Modeling and Valuation of Pumped Storage Hydropower Resources

FERC Technical Conference

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Pumped Storage Hydro Power Resources

- By far the largest storage resource in the current electric grid
  - Fast Ramping Capability
  - Energy and AS provision
  - Help in both shortage and surplus conditions (pumping and generation)
- Traditional Design not as flexible
  - Discrete operating range: block loaded especially in pumping mode
    - Need commitment decisions
    - Can have big impact on congestion
  - Historically there has not been a need for optimization because of predictable charge/discharge times

State of the Art

» PSH presently participates in majority of ISO products

- Offer as separate pump/generator participants
- **PJM** – Hydro optimizer, optimizes mode of operation to minimize cost and ensure SOC targets

» FERC Order 841: ISO/ RTO design proposals implementation details

Order 841 Aspect	NYISO	PJM	SPP	ISO-NE	MISO	CAISO
Participation Model	1. Most entities have proposed two separate participation models: Continuous (e.g., batteries) and discontinuous (e.g., PSH) models **Rationale**: ESRs are continuously dispatchable; PSH resources have forbidden operating regions that need to be accounted for appropriately 2. ESRs can participate in energy, AS, and capacity markets (wherever applicable) **Rationale**: Requirement from FERC Order 841					
	ESRs and **ELRs**; PSH cannot submit a charge and discharge offer in the same hour	**ESRs;** PSH plants can still use **pumped hydro optimizer**	**MSRs**; PSH plants cannot submit a charge and discharge offer in the same hour	**CSFs and BSFs (for PSH)**	**ESRs (also supports PSH)**	**NGRs and PSH model**

AS: Ancillary Service; **BSF**: Binary Storage Facility; **CSF**: Continuous Storage Facility; **ELR**: Energy Limited Resource; **ESF**: Energy Storage Facility; **ESR**: Electric Storage Resource; **MSR**: Market Storage Resource; **NGR**: Non-Generator Resource; **PSH**: Pumped Storage Hydro; **SOC**: State of Charge

Overall Project Objectives

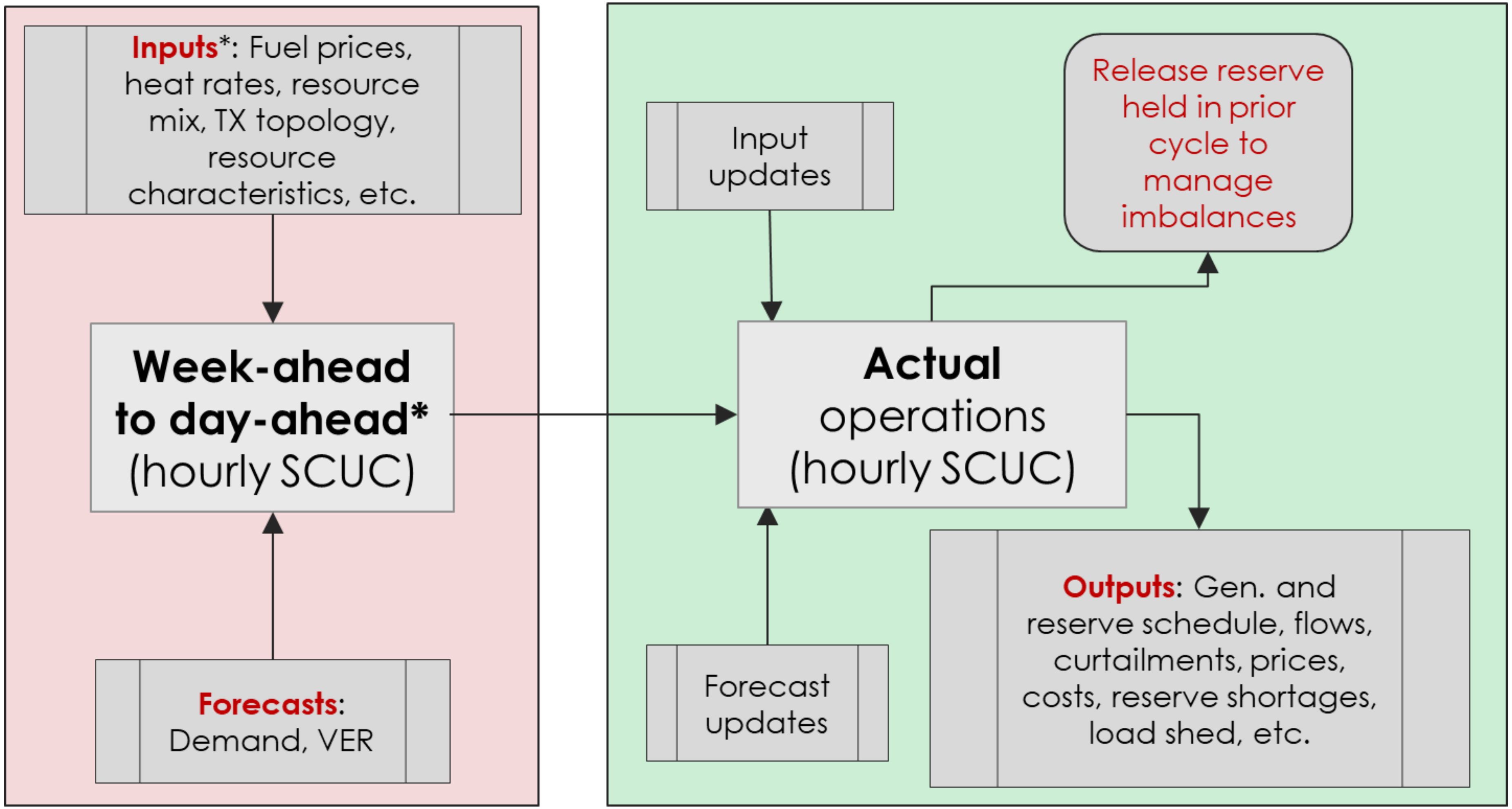
» Goal: Develop a framework and outline the parameters needed to analyze the energy and ancillary services pumped storage hydropower (PSH) provides to the electricity grid currently and how that value may change as the generation asset mix, especially as it relates to increased penetration of variable renewable energy (VRE), on the grid changes over time.

- Demonstrate current state-of-the-art in modeling of PSH operation
- Improve state-of-the-art modeling approaches to better capture value of provision of certain essential reliability services (e.g., ramping, regulation, etc.) coming from PSH
- Examine the value of different PSH technologies/configurations (e.g., traditional site-specific design, variable speed) and C rate (MWh/MW ratio) to better understand which technologies and storage durations may provide the most value
- Determine the optimal configuration of PSH technology (i.e., capabilities and C rate) that maximizes PSH economic and system resilience and reliability value given existing market structures at current and anticipated future VRE penetrations

Attain a Deeper Understanding of the Value of PSH

Modeling Approach

Southeast Utility Operations



The model is set up as illustrated in the figure, with a week-ahead run that is updated daily and simulated for every morning using updated information. Hourly 'actuals' will then be used for wind, solar, and load in the real-time run to ensure the impact of uncertainty is adequately captured in the model.

