H_2 at Scale:

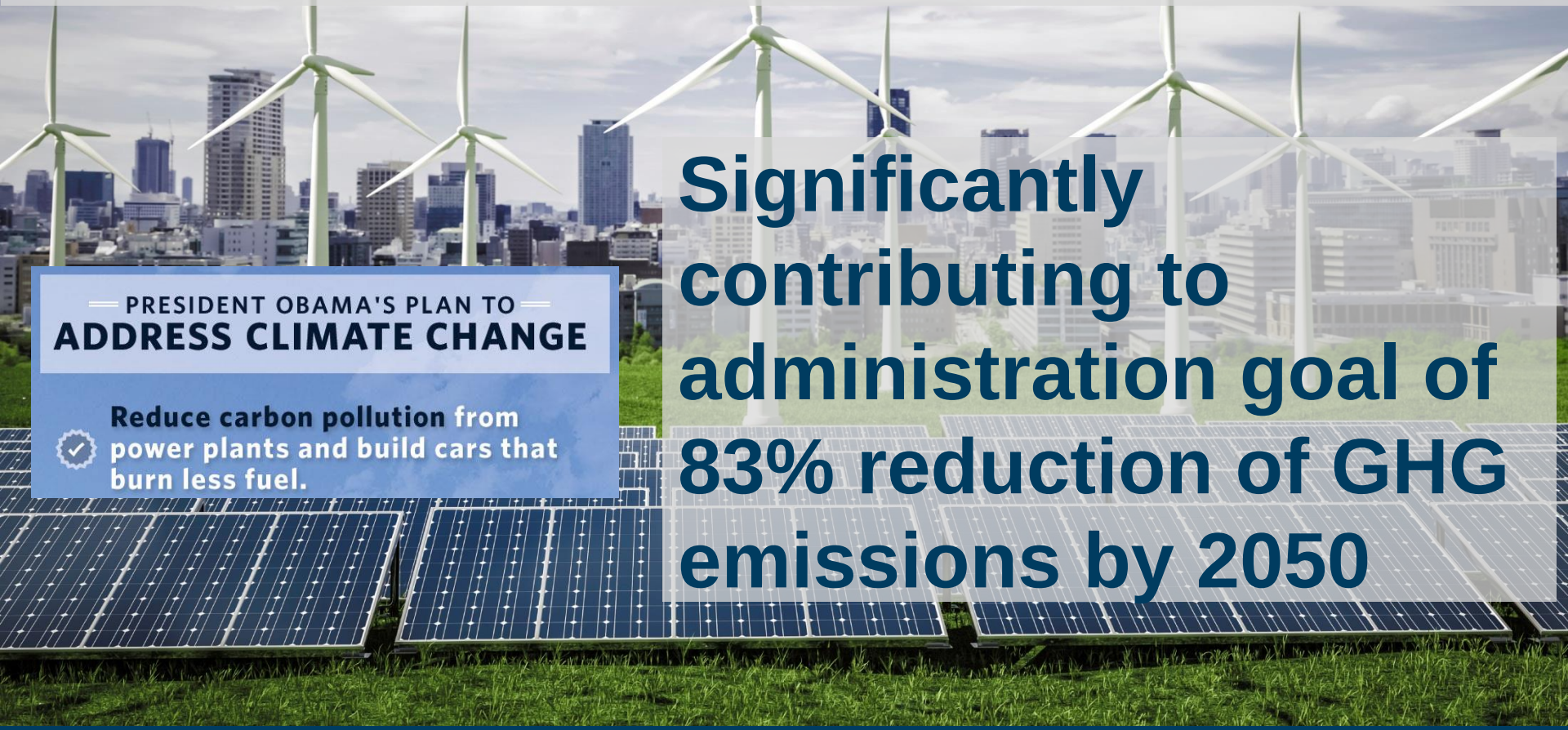
Deeply Decarbonizing our Energy System

IPHE

Shattuck Hotel
May 20, 2016

Why?.....Our Cities/Energy System

Decreases all U.S. carbon emissions by about half (2050)



Significantly contributing to administration goal of 83% reduction of GHG emissions by 2050

