DRAFT

Value of Automated Demand Response and Storage for Renewable Integration

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California Energy Commission

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Lawrence Livermore National Laboratory

Thomas Edmunds*
Alan Lamont, Philip Top,
Matt Simpson, Jeff Mirocha,
Vera Bulaevskaya, Steve Smith,
Yiming Yao, Carol Meyers,
Andrea Schmidt, Pedro Sotorrio

*edmunds2@llnl.gov, 925-423-8982

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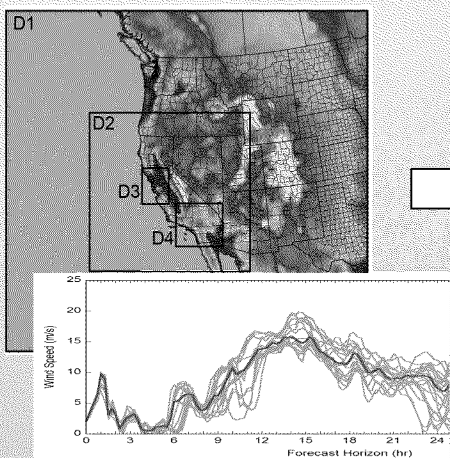
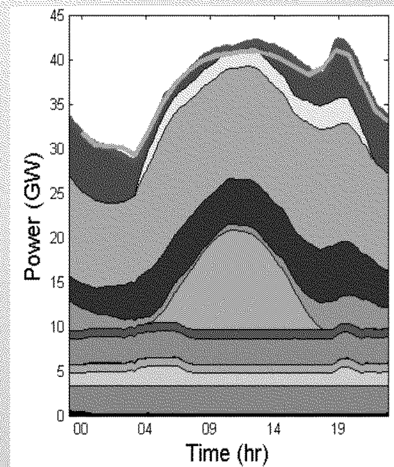
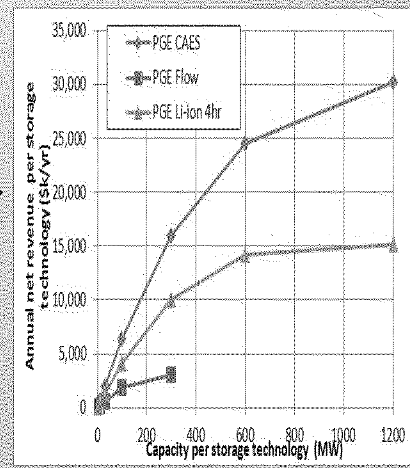
LLNL developed system to estimate value of storage and demand response under uncertainty



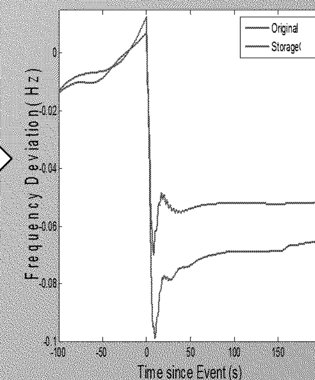
Ensemble weather forecasts capture uncertainty



Production modeling using stochastic unit commitment



Supply curves and other detailed analyses



Stability analysis

Data, models, and high performance computing infrastructure can now be used for other economic studies of California grid.

EPRI & CESA provided storage technology data; DRRC provided DR capacities

From Table E-1

Technology	Specific Capital Cost* ($/kw)	Specific Energy Cost ($/ kWh)	Plant Life (yrs.)	Round Trip Efficiency (%)
Li-Ion battery (15 min)	1,250	5,000	15	83
Li-Ion Battery (4hr)	3,600	900	15	85
Flow Battery (5 hr)	1,860	372	15	65
Flywheel (15 min)	1,900	7,600	25	87
Compressed air (5 hr)	2,000	400	35	70

*Cost of demonstration plant in 2012.

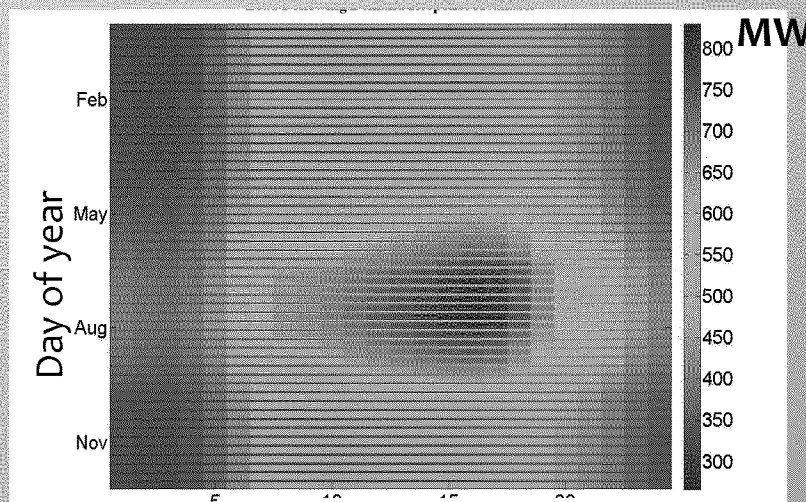


Figure D-6

Computation of energy prices at each hour of the year provide operational insights

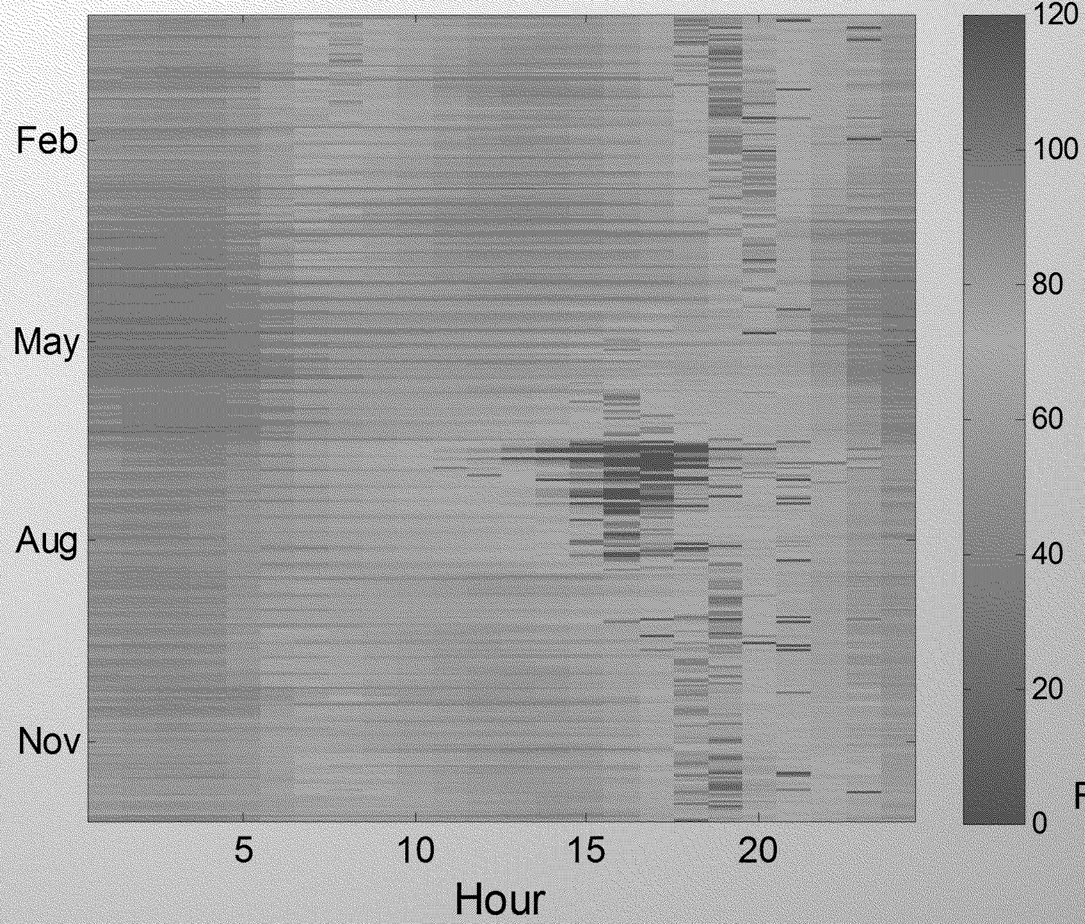


Figure 8-38

8 hour turn-around on HPC would have taken 4 months on a PC.

