

Technical and Cost Impacts of Integrating Renewables: A Case Study for California

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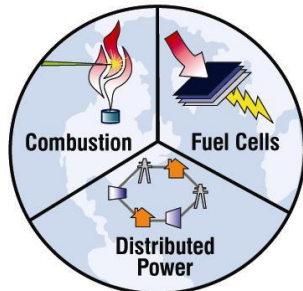
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**Advanced Power
and Energy Program**

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Motivation

- **California has the most aggressive Renewable Portfolio Standard (“RPS”) in the United States**
- **Legislative mandate for 20% retail sales by 2010**
 - California Senate Bill 107, 9/26/2006
 - Actually achieved 15-16% by 2010
- **Targeted 33% by 2020**
 - Executive Order S-14-08, 11/17/2008
- **Legislative mandate for 33% retail sales by 2020**
 - California Senate Bill X1 2, 4/12/2011

“With the amount of renewable resources coming on-line, and prices dropping, I think 40 percent, at reasonable cost, is well within our grasp in the near future.”

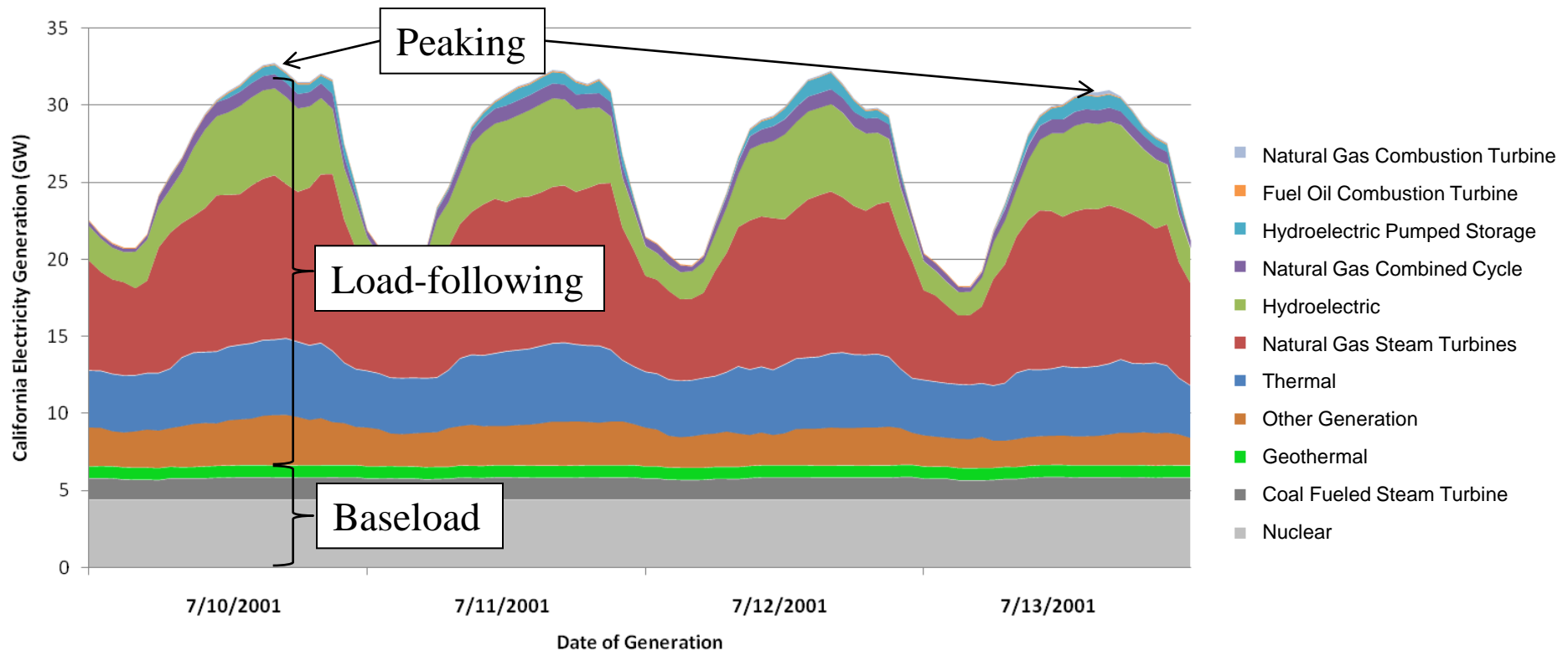
California Governor Edmund G. Brown, Jr.

Operational Reality

- **Electrical grid must continually be balanced**

- A variety of generating resources are required
- Each generating resource has a preferred duty cycle

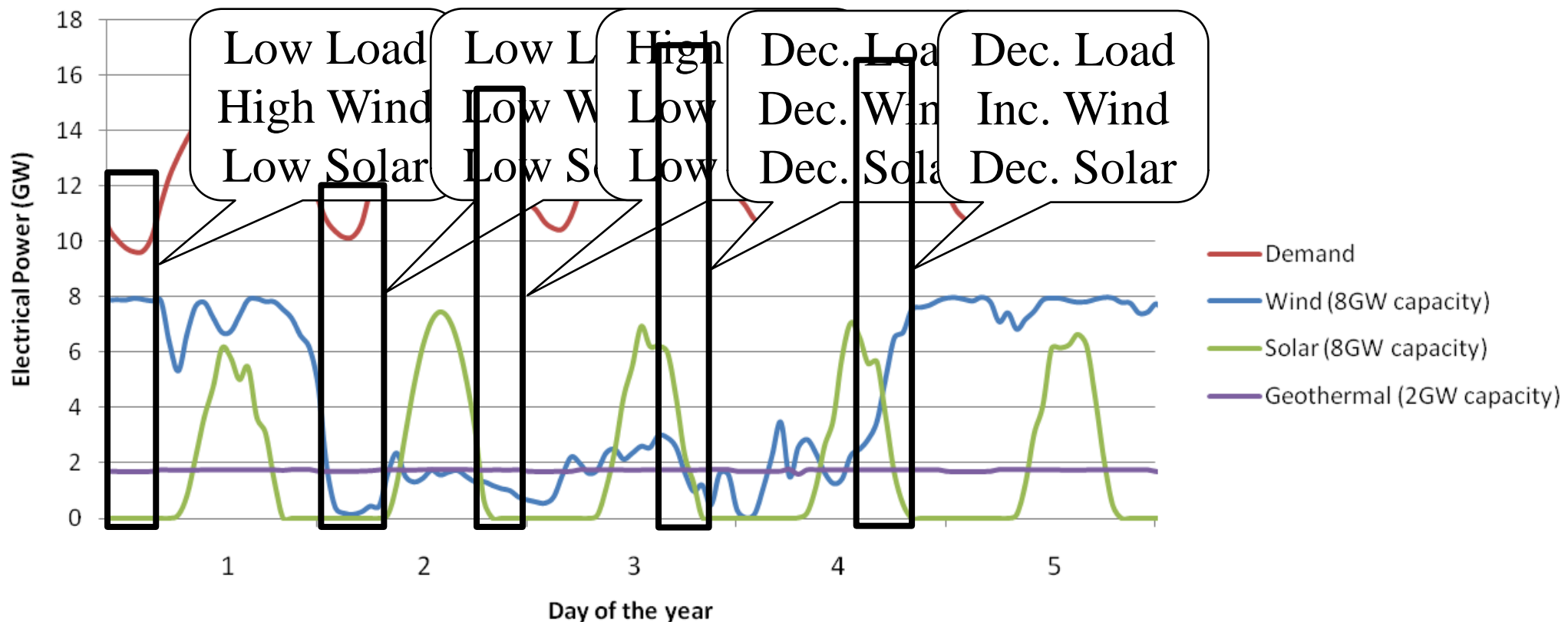
—Baseload —Load-following —Peaking —Intermittent