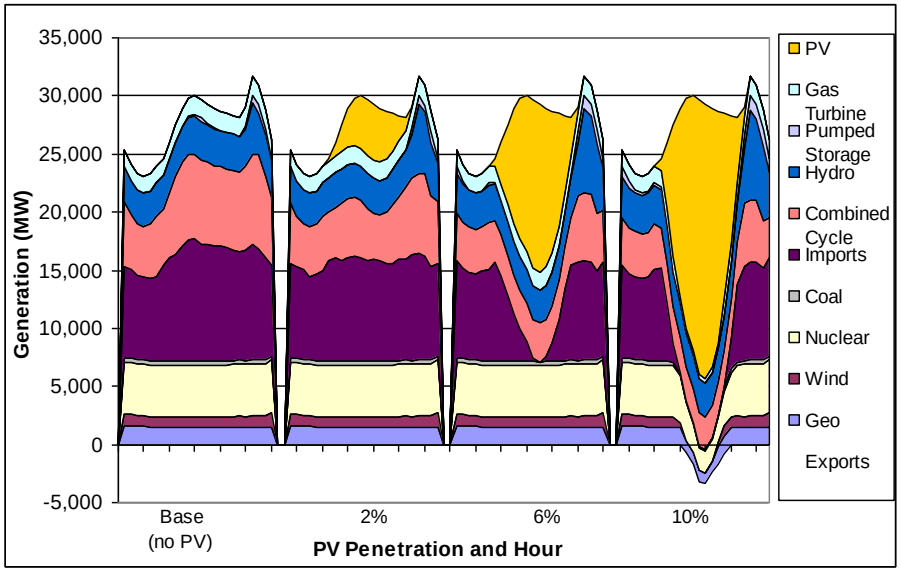
Energy System Challenges

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

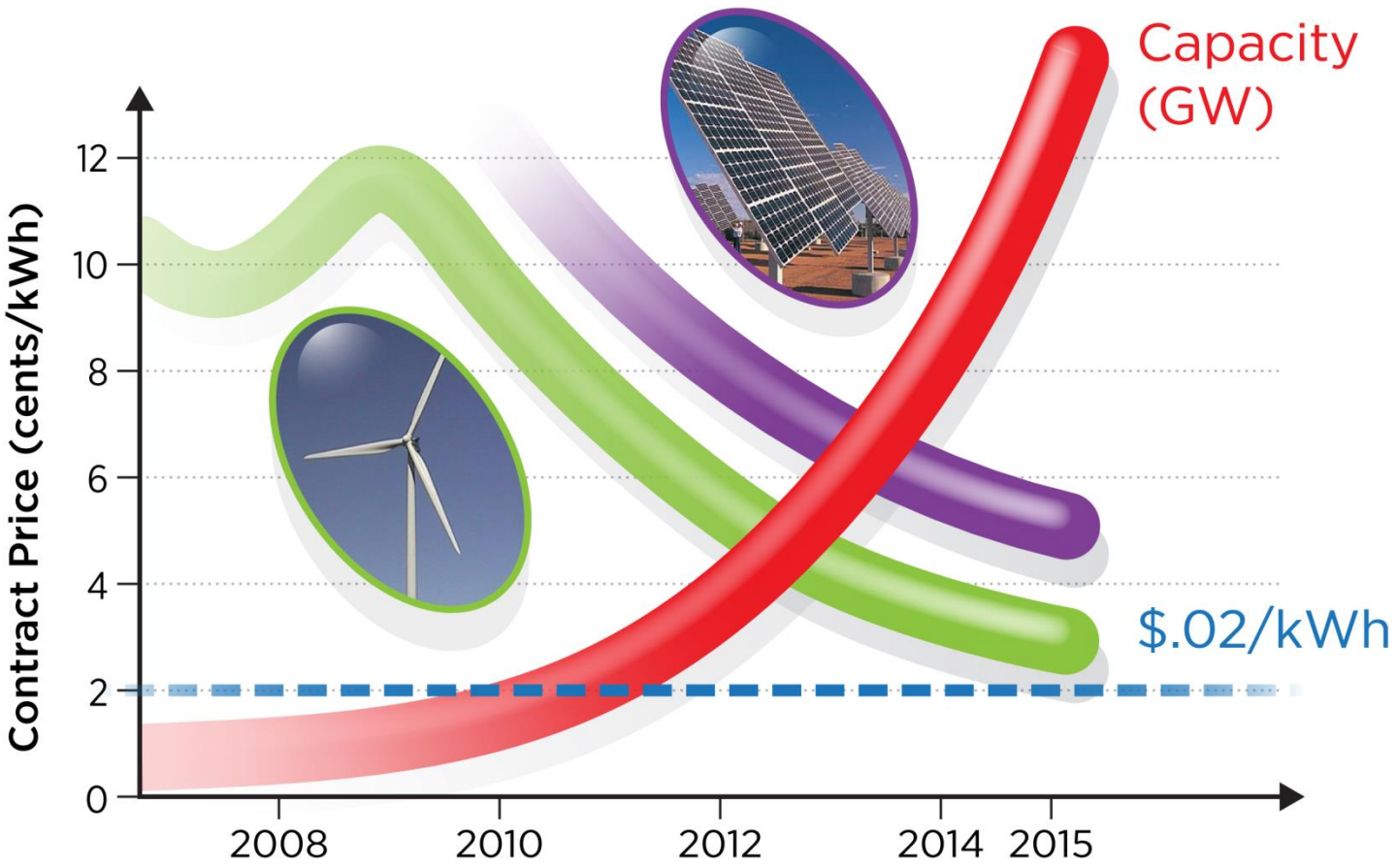
Over half of U.S. CO_2 emissions come from the industrial and transportation sectors

