Planning a Transition to 100% Renewable Power in Hawaii

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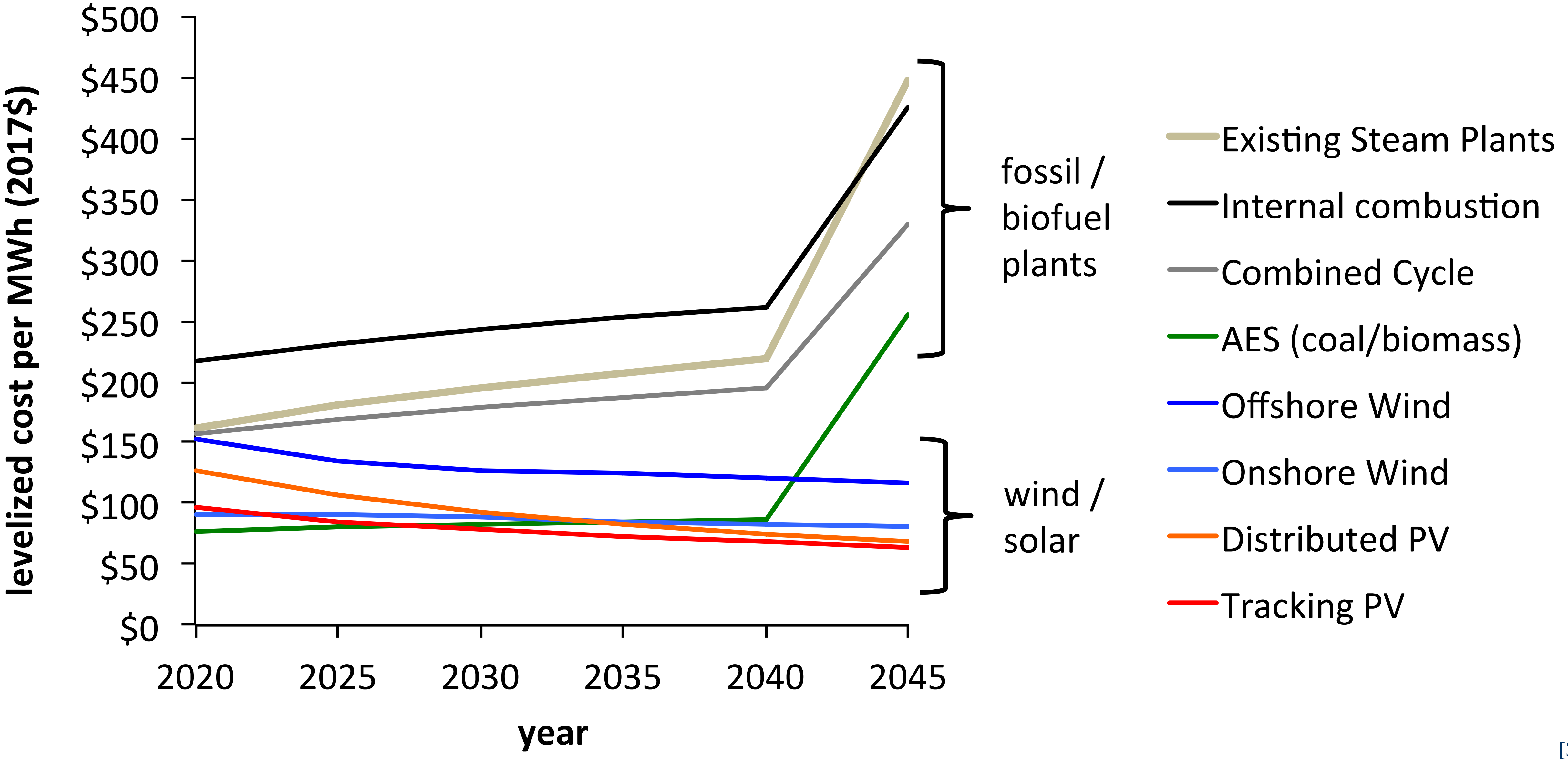
Planning for 100% Renewable Power

Hawaii adopted 100% RPS by 2045 in 2015

- What is the least-cost plan to achieve this transition?
- What factors do we need to get right to keep costs down?
- Can we make a plan that is robust against uncertain fuel prices?

The challenges Hawaii faces will also need to be addressed by market-based power systems as the cost of renewable power falls.

Levelized Power Costs (Oahu)



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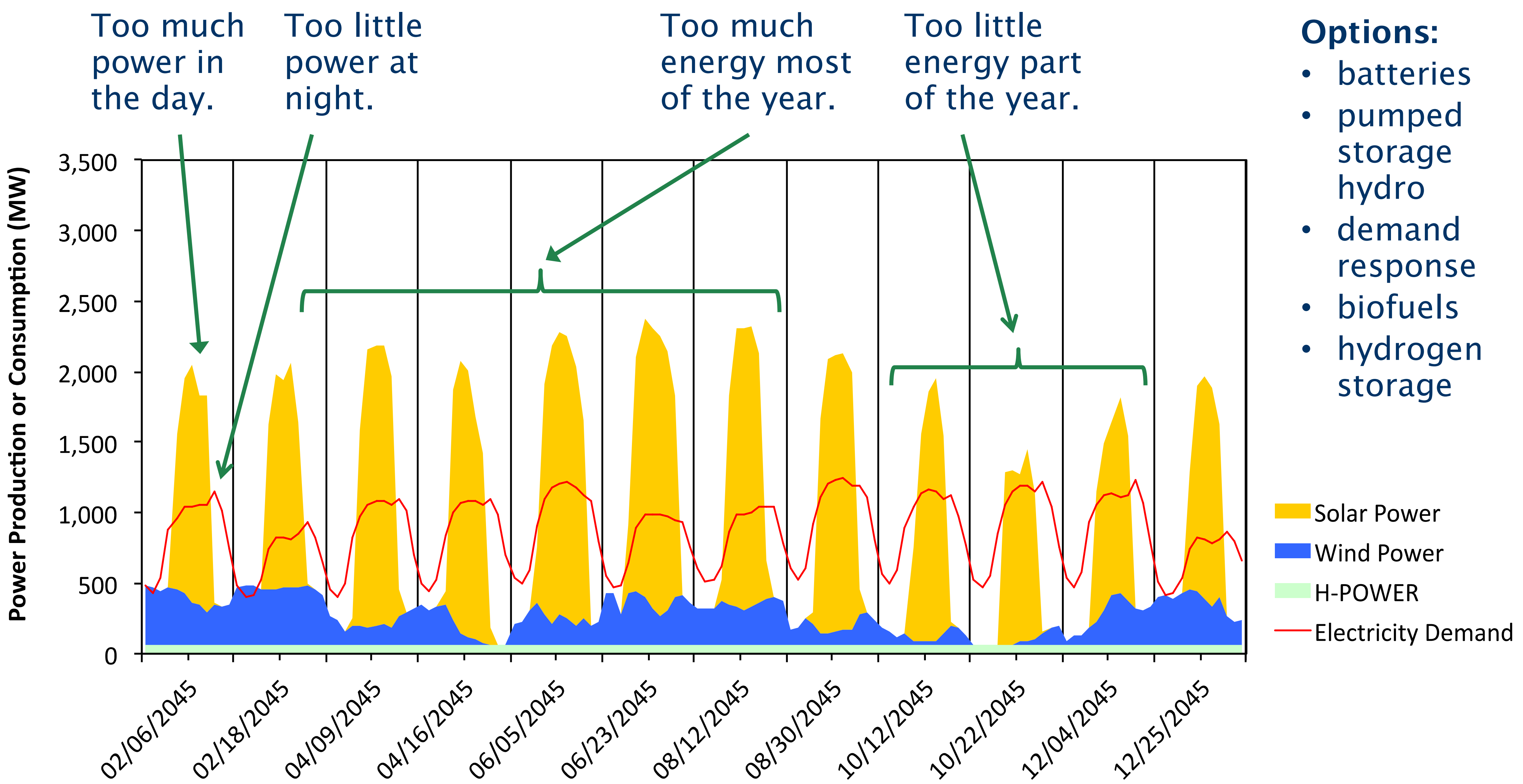
Challenges in Planning for 100% Renewable Power



Options:

- batteries
- pumped storage hydro
- demand response
- biofuels
- hydrogen storage

