Hydrogen towards deep decarbonization

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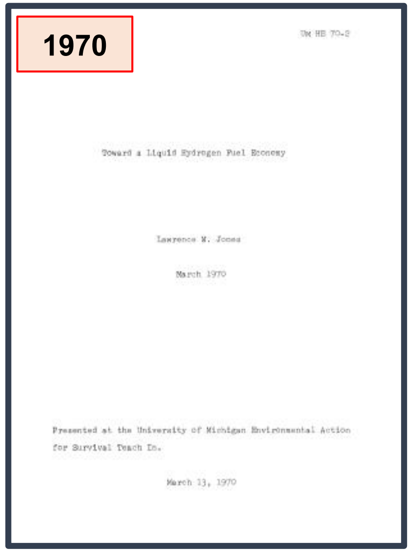
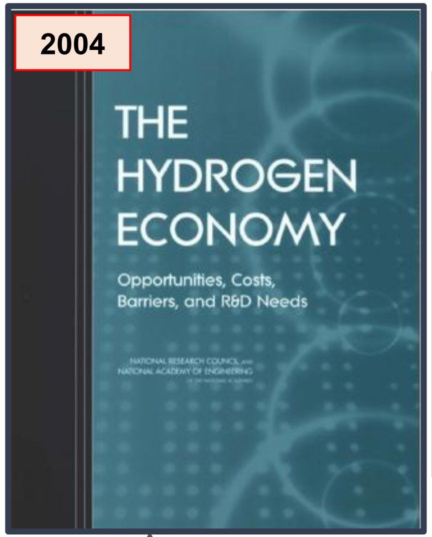
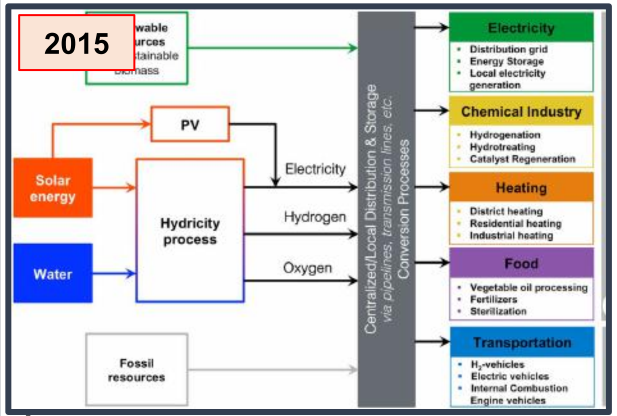
Though the hydrogen economy concept is not new, the motivation of resurgence changes over time…







Hydrogen for economy-wide deep decarbonization

Energy	Transportation	Transportation and distributed electricity	Food-Energy-Water	Hard to decarbonize

1870 · *1970* · *1990* · *2000* · *2010* · *2020*

"water will be the coal of the future"

