NATIONAL RENEWABLE ENERGY LABORATORY





Economic Analysis of Integrated Solar Power, Hydrogen Production, and Electricity Markets

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ICEPAG 2020 Hydrogen: A Platform for Sustainability

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.

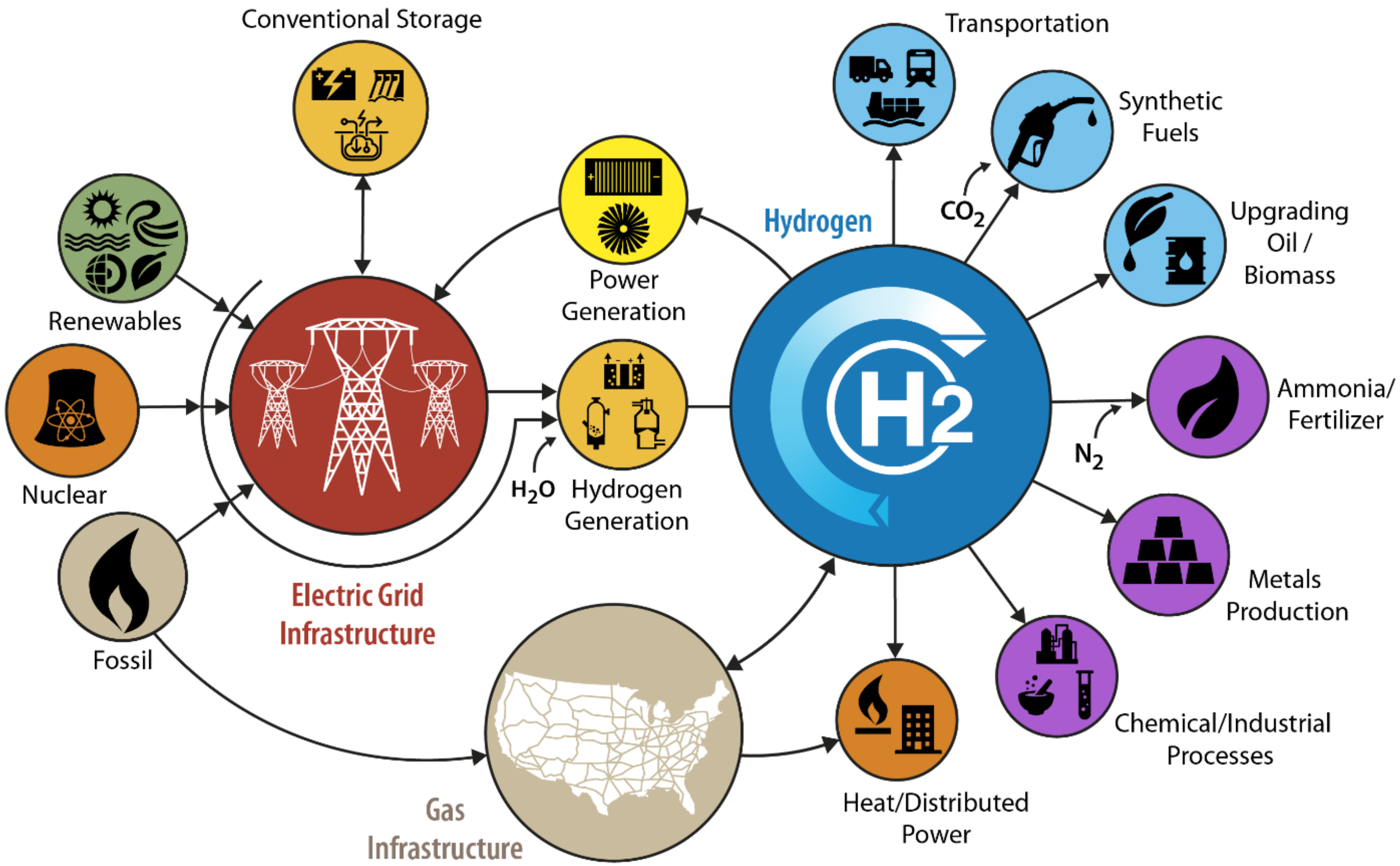
Motivation

Integration of electrolysis with on-site renewables and electricity markets presents a cost reduction opportunity due to the perceived future availability of low and zero-marginal cost renewable energy sources. Additionally, integrating electrolysis with renewables, particularly photovoltaics, can mitigate the value deflation effect with each additional unit.

The goal of this work is to model and evaluate an optimized integrated near-term renewable-electrolysis system within California to establish the potential benefits and facilitate broader adoption.

Project Partners

- Pacific Gas and Electric (PG&E)
- Department of Energy – Hydrogen and Fuel Cells Technologies Office (DOE HFTO)
- California Air Resources Board (CARB)
- Governor's Office of Business and Economic Development (GO-Biz)



