Simplified Chronological Capacity Expansion Planning Model with Storage, Demand Response and Unit Commitment

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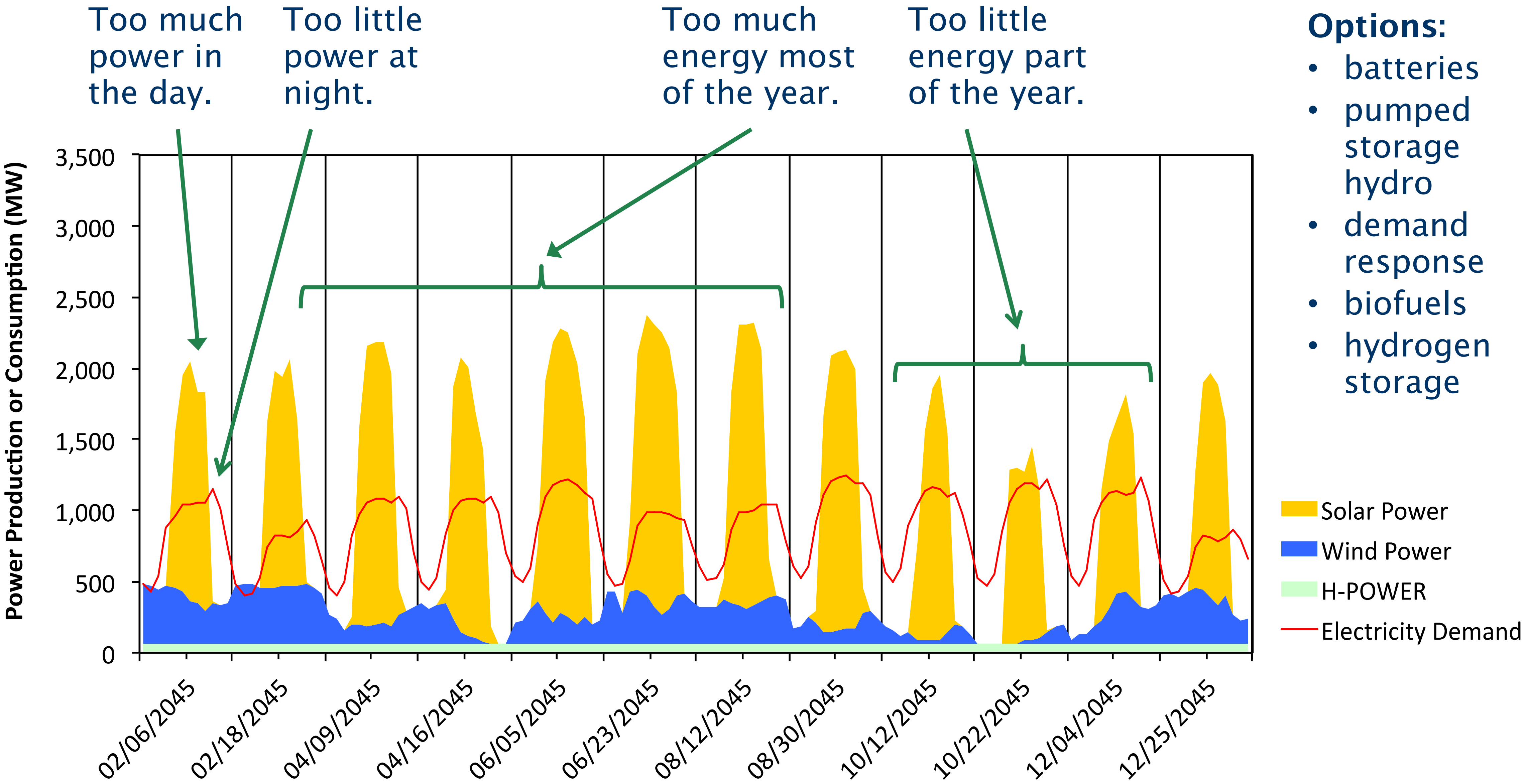
Matthias Fripp
University of Hawaii Economic Research Organization (UHERO)
Renewable Energy and Island Sustainability (REIS)
Asst. Prof. of Electrical Engineering
University of Hawaii at Manoa
mfripp@hawaii.edu

http://ee.hawaii.edu/~mfripp

Challenges in Planning for 100% Renewable Power



Options:

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

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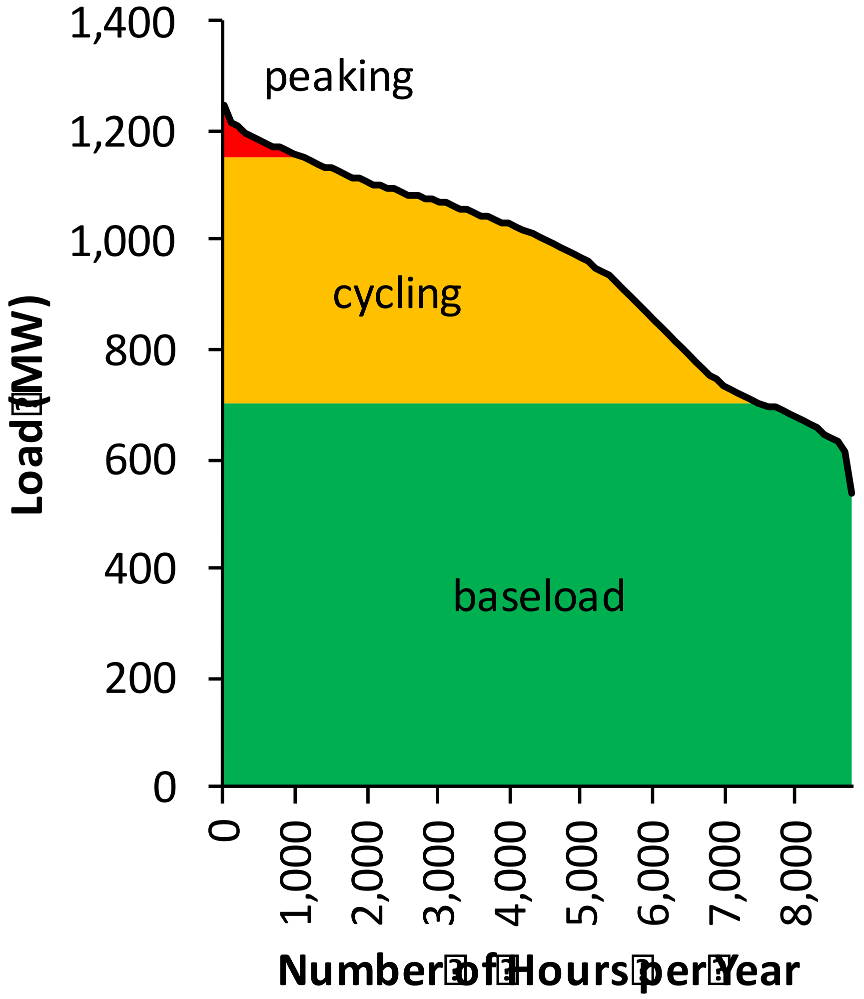
Traditional Capacity Expansion Models

- Objective
  - minimize capital and operating costs over a multi-year period
- Decision variables
  - **Investments**: how much capacity to add of each asset class, during several future investment periods
  - **Operation:** use generator portfolio to fill under a load duration curve or (equivalently) satisfy a collection of independent timepoints
- Main challenge: non-chronological timesteps
  - cannot accurately model unit commitment (startup costs, minimum up/down time) and intra-day load shifting via storage and demand response



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Newer Capacity Expansion Models

- One-stage capacity plan with 8760 hours of operation
  - can model intertemporal constraints
  - cannot model long-term transitions
- Multi-stage capacity plan with 365 days of operation per stage
  - only solvable with ~2 blocks per day (Plexos)
  - can model long-term transitions
  - cannot model intertemporal constraints accurately
    - unit commitment and storage in 12-hour windows is not very accurate

Long Timesteps Give Inaccurate Duty Cycles for Thermal Plants, Storage and Demand Response

