NREL
NATIONAL RENEWABLE ENERGY LABORATORY

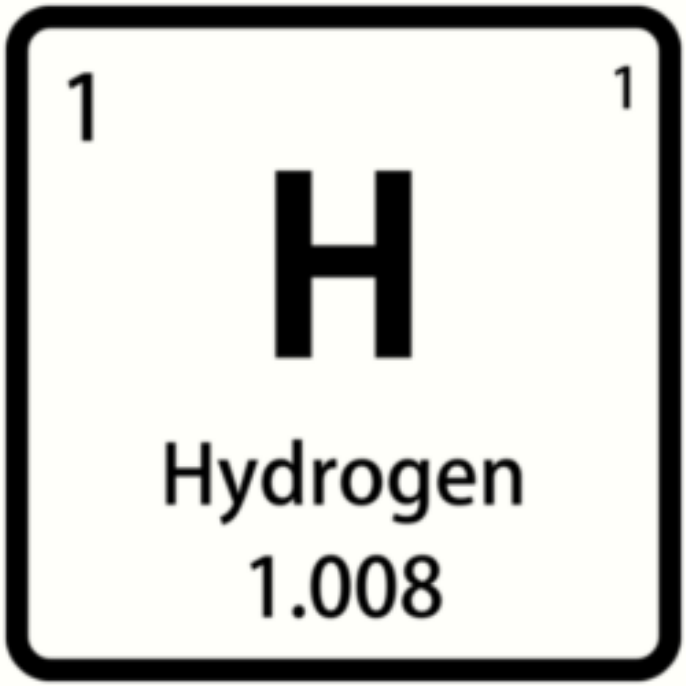
H2@Scale: Increasing H2 Implementation in the Energy System

Bryan Pivovar
National Renewable Energy Laboratory

ESIG
October 8, 2020

October 8 is H_2 Day

- Much like
  - Pi day 3/14
  - Star Wars day 5/4
- H_2 has a day
  - 10/08 based on atomic weight of 1.008



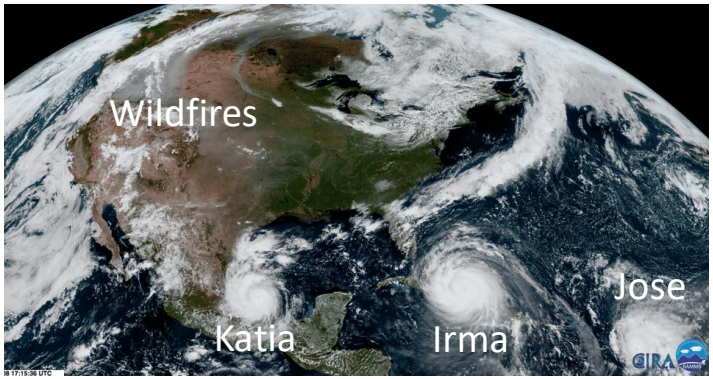
Select (Relevant) Megatrends

- Falling renewable costs
- Low cost, intermittent renewable electrons
- Energy policy
- Increased electrification

Renewable Portfolio Standards

Senate Bill 100, signed by Gov. Edmund G. Brown, Jr. codifies 60% by 2030 & 100% by 2045

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

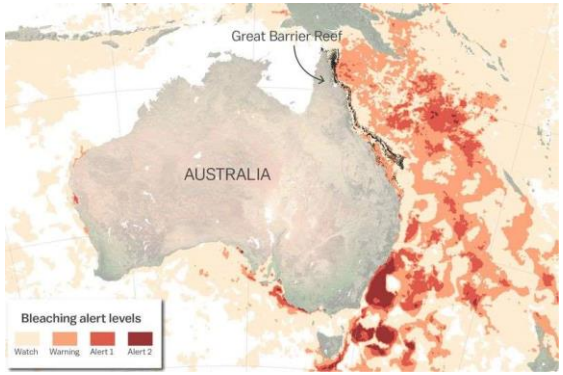


When the Planet Looks Like a Climate-Change Ad (9/12/17)