Previous work

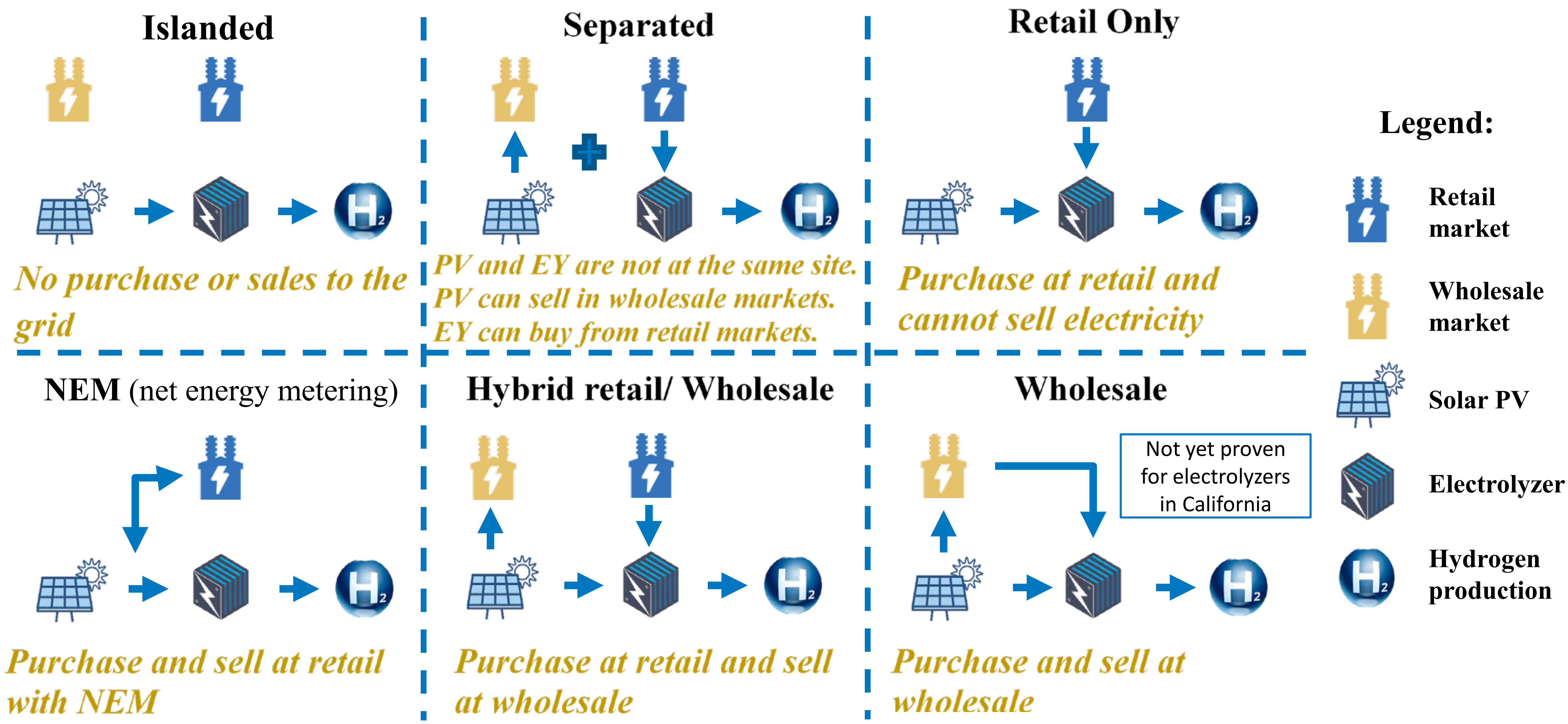
Electrolyzer Flexibility

1. Electrolyzer flexibility for grid services (www.nrel.gov/docs/fy14osti/61758.pdf, http://www.nrel.gov/docs/fy12osti/54658.pdf, https://doi.org/10.3390/en10111836, https://www.hydrogen.energy.gov/pdfs/review17/tv031_hovsapian_2017_o.pdf).
2. Electrolyzers to provide grid balancing in California (https://doi.org/10.1016/j.jpowsour.2018.07.101).

Cost assessment for hydrogen

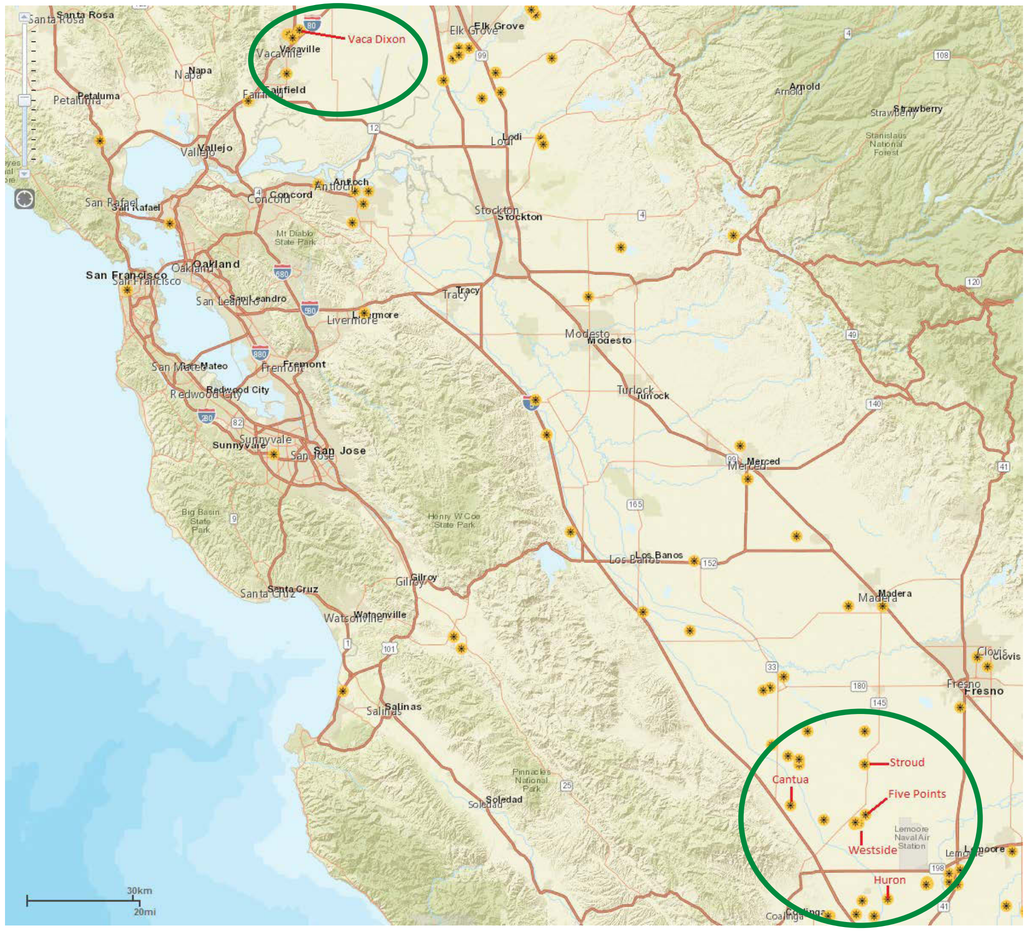
1. Wholesale integration of hydrogen equipment (www.nrel.gov/docs/fy16osti/65856.pdf)
2. California business-case analysis (http://www.nrel.gov/docs/fy17osti/67384.pdf,
3. U.S. Retail rate optimization (https://www.sciencedirect.com/science/article/pii/S2542435119303228).
4. Hydrogen blending into the natural gas pipeline (https://www.nrel.gov/docs/fy13osti/51995.pdf)
5. Long duration energy storage analysis (pubs.rsc.org/en/content/articlelanding/2020/ee/d0ee00771d#!divAbstract)
6. Business-case assessment for PV+Electrolysis (https://www.nrel.gov/docs/fy20osti/75635.pdf)

Market configurations (includes hydrogen production, compression and storage)



Renewable Site Selection

Location of selected solar power stations†



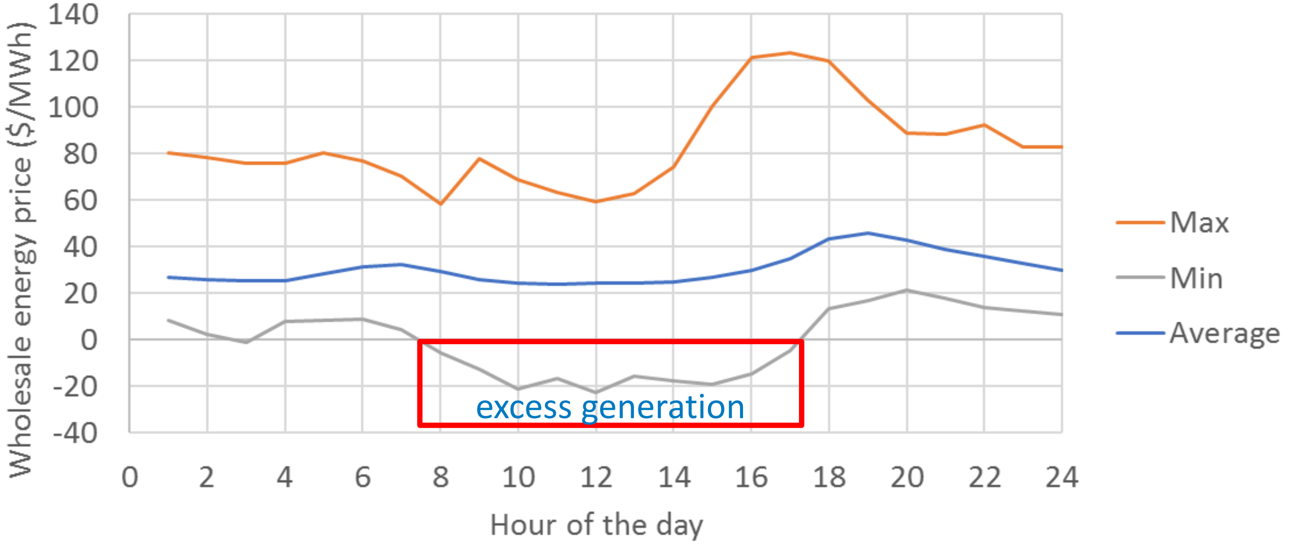
† Schedule 3 of Form EIA-860 Data: www.eia.gov/electricity/data/eia860/