Li-ion batteries were added to the base case model

Generation and charging for 50 MW, 4 hour
Li-ion battery in SCE service territory

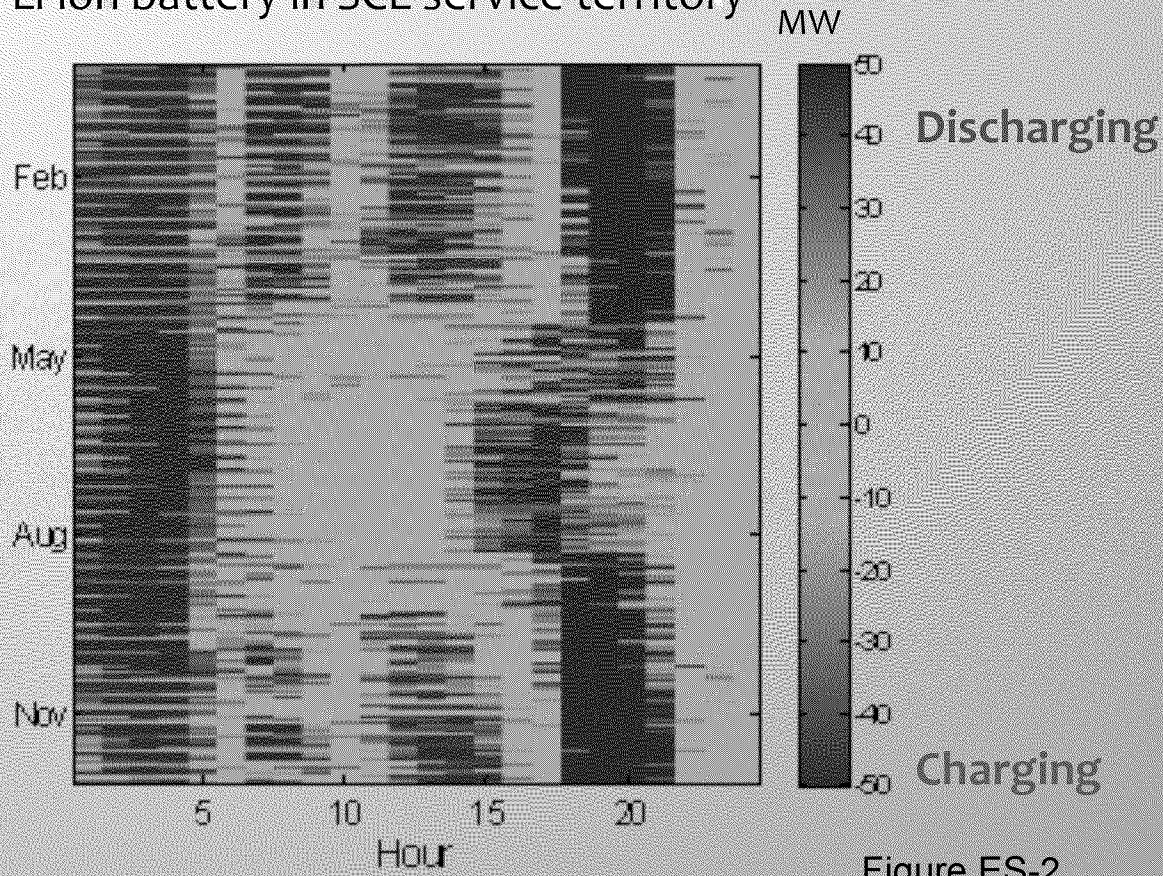


Figure ES-2

Optimal battery cycling is once in summer and twice other seasons.

Net revenues curves show increasing benefits up until about 1500 MW and 3 hour discharge time

