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Economics of High Renewable Penetration and the Role of Hydrogen

US-REGEN Modeling Analysis

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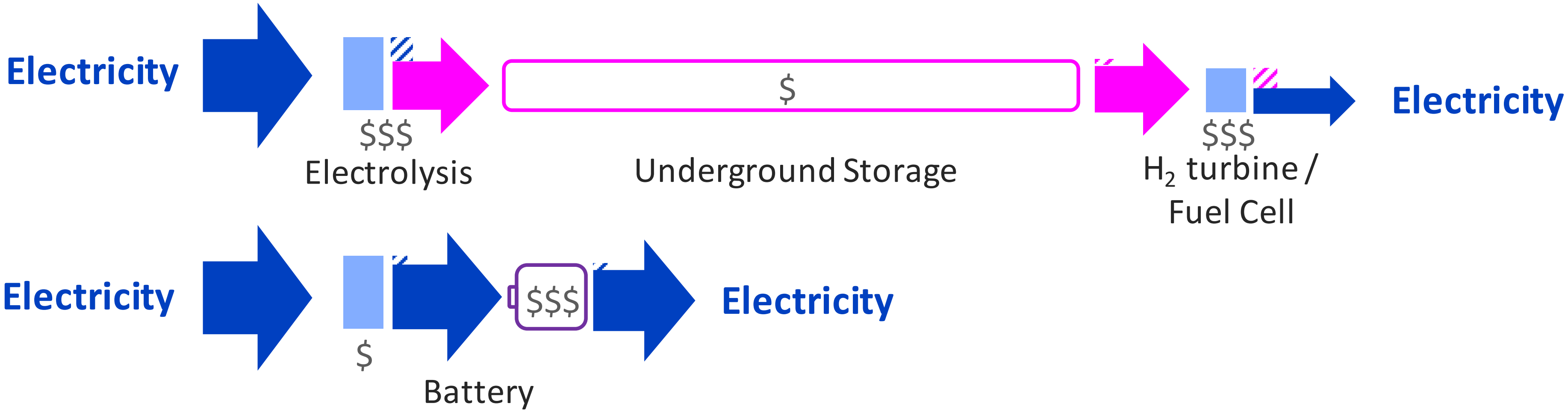
Overview

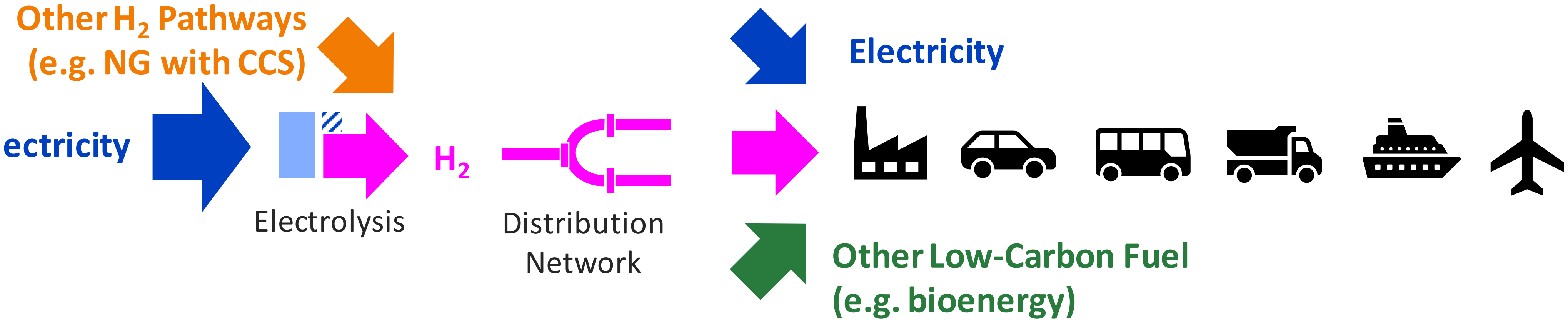
- Wind and solar costs continue to decline → intermittent renewables will have a significant share in decarbonized electricity
- However:
  - Marginal value of intermittent profiles decline with penetration
  - Must be accompanied by balancing resources
  - Operational challenges increase
- Under a constraint of very-low or zero carbon:
  - What is optimal level of renewable deployment?
  - What is optimal deployment of balancing resources?
  - What is the potential role for hydrogen?

