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Overview of the Hydropower Value Study

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Abhishek Somani
Senior Economist

U.S. DEPARTMENT OF ENERGY BATTELLE

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Project Overview

- Motivating questions:
  - How does hydropower contribute to grid services?
  - What services/capabilities will be needed by the grid in the future?
  - Can hydropower provide the services based on technical capabilities and cost?
- Project intent:
  - Foundational work to understand present hydropower operations trends, future expected changes, and hydropower capabilities analysis
- Project design:
  - Involved extensive data collection and analysis on market participation trends, operational practices, and technological capabilities
  - Did <u>not</u> involve design of new market rules, hydro operations models/tools
- Outcomes:
  - Understanding of hydropower's evolving value proposition
  - Understanding of high-impact future research needs – research roadmap

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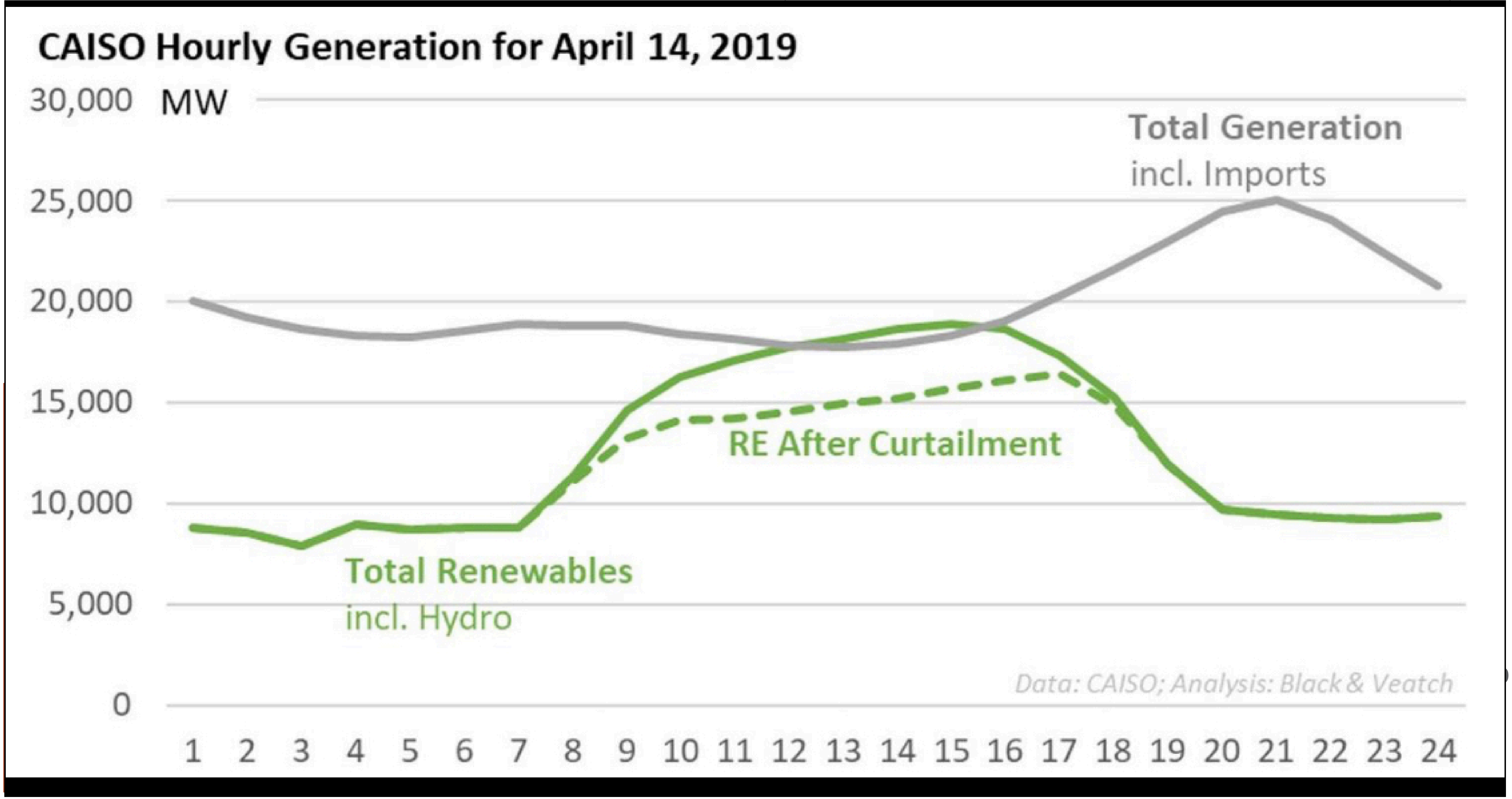
Project Tasks

