NREL
NATIONAL RENEWABLE ENERGY LABORATORY





Getting the *Really* High Renewable Energy Scenarios

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CFEE Conference
February 22, 2018

Moving towards 100% Renewables…..

So all that stuff that Mark just said….

It gets way more difficult.

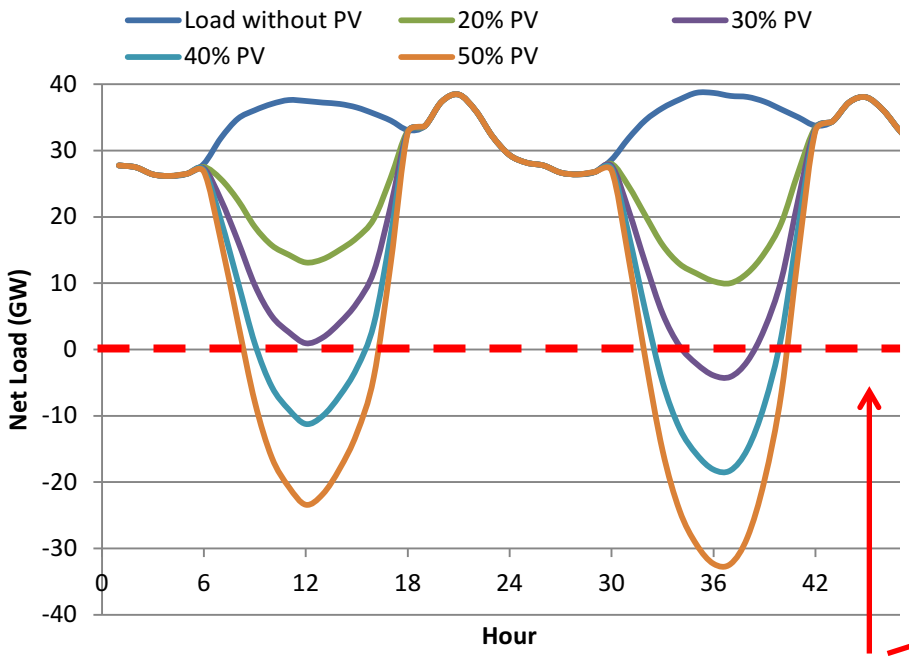
This presentation will focus on two elements of the challenges:

- Economics challenges of curtailed PV
- Technical challenges of maintaining a stable grid

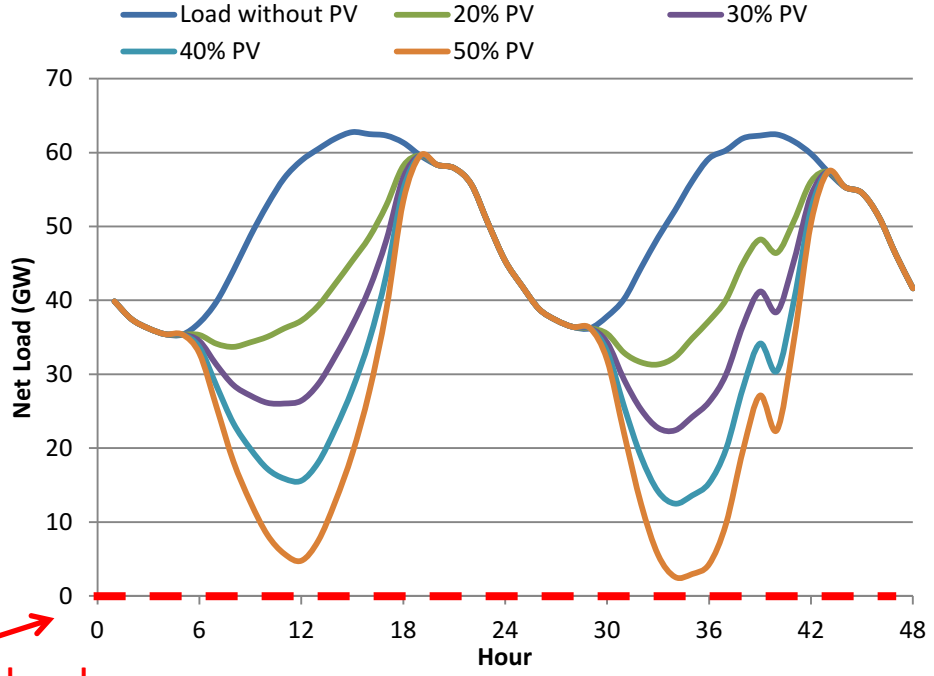
50% PV in California

- Figures show load and theoretical net load profiles for California during two days in the spring and summer when PV provides up to 50% of annual electricity, assuming no PV curtailment is required.
- Extreme changes in net load are well beyond what can be accommodated in the current power system (net load < 0 for ~2,200 hours per year).

