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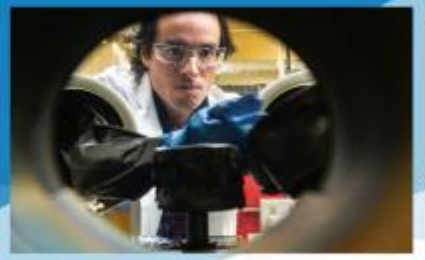


PG&E H2@Scale CRADA: Optimizing an Integrated Solar-Electrolysis System

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PG&E

CALIFORNIA AIR RESOURCES BOARD

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Project Summary

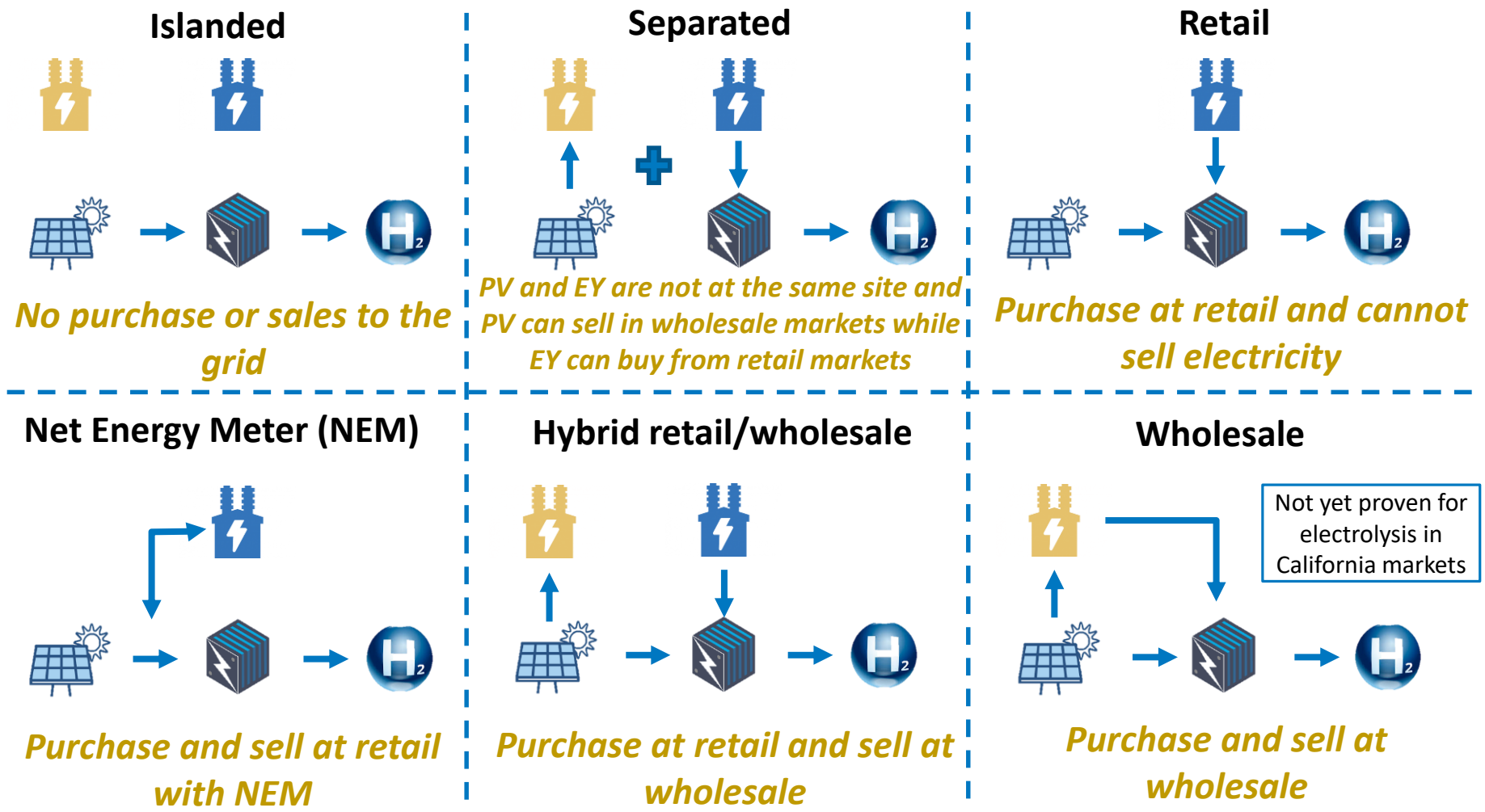
Background

- As more renewables, and particularly PV, are installed on the grid there is a deflation effect, making each new unit less competitive than the last.
- Electrolysis needs to reduce cost to better compete with market alternatives (e.g., steam methane reforming).