Discharge time fixed at 4 hours

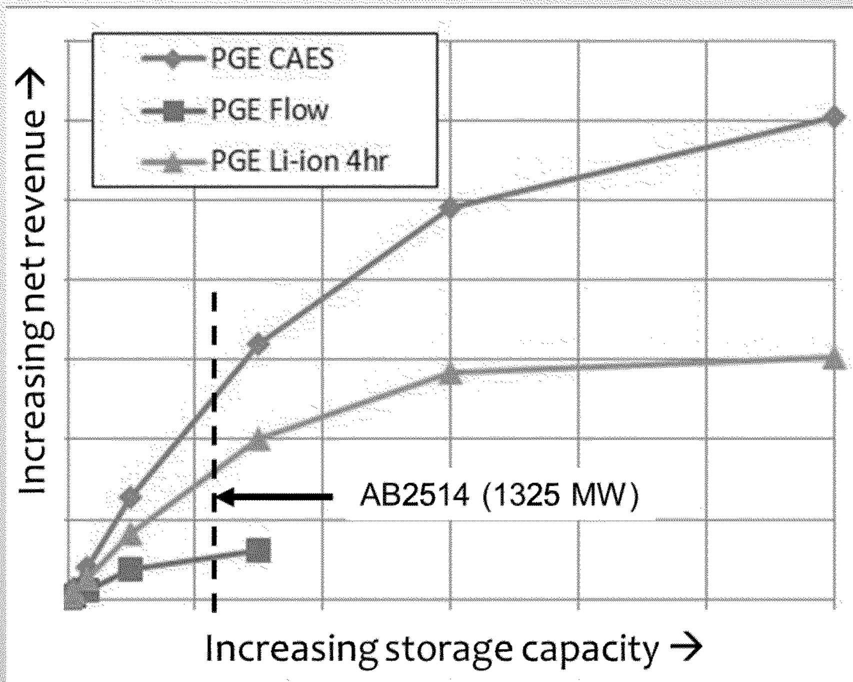


Figure ES-4

Capacity fixed at 300 MW

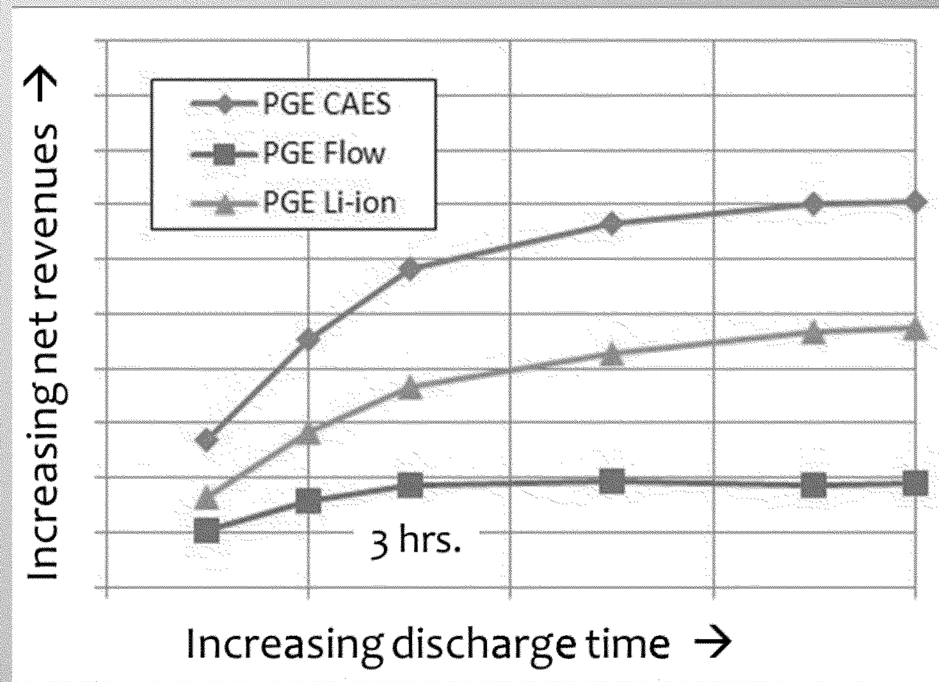


Figure ES-5

Provides more insight for setting storage goals than "first MW" analysis.

Storage reduces cycling of gas and other units

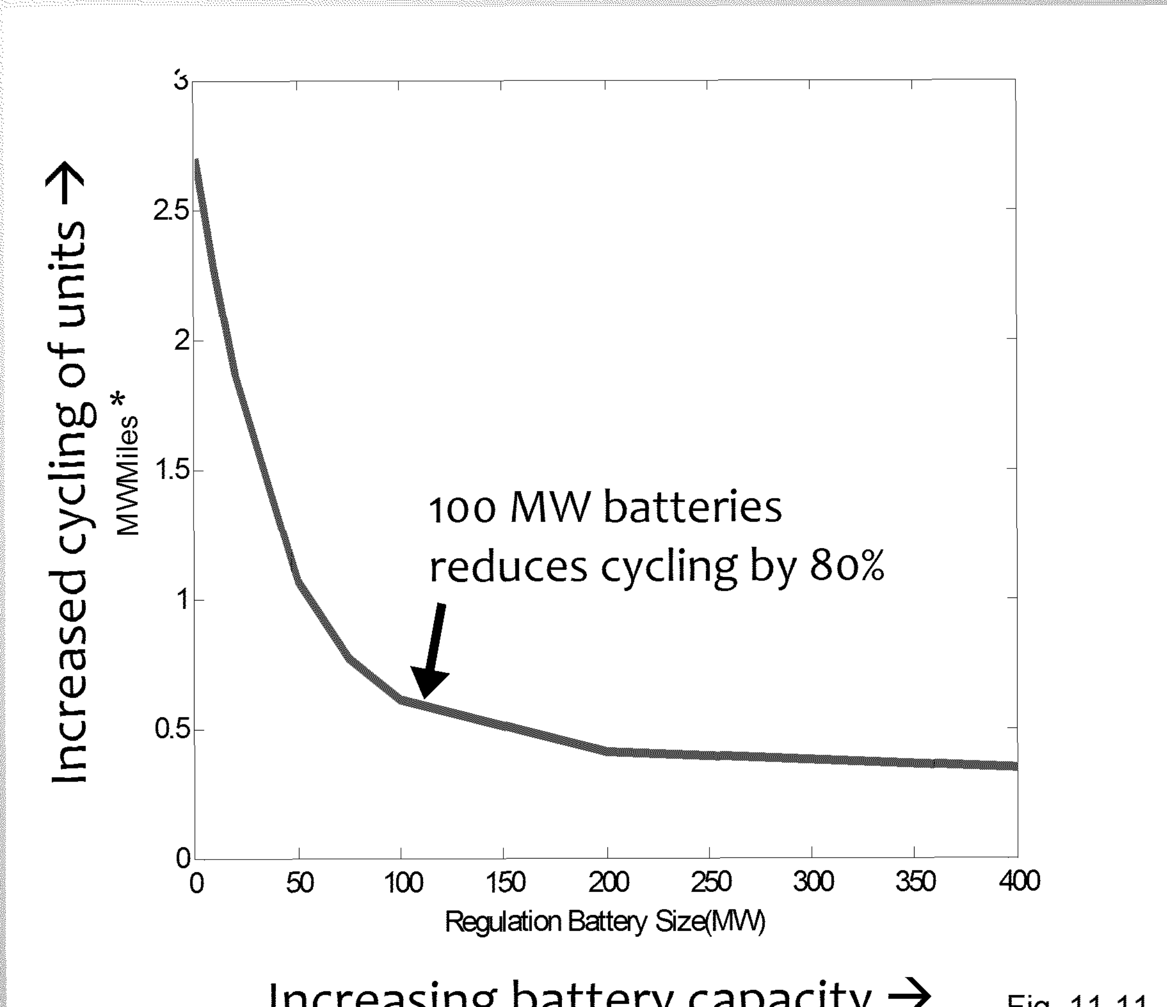
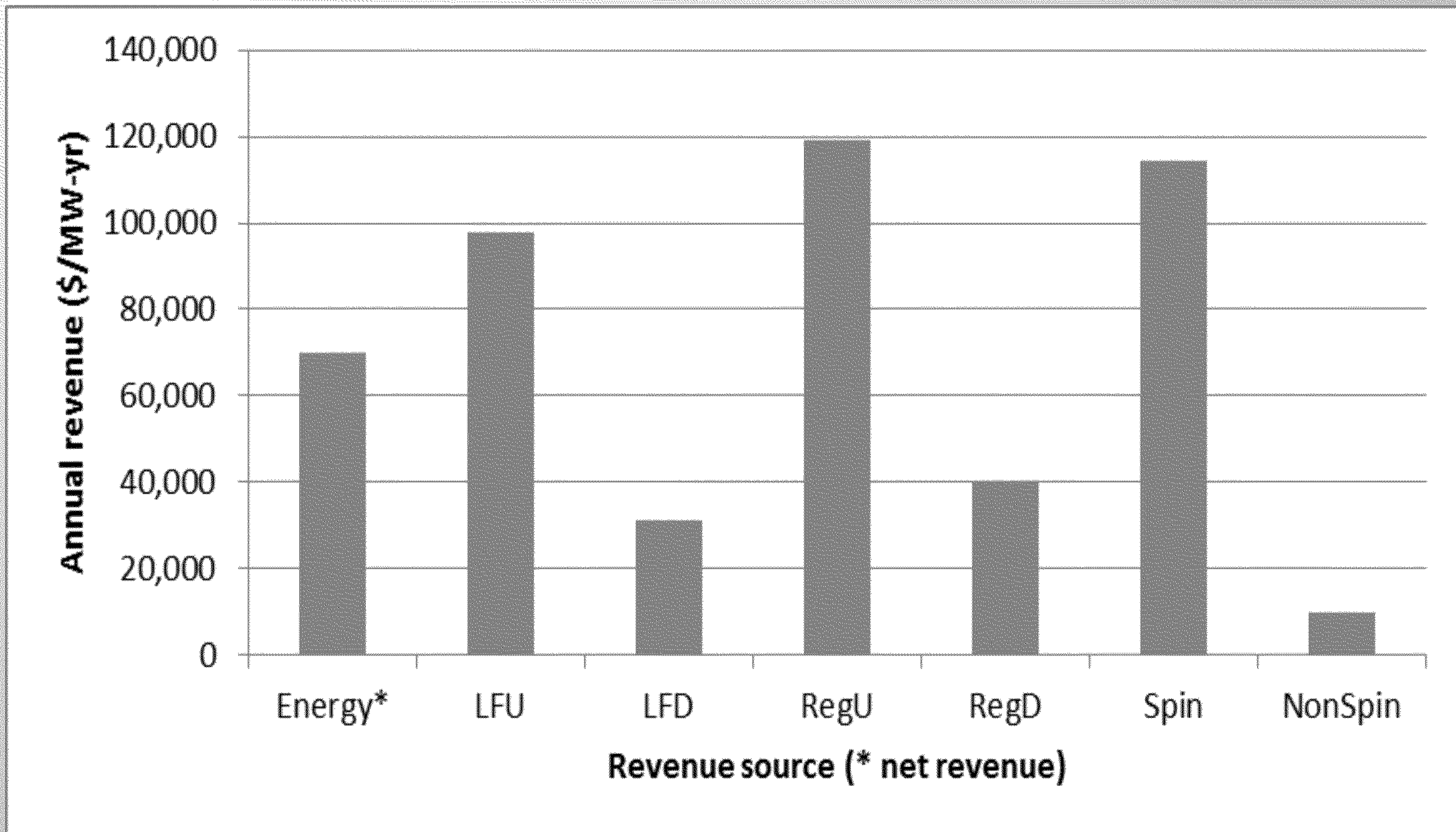