source: CA Energy Crisis FERC data

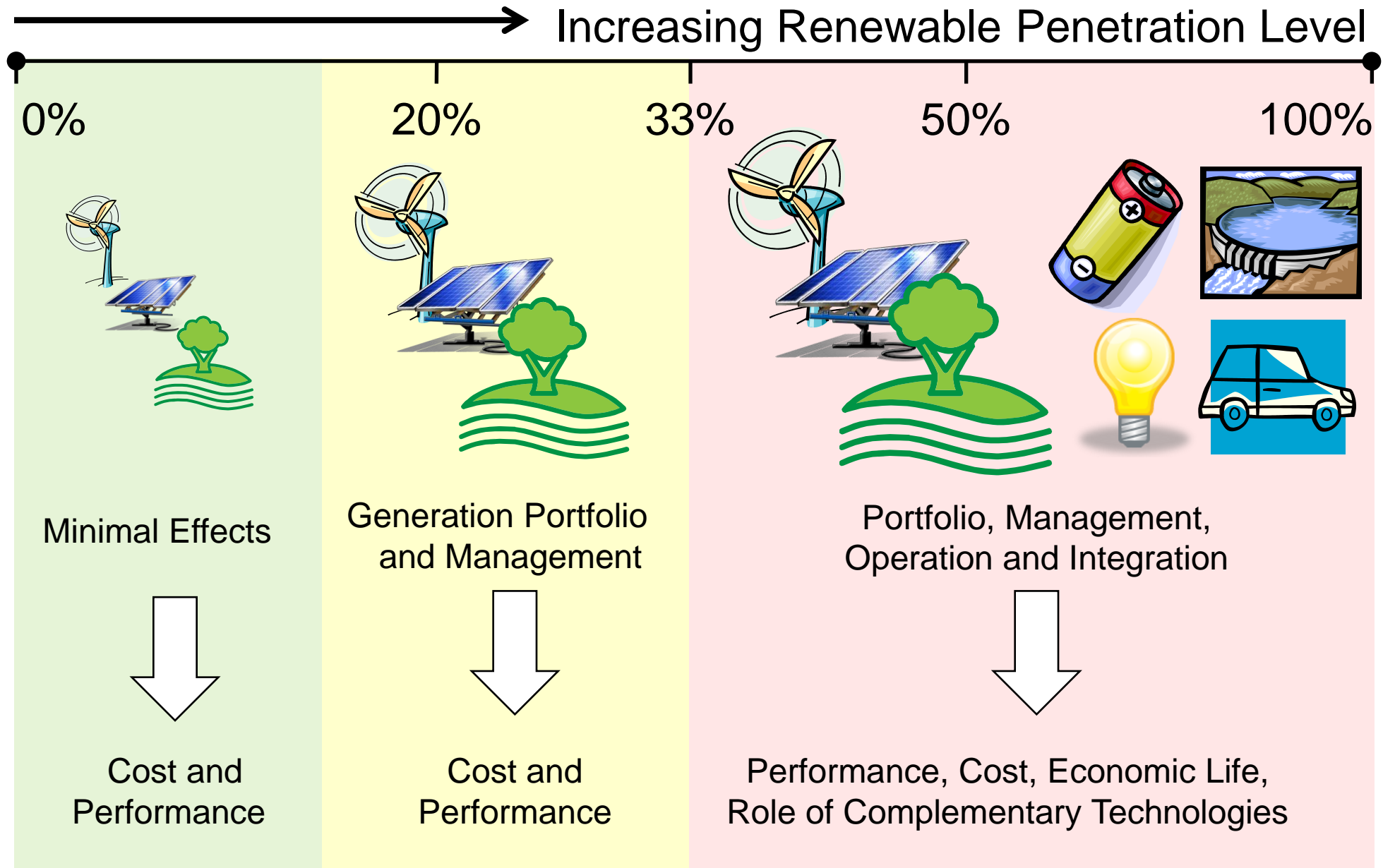
New Challenges to Balancing the Grid

- Intermittent renewable resources present new challenges to maintaining a balanced grid.