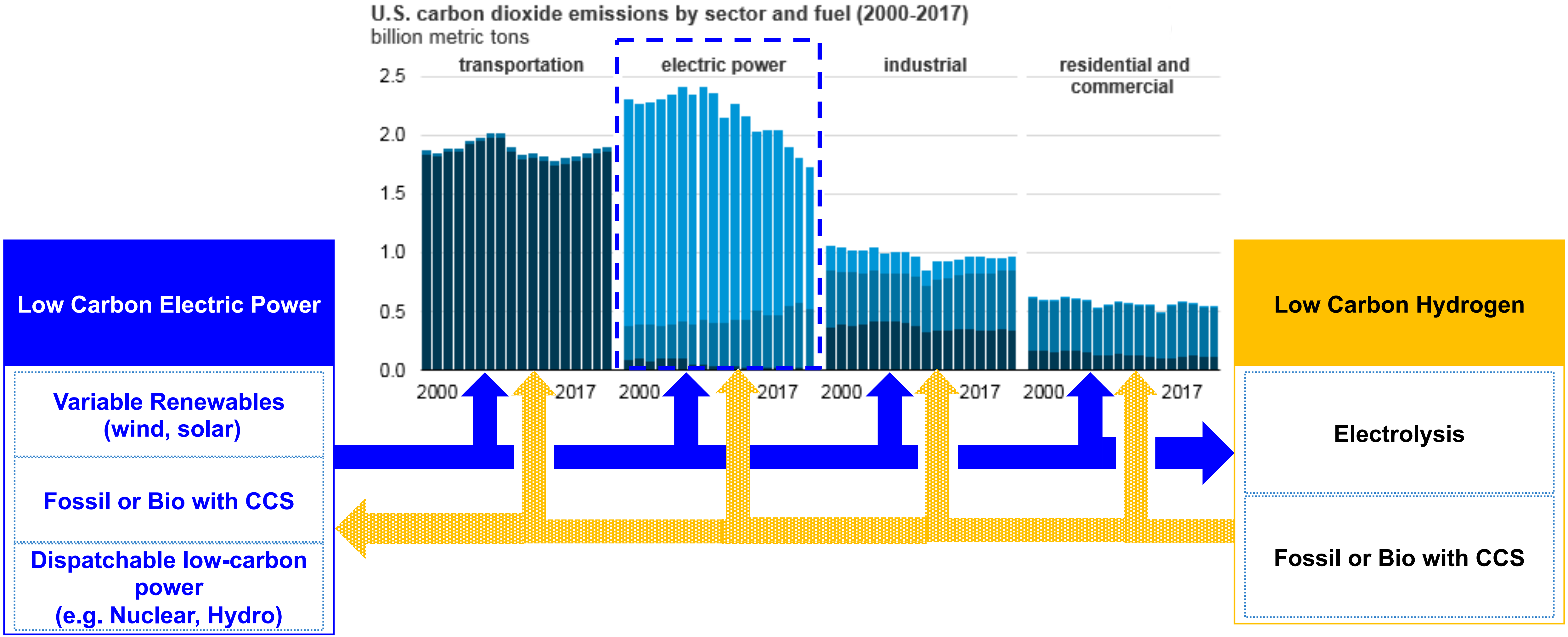
First hydrogen economy term

Increase energy security
Reduce environmental impacts

Solar cogeneration of hydrogen and electricity

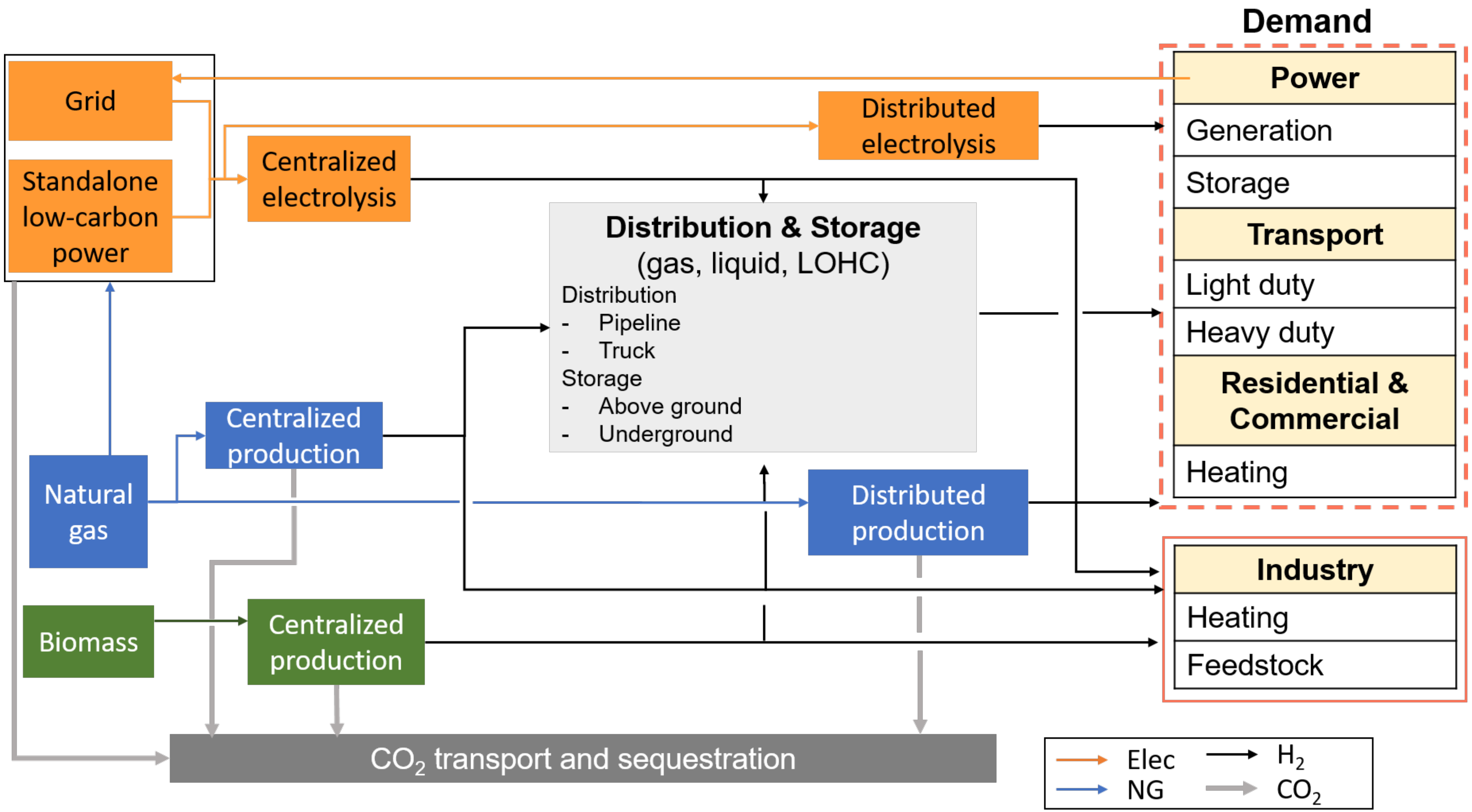
Sources: EIA, 2018

Low-carbon electricity pivotal for economy-wide deep decarbonization, but other energy carriers like hydrogen may be necessary



Sources: EIA, 2018

The exact integration of hydrogen into the energy system is uncertain but numerous opportunities exist both on the supply and demand side



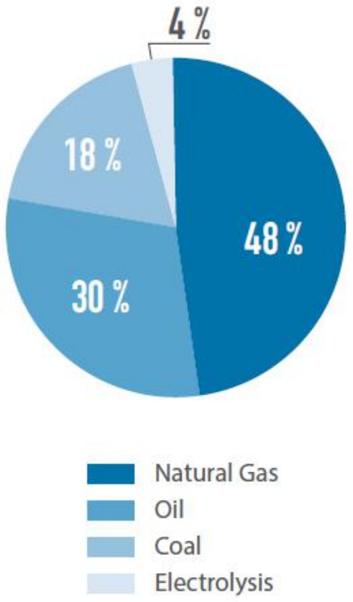
Sources: MITEI

Not all hydrogen are created equal – The role of hydrogen in economy-wide deep decarbonization is dependent on how hydrogen is produced

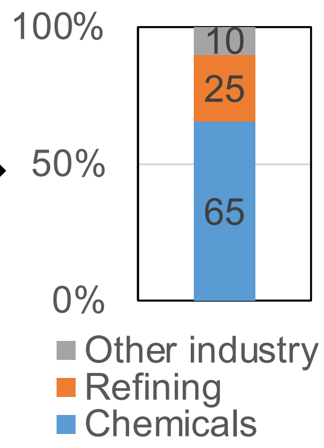
Currently, H_2 mainly consumed by industry with co-located, centralized H_2 production to minimize delivery costs – NG reforming is predominant supply source, little other infrastructure

Supply – demand picture

H_2 supply
(total = 8 EJ)[1]



Demand



Scale of H_2 infrastructure vs. other energy infrastructure

	Hydrogen	Other energy sources
Storage (GJ)[3,4]	~10^6	NG: ~10^{10}
Pipelines (miles)[5]	1600	NG: 300,000 Petroleum: 130,000
# of refueling stations[6]	39	168,000

Reference: U.S. Primary Energy consumption in 2018: 106.7 EJ[2]

