

System Implications of High Penetration of Renewables for Decarbonization

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The Deep Decarbonization Challenge

- How can we **eliminate** carbon from global electricity systems by 2050-2070 in light of the following constraints?
 - We will drive new end uses to electricity
 - We will provide electricity to 1.8 billion global citizens who have none
 - We will increase electricity supply to 2-3 billion global citizens who have *inadequate* access to electricity
 - We will minimize costs
 - We will maintain or improve current levels of system reliability
 - We will protect other environmental values

Confusion of ends and means is pervasive



Likely Characteristics of Successful Strategies

- Costs at parity with present levels
- Reliability held constant or improved
- Electricity markets in which investors get their money back
- Broad social acceptance of needed system build-out

Simplified Metrics are Misleading

- Resource-specific levelized-cost of electricity (LCOE) is meaningless
- Total system costs of decarbonization portfolios is what matters
- Alternative portfolios should be developed and compared on the basis of
 - Cost
 - Reliability
 - Carbon emissions
 - Secondary environmental impact
 - Social and political acceptability

Systems with 80-100 percent renewable penetration are

- Physically larger
- More expensive than diversified portfolios
- Prone to seasonal surpluses and deficits which are difficult to manage with storage, demand-response or gas production
- Challenging from a market design perspective

How much larger?

- Jacobson, Delucchi, *et. al.* for California
 - 624 GW – current system 75 GW
- Kombikraftwerk 2 for Germany
 - 409 GW – current system 180 GW
- ADEME for France
 - 200 GW – current system 129 GW

Why does size matter?

- Siting is difficult



How much more expensive?

- Williams, *et. al.*, U.S. Deep Decarbonization Pathways
 - High renewable pathway is 1.5 to 3 times costlier than diversified or high nuclear/fossil CCS for same levels of decarbonization
- Brick and Thernstrom, *Electricity Journal* 2016
 - 80 percent renewable portfolio is 1.5-2.5 times costlier than diversified portfolio
- Australian Energy Market Operator, 100 Percent Renewables Study
 - 100 percent renewable pathway yields wholesale costs that 2 – 2.5 times higher than present

Why do costs matter?

