H_2 @Scale:

Energy system-wide benefits of increased H_2 implementation

HTAC Meeting

May 4, 2017

H2@Scale 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

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

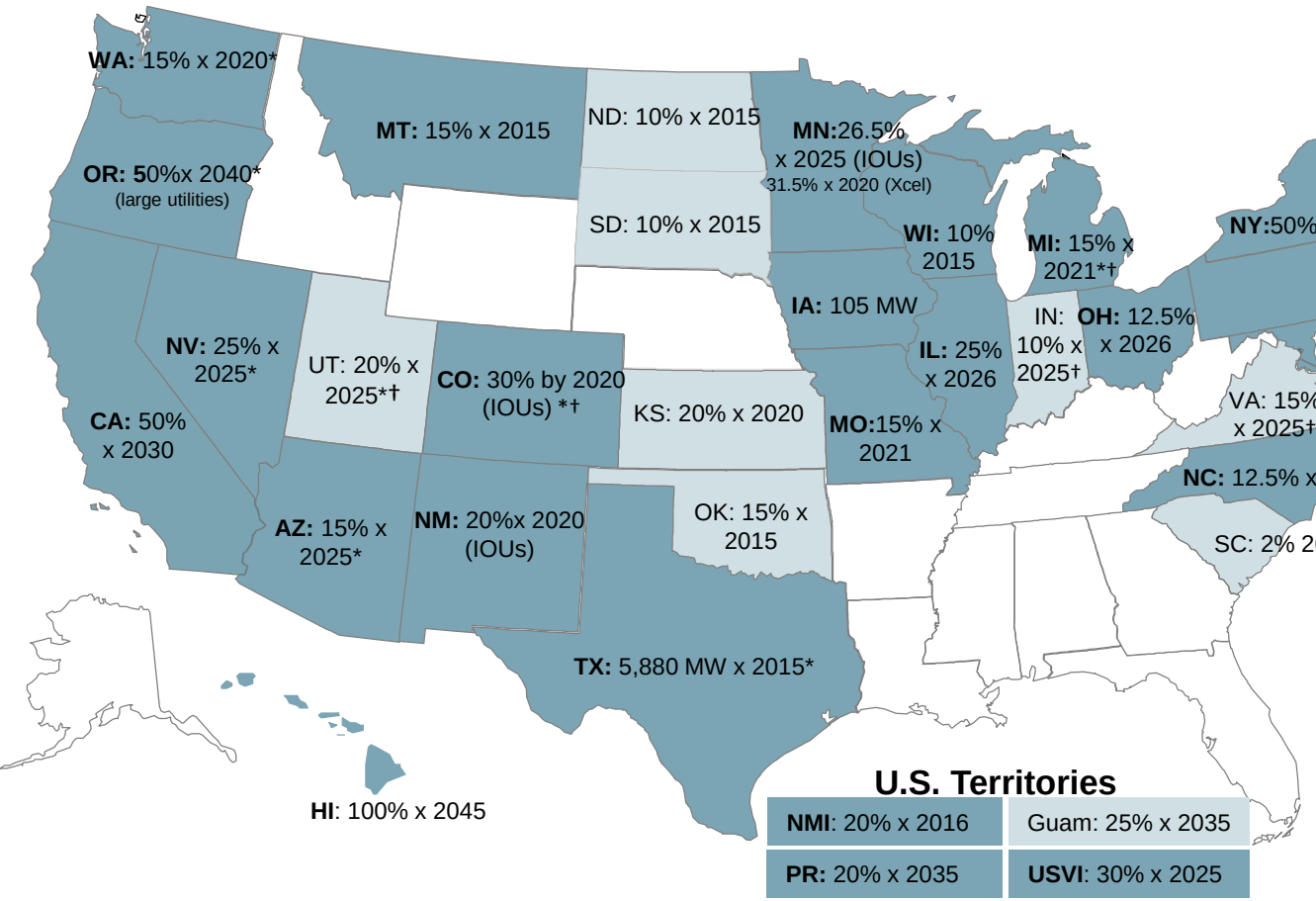
https://www.theguardian.com/environment/2016/apr/20/dangerous-air-pollution-us-population-report

Energy System Challenge

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

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

Changing Landscape - RPS



ME: 40% x 2017
NH: 24.8 x 2025
VT: 75% x 2032
MA: 15% x 2020(new resources)
6.03% x 2016 (existing resources)
RI: 38.5% x 2035
CT: 27% x 2020
NJ: 20.38% RE x 2020
+ 4.1% solar by 2027
PA: 18% x 2021†
DE: 25% x 2026*
MD: 25% x 2020
DC: 50% x 2032

