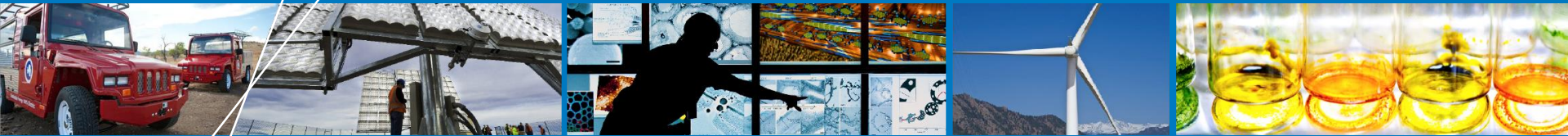


H2@Scale: Energy System-wide Benefits of Increased Hydrogen Implementation



Bryan Pivovar

November 7, 2017

Fuel Cell Seminar

Downtown Los Angeles



<http://www.latimes.com/local/la-me-air-pollution-0428-pictures-photogallery.html>

Air emissions in metropolitan areas has been linked to severe health effects, such as asthma and cardiovascular illnesses.

American Lung Association Website

Most Polluted Cities

By Ozone	By Year Round Particle Pollution	By Short-Term Particle Pollution
#1: Los Angeles-Long Beach, CA	#1: Visalia-Porterville-Hanford, CA	#1: Bakersfield, CA
#2: Bakersfield, CA	#2: Bakersfield, CA	#2: Fresno-Madera, CA
#3: Fresno-Madera, CA	#3: Fresno-Madera, CA	#2: Visalia-Porterville-Hanford, CA
#4: Visalia-Porterville-Hanford, CA	#4: San Jose-San Francisco-Oakland, CA	#4: Modesto-Merced, CA
#5: Phoenix-Mesa-Scottsdale, AZ	#5: Los Angeles-Long Beach, CA	#5: Fairbanks, AK
#6: Modesto-Merced, CA	#6: Modesto-Merced, CA	#6: San Jose-San Francisco-Oakland, CA
#7: San Diego-Carlsbad, CA	#7: El Centro, CA	#7: Salt Lake City-Provo-Orem, UT
#8: Sacramento-Roseville, CA	#8: Pittsburgh-New Castle-Weirton, PA-OH-WV	#8: Logan, UT-ID
#9: New York-Newark, NY-NJ-CT-PA	#9: Cleveland-Akron-Canton, OH	#9: Los Angeles-Long Beach, CA
#10: Las Vegas-Henderson, NV-AZ	#10: San Luis Obispo-Paso Robles-Arroyo Grande, CA	#10: Reno-Carson City-Fernley, NV
#11: Denver-Aurora, CO		#11: El Centro, CA
#12: Houston-The Woodlands, TX		#12: Lancaster, PA

CA: 7 out of top 8

CA: top 7

CA: 4 out of top 5



AMERICAN
LUNG
ASSOCIATION®

STATE
OF THE **AIR** 2017

<http://www.lung.org/our-initiatives/healthy-air/sota/city-rankings/most-polluted-cities.html>