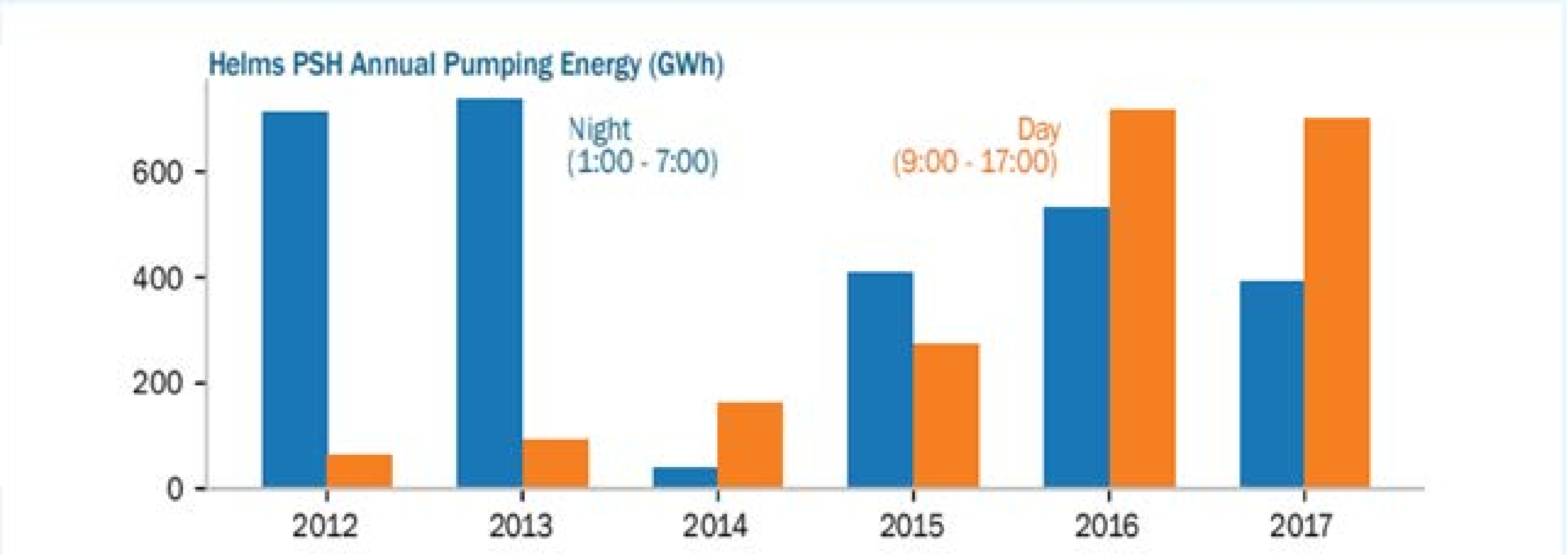
- Task 1 – Current landscape review
  - Market participation trends in different regions
  - Correlation analysis with other system variables, such renewables
  - Estimation of value from services not presently monetized, such as inertia and primary frequency response
  - Case studies on water management practices, and their impact on operations
- Task 2 – Future system needs & hydropower value
  - Future power system scenarios and resulting value drivers for hydropower
  - Hydropower value proposition in future based on system needs
- Task 3 – Hydropower capabilities & gap analysis
  - Comparison of current power system and hydro operations timelines
  - Develop understanding of plant/unit-level capabilities and constraints, based on various factors

