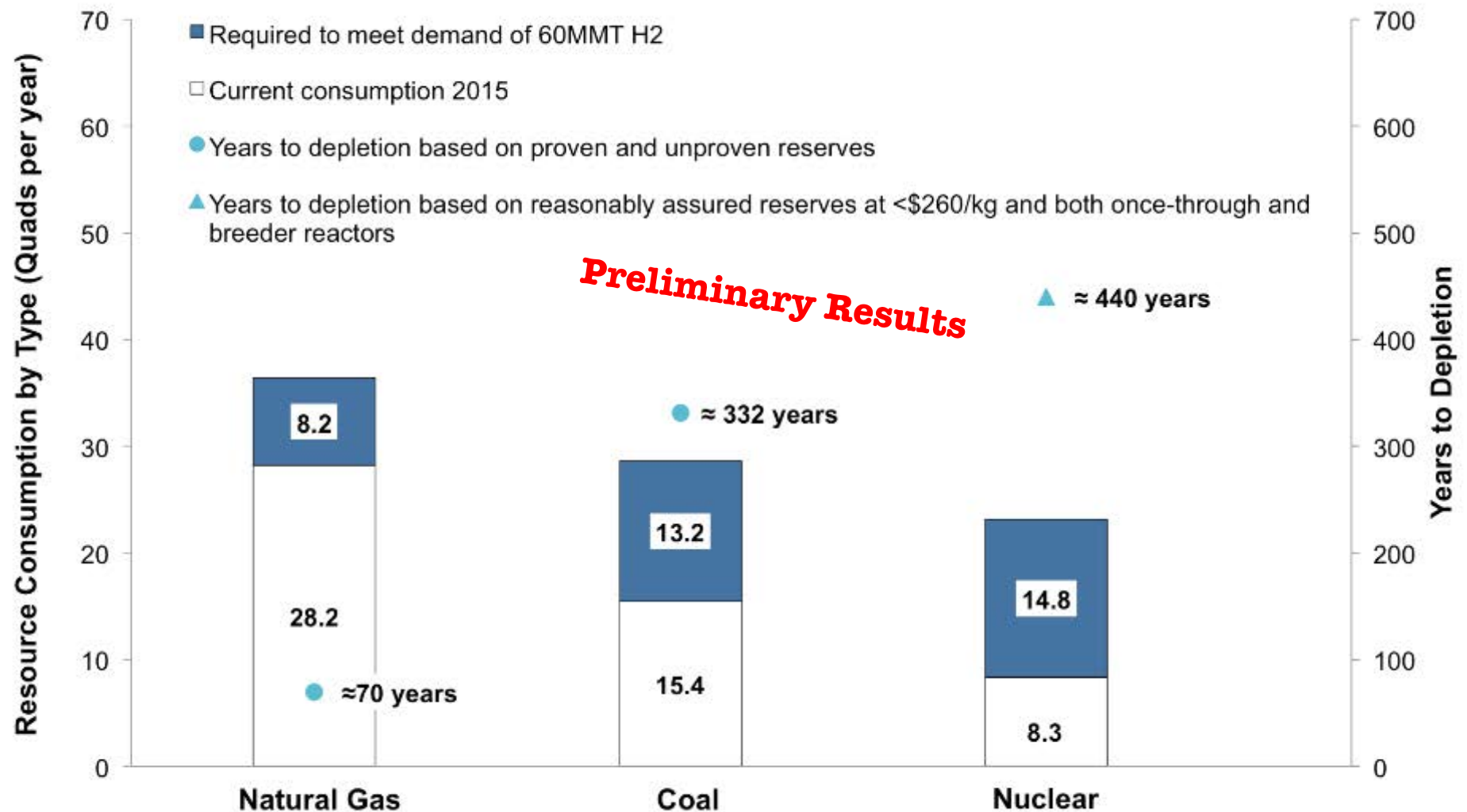


Solar Technical Potential



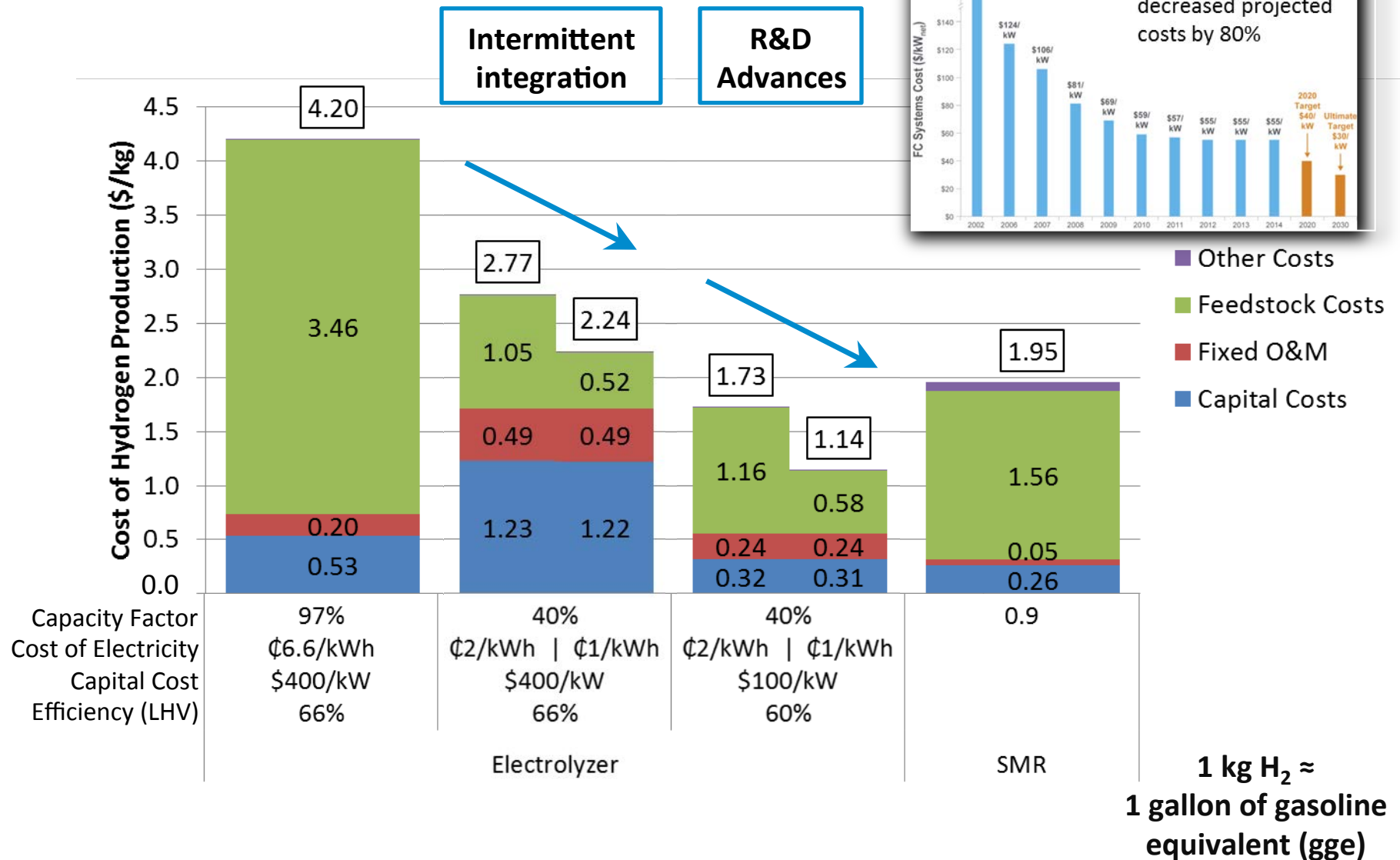
Total demand including hydrogen is satisfied by $\approx 6\%$ of wind, $<1\%$ of solar, and $\approx 100\%$ of biomass technical potential

