Optimizing the use of curtailed power in the electric grid

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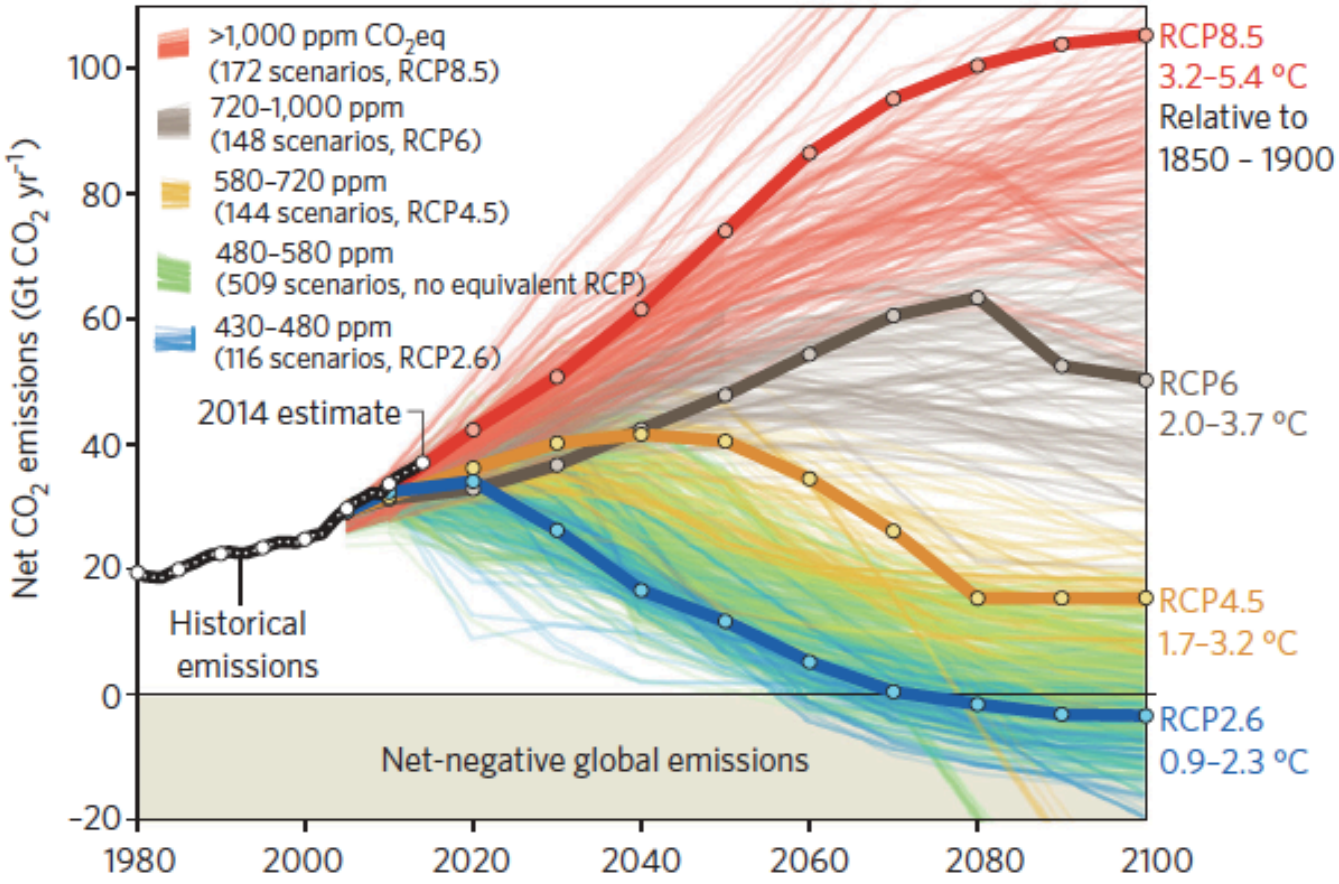
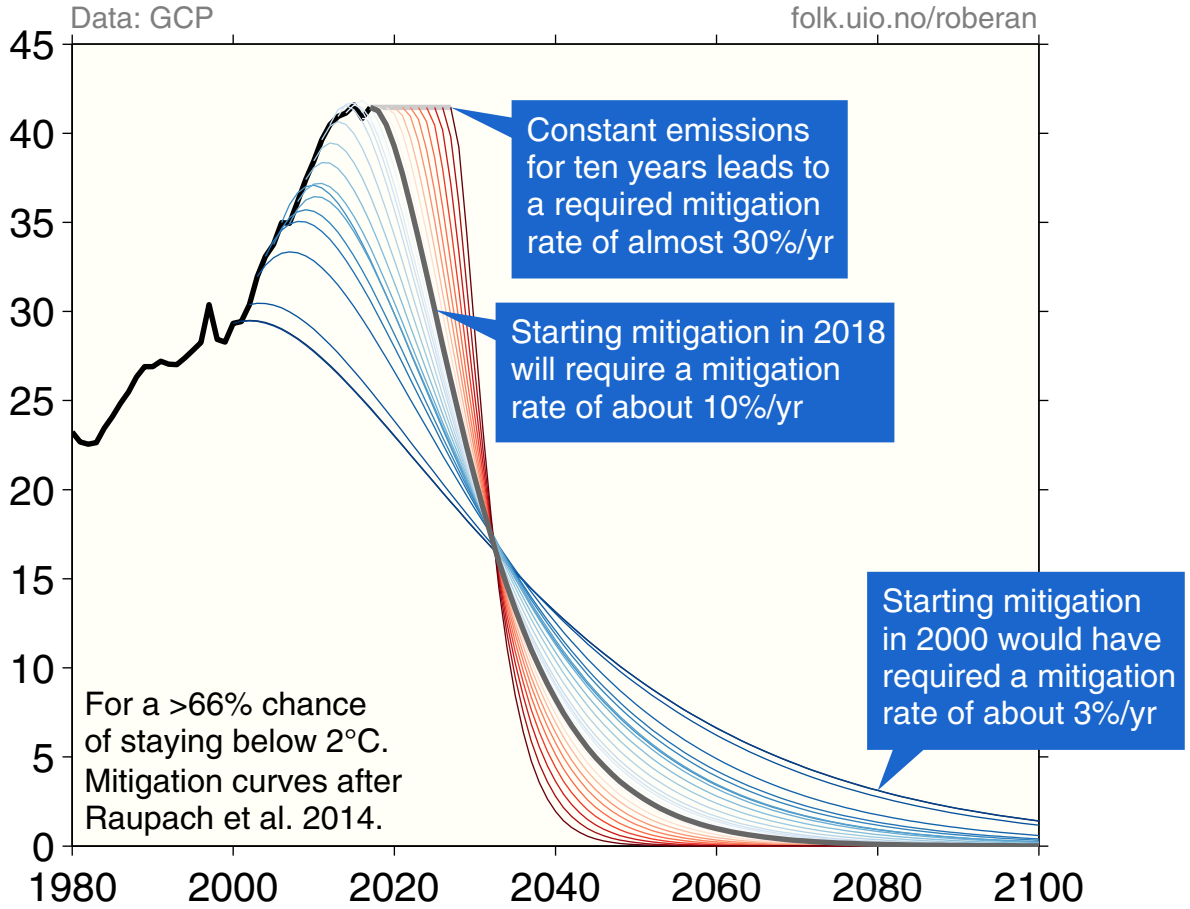
Getting to zero emissions poses a Herculean challenge