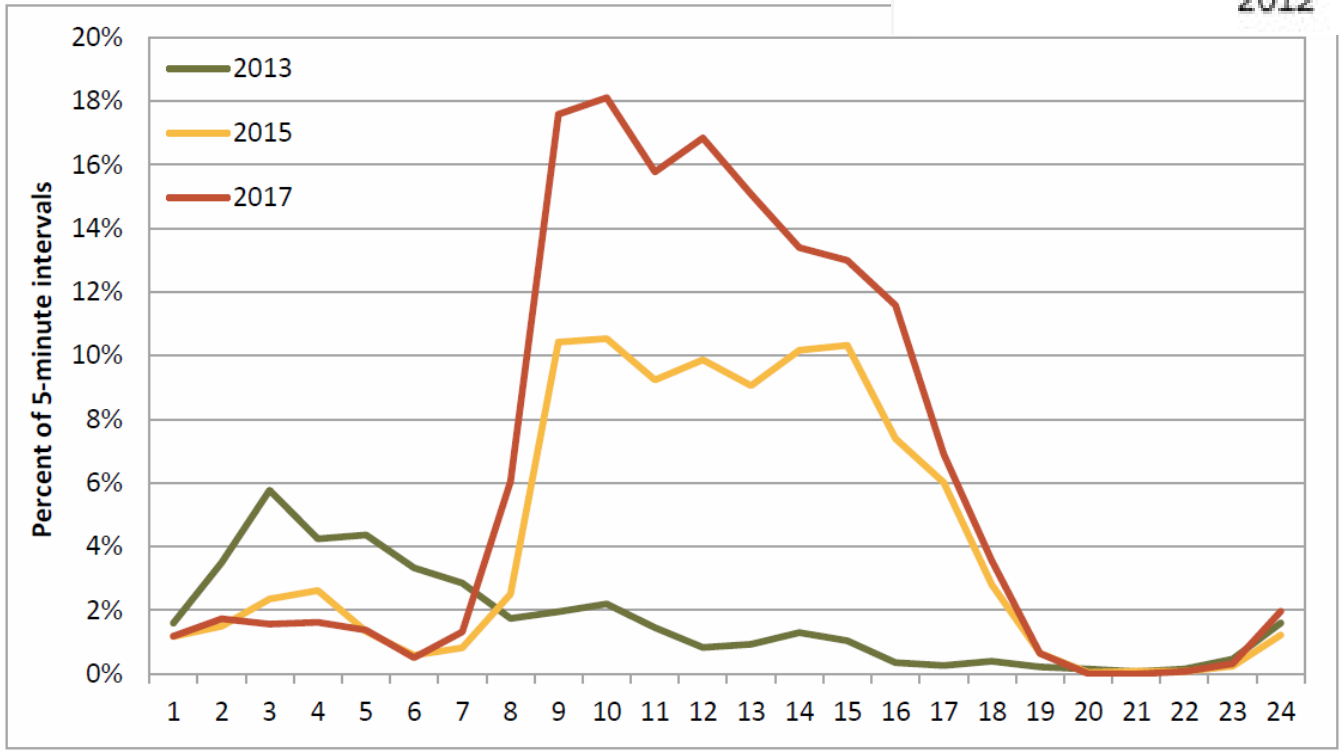
Changes on the Horizon: CAISO Net Load and Renewables Supply