Spring (April 9–10)



Summer (July 27–28)



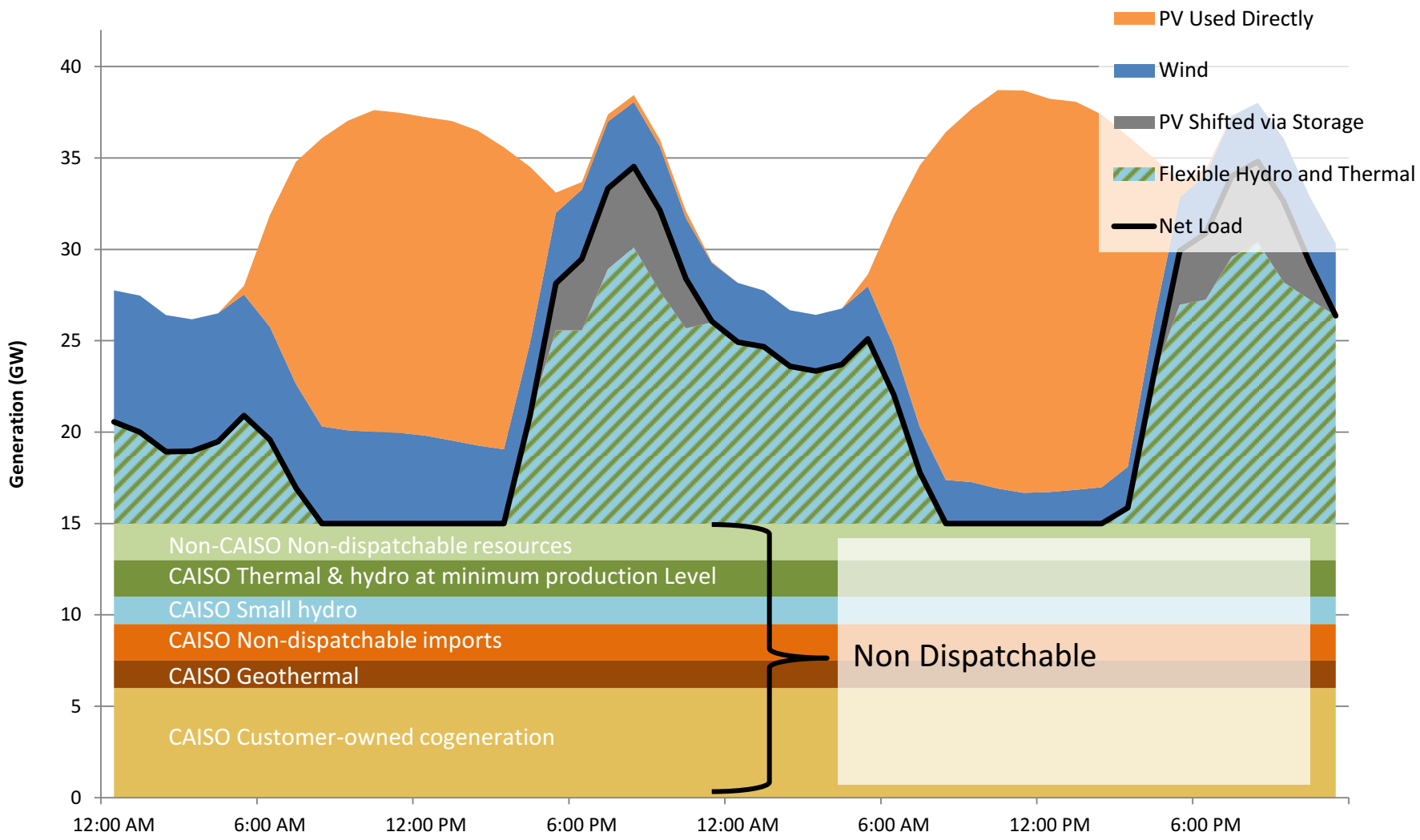
BAU Operation

What if there are limited changes in grid operations between now and in 2030?

- 15-GW minimum generation level on hydro and thermal capacity
- Retirement of Diablo Canyon nuclear plant before 2030
- No new demand response
- No electric vehicles (EVs)
- No exports of solar generation to surrounding states
- 4.4 GW of storage (based on existing + mandated new storage in California)
- Load grows to 320 TWh, 64.7 GW peak demand

