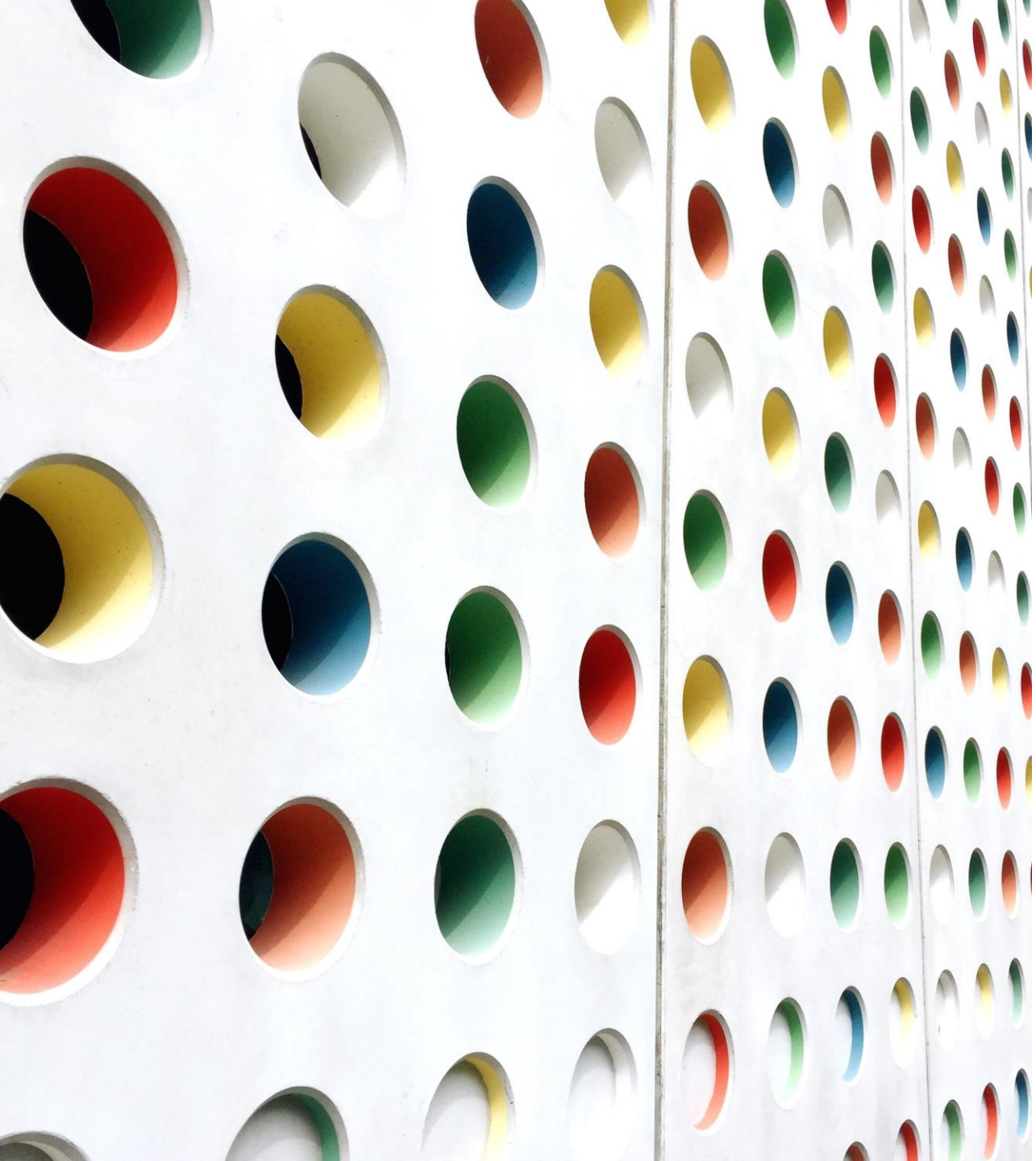


The Hydrogen Economy

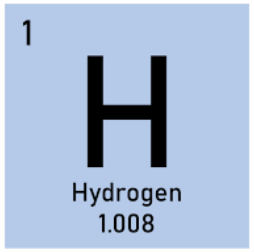
MAREA
March 30, 2021
Alison Hawkins

About Me

- 20+ years in industry, industrial gas centric
- Work experiences span environmental permitting, intellectual property, account management, business development, product management, and business management
- Focus area has been large hydrogen projects

- BS ChE – Lehigh University
- Live in Chandler, AZ
- Outdoor enthusiast

Hydrogen



- While hydrogen has been used for industrial uses dating back to the early 20th century, demand rapidly increased following passage of the Clean Air Act, most notably the 1990 amendment to address acid rain, ozone depletion, and toxic air pollution.
- As of 2020, 95% of all hydrogen is produced from fossil fuels
- Current global demand ~70 Million tons annually
- Main uses are petroleum refining, ammonia, methanol, metals, glass, semiconductors, food