Fig. 11-11

* MW-miles is the sum of absolute changes in generator output

Revenue streams from ancillary services are larger than energy arbitrage



LFU = load following up
LFD = load following down
RegU = regulation up
RegD = regulation down
Spin = spinning reserve
NonSpin = non-spinning reserve

Fig. 10-19

Profits from energy arbitrage currently lower than levelized capital cost by at least a factor of 4 (today)

Discount rate	15%			Levelized	Profits from
		Capital cost	Plant	capital cost	energy arbitrage
Technology		($/kw)	life (yr)	($/kw-yr)	($/kw-yr)
CAES		2,000	35	302	70
Flow		1,860	15	318	20
Li-ion 4 hr		3,600	15	616	45
Comb. turb.		750	15	113	

Table 10-6

4x

- Impact of technology advances – Li-ion costs may decrease by 75%
- Ancillary services – $100/kw-yr revenues
- Capacity credit - $113/kw-yr for deferral of combustion turbine
- CAES close to break-even (70+100+113 = 283 ~ 302)

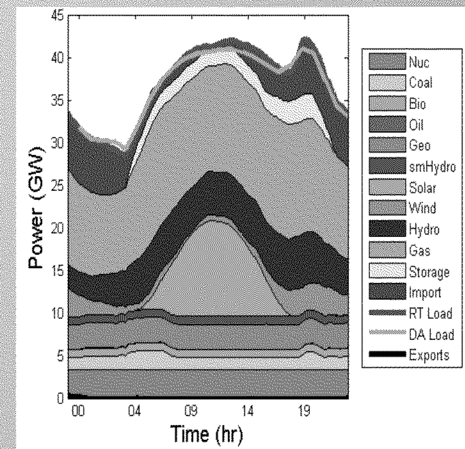
Summary of results

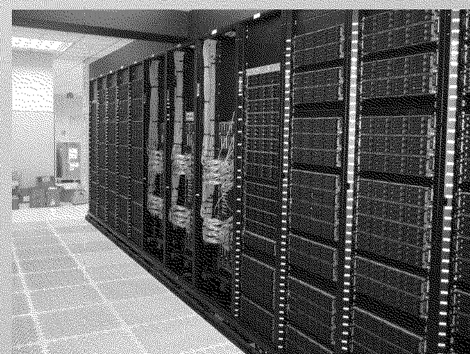
- Results
  - Arbitrage benefits significant up to about 1500 MW storage
  - Arbitrage benefits significant with < 4 hours discharge time
  - Regulation benefits up to 100-200 MW storage
  - DR can save $84M/yr in load following costs
  - DR can save $31M/yr in regulation costs
- Capabilities
  - High-resolution, stochastic weather/renewables model
  - Optimization under uncertainty
  - Parallel runs

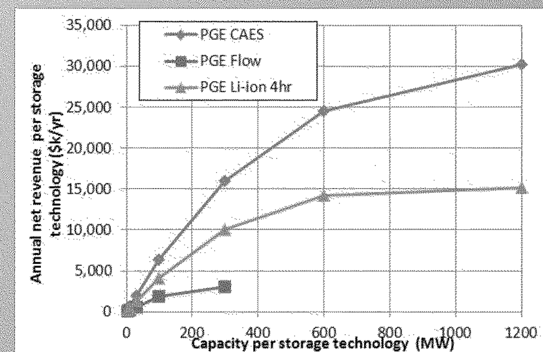
Backups

Project goal: estimate value of storage and DR with new tools enabled by high performance computing (HPC)

- Explore value for energy arbitrage, load following, and regulation
- Improve modeling of variability and uncertainty
- Evaluate massive number of options to find most cost-effective solutions