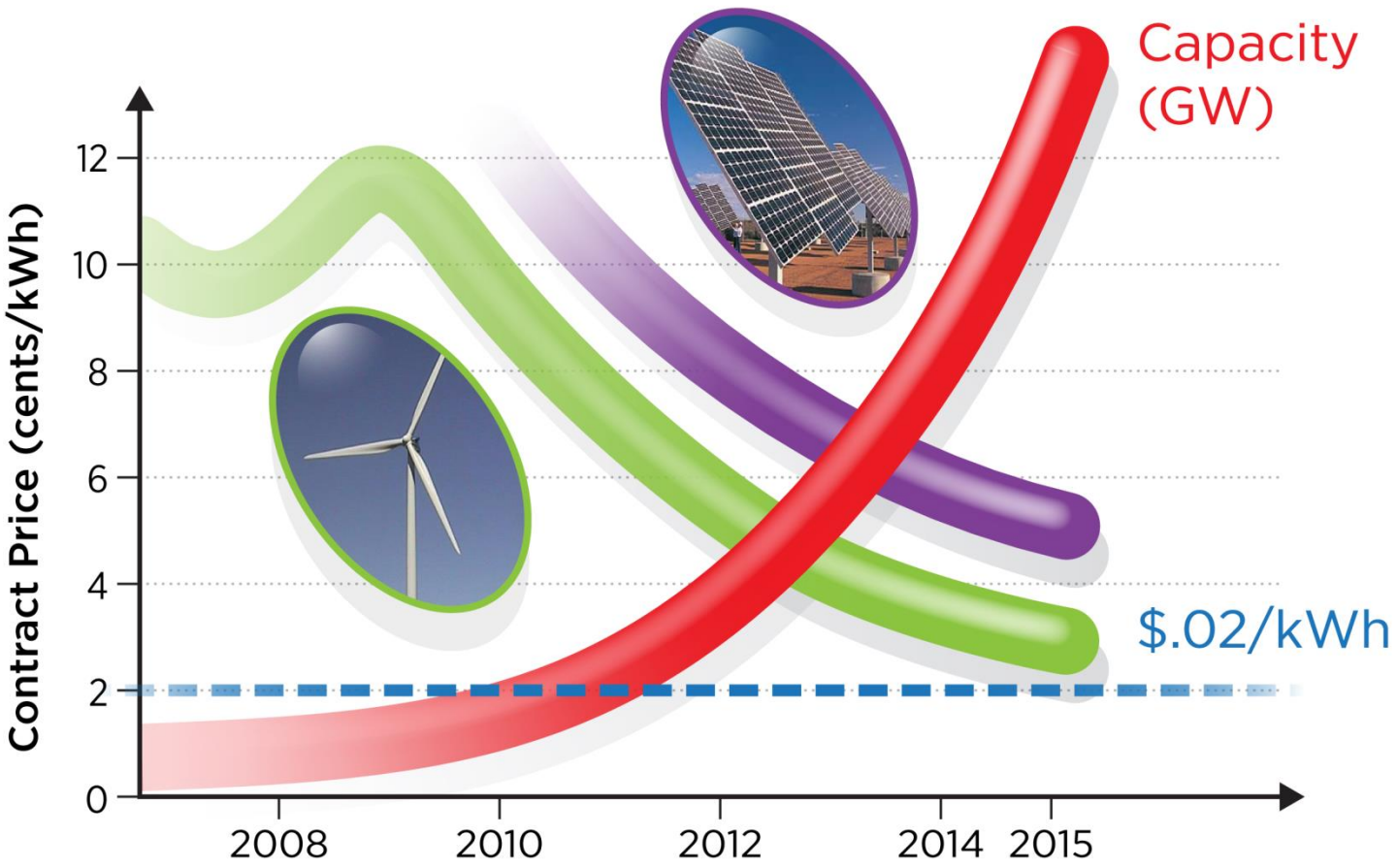
https://www.theatlantic.com/science/archive/2017/09/an-extraordinary-week-in-north-american-weather/539544/

