H_2 @Scale:

Energy system-wide benefits of increased H_2 implementation

CaFCP Meeting

April 25, 2017

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

H2@Scale Workshop Report available at
http://www.nrel.gov/docs/fy17osti/68244.pdf

NREL · SLAC National Accelerator Laboratory · Brookhaven National Laboratory · The Ames Lab · Los Alamos National Laboratory · NETL · Pacific Northwest National Laboratory · INL Idaho National Laboratory · Argonne National Laboratory · SRNL · Oak Ridge National Laboratory · Sandia National Laboratories · Lawrence Livermore National Laboratory · Berkeley Lab

Downtown Denver from NREL

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, report warns

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

Energy System Challenge

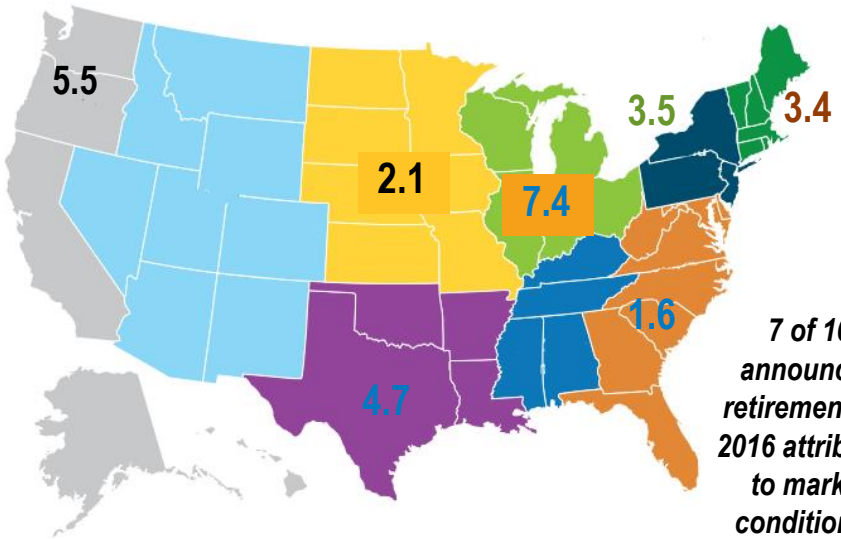
- **Multi-sector requirements**
  - Transportation
  - Industrial
  - Grid

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

Nuclear Energy Impacts

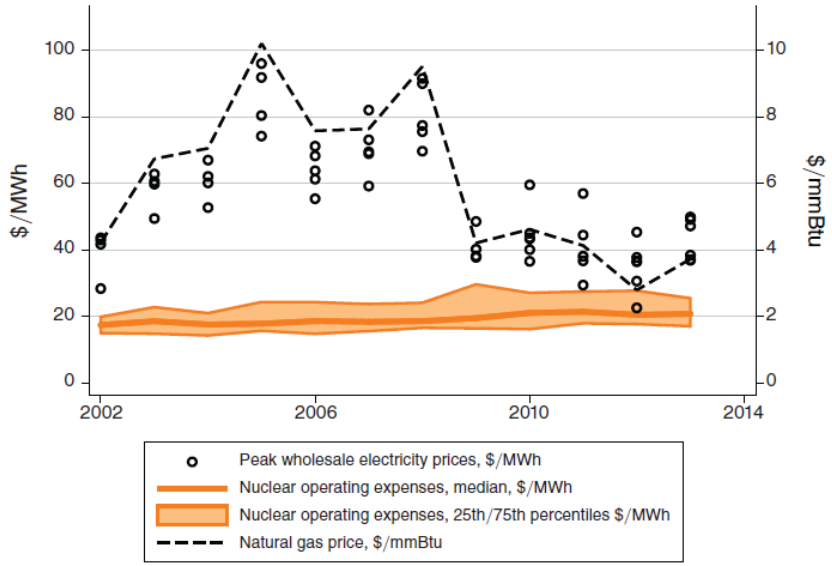
Nuclear Plants at Risk by 2030, or Recently Retired (GW) [1]