- **Global goals for decarbonization** are leading to renewed interest in H2 use across new sectors including transportation and power and for a renewed focus on **renewable hydrogen**

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Types of Hydrogen

	Term	Technology Employed	Electricity Source / Feedstock	Emissions
Electricity Based H_2	Green H_2 / Renewable H_2	Water Electrolysis	Wind/ Solar/ Hydropower/ Geothermal/ Tidal	None
	Purple/Pink H_2		Nuclear power	None
	*Yellow H_2		Mixed-origin grid energy	Low CO_2 emissions
Fossil Fuels Based H_2	Blue H_2	Natural Gas Reforming + CCUS / Gasification + CCUS	Natural Gas / Coal	
	Turquoise H_2	Pyrolysis	Natural Gas	Solid carbon by-product produced
	Grey H_2	Natural Gas Reforming	Natural Gas	Medium CO_2 emissions
	Brown H_2	Gasification	Brown Coal (a.k.a Lignite)	High CO_2 emissions
	Black H_2	Gasification	Black Coal	High CO_2 emissions

Other terms used:

- Clean H_2
- Zero-Carbon H_2
- Carbon-Neutral H_2

Low Carbon H_2

All information stated is correct at time of writing (Feb 2021) and may be subject to change.

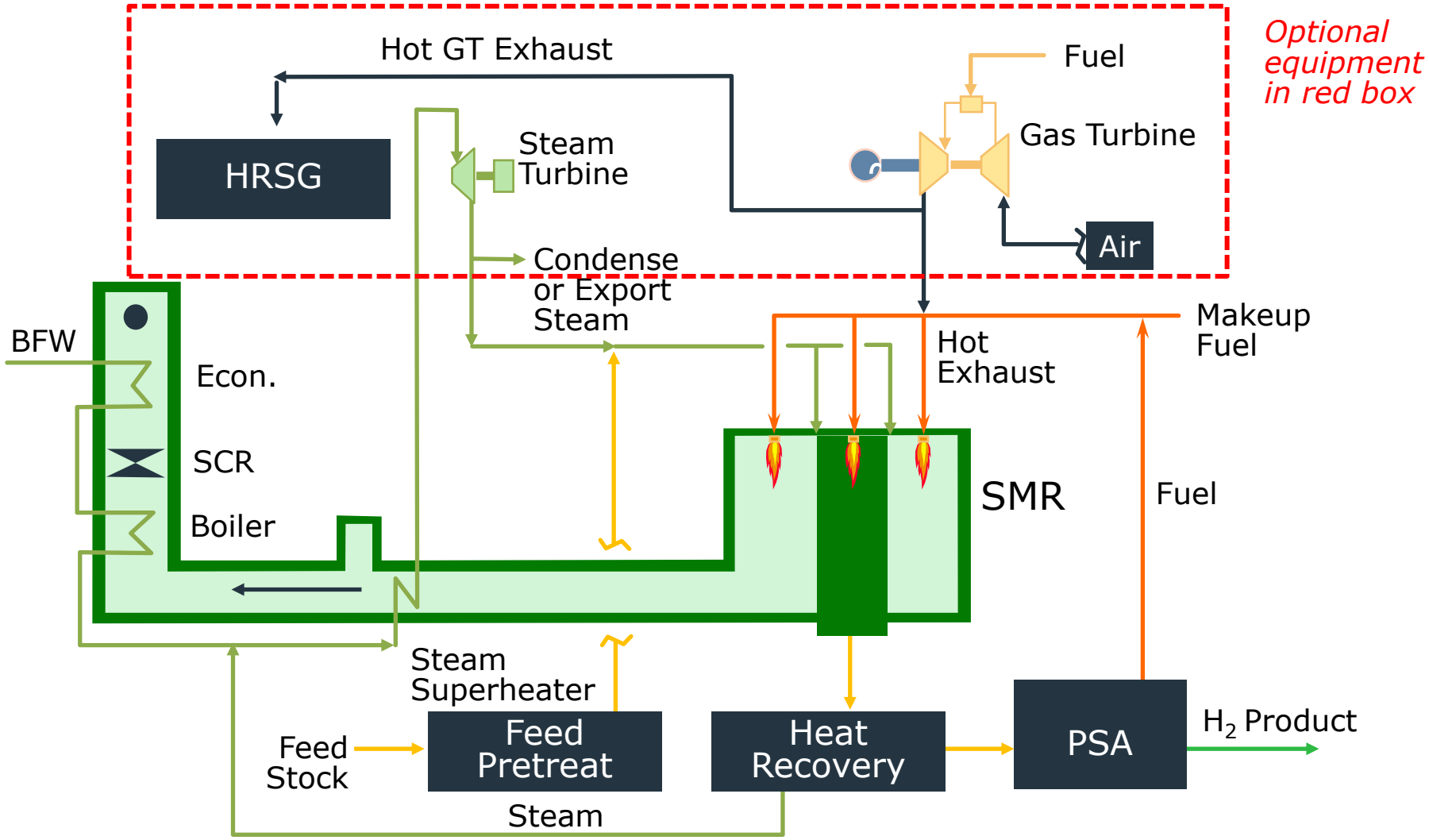
**There is still some ambiguity around Yellow H_2, besides mixed-origin grid energy it has also been used to describe:*