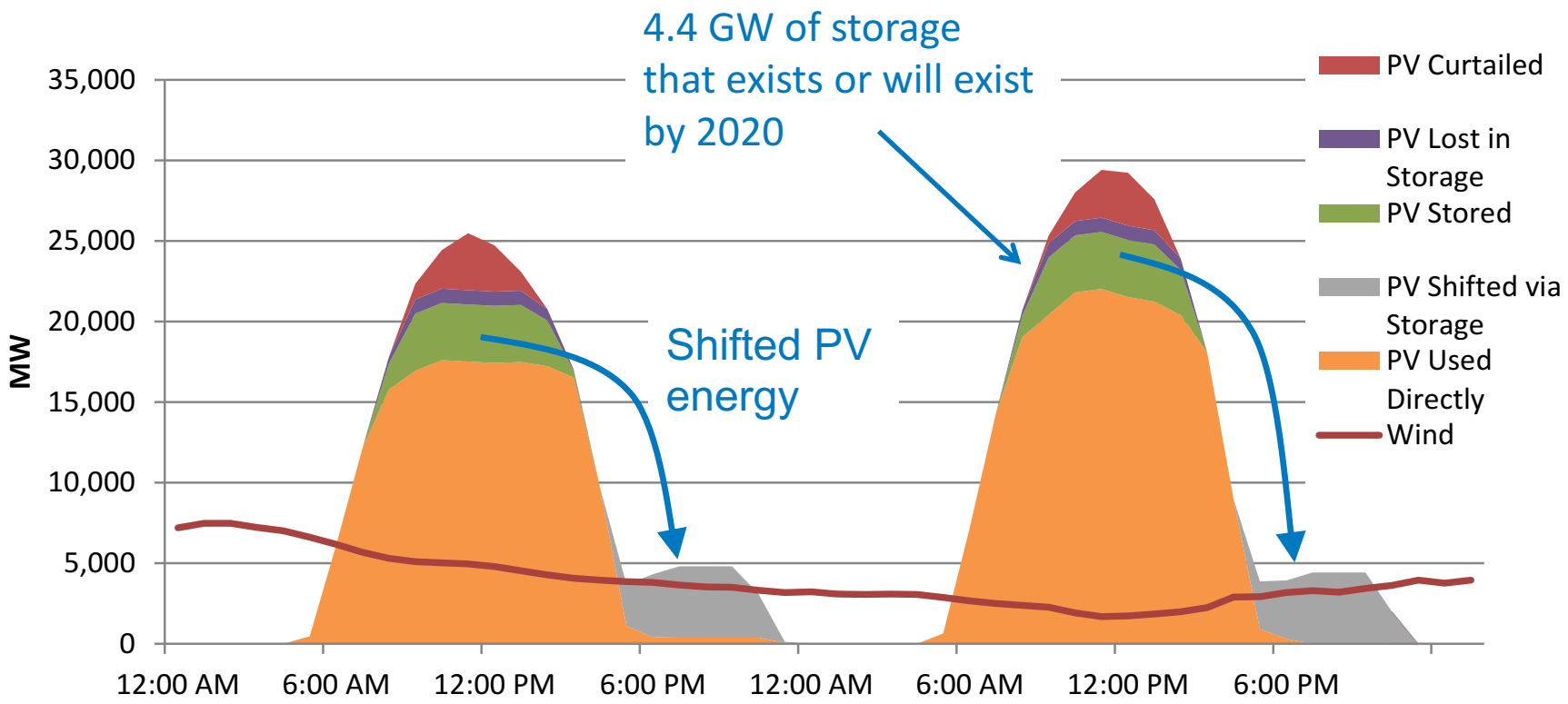
BAU System Dispatch at 20% PV, April 9–10

Midday wind and solar exceed what can be accommodated at 15-GW minimum generation, resulting in "overgeneration" and curtailment