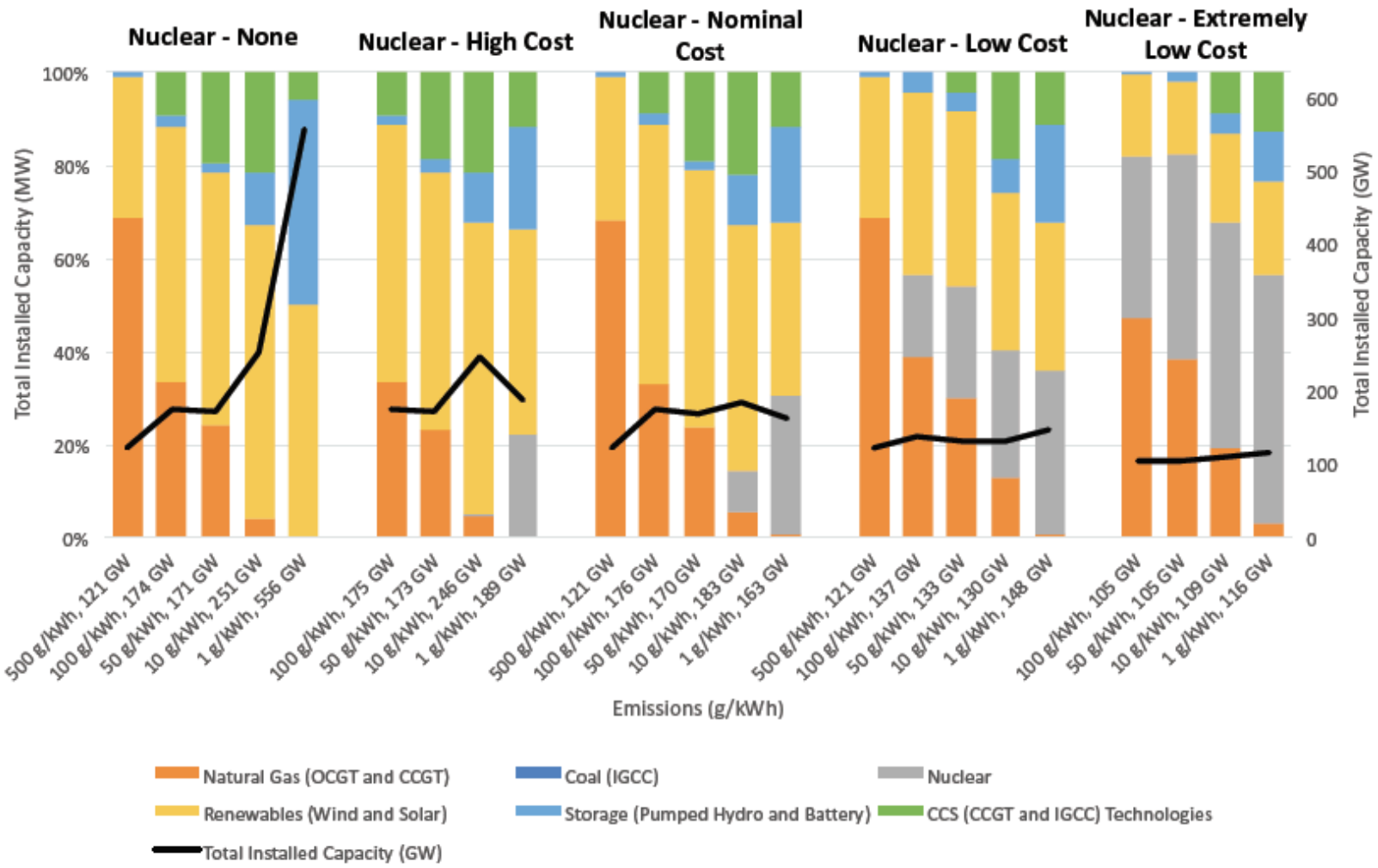
Fuss *et al* (2014) *Nature Climate Change* 4(850–853)



Raupach MR *et al* (2014) *Nature Climate Change* 4(873-879)