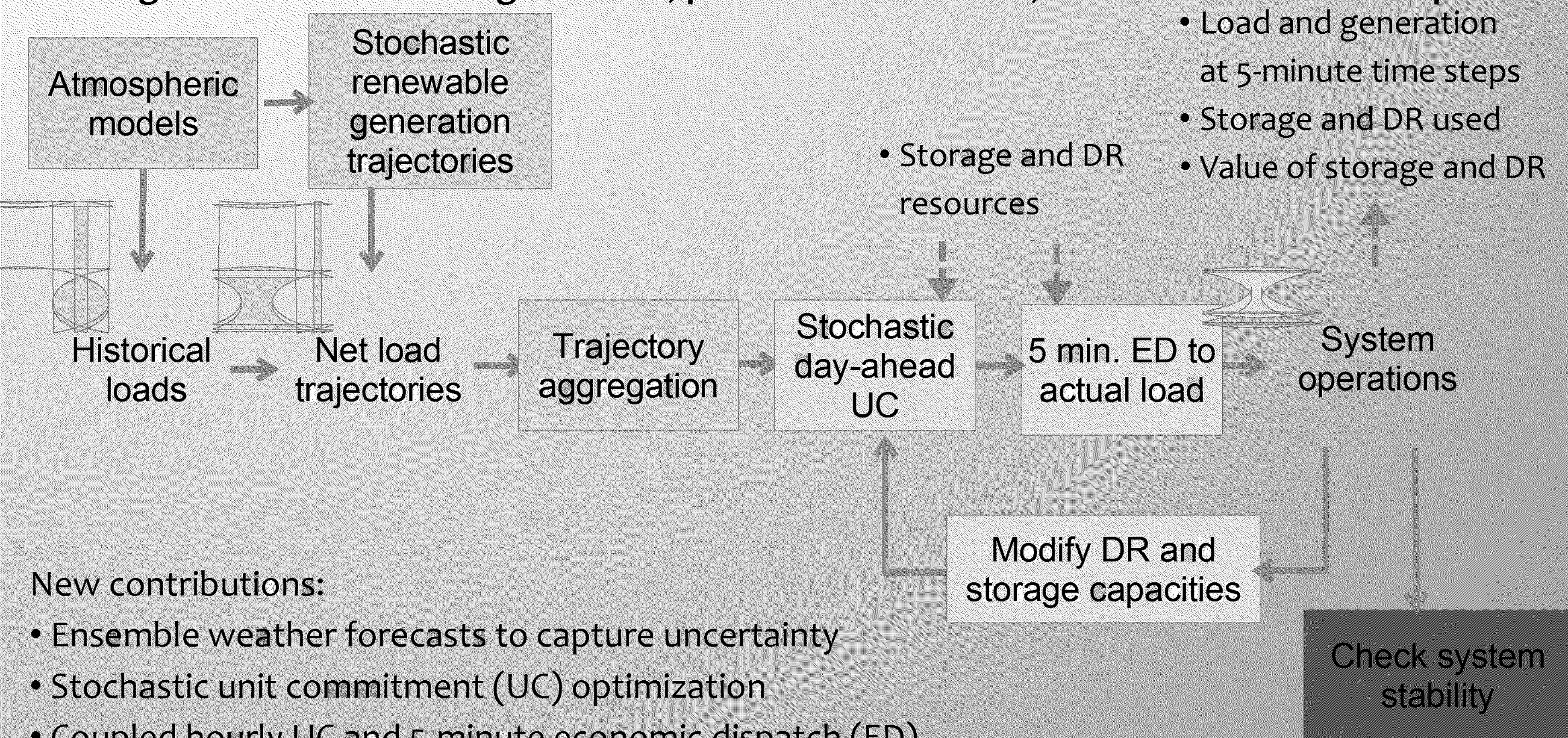




Storage and DR valuation in a high-renewables environment required leap-ahead analysis methods.

We coupled stochastic weather and production simulation models to better estimate value of DR and storage

Figure ES□1: Renewable generation, production simulation, and resource evaluation process



New contributions:

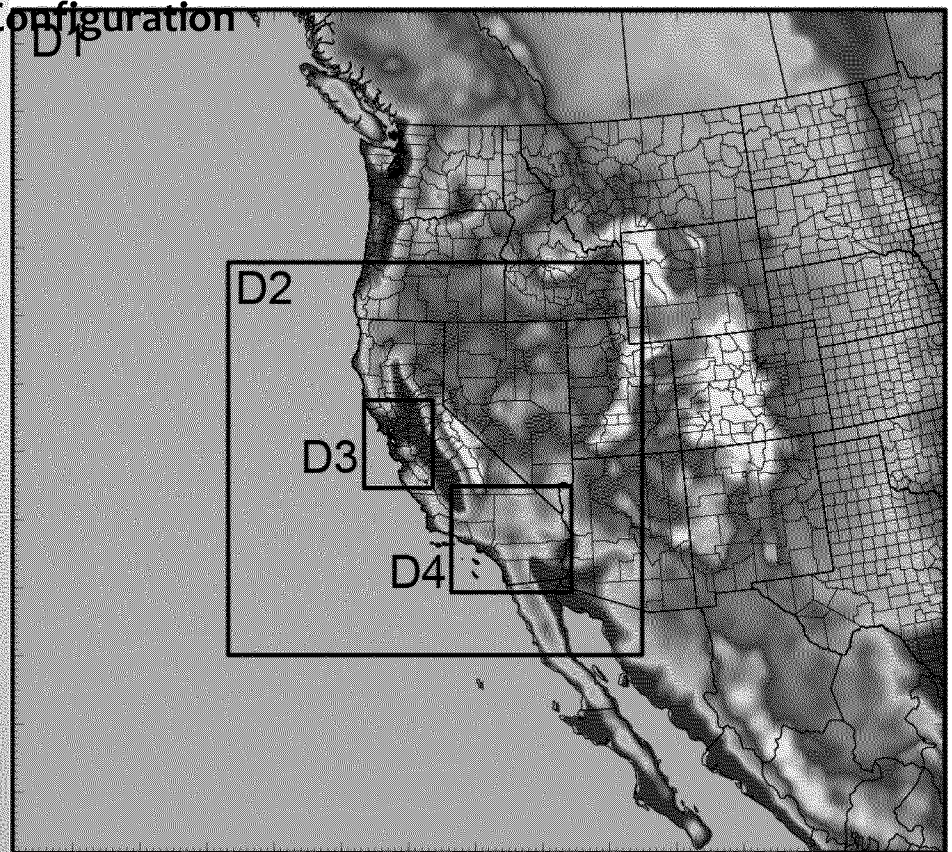
- Ensemble weather forecasts to capture uncertainty
- Stochastic unit commitment (UC) optimization
- Coupled hourly UC and 5-minute economic dispatch (ED)

How much storage and DR should be built in California?

Model of WECC developed with Weather Research and Forecasting (WRF) code

- Spatial and temporal resolution
  - 3 km at key resource areas in California
  - 9 km for the rest of state
  - 27 km for rest of WECC
  - Output at 15 minute intervals
- WRF fluid dynamics calculations
  - Wind speed, solar insolation, temperature
- Computations
  - > 1 million core-hours (>1 core-century)
- Big data
  - 500 TB data set

Figure 2□1: Atmospheric Model Domain Configuration



Demand Response Research Center provided capacity forecasts for each hour of the year

- Economic – bid in day ahead market
- Load following – dispatched at 5 minute intervals in real time market
- Regulation – controlled at 4 second intervals