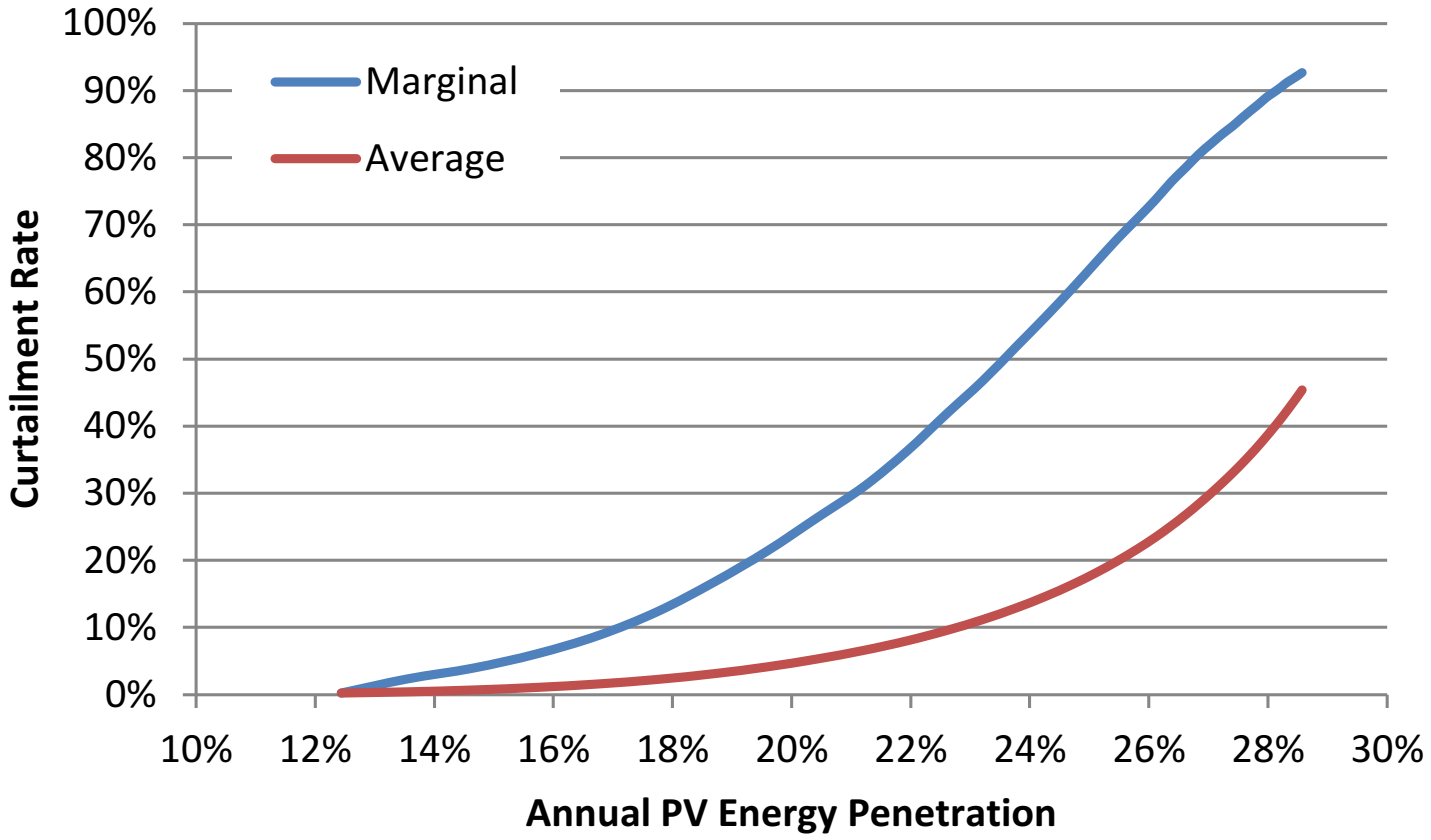
BAU PV Dispatch at 20% PV, April 9–10

- Existing and projected storage eliminates most curtailment.
- About 5% of potential PV is curtailed annually, including storage losses.



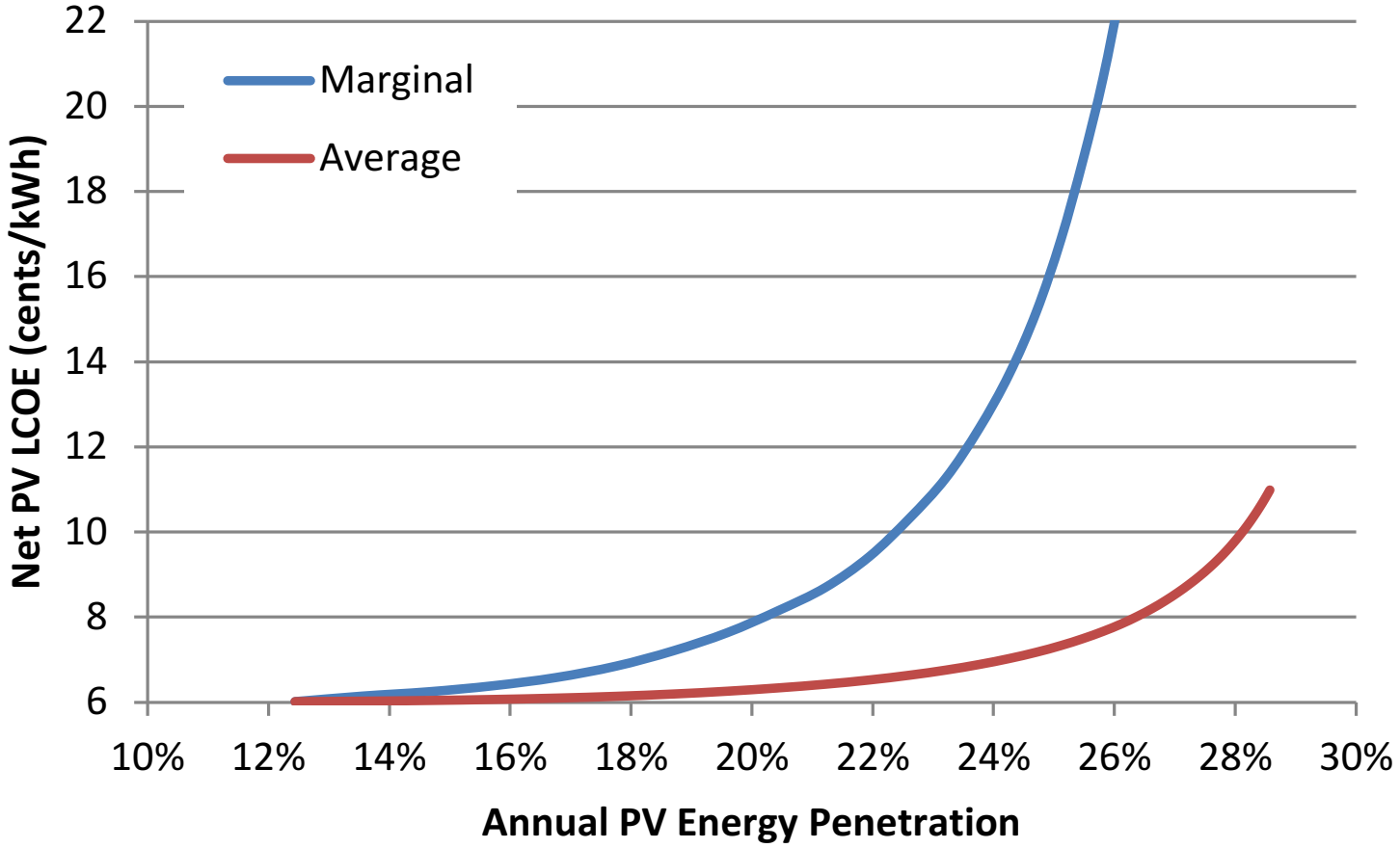
BAU Scenario: Curtailment Rate at Various PV Levels