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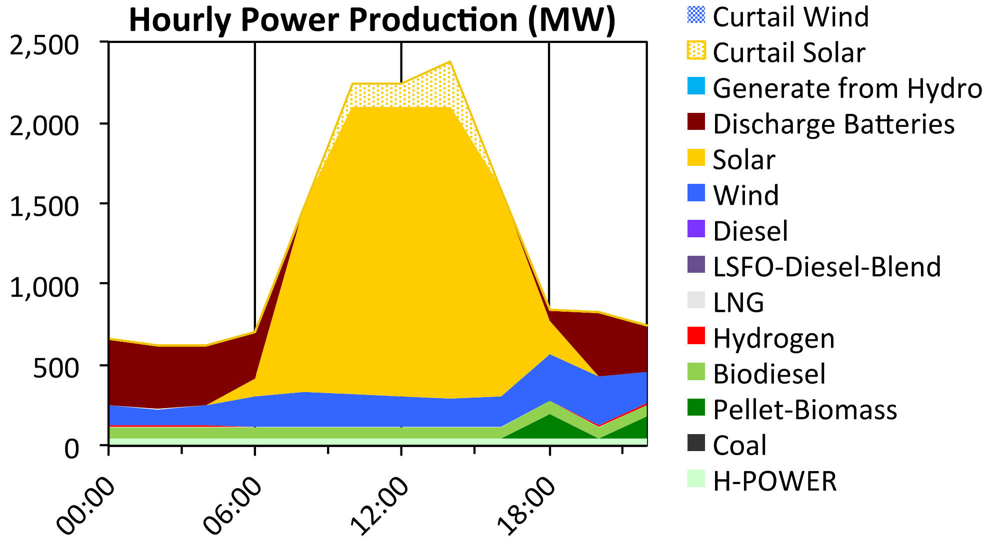
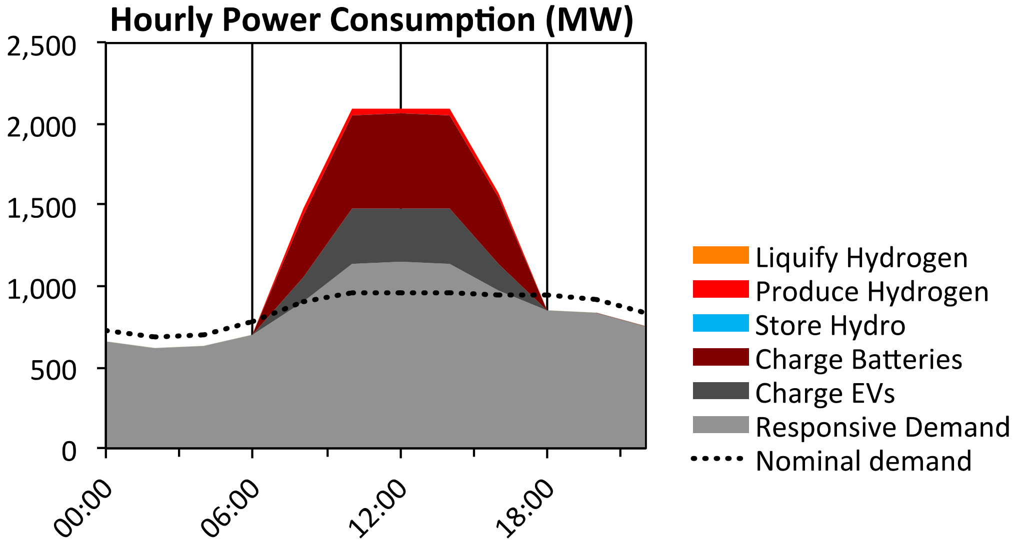
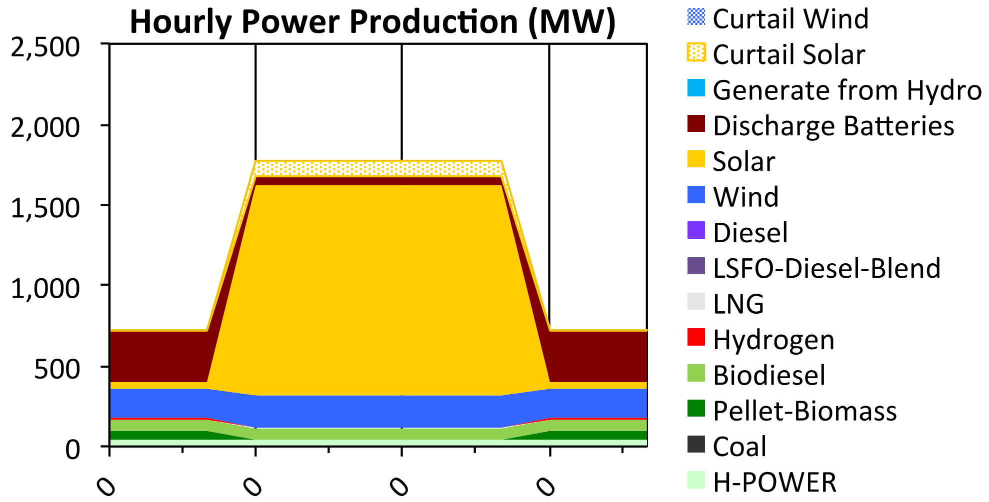
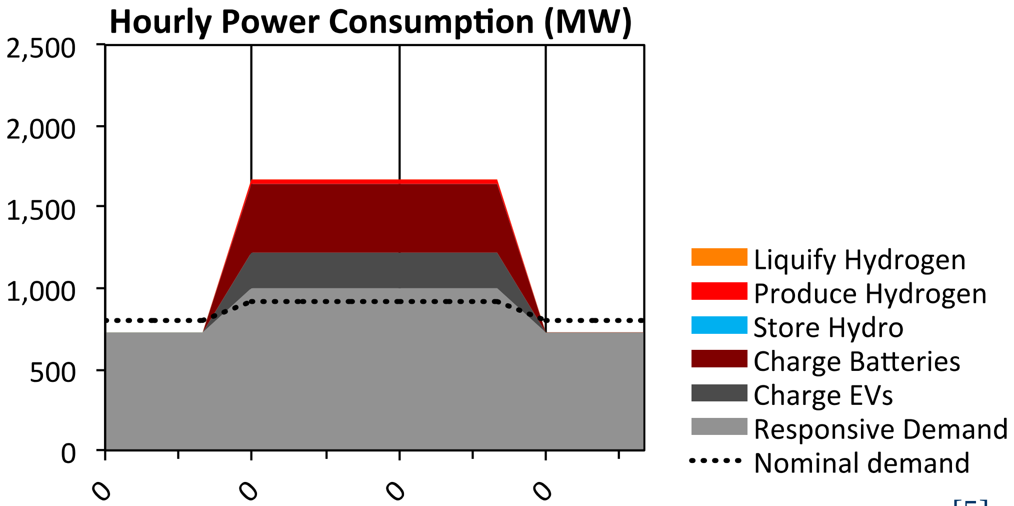
2 hour timesteps





12 hour timesteps





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Production Cost Models

- Objective
  - minimize operating cost over the study period
- Inputs
  - **Investments:** how much capacity to add of each asset class, during each investment period
- Decision variables
  - **Operation:** Power production or consumption by each asset, each hour
    - Often uses 8760+ hours of chronological data
    - Can model intermittency, storage and demand response
- Main challenge
  - Portfolio selection is heuristic or expert-driven
  - Results may not reflect an optimal system design
  - Can’t adapt easily or consistently to different policies or conditions

Switch – a New Kind of Capacity Planning Model

- Switch ≈ "Integrated Solar, Wind, Hydro, Conventional Generation and Transmission Planning Model"
- Switch is an open-source expansion-planning model for power systems with large shares of renewable energy
- Switch uses a *user-defined* number of *sample days* within each planning stage
  - Modeling whole days with chronological timesteps allows representation of intertemporal constraints on operation
  - Modeling fewer than 365 days allows optimization of multiple planning stages in a single model