‡ ABB Ability Velocity Suite, 2018 (see backup slides for more details)

Technical specifications for the selected solar stations†

Name	DC Net Capacity (MW)	Tilt Angle	DC/AC ratio	Fixed Tilt?	Crystalline Silicon?
Vaca Dixon	2.6	30	1.30	Yes	Yes
Stroud	24.6	25	1.23	Yes	Yes
Five Points	17.6	25	1.17	Yes	Yes
Westside	18.5	25	1.23	Yes	Yes
Cantua	26.3	25	1.32	Yes	Yes
Huron	26.8	25	1.34	Yes	Yes

Average 2016 Wholesale Locational Marginal Prices (LMP) for all sites ‡



Lower, or even negative prices (particularly during the afternoon), challenge the business cases for new and existing PV plants

Technical Assumptions

Property	Values
Renewables	2-20 MW AC output
Electrolyzer	0.1-20 MW, Eff=54.3 kWh/kg (61.4% LHV)[1]
Storage	8 hours of storage at rated electrolyzer power (except for islanded systems)
Compressor	Sized to max flowrate of electrolyzer (1.8 - 361 kg/hr), Eff=1.1kWh/kg
Electricity rate	Retail: PG&E E-20 (for 1MW+) [2] NEM for net metering (used PG&E Net Surplus Compensation Rate (NSCR) for 2016, non-bypassable charge of $19.19/MWh) Wholesale: PG&E 2016 LMP prices[3] T&D costs included for wholesale purchase based on PG&E E-20[2]
Credits and Incentives	LCFS for FCEV pathway @ $180/credit REC @ $12/MWh Investment Tax Credit: 0% (default), 10% and 30% State tax credits: 0% (default), 3.9%

Source: 1. DOE H2A distributed PEM v3.101
2. PG&E Tariffs (www.pge.com/tariffs/assets/pdf/tariffbook/ELEC_SCHEDS_E-20.pdf)
3. ABB Ability Velocity Suite, 2018

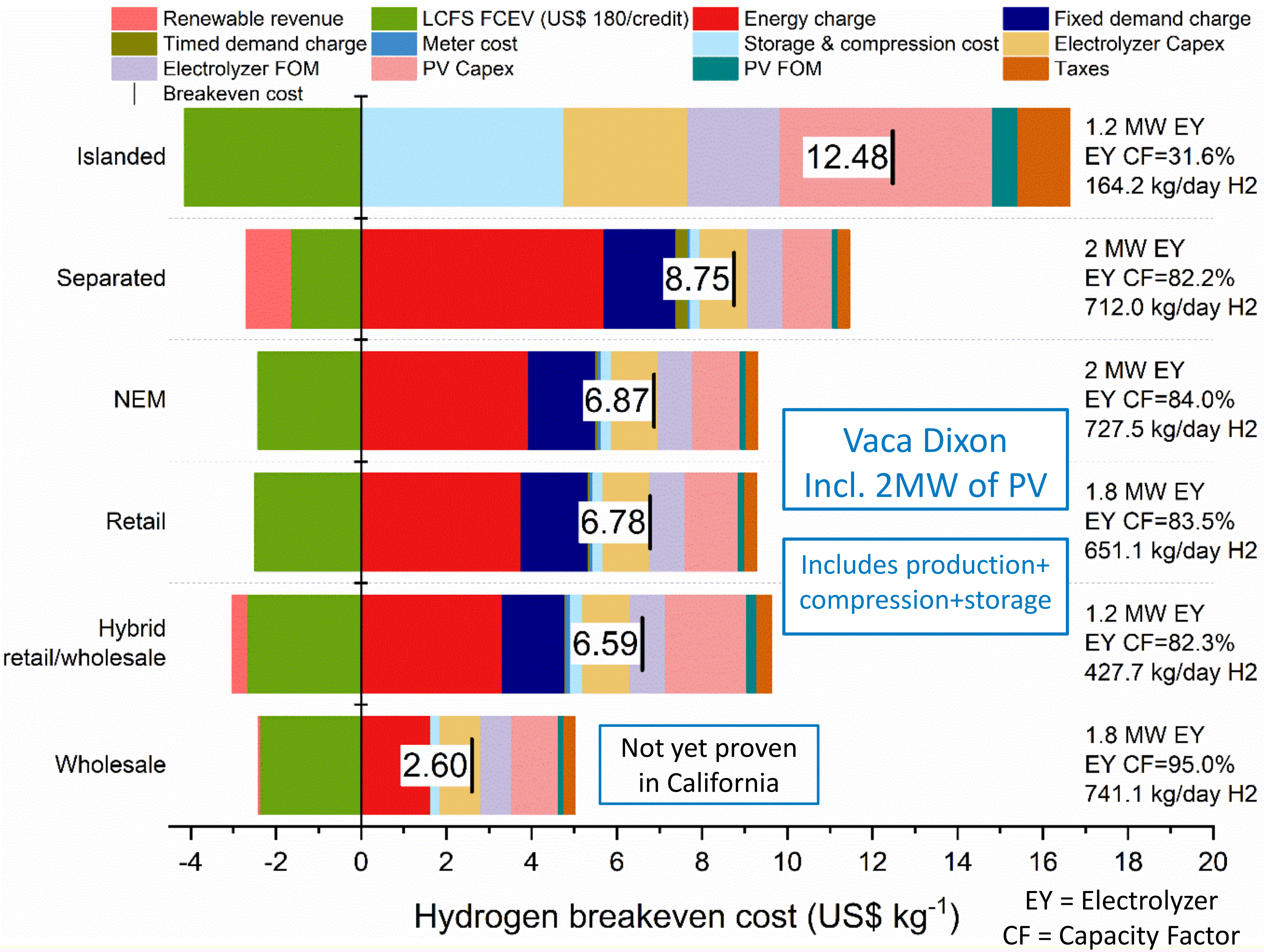
Financial Assumptions

Property	Values
Renewables	Capital: $1,746/kW[2], Fixed O&M: $15.6/kW-year[2], Lifetime: 20yr
Electrolyzer	Capital: $1,691/kW[1], Fixed O&M: $93.8/kW-year[1], Lifetime: 20yr
Storage	Capital: $822/kg of storage[3], Lifetime: 20yr
Compressor	Based on required flowrate[3] (see slide in backup), Lifetime: 20yr
Financial properties	Federal tax rate: 21% State tax rate: 8.84% (default), 4.9% (see backup slide for more details) Investment Tax Credit: 0% (default), 10% and 30% 5-year MACRS depreciation, depreciation bonus: 0%, 50% (default), 100% Weighted average cost of capital (WACC): 7% Percent equity: 42% (Percent debt: 58%) Load period: 20 years U.S. Inflation: 1.9% Debt interest rate: 4.81%

Source: 1. DOE H2A distributed PEM v3.101
2. NREL 2017 Annual Technology Baseline
3. H2First Reference Station Design Task (www.nrel.gov/docs/fy15osti/64107.pdf)