- Marginal curtailment rates can indicate the threshold at which PV becomes uncompetitive with alternative resources.
- Under the base scenario, PV's marginal curtailment rate increases rapidly once PV penetration rises above 20%.



BAU Scenario: Net PV LCOE at Various PV Levels

- We calculate net LCOE assuming a base (unsubsidized) PV LCOE of 6 cents/kWh.
- The shape of the marginal curve means even very low-cost PV would require additional grid flexibility to achieve penetrations beyond 25%.

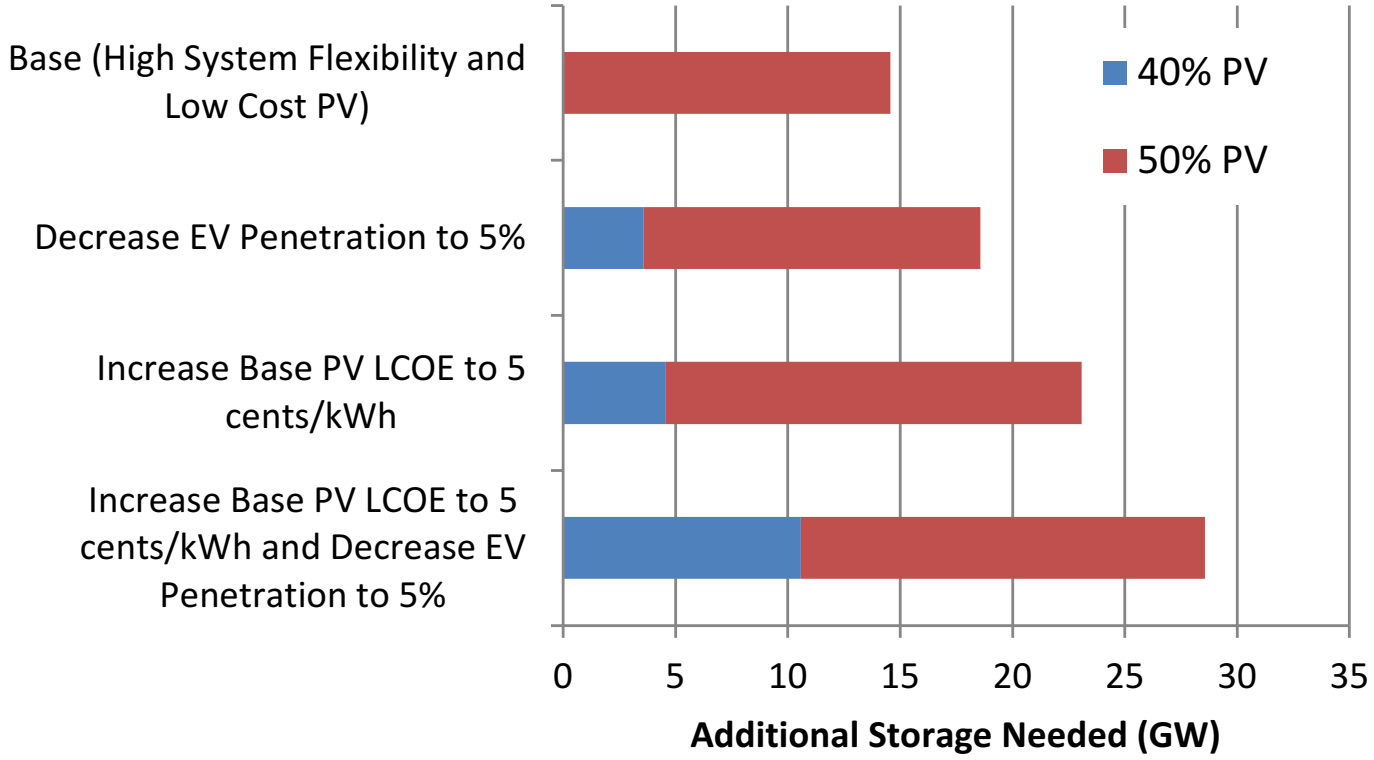


Flexibility Options

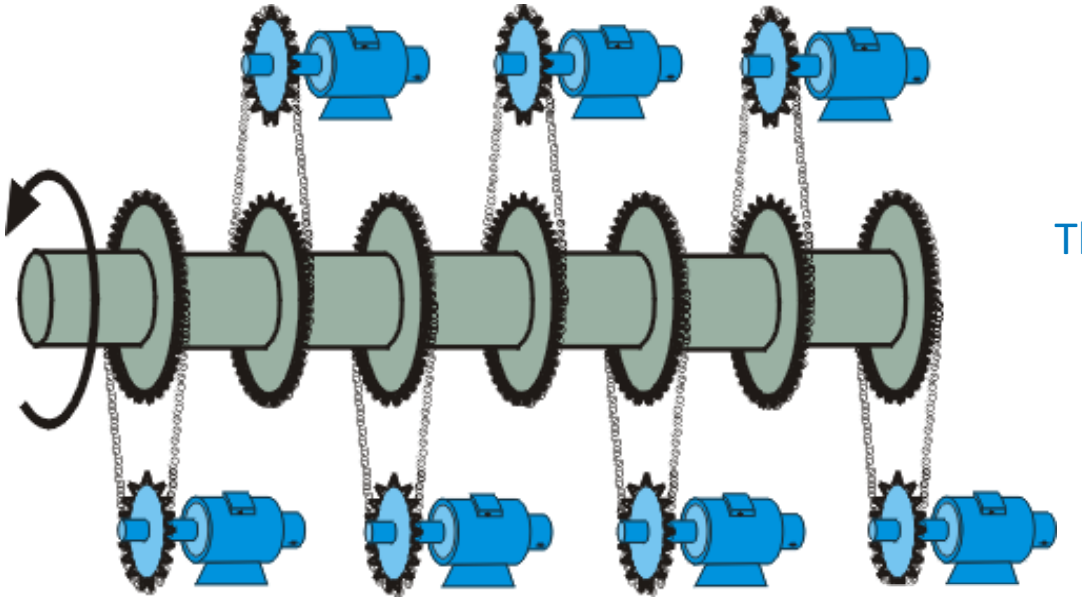
- Flexible Generation/Lower Minimum Generation Levels
  - Changing long-term contracts with combined heat and power plants and other thermal generators
  - Learning the true costs of frequent thermal plant cycling
  - Incorporating improved forecasting
  - Using curtailed variable generation for reserves