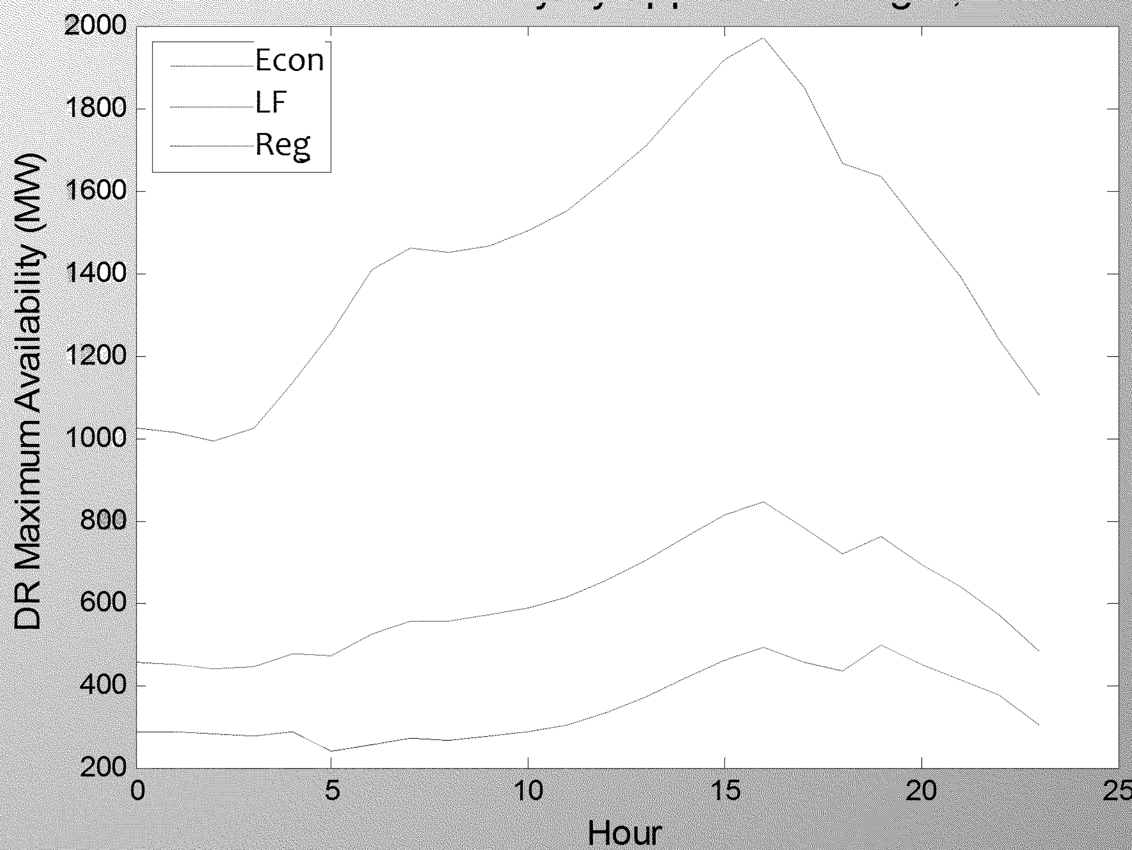


Figure D-2

SCE Sunday Aug. 2, 2020

Base case runs also provide estimates of ancillary service prices

Regulation up

- Periods of high prices at random times throughout the year
- High prices in late afternoon in July

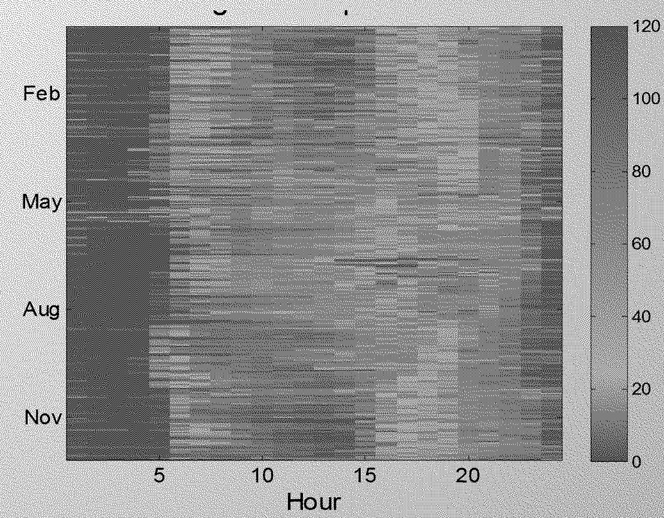


Figure 8-41

Regulation down

- Similar to patterns for load following down

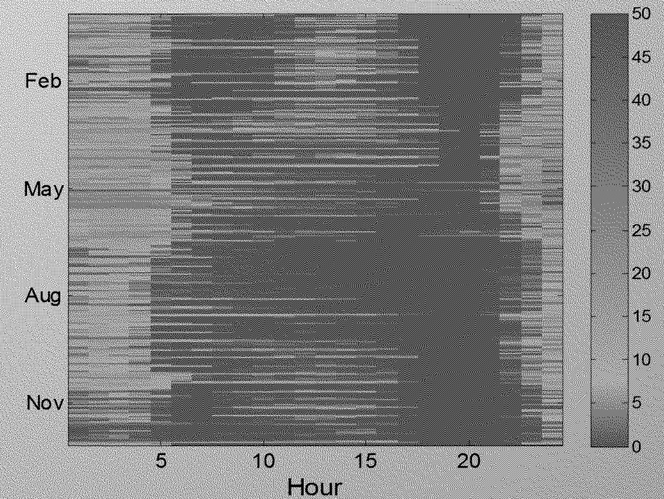


Figure 8-42

Value of a load following ancillary service

Load following up prices peak twice daily

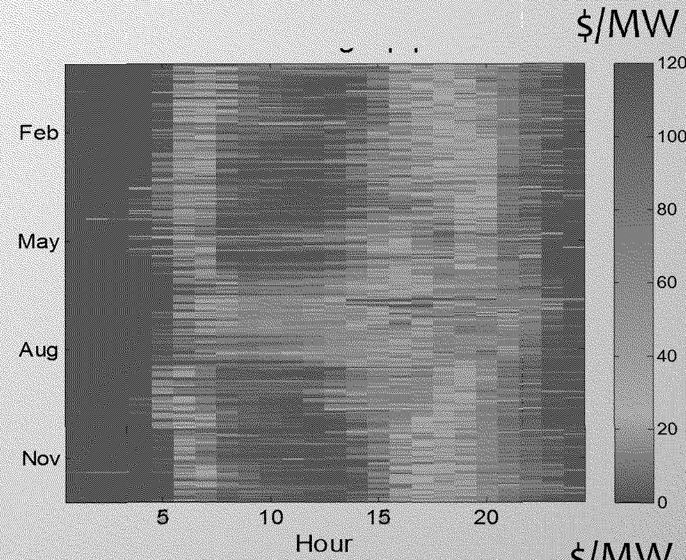


Figure 8-39

Load following down prices peak at night

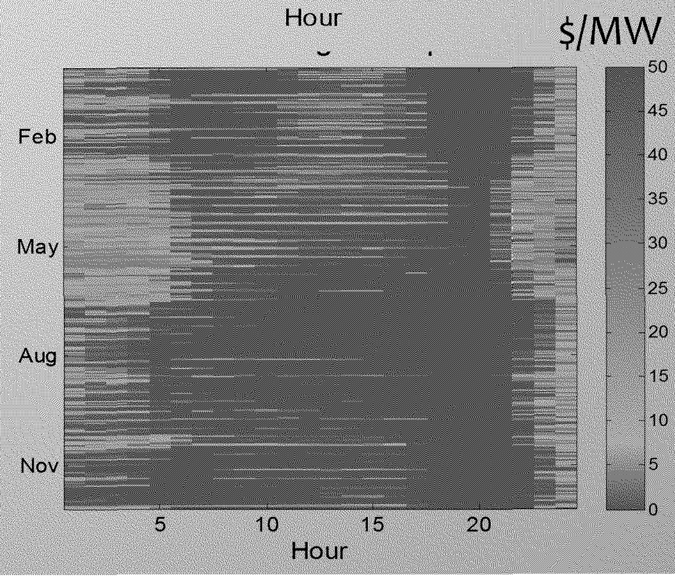


Figure 8-40

Spinning and non-spinning reserve prices reflect predictable ramping and random events

<u>Spinning reserve</u>

- Periods of high prices at random times throughout the year
- High prices in late afternoon in July