Potential Role of Hydrogen / Electrolysis

- Power-gas-Power for longer term storage



- Power-to-gas for end-use fuel demand



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Point 1: Power-gas-power storage is a last resort

- Seasonal balancing can be provided by nuclear, CCS, or even conventional gas turbines with very low annual emissions
- Value of power-gas-power emerges only with very high carbon prices or requirements for 100% renewables
- US example:
  - \$100/tCO_2 pushes emissions down to 95% below 2005 with GTs supplying ~1/3 of firm capacity, negligible deployment of hydrogen
  - \$300/tCO_2 pushes emissions down to 99.6% below 2005 with hydrogen replacing about half of GT capacity
  - 100% renewables requirement forces all GT to be replaced with hydrogen, but with a significant cost increase

US Generation Capacity Scenarios for 2050

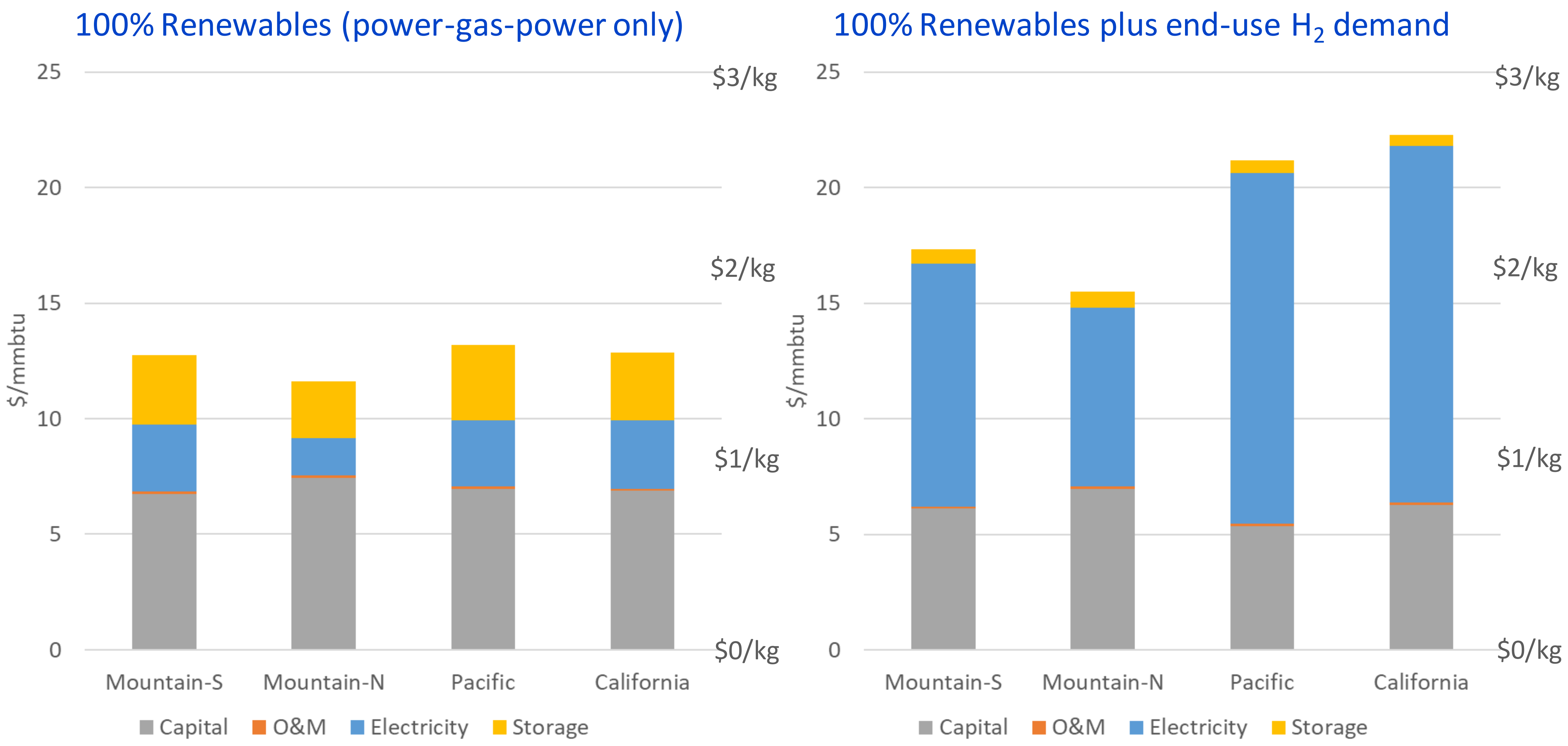
Results of a long-run equilibrium simulation of US power grid in 2050: reflects energy and capacity at hourly resolution plus inter-regional transmission between major electricity markets. Does not include operational constraints or other ancillary services.