Changing Operations of PSH due to Changing Grid Conditions – CAISO Example

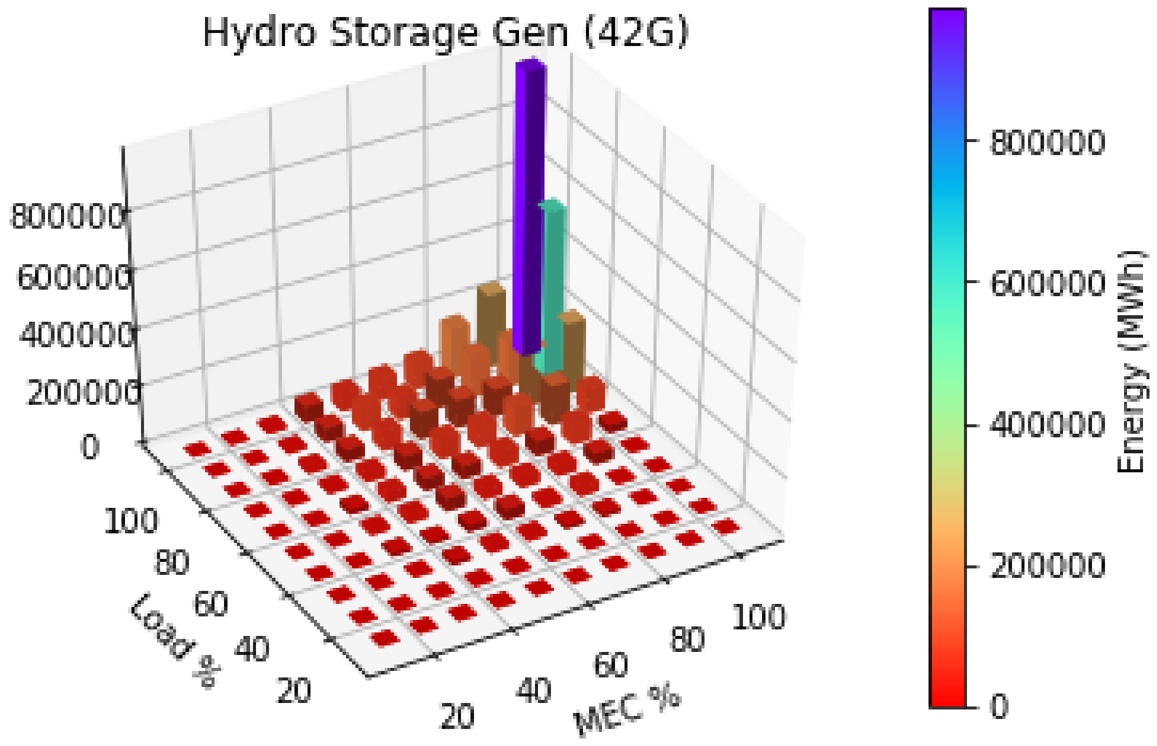
PSH conventionally operated in day-night arbitrage patterns, but the patterns are now changing, presumably to provide other grid services