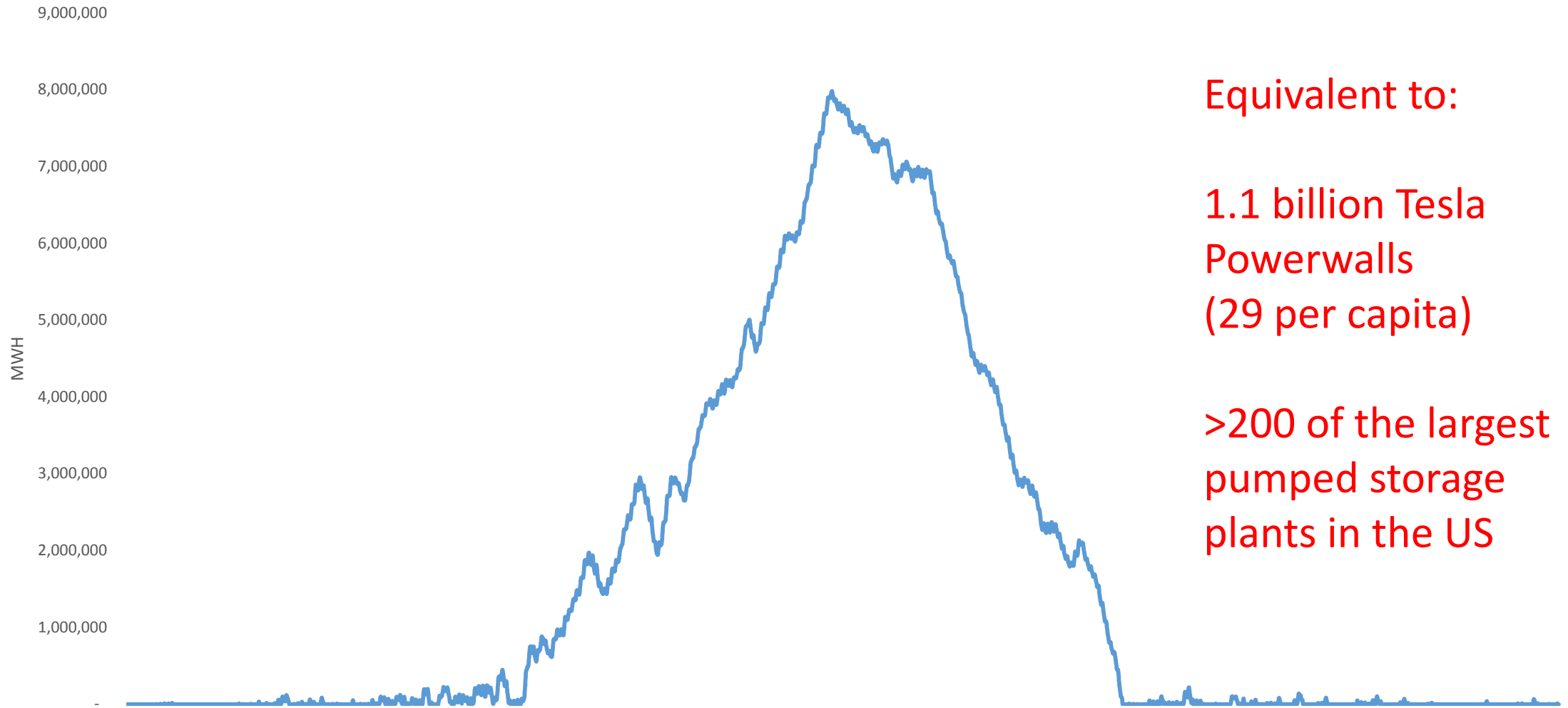
- Consumer tolerance for increased electricity costs is limited
- Tolerance is even less amongst business and industry



The Challenge of Seasonal Surplus and Deficit

- Beginning at about 60 percent variable renewable penetration, season surpluses and deficits occur
- As penetrations rise, the surpluses become unmanageably large
- As penetrations rise, the deficits remain stubbornly unchanged