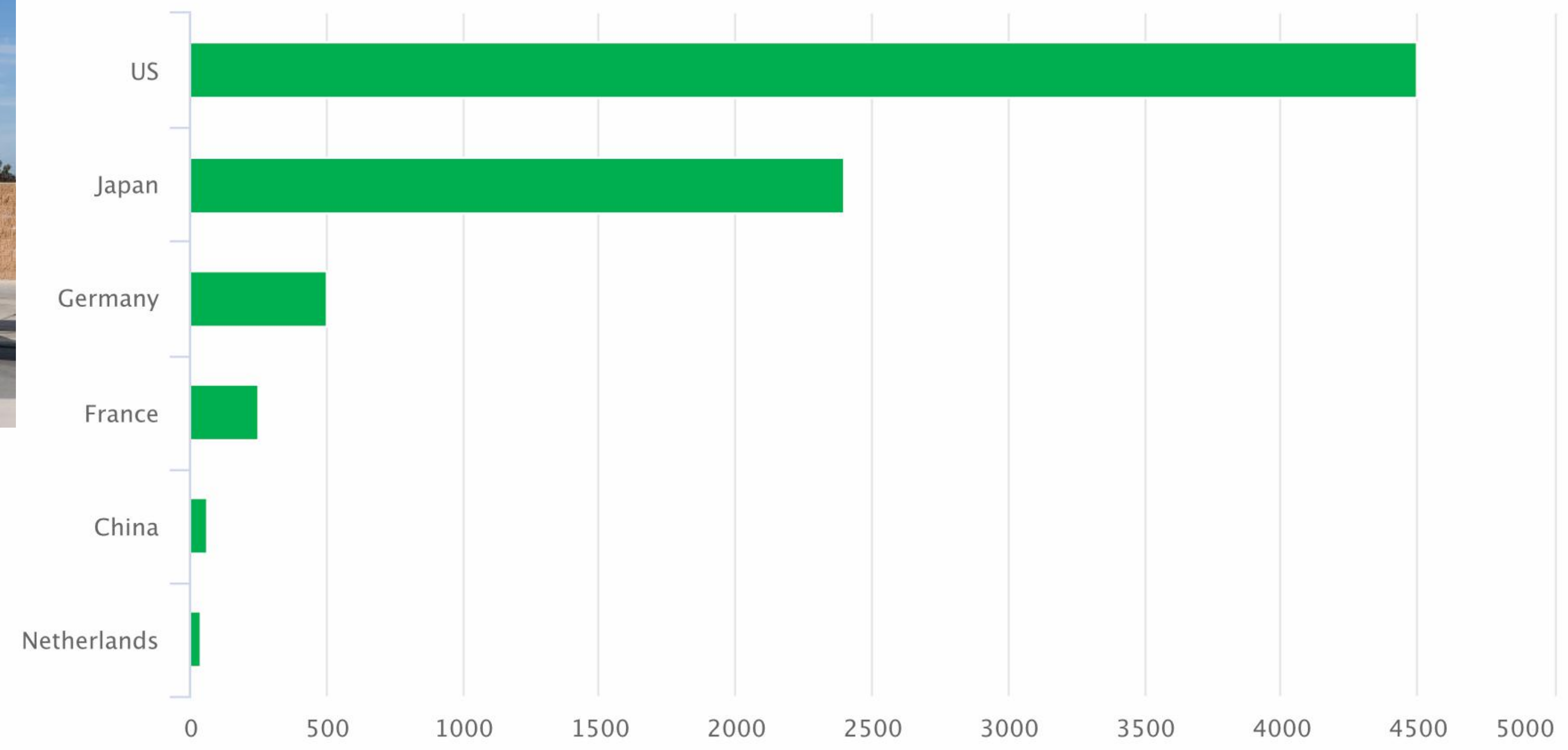
1. IRENA, Hydrogen From Renewable Power Technology Outlook for the energy transition, 2018; 2 Lawrence Berkeley National Laboratory: https://flowcharts.llnl.gov/
3. H2 storage capacity estimated by mulitiplying storage capacity of a single storage facility (Chevron Terminal, TX) with number of facilities operating in U.S. (5)
4. U.S. EIA: https://www.eia.gov/dnav/ng/ng_stor_cap_dcu_nus_a.htm
5. U.S. Drive Hydrogen Delivery Technical Team Roadmap, 2017, 6. U.S., Department of Energy, energy.gov

Transportation

The global fuel cell electric vehicle (FCEV) car stock reached 8 000 units in April 2018. The United States represents the largest fleet with 4 500 FCEV

Toyota Mirai ($57,500)
Fuel Economy = 106 km/kg H_2
Tank ~ 5 kg
Range = 550 km (340 miles)

Total FCEV fleet



Japan has more than twice as many fueling stations relative to the US (100 vs. 38)

Sources: EIA, 2019

Exploring the life cycle greenhouse emissions of various hydrogen pathways relative to vehicle types