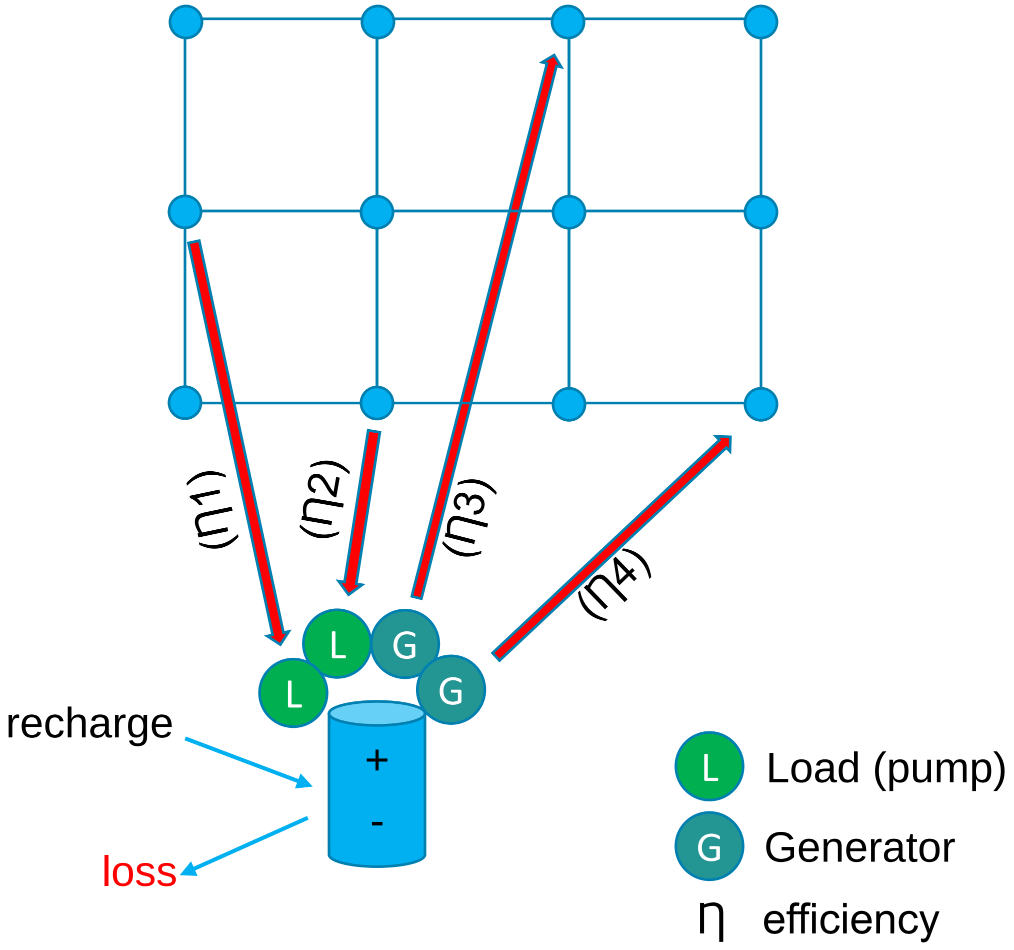
*DASCUC is run at 7AM on the current operating day due to less stressed conditions from midnight – 7am (ISOs/RTOs typically run their DAM at 11AM on the previous operating day or midnight), and run to end of 7 days out

PSH Facilities Modeling Approach in PSO

Power System Optimizer

Enhanced Model

(multiple injectors)



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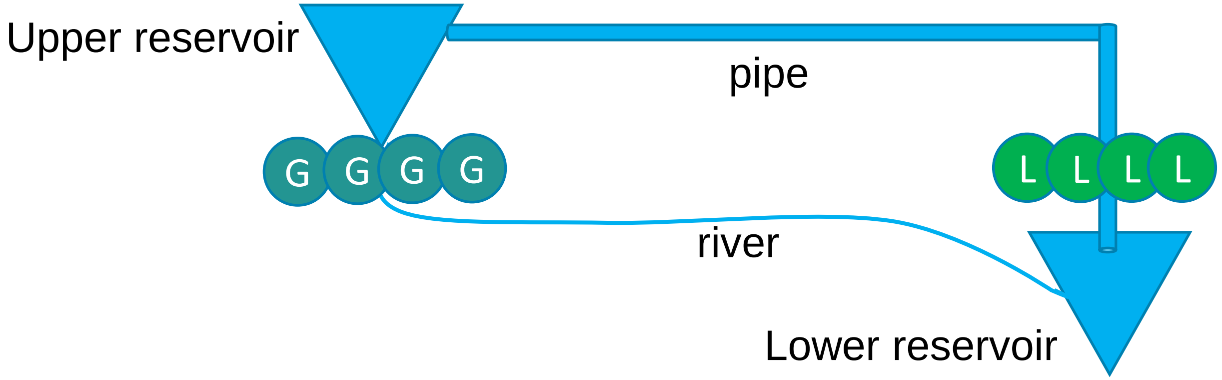
Southeast Utility: PSH Facilities Modeling Approach

PSH 1

- Upper reservoir: 25,000 MWh
- SSOC = TSOC = 12,500 MWh
- Roundtrip efficiency: 80%
- PSH 1 modeled as four pumps and four turbines (i.e., eight injectors in total)
  - Turbines: 250 – 350 MW
  - Pumps (block-loaded): Off (0 MW) and On (308 MW)
  - Pumps and turbines not allowed to operate simultaneously