Point 2: Power-to-gas competes with Power-gas-power

- "Sector coupling" narrative is conceptually intuitive, *however:* the synergy between electrolytic (i.e. "green") hydrogen and variable renewable generation is complex
- If the power system is not deploying power-gas-power storage, electrolytic hydrogen demand is a flexible load, which can slightly lower average cost of power production (~5%)
- If the power system is using power-gas-power, effect is opposite
- US Example:
  - With a 100% renewables power system, adding end-use demand for electrolytic hydrogen doubles its price and raises power costs

Average Cost of Hydrogen from Electrolysis in WECC

Excluding Distribution



Point 3: Power-to-gas competes with other H_2 pathways

- Significant cost reductions in electrolysis technology are required to make “green” hydrogen cost-competitive with “blue” hydrogen e.g. via steam methane reforming (SMR) with CCS in the US
- Electrolytic hydrogen costs will vary by region depending on generation mix: capacity factor vs. electricity price
- Decreasing returns to scale with high intermittent share of energy
- US Example:
  - Lowest costs are in wind-heavy regions, range across regions of $1.80 - $2.60/kg (production costs only) with base technology assumptions
  - SMR+CCS estimated cost is $1.25/kg (assuming $4/mmbtu gas)

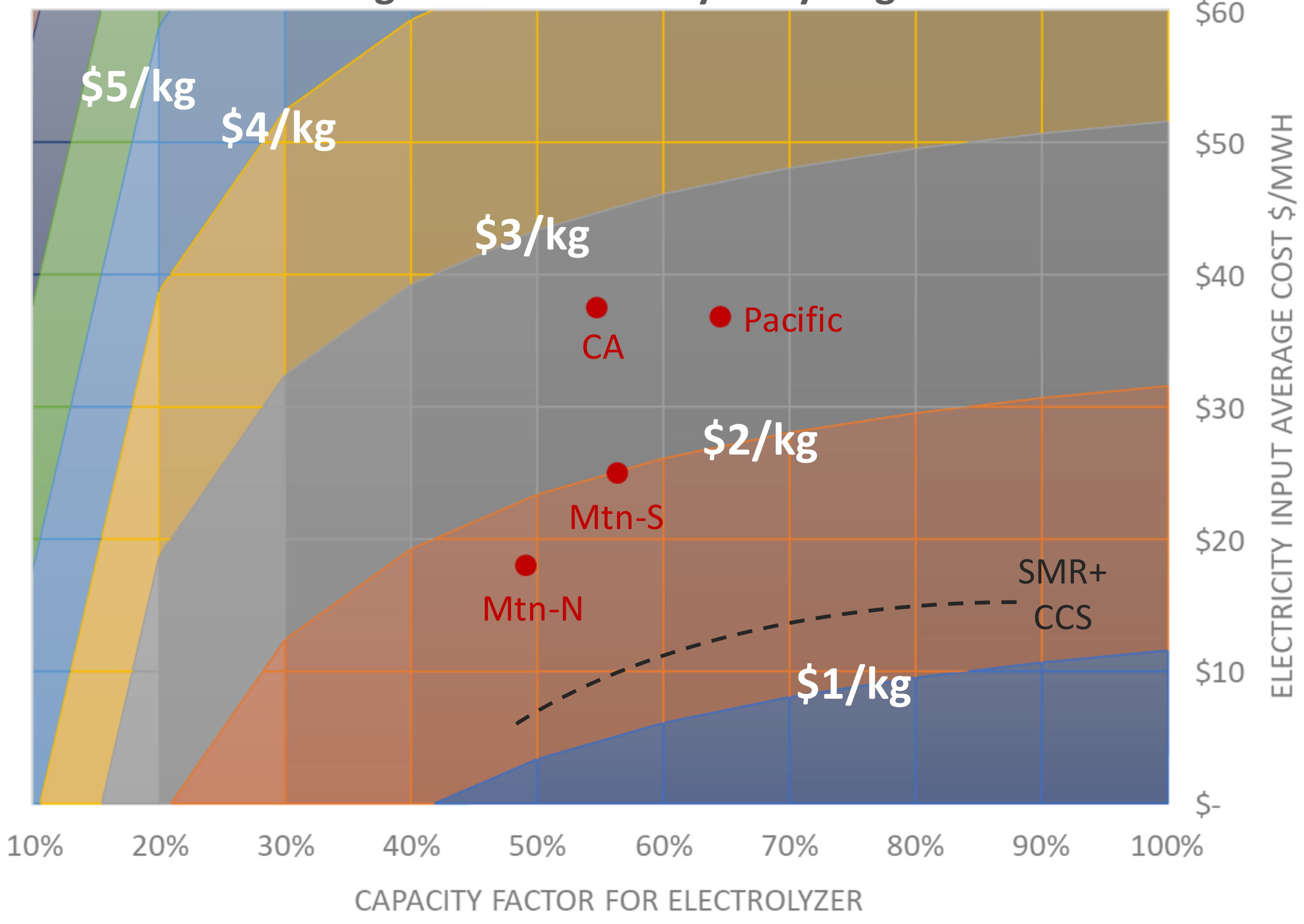
Equilibrium price of electrolytic hydrogen

- Cost structure of electrolytic hydrogen depends on system mix: capacity factor vs. electricity price
- Grid-integrated electrolysis could take advantage of low-price hours of high renewable generation – but how many?

● Indicates regional CF/price combinations for electrolysis with 100% renewables plus end-use hydrogen demand