U.S. Territories

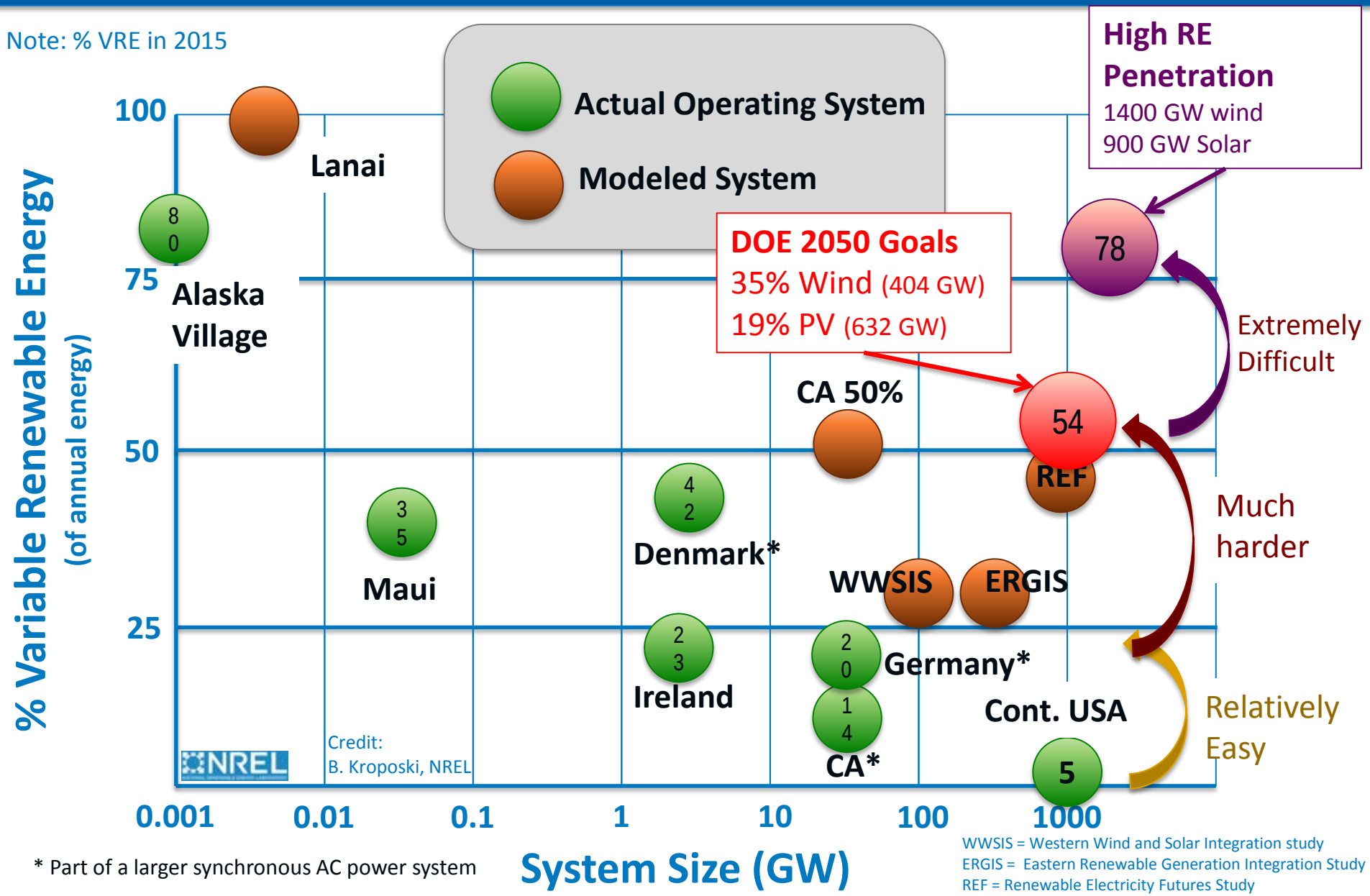
NMI: 20% x 2016	Guam: 25% x 2035
PR: 20% x 2035	**USVI**: 30% x 2025

29 States + Washington DC + 3 territories have a Renewable Portfolio Standard
(8 states and 1 territories have renewable portfolio goals)

Renewable portfolio standard
Renewable portfolio goal

* Extra credit for solar or customer-sited renewables
† Includes non-renewable alternative resources