- By collocating PV and electrolysis we can provide a hedge against price deflation and uncertainty for PV and reduce the electricity costs for electrolysis.

Goal

- Model and evaluate an optimized integrated renewable-electrolysis system to establish the potential benefits and facilitate broader adoption.
  - We used the Revenue Operation and Device Optimization (RODeO) model to optimize size, design and operation of the PV+Electrolysis systems.
  - The optimization in RODeO includes device parameters, retail and wholesale electricity rates, taxes, credits, incentives, financing properties, etc.

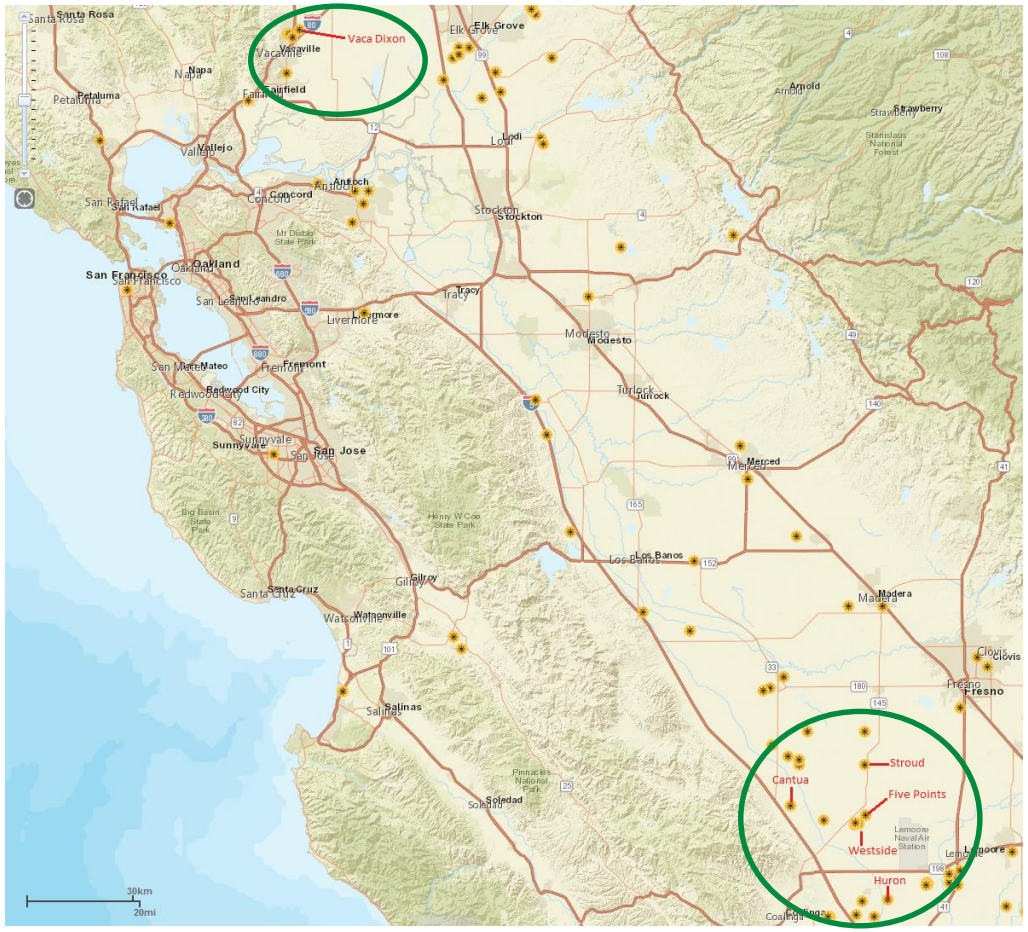
Market configurations (analysis includes production, compression and storage)