CALIFORNIA CUMULATIVE SURPLUS 80 PERCENT RPS

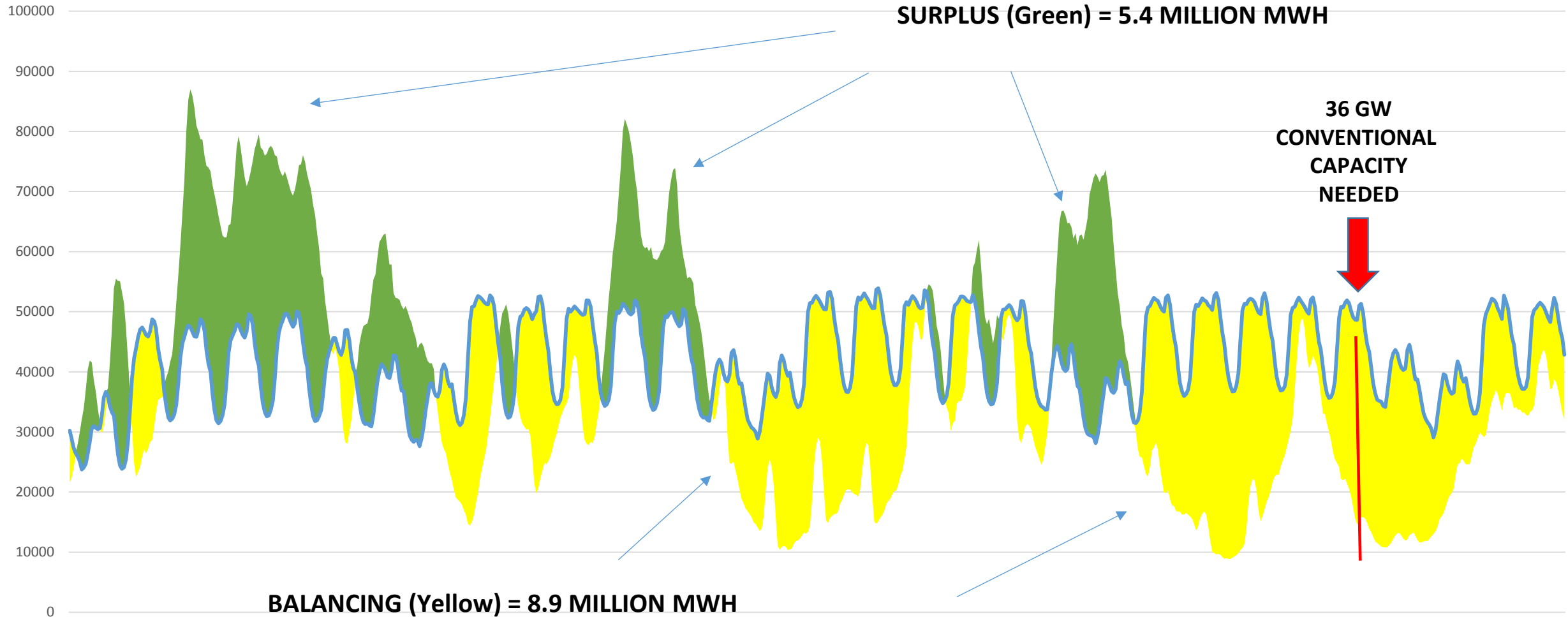


Equivalent to:

1.1 billion Tesla
Powerwalls
(29 per capita)

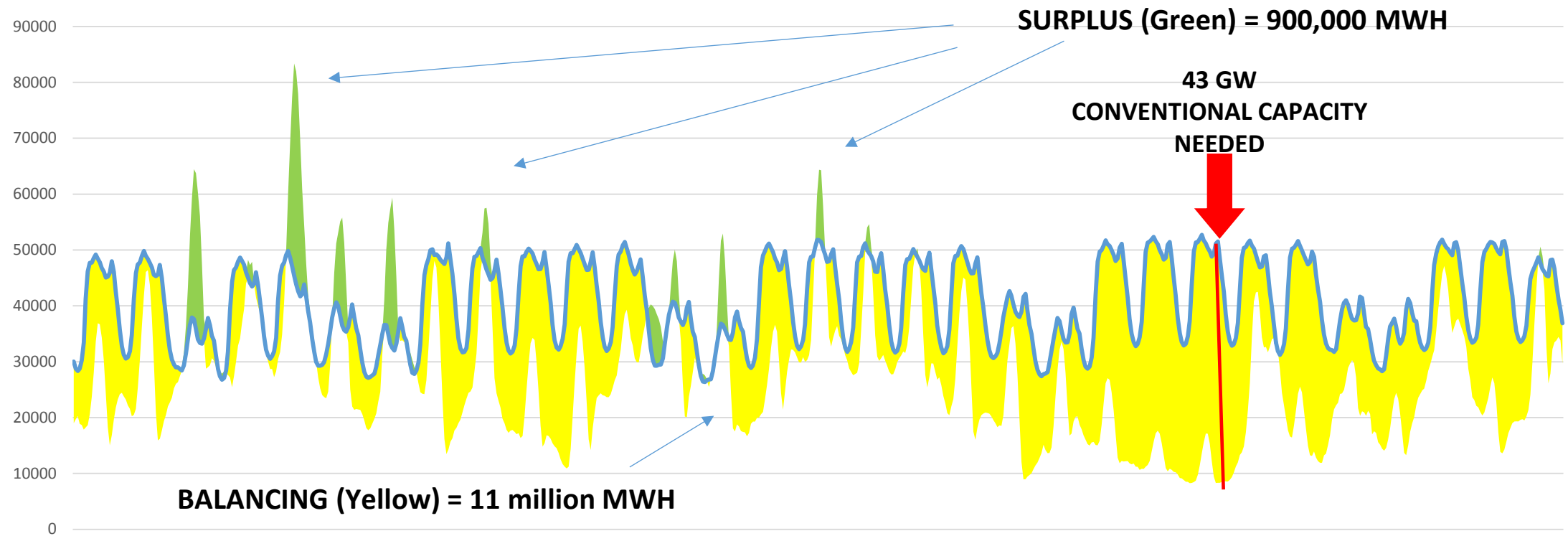
>200 of the largest
pumped storage
plants in the US