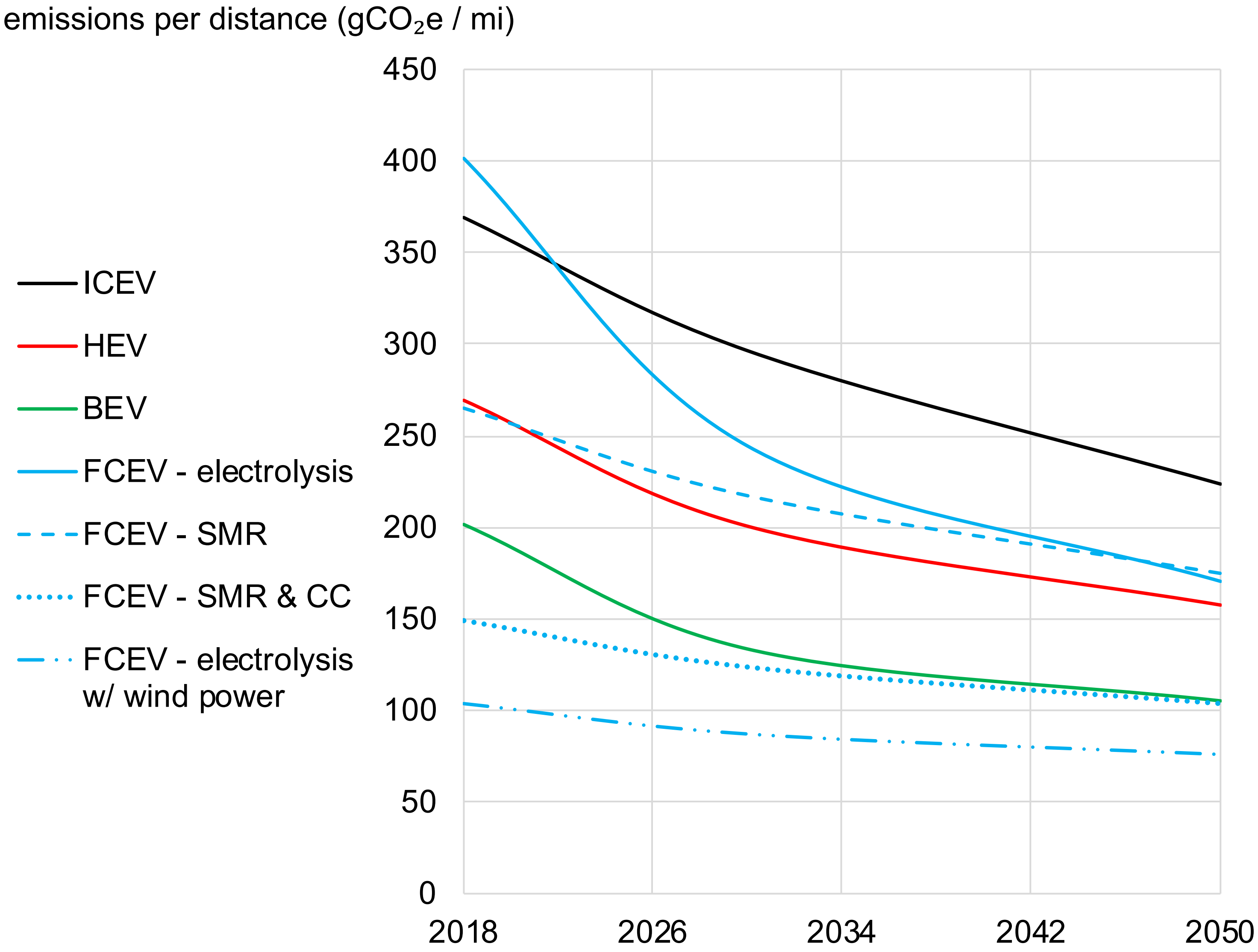
- Car models chosen to facilitate apples-apples comparisons—i.e., minimize differences in non-powertrain features.

Toyota Camry ICEV	Toyota Camry HEV	Honda Clarity PHEV	Honda Clarity BEV	Honda Clarity FCEV
				

Interior volume (ft^3): 115 | 115 | 117 | 116 | 113

Sources: EIA, 2018

FCEV GHGs with Hydrogen via Different Methods

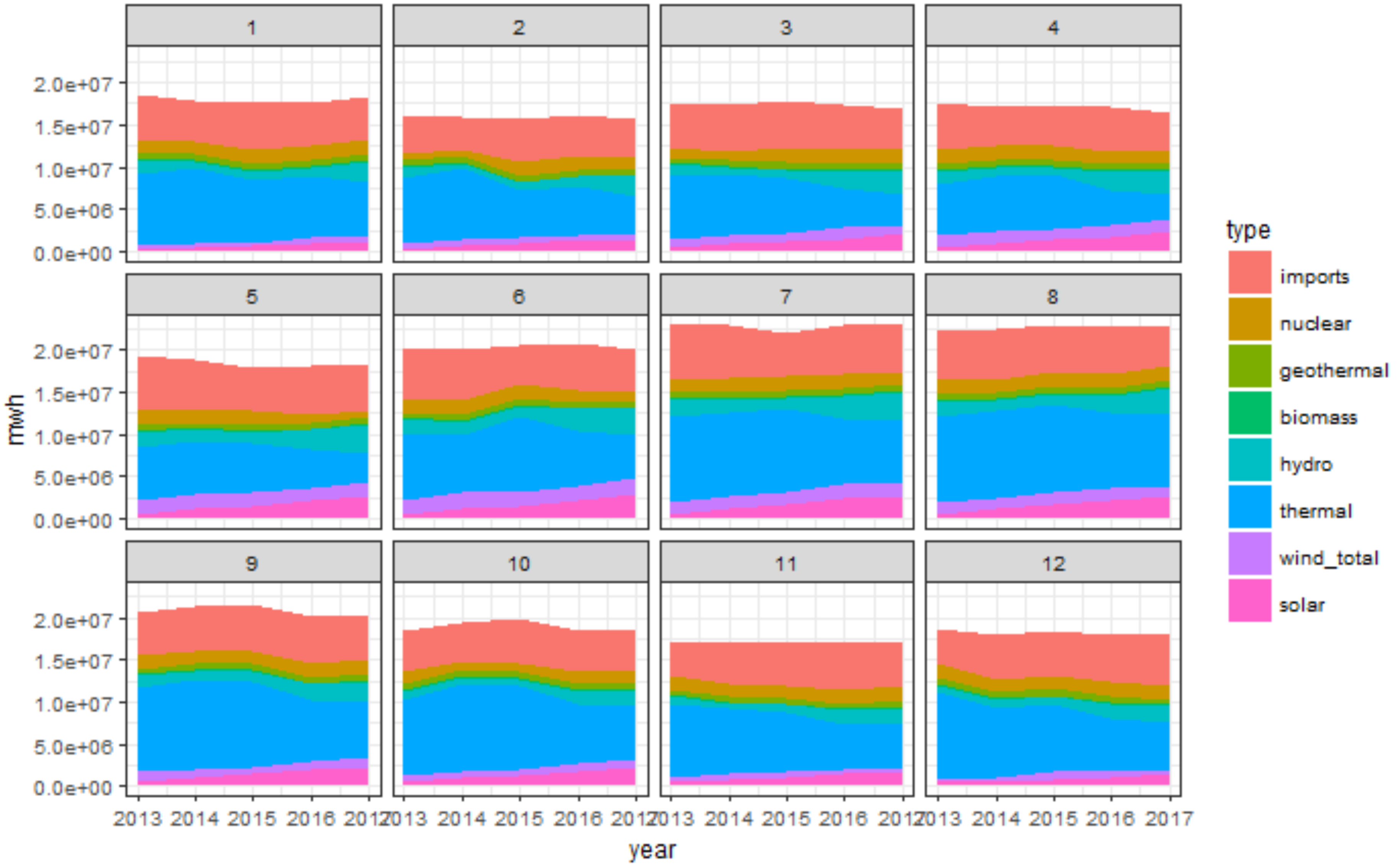


1. Electrolysis w/ wind is cleanest.
2. Compared to SMR, electrolysis w avg grid does not have carbon benefits for FCEVs, even with ~50% drop in grid carbon from 2018 to 2050.
3. Adding carbon capture to SMR reduces FCEV emissions to similar level as BEVs.