1. Source: U.S. DOE Quadrennial Energy Review, 01/2017



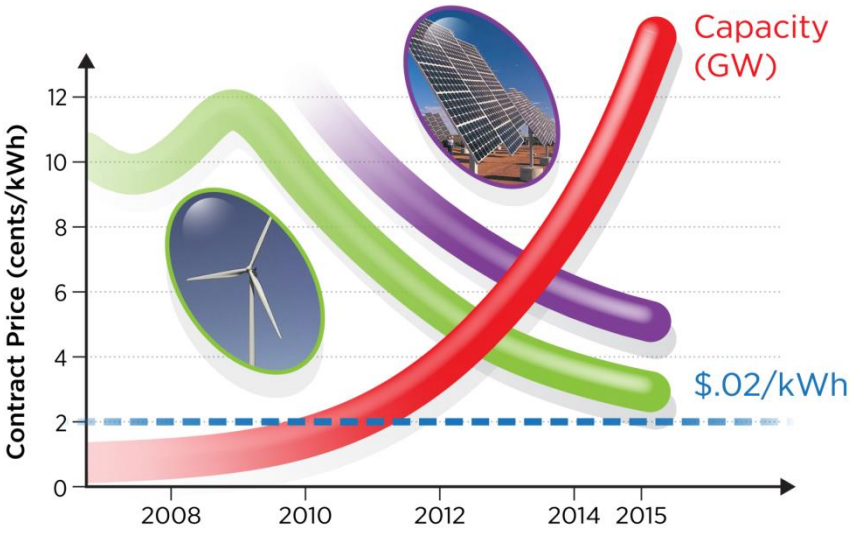
7 of 10 announced retirements in 2016 attributed to market conditions.[1]

Source: L. Davis and C. Hausman, American Economic Journal, Applied Economics, 2016
Market Impacts of a Nuclear Power Plant Closure



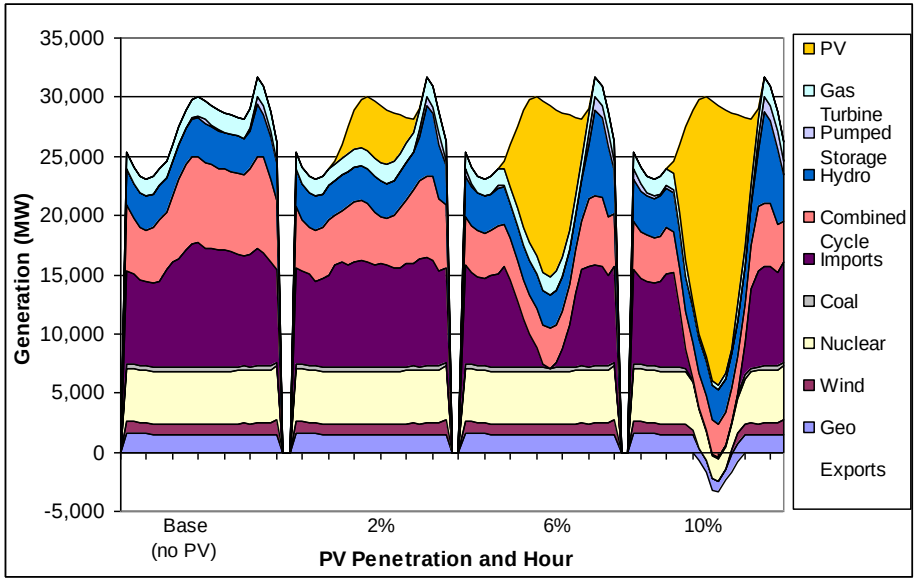
Actual cost of electricity production by nuclear plants in the United States