i. H_2 produced via electrolysis powered solely by solar electricity

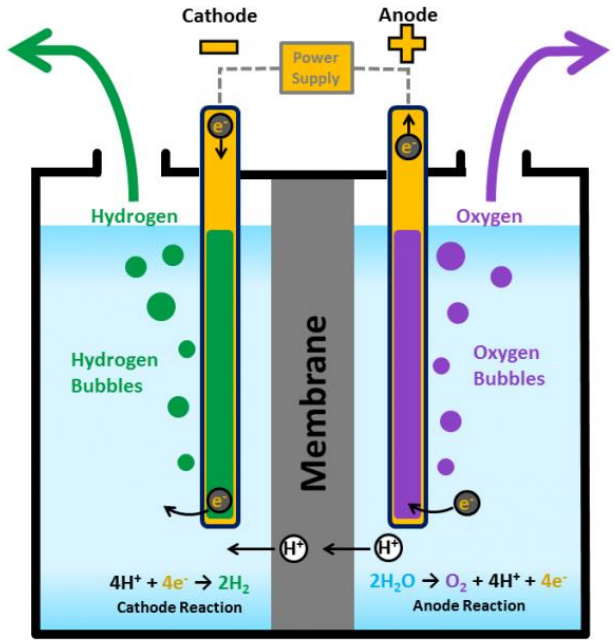
ii. H_2 produced via electrolysis powered by nuclear

By: Dr. Madana Leela Nallappan, Energy Industries Council (EIC UK)