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



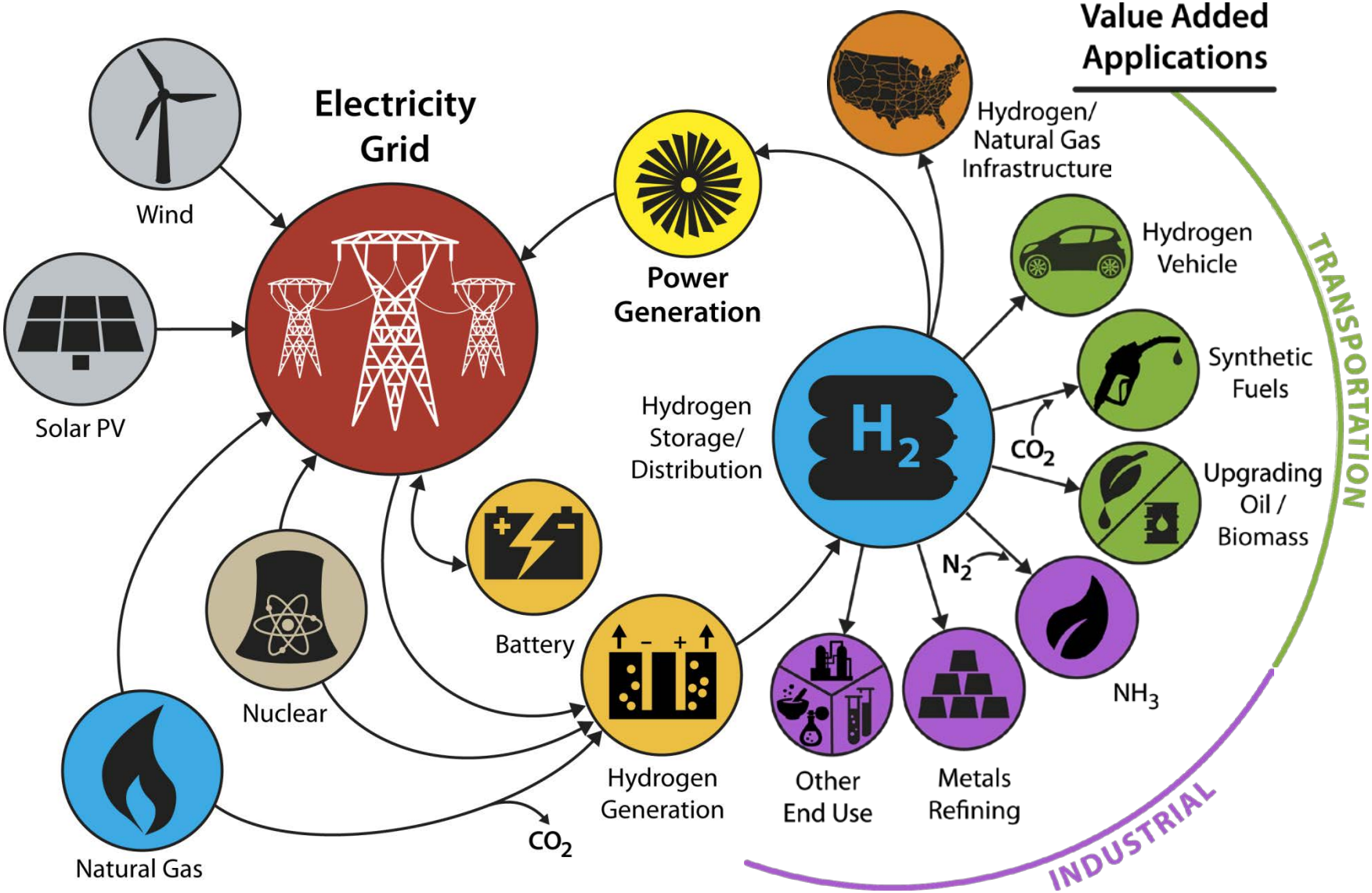
* Part of a larger synchronous AC power system

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

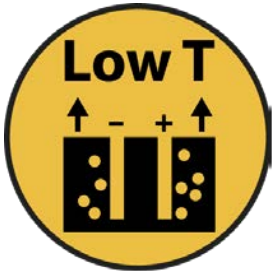
- **Attributes**
  - Large-scale, clean, energy-carrying intermediates for use across energy sectors
  - Increased penetration of variable renewable power and nuclear generation
  - Expanded thermal generation (nuclear, CSP, geothermal) through hybridization
  - Increased H2 from methane (carbon capture/use 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.