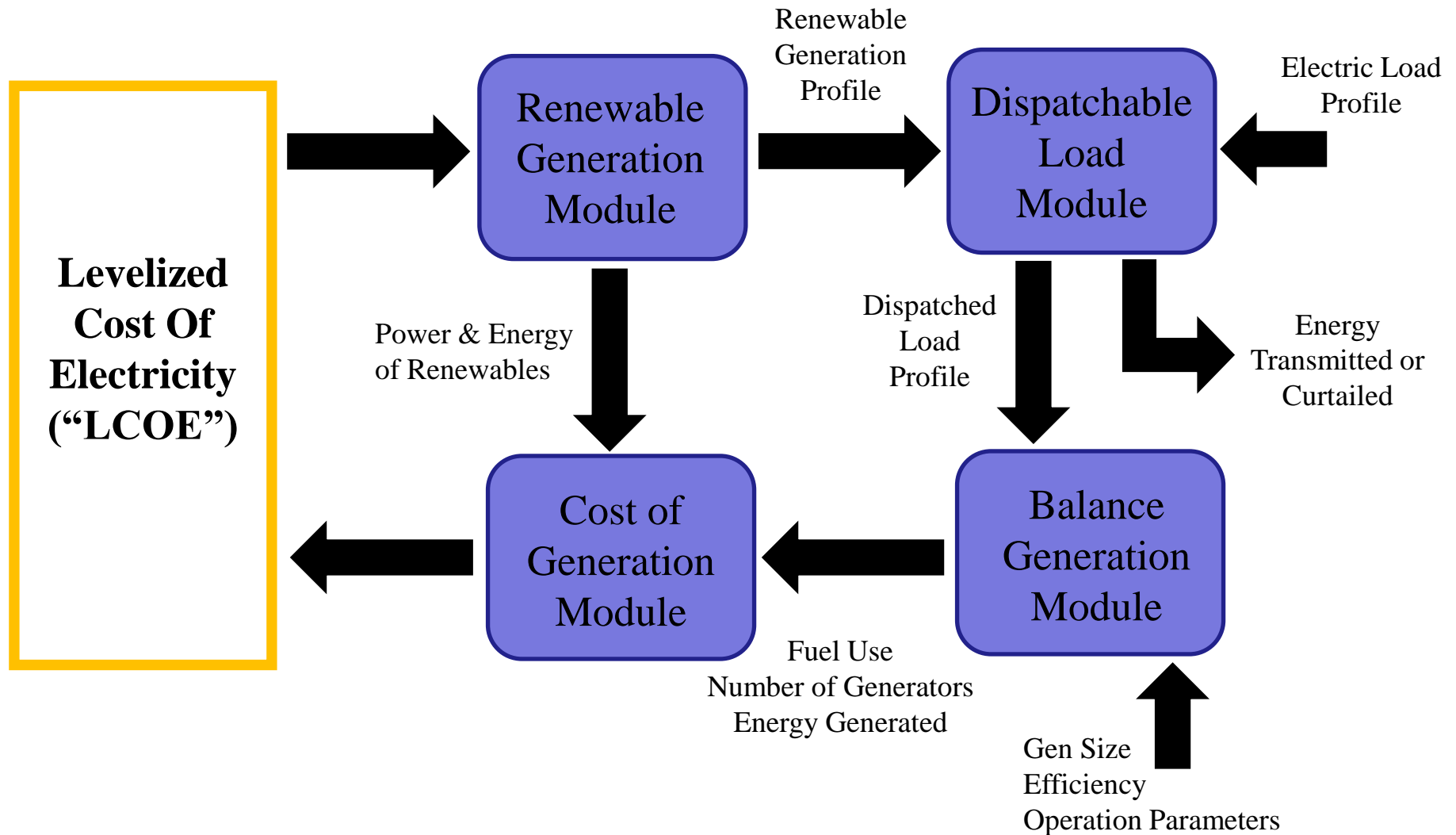


- As renewables penetration levels increase what is the best way to balance the grid?