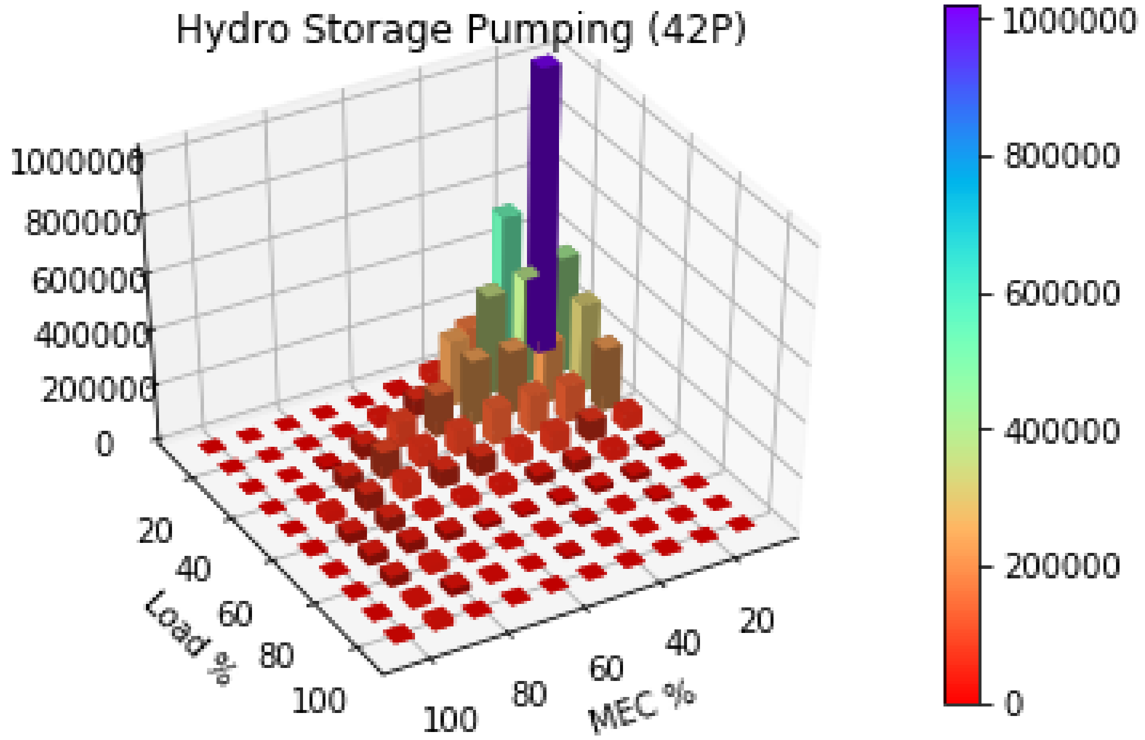


Are the increased day-time pumping operations at Helms plant due to increase in negative price during the day-time hours, corresponding to periods with high PV production?

PSH Operations in MISO are still based on Arbitrage due to Load Patterns (NOT Wind)



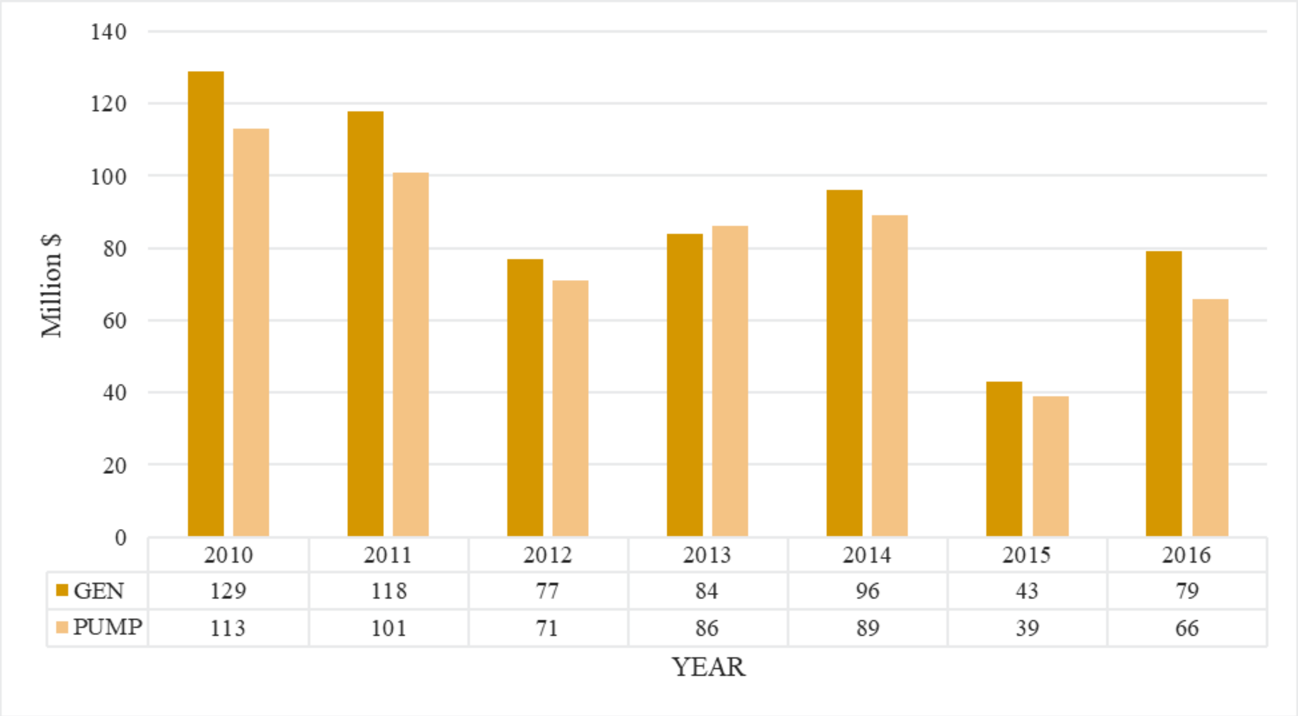
Generation: PSH plants generate most of the times during high price periods, as expected