Steam Methane Reformer - Simplified PFD



Water Electrolyzer Process for H2 Production

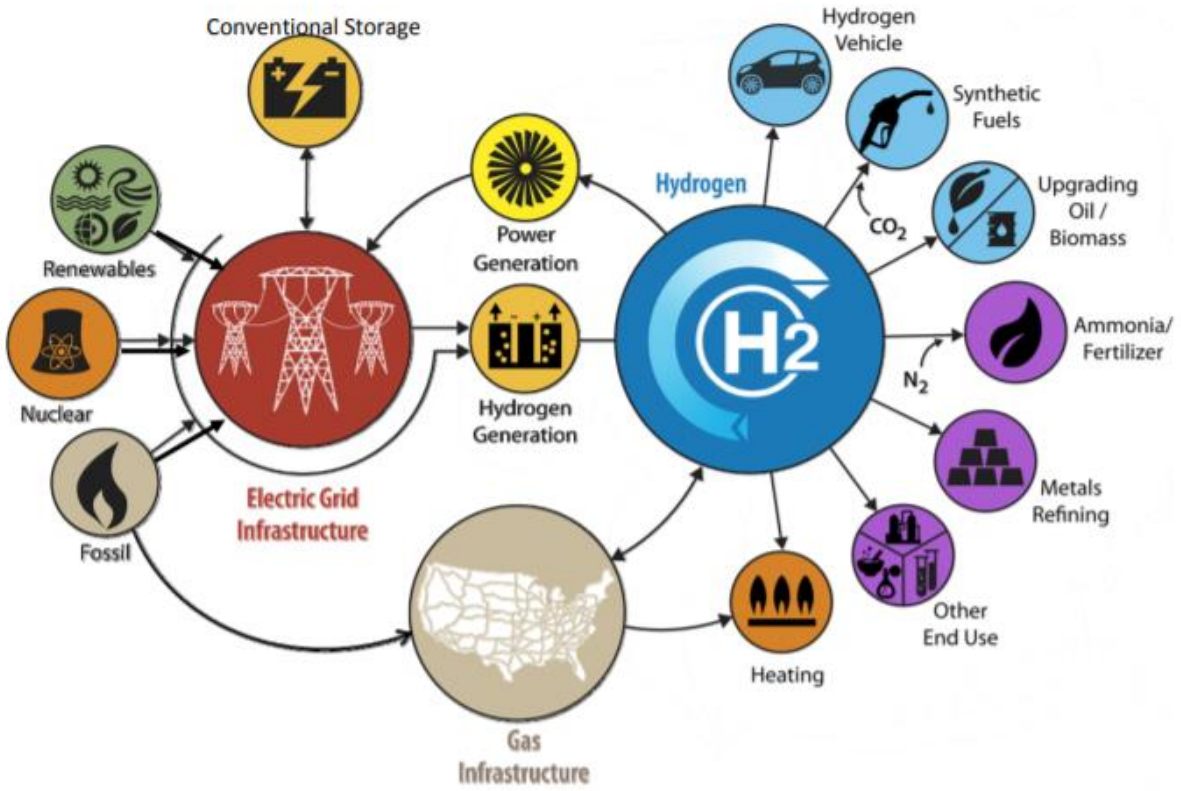


•Water reacts at the anode to form oxygen and positively charged hydrogen ions (protons).
•The electrons flow through an external circuit and the hydrogen ions selectively move across the PEM to the cathode.
•At the cathode, hydrogen ions combine with electrons from the external circuit to form hydrogen gas.
Anode Reaction: $2H_2O \rightarrow O_2 + 4H^+ + 4e^-$
Cathode Reaction: $4H^+ + 4e^- \rightarrow 2H_2$

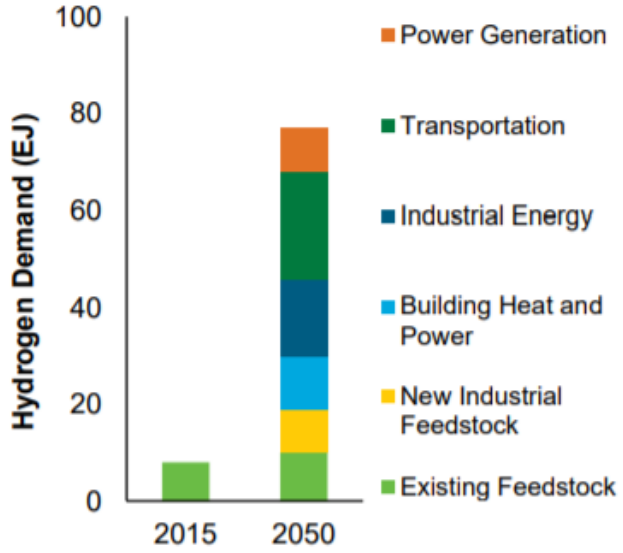
3 Main Types:

- Polymer Electrolyte Membrane (PEM)
  - Electrolyte is a solid specialty plastic material
- Alkaline Electrolyzers
  - Operate via transport of hydroxide ions (OH^-) through the electrolyte from cathode to anode with H2 generated on the cathode side
- Solid Oxide Electrolyzers
  - Use a solid ceramic material as the electrolyte that selectively conducts negatively charged oxygen ions

H_2@Scale: Enabling affordable, reliable, clean, and secure energy across sectors



VALUE PROPOSITION[2]



2. Source: "Hydrogen Scaling Up." Hydrogen Council. November 2017. http://hydrogencouncil.com/wp-content/uploads/2017/11/Hydrogen-scaling-up-Hydrogen-Council.pdf

Reference: Energy.gov/eere/fuelcells/h2scale

U.S. DEPARTMENT OF ENERGY | OFFICE OF ENERGY EFFICIENCY & RENEWABLE ENERGY | FUEL CELL TECHNOLOGIES OFFICE

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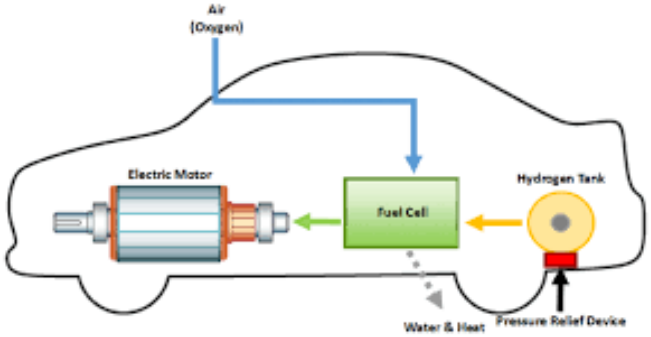
Fuel Cell Hydrogen Uses in Transportation



Type of Vehicle	Commercial Stage	Kg H2 per fill
Forklifts	Available	~1.5
Light duty vehicles	Available in limited markets	4-5
Buses	Available, development ongoing	20-30
Trucks	Under development/ limited market entry 2021-2024	60-100
Rail	Under development	200-350
Marine	Under development	TBD
Aviation	Under development	TBD
Large Industrial Equipment	Under development – mining, construction related	TBD

Duty Cycle Increasing

H2 Usage Increasing

FCEV = Electric vehicle that carries its own charging medium – H2

Benefits of FCEV – compared to BEV:

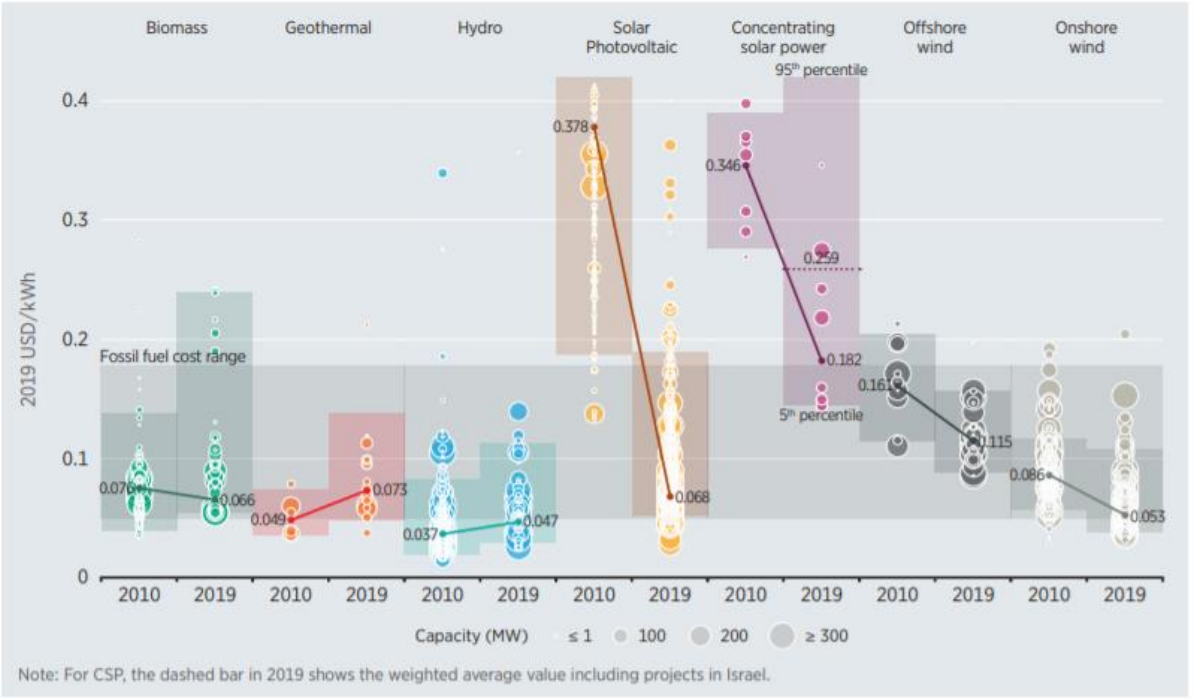
- Vehicle weight
- Refuel time
- Lifecycle costs
- Range

Decarbonization of Power

Biden has pledged to set the U.S. on the path to net-zero greenhouse gas emissions by 2050 with an interim target of decarbonizing the U.S. power sector by 2035

- Renewable costs greatly reduced but interruptible nature poses challenges
- Seasonal storage/ grid balancing needed for reliability
- Micro-grids on the rise
- Additional demand on grid from electrification = 3X current
- Major utilities have been pledging net zero carbon by 2050

Figure 1.2 Global LCOEs from newly commissioned utility-scale renewable power generation technologies, 2010-2019