- Electricity Exports
  - Expanding footprint of day-ahead and real-time exports
- Demand Response and Shiftable Load
  - Increasing the number of consumers using real-time pricing, time-of-use pricing, and/or utility-controlled loads
- Additional Load from Electric Vehicles (EVs)
  - Adding EVs to California's fleet and optimizing EV charging
- Energy Storage

How we can do 50% PV (70% RE) in California

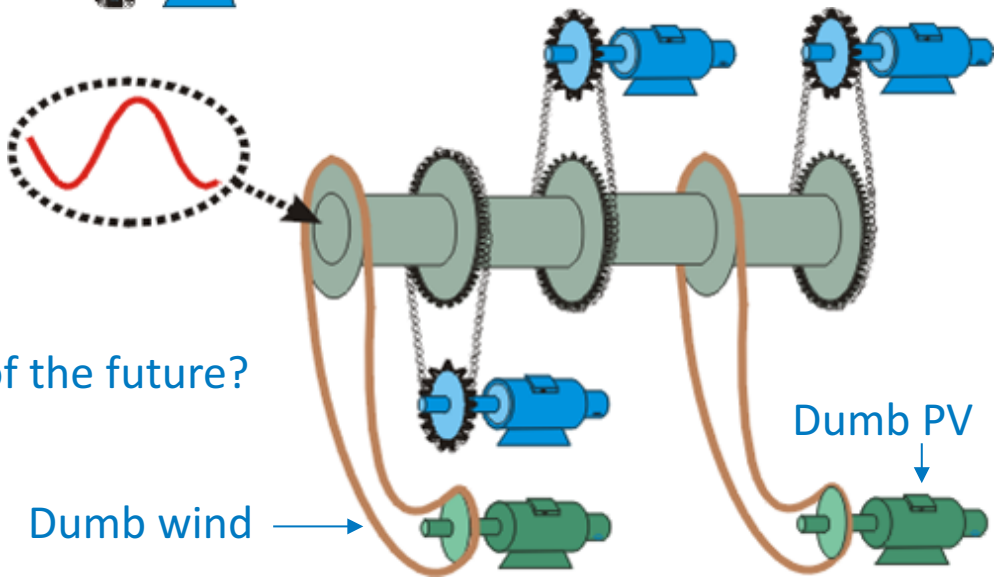
- In the high-flexibility scenario with base PV cost of 3 cents/kWh, about 15 GW of additional energy storage are required to achieve 50% PV at a marginal net PV LCOE of 7 cents/kWh (top bar).
- Decreasing EV penetration, increasing the base PV cost, or doing both increases the additional storage requirements (other bars).
- Achieving only 40% PV penetration reduces the storage requirements substantially.