<u>Non-spinning reserve</u>

- Nonzero during summer peak

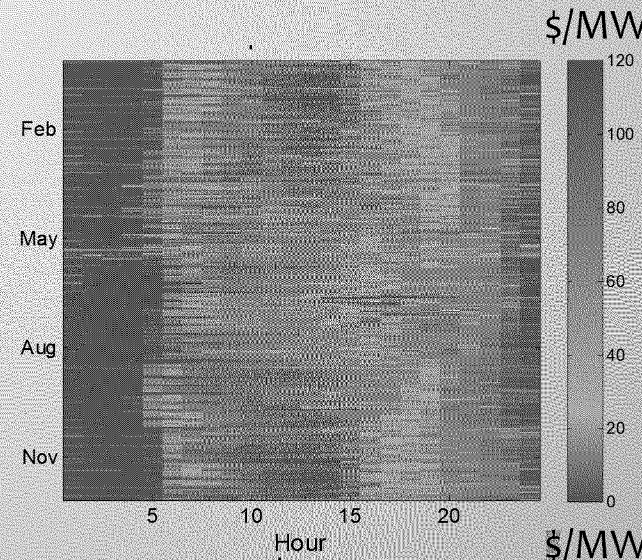


Figure 8-43

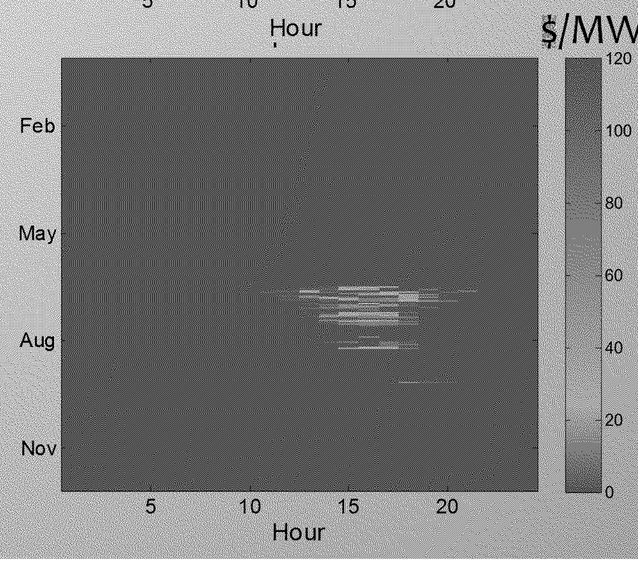
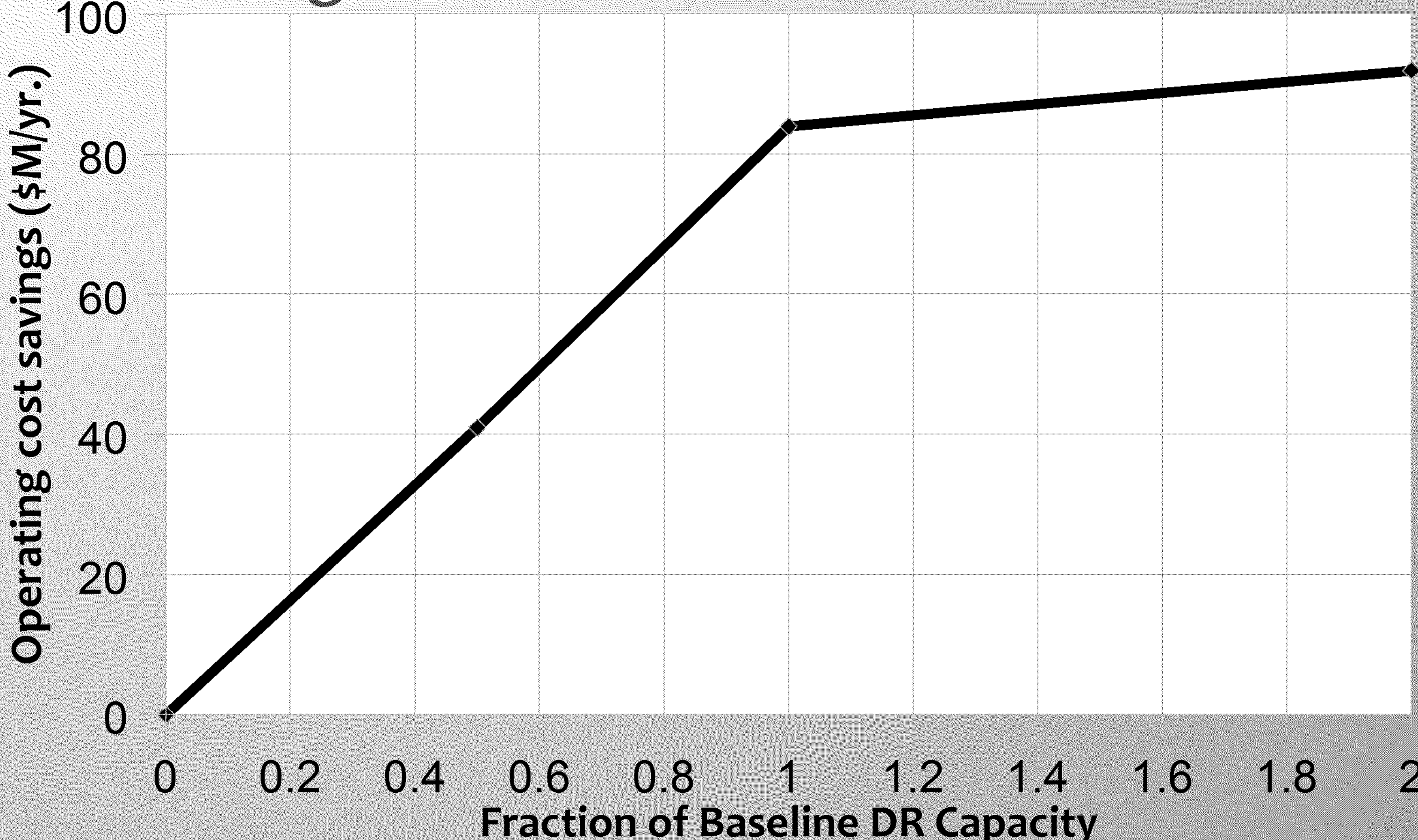


Figure 8-44

Simulation results show automated DR can reduce load following costs for California



Benefits saturate at 1x baseline DR capacity estimates.