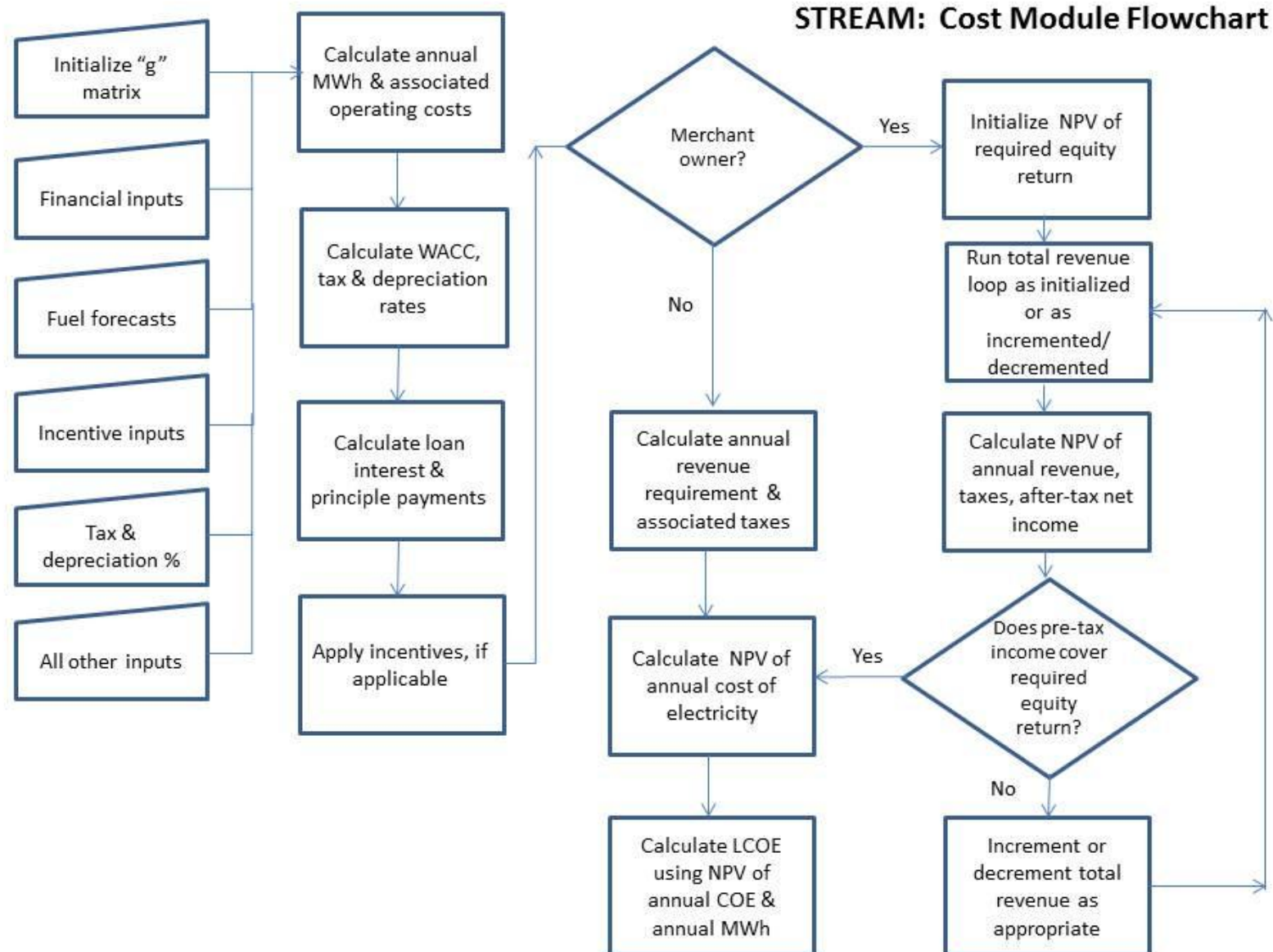
More Renewables, More Challenges



STREAM: Integrated Model Flowchart

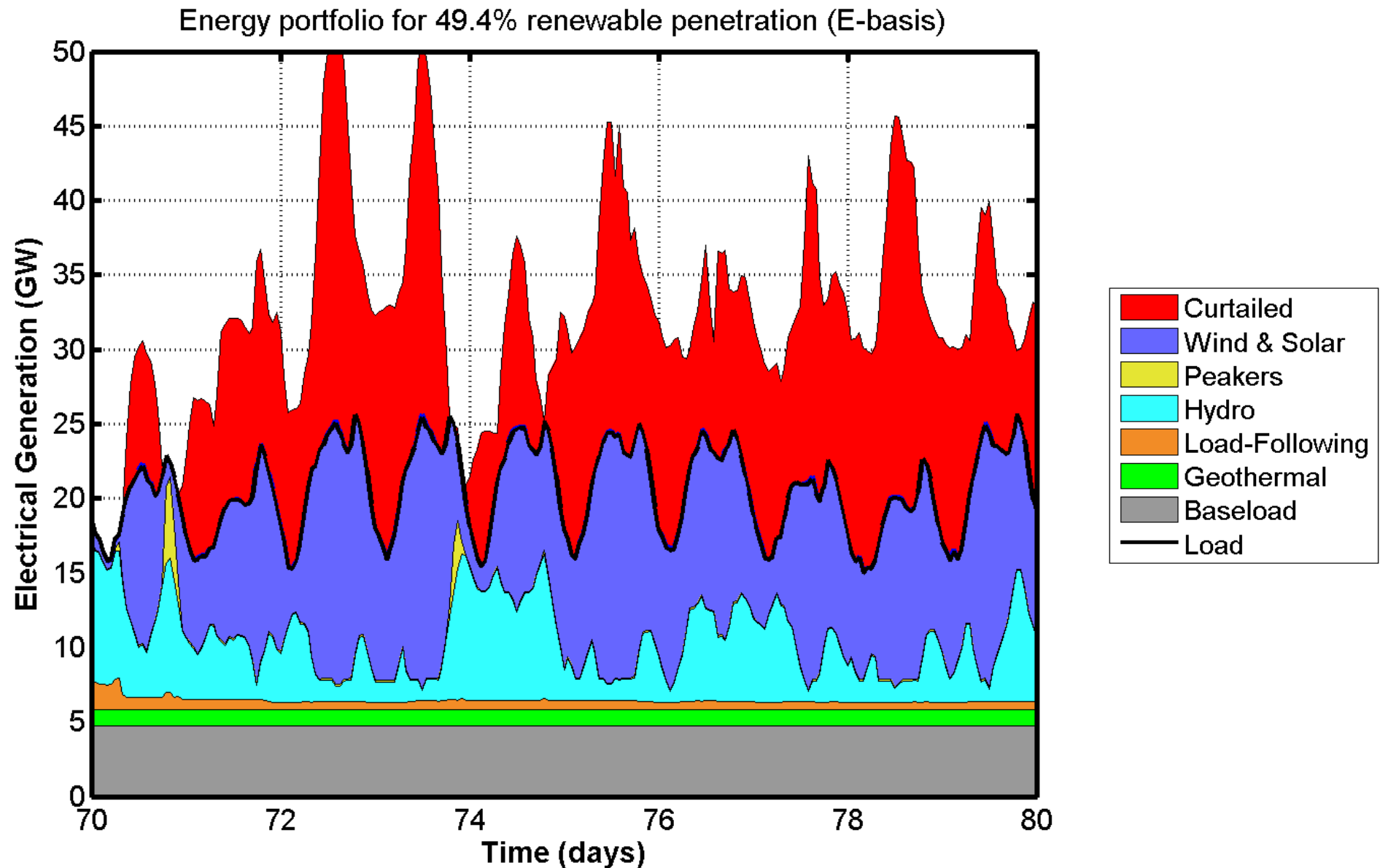