Renewable Energy Impacts

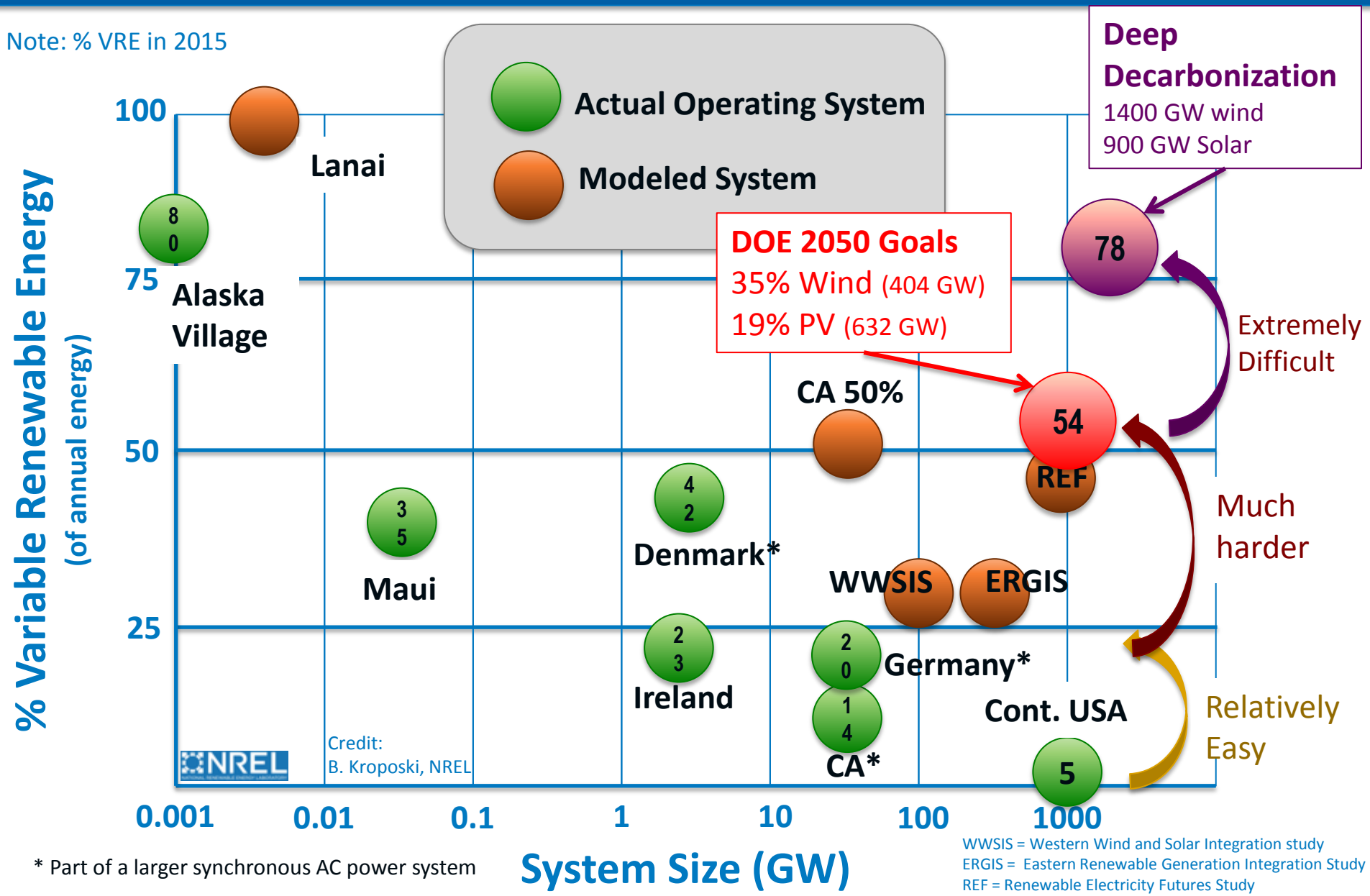


Source: (Arun Majumdar) 1. DOE EERE Sunshot Q1'15 Report, 2. DOE EERE Wind Report, 2015

Denholm et al. 2008



What constitutes "a pace and scale that matters" for our efforts to transform clean energy systems?