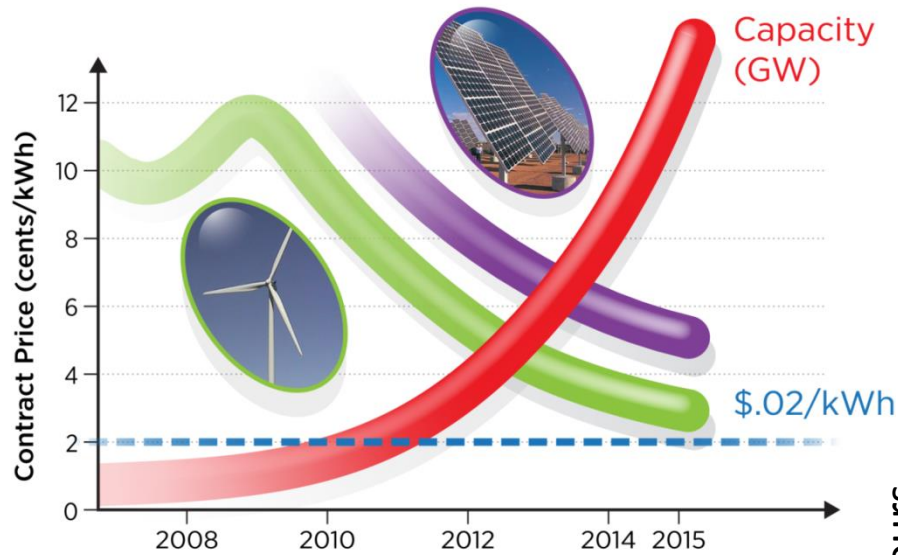
Energy System Challenge

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

**How do we supply all
these services in the
best way?**

Changing Economics: Intermittent Electricity

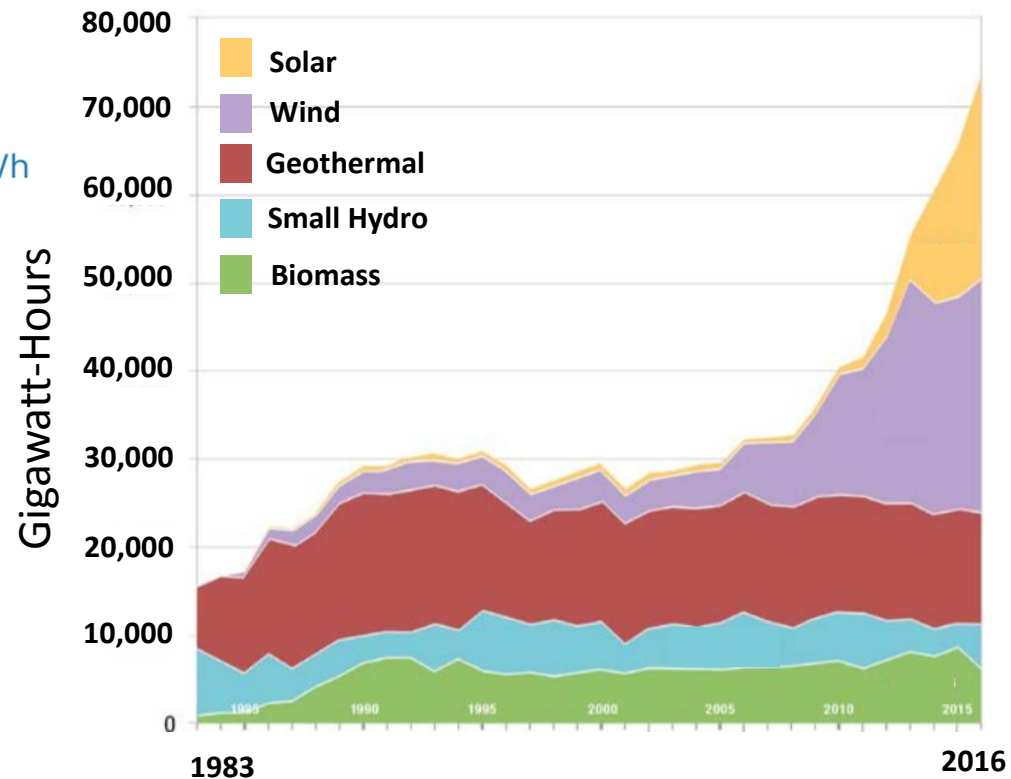
Falling Renewable Prices



Source: (Arun Majumdar)