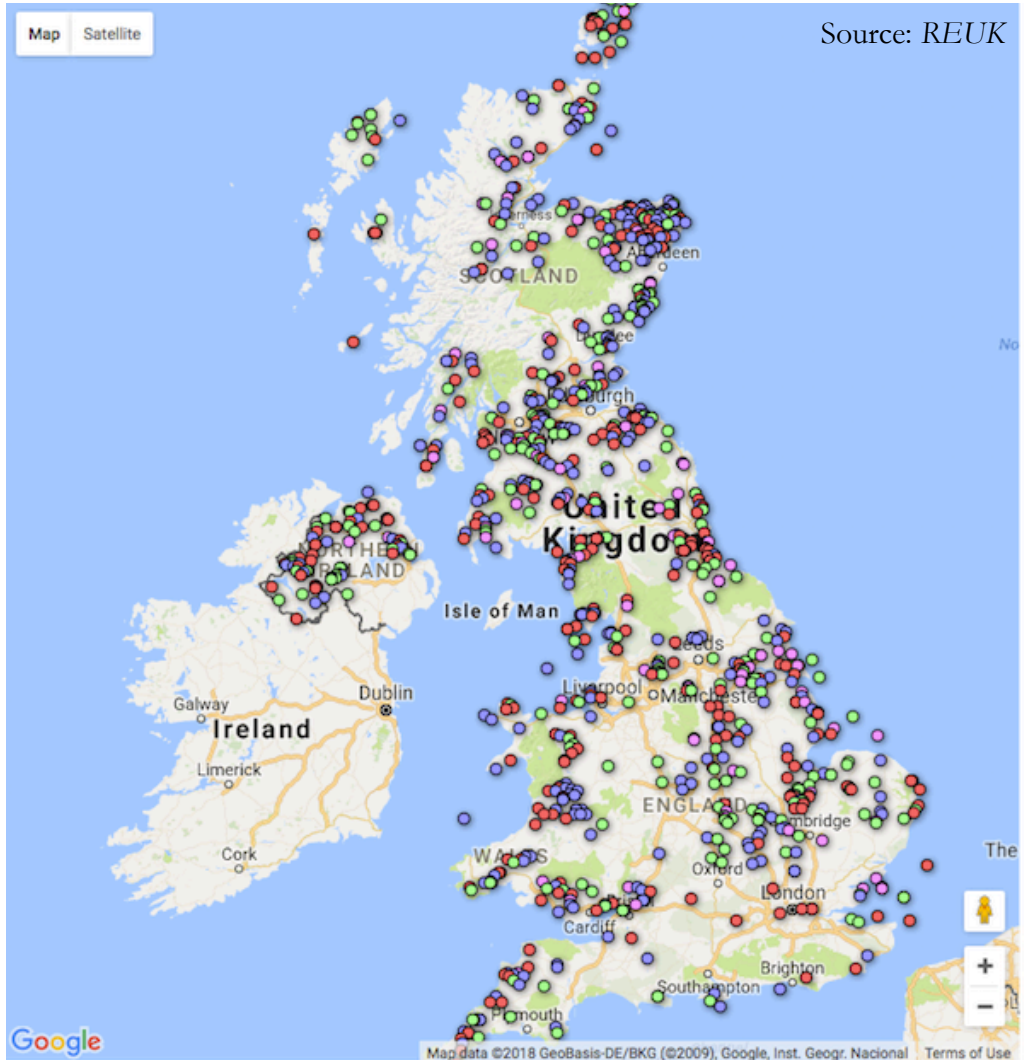
Existing models are misleading

Figure 1.4b: Optimal capacity mixes for Texas



Electricity curtailment is a pressing problem

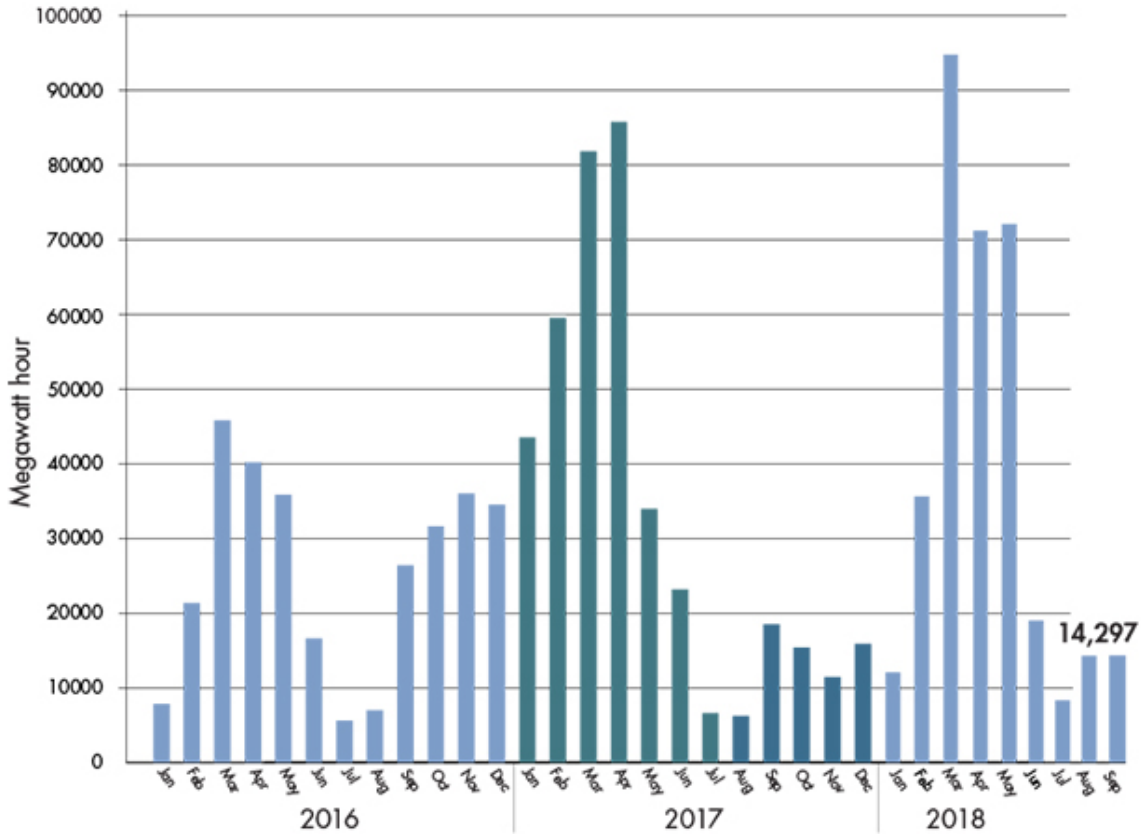
- Jurisdictions with high renewable energy penetration seeing increased curtailment:
  - Reduction in power production from a generator to accommodate grid or environmental constraints
- Wind power:
  - UK system operator **curtails 100–300 GWh** of wind power per month
  - Millions in cost to ratepayers
  - Proposed solutions—e.g. geographical dispersion of production to reduce variability—limited in effectiveness



Not limited to wind: CAISO curtails utility-scale solar power

Solar power responsible for 80% of curtailment in California over the past 5 years