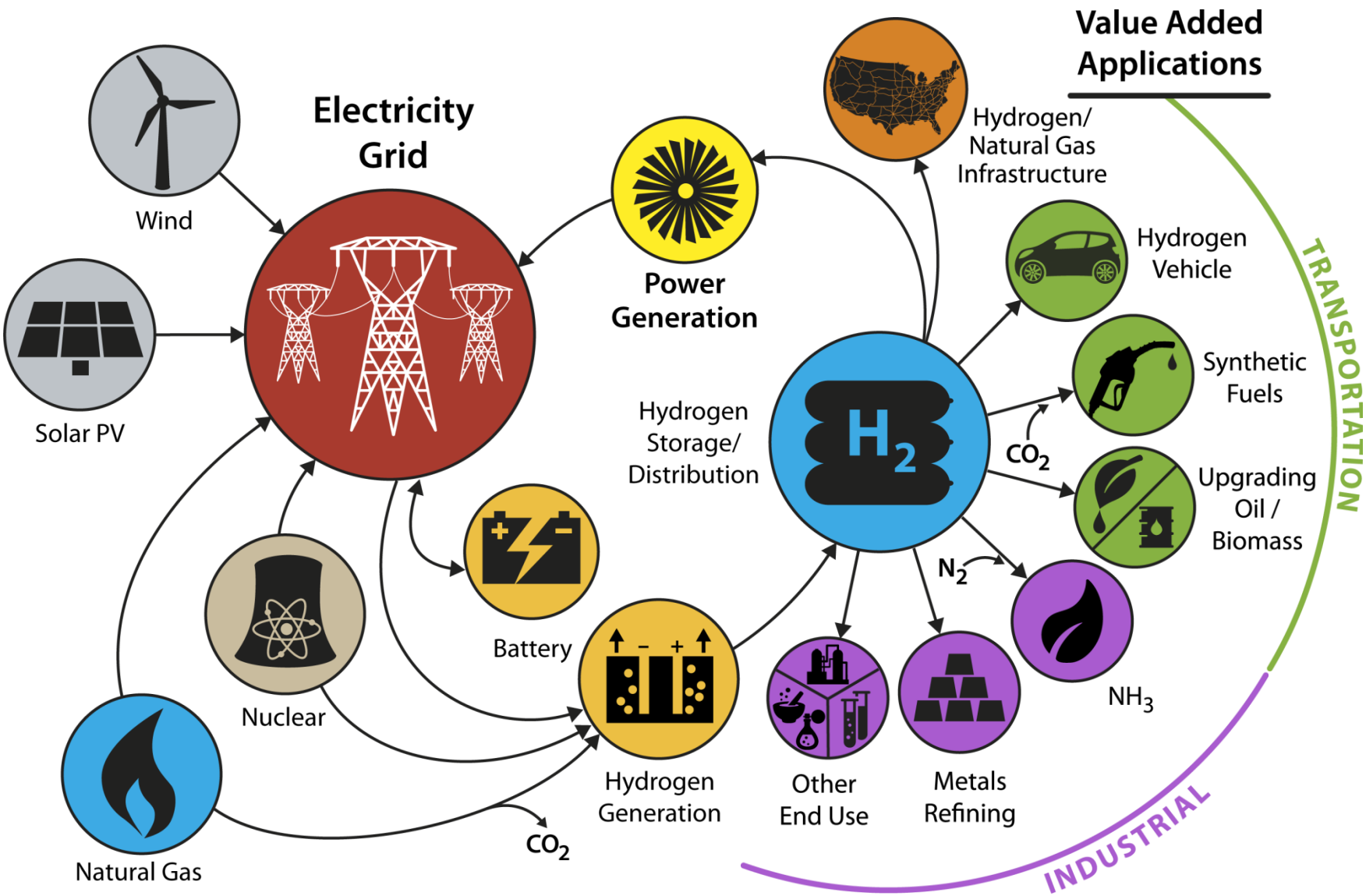
* Part of a larger synchronous AC power system

WWSIS = Western Wind and Solar Integration study
ERGIS = Eastern Renewable Generation Integration Study
REF = Renewable Electricity Futures Study

- **Dwight D. Eisenhower**

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

Conceptual H_2 at Scale Energy System*



*Illustrative example, not comprehensive

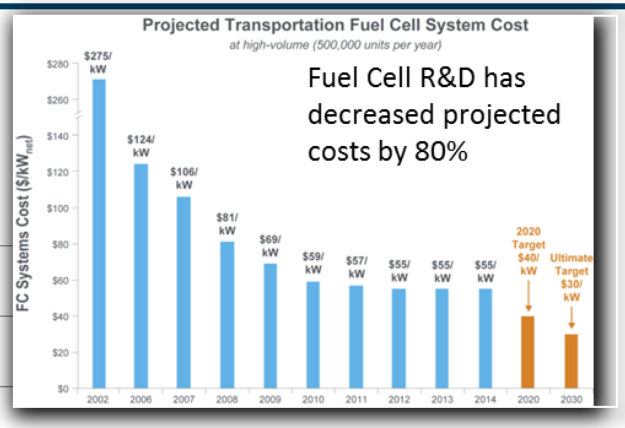
H2@Scale Vision

- **Attributes**
  - Large-scale, clean, energy-carrying intermediates for use across energy sectors
  - Increased penetration of variable renewable power and nuclear generation
  - Expanded thermal 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.

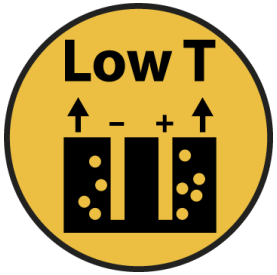
Improving the Economics of Renewable H_2



1 kg H_2 ≈ 1 gallon of gasoline equivalent (gge)

What is needed to achieve H_2 at Scale?