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"Switch" Capacity Expansion Model for High-Renewable Power Systems (up to 100%)

Mixed-integer linear program, open-source software (http://switch-model.org)

Decision variables (co-optimized)

- **Investments every 5 years**: How much capacity to add in each potential project
  - Options include wind and solar farms, thermal and hydro power plants, battery storage and hydrogen equipment
- **Operation on sample days:** unit commitment and dispatch, storage, demand response
  - 12 sample days are modeled with hourly detail during each period, using synchronized profiles for wind, solar and load
  - Follow-up stage can test and refine plans using 8760+ hours

Objective

- minimize NPV of costs (capital recovery, fuel, O&M, emission taxes)

Constraints

- physical limits of equipment, weather, demand response
- provide enough electricity and reserves every hour
- meet RPS target

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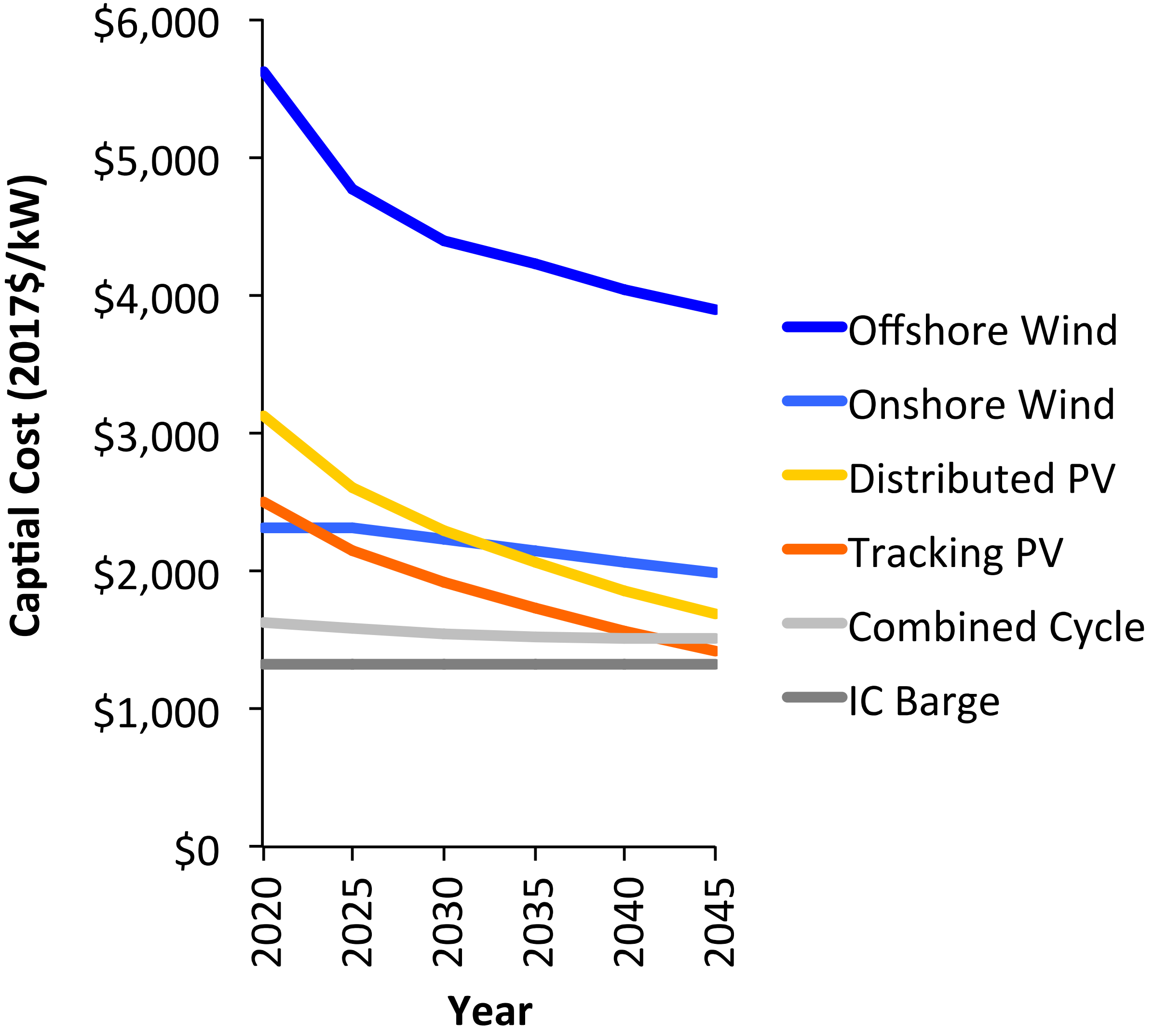
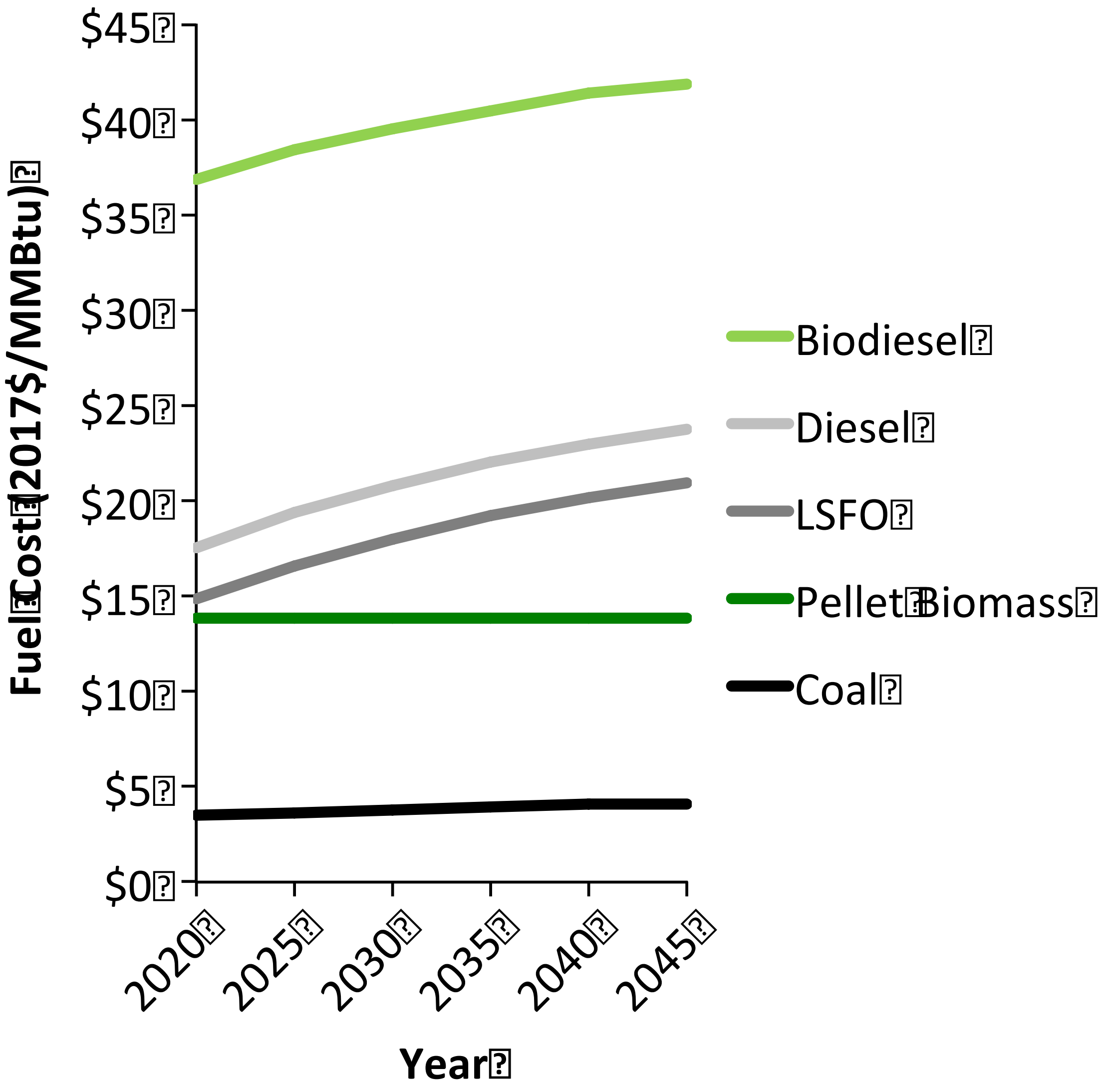
Input Data for Switch-Hawaii