System boundary:
All systems include production, and compression and storage in preparation for delivery vehicles

Renewable Site Selection

Location of selected solar power stations†



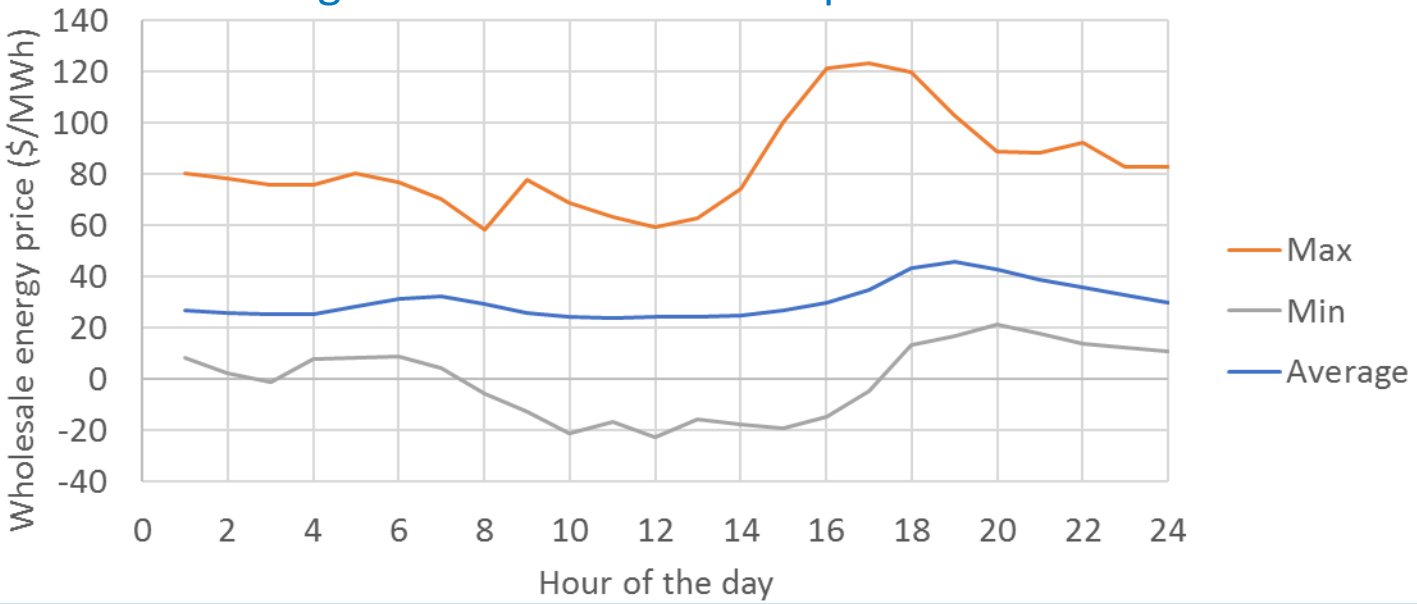
† Schedule 3 of Form EIA-860 Data:
https://www.eia.gov/electricity/data/eia860/