Hydrogen cost results

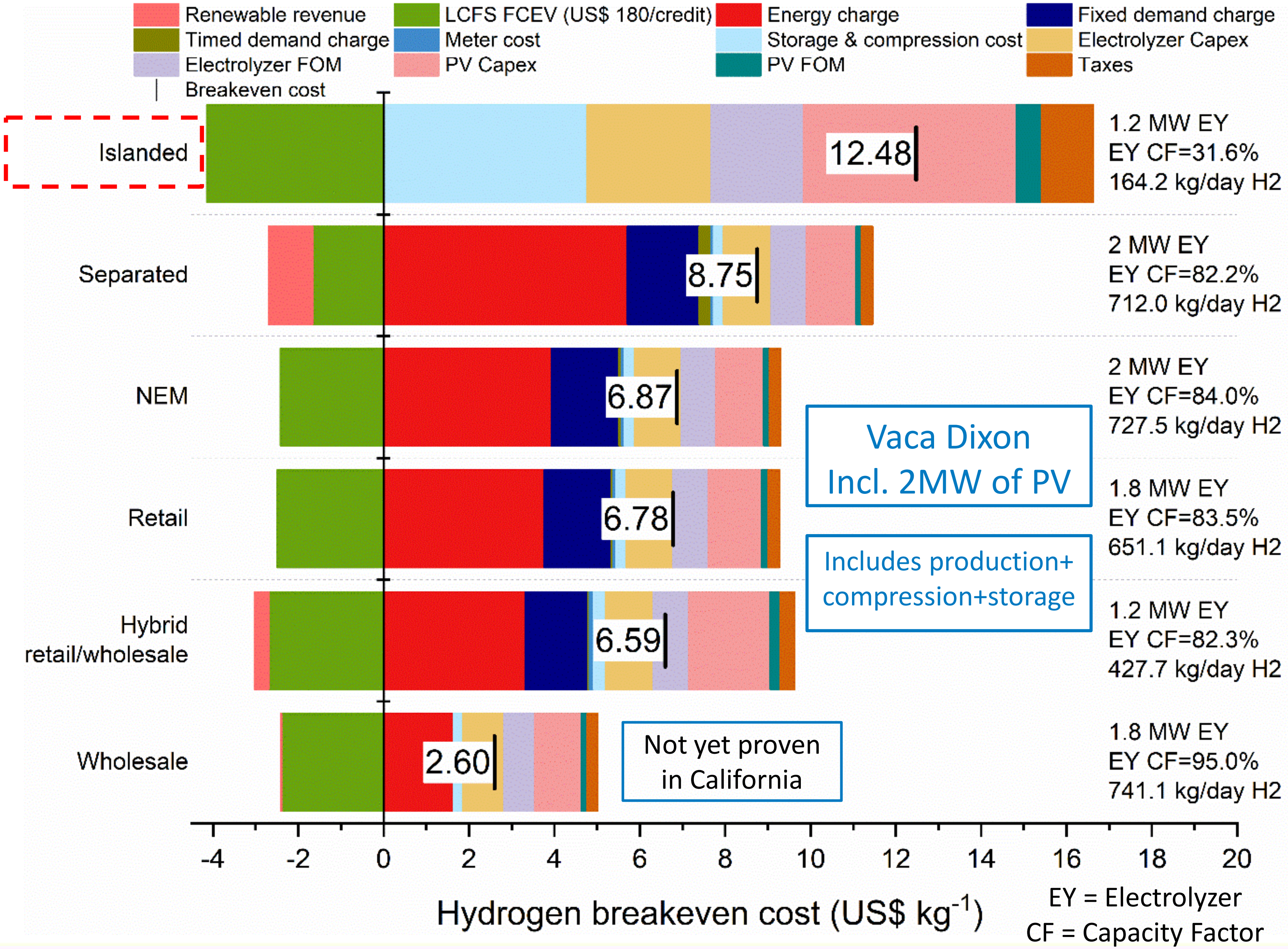
- Compare production + compression + storage costs for each scenario
- Sizing and capacity factor (CF) are optimized
- Uses default financial properties (see assumptions)



EY = Electrolyzer
CF = Capacity Factor

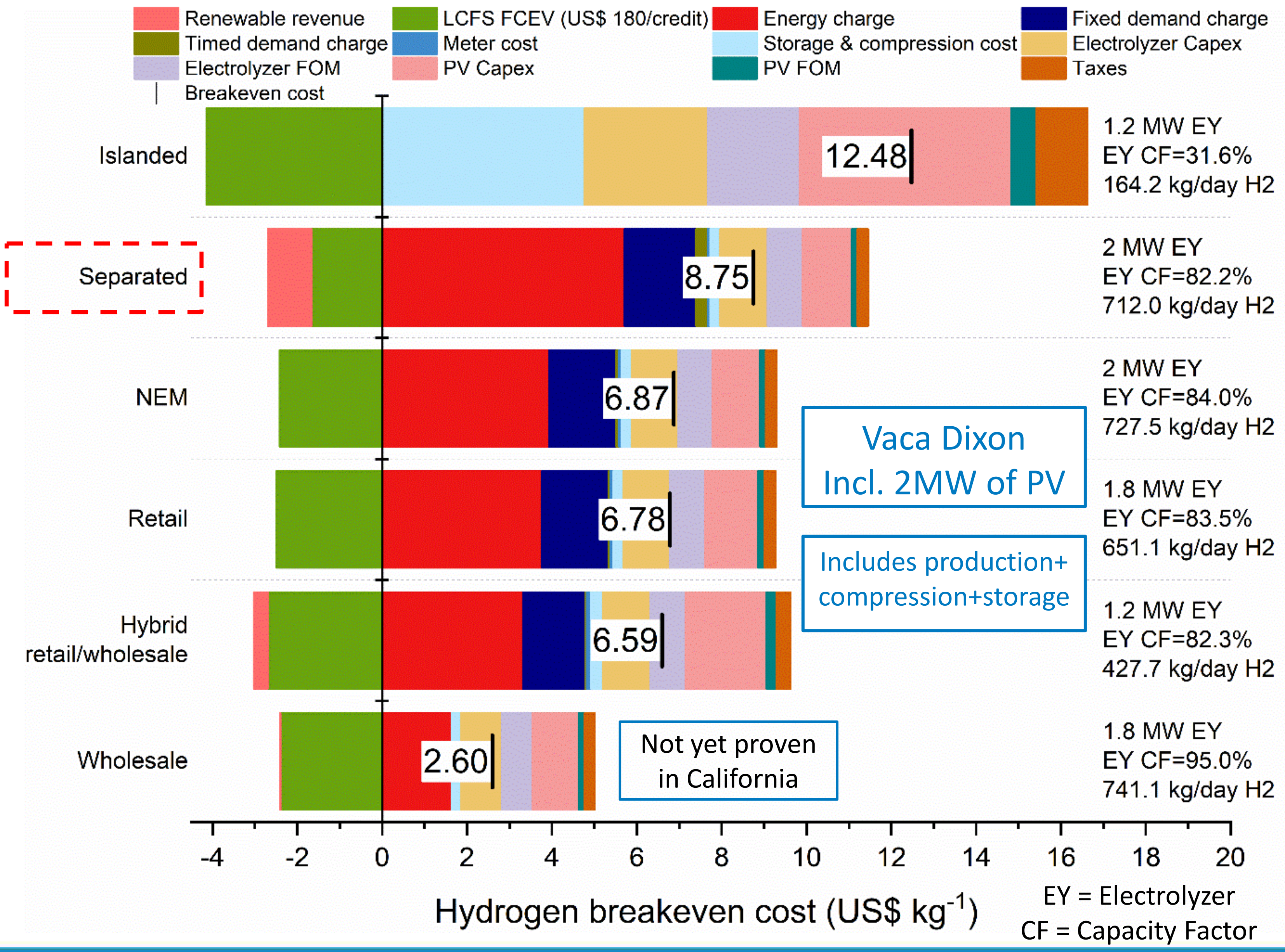
Hydrogen cost results: Islanded scenario

- Islanded systems with only PV have a low capacity factor (CF)
- Islanded systems are highly capital intensive.
- The low CF drives up costs, which cannot be overcome by additional LCFS revenue and removal of electricity costs.