Source: *CAISO*



Leveraging curtailed electric power

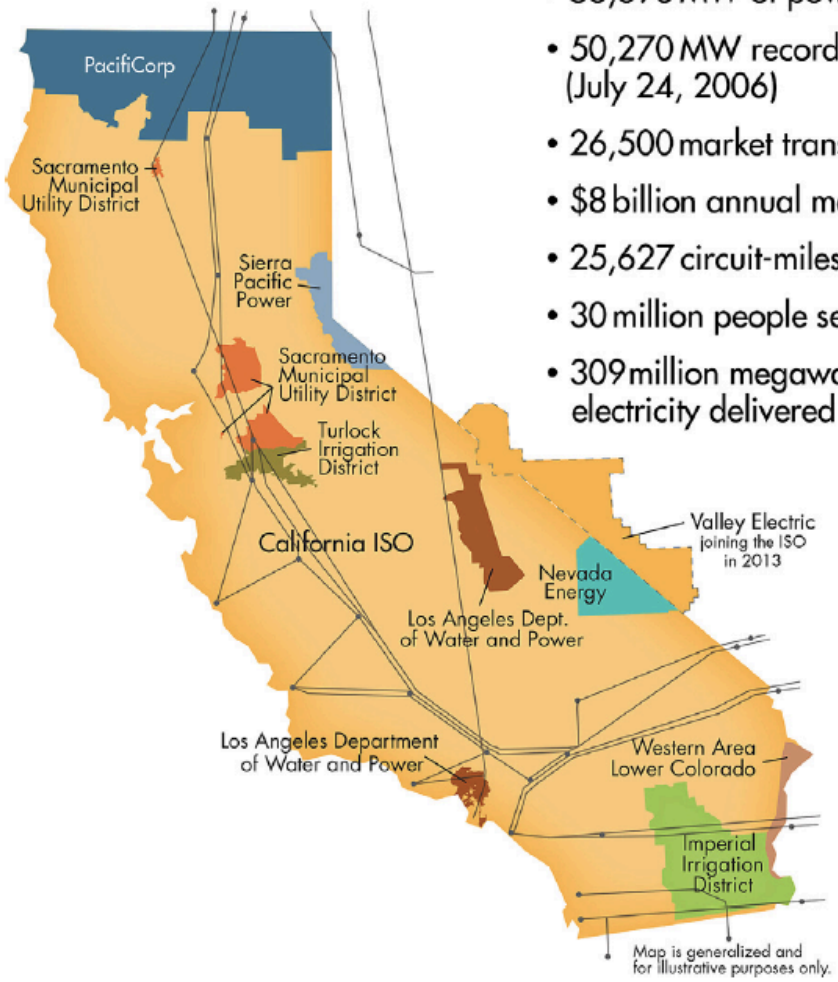
① We have a large number of generators whose variability causes electricity curtailment

② We have a pressing challenge that requires, among other things, "free electrons" to solve

Can we transform risks into benefits by powering technologies that could exploit curtailed generation across California?

Data – ① Curtailment

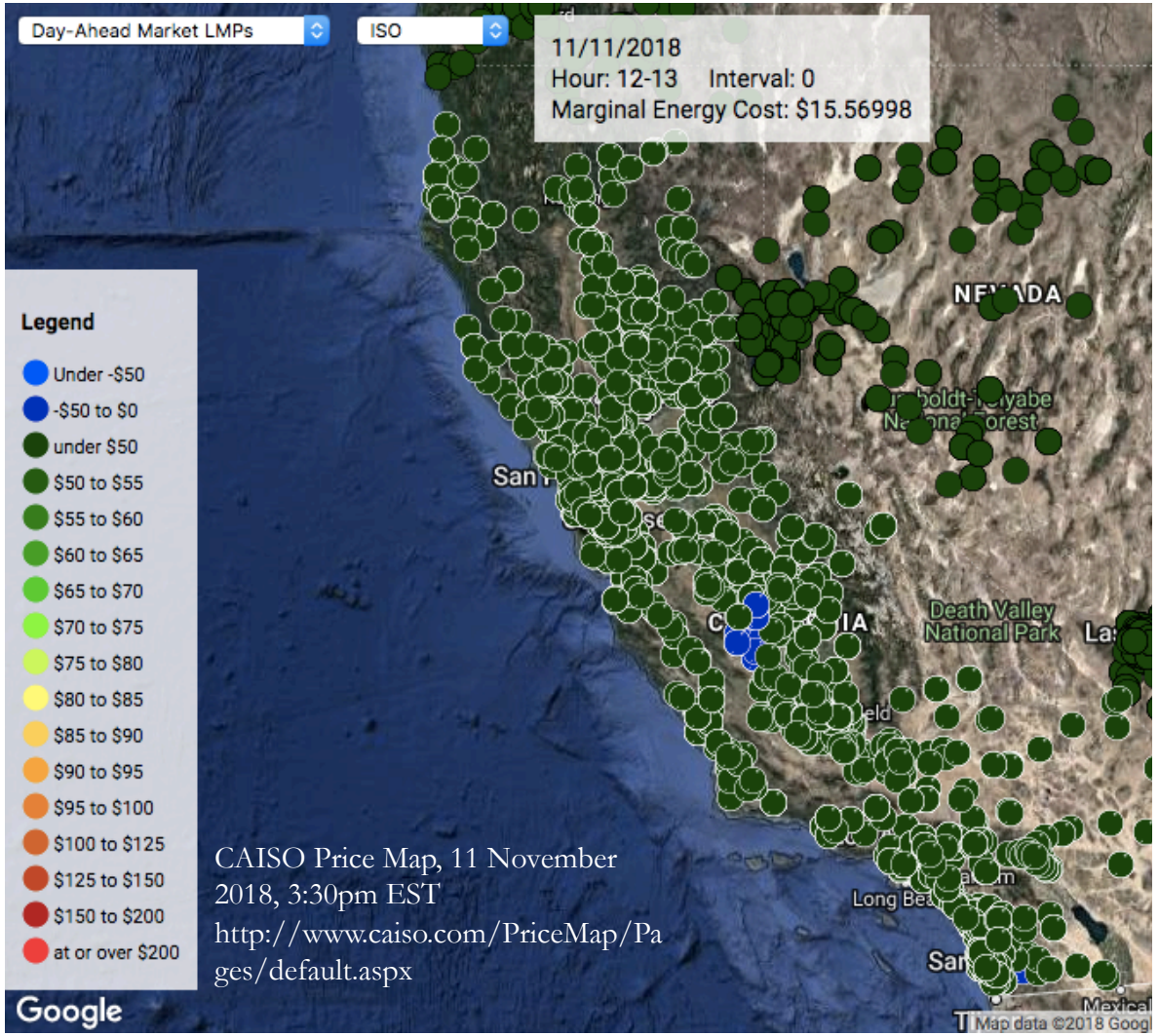
- CAISO has recently made its curtailment data public
  - 4-year dataset
  - System-wide
  - Wind and solar MWh curtailed
  - 5-minute intervals



- 58,698 MW of power plant capacity
- 50,270 MW record peak demand (July 24, 2006)
- 26,500 market transactions per day
- $8 billion annual market (2012)
- 25,627 circuit-miles of transmission lines
- 30 million people served
- 309 million megawatt-hours of electricity delivered annually