What is needed to achieve H_2 at Scale?

Low and High Temperature H_2 Generation



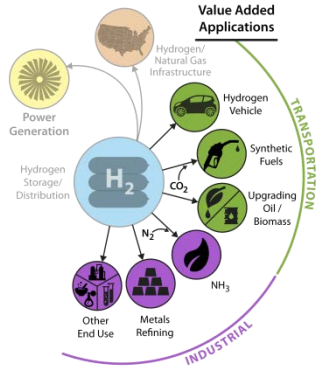
Development of **low cost, durable, and intermittent H_2** generation.

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



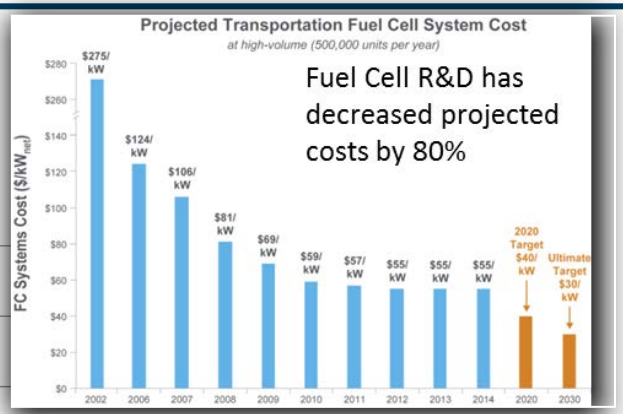
H_2 as game-changing energy carrier, revolutionizing energy sectors.

Analysis

Foundational Science

Future Electrical Grid

Improving the Economics of Renewable H_2

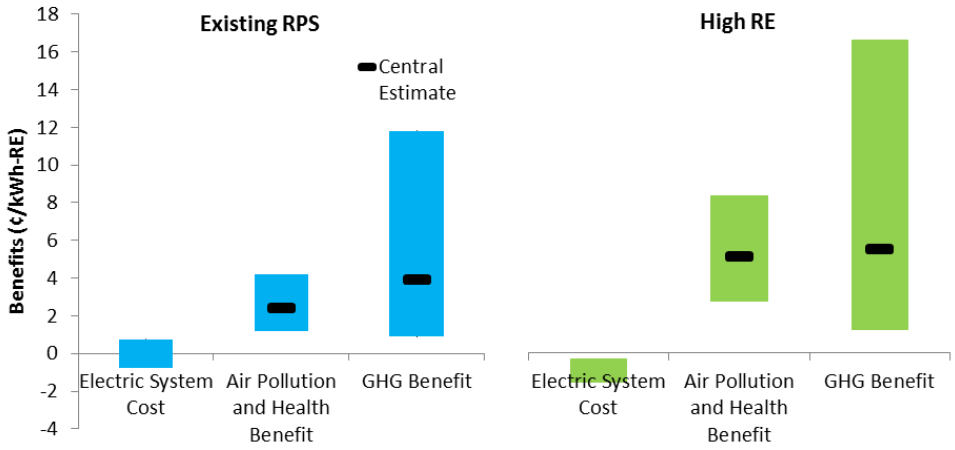


1 kg H_2 ≈ 1 gallon of gasoline equivalent (gge)

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		reduced by ↓ 29%, 11.1 million metric tons SO_2	
	NITROGEN OXIDES	reduced by ↓ 6%, 2.5 million metric tons NO_x	equivalent to $97 billion (2.4¢/kWh-RE) (estimates span $48 billion-$175 billion (1.2-4.2¢/kWh-RE))	reduced by ↓ 29%, 12.8 million metric tons NO_x	equivalent to $558 billion (5.0¢/kWh-RE) (estimates span $303 billion-$917 billion; 2.7-8.2¢/kWh-RE)
	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

H_2 at Scale Big Idea Teams/Acknowledgement

Steering Committee:

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

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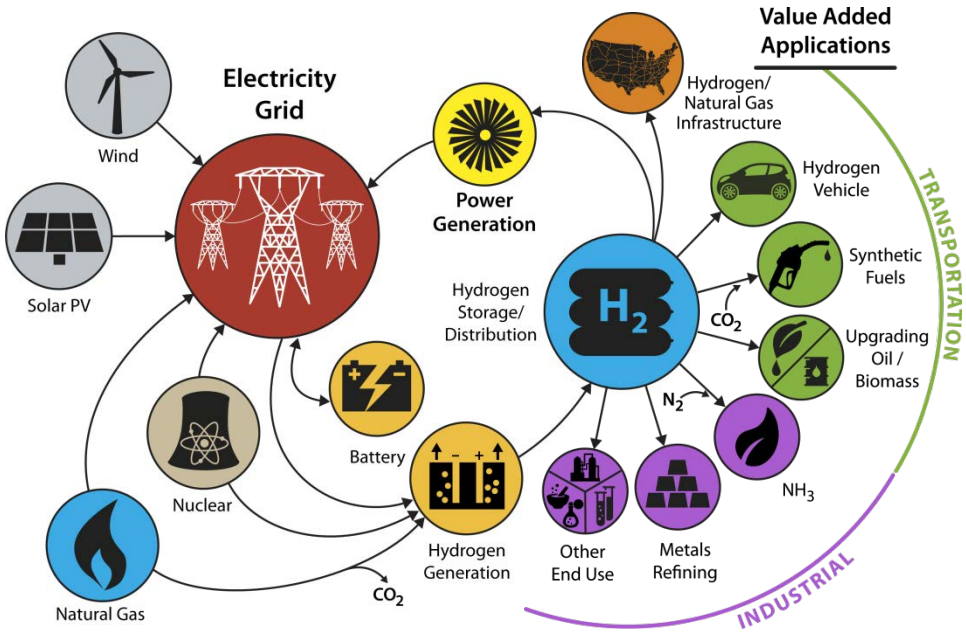
Stakeholder Groups - Workshops - Roadmaps

- 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

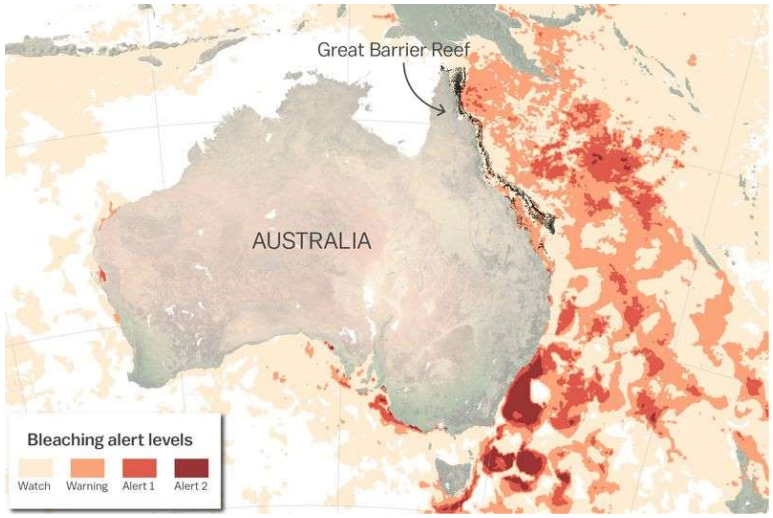
Orange: Limited engagement

Black: Little engagement

Next Workshop Houston May 23-24, 2017

Future Impact?

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



Mysterious Whale Swarms Perplexing Scientists

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

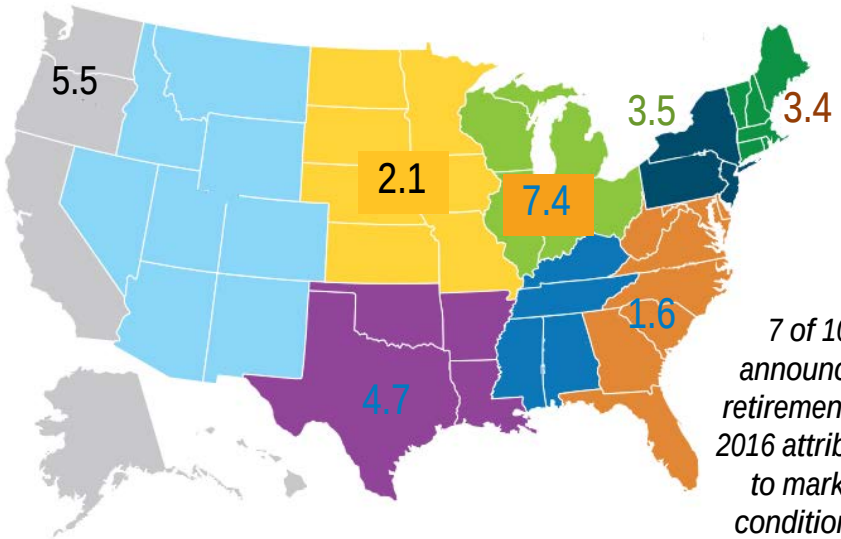
Images:
1. http://www.msn.com/en-gb/travel/news/the-great-barrier-reef%e2%80%99s-catastrophic-coral-bleaching-in-one-map/ar-BBA1t2n?li=BBoPU0T
2. http://news.nationalgeographic.com/2017/03/humpback-whales-swarms-south-africa/