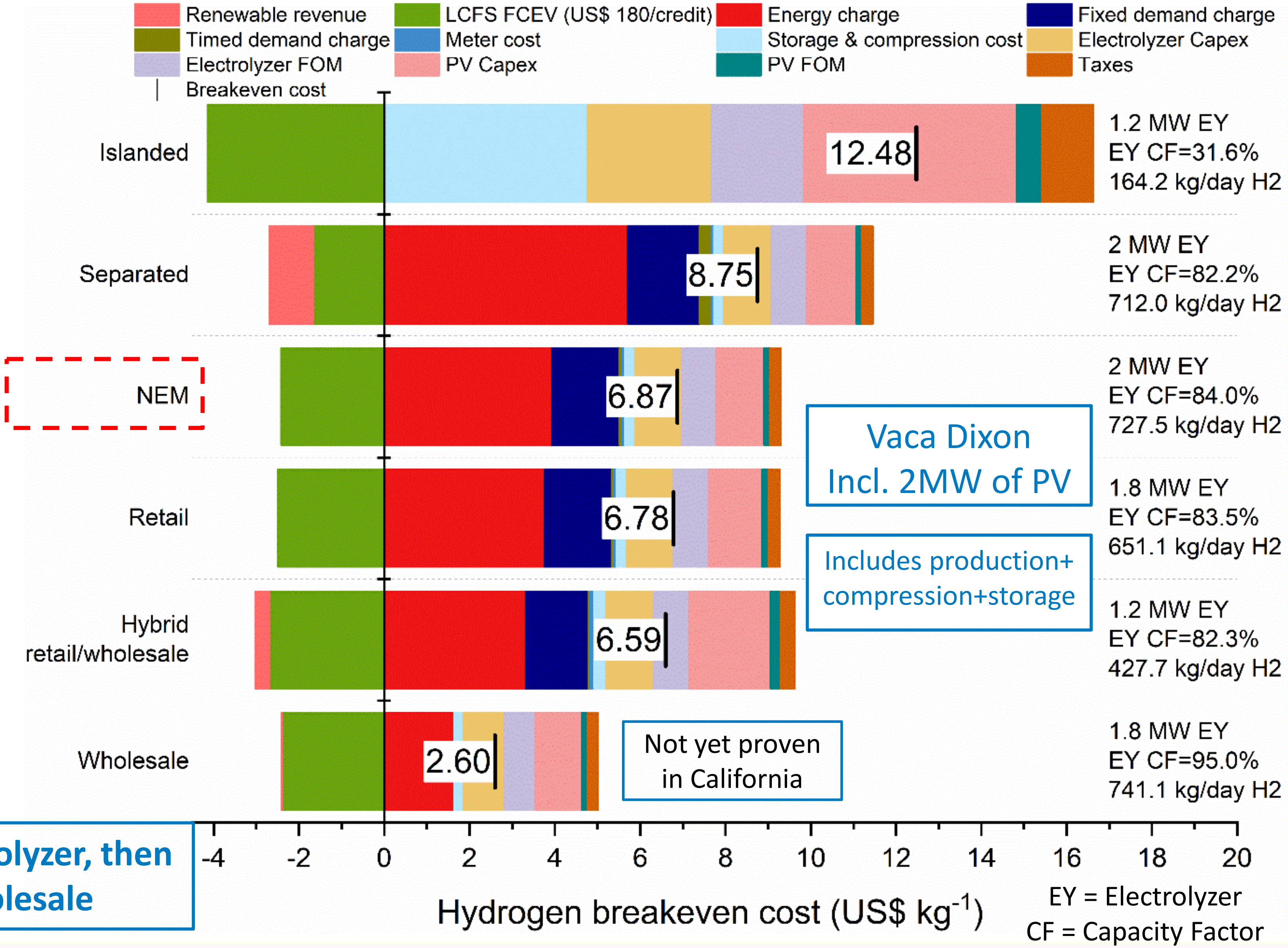
Hydrogen cost results: Separated scenario

- Separated systems represents the least amount of integration
- Electricity costs increase and the potential revenue from LCFS reduces when not integrated.



Hydrogen cost results: Retail only with NEM scenario

- NEM enables the reduction of electricity costs and can provide compensation for surplus generation
- This formulation assumes that the renewable system size can't be larger than the electrolyzer.
- Shifting product values causes a reduction in size and an increase in CF
- NEM participation for large renewable systems needs to be reviewed with utility

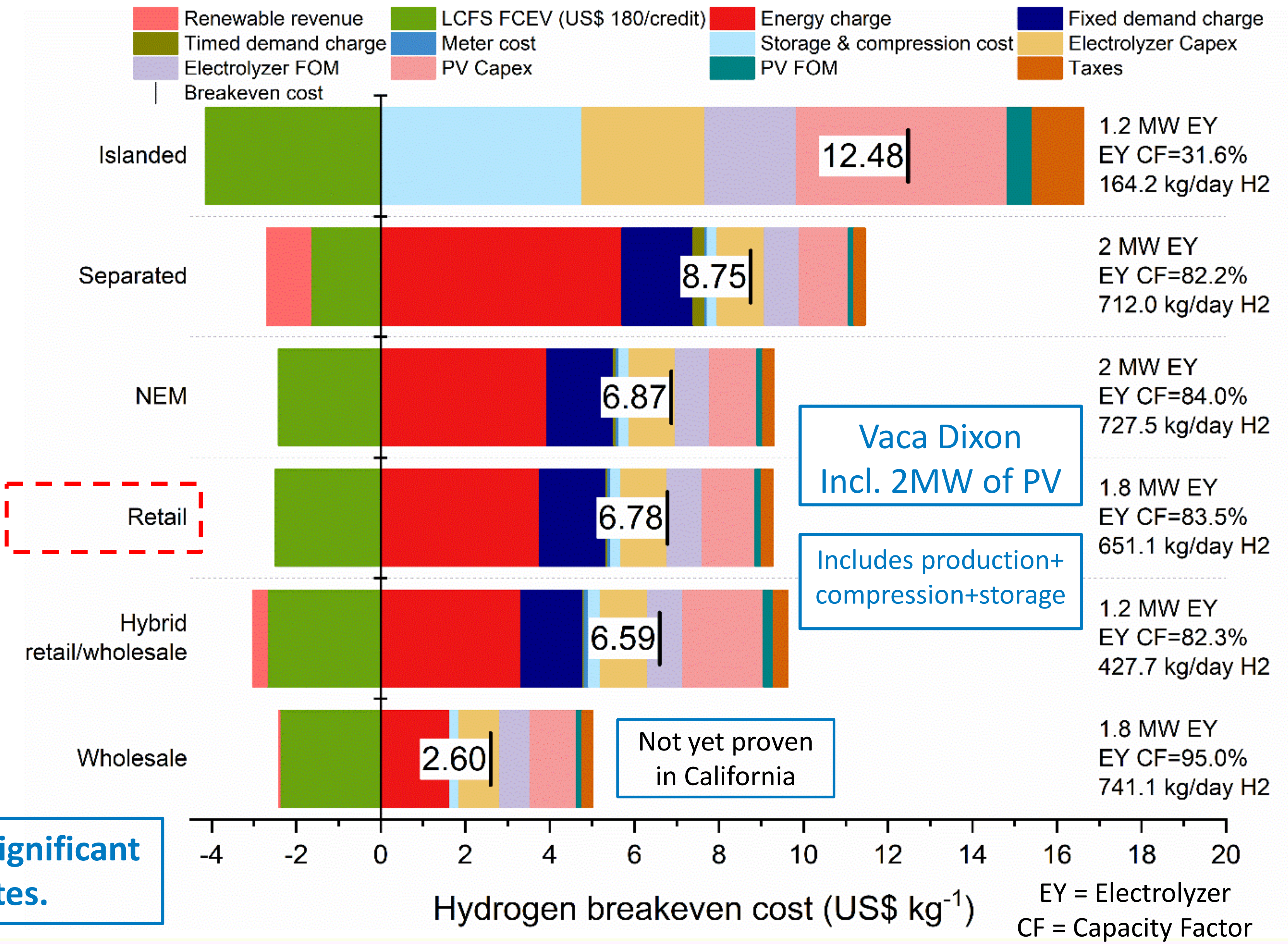


EY = Electrolyzer
CF = Capacity Factor

If renewables can be larger than the electrolyzer, then NEM is competitive with Hybrid retail/wholesale