Sources: MITEI Analysis I. Miller and E.Gençer, SESAME model

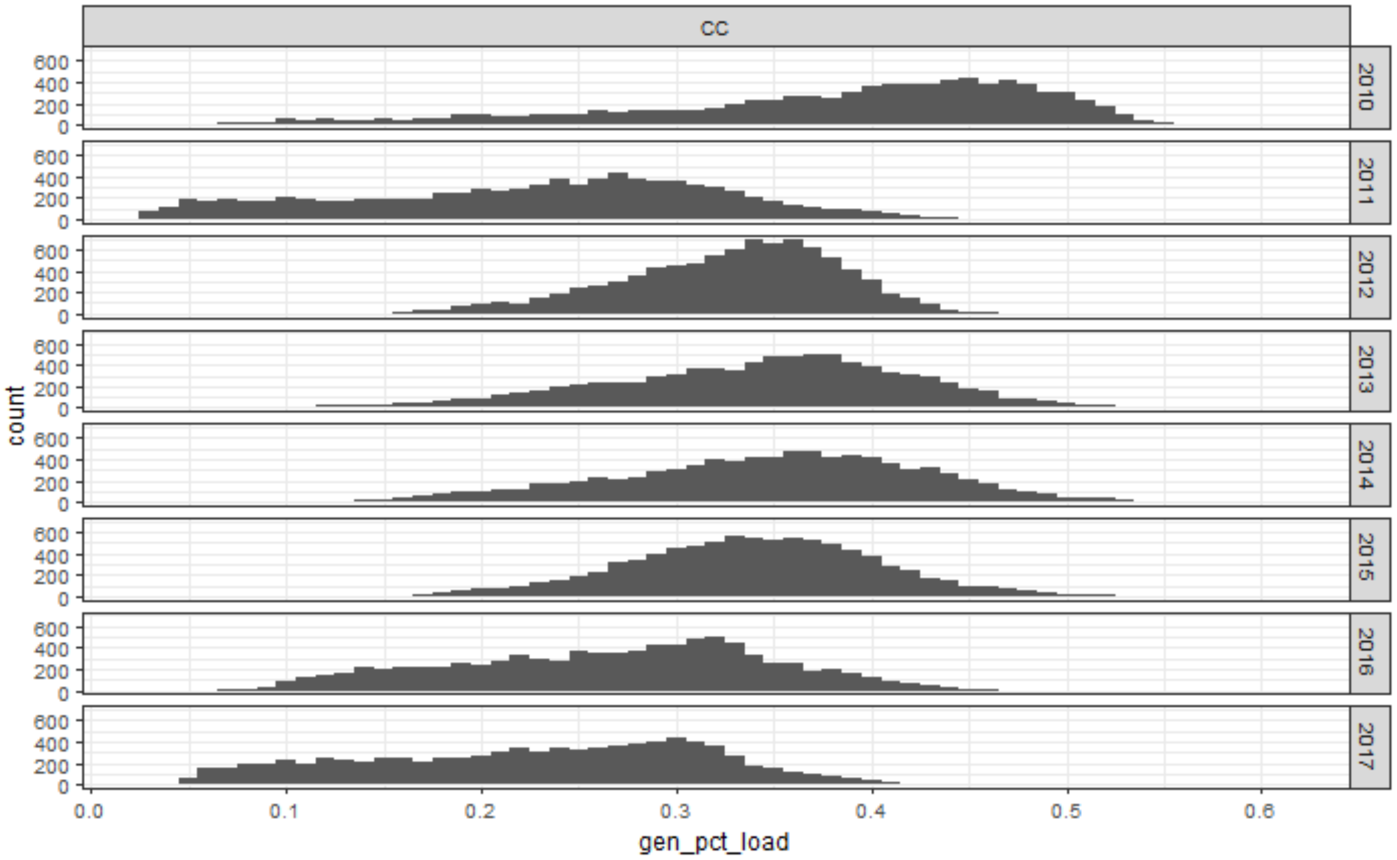
Power sector

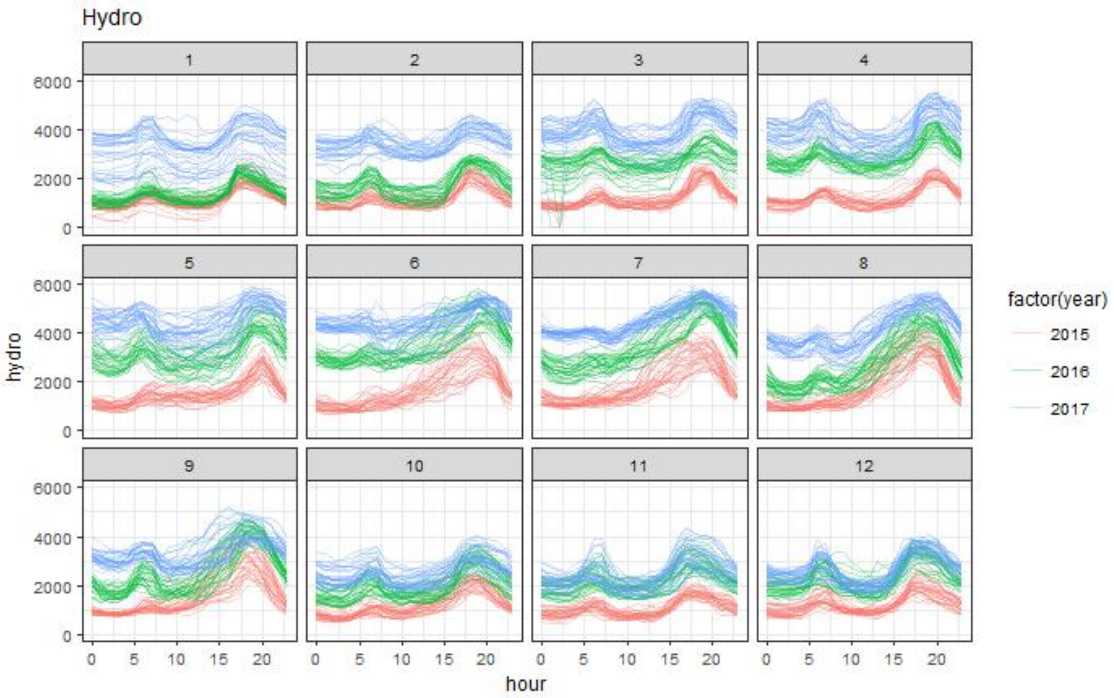
Moving from marginal to meaningful levels of renewable power generation necessitates long term and large scale energy storage to account for seasonal and year-to-year variabilities