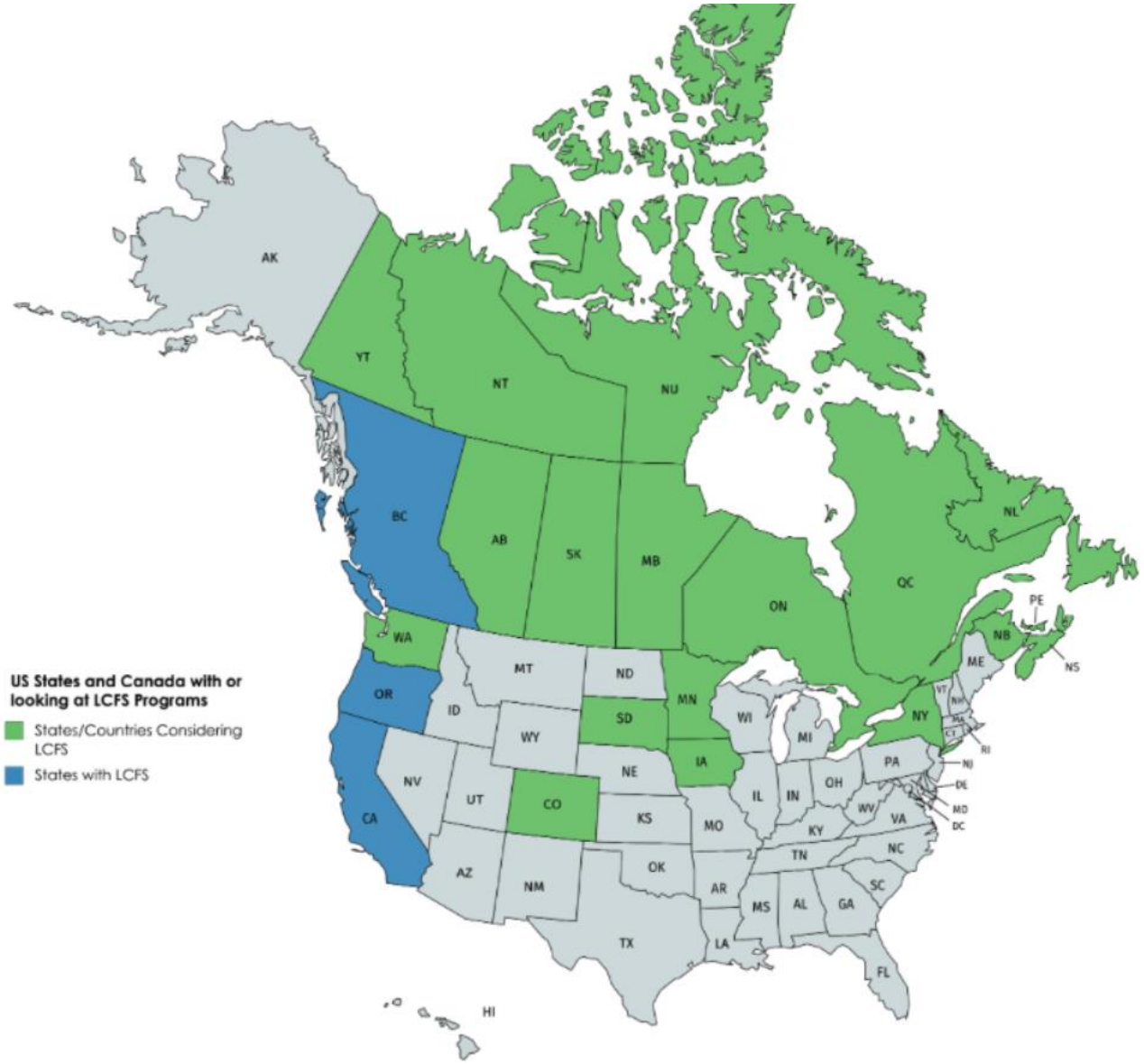


Source: IRENA Renewable Cost Database.

Note: This data is for the year of commissioning. The diameter of the circle represents the size of the project, with its centre the value for the cost of each project on the Y axis. The thick lines are the global weighted-average LCOE value for plants commissioned in each year. Real weighted average cost of capital (WACC) is 7.5% for OECD countries and China and 10% for the rest of the world. The single band represents the fossil fuel-fired power generation cost range, while the bands for each technology and year represent the 5th and 95th percentile bands for renewable projects.

Regulatory Framework for Carbon Reduction

- California leads the nation in a Low Carbon legislative framework
  - Low Carbon Fuel Standard (LCFS) requires that fuel providers reduce the carbon content of the transportation fuels they sell in CA
  - Innovative Clean Transit (ICT), mandatory phase out to 100% ZEBs by 2035
  - ICE phase-out: Newsom's order requires that all new cars and passenger trucks be ZEVs by 2035, drayage trucks by 2035, other medium and heavy duty vehicles by 2045
- Other states now following CA's lead