JANUARY 2050 GERMAN POLICY SCENARIO



Worst month ...

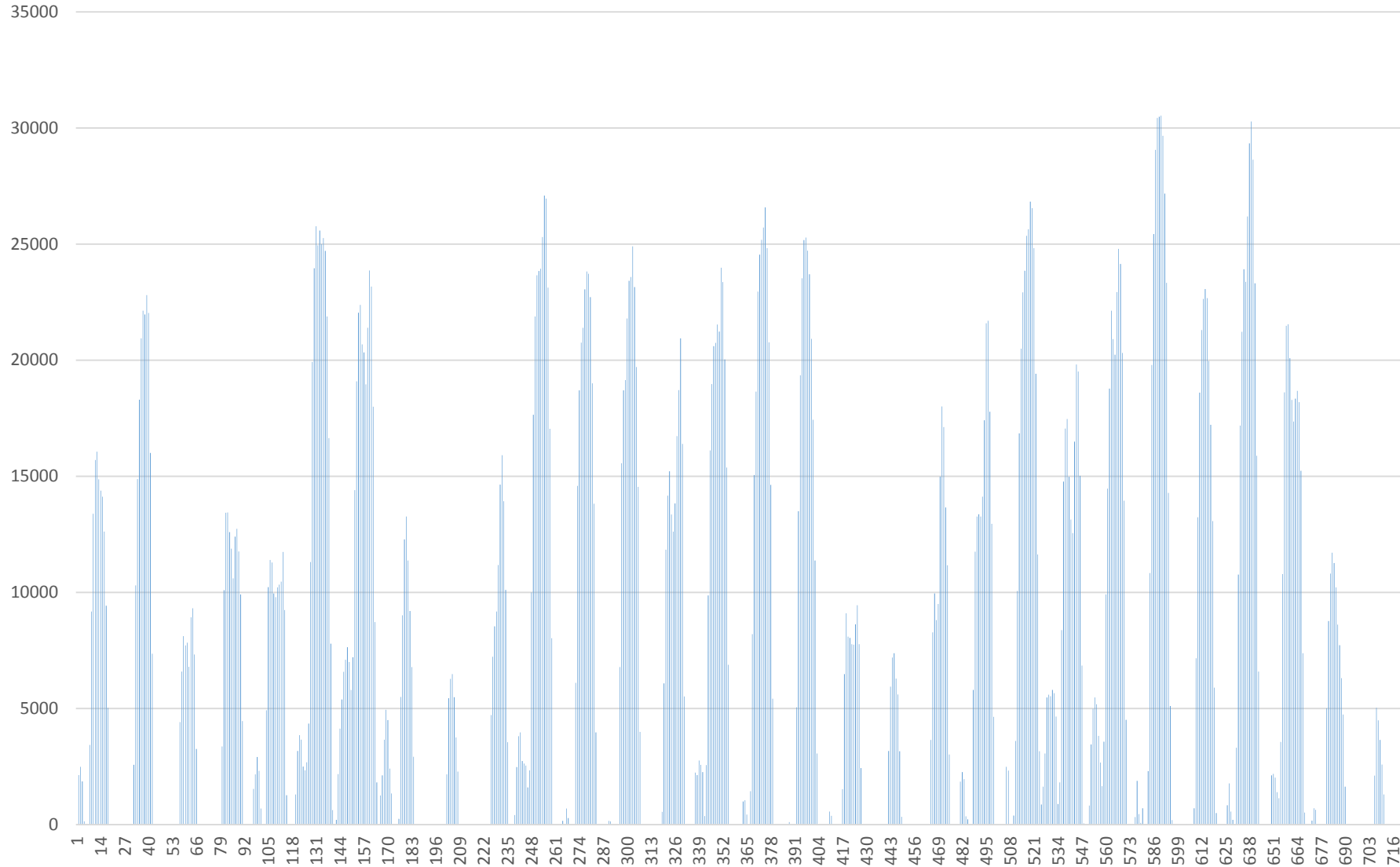
OCTOBER 2050 GERMAN POLICY SCENARIO



Why do surpluses and deficits matter?

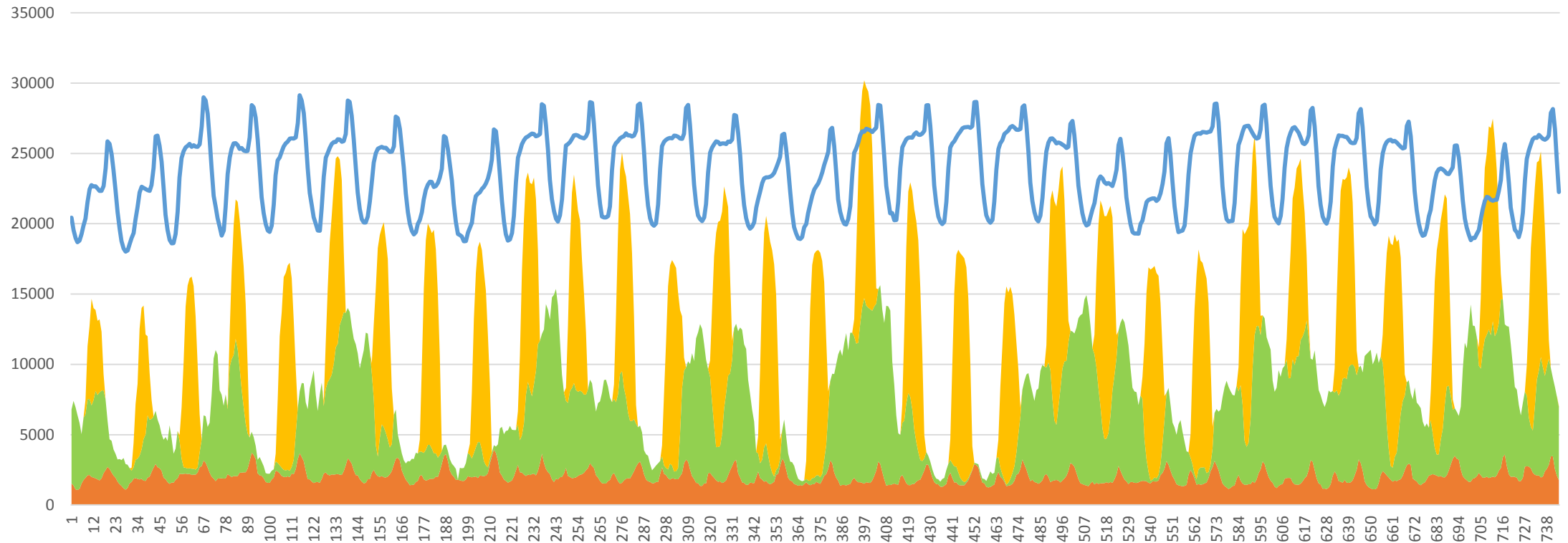
- Successfully managing surpluses and deficits requires both
 - Large investment in storage, gas production
 - Large investment in back-up capacity to bridge deficit periods
- **BOTH CLASSES OF TECHNOLOGY WOULD OPERATE AT UTILIZATION RATES THAT ARE LIKELY TO BE ECONOMICALLY UNFEASIBLE**
- **THE PROBLEMS OF INTERMITTENCE CAN'T BE SOLVED BY BUILDING A SECOND, EVEN MORE INTERMITTENT TECHNOLOGY ON ITS BACK**
- Left unmanaged, surpluses mean wasted power and eroding economics; deficits mean power interruptions
 - Current market problems in Germany, Texas, and California are object lessons for what is likely to come