Sources: MITEI Analysis B.Clinton and E.Gençer, SESAME model, California Generation Data

In California natural gas combined cycle plants increasingly dynamic role in balancing the power system
– This paradigm increases marginal emission levels and will be a technical challenge for CCS integration

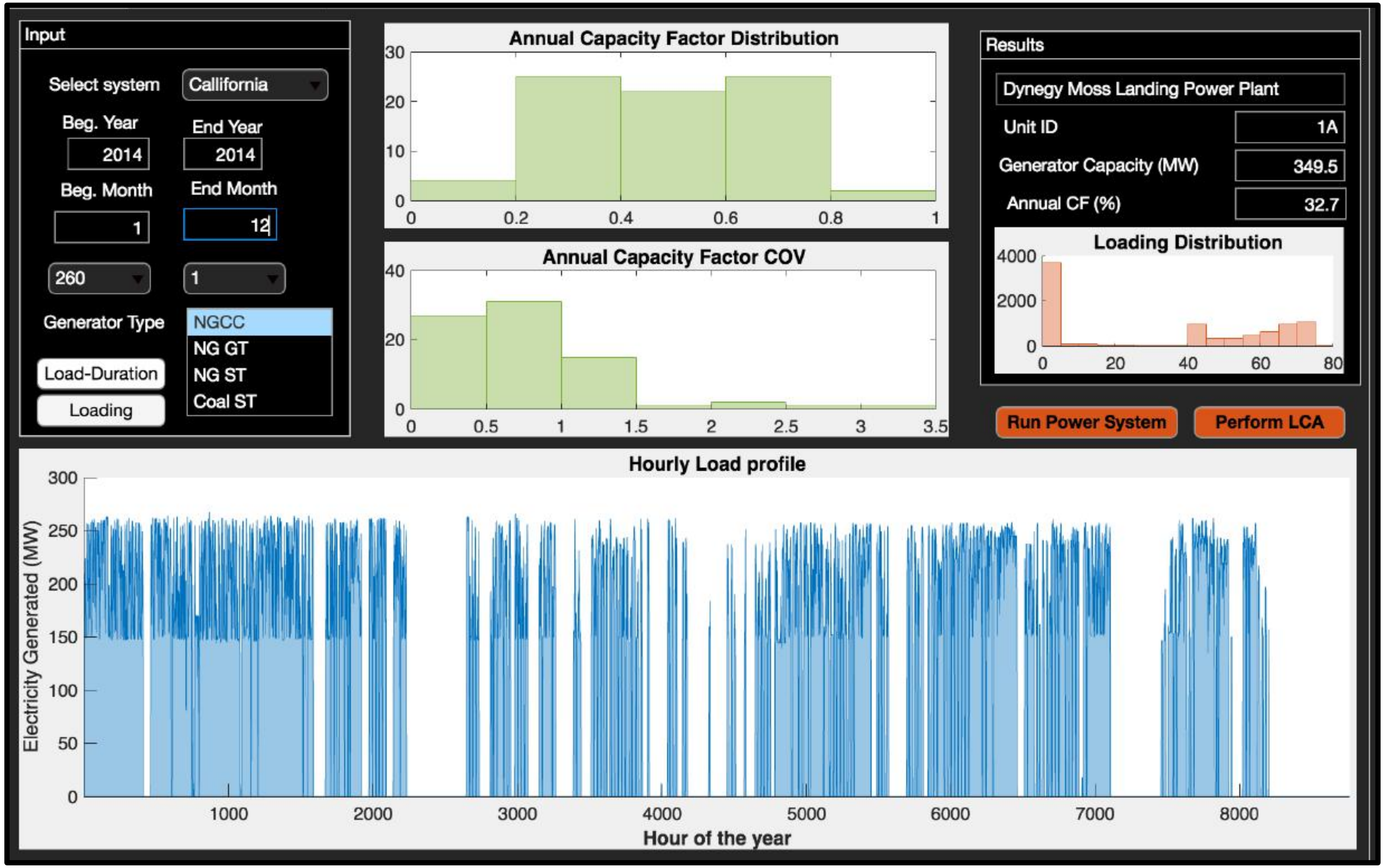




In-state hydropower generation:
36,920 GWh in 2017
24,410 GWh in 2016

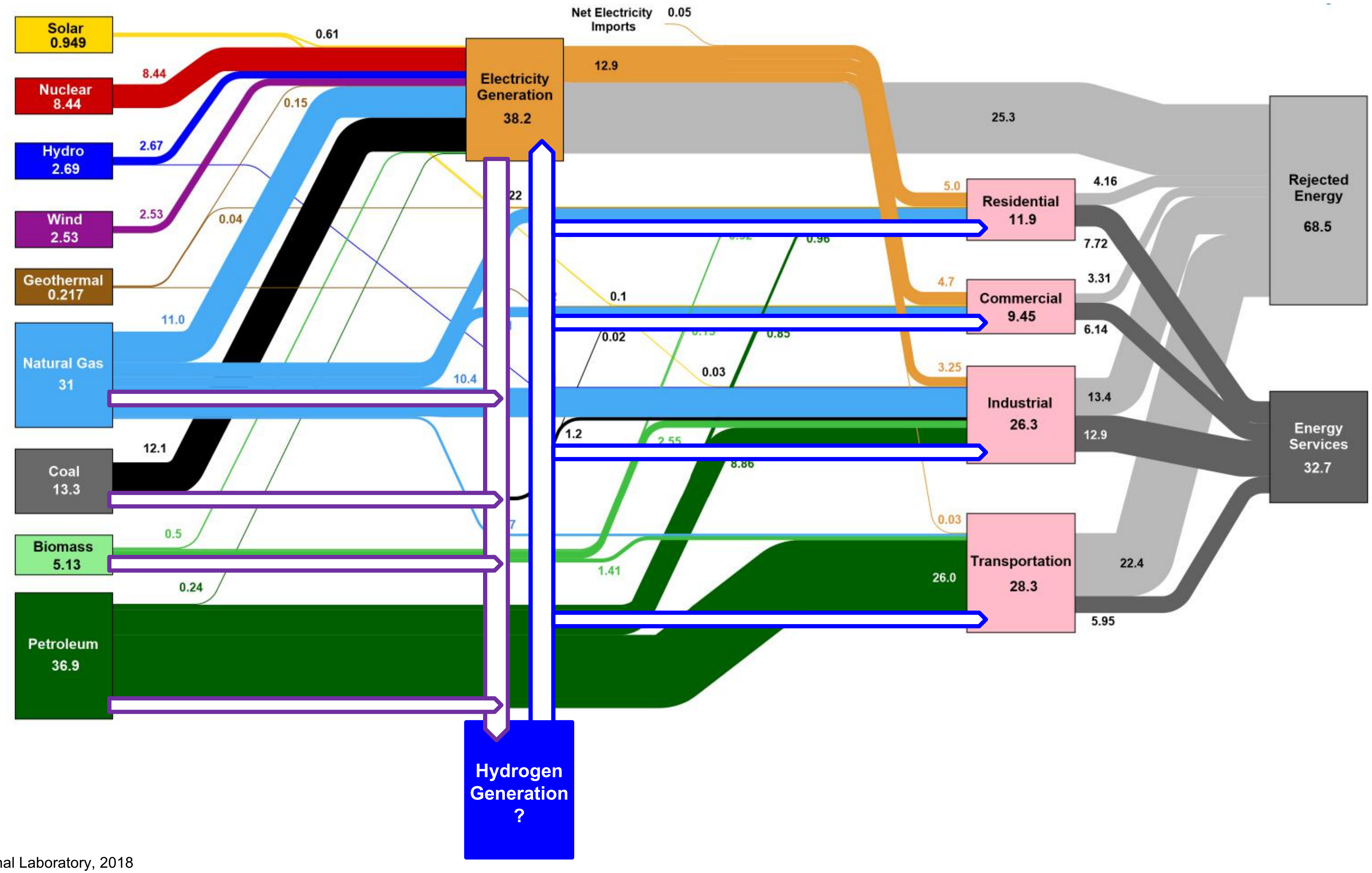