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

Technical specifications for the selected solar stations†

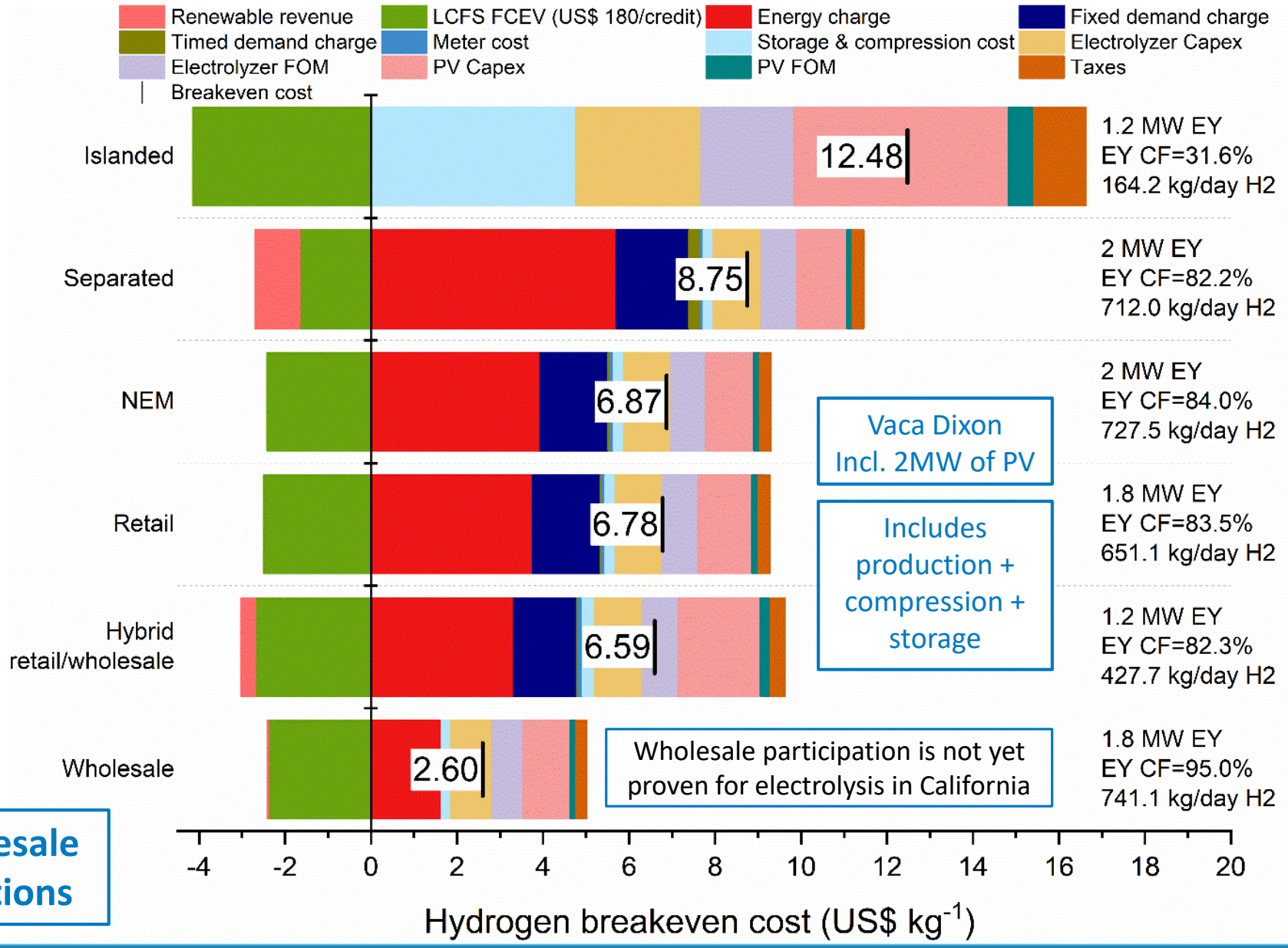
Name	DC Net Capacity (MW)	Tilt Angle	DC/AC ratio	Fixed Tilt?	Crystalline Silicon?
Vaca Dixon	2.6	30	1.30	Yes	Yes
Stroud	24.6	25	1.23	Yes	Yes
Five Points	17.6	25	1.17	Yes	Yes
Westside	18.5	25	1.23	Yes	Yes
Cantua	26.3	25	1.32	Yes	Yes
Huron	26.8	25	1.34	Yes	Yes