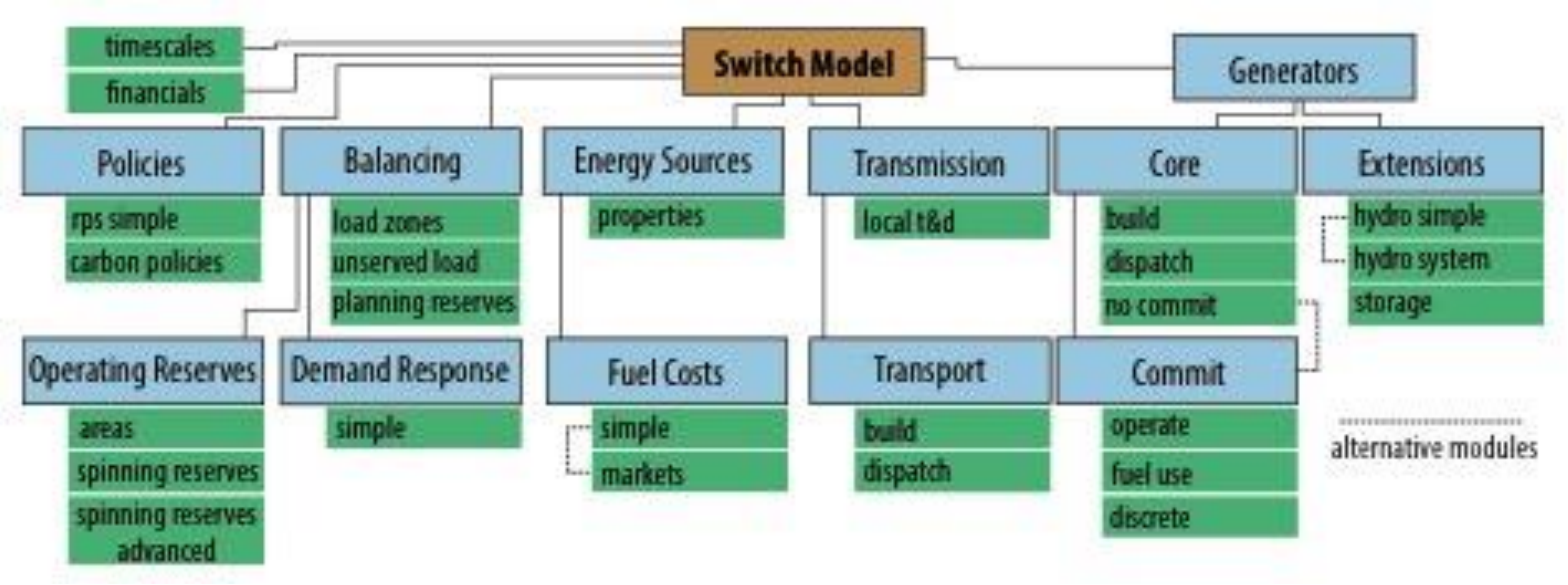
Switch Power System Planning Model

- Switch gives the “best of both worlds” between traditional capacity-expansion models and production cost models
  - Automated and consistent portfolio design
  - Ability to study the effects of storage, demand response, curtailment and renewable-driven changes to peak demand
- Switch 1.0 was introduced in 2008
- Switch 2.0 is now available; adds unit commitment, spinning reserves and numerous technology models
- Switch is open-source software, available at http://www.switch-model.org

SWITCH Model Design

- **Decision Variables (co-optimized)**
  - **Investments in each planning period**: How much capacity to add in each potential project
    - Potential projects include wind and solar farms, rooftop PV, fossil-fueled and hydro power plants, battery and hydrogen storage and transmission capacity
  - **Operation each hour:** power and reserves supplied by each project, transfer via transmission, consumption by flexible demand, fuel consumption
    - In capacity planning mode, 12-24 days of hourly behavior are typically modeled during each period, using synchronized profiles for wind, solar and load
    - Production-cost mode is used to evaluate and refine plans using 8760+ hours
- **Objective**
  - minimize NPV of costs (capital recovery, fuel, O&M, emission taxes)
- **Constraints**
  - physical limits of equipment and project sites
  - provide enough electricity and reserves every hour
  - policy constraints (RPS, CO_2, other emissions)