Data – ② Electricity prices

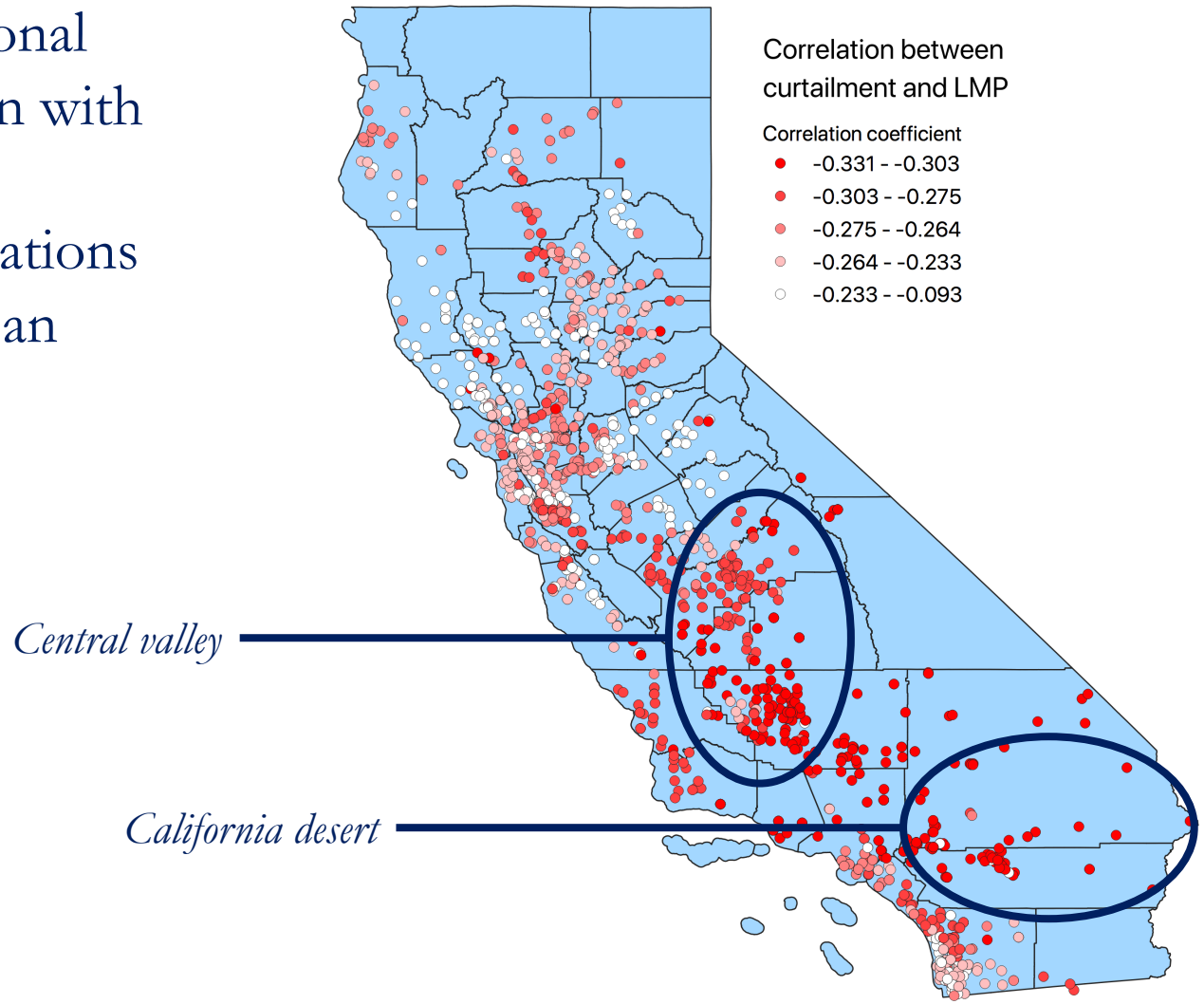
- CAISO locational marginal price (LMP) data:
  - 2,202 aggregate pricing nodes
  - Hourly prices
  - Divided into "Energy", "Congestion", and "Loss" components
  - Both day ahead (DAM) and real-time unit commitment (RUC) LMPs



CAISO Price Map, 11 November 2018, 3:30pm EST
http://www.caiso.com/PriceMap/Pages/default.aspx

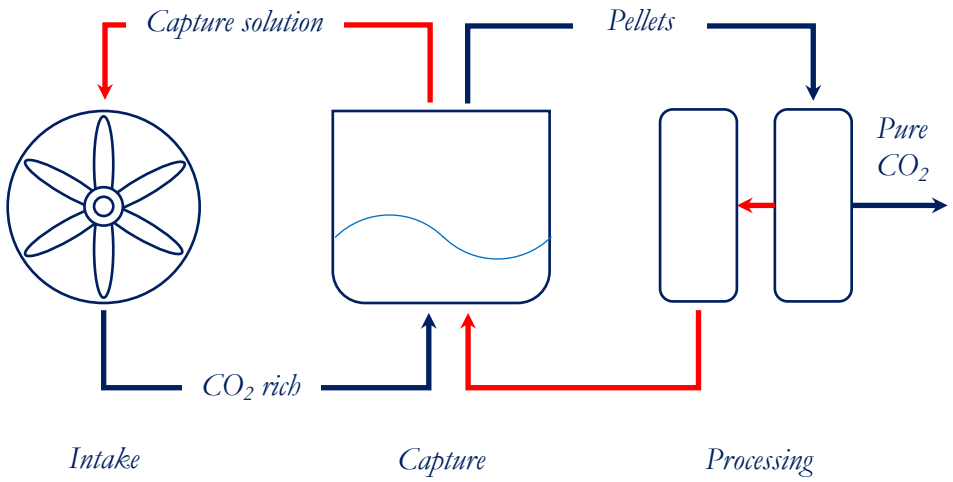
Data – ② Electricity prices – pockets of negative prices

- Exploratory data analysis: CAISO locational marginal price (LMP) Pearson correlation with curtailment
- Pockets of high negative correlation; locations with renewable generators and some urban areas



Data – ③ Three clusters of technologies

Option 1: Direct Air Capture (DAC)