Average 2016 Wholesale LMP prices for all 6 sites ‡



Hydrogen breakeven cost results for Vaca Dixon site

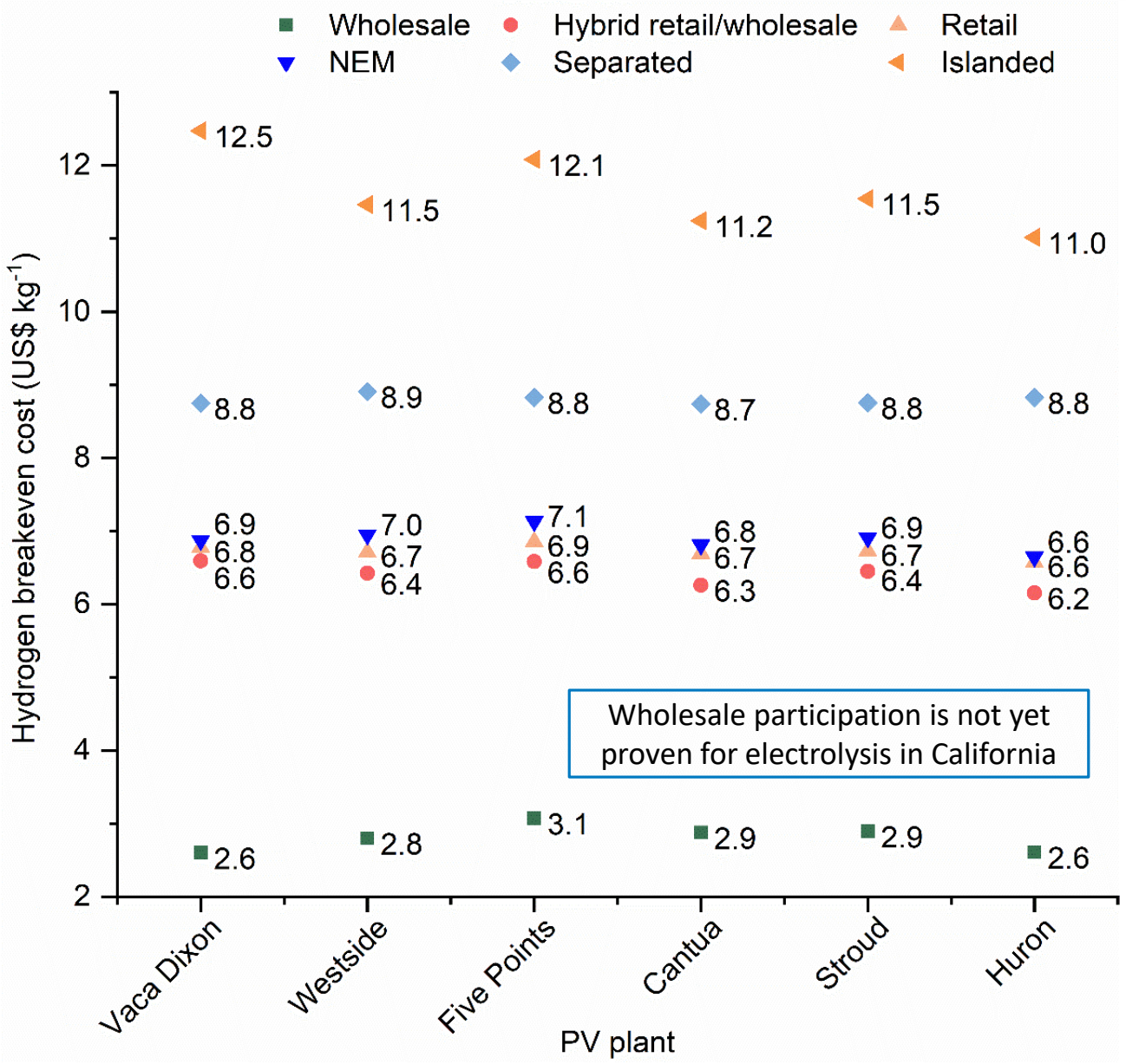
- Optimal solutions balance capital investment with electricity cost, incentives, and financial parameters to determine the electrolyzer size and capacity factor (CF) that achieves the lowest cost.
- The most promising configurations are wholesale and hybrid retail/wholesale.