Hydrogen cost results: Retail Only scenario

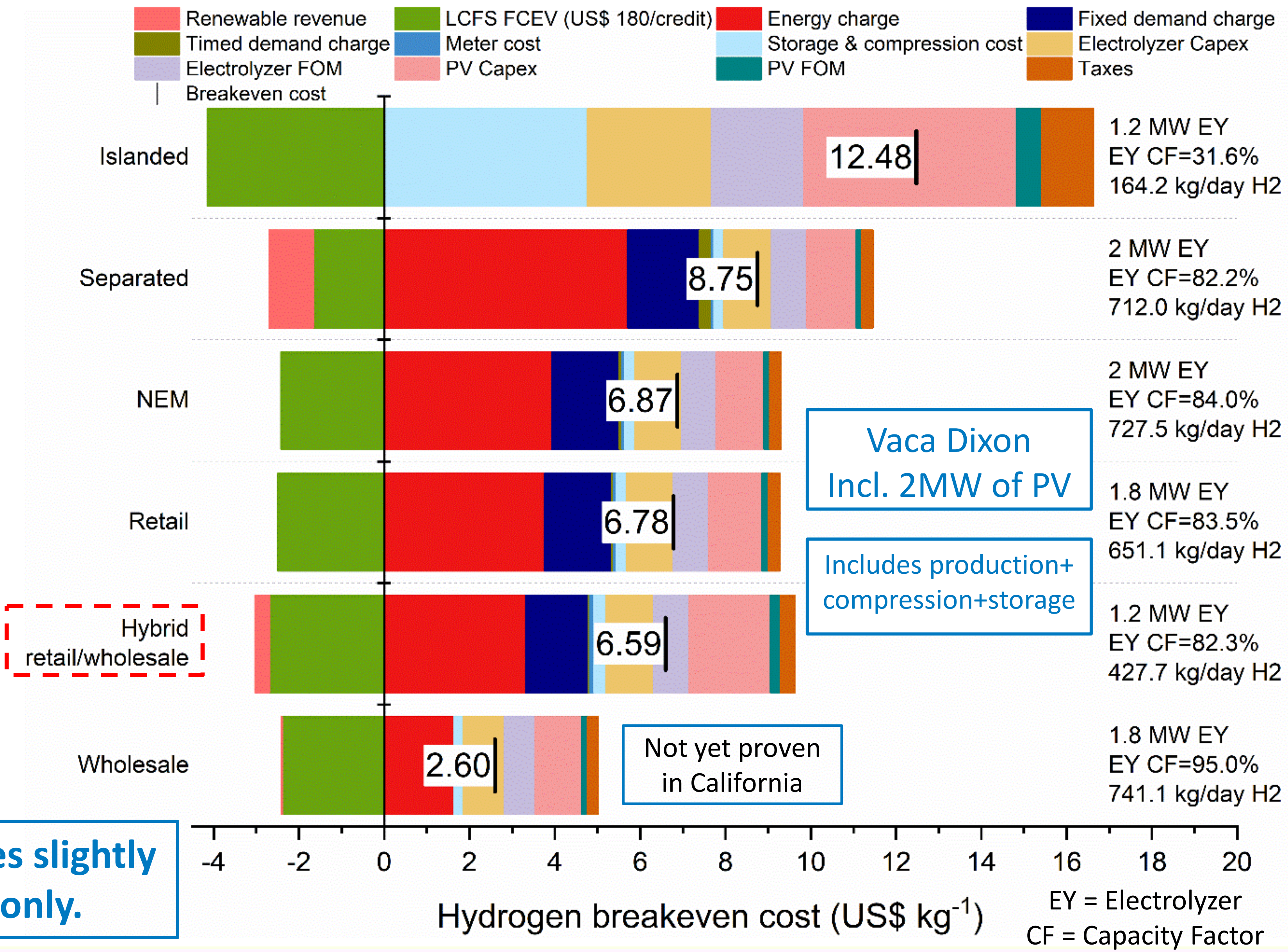
- Integrating PV + EY behind the meter creates a significant opportunity to reduce hydrogen cost
- Nearly all the solar is used for producing hydrogen
- Largest reduction comes from electricity costs



Behind-the-meter integration creates a significant cost reduction compared to separated sites.

Hydrogen cost results: Hybrid retail/wholesale scenario

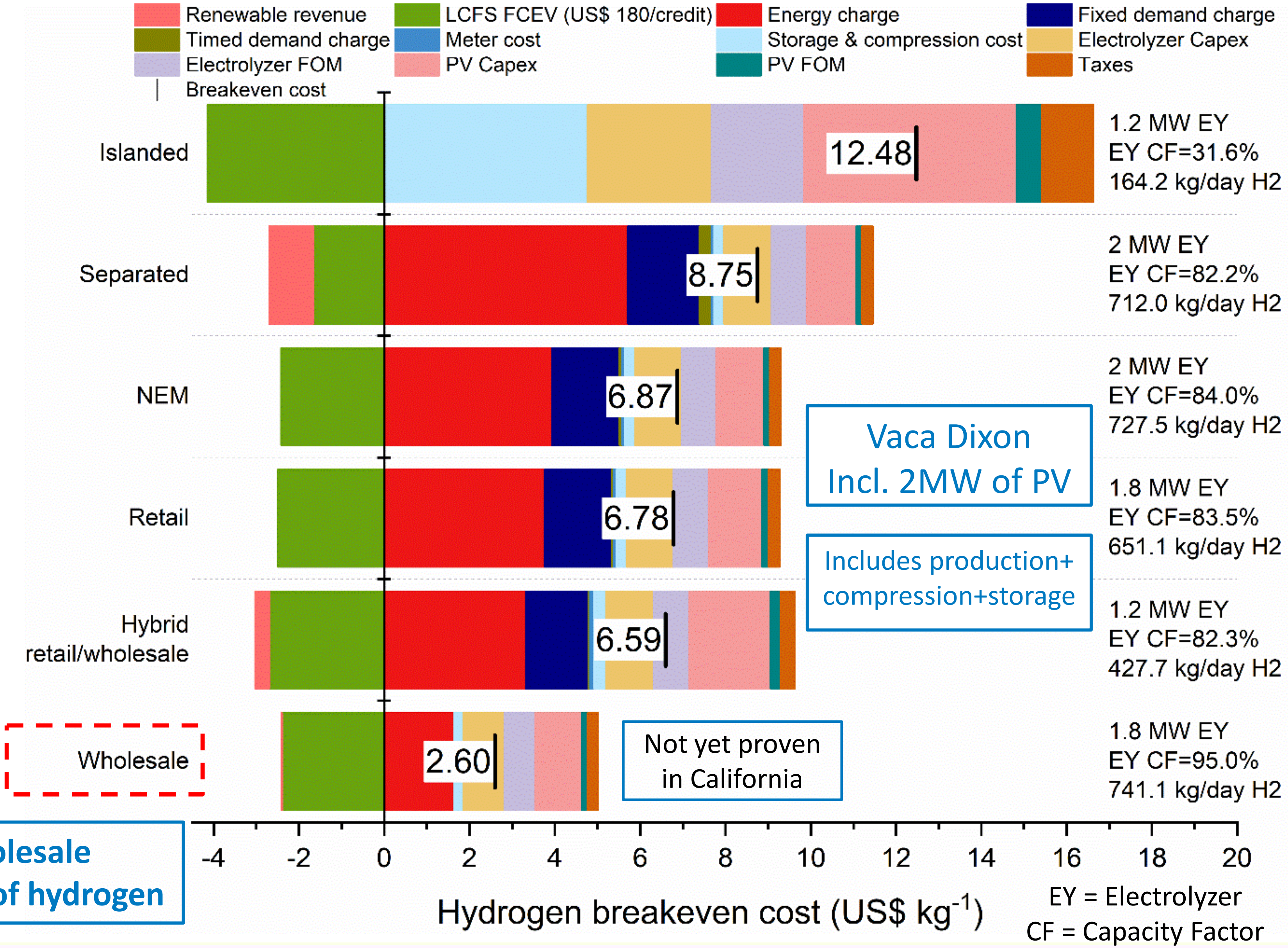
- Because of the value of hydrogen and the comparably lower wholesale prices, there isn't much renewable energy sold except during price spikes