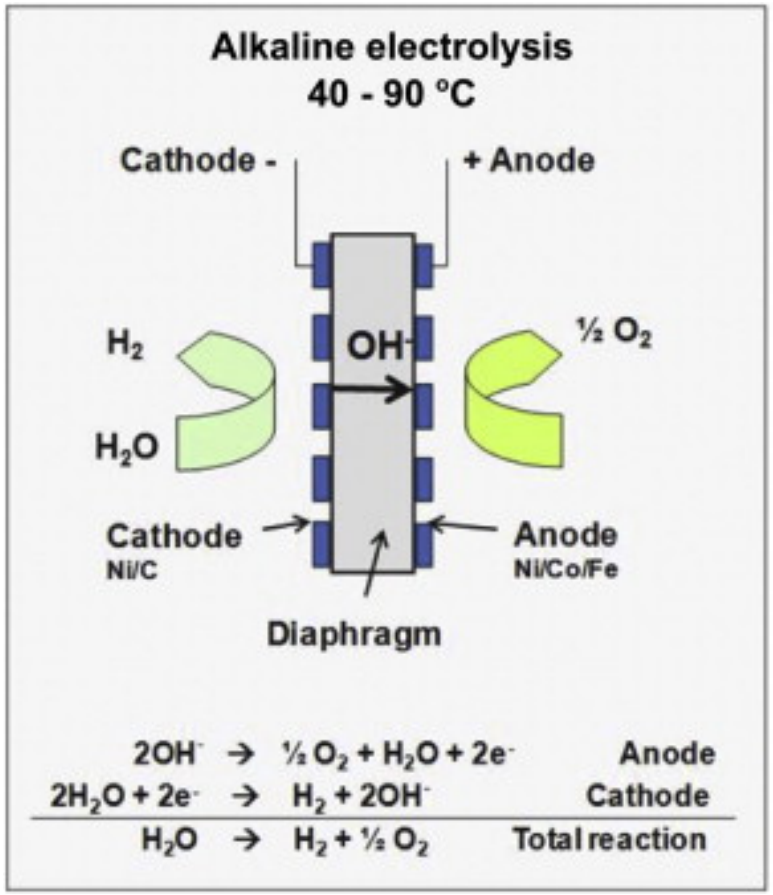
- Global Thermostat
- Carbon Engineering
- Climeworks

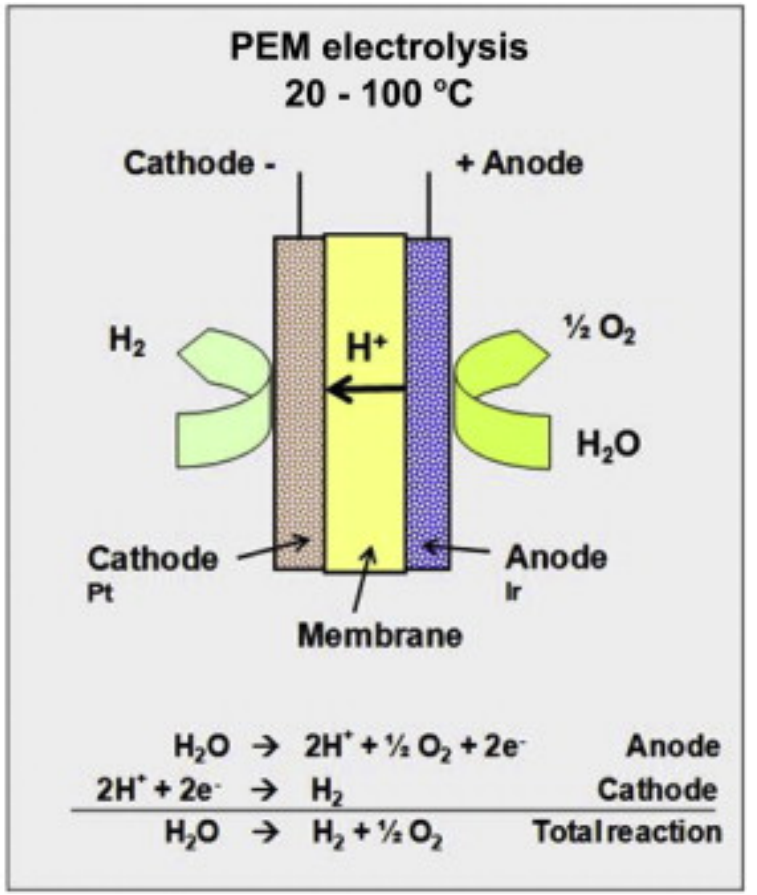
Data – ③ Three clusters of technologies

Option 2: Power to Gas (P2G)

- Alkaline electrolysis (AEL)
- Polymer electrolyte membrane fuel cells (PEM)
- Various biological methanation techniques

Carmo et al (2013) A comprehensive review on PEM water electrolysis. *International Journal of Hydrogen Energy* **38**(12): 4901-4934.