- **Renewable challenges**
  - Variable
  - Concurrent generation

Denholm et al. 2008



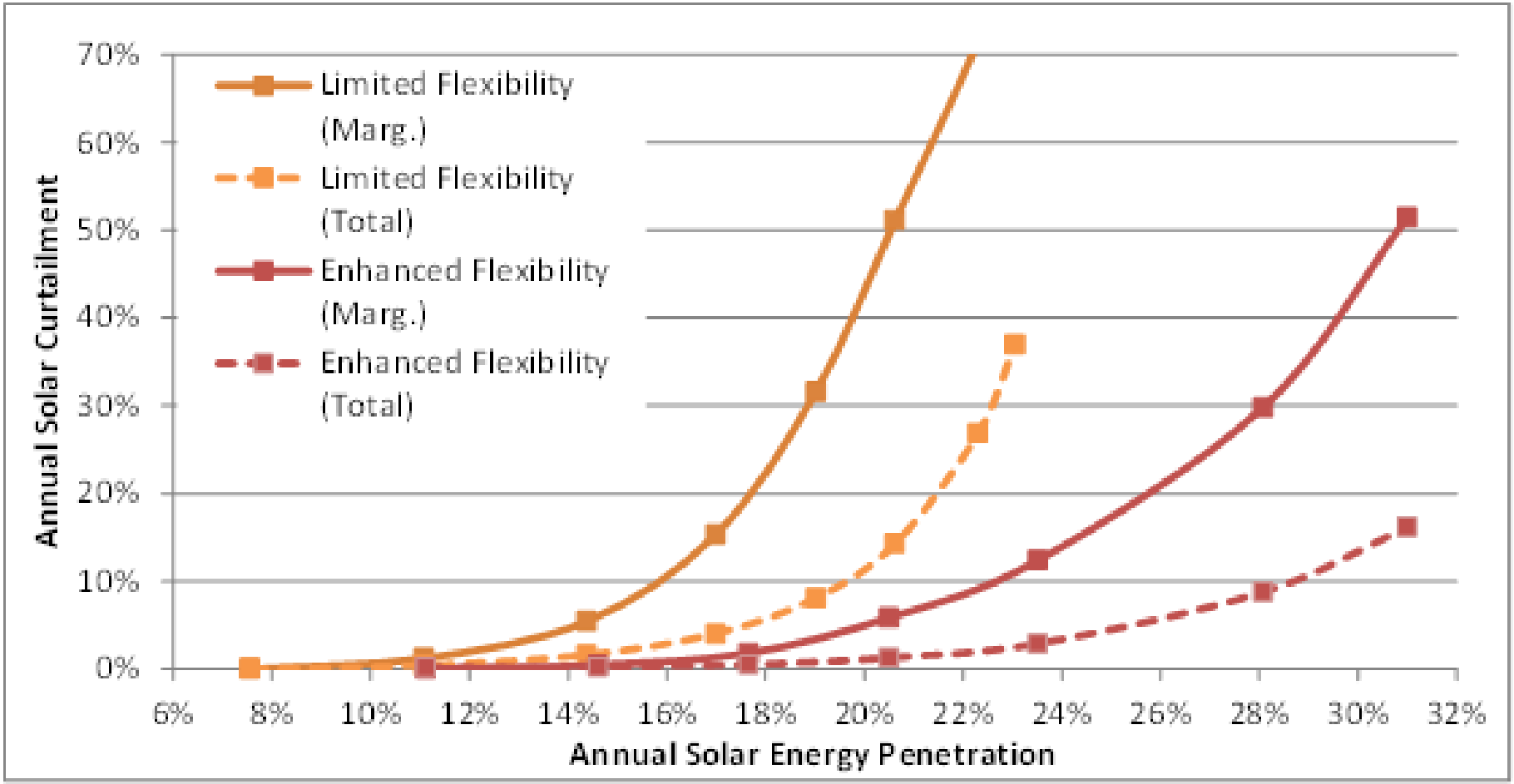
Why now? Carbon-free electricity prices



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

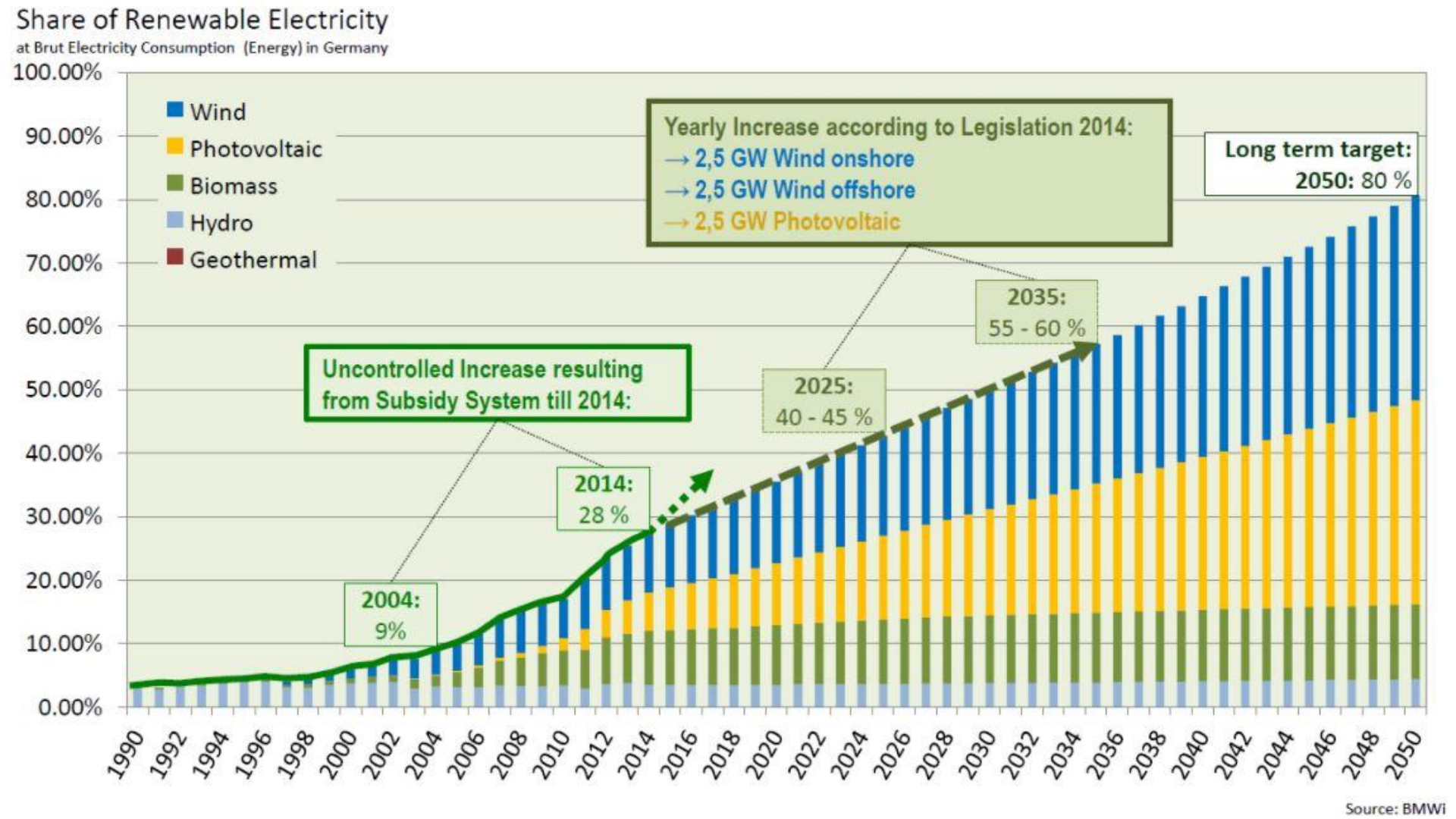
Limitations of Variable Inputs