Low and High Temperature H_2 Generation



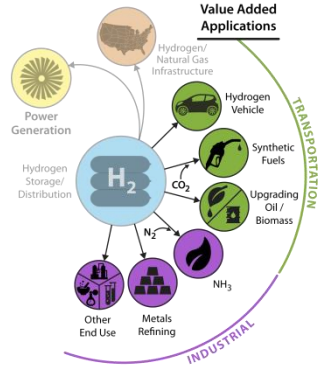
Development of **low cost, durable, and intermittent H_2** generation.

Development of **thermally integrated, low cost, durable, and variable H_2** generation.

H_2 Storage and Distribution

Development of **safe, reliable, and economic storage and distribution** systems.

H_2 Utilization



H_2 as game-changing energy carrier, revolutionizing energy sectors.

Analysis

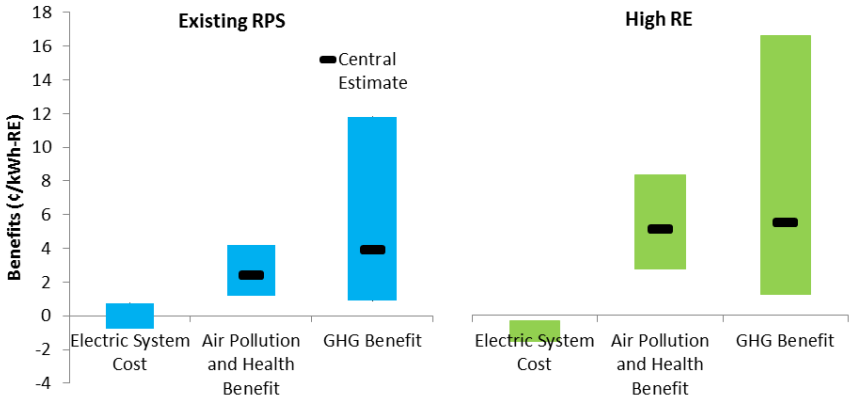
Foundational Science

Future Electrical Grid

Value Proposition Development

- **Trying to build off/follow in tracks of others**

		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 (estimates span +/- 0.75¢/kWh-RE)	range from 0.6% to 4.5%	equivalent to $23 billion– $194 billion (estimates span 0.26-1.5¢/kWh-RE)
	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 metric tons SO_2	equivalent to $97 billion (2.4¢/kWh-RE) (estimates span $48 billion-$175 billion (1.2-4.2¢/kWh-RE))	reduced by ↓ 29% | 11.1 million metric tons SO_2	equivalent to $558 billion (5.0¢/kWh-RE) (estimates span $303 billion-$917 billion; 2.7-8.2¢/kWh-RE)
	NITROGEN OXIDES	reduced by ↓ 6% | 2.5 million metric tons NO_x		reduced by ↓ 29% | 12.8 million metric tons NO_x	
	PARTICULATE MATTER 2.5	reduced by ↓ 5% | 0.3 million metric tons $PM_{2.5}$		reduced by ↓ 29% | 1.8 million metric tons $PM_{2.5}$	
	GREENHOUSE GAS EMISSIONS	reduced by ↓ 6% | 4.7 billion metric tons CO_2e	equivalent to $161 billion (3.9¢/kWh-RE) (estimates span $37 billion-$487 billion (0.9-11.8¢/kWh-RE))	reduced by ↓ 23% | 18.1 billion metric tons CO_2e	equivalent to $599 billion (5.4¢/kWh-RE) (estimates span $132 billion-$1,821 billion (1.2-16.3¢/kWh-RE))
	WATER USE	reduced by ↓ 4% consumption | 3% withdrawal		reduced by ↓ 18% consumption | 18% withdrawal	
IMPACTS	NATURAL GAS	reduced by ↓ 35 quads (3.3%)	equivalent to $78 billion impact 1.9¢/kWh-RE	reduced by ↓ 46 quads (4.3%)	equivalent to $99 billion impact 0.9¢/kWh-RE
	RE JOB NEEDS	increase in ↑ 19% RE-employment	equivalent to 4.7 million RE job-years	increase in ↑ 47% RE-employment	equivalent to 11.5 million RE job-years



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

HTAC Presentation May 4, 2017
Newest Analysis Results

H_2 at Scale Big Idea Teams/Acknowledgement

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.