1. DOE EERE Sunshot Q1'15 Report,
2. DOE EERE Wind Report, 2015

Growth in California Renewable Generation

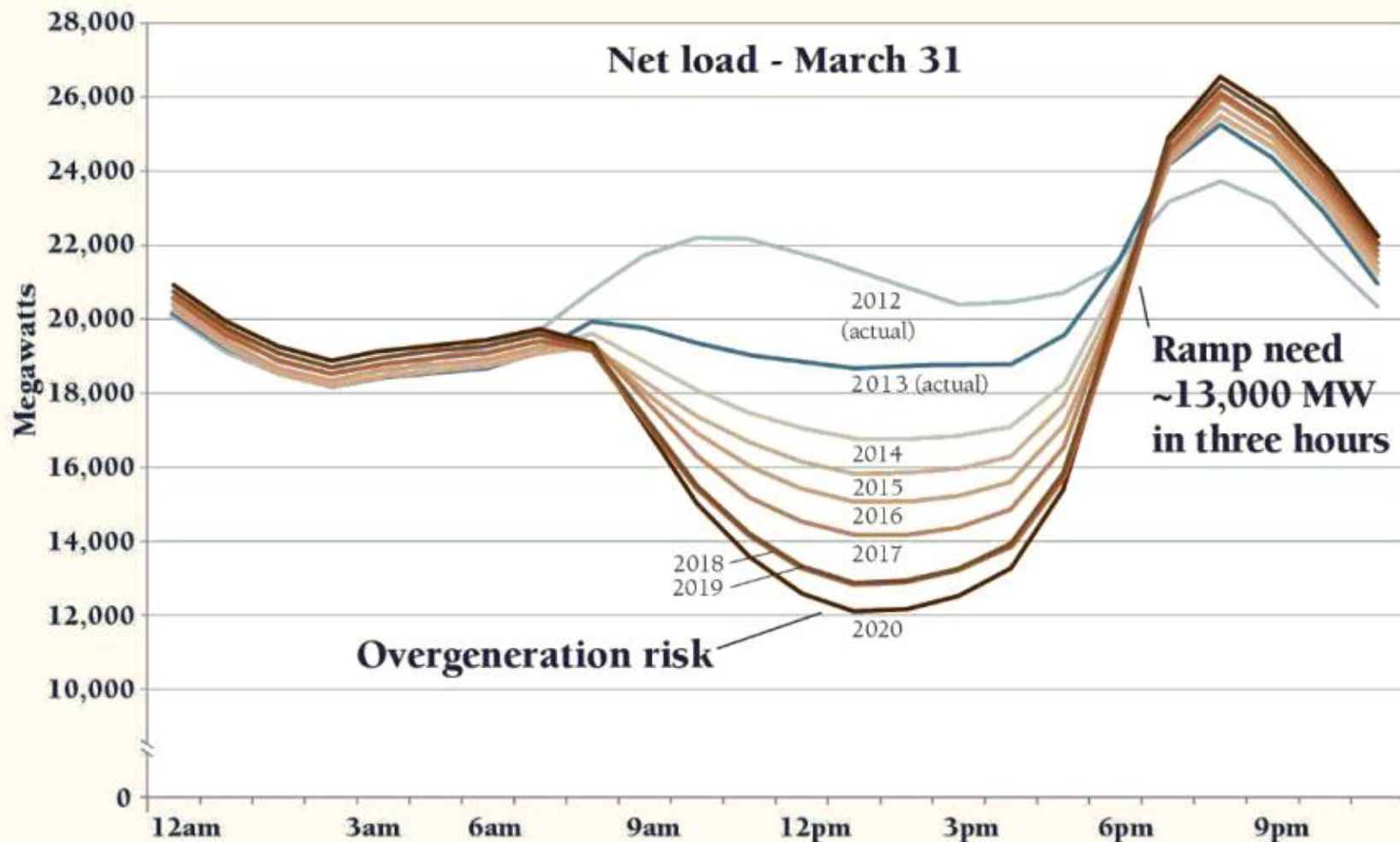


Source: California Energy Commission

http://www.energy.ca.gov/renewables/tracking_progress/documents/renewable.pdf

Changing Energy System: Grid Flexibility

California Independent System Operator Duck Curve¹

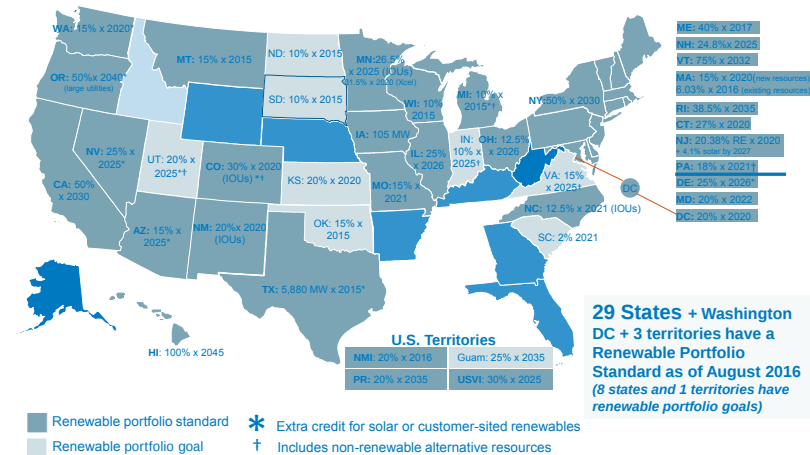


Changing Energy System – Policy

Renewable Portfolio Standards (RPS)

Senate Bill 350, signed by Gov. Edmund G. Brown, Jr. codifies 50% by 2030 RPS (2015)

<http://www.energy.ca.gov/renewables/>



Zero Emission Vehicles (ZEV)