Denholm, P.; M. O'Connell; G. Brinkman; J. Jorgenson (2015) Overgeneration from Solar Energy in California: A Field Guide to the Duck Chart. NREL/TP-6A20-65023



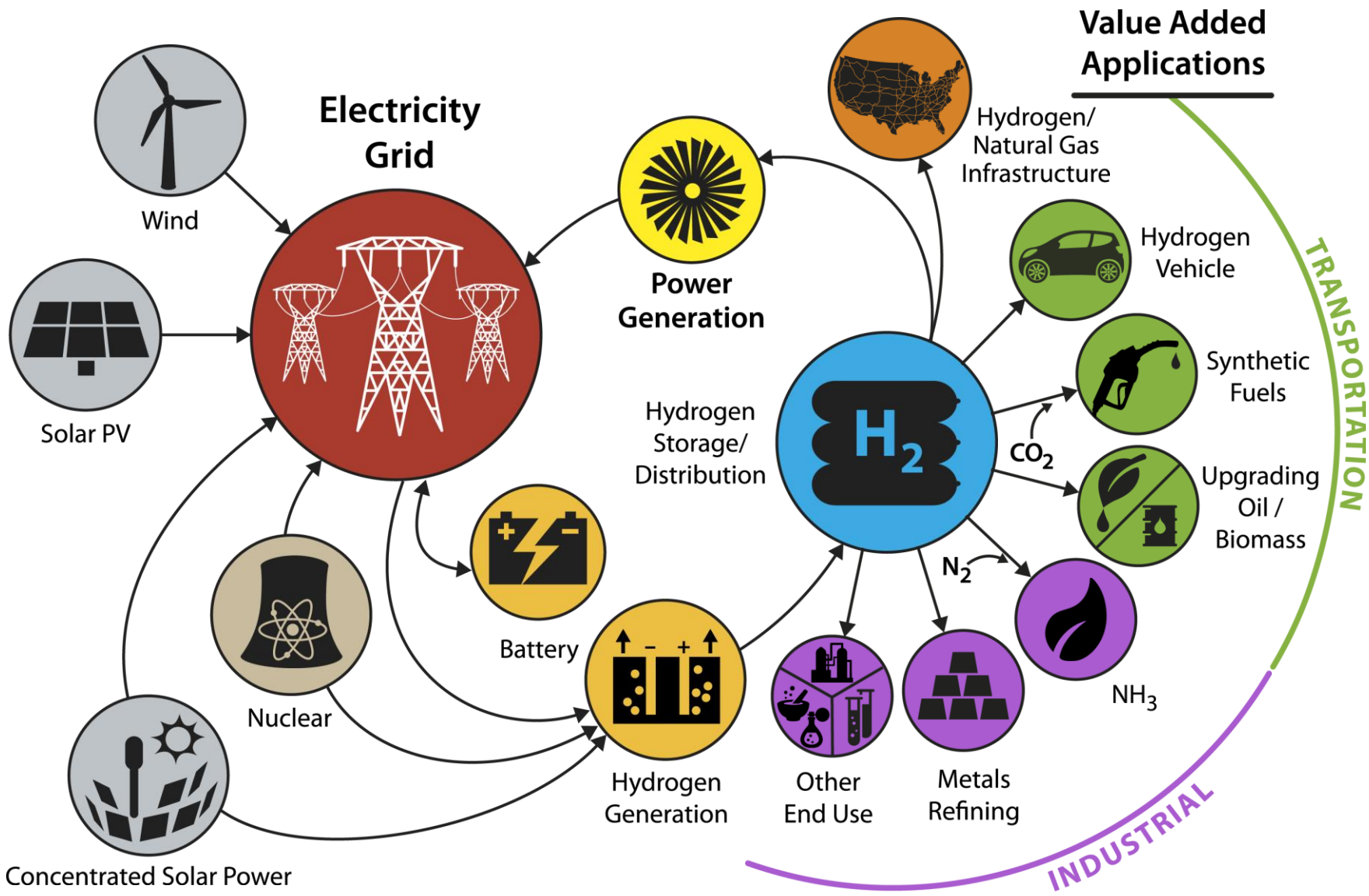
Curtailment will lead to an abundance of low value electrons, and we need solutions that will service our multi-sector demands