PSH 2

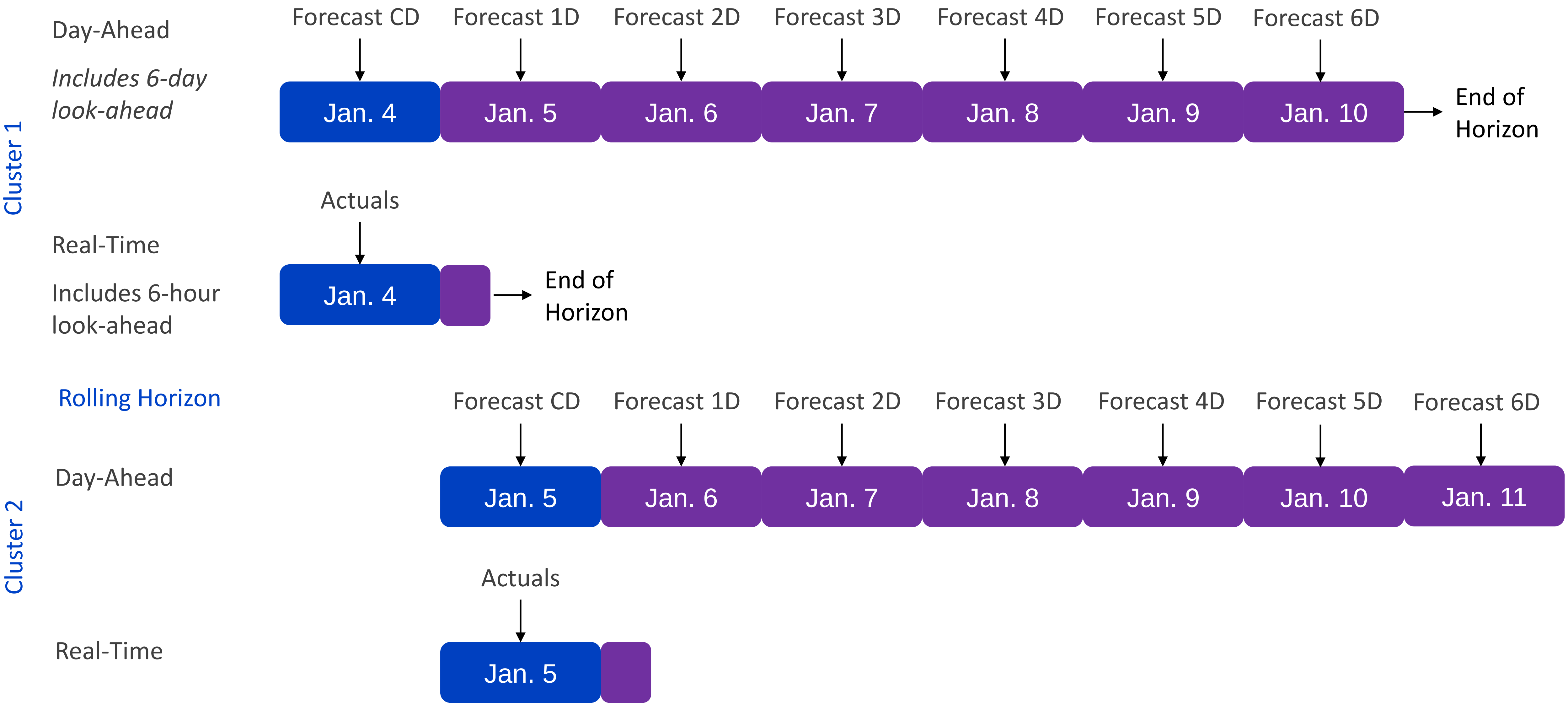
- Upper reservoir: 20,000 MWh
- SSOC = TSOC = 10,000 MWh
- Roundtrip efficiency: 80%
- PSH 2 modeled as four pumps and four turbines (i.e., eight injectors in total)
  - Turbines: 170 – 195 MW
  - Pumps (block-loaded): Off (0 MW) and On (205 MW)
  - Simultaneous pumping and generation allowed, but restricted to specific combinations of pumps and turbines



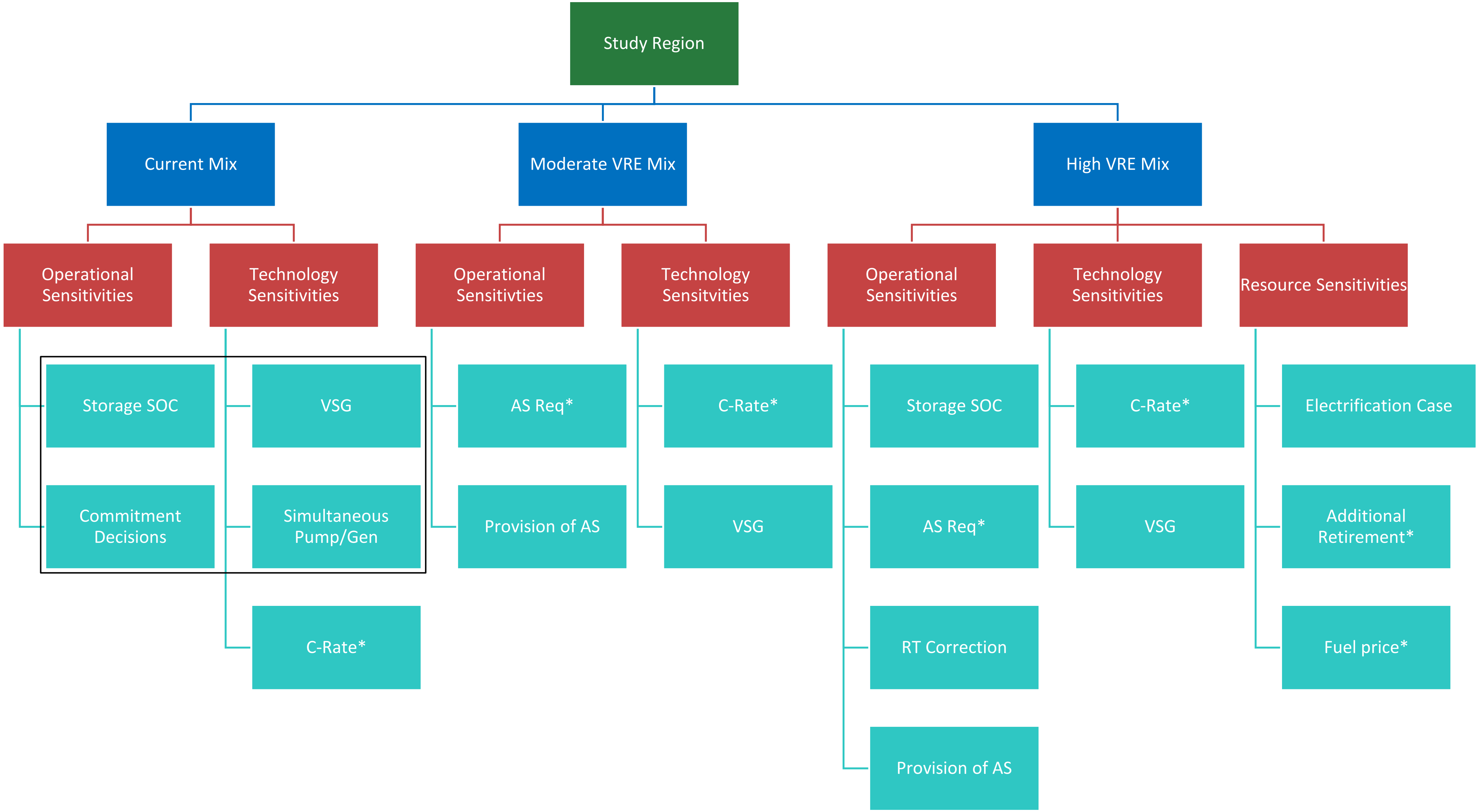
Initial storage levels in day-ahead were adjusted using the real-time cycle's (i.e., the last cycle's) results