Downtown Denver from NREL's Energy System Integration Facility

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

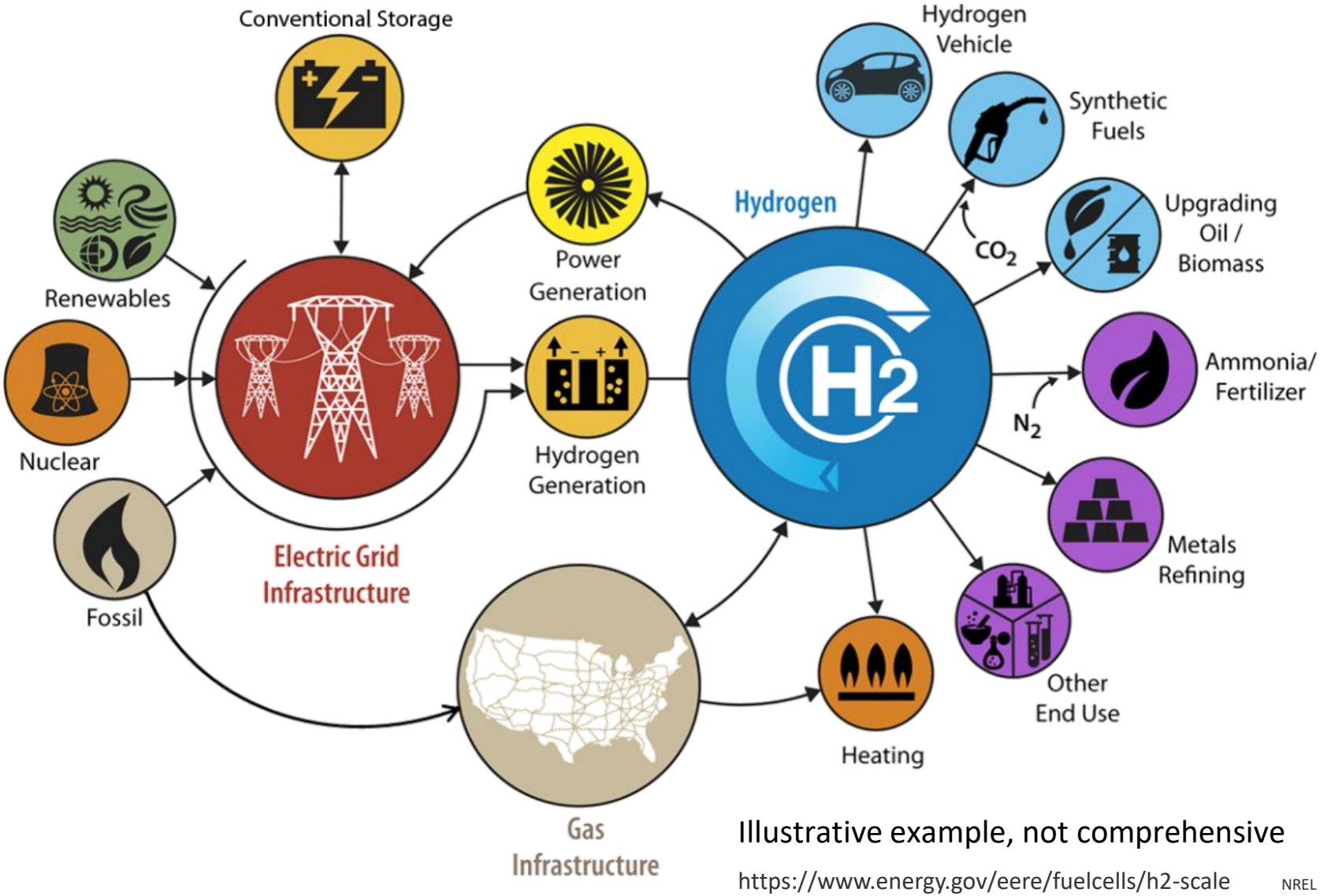


Renewable electricity price trends



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

H2@Scale Opportunity



Illustrative example, not comprehensive

https://www.energy.gov/eere/fuelcells/h2-scale

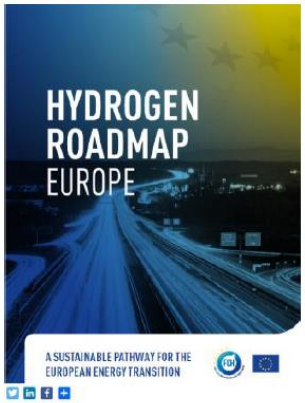
H2@Scale Vision

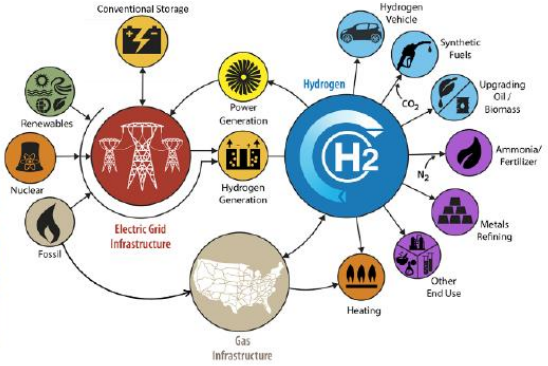
- Attributes
  - Cross-sectoral and temporal energy impact
  - Clean, efficient end use

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

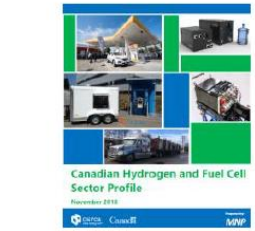
Getting all these benefits in a single energy system significantly enhances value proposition.