Example: Germany already limiting RE penetration rate



Source: BMWi

Conceptual H_2 at Scale Energy System*

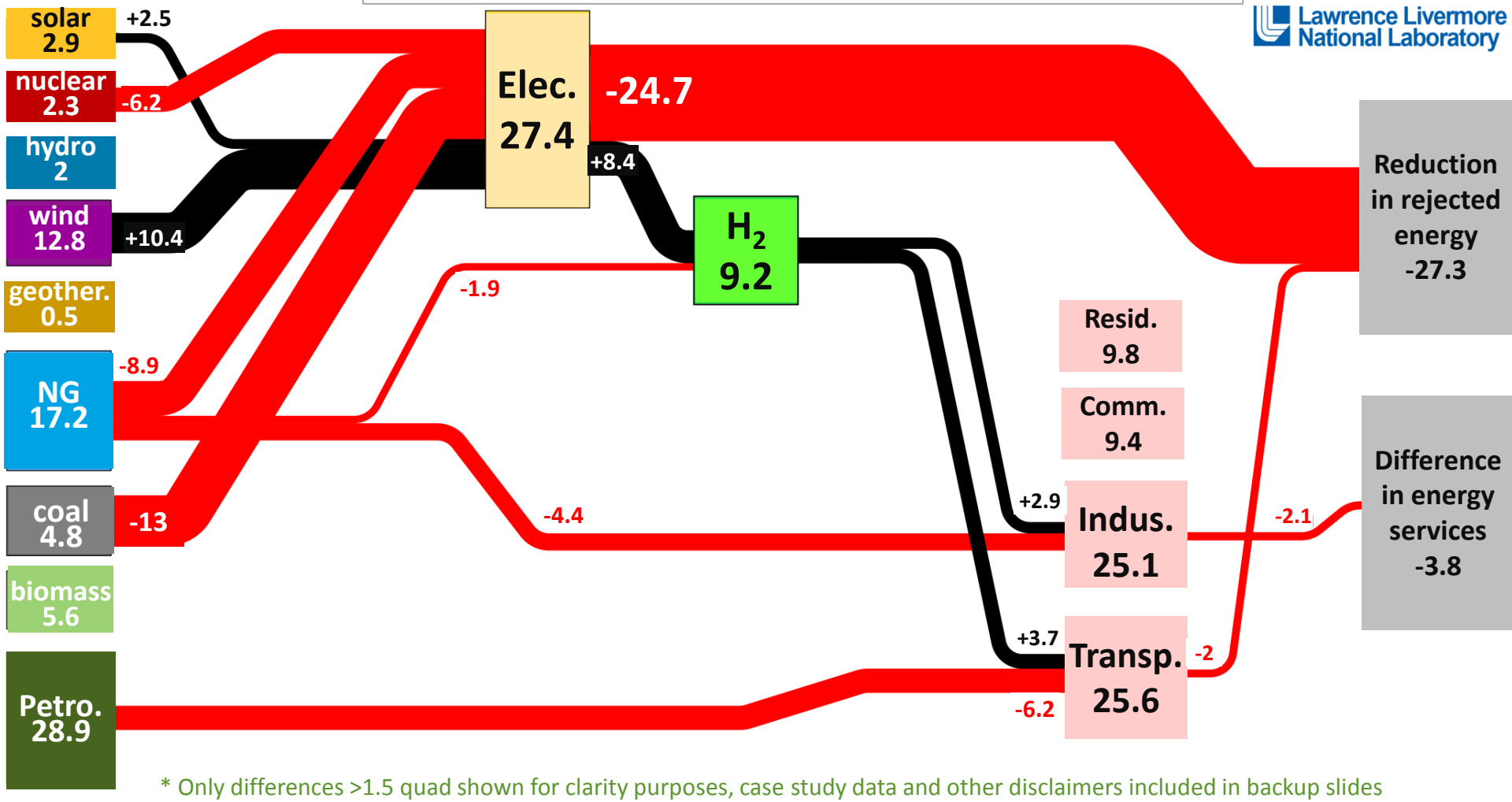


*Illustrative example, not comprehensive

BAU (Business As Usual) vs. High H_2 – Energy Difference*

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