Pumping: PSH plants operate in pumping most of the times during low price periods, as expected

Mid-Continent ISO Hydropower Revenue Trends for Different Grid Services

- A slight decline in revenues has been observed, which is consistent with declining energy prices
- Energy is still the primary source of overall revenue mix



		Average Daily Supply	Estimate of Total Revenue ($M)
Regulation	Pumped Hydro	255 MW	$2,4
	Conventional	241 MW	$1,6
Energy	Pumped Hydro	4,573 MWh	$129
	Conventional	20,086 MWh	$345

Hydropower Provides Flexible Resource Adequacy Capacity in CAISO

	Category 1 – Base Ramping	Category 2 – Peak Ramping	Category 3 – SuperPeak Ramping
Economic Bid – Must offer Obligation	5:00AM – 10:00PM	5 hour block 12 PM to 5 PM for May – September 3 PM- 8 PM for January- April and October-December	5 hour block 12 PM to 5 PM for May – September 3 PM- 8 PM for January- April and October-December
	Minimum 6hrs at Effective	Minimum 3hrs at Effective	Minimum 3hrs at Effective
Other limitations	No limitations that translate to less than the daily requirements	No limitations that translate to less than the daily requirements	Must be capable of responding to at least 5 dispatches per month
Examples of types of resources	Conventional gas fired resources, wind, hydro, storage with long discharge capabilities	Use-limited conventional gas fired generation, solar, conventional gas fired peaking resources	Short discharge battery resource providing regulation and demand response resources

Resource type	Category 1		Category 2		Category 3	
	Average MW	Total %	Average MW	Total %	Average MW	Total %
Gas-fired generators	8,890	76%	293	25%	3	3%
Use-limited gas units	1,665	14%	819	71%	61	72%
Hydro generators	1,099	9%	47	4%	6	7%
Geothermal	28	0.2%	0	-	0	-
Energy Storage	17	0.1%	1	0.1%	15	17.6%
Total	11,700	**100%**	1,160	**100%**	85	**100%**

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Compensation for Fast Frequency/Primary Frequency Response