- Hourly production profiles for all possible wind and solar resources
  - Land-use screens, Google Maps roof images, meteorological models, National Solar Radiation Database
- Hourly loads for sample days in future years
  - From FERC Form 714 filings for 2007-08, adjusted to match peak and average forecasts from PSIP
- Costs for generators, batteries and other equipment
  - Hawaiian Electric Power Supply Improvement Plan (PSIP), Dec. 2016
  - Hydrogen from U.S. DOE studies
- Fuel price forecasts
  - US EIA Annual Energy Outlook, indexed to Hawaii
- Demand reponse potential (10%) and EV adoption (55% by 2045)
  - from PSIP

Projected Costs for Equipment and Fuel





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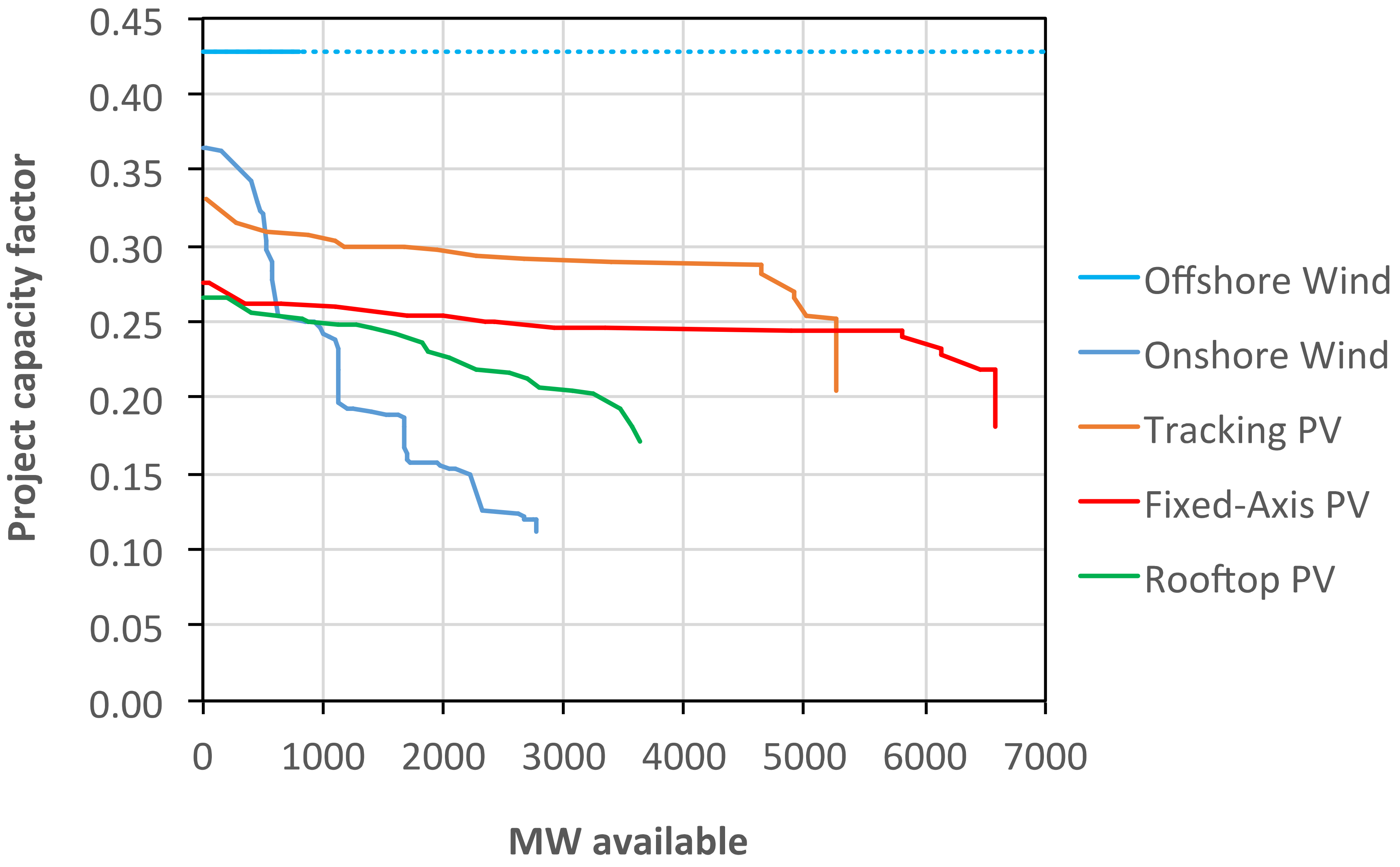
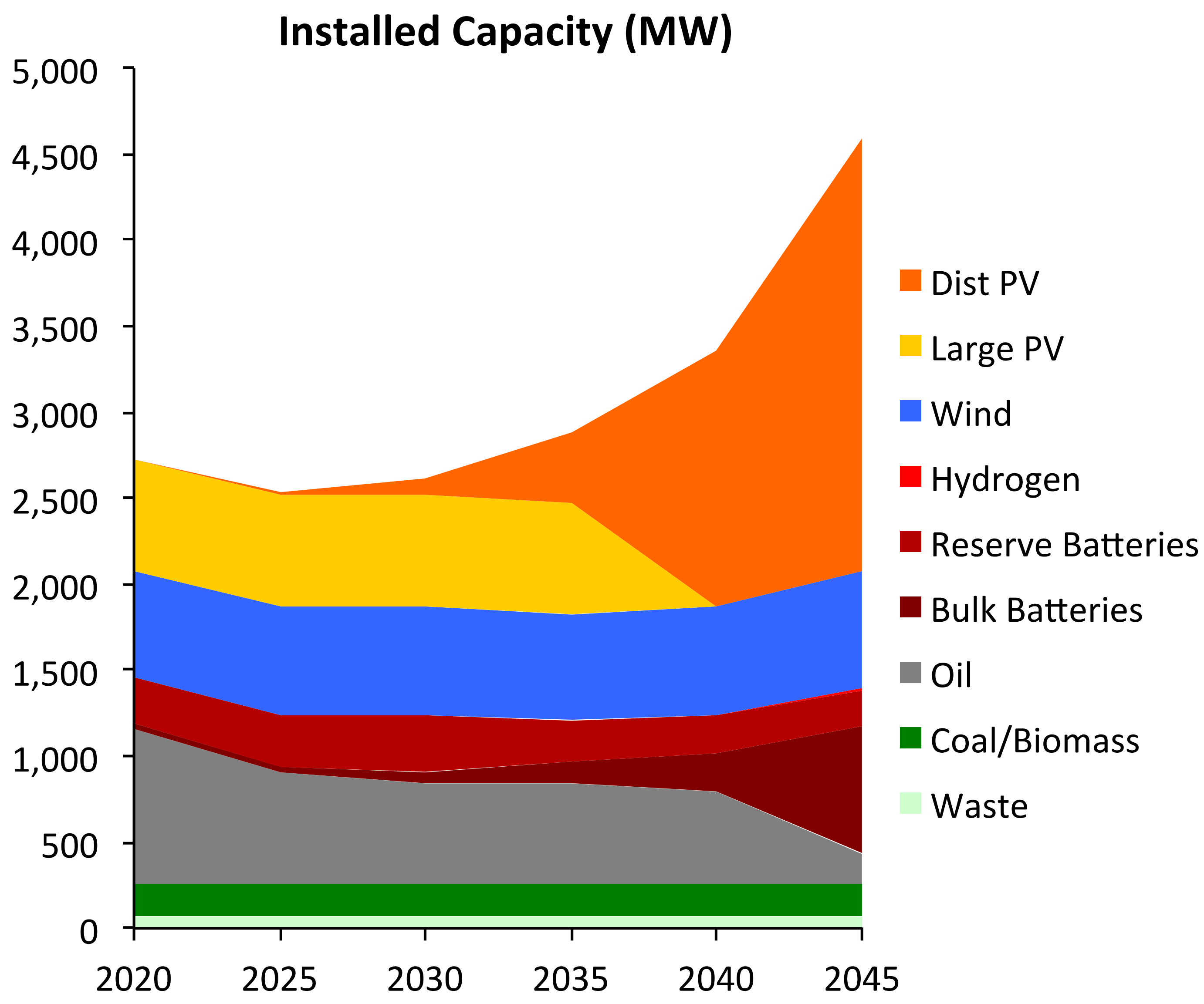
Oahu Renewable Resource Supply Curves