STREAM Model: Cost Module

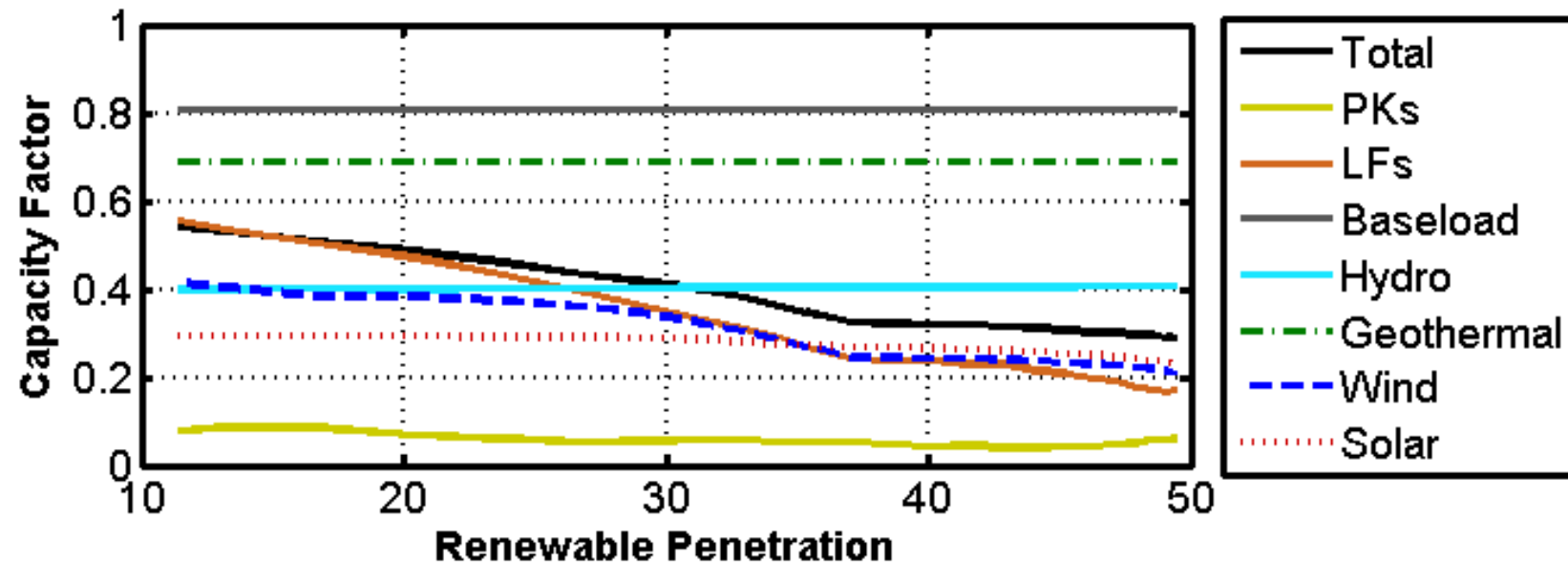
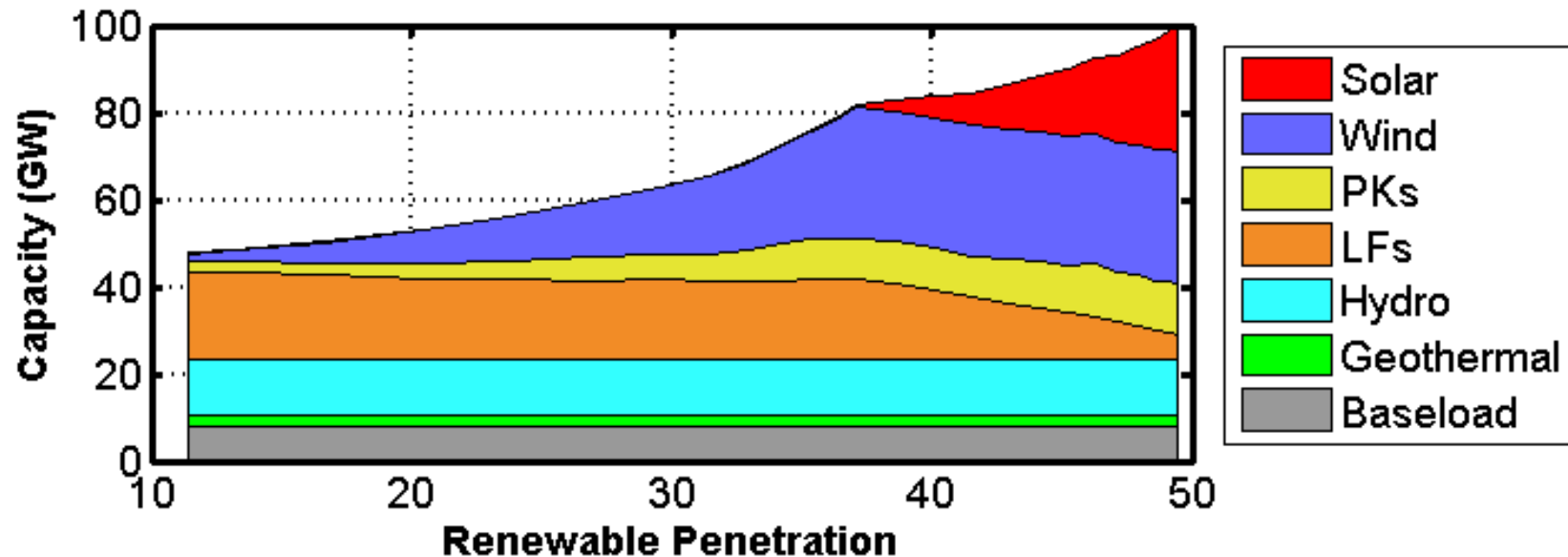