Source of Map: thejacobsen.com

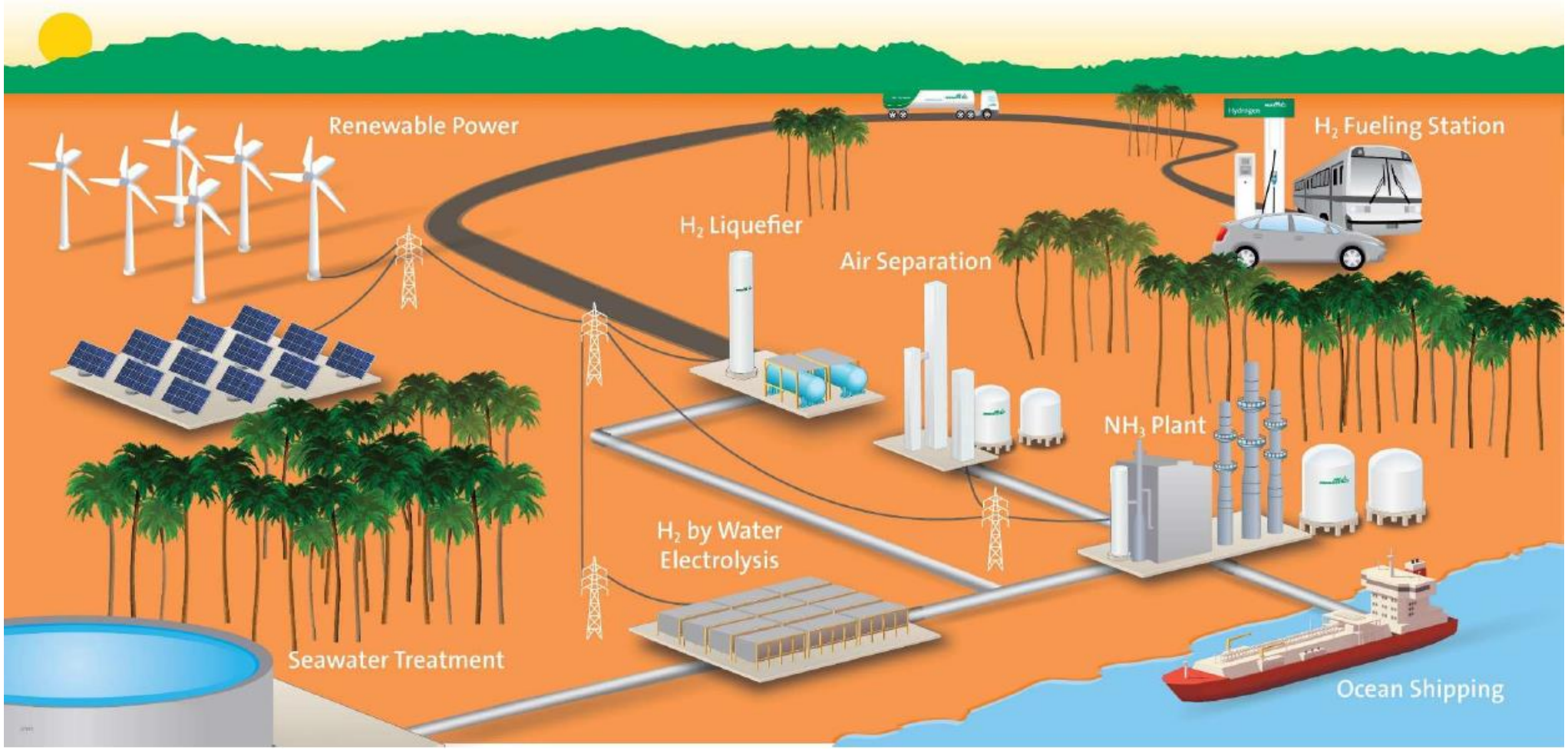
November 16, 2020

Announced Hydrogen Mega-Projects > 1.5 GW

Project Name	Location	Source of Renewable Power	Capacity	Anticipated Onstream
Asian Renewable Energy Hub	Western Australia	Onshore wind + solar	14 GW/ 1.75 MM tpy	2027-2028
NortH2	Netherlands	Offshore wind	10 GW/ 1 MM tpy	2040
AquaVentus	Germany	Offshore wind	10 GW/ 1 MM tpy	2035
Murchison Renewable Hydrogen Project	Western Australia	Onshore wind + solar	5 GW/ tbd	2028
Beijing Jingneng Inner Mongolia	Inner Mongolia, China	Onshore wind + solar	5 GW/ 0.4-0.5 MM tpy	2021
Helios Green Fuels Project	Neom, Saudi Arabia	Onshore wind + solar	4 GW/ 0.24 MM tpy	2025
Pacific Solar Hydrogen	Queensland, Australia	Solar	3.6 GW/ 0.2 tpy	tbd
H2-Hub Gladstone	Queensland, Australia	Not yet specified	3 GW/ tbd	2025+
HyEx	Antofagasta, Chile	Solar	1.6 GW/ 0.124 MM tpy	2030