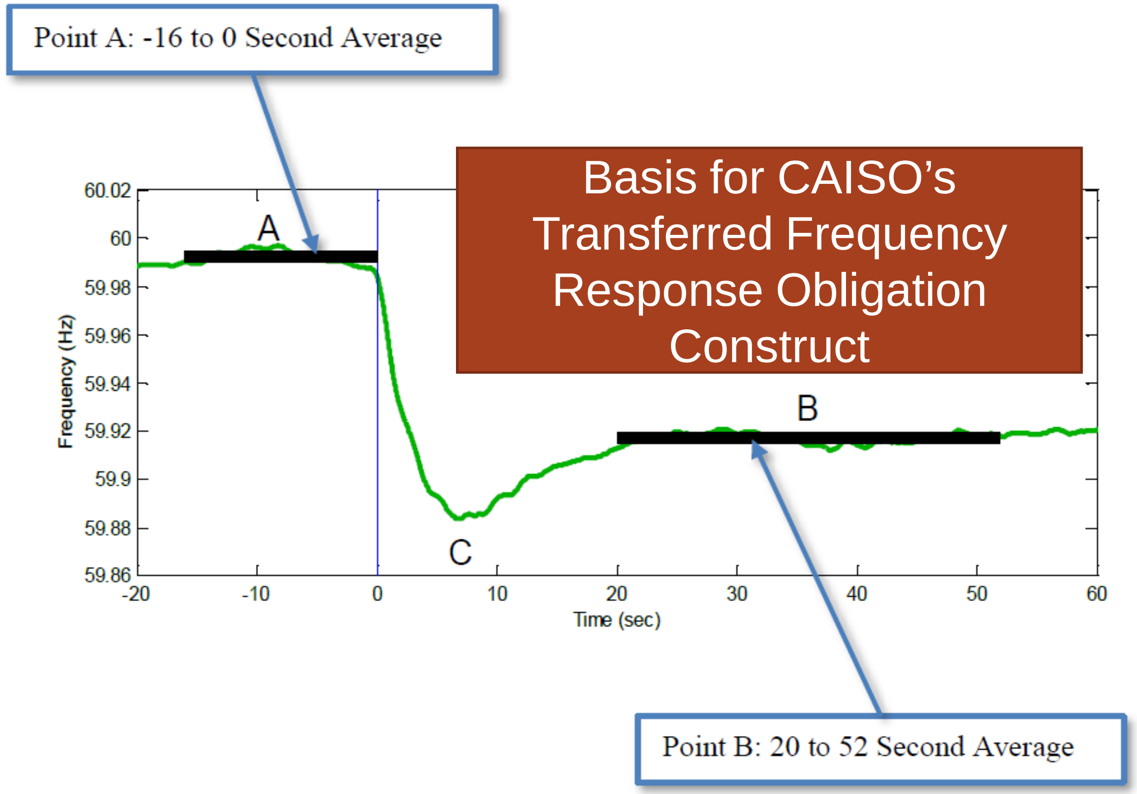
	Ireland	UK	Nordic	Quebec	South Australia	ERCOT
Monitor inertia & possible contingencies in Real-Time	✓	✓	✓	✓	✓	✓
Forecasts Inertia from DA into Real-Time	✓	✓				✓
Dynamic Assessment of Reserves based on inertia conditions and largest resource contingency		✓				✓
Limit RCC based on inertia conditions	✓	✓		✓	✓	
Synchronous Condensers (for inertia)	✓	✓			✓ (particularly looking at high inertia SCs)	
Enforce minimum inertia limit	✓	✓			✓ (for minimum inertia req.)	✓
Inertia market/auction/service inertia	✓				✓ (for above minimum inertia levels)	
Faster Responding Reserves	FFR	Enhanced Frequency Response Service		Synthetic inertia from wind	"Contingency" FFR (frequency trigger) and "Emergency" FFR (direct event detection)	Load Resources providing RRS

Planned mitigation measures are shown in blue, while already existing mitigation measures are shown in black; Source: ERCOT

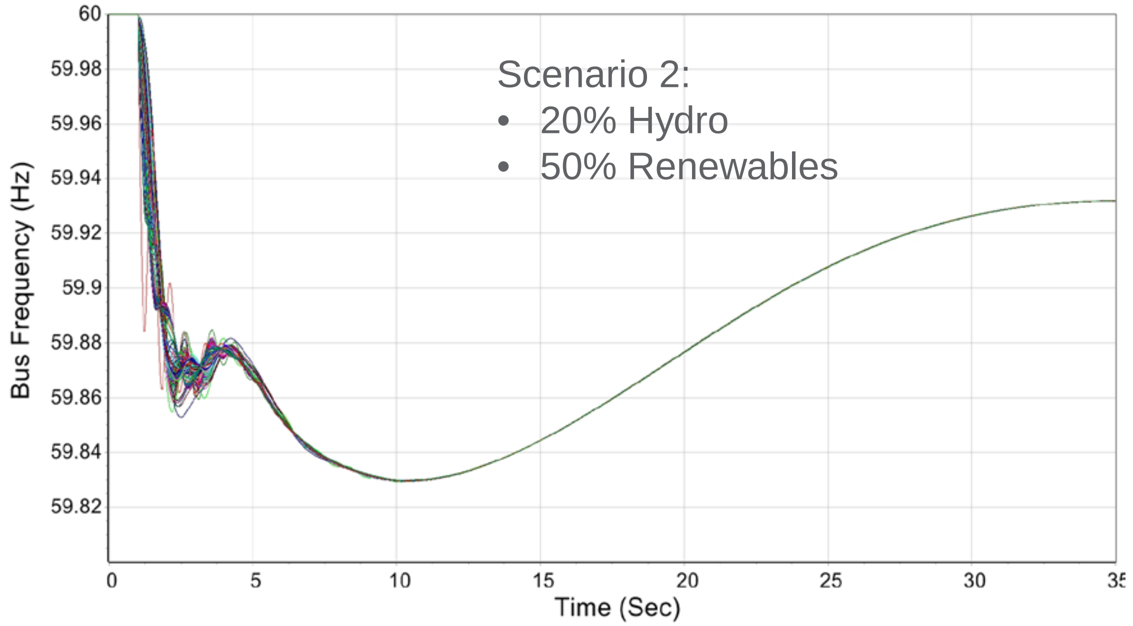
NERC BAL-001 Standard: Frequency Response Measure