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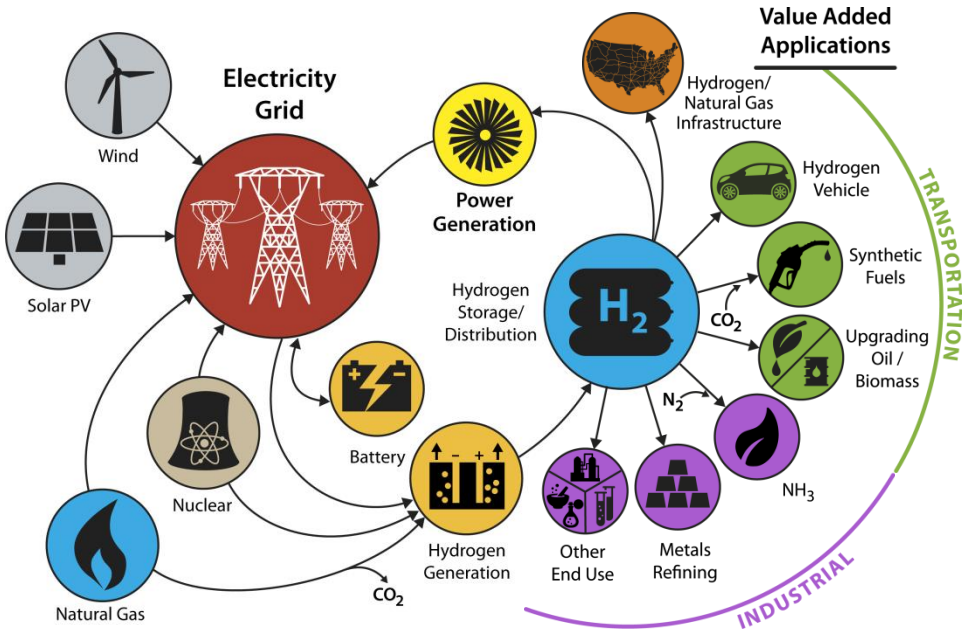
Stakeholder Groups - Workshops - Roadmaps

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

- Analysis
- Investors



Blue: High engagement and support

Green: Engaged with interest/support

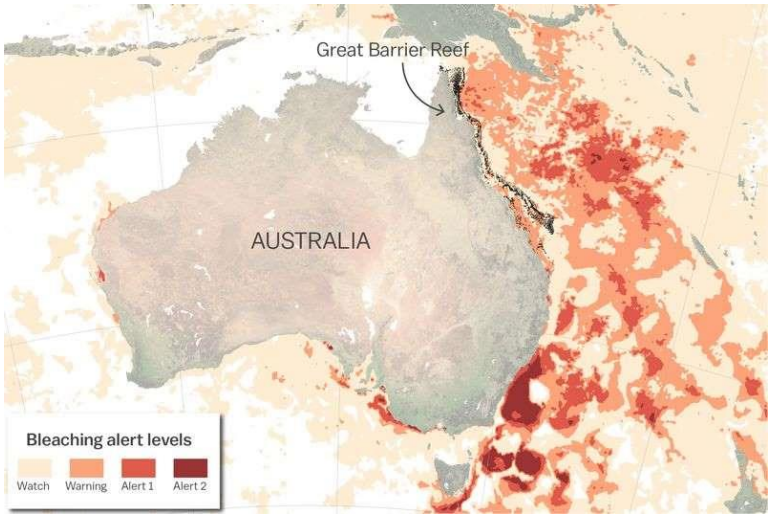
Orange: Limited engagement

Black: Little engagement

Next Workshop Houston May 23-24, 2017

Future Impact?

The Great Barrier Reef's catastrophic coral bleaching, in one map



http://www.msn.com/en-gb/travel/news/the-great-barrier-reef%e2%80%99s-catastrophic-coral-bleaching-in-one-map/ar-BBA1t2n?li=BBoPU0T

Mysterious Whale Swarms Perplexing Scientists

"Super-groups" of up to 200 humpback whales—a normally solitary species—are gathering off South Africa.