A New Paradigm for Grid Stability…



The grid now

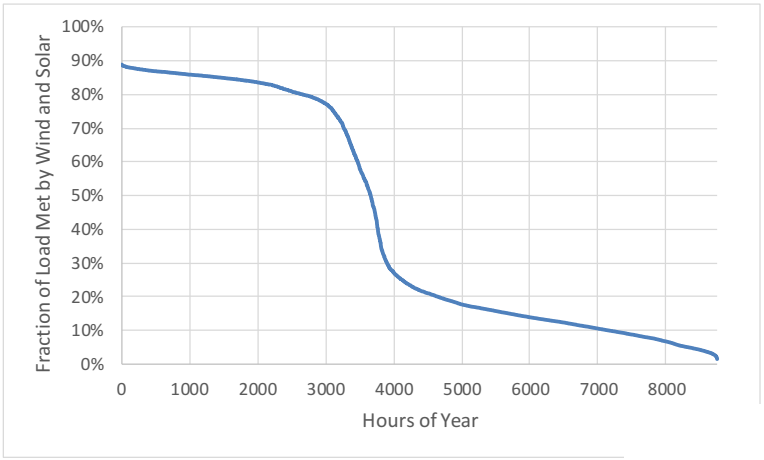


The grid of the future?

Dumb PV

Dumb wind

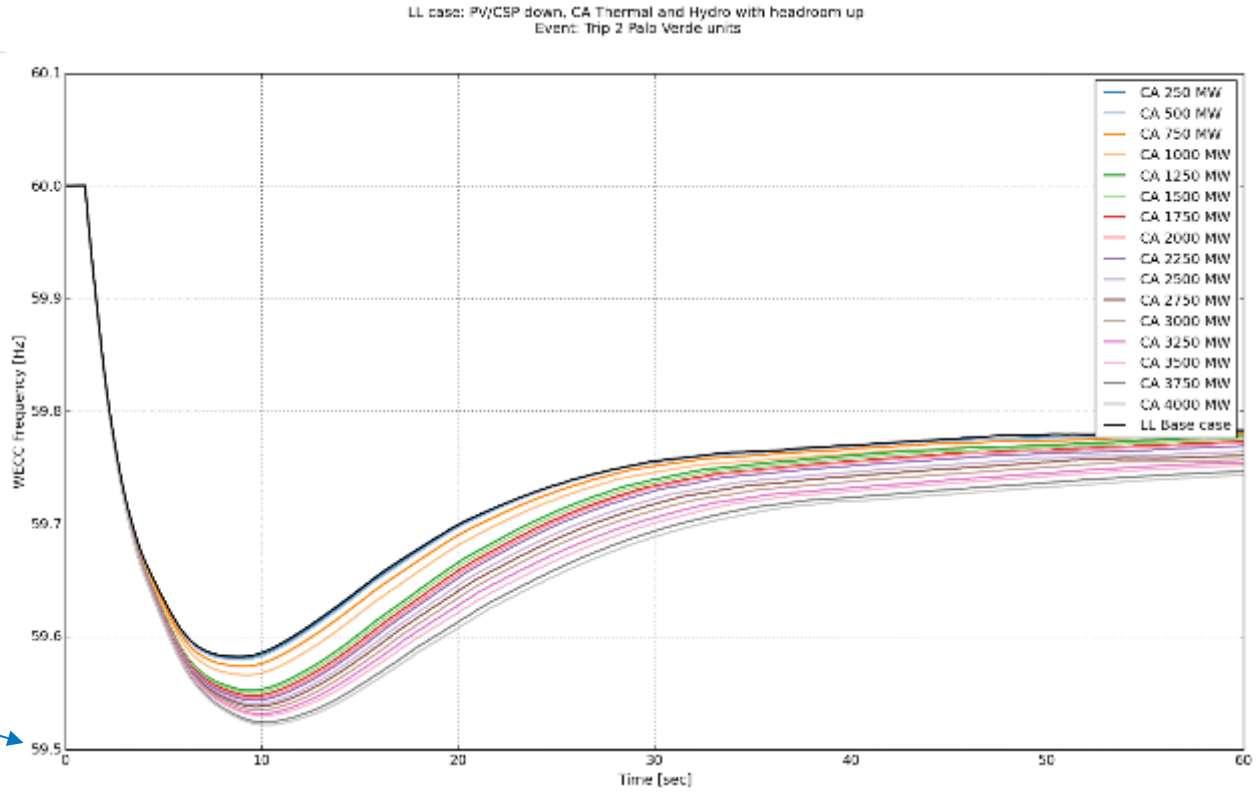
Dumb PV and dumb wind will break the grid (eventually)