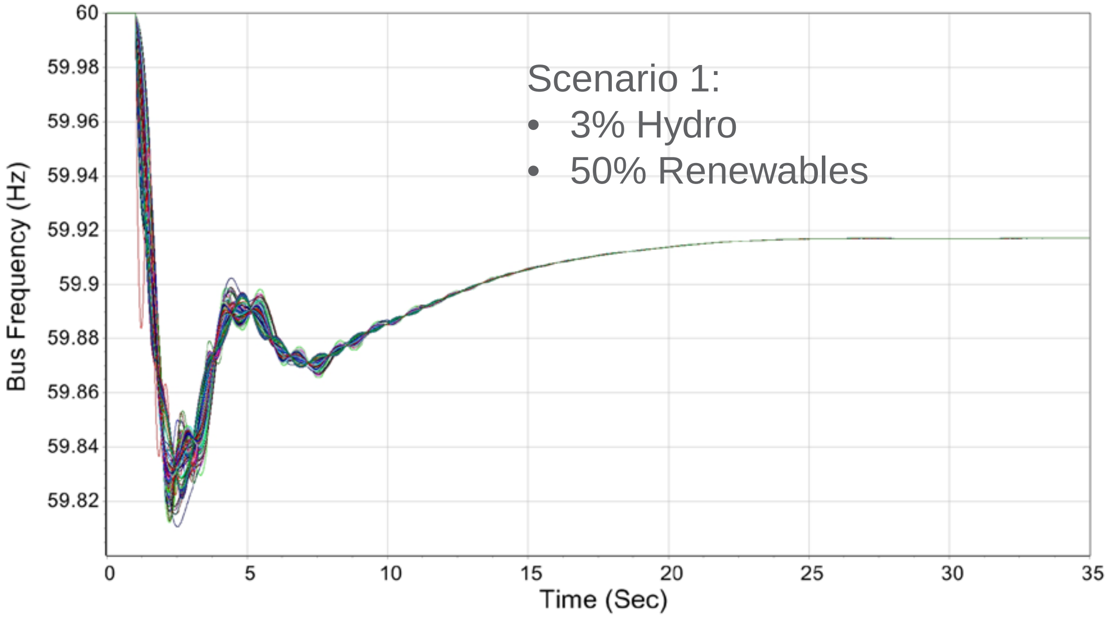
Table 11: Recommended Resource Contingency Protection Criteria

Interconnection	Resource Contingency	Basis	MW
Eastern	Largest Resource Event in Last 10 Years	August 4, 2007 Disturbance	4,500
Western	Largest N-2 Event	2 Palo Verde Units	2,740[46]
ERCOT	Largest N-2 Event	2 South Texas Project Units	2,750[47]



Hydropower Operations in a High Inverter-based Resources Future: Inertial and PFR





Hydropower responds reliably during frequency arrestation period (0-5 sec) and during recover period (>20 sec), but can be slow to respond in the interim

FERC Order 842 (2018) will require all new resources to reserve headroom for frequency response, but the exact requirements are yet to be determined

Future work and collaboration opportunities

- Need to fully understand the evolving value streams
  - How will the grid operational requirements change in future
  - How will that change the reliability and performance standards/requirements
  - How will that impact the definitions and requirements for grid services
  - What are the implications for market design(s) of the future

- Collaboration opportunities:
  - Ongoing: IEA Annex IX whitepaper on comparisons of markets across countries

- Please provide inputs on additional topics along these lines

→ Cost vs. Price vs. Value vs. Compensation