Disclaimer: Assumed specifications in the model.
SSOC: Start State of Charge; **TSOC**: Target State of Charge;

Southeast Utility Operations: Scheduling Process



Proposed Case Studies

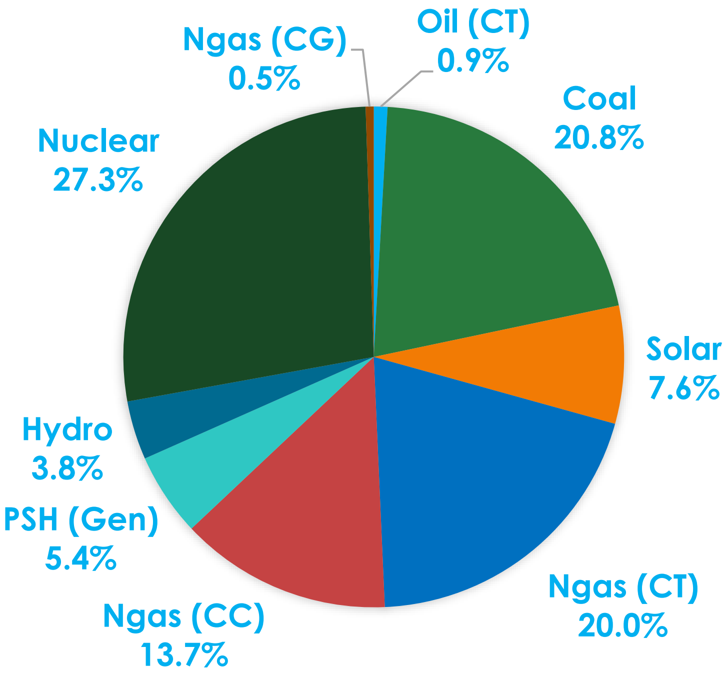


Modeling Results

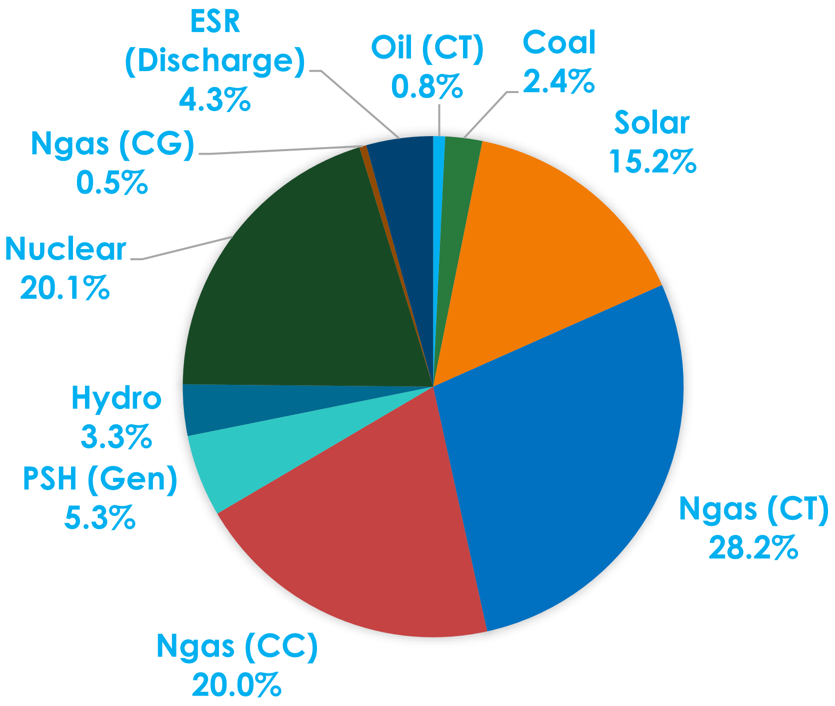
System Characteristics

	Current VRE Mix	Medium VRE Mix
Installed Capacity (GW)	40.6	46.5
Peak RT Load (GW)	33.1	37.8

CURRENT VRE MIX



MEDIUM VRE MIX



Modeling Results: Sensitivity Analysis (Current VRE Mix)

» **Five Sensitivity Analysis Cases**

- **Case 1: Base Case**
  - Nomogram constraints to prevent simultaneous gen. and pumping
  - Limited Dispatchability Range
  - Adjustment of DA SOC based on latest RT information
  - PSH recommitment in RT
- **Case 2: No PSH nomogram constraint**
- **Case 3: Increased Dispatchability Range (50%)**
- **Case 4: No Adjustment of DA SOC**
- **Case 5: PSH Commitment fixed in DA**

Modeling Results: Sensitivity Analysis (Current VRE Mix)

Period of study: July 1st – 31st, 2019

Disclaimer: Assumed test case. Results may not reflect exact operations.

	Total RT Cost ($MM)	% Cost Change
Case 1: Base Case*	249.7	-
Case 2: Simultaneous gen/pump allowed	249.6	-0.06%
Case 3: Variable Speed Technology (50%)	248.8	-0.36%
Case 4: No Adjustment of DA SOC	250.3	+0.21%
Case 5: PSH Commitment Fixed in DA	251.6	+0.73%

* Disallows Simultaneous gen/pump is not allowed, Fixed Speed Technology, Adjusts DA SOC based on RT telemetry, Allows PSH recommitment in RT