“Hydrogen – at Scale and Sector Coupling” – A Common Vision Across Multiple Regions in the World





Global Action Agenda released at Hydrogen Energy Ministerial, Tokyo (9/25/2019)
Aspirational Targets:
“10, 10, 10”
10M systems,
10K stations, 10 years



High priority areas include: Global harmonization of codes and standards and addressing gaps, safety
From 10/19 IPHE meeting: Establish common definition of clean hydrogen to facilitate international trade

https://www.hydrogen.energy.gov/pdfs/htac_nov19_01_satyapal.pdf

H_2 is different today and changing fast

- H_2 Council*
  - Launched in January 2017 its members include leading companies with over $10 billion in investments along the hydrogen value chain, including transportation, industry, and energy exploration, production, and distribution.

> ***Potential Impacts from Hydrogen Council Roadmap Study. By 2050:***
> - *$2.5 trillion in global revenues*
> - *30 million jobs*
> - *400 million cars, 15-20 million trucks*
> - *18% of total global energy demand*

13 members (Jan 2017).

32 steering members and 20 supporting members (Nov 2018).

92 members (Sept 2020).

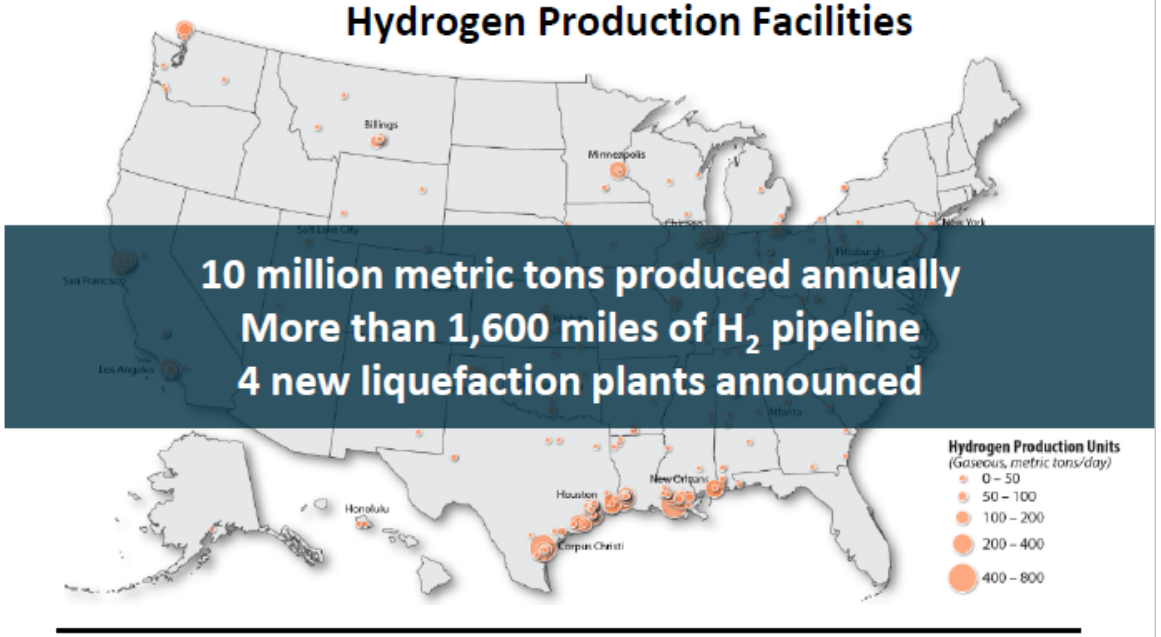
*Steering members shown, additional supporting members
www.hydrogencouncil.com

U.S. Snapshot of Hydrogen and Fuel Cells Applications

Examples of Applications in the United States

- **>500MW** Stationary Power
- **>28,000** Forklifts
- **>30** Fuel Cell Buses
- **>40** H_2 Retail Stations
- **>7,800** Fuel Cell Cars

Hydrogen Production Facilities



Hydrogen Stations: Examples of Plans Across States

California
CaFCP roadmap: 1,000 stations by 2030

Northeast
12 – 20 stations planned

HI, OH, SC, NY, CT, MA, CO, UT, TX, MI, and others
with interest

https://www.hydrogen.energy.gov/pdfs/htac_nov19_01_satyapal.pdf

US Hydrogen Study/Roadmap

Potential benefits of hydrogen in the US in the ambitious scenario – by the numbers