Back up slides

Nuclear Energy Impacts

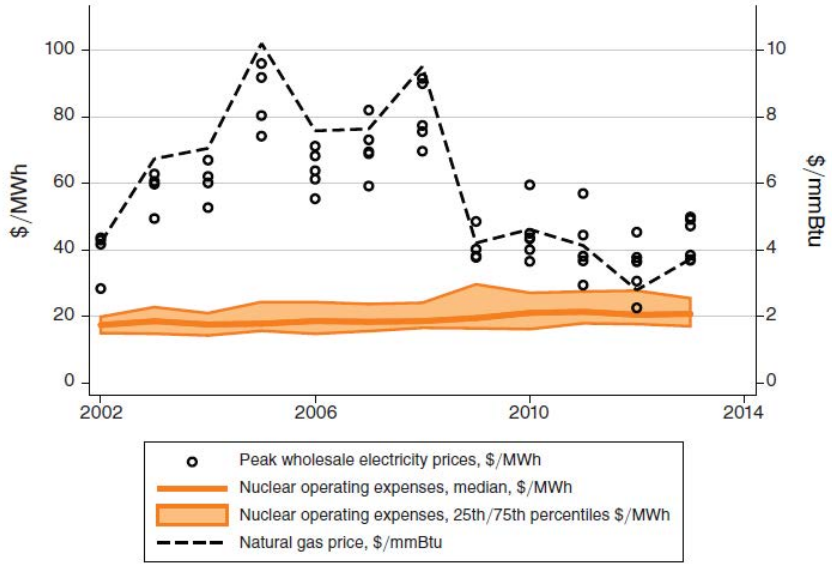
Nuclear Plants at Risk by 2030, or Recently Retired (GW) [1]

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



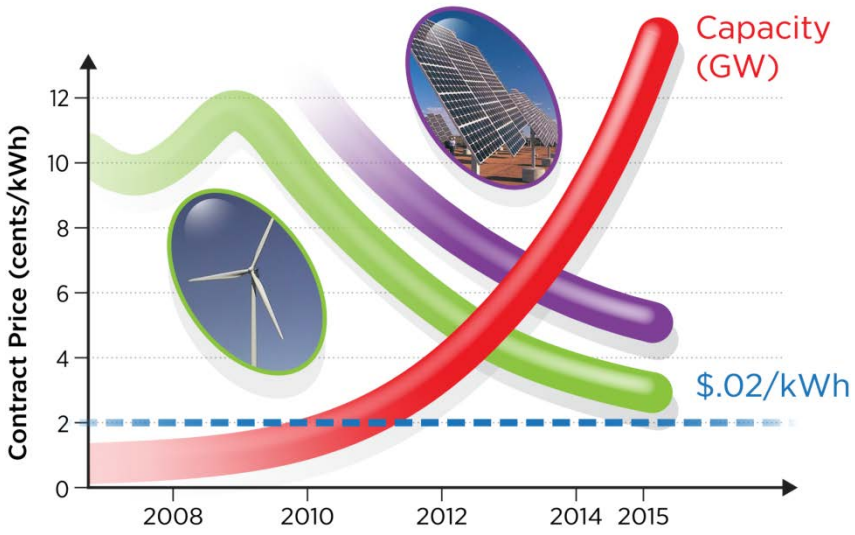
7 of 10 announced retirements in 2016 attributed to market conditions.[1]