Modeling Results: Total Real-time Energy Cost

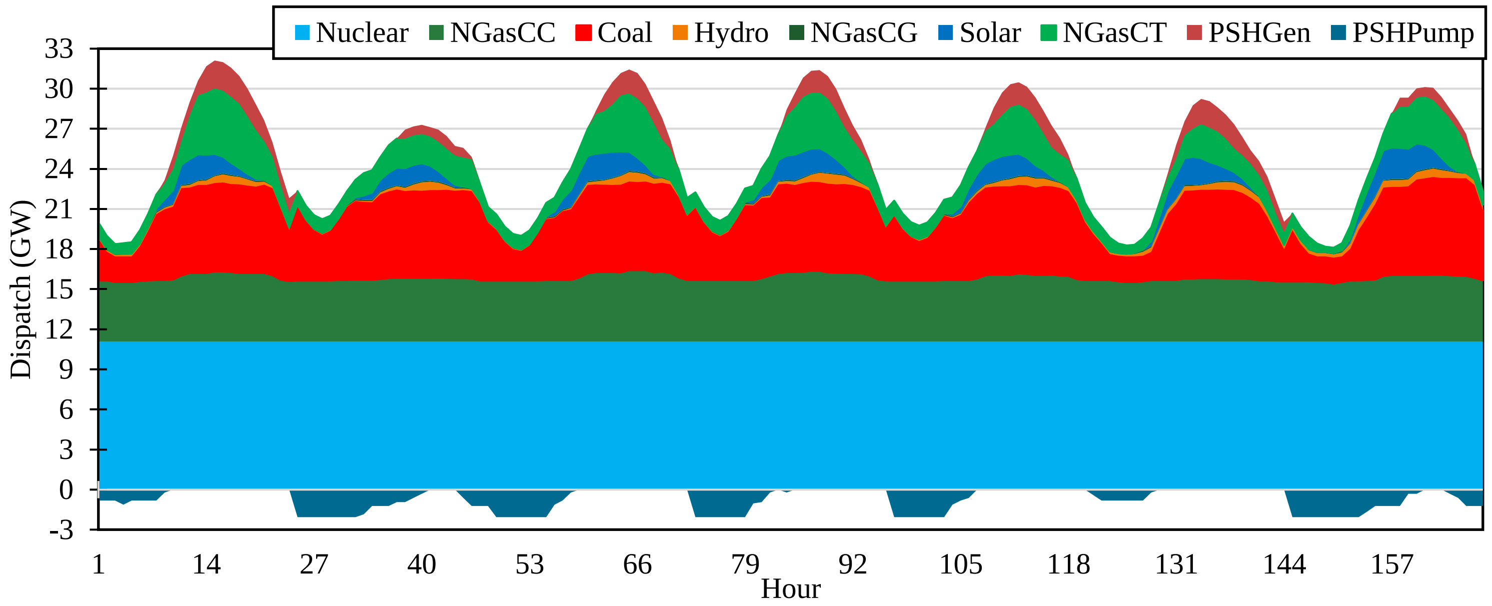
Period of study: July 1st – 31st, 2019

Disclaimer: Assumed test case. Results may not reflect exact operations.

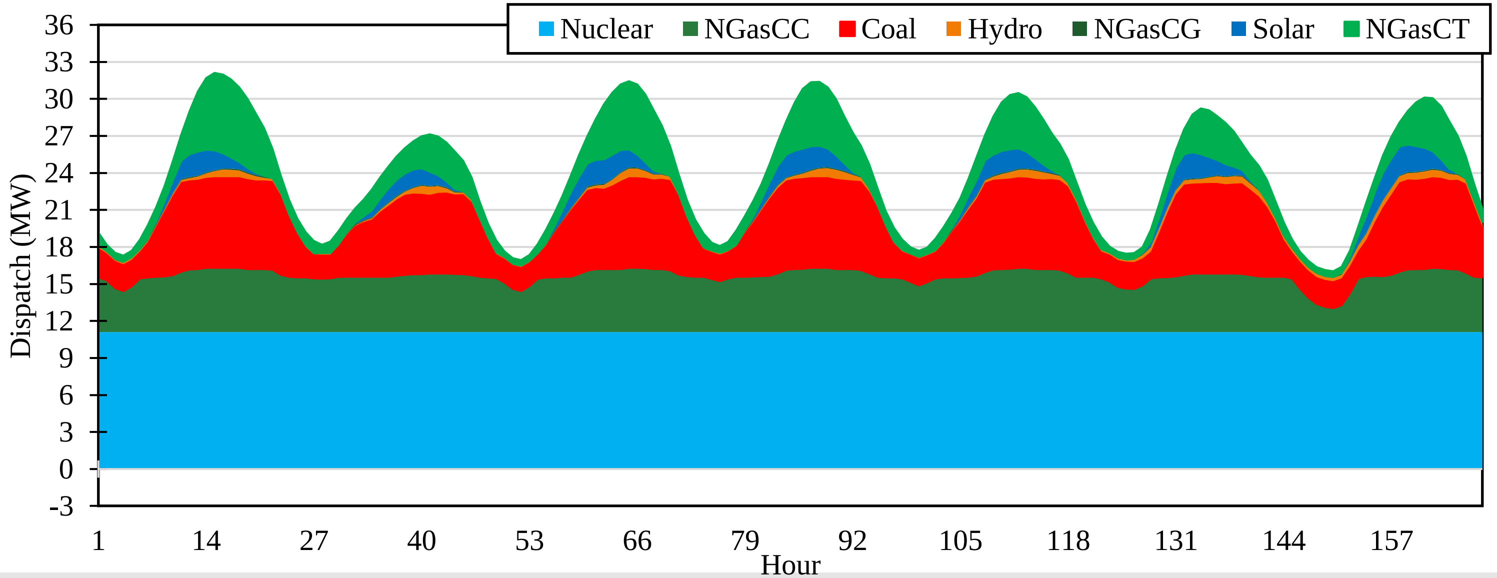
	Current VRE Mix		Medium VRE Mix	
	With PSH	Without PSH	With PSH	Without PSH
RT Cost ($MM)	249.7	256.5	205.6	228.8
% Cost Increase	-	2.7%	-	11.3%

PSH reduces the total energy production costs by 2.7% (11.3%) in current (medium) solar penetration scenarios

Generation Dispatch Profile in RT (Current VRE Mix)