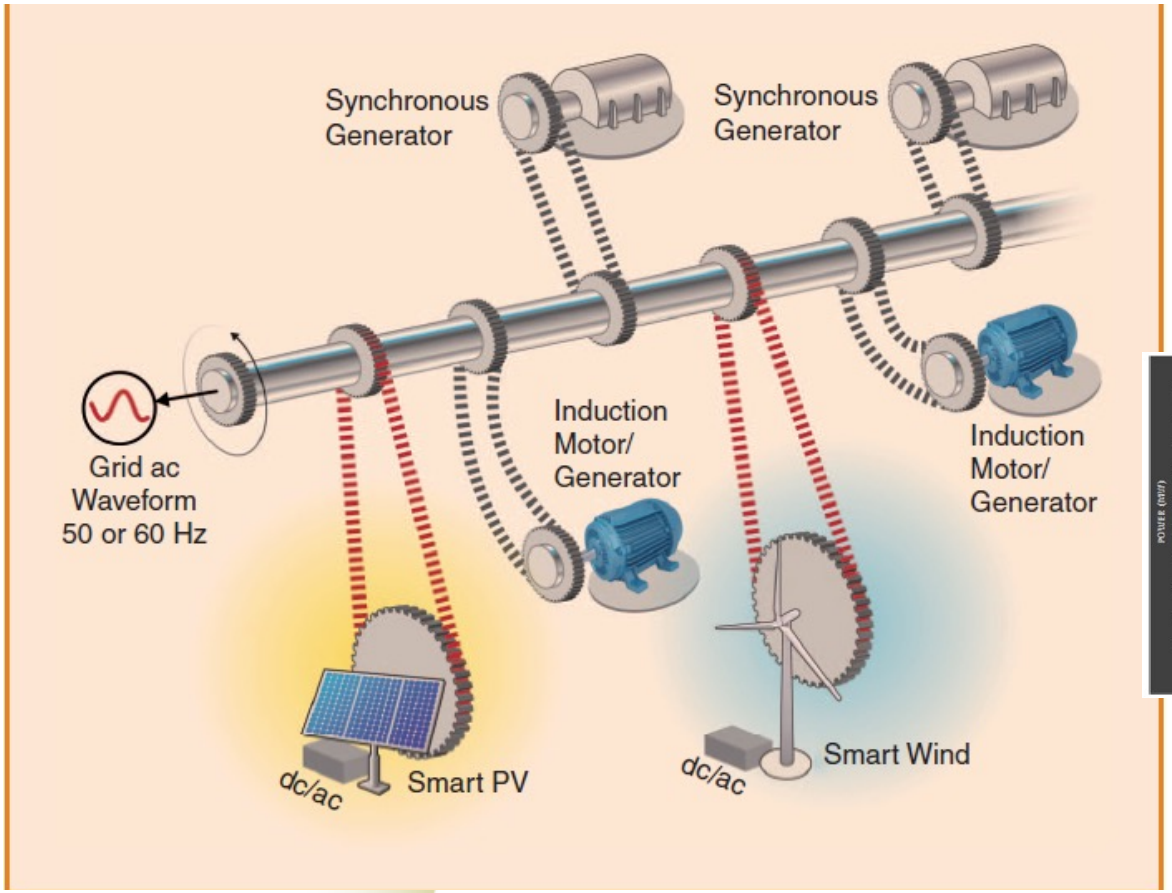
Instantaneous penetration of non-synchronous generation at 50% wind and solar

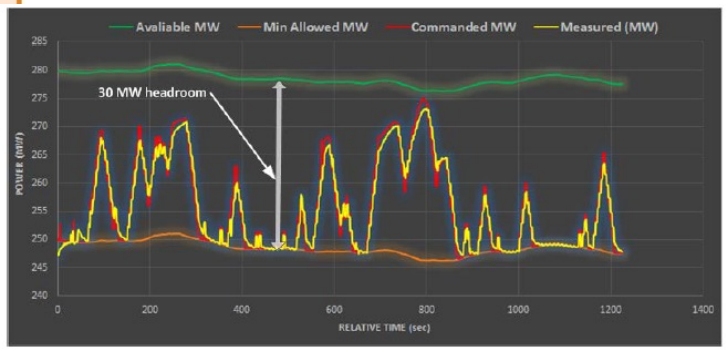
Frequency decline at greater solar penetration (if we don't do anything)

The lights go out here



Smart PV and Smart wind are now available





California ISO

FAQ

NREL

First Solar.

USING RENEWABLES TO OPERATE A LOW-CARBON GRID

https://www.caiso.com/Documents/UsingRenewablesToOperateLowCarbonGrid-FAQ.pdf

Final Thoughts

- We think this is doable
- Someone needs to coordinate all this
  - Without intelligent controls this isn't going to work
  - Simple TOU rates are not enough
  - Real-time prices are not sufficient for intelligent storage control – optimization over longer time periods is needed

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