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



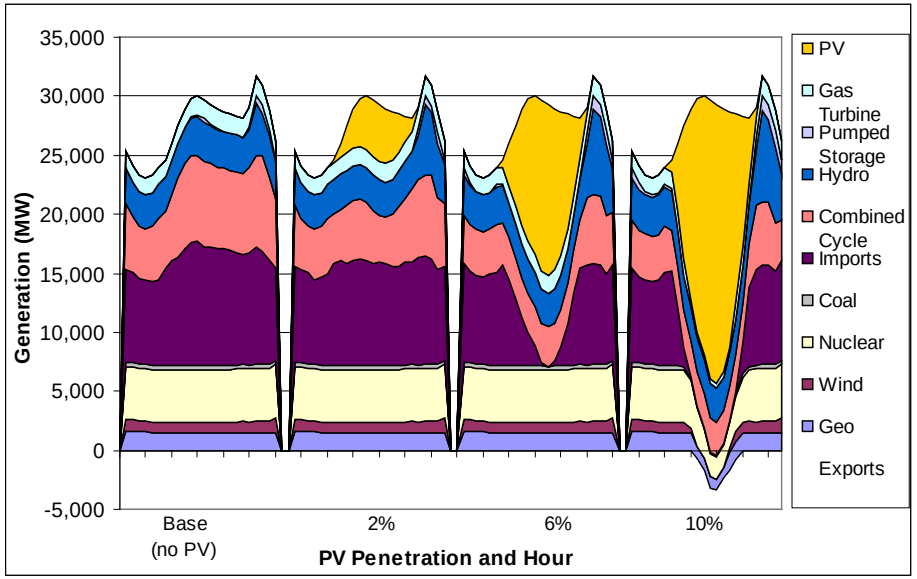
Actual cost of electricity production by nuclear plants in the United States