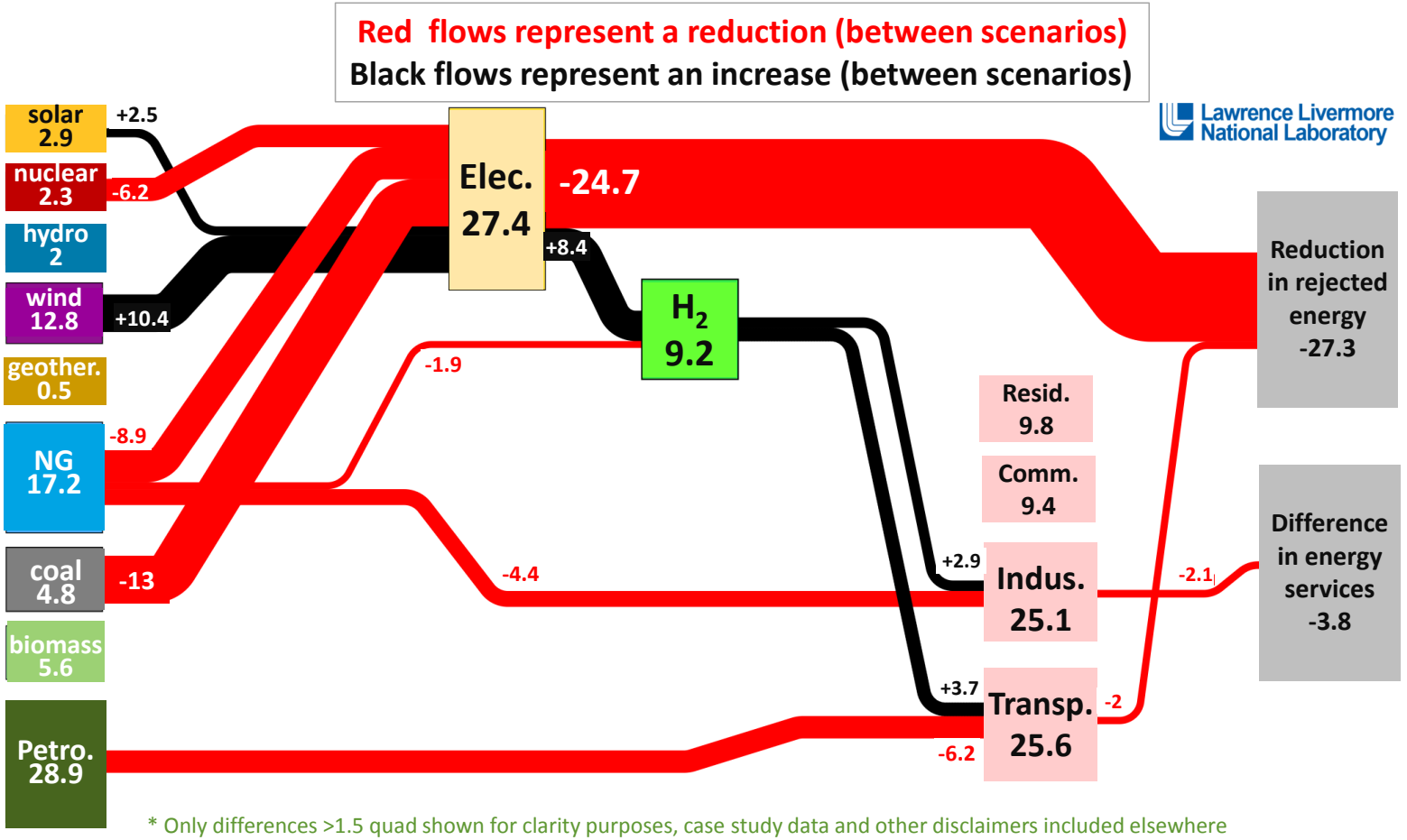
http://news.nationalgeographic.com/2017/03/humpback-whales-swarms-south-africa/