Allowing PV to sell at wholesale prices slightly reduces the costs compared to retail only.

Hydrogen cost results: Wholesale scenario

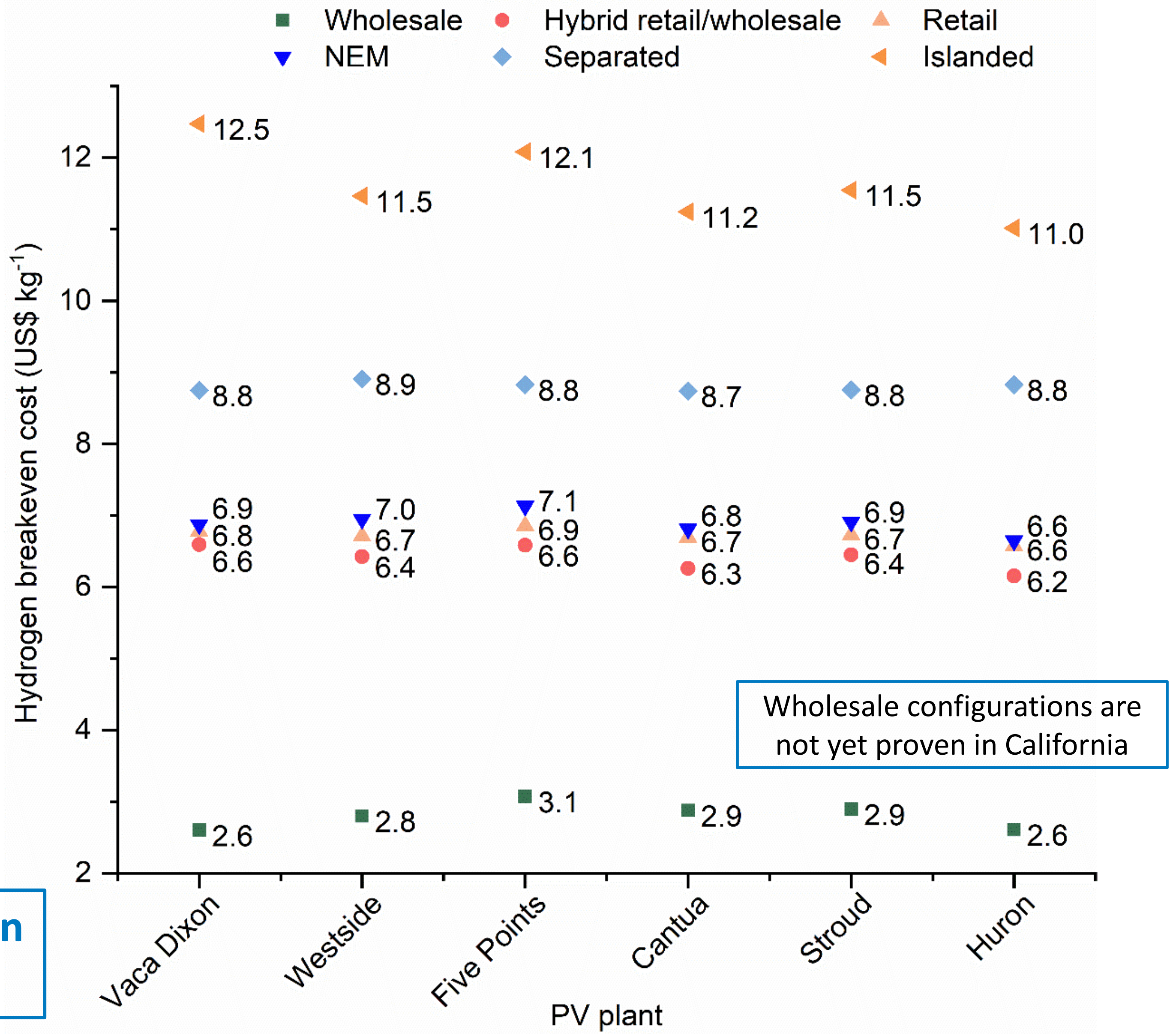
- Enabling wholesale purchase of electricity (even with T&D charge) greatly impacts the balance of values
- The average retail energy price is $85.2/MWh while wholesale is $25.7/MWh
- Thus the size of the electrolyzer goes up and the CF goes up.



While not currently proven in California, wholesale market access could greatly reduce the cost of hydrogen

Comparison to other sites

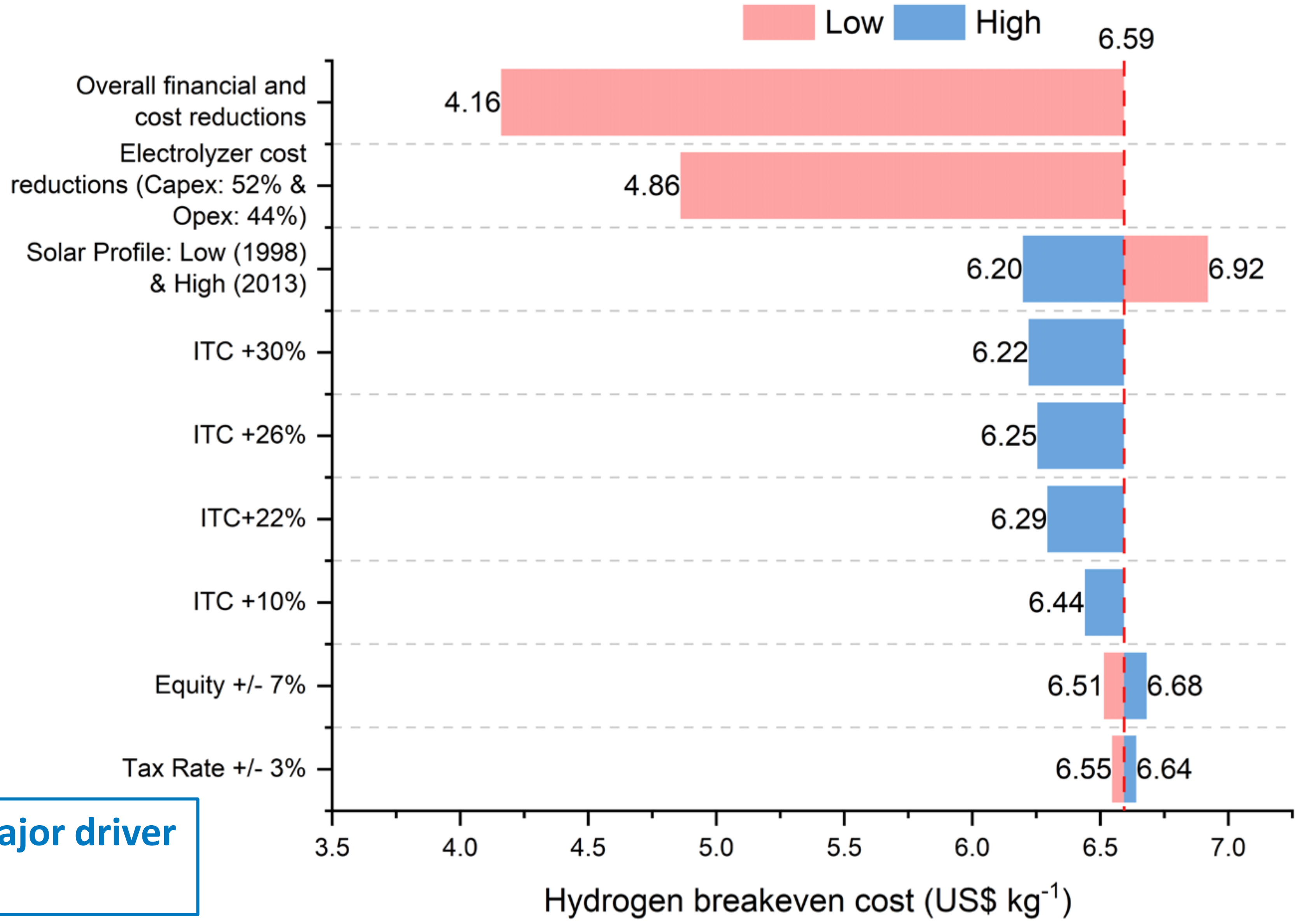
- The clustering of Retail, NEM and Hybrid (which all integrate PV and use retail rates) becomes more apparent.
- There are uncertainties around the costs for grid interconnection for all configurations except Islanded