Potential Supply from Fossil & Nuclear Resources

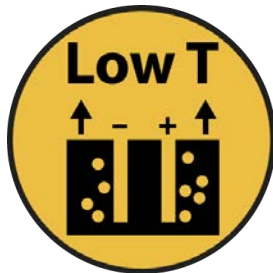


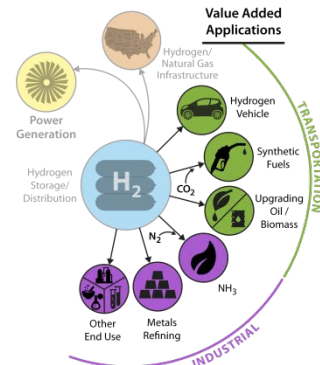


Hydrogen can be produced from diverse domestic resources to meet aggressive growth in demand

Improving the Economics of Electrolytic H₂



What is needed to achieve H₂ at Scale?

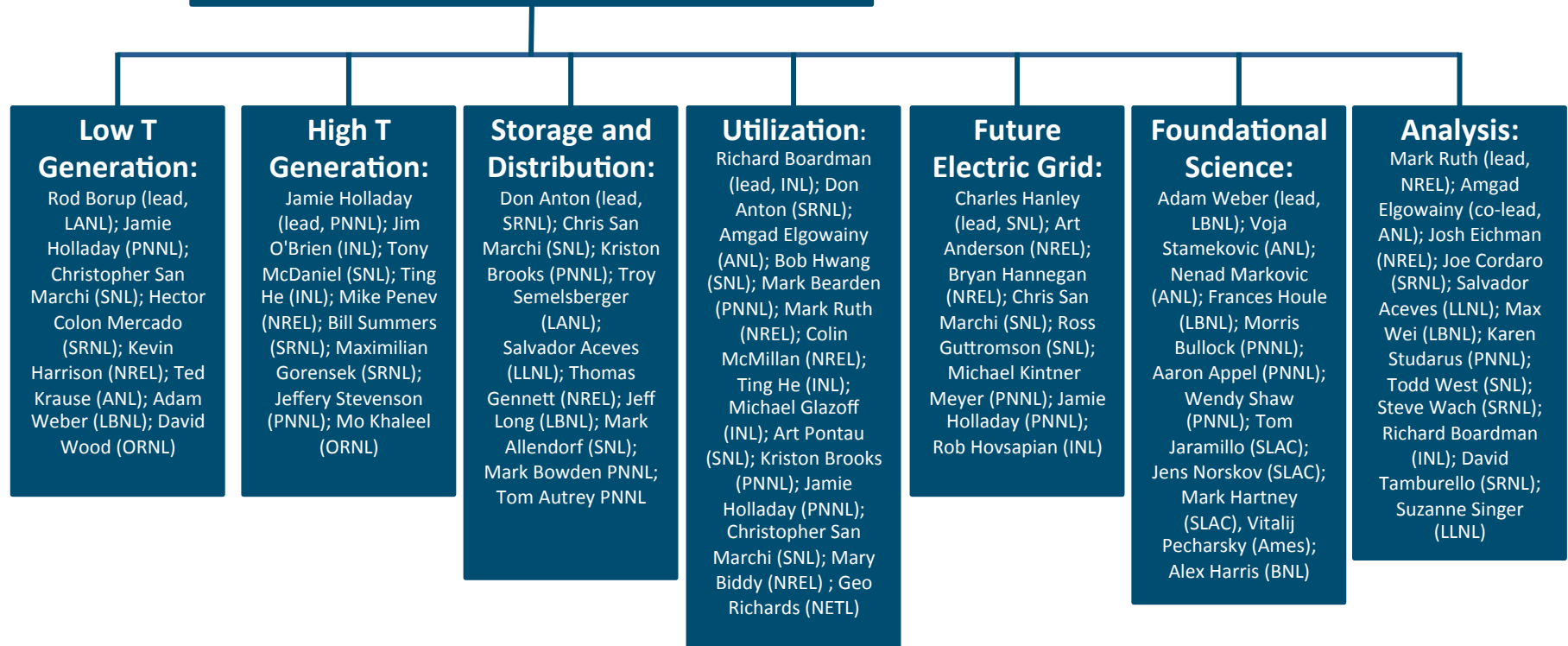
| Low and High Temperature H ₂ Generation | | H ₂ Storage and Distribution | H ₂ Utilization |
|---|---|---|--|
|  |  |  |  |
| Development of low cost, durable, and intermittent H₂ generation. | | Development of thermally integrated, low cost, durable, and variable H₂ generation. | Development of safe, reliable, and economic storage and distribution systems. |
| H ₂ as game-changing energy carrier, revolutionizing energy sectors. | | | |
| Analysis | | | |
| Foundational Science | | | |
| Future Electrical Grid | | | |