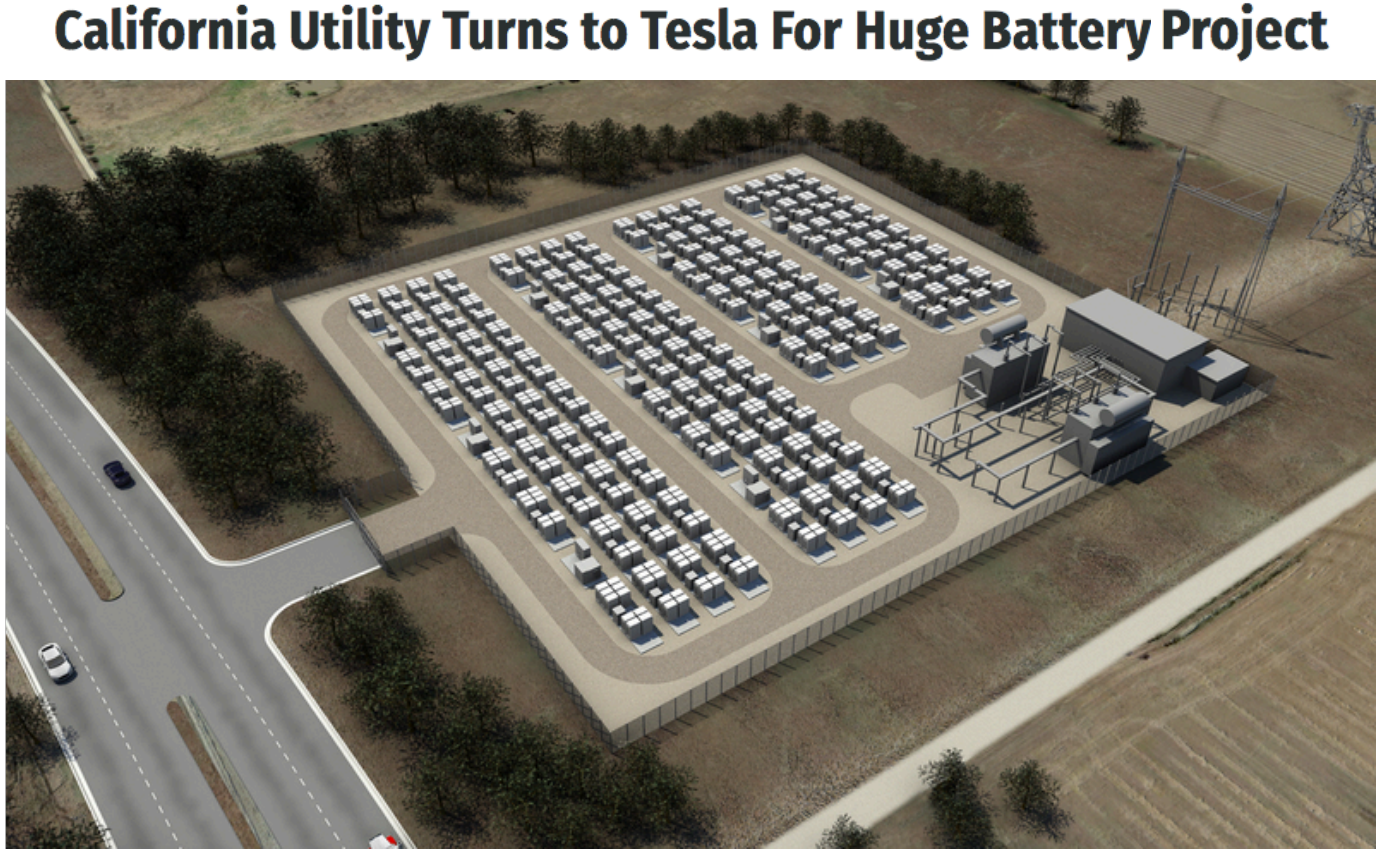


Data – ③ Three clusters of technologies

Option 3: Energy storage

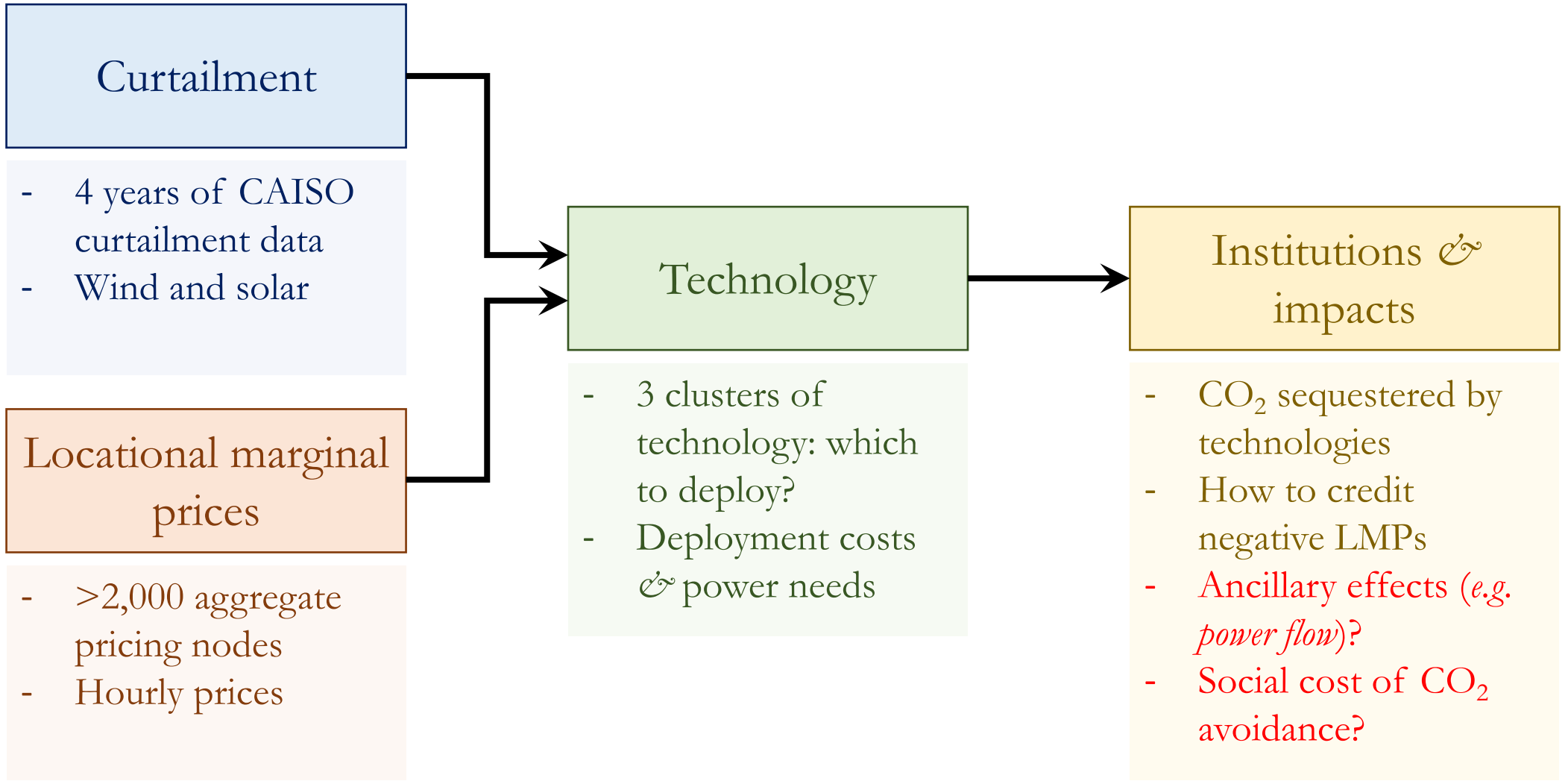
Utility scale:

- Lithium ion batteries
  - Weight, power density, safety of flow batteries
  - Global supply chain reoriented for Li-ion, driving down costs
- Redox flow batteries



Fehrenbacher K (2016) California Utility Turns to Tesla For Huge Battery Project. *Fortune*. Accessed 10 November 2018. http://fortune.com/2016/09/15/tesla-grid-battery-project/