SWITCH 2.0 Modular Design

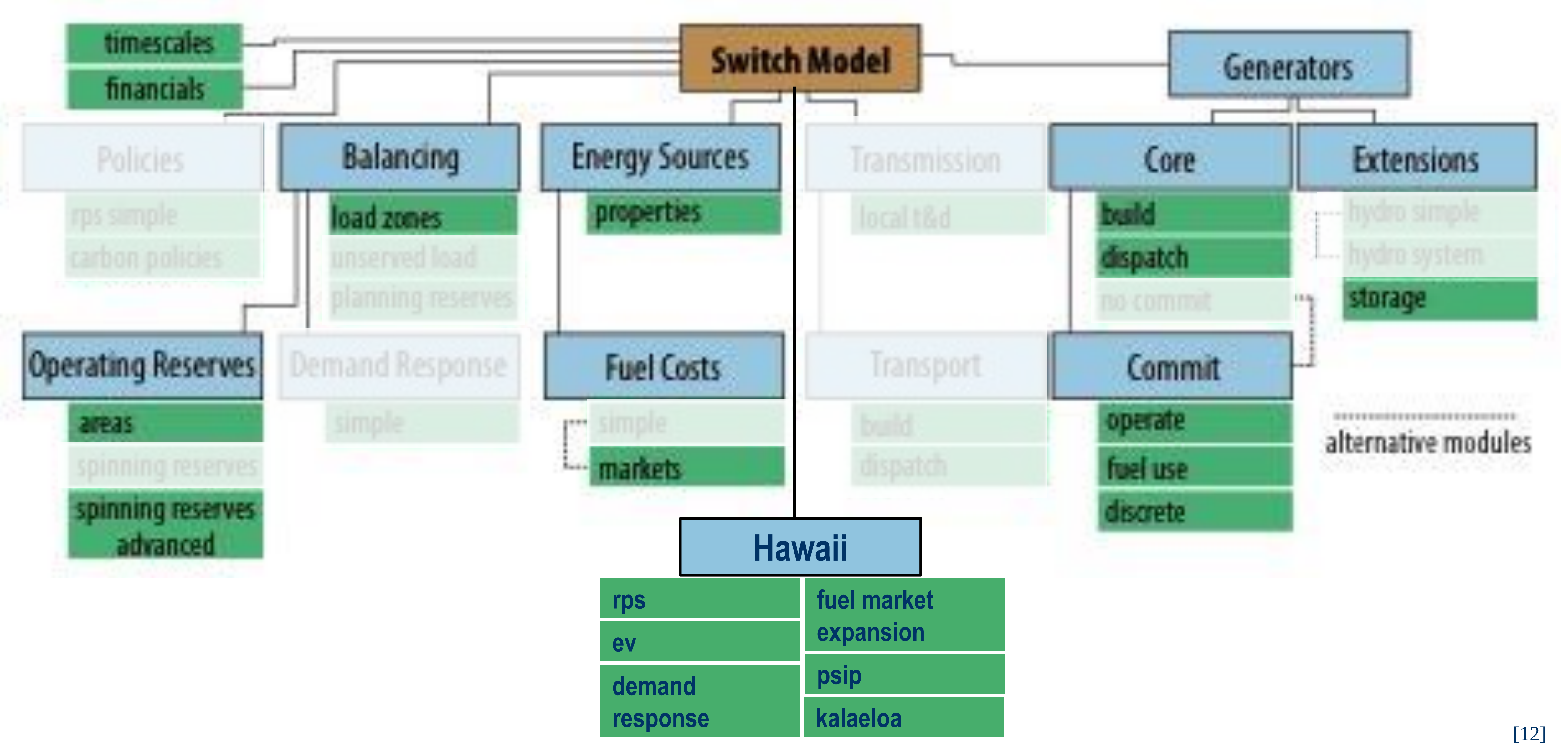


Core modules: timescales, financials, generators.core, energy sources, balancing.load_zones, fuel costs.

All others are optional. Dotted lines represent either-or alternatives.

CASE STUDY: reserves from load-shifting batteries and demand response

Modules Used for Reserve Case Study



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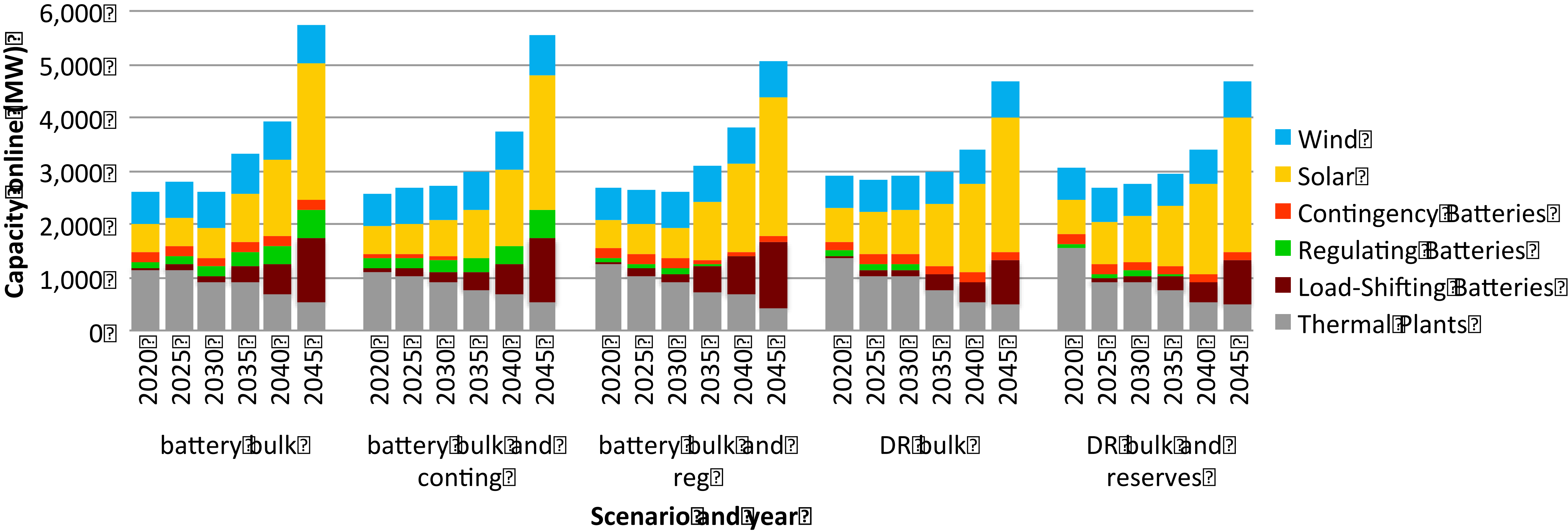
Scenarios for Batteries and DR Study