Sources: MITEI Analysis B.Clinton and E.Gençer, California Energy Commission, EPA CEMS data

Decoupling power generation and carbon capture to overcome low capacity factor and operational variations – Centralized SMR with CCS can fuel the existing natural gas fleet



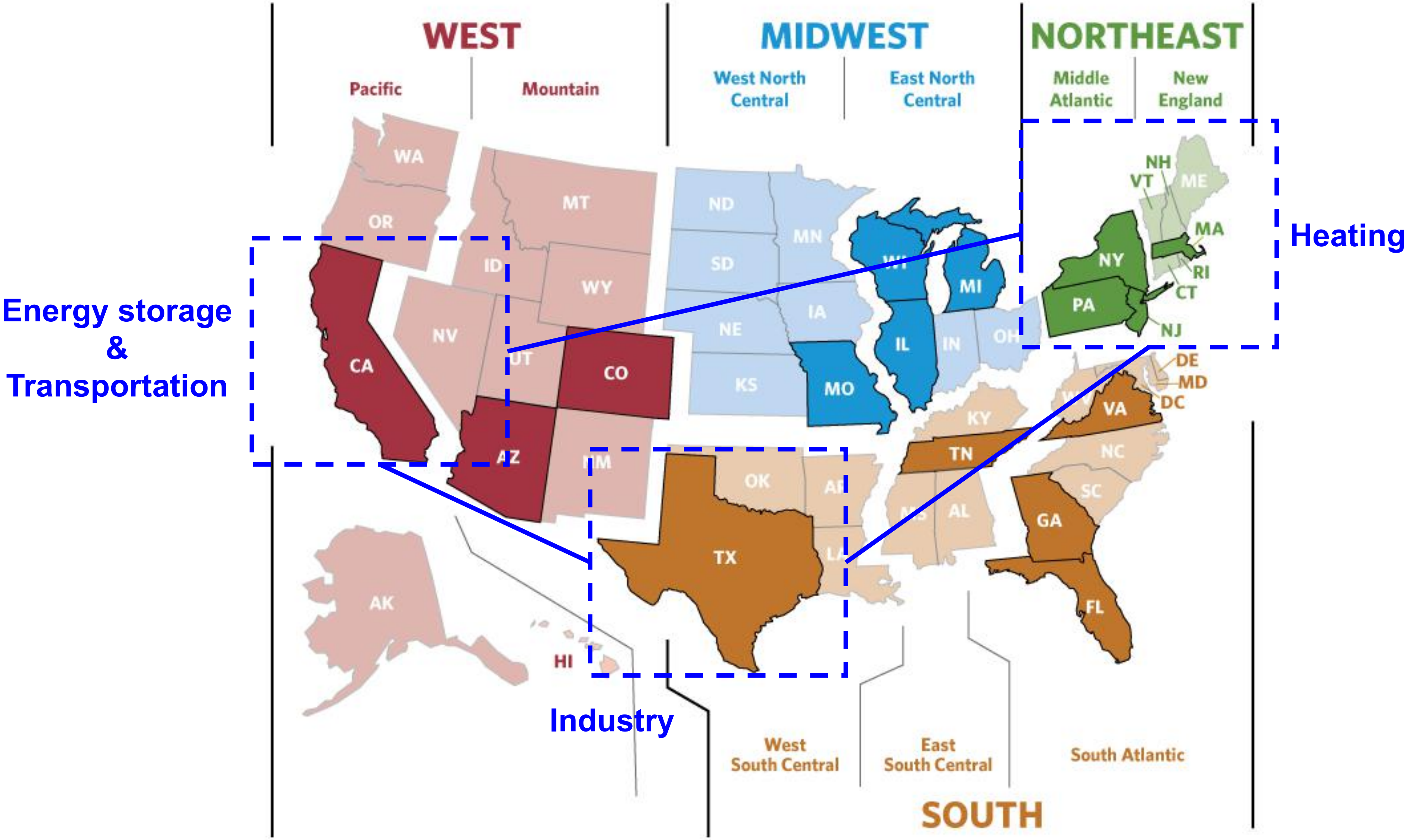
Sources: MITEI Analysis SESAME model

Hydrogen value chain should be significantly scaled-up to have an impact in the current energy system – 2018 H_2 production ~10 Mtons (1.2 EJ) vs. 2018 energy demand ~101.2 Quad (106.8 EJ)