H₂@Scale Big Idea National Laboratory Team

Steering Committee:

Bryan Pivovar (lead, NREL), Amgad Elgowainy (ANL), Richard Boardman (INL), Shannon Bragg-Sitton (INL); Adam Weber (LBNL), Rod Borup (LANL), Mark Ruth (NREL), Jamie Holladay (PNNL), Chris Moen (SNL), Don Anton (SRNL)

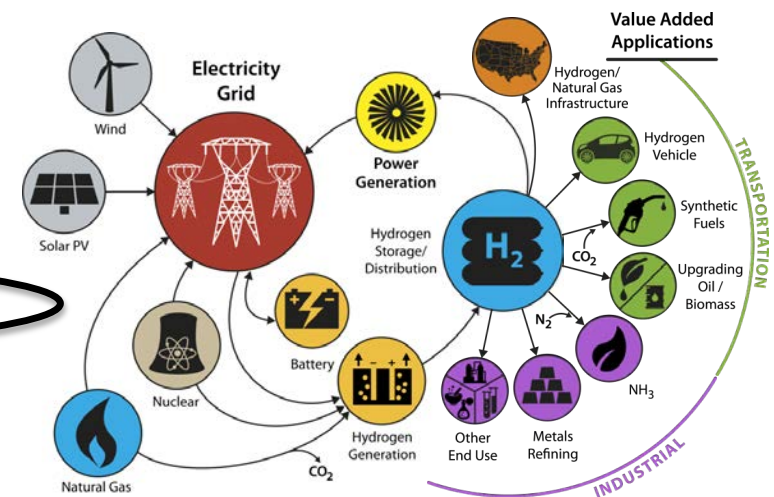
H2@Scale has moved beyond this National Lab team to include DOE offices, and industrial/other stakeholders.



H2@Scale Involves Many Stakeholders

- Nuclear
- Wind
- Solar
- Fossil
- Grid/Utilities
- Electrolysis
- Industrial Gas
- Auto OEMs/supply chain
- Fuels Production (Oil, Biomass)
- Metals/Steel
- Ammonia
- Regulators
- Analysis
- Investors

Blue: High engagement and support
Green: Engaged with interest/support
Orange: Limited engagement
Black: Little engagement



Stakeholder groups presenting at this workshop are identified with ovals.

Motivation for Future Impact

27 September 2016 / GENEVA - A new WHO air quality model confirms that 92% of the world's population lives in places where air quality levels exceed WHO limits.

More than half US population lives amid dangerous air pollution

<https://www.theguardian.com/environment/2016/apr/20/dangerous-air-pollution-us-population-report>



Credit: Warren Gretz – NREL Pix 07070.jpg



Credit: Bryan Pivovar

Energy and environmental challenges grow as the population grows and economies advance
H2@Scale would help meet challenges