Hydrogen in the US could …

Strengthen the US economy, supporting up to:

Create a highly competitive source of domestically produced low-emission energy

Provide significant environmental benefits and improve air quality

Benefit the US energy system

~$140 bn in revenue

~100% domestically produced

Less CO_2, NO_x, SO_x, and particulate emissions in cities

0.7 m jobs

… in 2030

~$750 bn in revenue

~100% domestically produced

-16% CO_2

~14% of final energy demand

3.4 m jobs

-36% NO_x

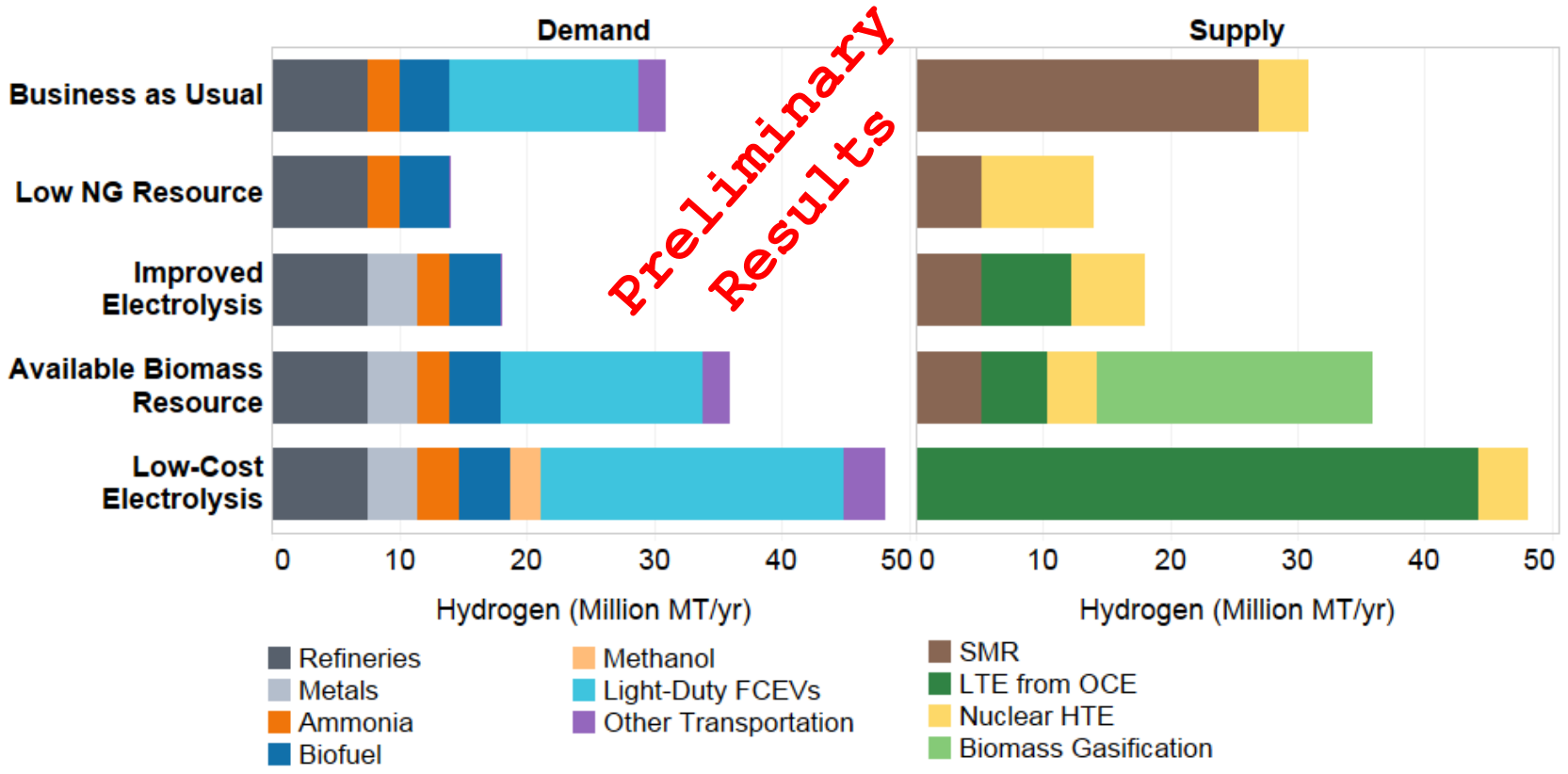
… in 2050

This report was developed with input from 19 companies and organizations:

- Air Liquide
- American Honda Motor Co., Inc
- Audi
- Chevron
- Cummins Inc.
- Daimler AG: Mercedes-Benz Fuel Cell GmbH/Mercedes-Benz Research & Development North America
- Engie
- Exelon Corporation
- Hyundai Motor Company
- Microsoft
- Nikola Motors
- Nel Hydrogen
- Plug Power
- Power Innovations
- Shell
- Southern California Gas Company
- Southern Company Services, Inc.
- Toyota
- Xcel Energy

http://www.fchea.org/us-hydrogen-study

H2@Scale Analysis Overview

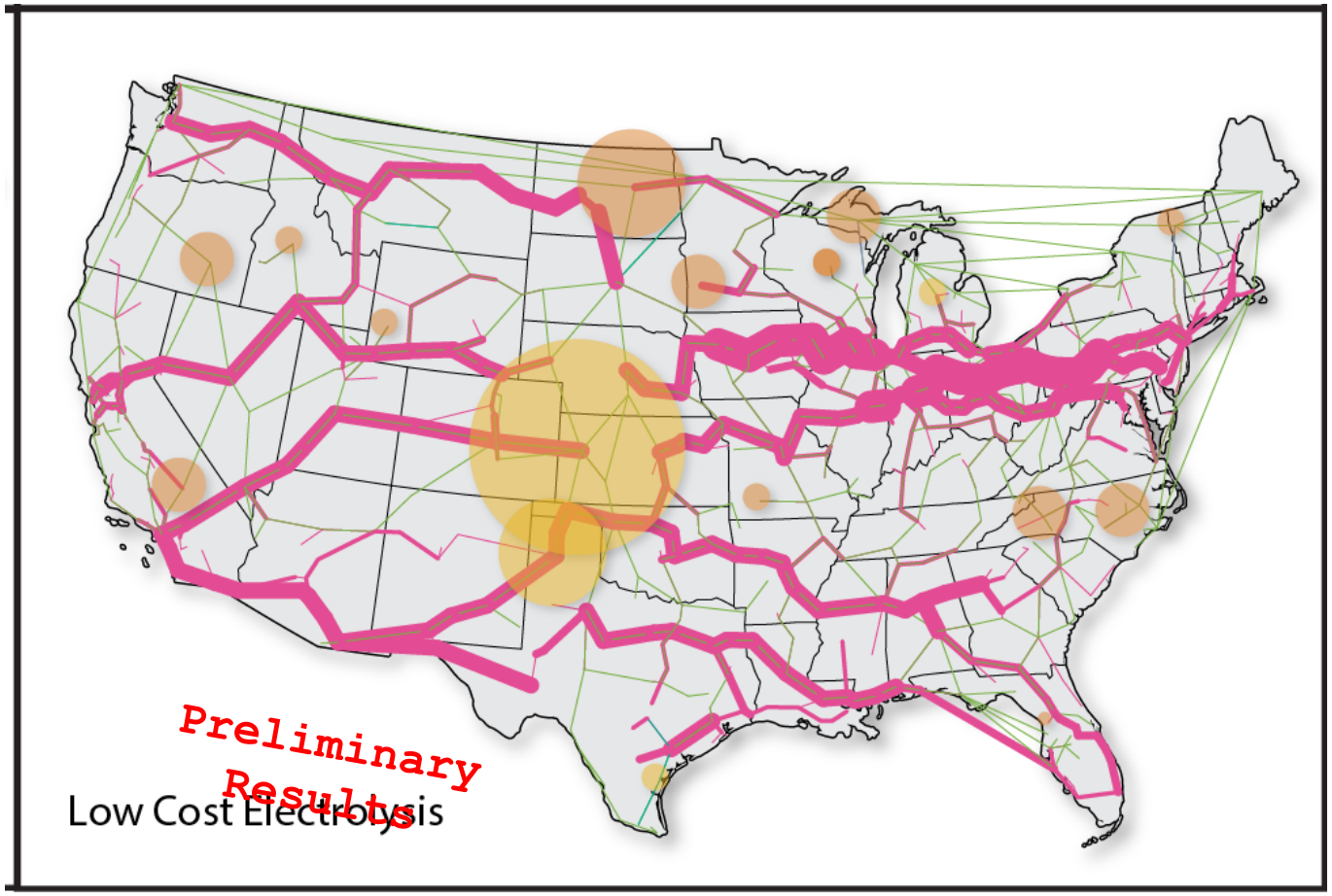


Accomplishment: Developed and Reviewed Economic Potential Results: ***14 - 48 MMT H_2 / yr***