R1 (25 AUG 2011)

STREAM Model: Preliminary Results

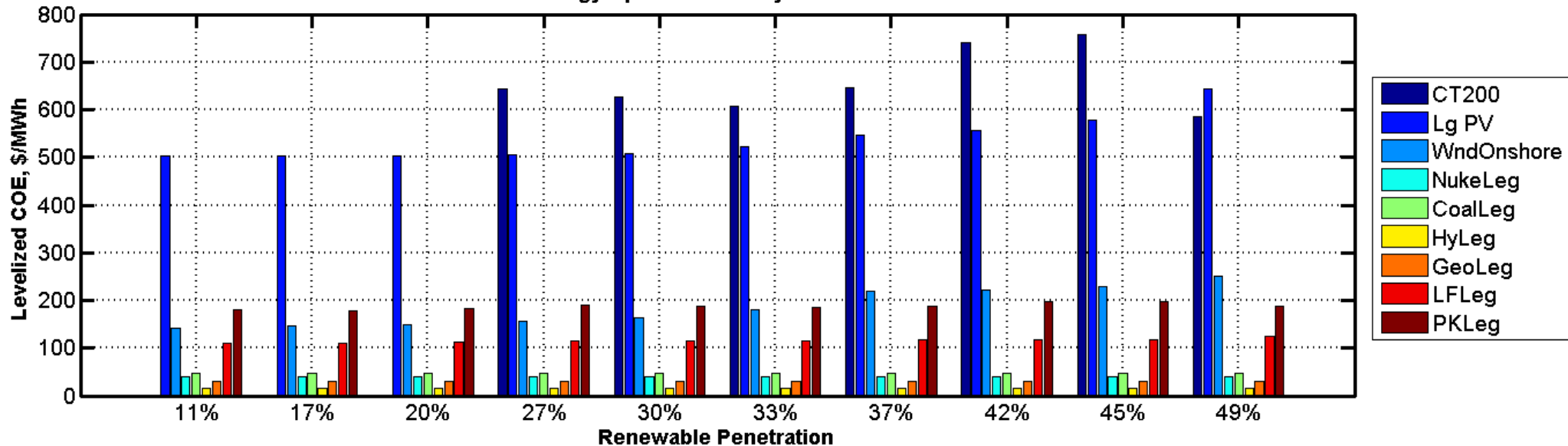


Higher Capacity, Lower Capacity Factors

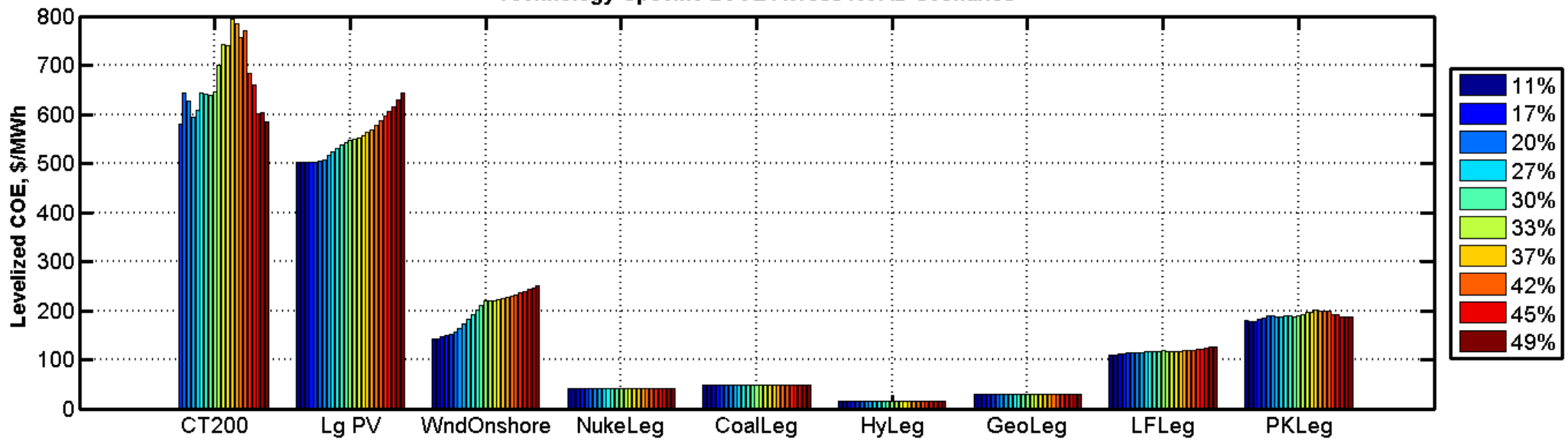


Lower Capacity Factors, Higher LCOE

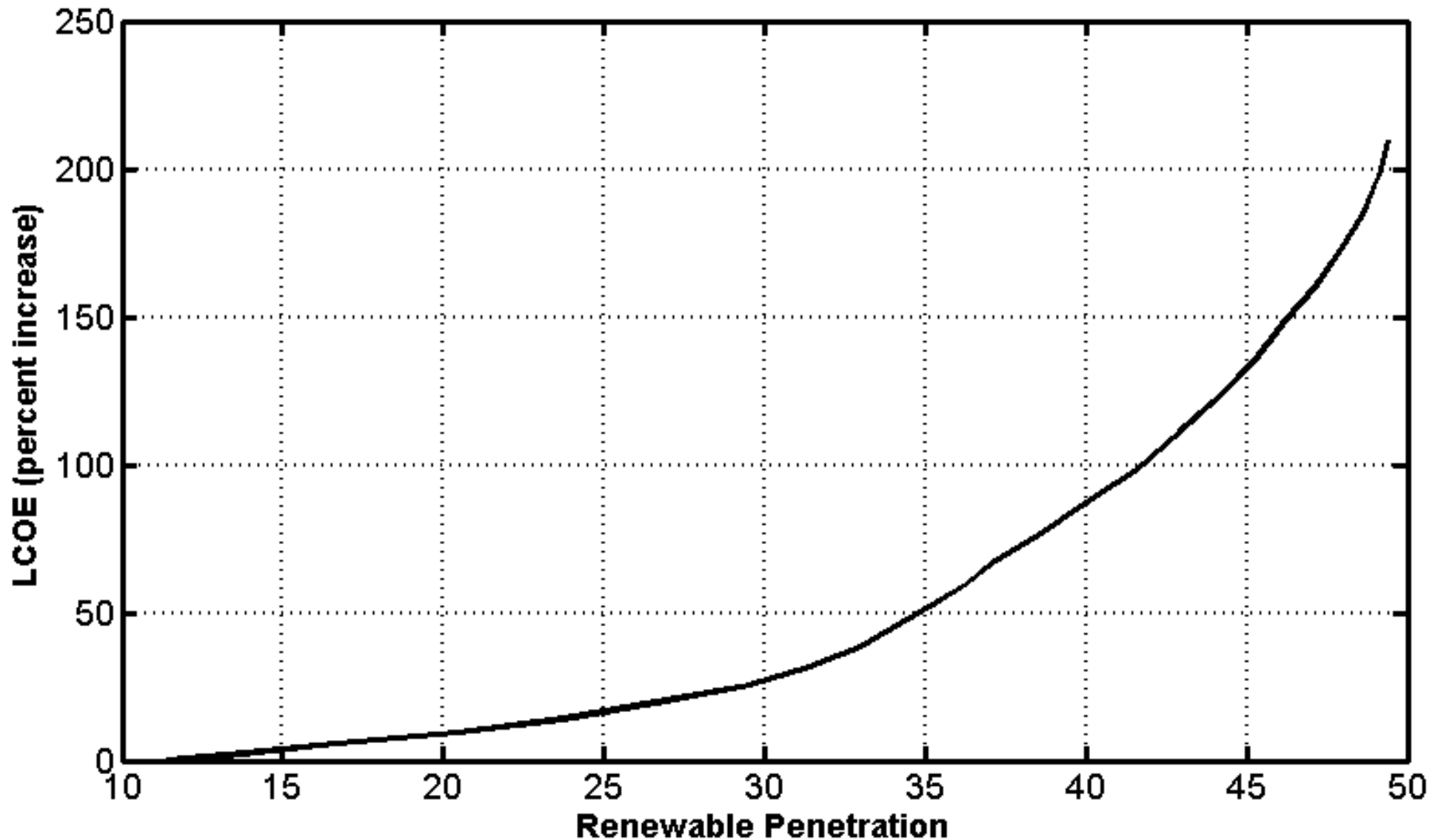
Technology-Specific LCOE by ROAD Scenario



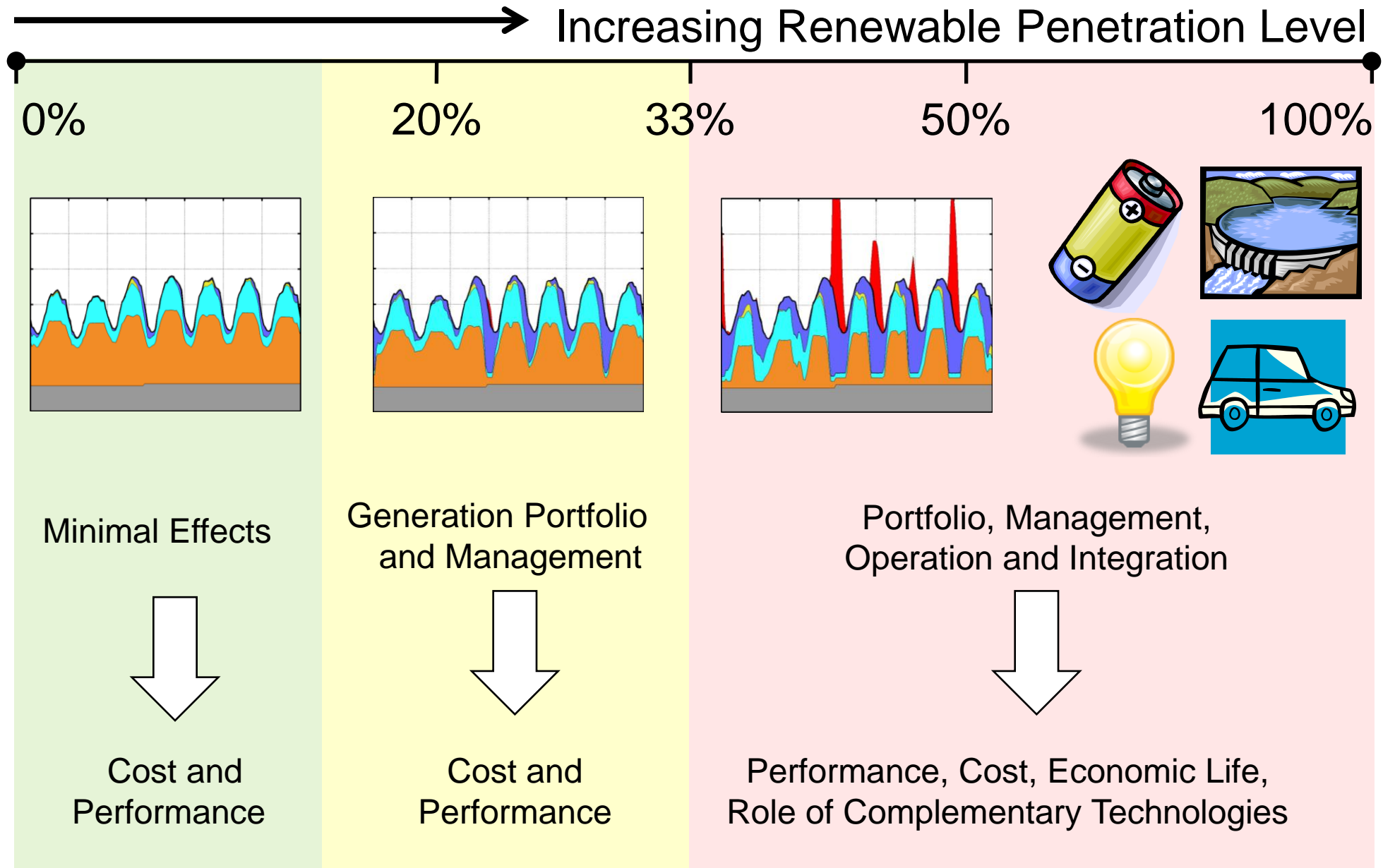
Technology-Specific LCOE Across ROAD Scenarios