That breakeven cost and the relationship between configurations are similar for all sites considered.

Sensitivities

- Capital cost reductions to align with DOE H2A future cost projections are the most influential.
- Depending on site selection, the solar resource can affect the cost. The extreme case shows ±5% impact.
- Allowing the electrolyzer to access the ITC can reduce costs by between 5.4% and 2.3%.
- Financing plays an important role in successful project outcome. Changes in WACC, equity/debt ratio, tax rate, etc. each have an impact on the results.

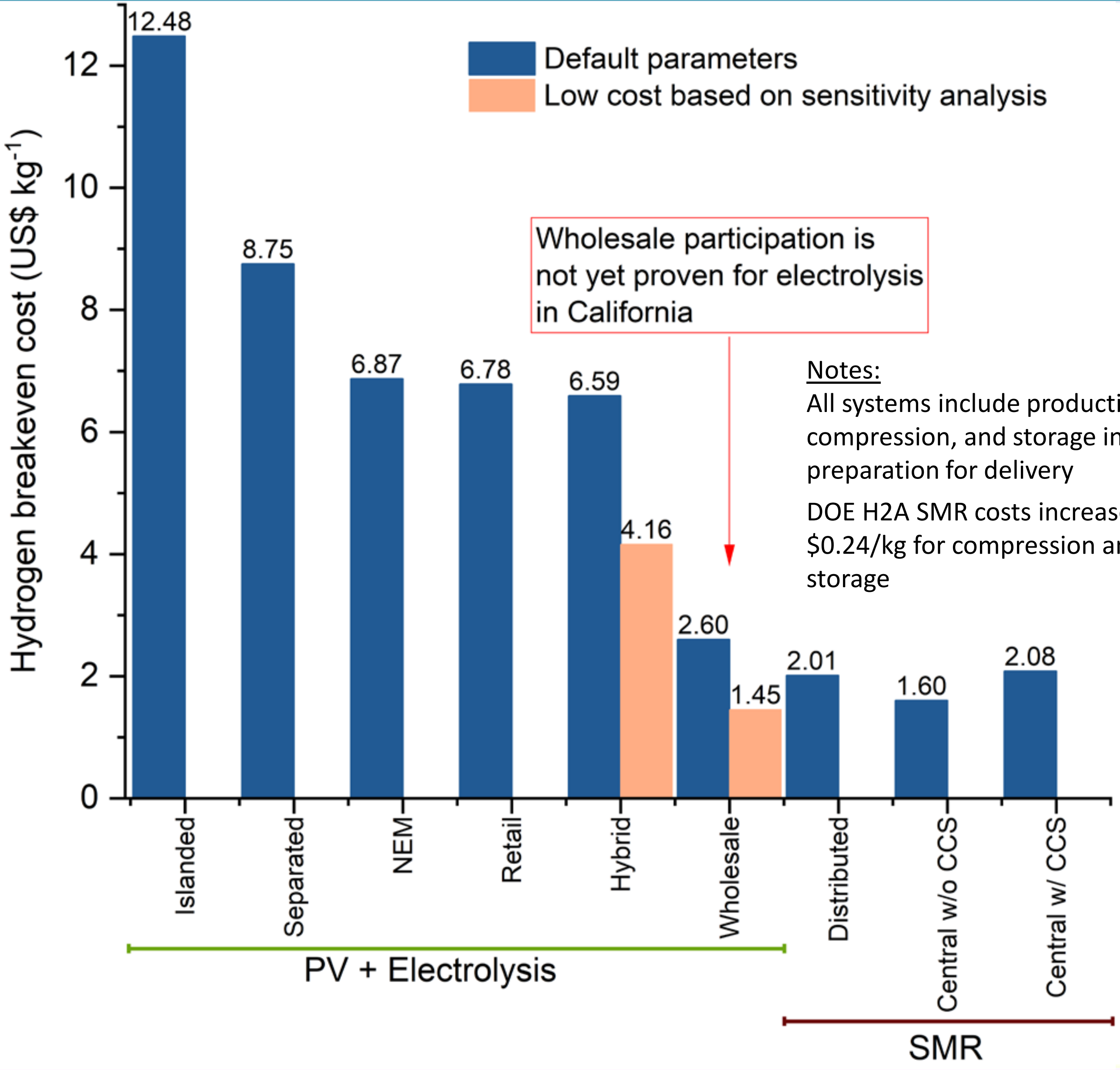


Electrolyzer cost reductions are a major driver for achieving cost competitiveness

Putting results into context

- Combining all sensitivity properties (except solar resource), the hybrid and wholesale configurations reduce significantly
- Between hybrid and wholesale configurations there are a spectrum of feasible and competitive solutions

Driven by future cost reductions, we can see a potential pathway to cost competitiveness for electrolysis solutions



Notes:
All systems include production, compression, and storage in preparation for delivery

DOE H2A SMR costs increased by $0.24/kg for compression and storage

Conclusions and additional outcomes from the research

Conclusions

- Integration with PV reduces the cost of hydrogen in comparison to separated systems.
- Results are similar for each of the selected sites.
- Electrolyzer cost reductions are a major driver for achieving cost competitiveness.
- Wholesale and hybrid retail/wholesale are the most promising configurations

Additional outcomes in the full report (**www.nrel.gov/docs/fy20osti/75635.pdf**)

- Exploration of renewable hydrogen premiums
  - Examples that help us understand potential renewable hydrogen premiums
- Qualitative discussion about site selection
  - Must balance access to high renewable resource with wholesale prices, availability of electricity and gas infrastructure, and delivery to customers
- Resulting renewable penetration
  - Spoiler: ~50% of electrons from renewable energy was determined to be optimal
- Plus lots more…

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