Sources: Lawrence Livermore National Laboratory, 2018

The primary sector for hydrogen demand will be determined by regional dynamics



Sources: Map-EIA 2018

Takeaways

- Meaningful climate change mitigation efforts must target all sectors, not just power – the versatility of H_2 makes it an appealing energy carrier to serve traditionally difficult-to-electrify end uses.

- For light duty transportation (FCEV), hydrogen production determine the ranking among other options. FCEV GHGs ~quadruple with H_2 from coal gasification vs. electrolysis + wind.

- Due to growth of renewable power, there is a growing need for long-term/seasonal energy storage. For hydrogen to fill this gap;
  - Cost and performance for production, storage, and power generation options.
  - Decoupling hydrogen production and power generation to use hydrogen as an energy carrier.
  - Infrastructure requirements.

- The primary role of hydrogen in different regions is likely to be different.

Backup

Hydrogen is not a primary energy source

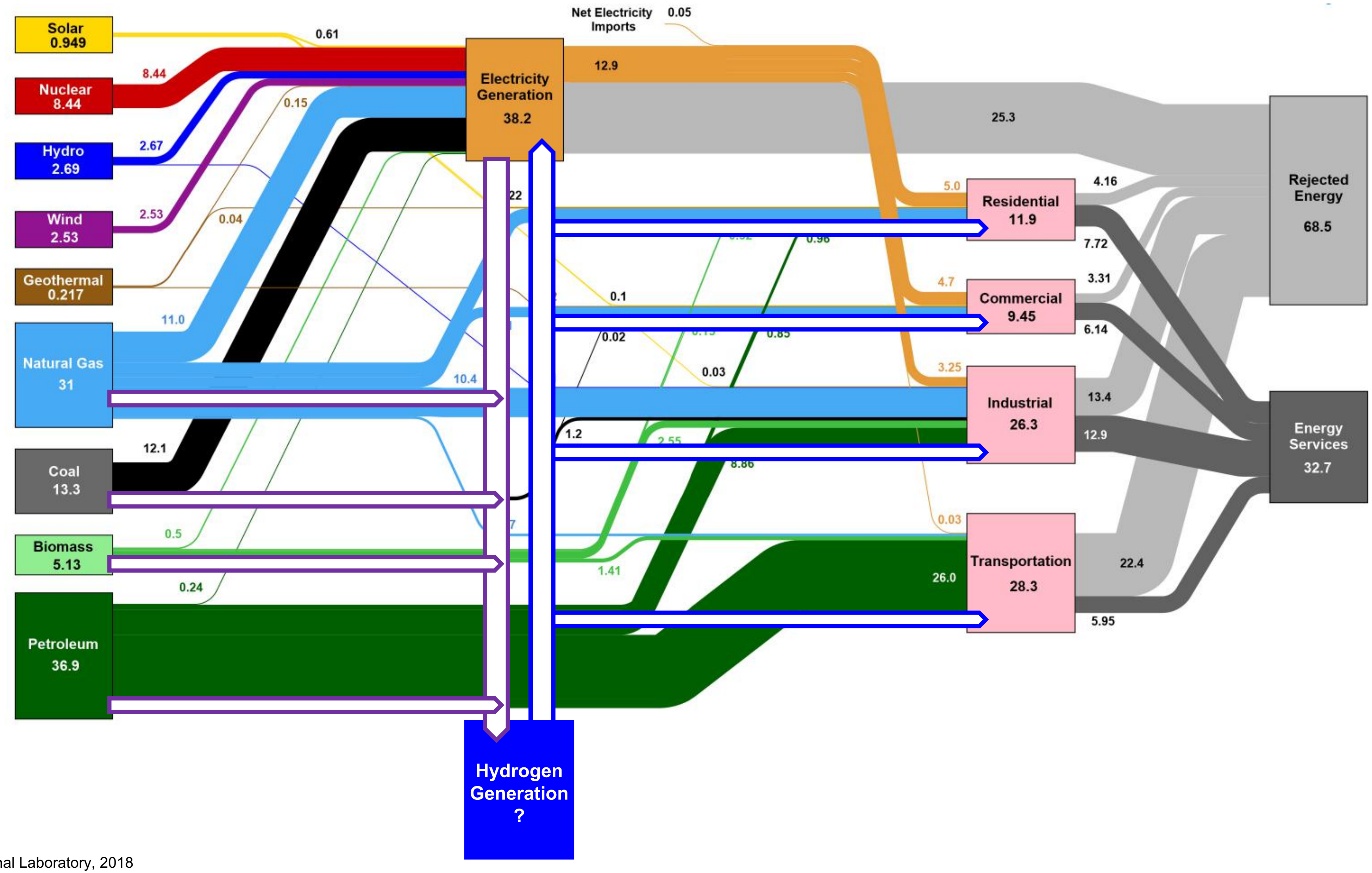
Transportation	Electric Power	Residential & Commercial	Industrial
29.9 EJ	40.4 EJ	12.3 EJ	24.3 EJ
y			
2 EJ	Total: 4178 TWh (15 EJ) NG: 1468 TWh (5.3 EJ) Coal: 1146 TWh (4.1 EJ)	12.3 EJ	24.3 EJ

Sources: EIA, 2018

Chemical energy storage steps

Production	Transport	Storage	Conversion

Hydrogen is not a primary energy source



Sources: Lawrence Livermore National Laboratory, 2018