Renewable Energy Impacts



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

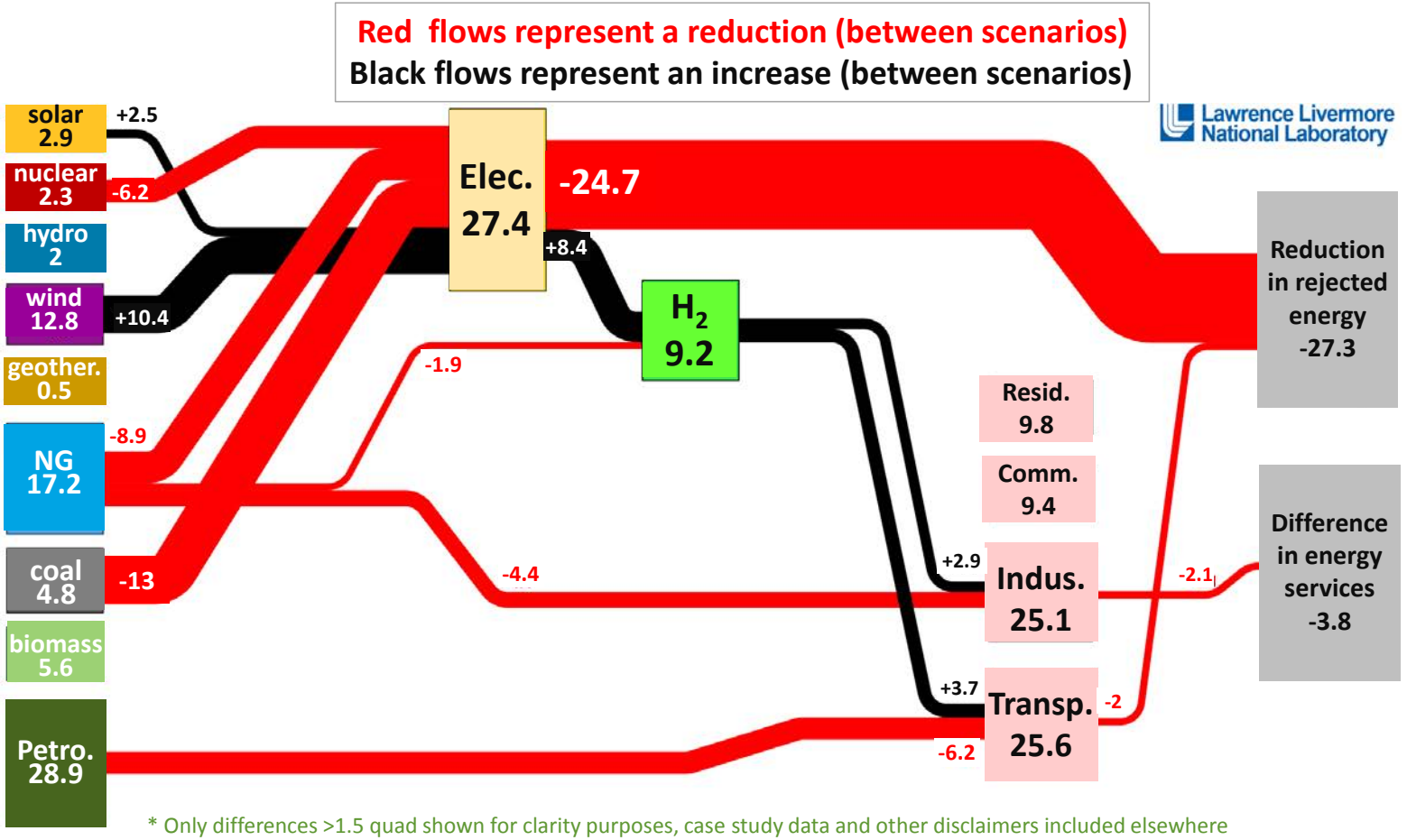
Denholm et al. 2008



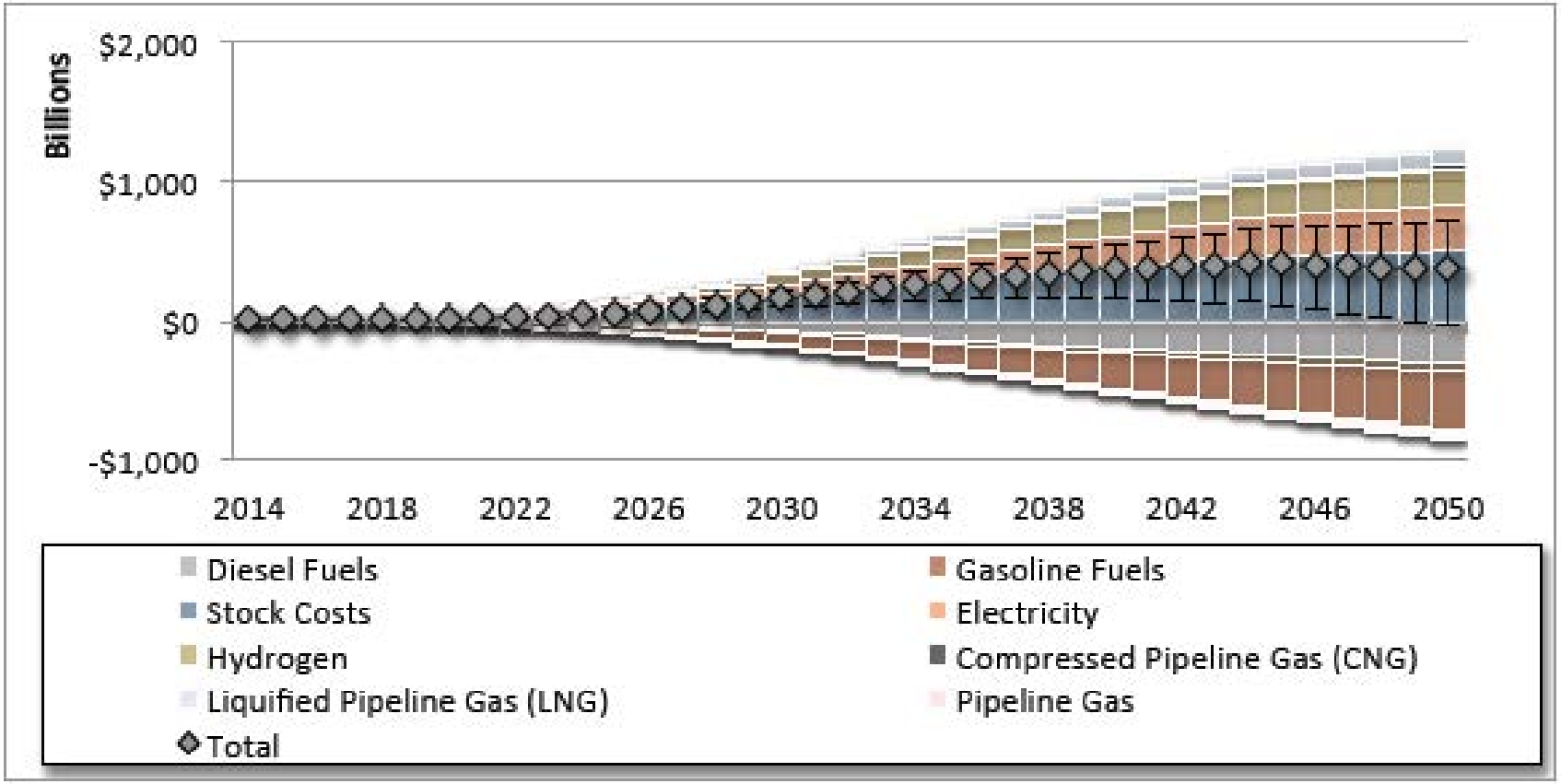
Evolving H_2@Scale vision/message

- **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)



There are a lack of energy system-wide models.
Hydrogen tends to be prominent.
High cost uncertainties exist, but costs don't appear prohibitive.

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