Preliminary Generation Portfolio LCOE



More Renewables, More Challenges

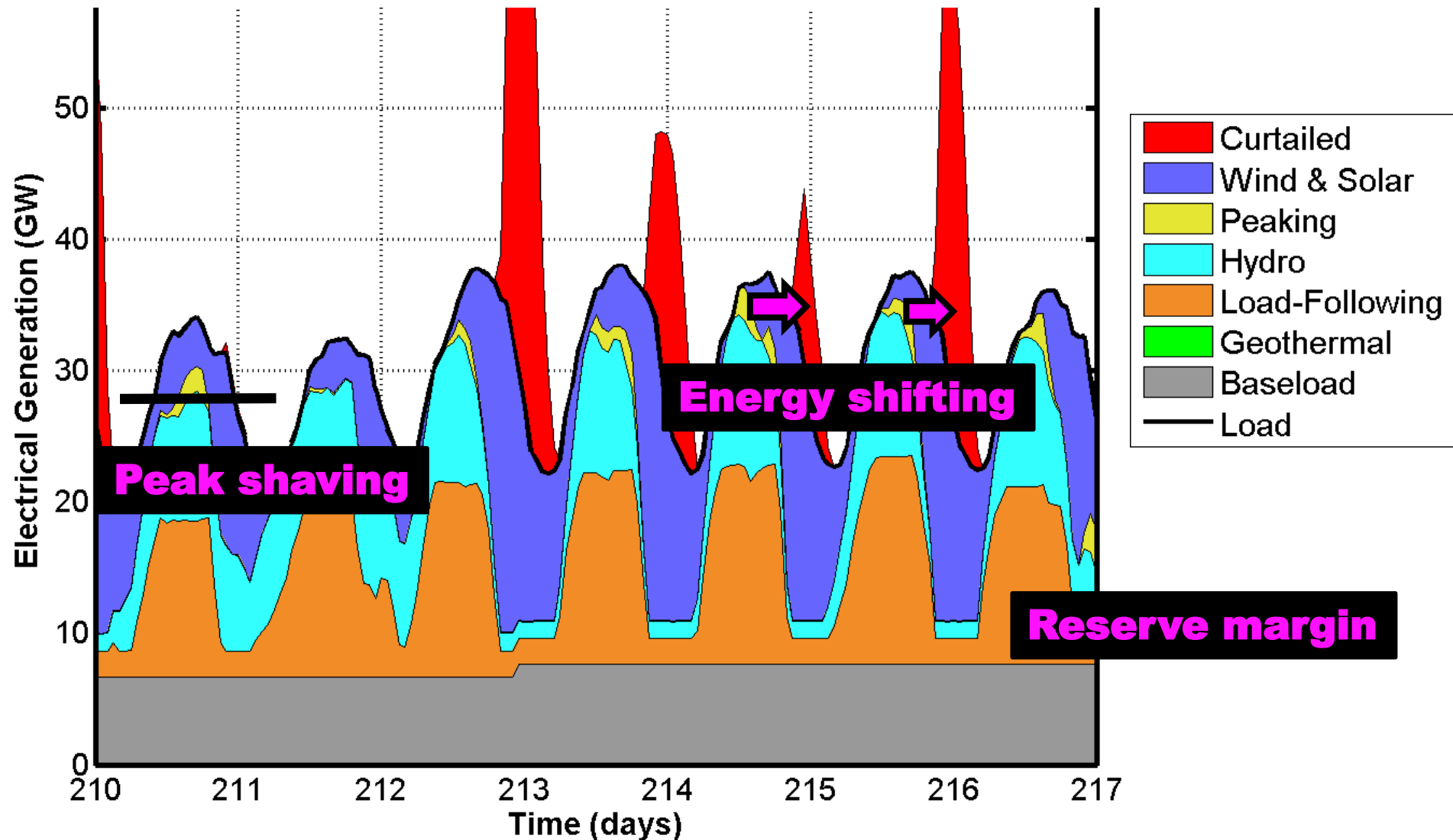


Need for Complementary Technologies

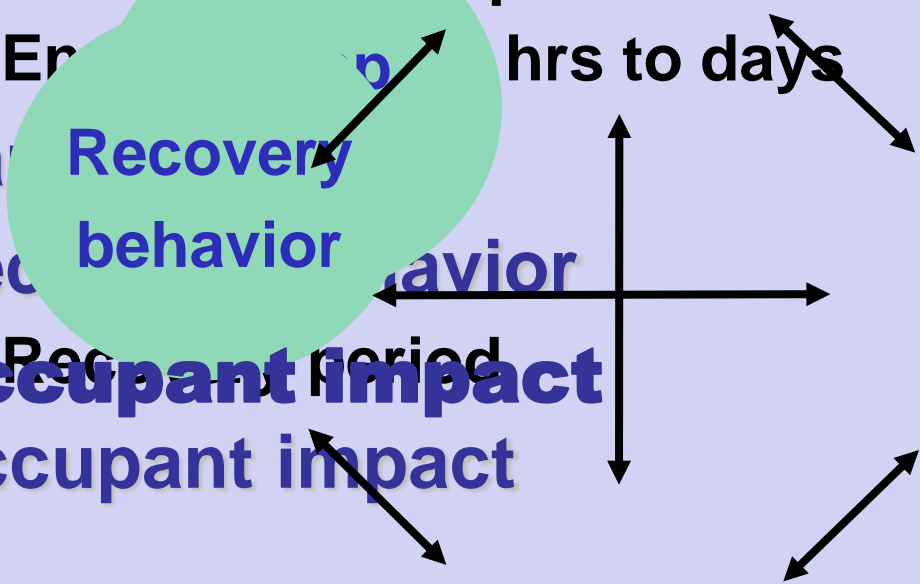
- Preliminary findings demonstrate increased role of complementary technologies as renewable penetration levels increase
- Complementary Technologies initially considered in STREAM model will include:
 - Demand Response (“DR”) Measures
 - Peak Shaving
 - Load Shifting
 - Energy Storage
 - Pumped Hydro
 - Compressed Air Energy Storage
 - Flow Batteries

Demand Response Services

- What grid-related services can DR provide?