Wholesale and hybrid retail/wholesale are the most promising configurations

Results comparison for all sites

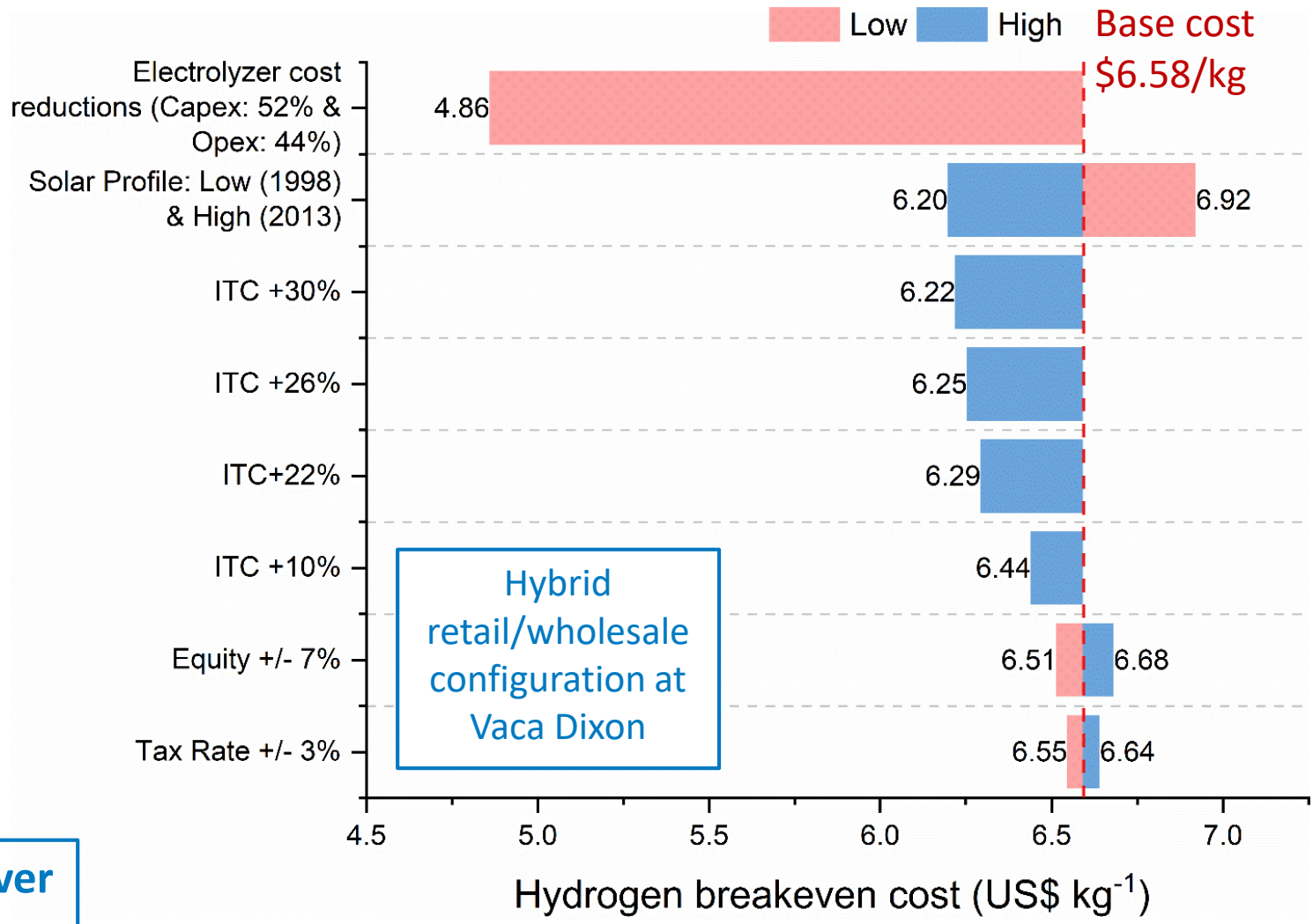
- The clustering of Retail, NEM and Hybrid (which all integrate PV and use retail rates) becomes more apparent.
- There are uncertainties about the costs for grid interconnection for all configurations except Islanded



Results are similar for each site (differences caused by resource potential and wholesale prices).