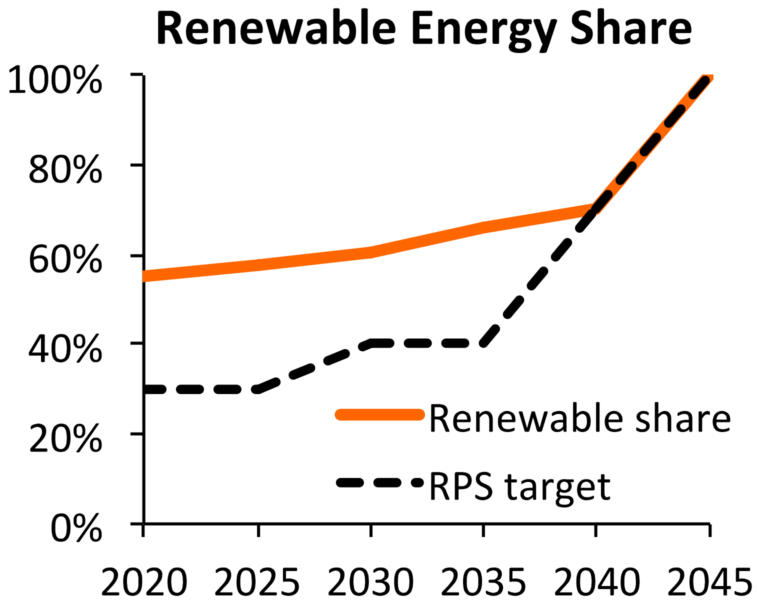


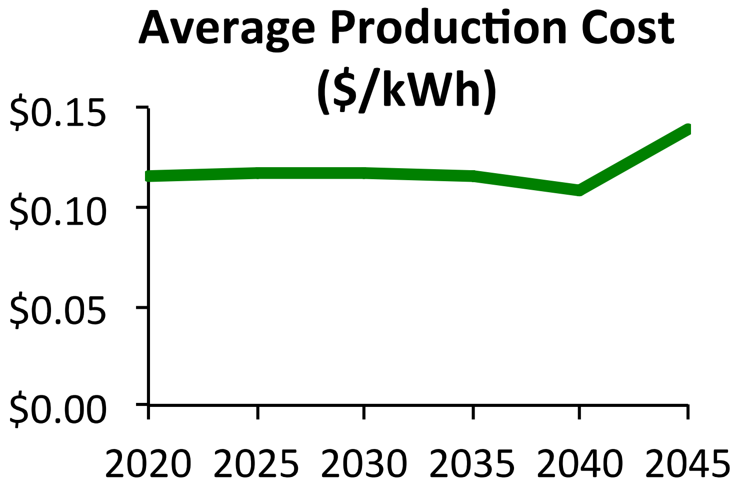
Switch chooses the optimal mix of resources to build, based on cost and hourly behavior

RESULTS

Least-Cost Transition to 100% Renewable Power







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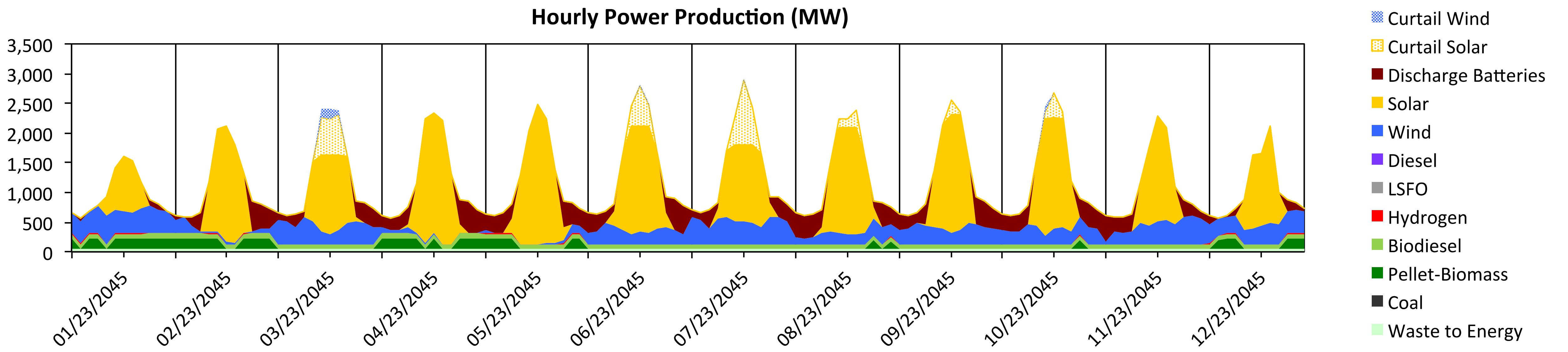
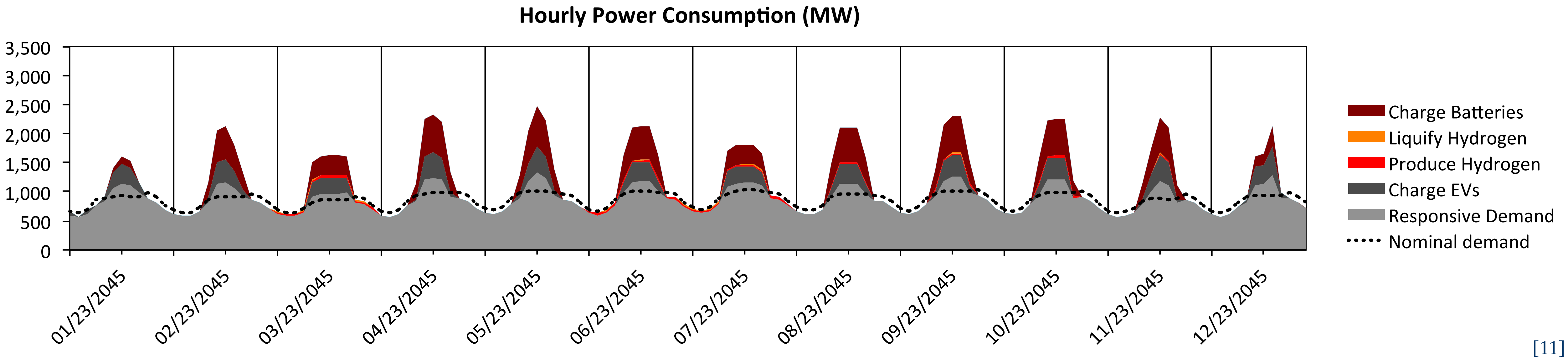
Hourly Energy Balance in Reference Plan ($139/MWh)