2016 ZEV Action Plan toward 1.5 million ZEVs by 2025.

https://www.gov.ca.gov/docs/2016_ZEV_Action_Plan.pdf

Renewable Gas Standard

SB-687 Renewable gas standard

http://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201520160SB687

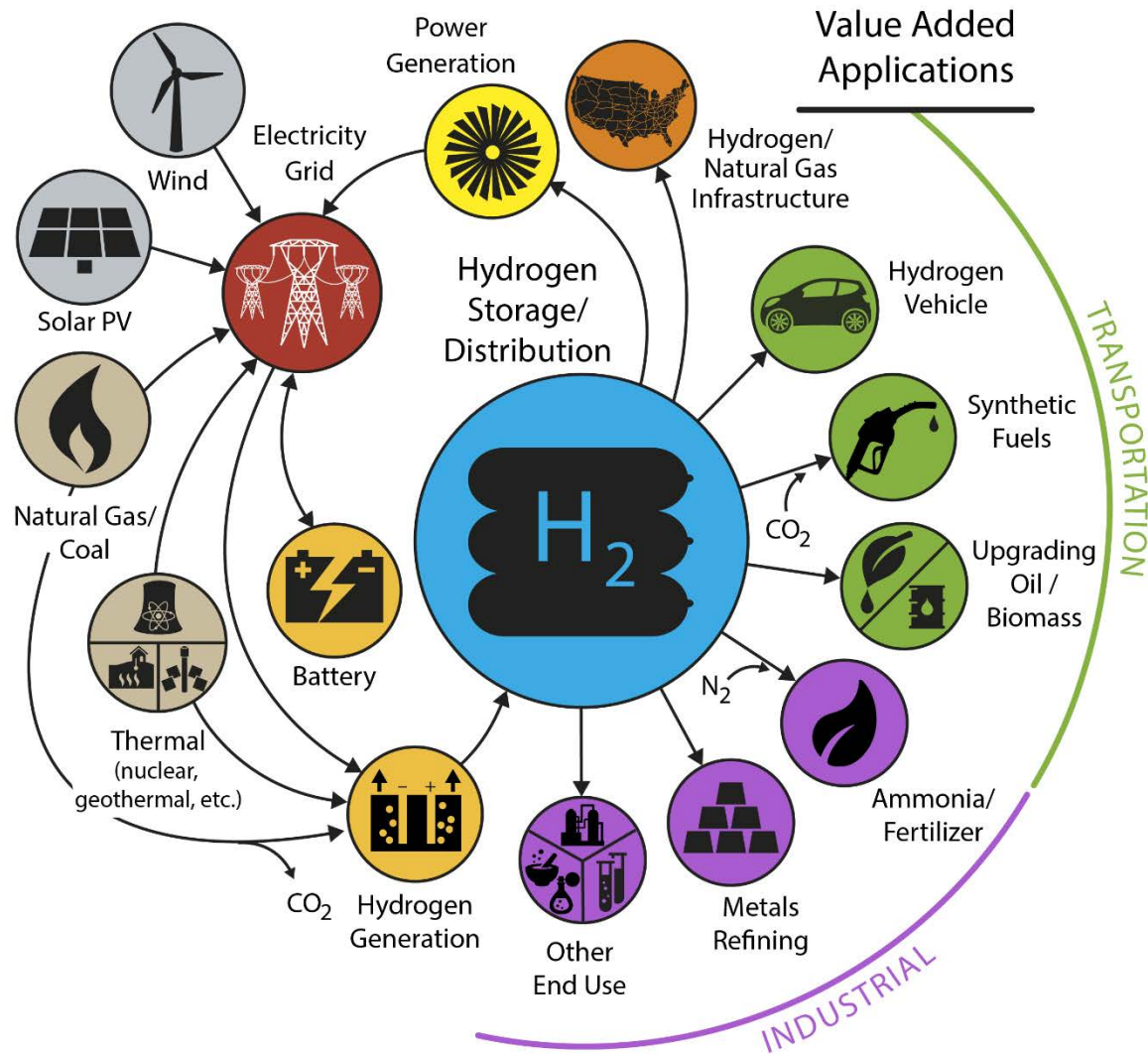


<https://www.c2es.org/us-states-regions/policy-maps/zev-program>

- **Dwight D. Eisenhower**

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

Conceptual H2@Scale Energy System*



*Illustrative example, not comprehensive

H2@Scale Vision

- **Attributes**

- o Large-scale, clean, cross-sector energy
 - Unique ability to cleanly and efficiently power industry and transportation
- o Energy system flexibility, resiliency, and hybridization
 - Increased renewables
 - Expanded thermal generation (nuclear, CSP, geothermal) through hybridization