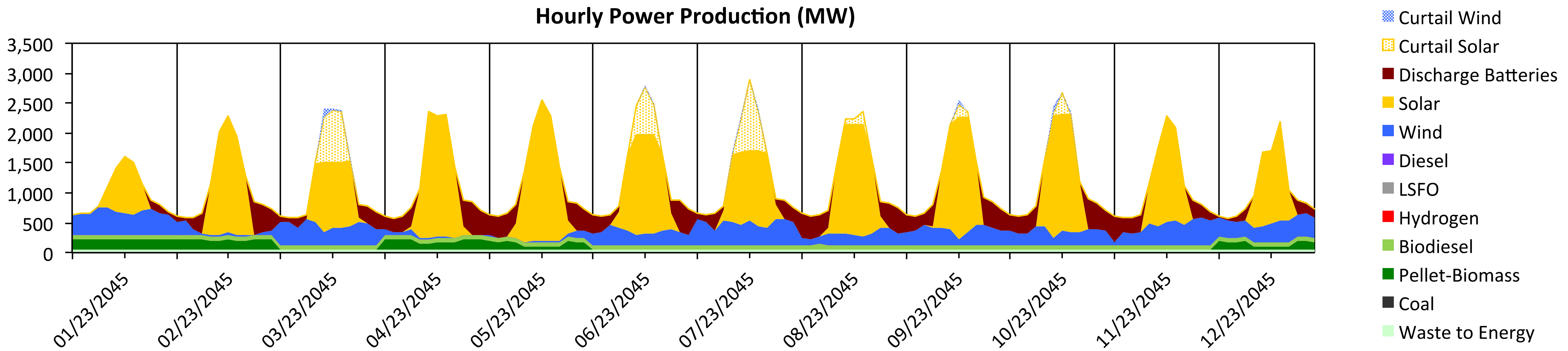
- **battery bulk**
  - load-shifting batteries only provide bulk inter-hour load-shifting, not reserves
  - no demand response (DR)
  - electric vehicles (EVs) charge at business-as-usual times
- **battery bulk and conting**
  - same as "battery bulk", but load-shifting batteries can also provide contingency reserves
- **battery bulk and reg**
  - same as battery bulk and conting, but load-shifting batteries can also provide regulating reserves
- **DR bulk**
  - same as "battery bulk and reg" plus
    - DR can provide bulk load-shifting (up to 10% of demand can be moved from each hour to any other hour, provided it doesn't raise demand by more than 80% in any hour),
    - EVs charge at optimal times each day
- **DR bulk and reg**
  - same as "DR bulk", plus DR and EVs can provide up and down contingency and regulation reserves (subject to minimum and maximum allowed loads)