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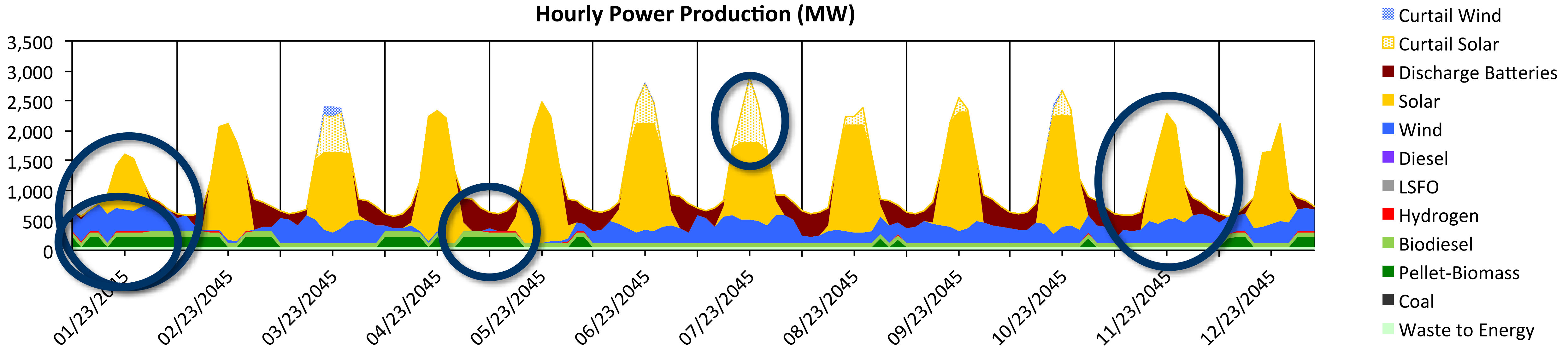
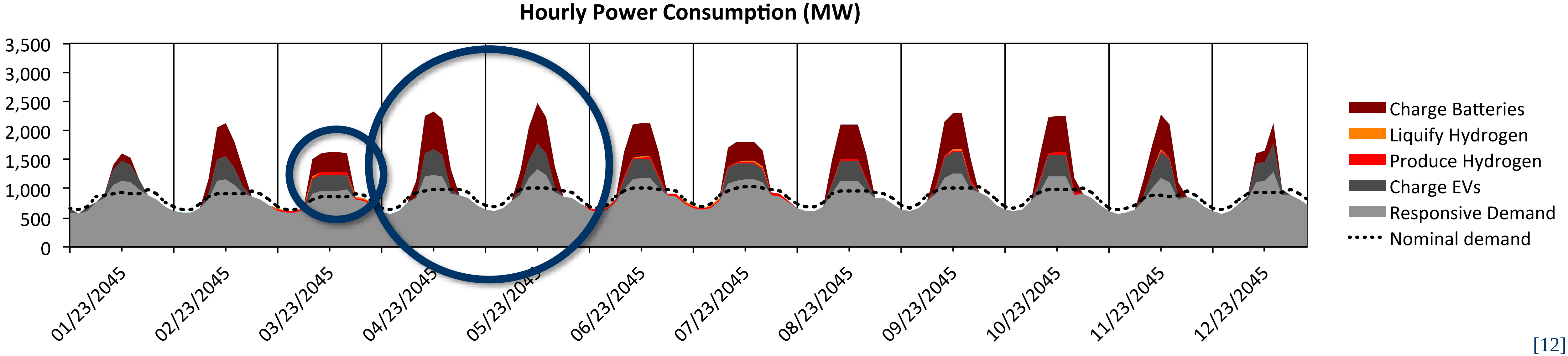
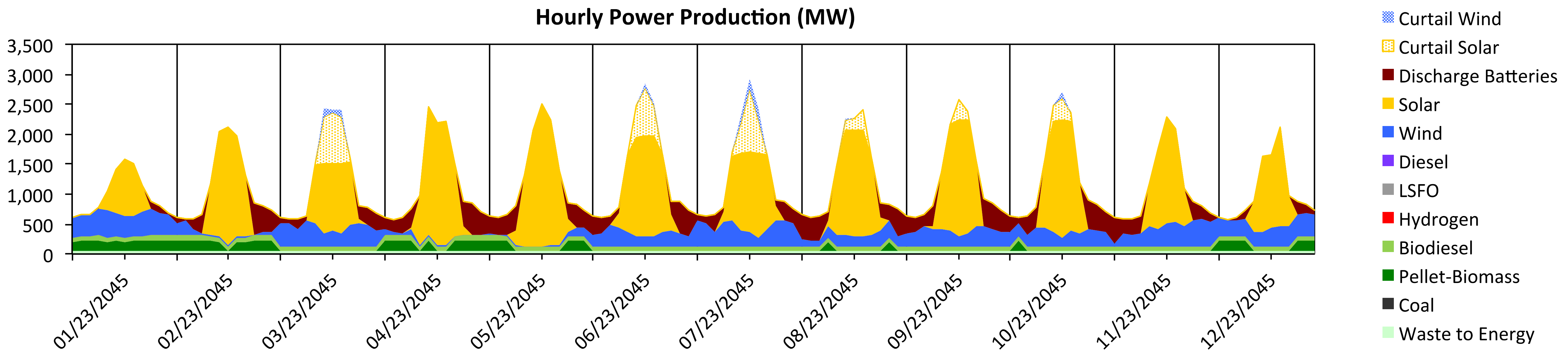
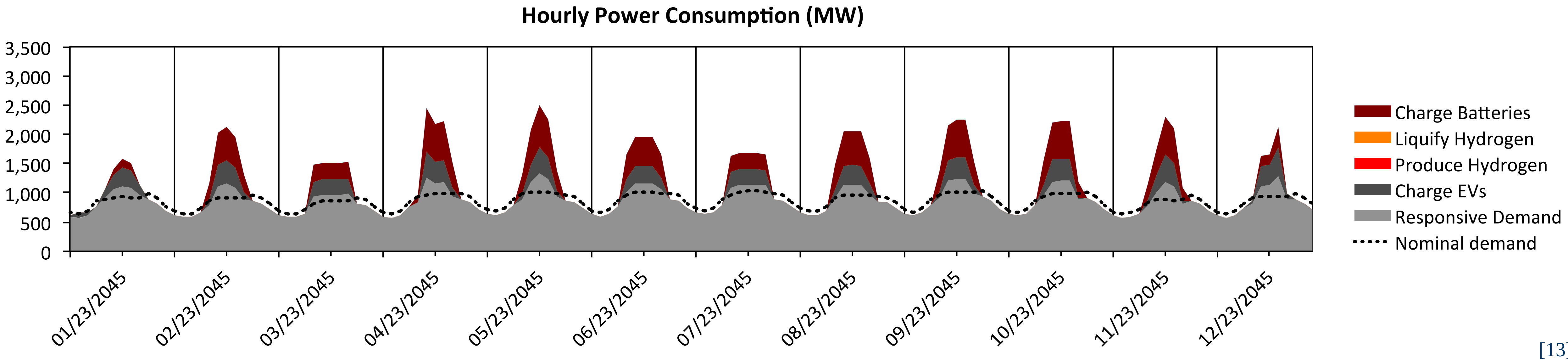


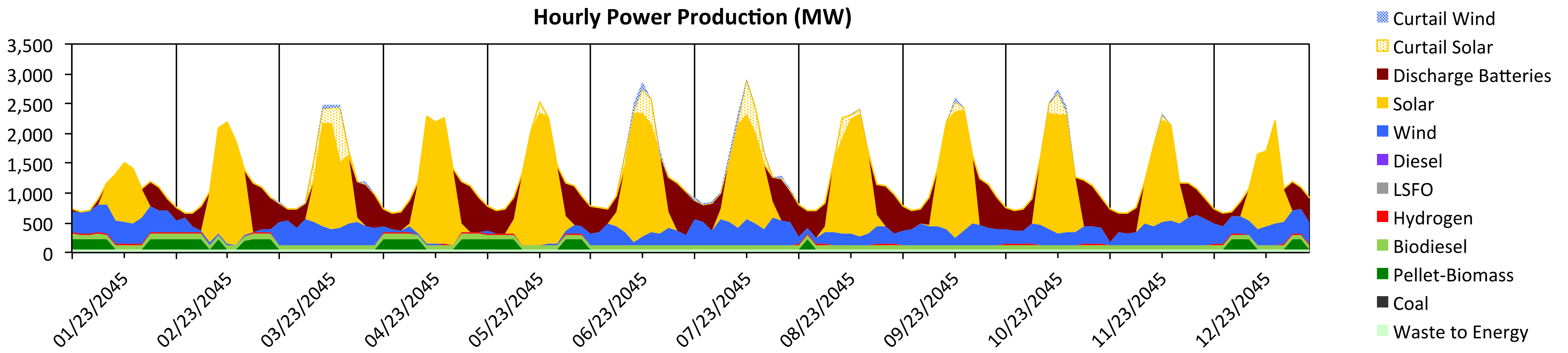


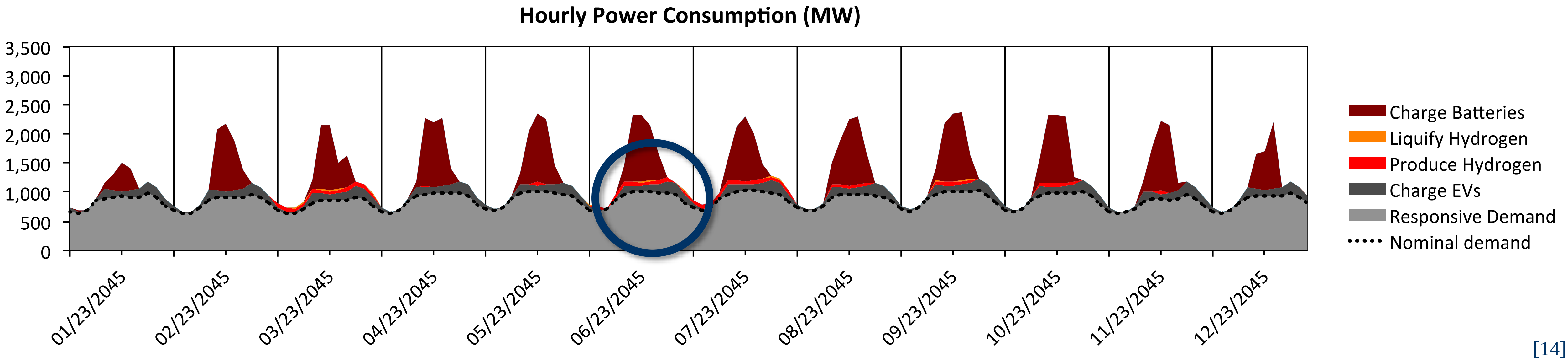
Energy Balance with No Hydrogen ($139/MWh)