w/ PSH



No PSH

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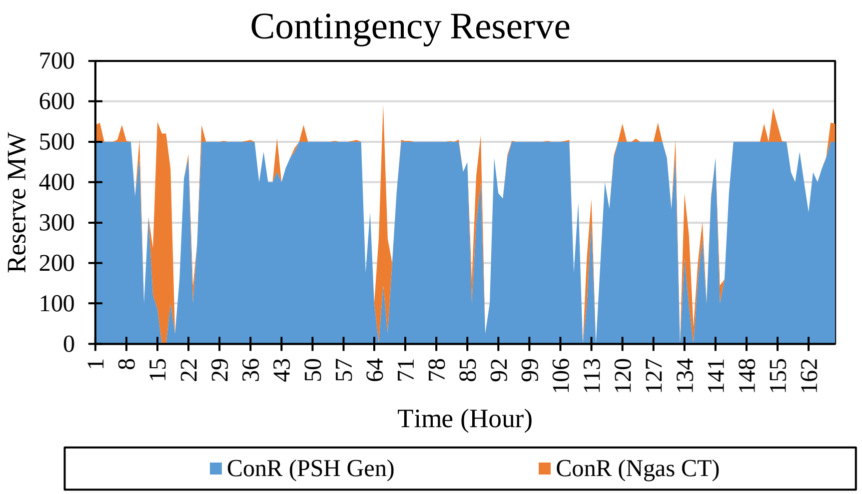
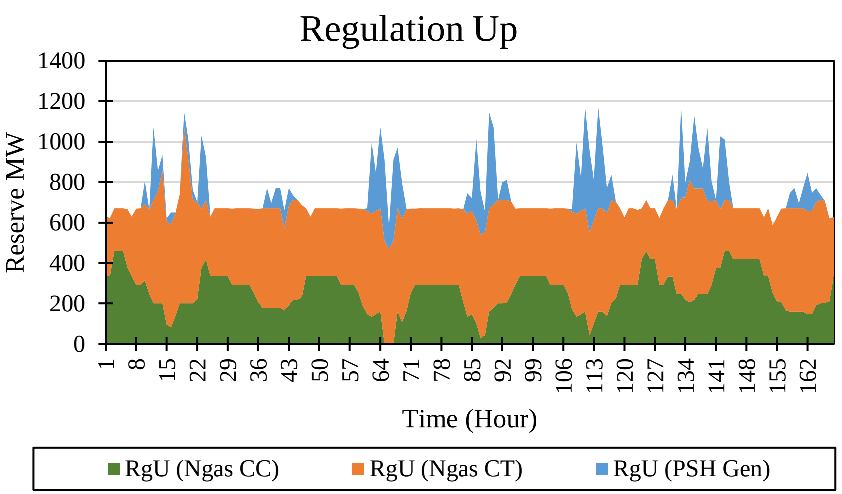
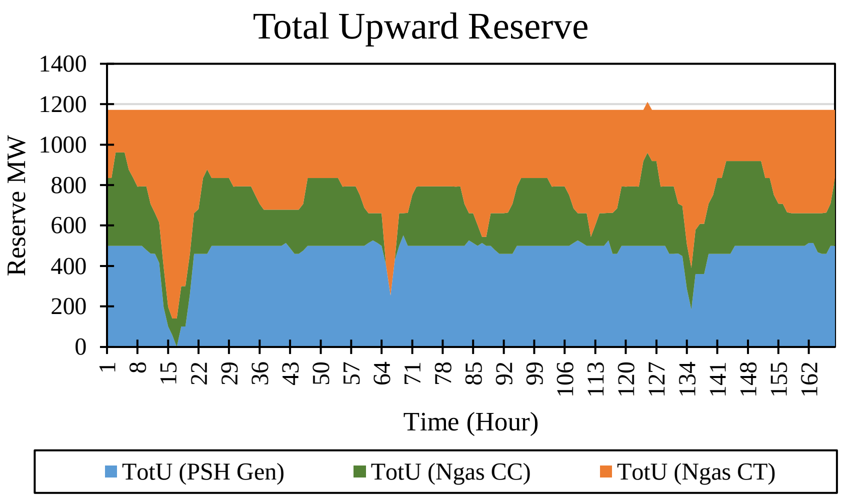
Cleared RT Reserve Profile (Current Penetration)







Cycling of Thermal Generators (Current VRE Mix)

» Increased cycling of Combined Cycle and Combustion Turbine generators in absence of PSH resources

Number of Startups per Technology Type

	Coal	Ngas (CC)	Ngas (CT)	Oil (CT)	PSH (Gen)	PSH (Pump)
w/ PSH	13	33	658	0	229	249
w/o PSH	18	42	1038	3	0	0

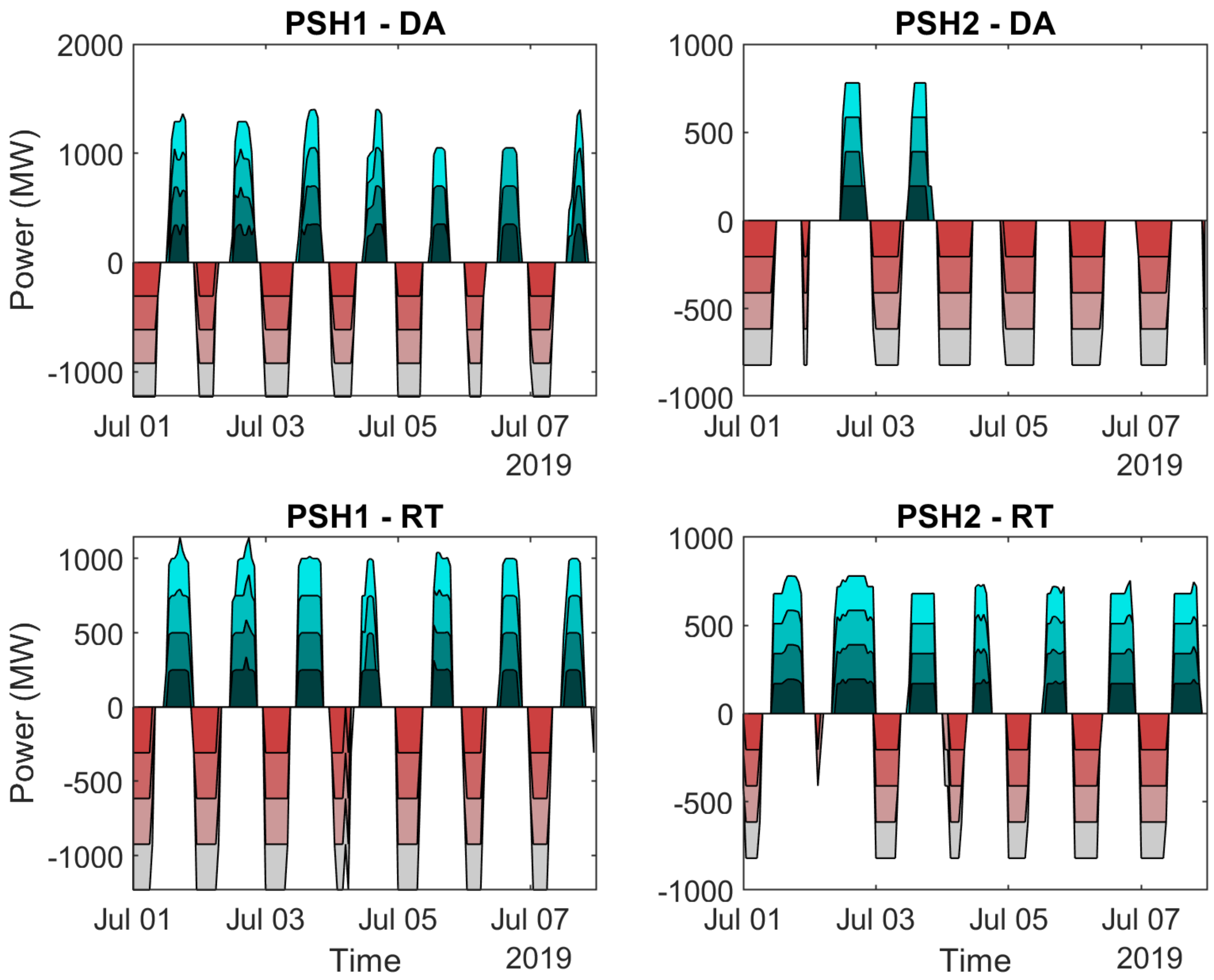
Startup Cost per Technology Type

	Coal	Ngas (CC)	Ngas (CT)	Oil (CT)	PSH (Gen)	PSH (Pump)	Total
w/ PSH	0.46	0.36	2.49	0.00	0.34	0.00	3.64
w/o PSH	0.51	0.46	3.75	0.09	0.00	0.00	4.81