Red flows represent a reduction (between scenarios)
Black flows represent an increase (between scenarios)

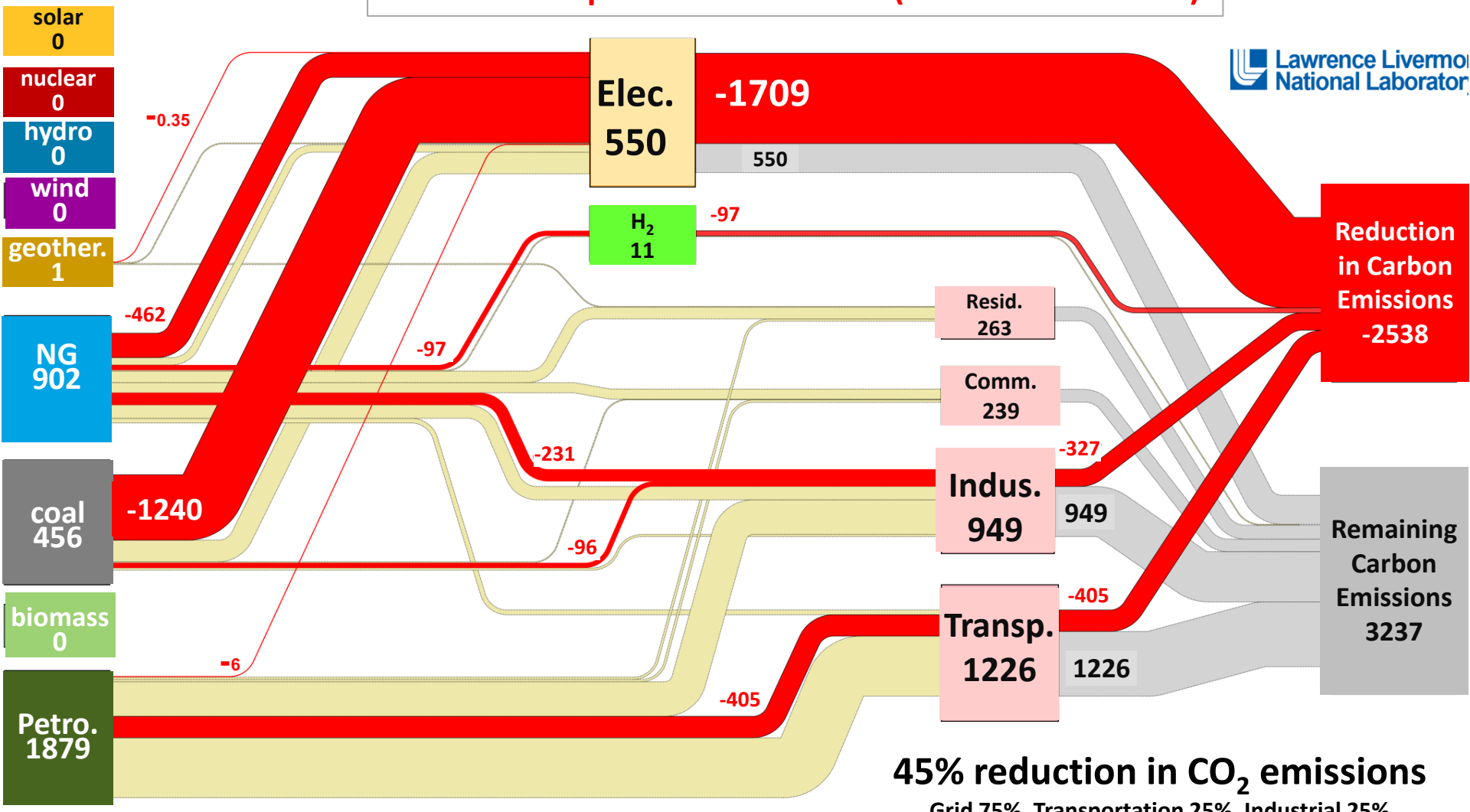


* Only differences >1.5 quad shown for clarity purposes, case study data and other disclaimers included in backup slides