https://www.hydrogen.energy.gov/pdfs/review19/sa171_ruth_2019_o.pdf

Initiated Analysis of Spatial and Temporal Issues

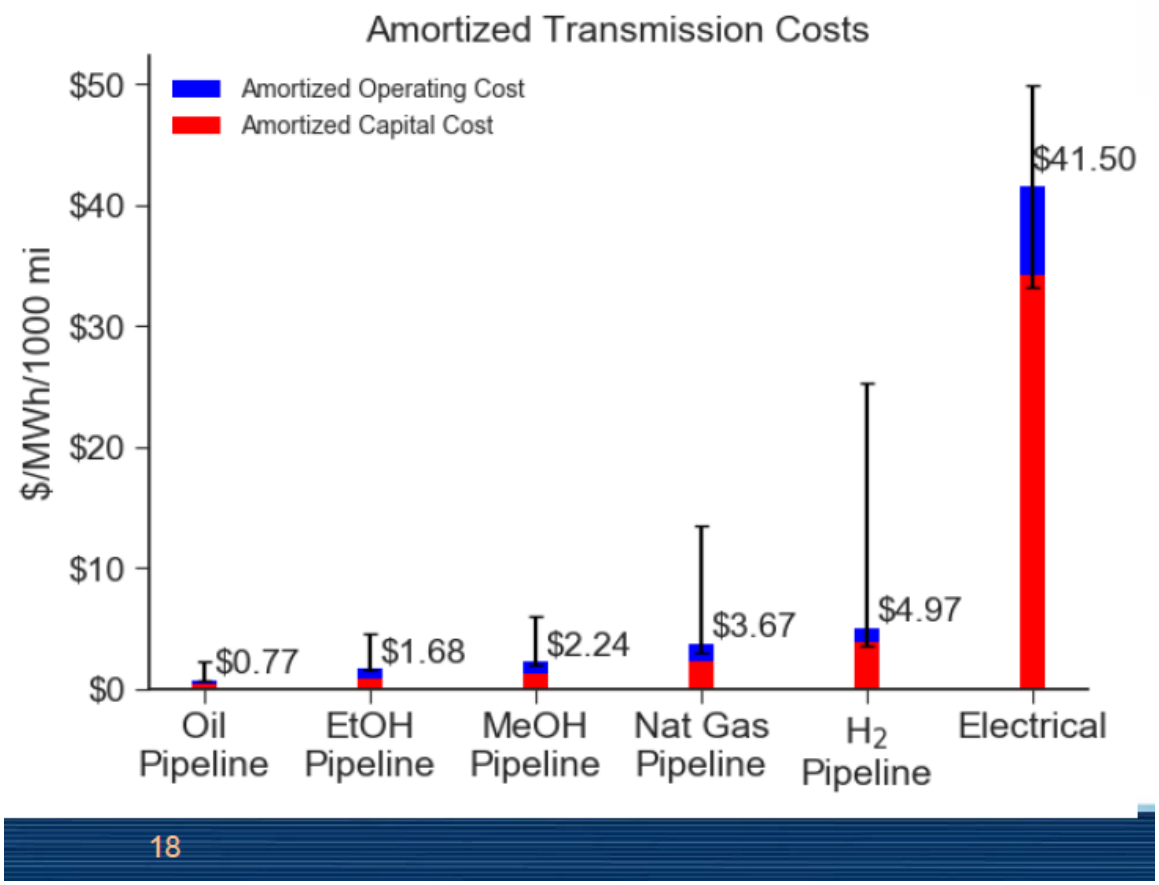
Looks for most economic build out options, in this case pipeline transport and salt caverns storage found as optimal.