 - Increased H2 from methane (carbon capture/use potential)

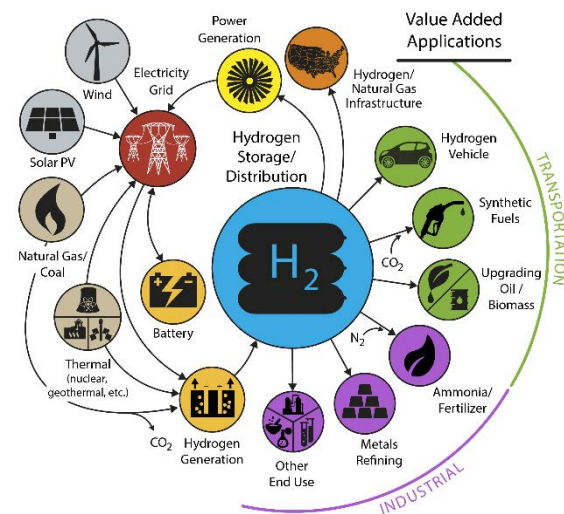
- **Benefits**

- o Economic factors (jobs, GDP)
- o Enhanced Security (energy, manufacturing)
- o Environmental Benefits (air, water)

Whole > Sum of Parts

Hydrogen will help us do better

- Transition in scale and end uses, where the unique attributes of H₂ make it a parallel to electrons in society's energy use.
 - Satisfy broad demands (grid, buildings, transportation, industry)
 - Technical potential of demand: 60 MMT/year¹
 - Enables aggressive growth in renewable penetration
 - Establish markets and industry to support energy at the global scale.
 - H₂ energy sector has established industry and profitability



We are critical to creating a sustainable future.

1. Preliminary analysis, https://www.hydrogen.energy.gov/pdfs/review17/tv045_ruth_2017_o.pdf