Putting it all together



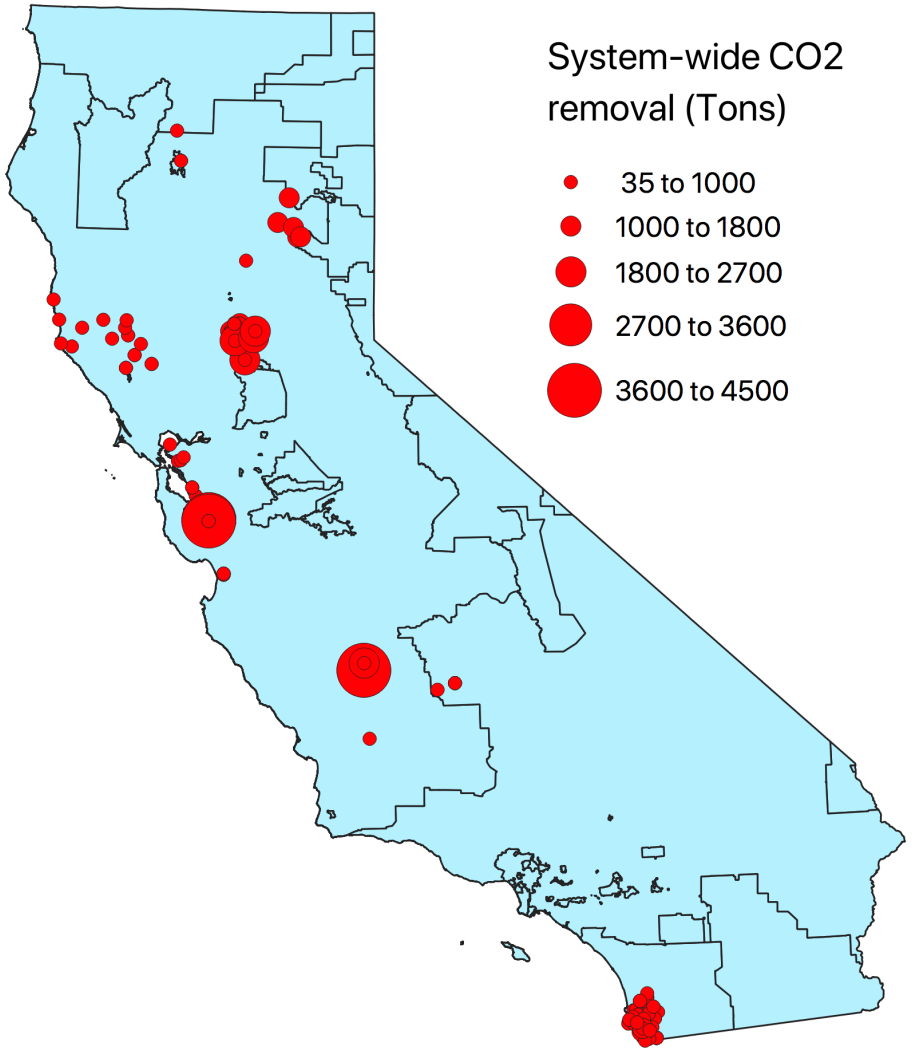
Results – CO_2 removal system-wide

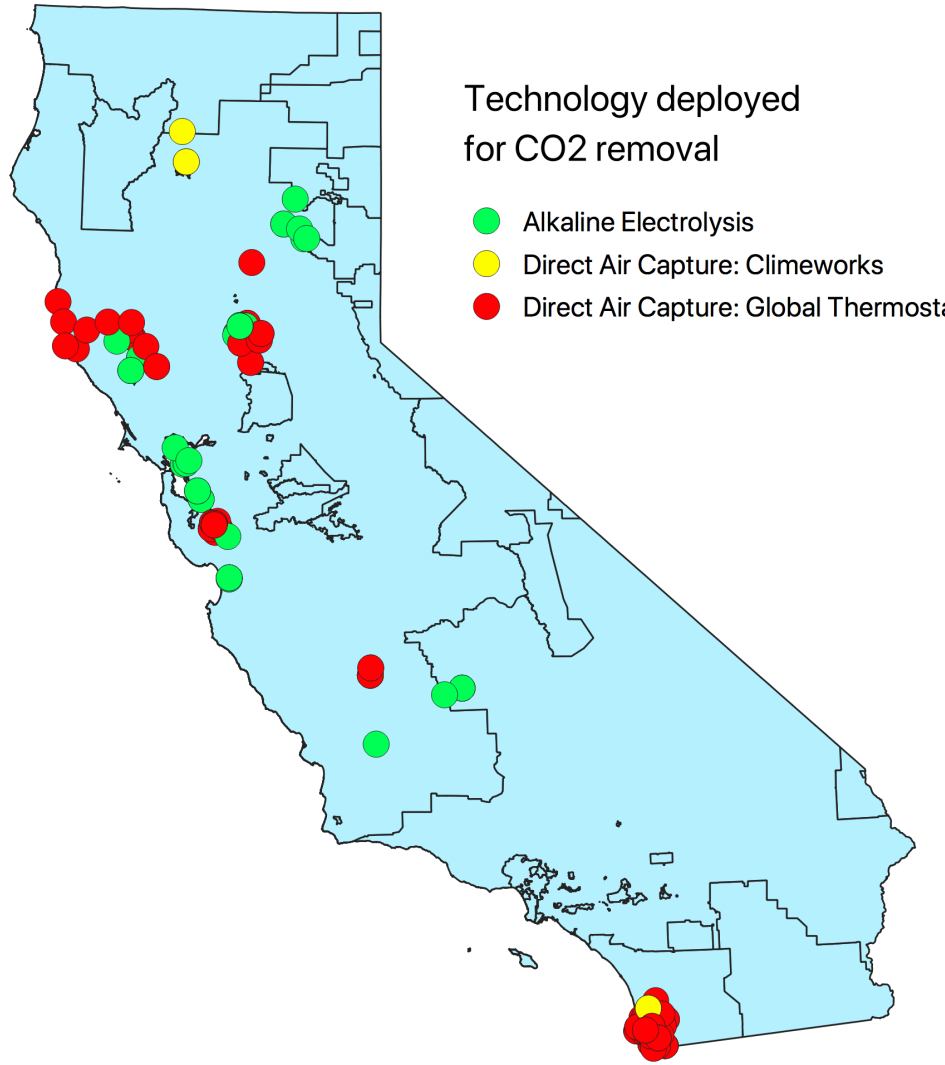
- CO_2 removal supported by curtailed energy done using least-cost technology:
  - Direct Air Capture (Global Thermostat)
  - > 6,230,000 Tons of CO_2 removed
- CO_2 removal supported by negative LMPs:
  - 10% of nodes have negative enough LMPs to support these technologies

Technology	**Share of deployment**	**Share of CO_2 removed**
Alkaline electrolysis	32% (146 of 224 locations)	86% (80k T)
Direct air capture *(Climeworks)*	3% (6 of 224 locations)	4% (3.6k T)
Direct air capture *(Global T.)*	65% (72 of 224 locations)	10% (9,6k T)

- In total, these technologies would remove >**6,300,000 Tons of CO_2**, equivalent to removing >1.3 million cars removed from the road.

Results – CO_2 removal supported by negative LMPs





Thank you for your attention

Questions?

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