Excluding Storage and Distribution

Average Cost of Electrolytic Hydrogen



Based on $1000 per kg/day and 50 KWh/kg
= $480/kW @ 70% efficiency

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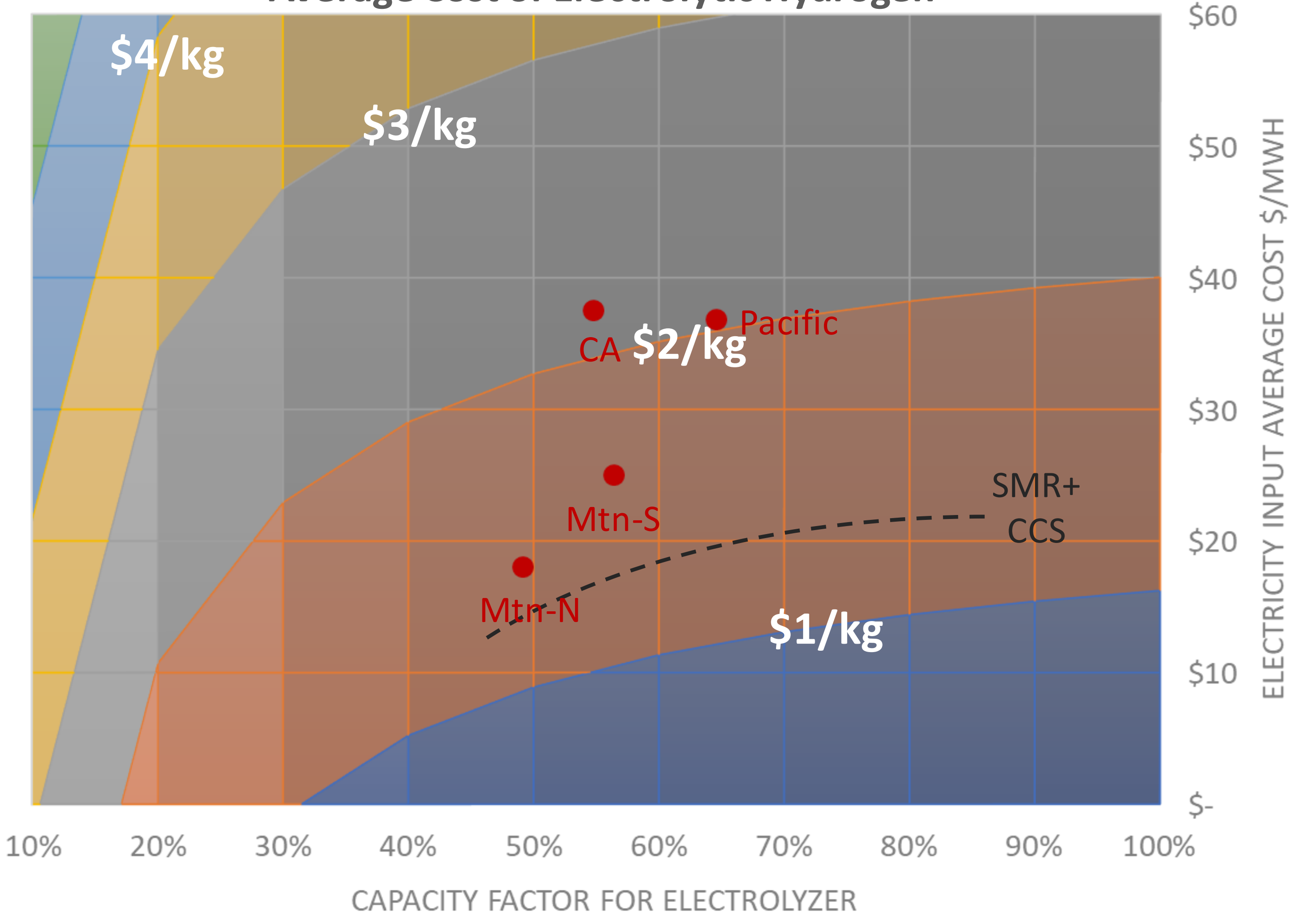