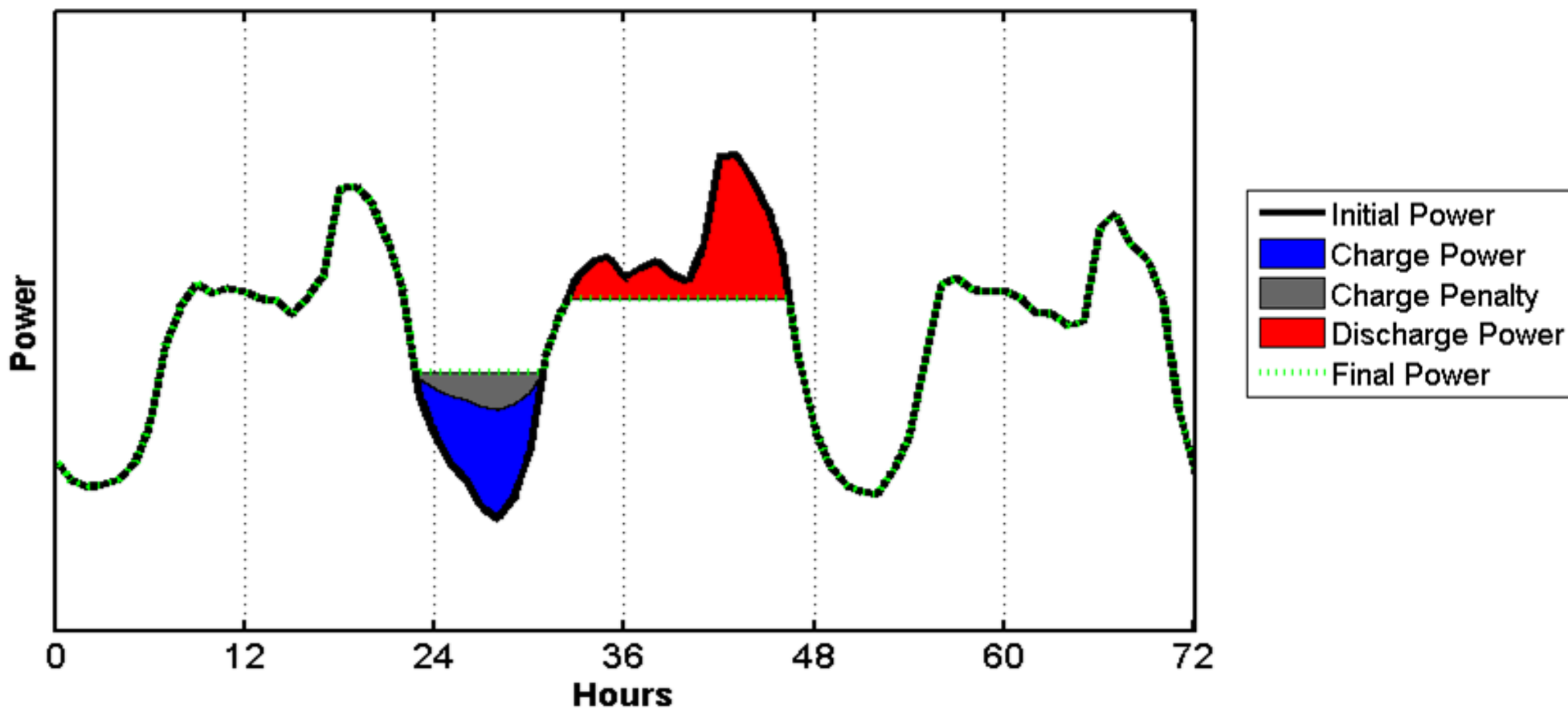


Evaluation Metrics

- Response period
 - Sustained response period
 - Response time: ~ 15-30 min
 - Peak response up to 6 hrs
 - End of response hrs to days
 - Recovery behavior
 - Recovery period
 - Occupant impact
- 

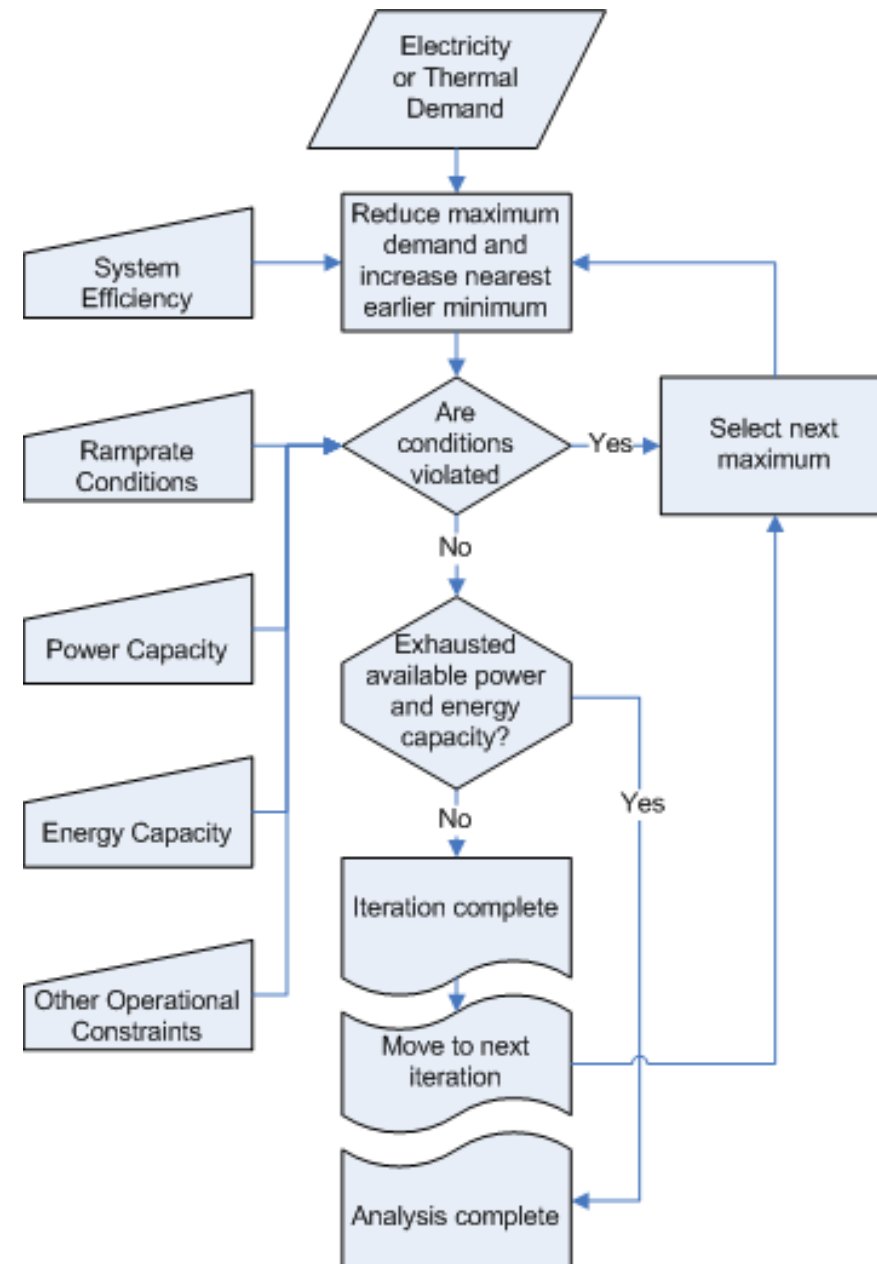
Energy Storage Services

- **Benefit:** Shifts energy from high-demand to low-demand periods
- **Cost:** Round-trip efficiency penalty may be high



STREAM Model: Energy Storage Module

- **Energy Storage**
 - Operational parameter inputs:
 - Efficiency
 - Ramp Rate
 - Power Capacity
 - Energy Capacity
 - Must calculate cost uniquely for input parameters



Conclusions

- **A model to explore various renewable penetrations for California has been developed and verified**
- **Importance of renewables integration and management increases with renewables penetration level**
- **Complementary technologies are required for high renewable penetration levels**
- **Continued research needed**
 - **Running various renewable penetration scenarios**
 - **Enabling renewable cost minimization**
 - **Exploring the resulting portfolio generation and cost vectors**

Future Plans

- **Impose an explicit renewable curtailment penalty**
 - Capacity factor penalty implicit in current model
- **Include electric vehicles for energy storage**
 - Value ability to control timing of charging
- **Include hydrogen production for energy storage**
 - **Grid-driven**
 - Produce as much hydrogen as warranted by grid benefits
 - Possible driver for hydrogen fuel cell vehicles
 - **Demand-driven**
 - As hydrogen fuel cell vehicle fleet size increases