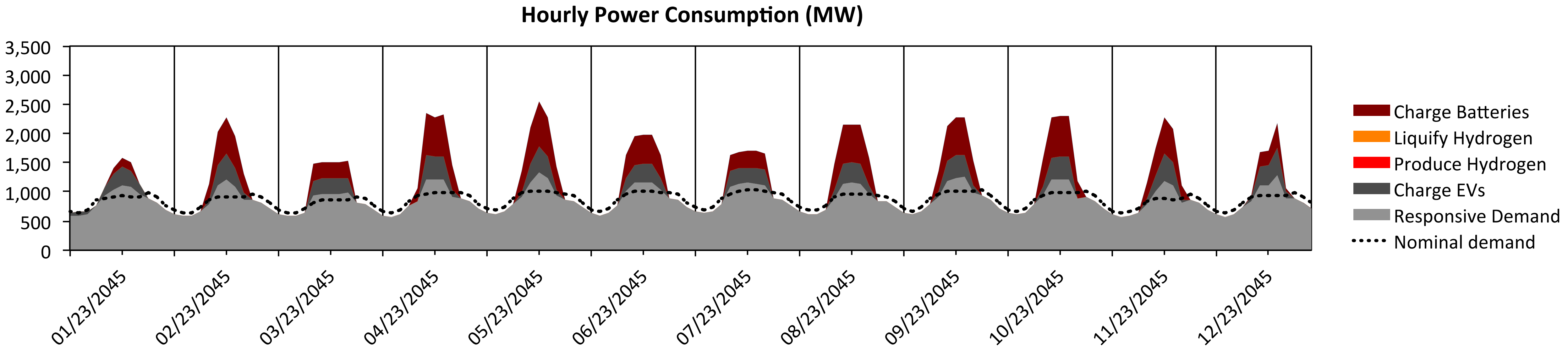
Case Study Results



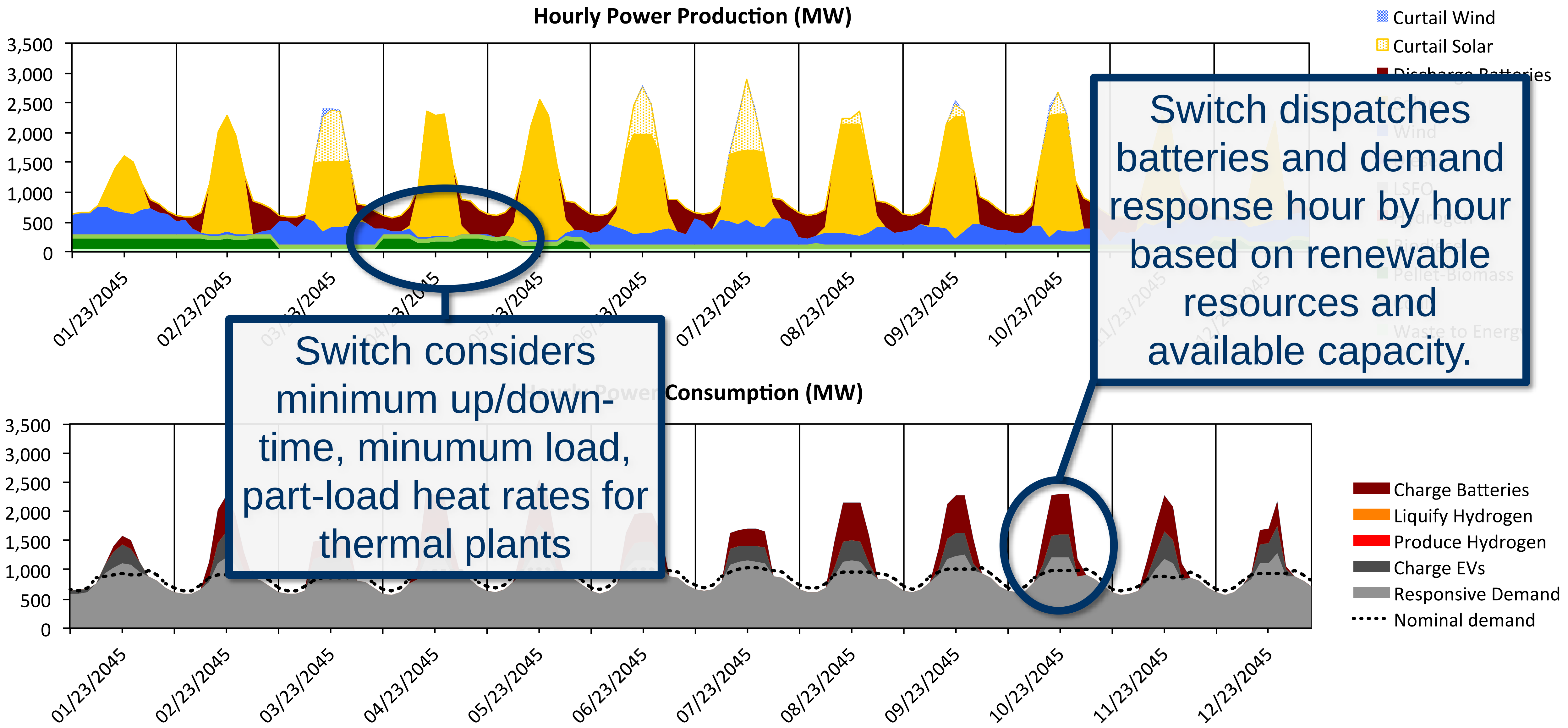
Savings per customer, vs. "battery bulk" (NPV over 2020–45)				
battery bulk	battery bulk & conting	battery bulk & reg	DR bulk	DR bulk & reg
–	$62	$413	$2,173	$2,255

Energy Balance – "DR bulk"