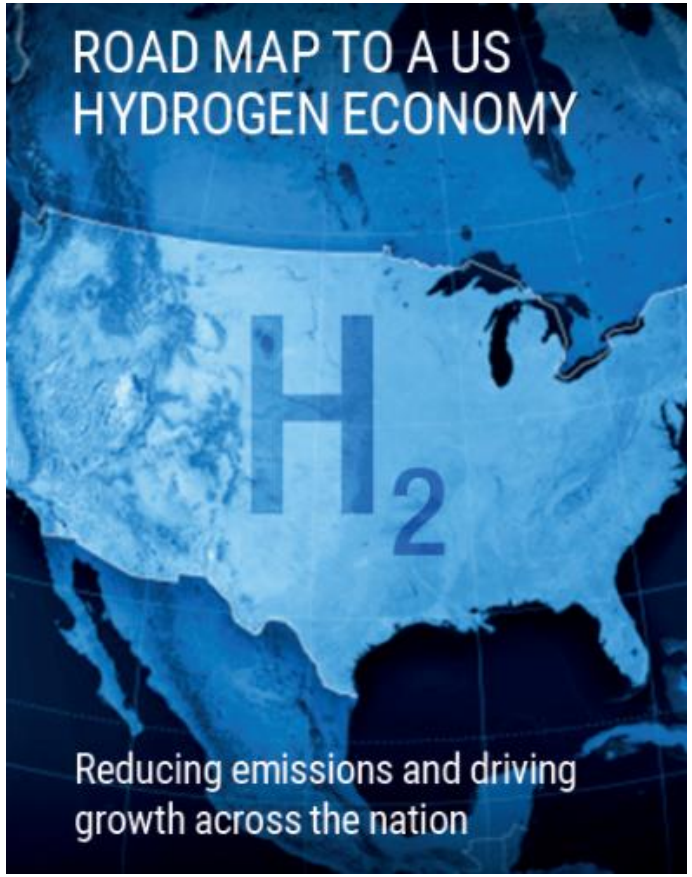
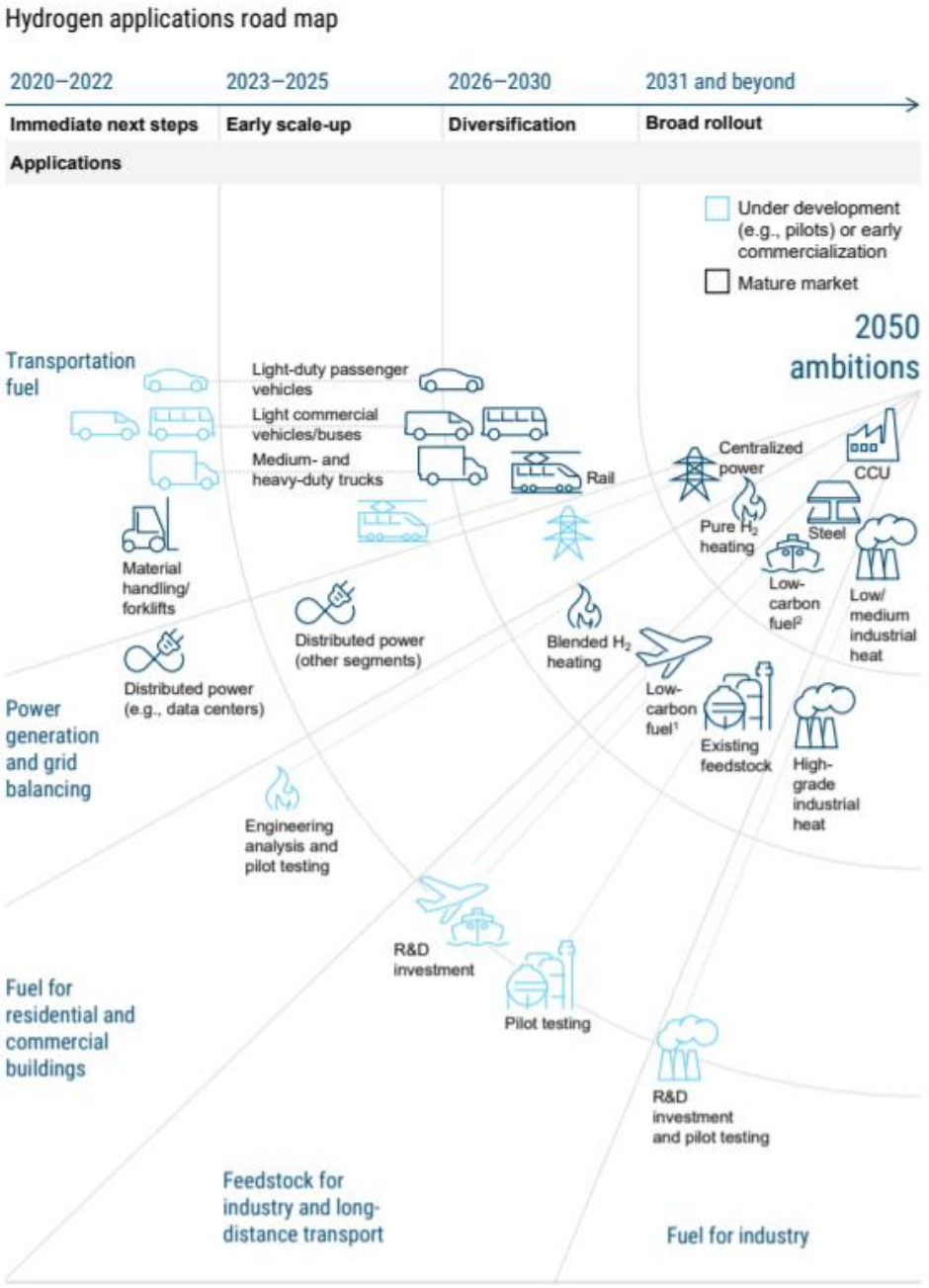
Source: Rechargenews.com Dec. 21, 2020

Helios Green Fuels Project



AIR PRODUCTS

For additional information visit:



fchea.org/us-hydrogen-study