Based on $500 per kg/day and 42 KWh/kg = $285/kW @ 85% efficiency

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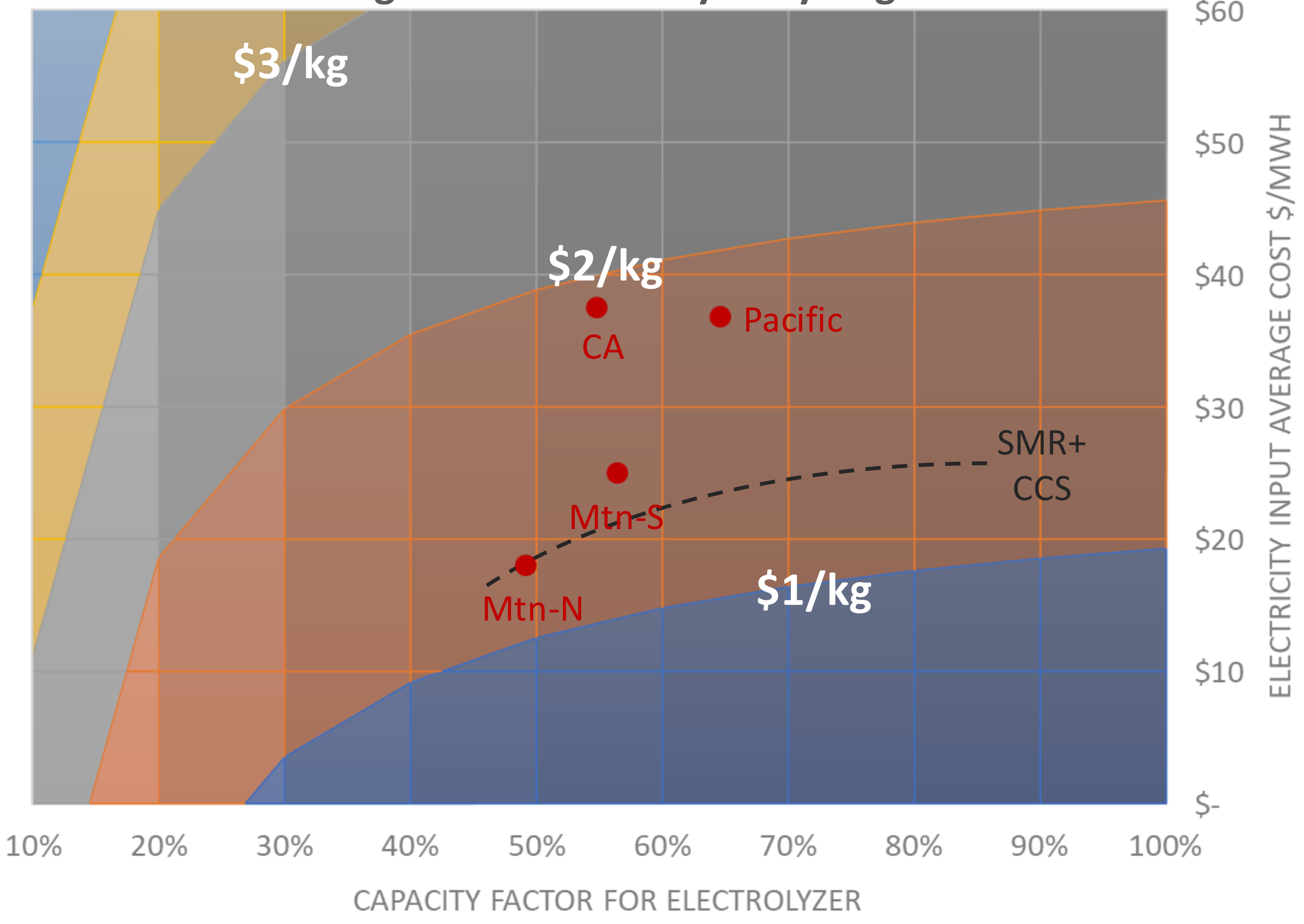

Based on $250 per kg/day and 38 KWh/kg = $158/kW @ 93% efficiency

Key Observations

- Optimal intermittent share in a decarbonized electric sector is likely in the range of 50% - 80% of energy
  - Assuming advanced nuclear / gas-CCS technologies are on the table, intermittent shares of 90-100% likely not cost-effective
- Hydrogen could emerge as important low-carbon end-use fuel
- Three observations from modeling the interaction:
  - Power-gas-power storage is a last resort
  - Power-to-gas competes with power-gas-power
  - Power-to-gas competes with other hydrogen pathways
- Technology development for electrolysis is a key uncertainty

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