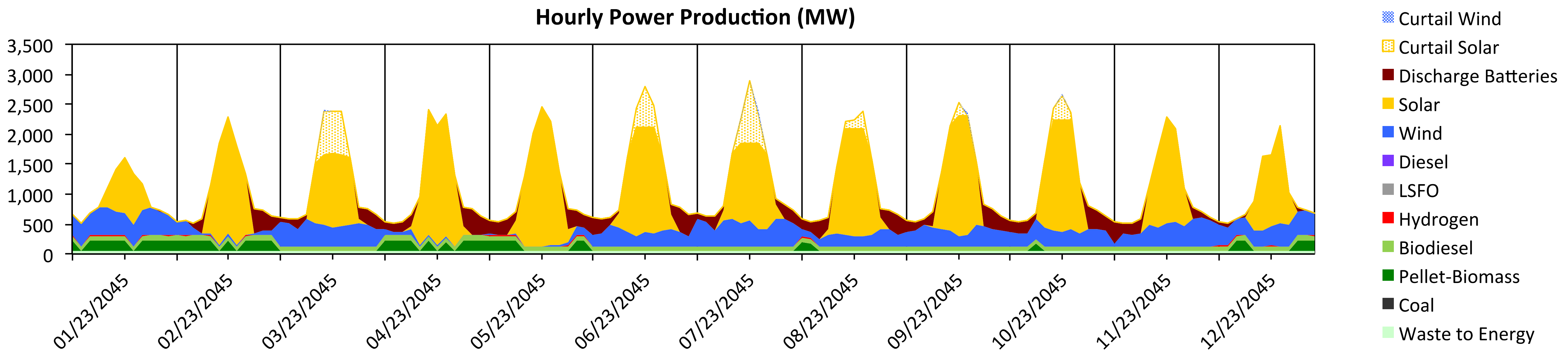


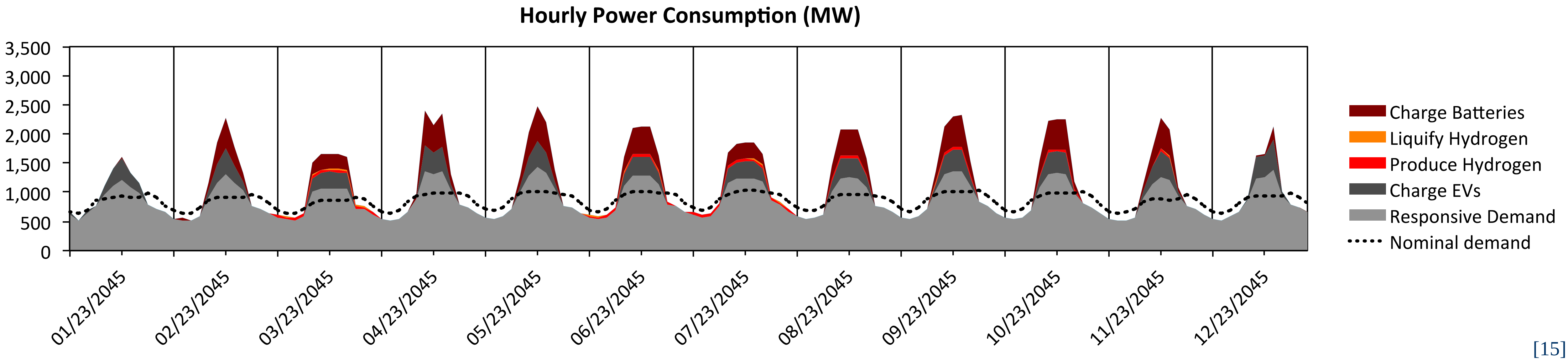
No Demand Response ($150/MWh)



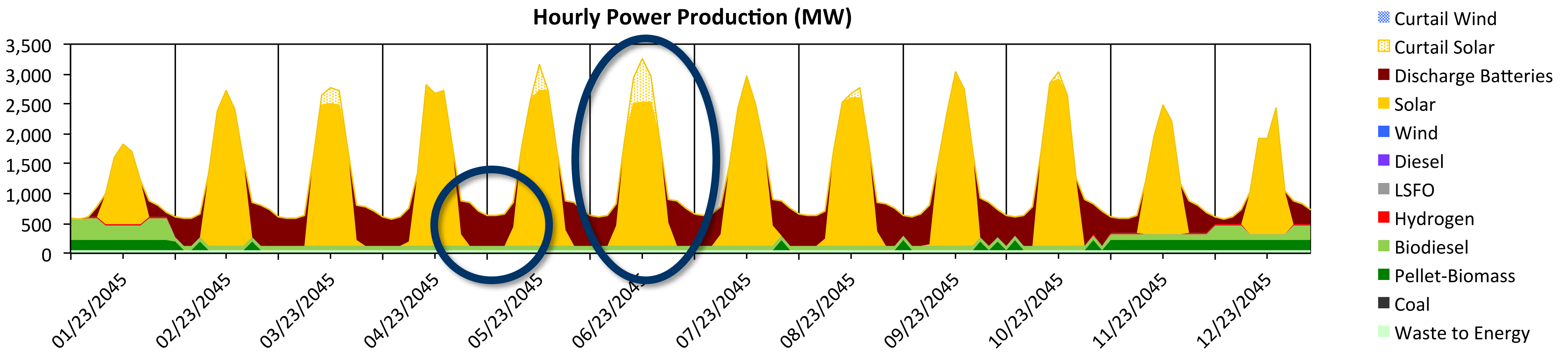


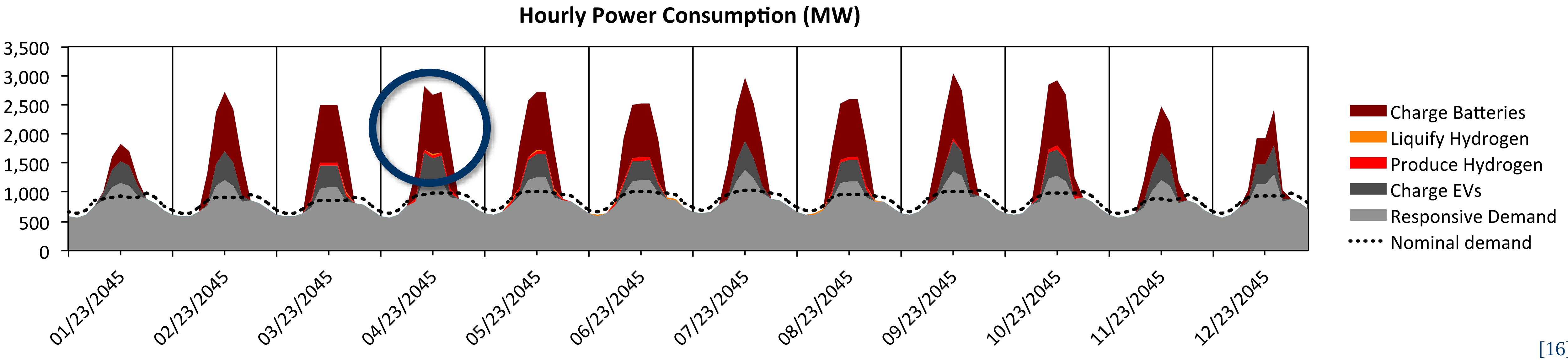
20% Demand Response ($131/MWh)