BAU (Business As Usual) vs. High H_2 – CO_2 Difference*

Emissions difference between 2050 high-H_2 and AEO 2040 scenarios (million MT)

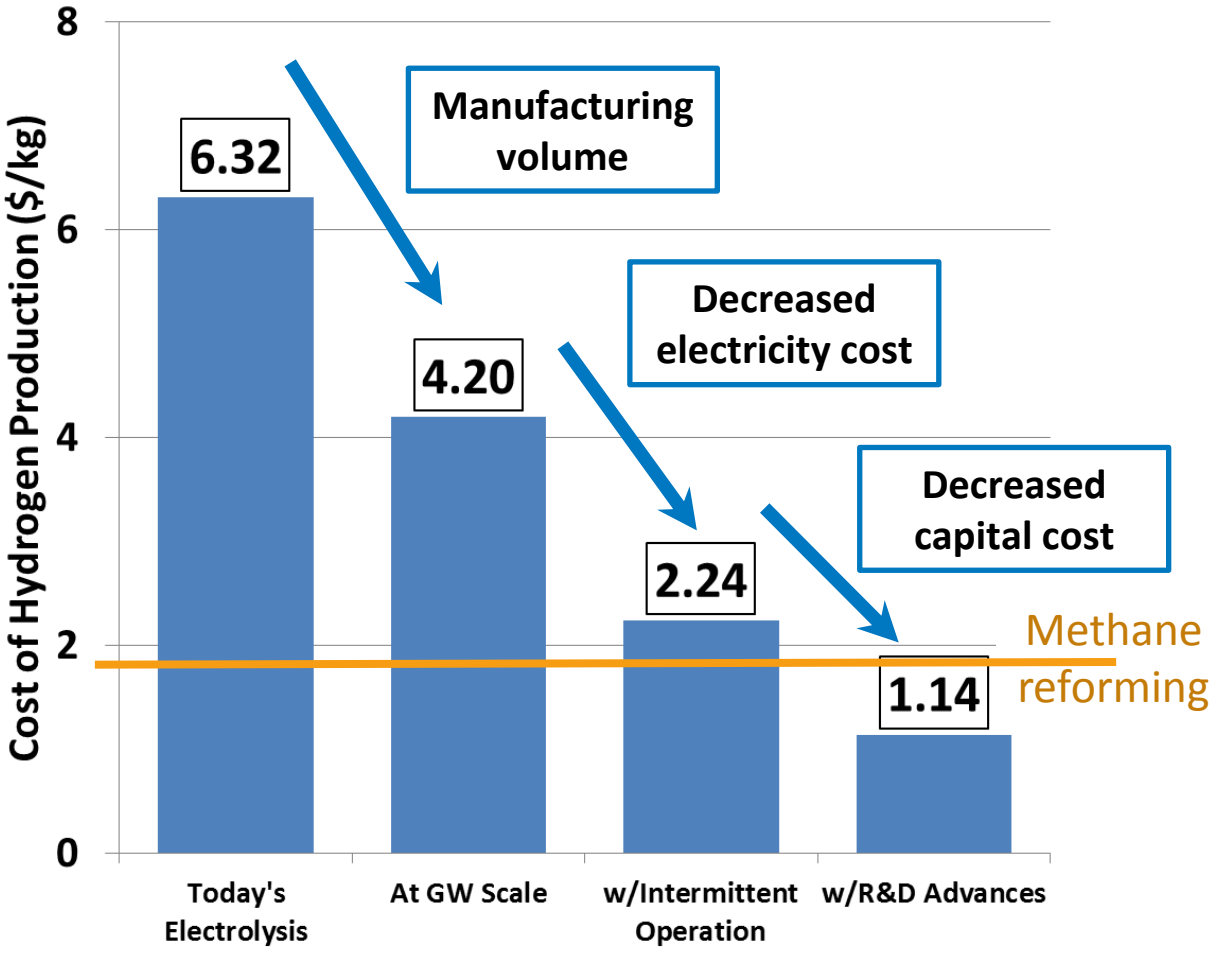
Red flows represent a reduction (between scenarios)



45% reduction in CO_2 emissions

Grid 75%, Transportation 25%, Industrial 25%

Improving the Economics of H_2 (Production)



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

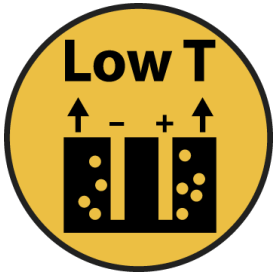
Target:

$1/kg H_2

This will revolutionize our Energy System

What is needed to achieve H_2 at Scale?

Low and High Temperature H_2 Generation



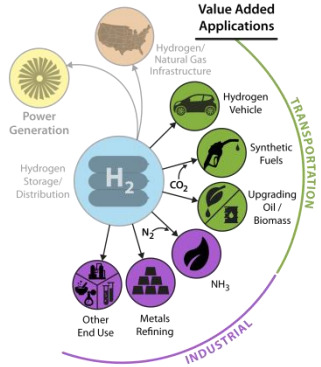
Development of **low cost, durable, and intermittent H_2** generation.