Sensitivity analysis for Hybrid configuration at Vaca Dixon

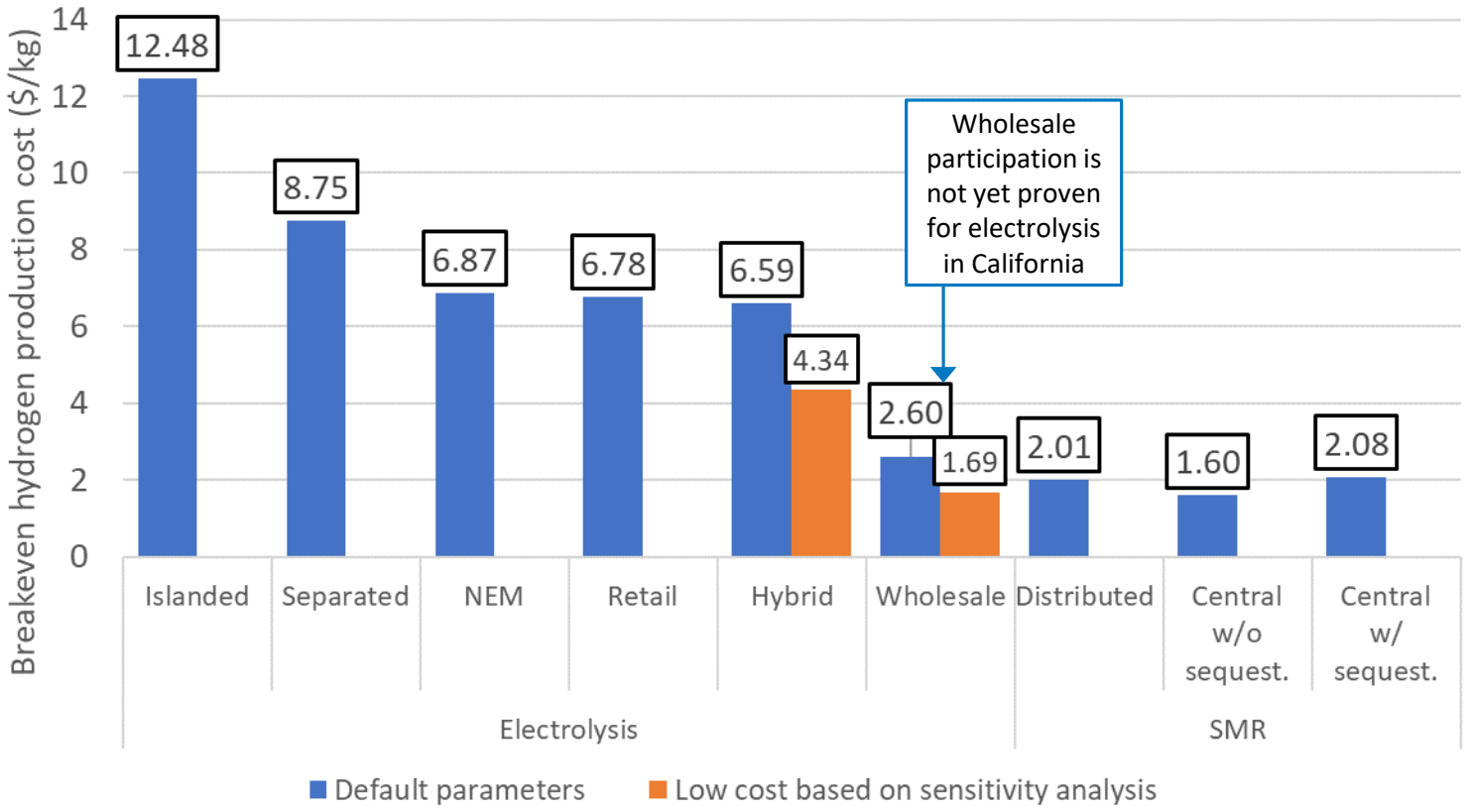
- Capital cost reductions to align with DOE H2A future cost projections are the most influential.
- Depending on site selection, the solar resource can affect the cost. The extreme case shows ±5% impact.
- Allowing the electrolyzer to access the ITC can reduce costs by between 5.4% and 2.3%.
- Financing 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

Compare to incumbent technologies

- 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 have laid out a pathway to cost competitive electrolysis solutions

Notes:

All systems include production, and 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 not in this presentation

- 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% is optimal)
- Plus lots more…