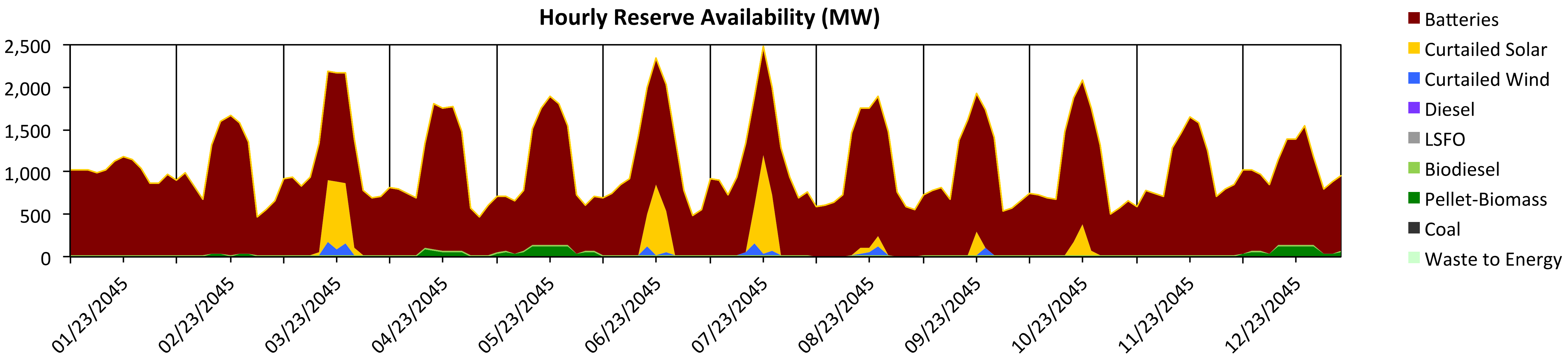


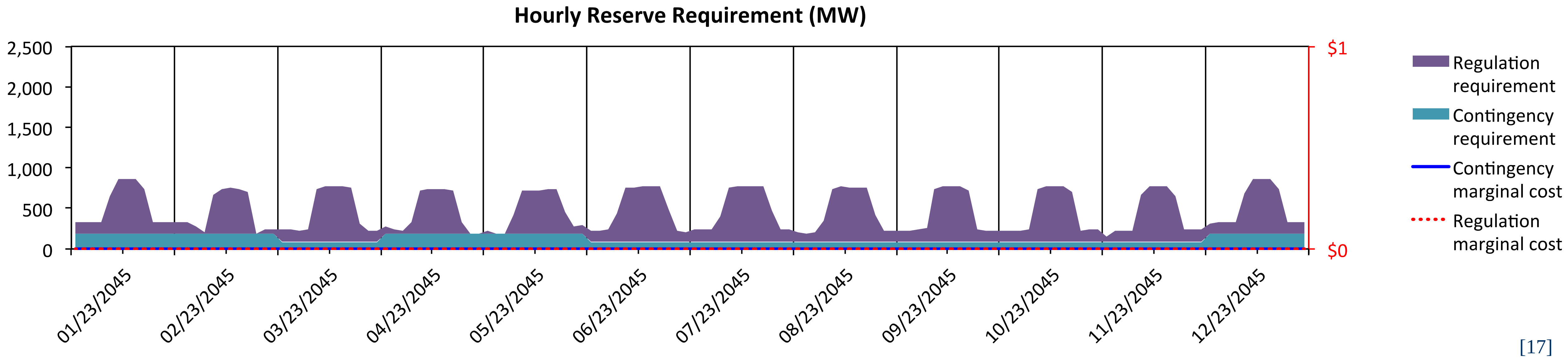


Energy Balance – "DR bulk"

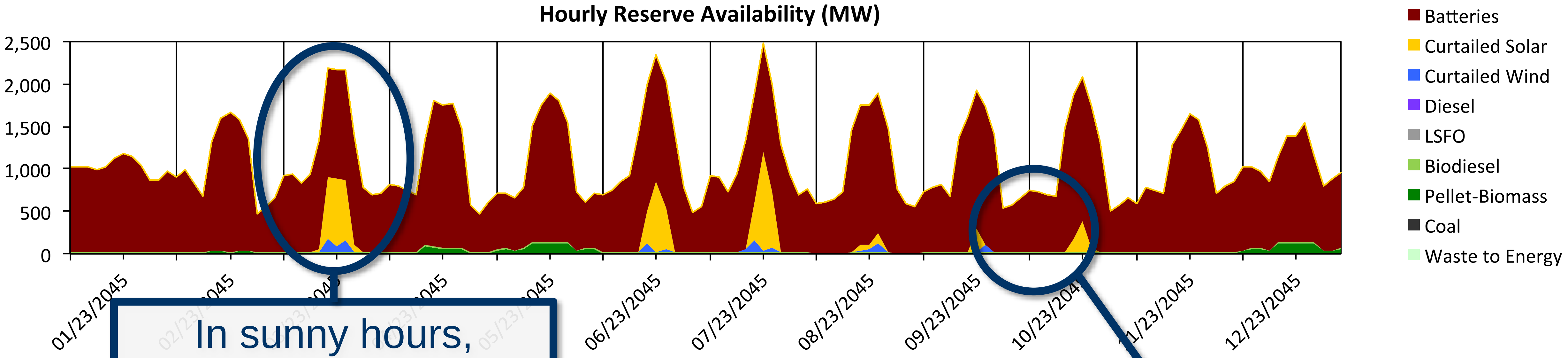


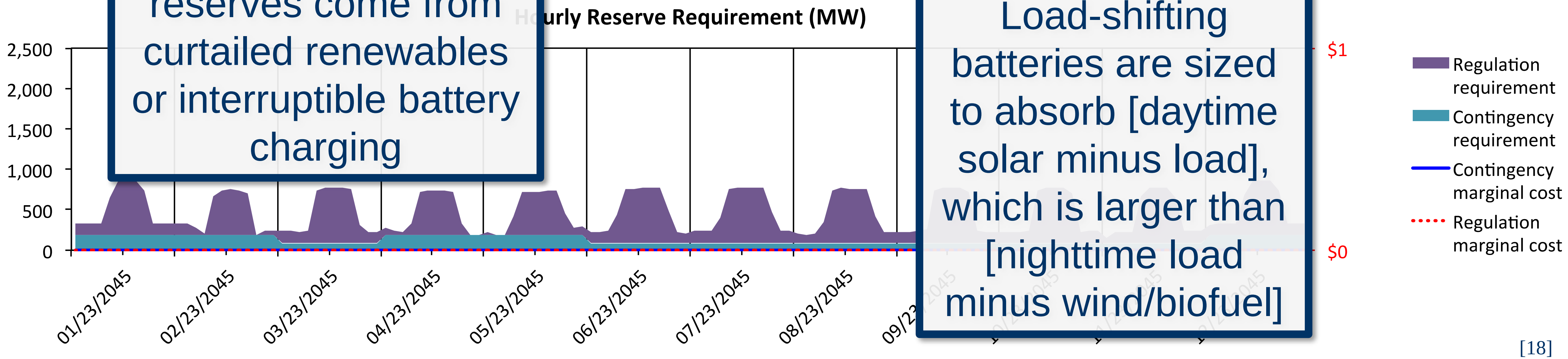
Reserve Balance – “DR bulk”





Reserve Balance – "DR bulk"





In sunny hours, reserves come from curtailed renewables or interruptible battery charging

Load-shifting batteries are sized to absorb [daytime solar minus load], which is larger than [nighttime load minus wind/biofuel]

Conclusions

- **Switch** provides a new option for capacity planning, with enough temporal detail to directly model unit commitment, storage and demand response
- **Switch** is modular, open-source software that can be customized for a wide variety of studies
- In this case study, **Switch** was used to evaluate various options for obtaining load-shifting and reserves in a 100% renewable system
  - it will be helpful to obtain reserves from load-shifting batteries
  - it will be helpful to obtain load-shifting services from demand response
  - it may not be important to obtain reserves from demand response, since there will be enough load-shifting batteries to provide down reserves at most times
- Other features (not shown):
  - 8760-hour production-cost mode, iterative solutions with any demand system, robust solutions across multiple scenarios, security-constrained unit commitment (experimental), higher resolution via parallel solutions (future)