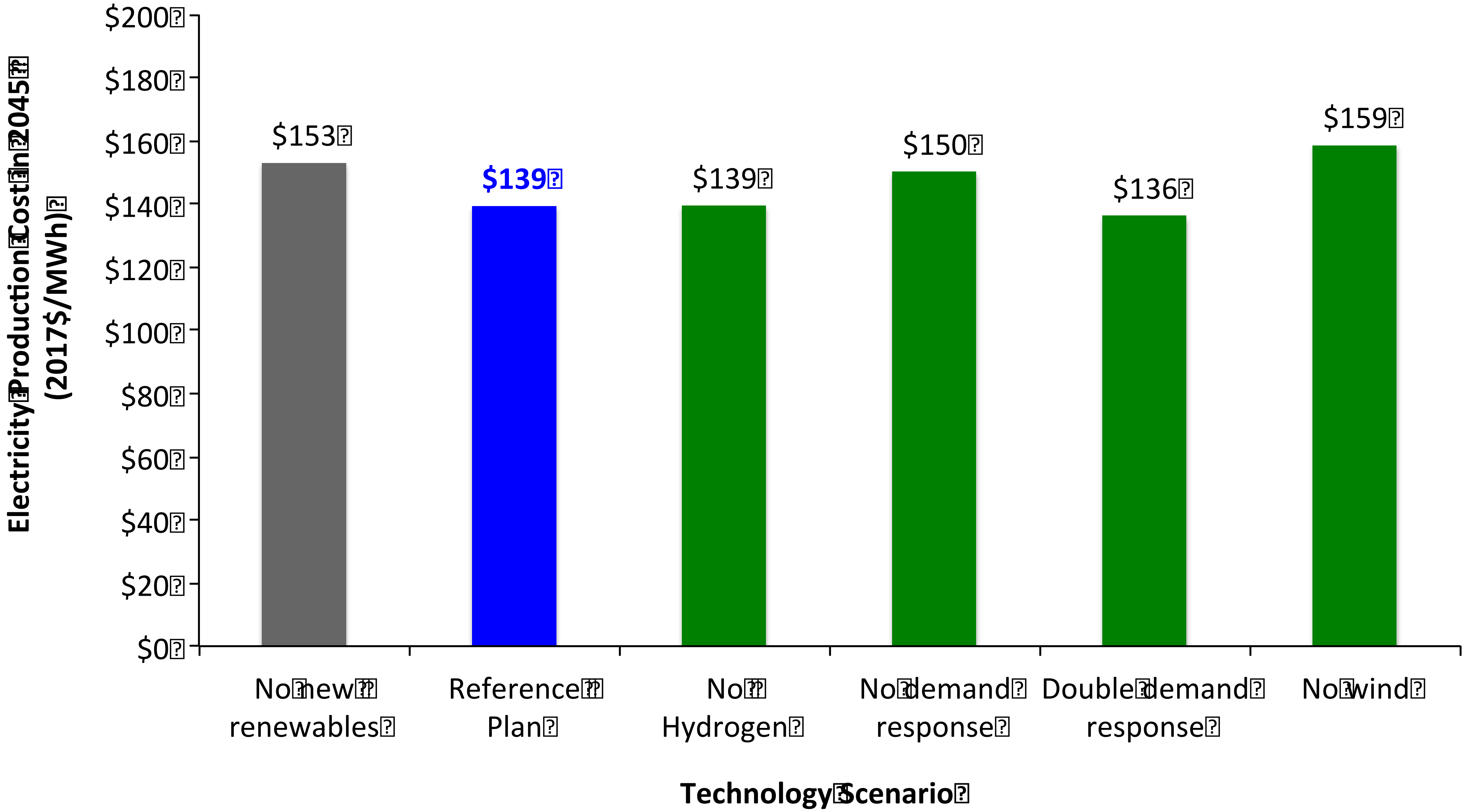


No Wind Power ($159/MWh)