CAISO 80 PERCENT RPS JUNE SURPLUS EPISODES



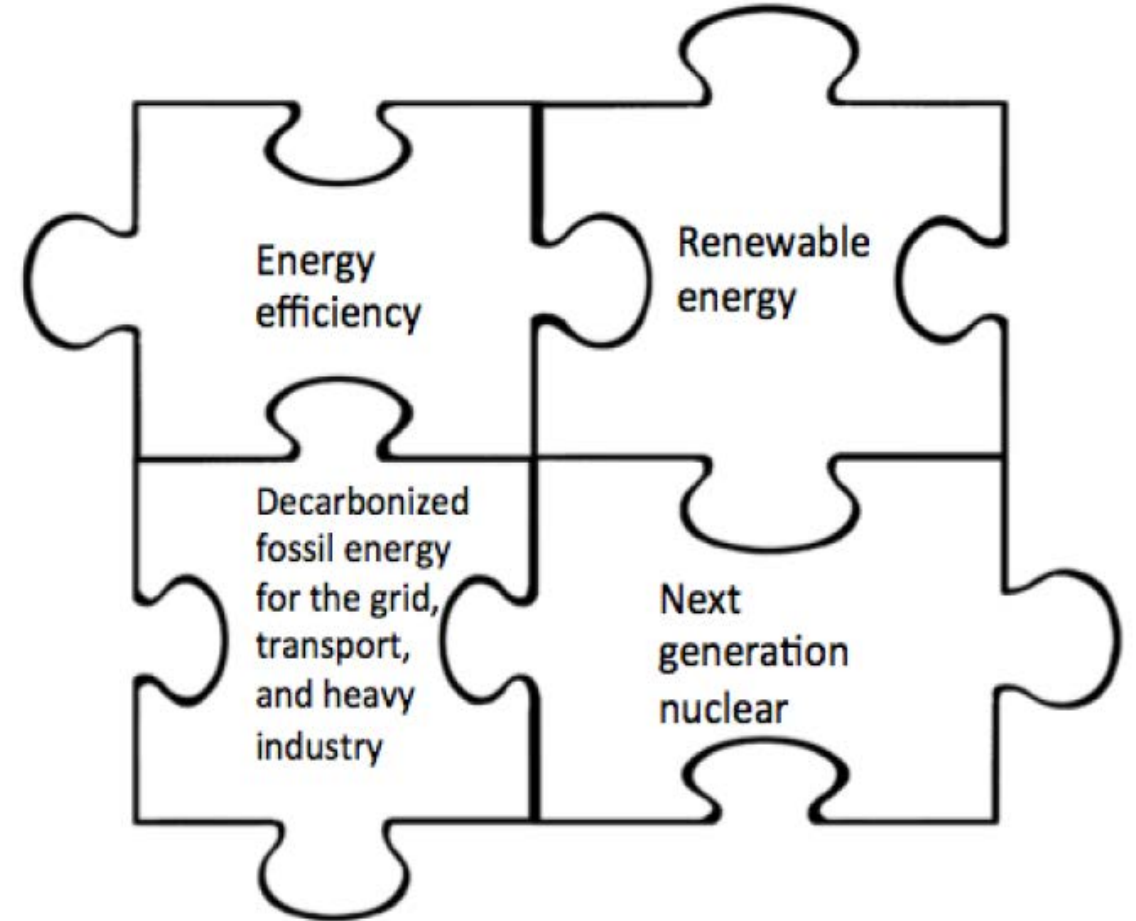
Can overreliance on intermittent renewables close the door to zero- and low carbon baseload?

California March
50 percent RPS



Balanced Portfolios

- Cheaper
- Smaller
- Resilient



Final word

- Refocus the policy discussion on deep decarbonization