Modeling Results: DA and RT PSH Schedule (Current VRE Mix)

PSH1:

- Reservoir: 25,000 MWh
- Roundtrip efficiency: 80%
- Four pumps and four generators
  - Generators: 250 – 350 MW
  - Pumps (block-loaded): Off (0 MW) and On (308 MW)
  - Pumps and turbines not allowed to operate simultaneously



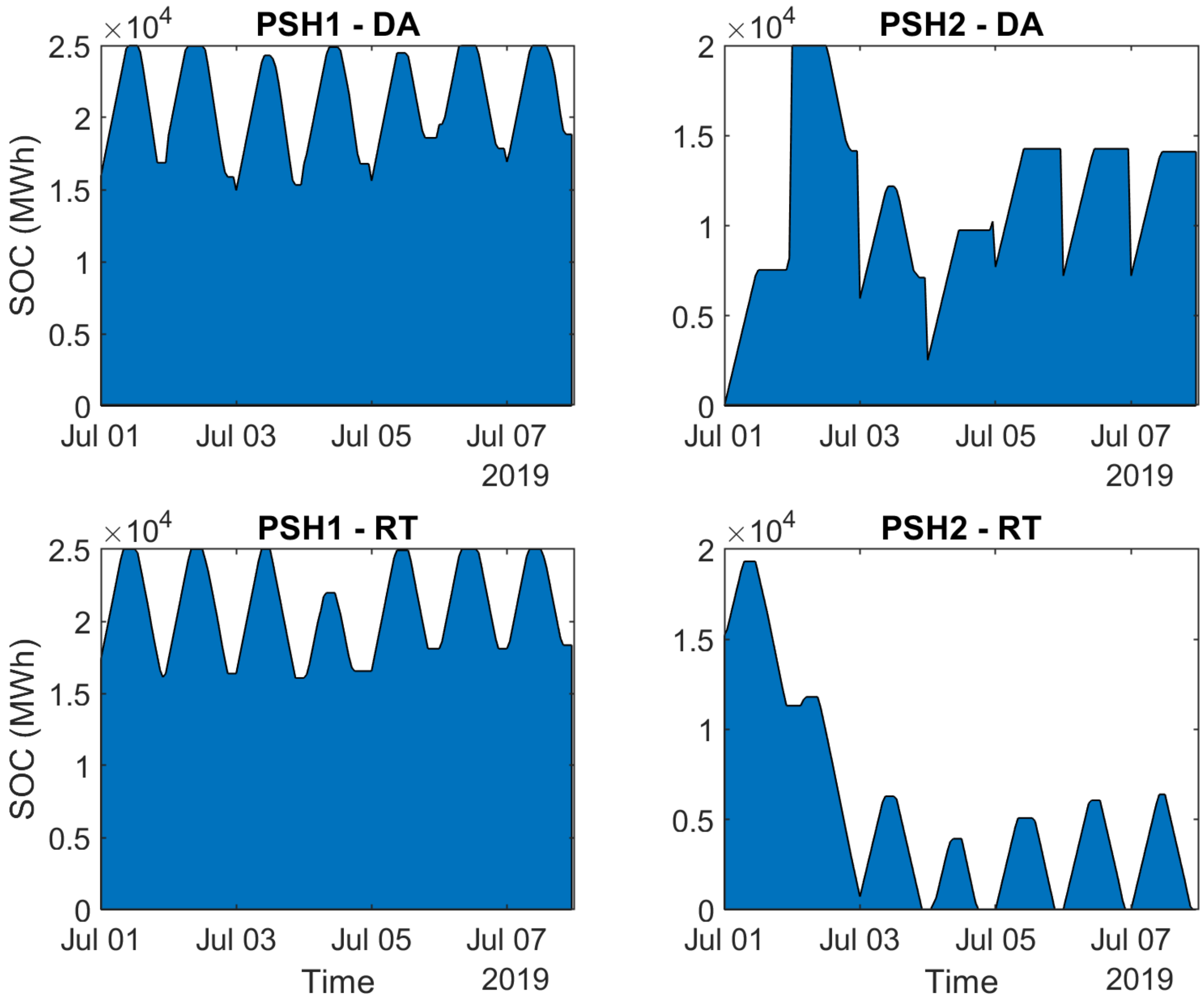
Period of study: July 1st – 31st, 2019

Disclaimer: Assumed test case. Results may not reflect exact operations.

PSH2:

- Reservoir: 20,000 MWh
- Roundtrip efficiency: 80%
- Four pumps and four generators
  - Generators: 170 – 195 MW
  - Pumps (block-loaded): Off (0 MW) and On (205 MW)
  - Under certain combinations, simultaneous Pump and generation is allowed

Modeling Results: DA and RT PSH SOC (Current VRE Mix)



Period of study: July 1st – 31st, 2019

Disclaimer: Assumed test case. Results may not reflect exact operations.