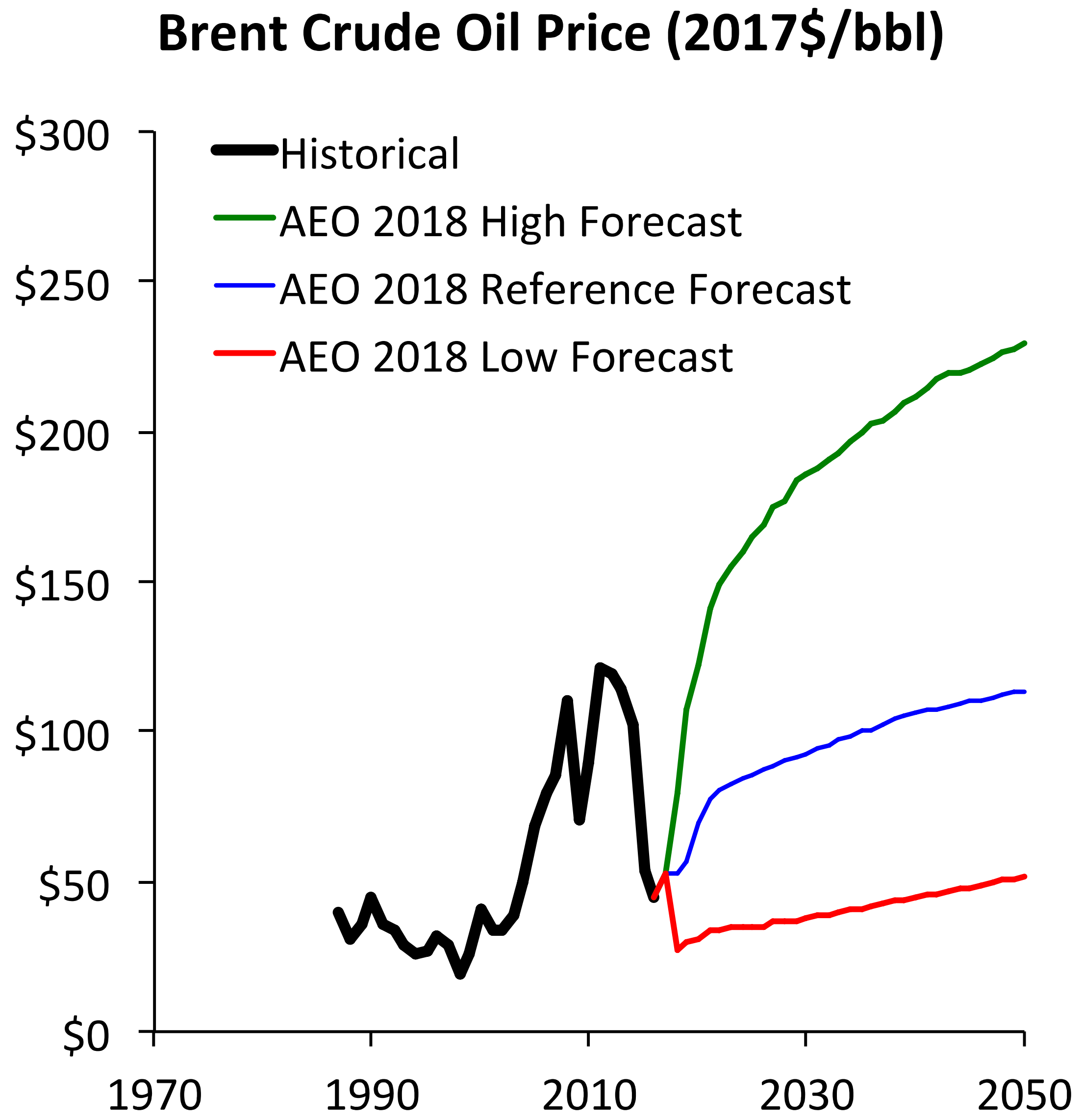


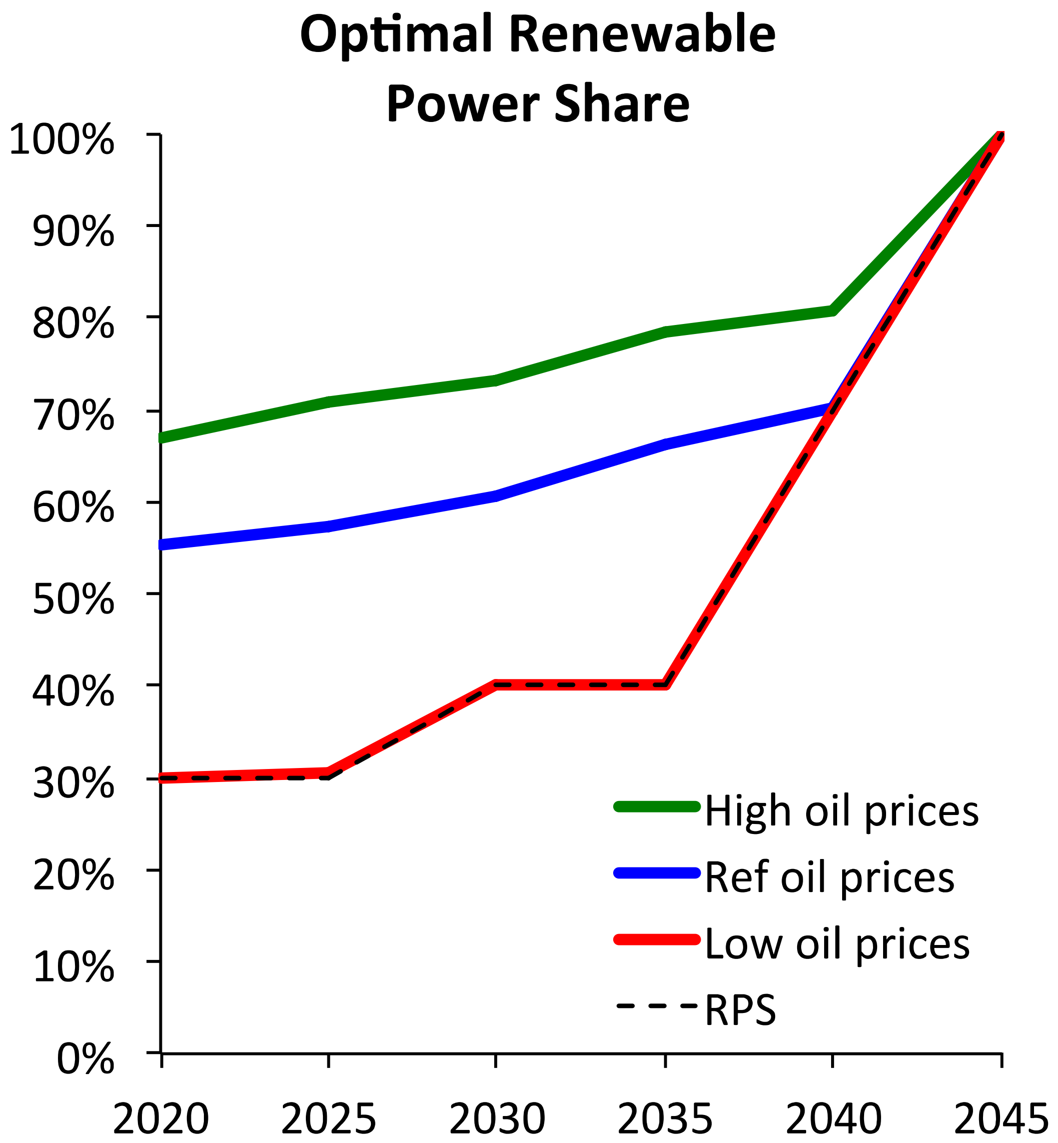


Cost Summary (in 2045)

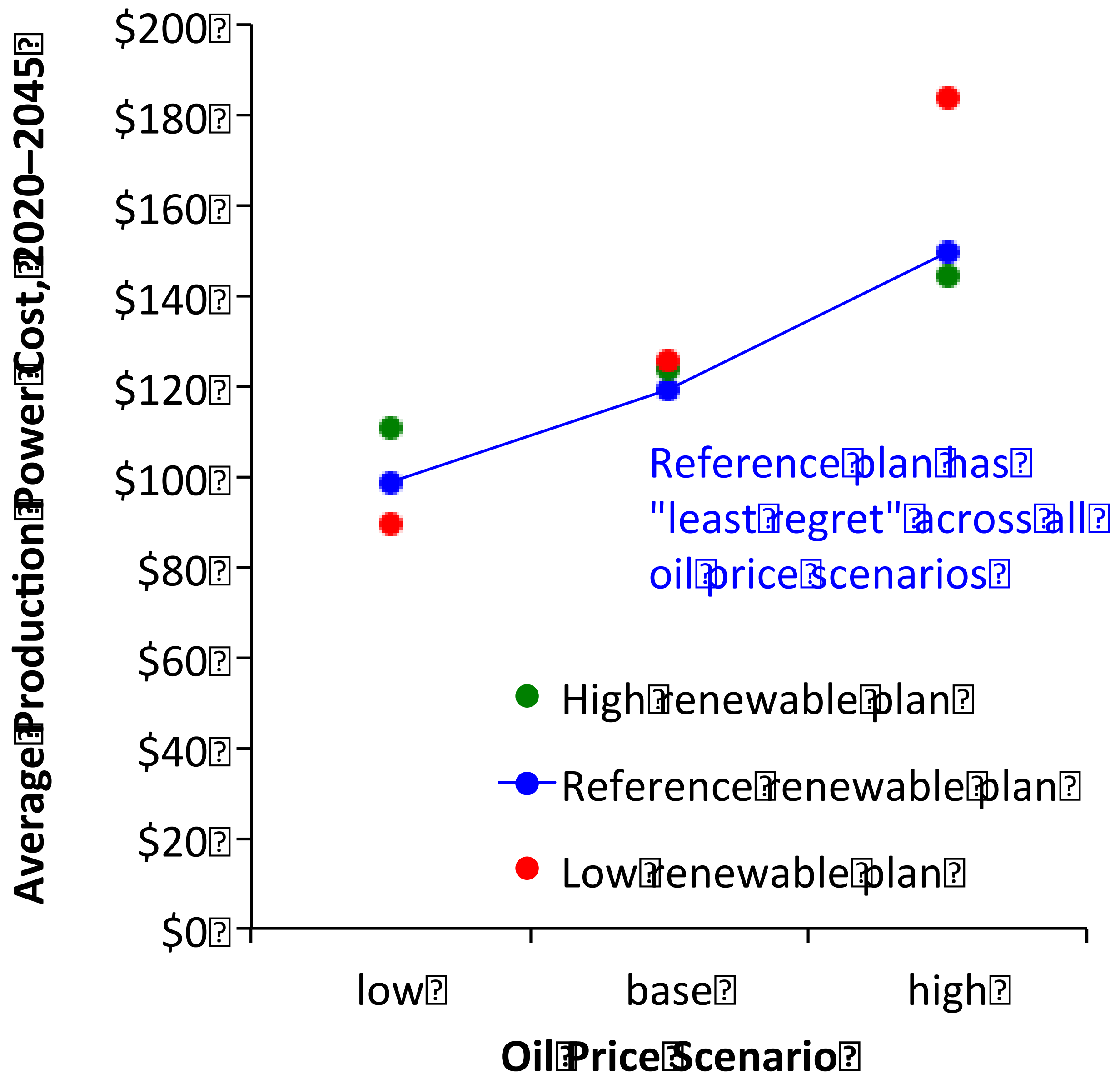


Optimal Transitions for Different Oil Prices





Robust Planning for Different Oil Prices



Portfolio	Average Prod. Cost Across all Scenarios ($/MWh)	Max. Regret Across all Scenarios ($/MWh)
High RE	$126	$22
Ref. RE	**$122**	**$9**
Low RE	$131	$39

Findings from Switch–Hawaii (Oahu-Focused)

- 100% renewable power is possible at reasonable costs
  - optimal plan is above RPS through 2040
  - optimal plan is 55% renewable by 2020
- Optimal designs only move about 15% of energy through storage
- Wind and demand response are important for keeping costs down
- Reference plan minimizes expected cost and regret in the face of higher or lower oil prices
- Future work: directly optimize first-stage plan for multiple cost scenarios for fuel and equipment, with adaptation in later stages

Implications for Market Design

- ISOs could (should?) use Switch-like models for capacity markets
  - non-discriminatory selection among different resource options
  - no need for simplifying/biasing statistics (“capacity value”)
  - long-term markets would provide secure finance
- Challenge: long-term planning requires forecasts
  - cost of future projects, not bidding today
  - future cost of fuels
  - who should carry the risk that the forecast is wrong?