Source: Ruth, et al. "The Technical and Economic Potential of H2@Scale within the United States" (2019) – **Version for External Review**

Electrolysis includes low-temperature and high-temperature electrolysis

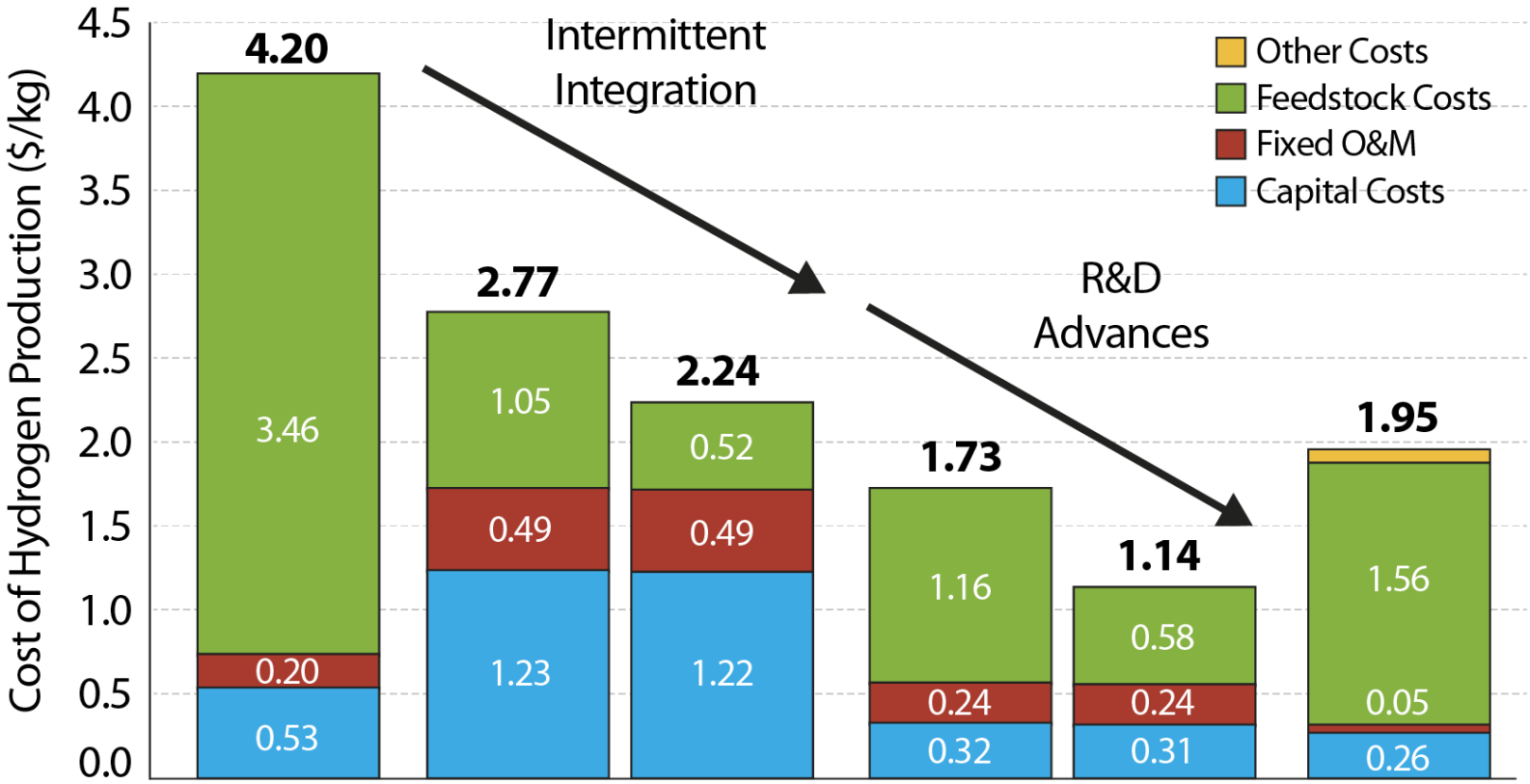
Energy Vectoring Costs



The costs of energy transmission are also being investigated.

https://www.hydrogen.energy.gov/pdfs/review18/pd102_james_2018_p.pdf

Electrolysis cost pathway



Capacity Factor	97%	40%	40%	0.9
Cost of Electricity	¢6.6/kWh	¢2/kWh | ¢1/kWh	¢2/kWh | ¢1/kWh	
Capital Cost	$400/kW	$400/kW	$100/kW	
Efficiency (LHV)	66%	66%	60%	
	Electrolyzer			**SMR**

Thank You

Bryan.Pivovar@nrel.gov

www.nrel.gov

Expanded content included in this presentation available at

https://www.hydrogen.energy.gov/pdfs/review19/sa171_ruth_2019_o.pdf
https://www.hydrogen.energy.gov/pdfs/htac_nov19_01_satyapal.pdf

NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

NREL
NATIONAL RENEWABLE ENERGY LABORATORY