Key Observations

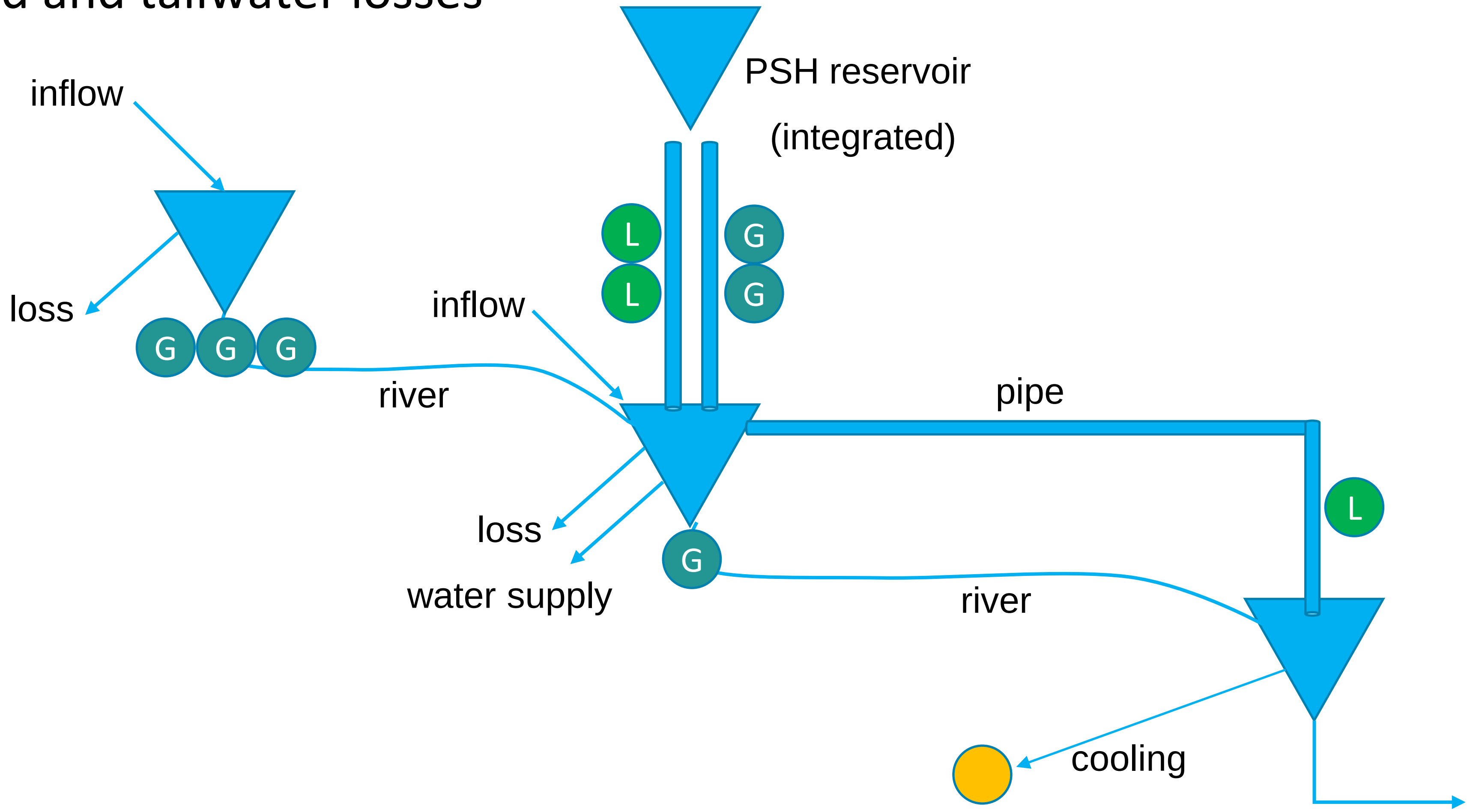
- Total energy production costs increase in absence of PSH resources (by ~2.7% in current penetration, and 11.3% in future medium penetration)
- PSH reduces cycling of thermal generators (CCs and CTs)
- PSH contributes considerably to RT contingency reserve, and regulation up and down reserves
- Allowing simultaneous generation and pumping may not result in considerable cost savings for an uncongested system
- Block loading has an increased likelihood of resulting in increased operating cost
- Variable Speed Technology enhances flexible operation
- There is a need to better understand how adjusting the initial SOC in the DA based on latest RT info can impact the market solution
  - Example: ERCOT

Other Considerations: management of water quantities

» Cascading systems with time requirements for flow between reservoirs

» Constraints on river flows

» Impact of reservoir head and tailwater losses



Together…Shaping the Future of Electricity

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Order 841: State of Charge Management

» Required ISO to allow self-management of SOC by ESR

» Required “consideration” of SOC related parameters through bidding, telemetry, or otherwise (e.g., SOC limits, round-trip efficiency)

[1] *Electric Storage Participation in Markets Operated by Regional Transmission Organizations and Independent System Operators, FERC Order 841, Final Rule, 162 FERC 61, 127 (February 15, 2018) (“Order No. 841”).*

ISO/RTO Design Proposals: Implementation Details

Order 841 Aspect	NYISO	PJM	SPP	ISO-NE	MISO	CAISO
State of Charge Management	1. Only a few ISOs are offering <u>both</u> **ISO-SOCM** and **Self-SOCM**. Other ISOs are offering a hybrid **SOCM-Lite** option. 2. **ISO-SOCM**: SOC is a <u>variable</u> in multi-interval optimization and the ISO ensures SOC feasibility. **SOCM-Lite**: SOC is a <u>parameter</u> in sequential optimization and the ISO ensures SOC feasibility. **Rationale**: Requirements from FERC Order 841; SOCM option is also impacted by the market clearing software design					
	ISO-SOCM (excludes desired ending SOC level) and **Self-SOCM** (does not ensure SOC feasibility, but ISO will align schedules with telemetered SOC in the RTM); NYISO can suspend ISO-SOCM and default to Self-SOCM; **PSH plants – Self-SOCM**; ESRs have the option to switch b/w SOCM modes within RTM, and b/w DAM and RTM	**ESRs – SOCM-Lite** (ensures SOC feasibility and accounts for SOC, and SOC limits in its sequential optimization); **PSH plants – ISO-SOCM**	**SOCM-Lite** (ensures SOC feasibility in sequential optimization); can submit max daily MWh limit	**SOCM-Lite** (includes two new telemetered points in RT, i.e., 15-minute and 1-hour available energy and available storage, to ensure SOC feasibility in sequential optimization); ESFs can submit max daily MWh charge and discharge limits in the DAM. No SOC-specific parameters in DAM.	**SOCM-Lite** (ensures SOC feasibility in sequential optimization); max daily MWh limit included only for PSH plants	**ISO-SOCM** (excludes desired ending SOC level) and **Self-SOCM** (does not ensure SOC feasibility); can submit daily min and max energy limits for DAM

AS: Ancillary Service; **BSF**: Binary Storage Facility; **CSF**: Continuous Storage Facility; **DAM**: Day-ahead Market; **DR**: Demand Response; **ESF**: Energy Storage Facility; **ESR**: Electric Storage Resource; **MSR**: Market Storage Resource; **NGR**: Non-Generator Resource; **POI**: Point of Interconnection; **PSH**: Pumped Storage Hydro; **RTM**: Real-time Market; **SOC**: State of Charge; **SOCM**: SOC Management

State of Charge Management: Options

Self-Schedule

- ESR self-dispatches its output and is insensitive to price.

Allowed by all ISOs/RTOs

Self-SOC-Management

- ESR provides an offer curve analogous to traditional resources.
- ESRs can set offers to ensure desired and feasible SOC.
- ISO schedules without SOC consideration

CAISO, NYISO ESRs, NYISO PSH units

SOC-Management-Lite

- ESR provides an offer curve.
- ISO does not schedule ESR if it would lead to infeasible SOC.
- Schedules are not optimized across time to optimize ESR schedules.

SPP, ISO-NE, MISO, PJM

ISO-SOC-Management

- ESR may or may not provide an offer curve.
- ISO ensures SOC feasibility and optimizes ESR schedules across time to minimize cost.

CAISO, NYISO ESRs, PJM PSH units

→ ISO Scheduling Responsibility / Theoretical Economic Efficiency and Reliability Benefits / Complexity

← ESR Asset Owner Participation Responsibility and Flexibility / Computational Efficiency