Back up

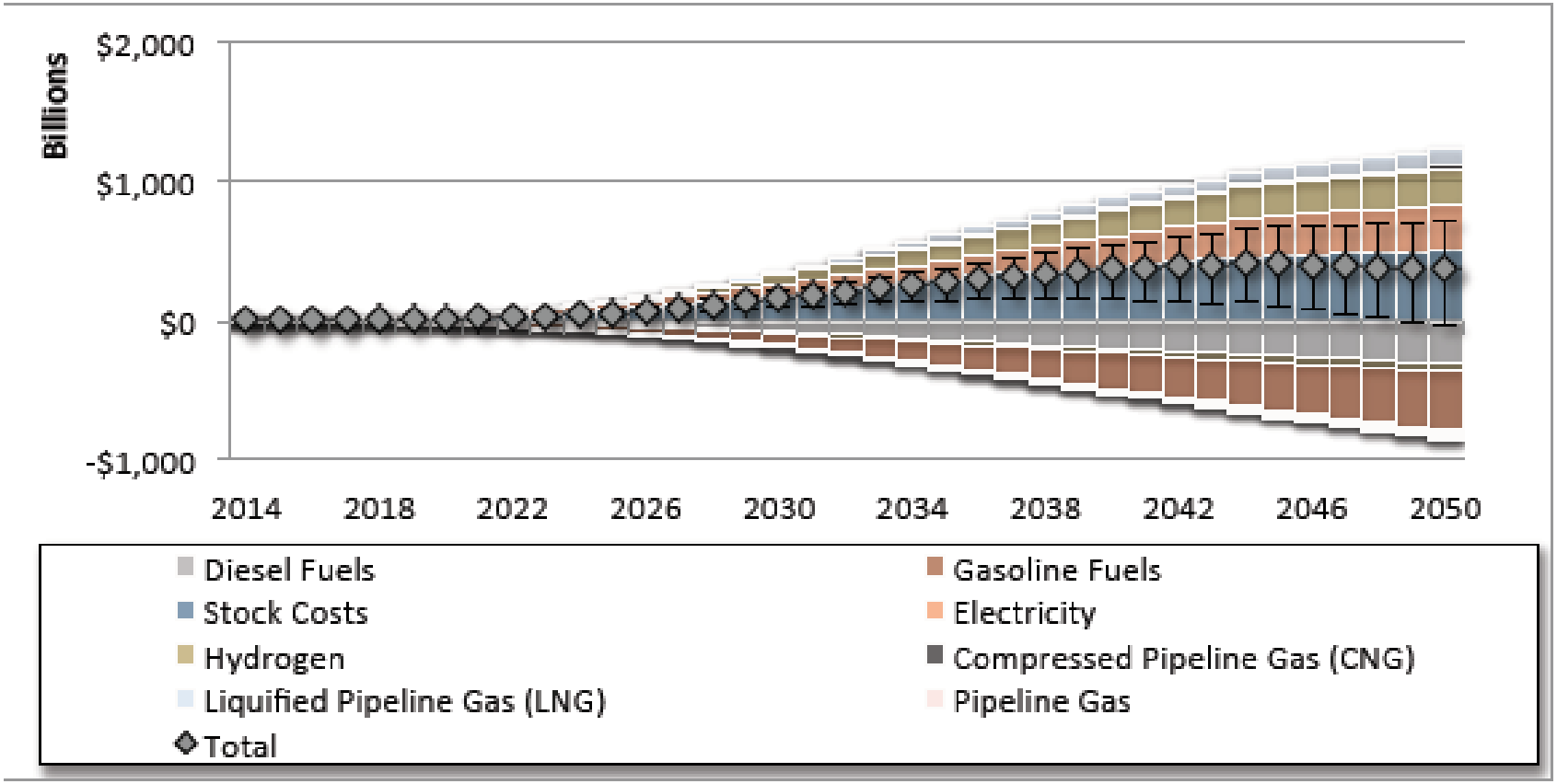
Evolving H_2@Scale vision/message

- **Quantifying energy-system wide value proposition**
  - Based on Scenario Development (like that shown below)

Energy Use difference between 2050 high-H_2 and AEO 2040 scenarios (Quad Btu)



Energy System-Wide Models (E3)



Assessing Economic Impact

ICF Results using E3 inputs

RESULTS SUMMARY: NATIONAL IMPACTS

National Level GDP ($ Billion)

	2020	2025	2030	2040	2050
Reference Case	**$18,745**	**$20,708**	**$22,765**	**$26,746**	**$31,317**
High Renewables	$18,772	$20,760	$22,910	$26,959	$31,607
Difference	26	52	145	213	290
% Change	0.1%	0.3%	0.6%	0.8%	0.9%
Mixed Case	$18,770	$20,777	$22,909	$26,921	$31,500
Difference	24	69	144	175	183
% Change	0.1%	0.3%	0.6%	0.7%	0.6%

- **GDP impact trends are similar to the employment results**
  - Impacts comparable across both scenarios around 2030
    - About a half percentage point increase over the Reference Case
  - High RE Case shows more pronounced impacts in the long run
    - Close to a full percentage point more than the Reference Case