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

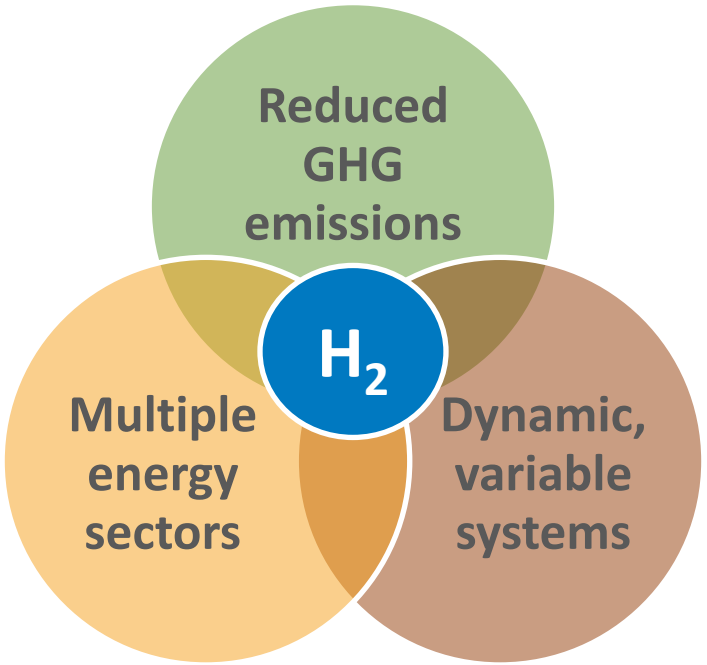
Future Electrical Grid

H_2 at Scale Value Summary

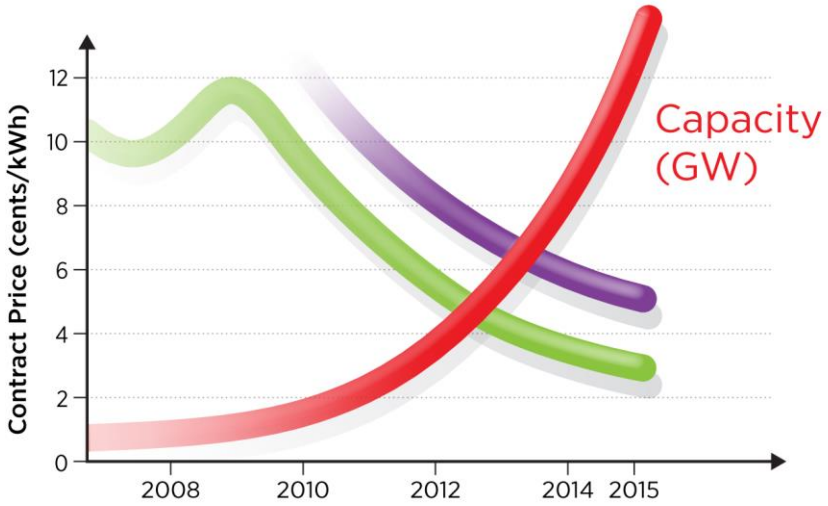
- Reducing emissions across sectors (GHG, criteria pollutants)
- Support needs of dynamic, variable power systems (dispatchable, scalable, 'one-way' storage)

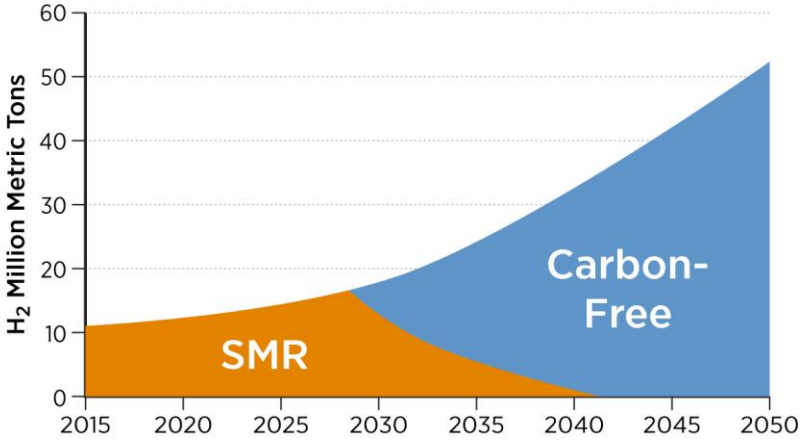
Unique potential of H_2 to positively impact all these areas

- Other benefits
  - Energy security (diversity/resiliency/domestic)
  - Manufacturing competitiveness/ job creation
  - Decreased water requirements



What does success look like?





Going from 10 million MT of H_2 from SMR to 50 million MT from carbon-free sources, will enable a 50 % decrease in CO_2 emissions by 20 50

H_2 @ Scale

Reduction by Sector

75%
Grid

25%
Transportation

25%
Industrial

Creating a sustainable future

50% fewer GHG emissions than today . . . by **2050**

MORE
Jobs
Security
Resiliency