from Table 10-1

Addition of 200 MW of storage for regulation improves response to contingencies

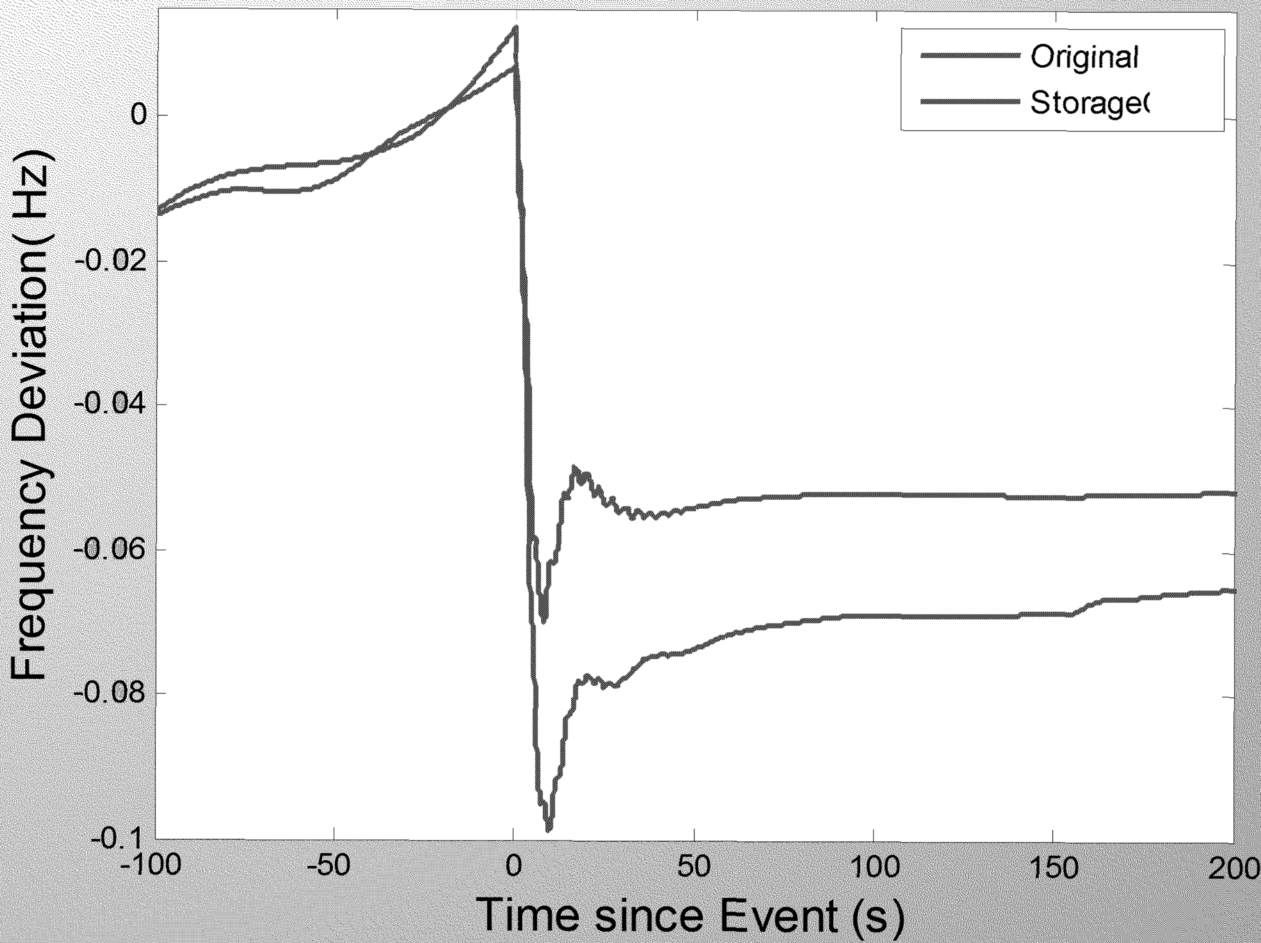
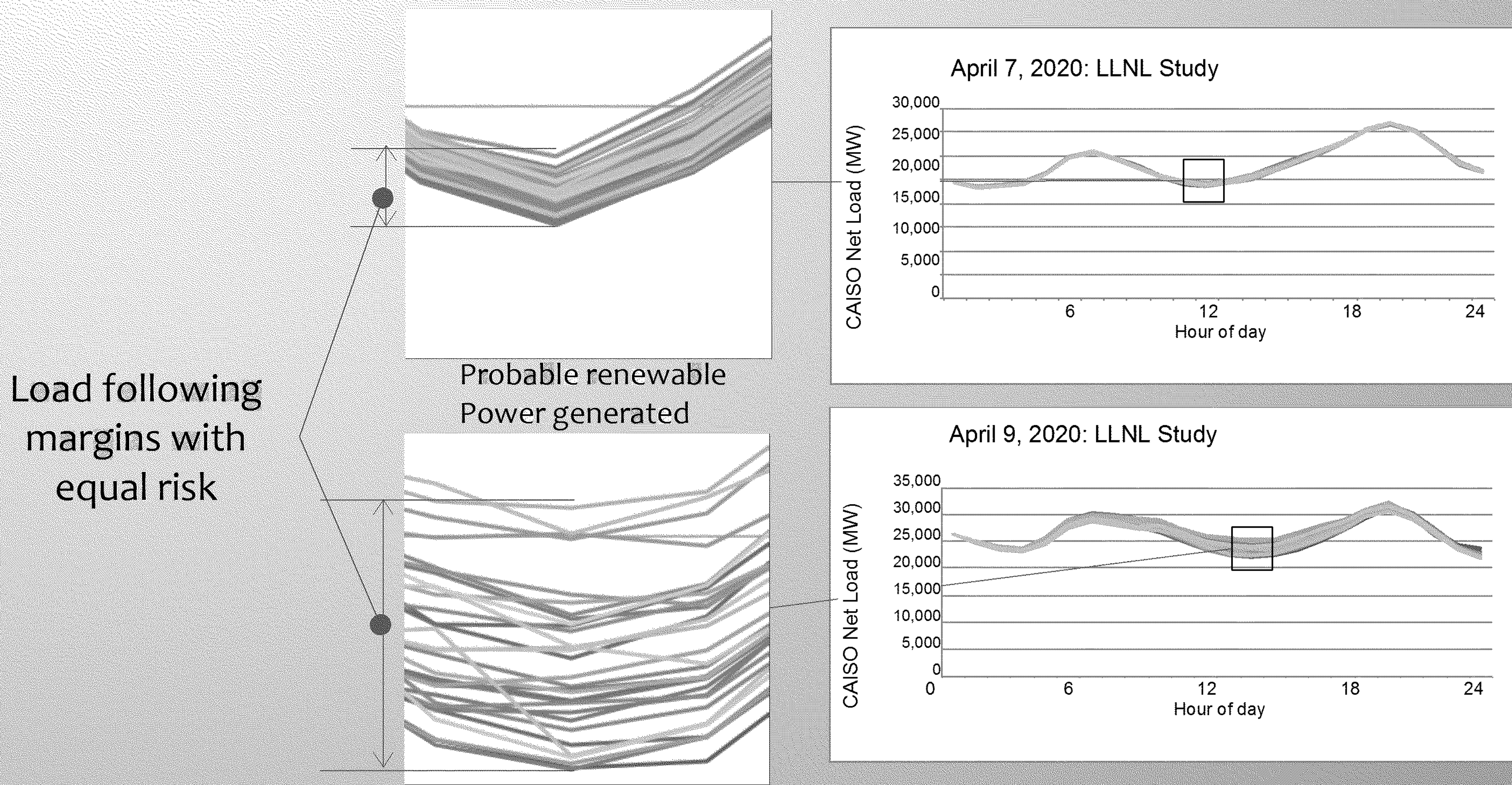


Fig. 11-21

Ensemble forecasts predicting hourly uncertainty can be used to set dynamic reserve margins



CEC now has a suite of state-of-the-art models and data sets

- High resolution weather/renewables model with ensemble forecast
  - Captures 15 minute variability and uncertainty in wind, solar, and load
  - 3 km resolution
- PLEXOS production simulation
  - Stochastic unit commitment that use ensemble forecasts
  - 5 minute economic dispatch
  - Valuation of demand response and storage technologies over an entire year
- Sub-5-minute regulation analysis
  - Models for stability analysis
- Data sets for weather, renewables, and system prices
- Implemented in high performance computing environment

Infrastructure built with this project can be used to support critical policy decisions

1. Best places to add storage, DR, generation, and trans. (AB2514)
2. Robustness of decisions to gas prices or CO_2 costs
3. How to configure infrastructure and incentives for DR

We collaborated with other organizations and leveraged previous work

Team

- Subcontract California Institute for Energy and Environment
- Subcontract with KEMA Corp.: Kermit software, consulting
- Demand Response Research Center

Collaborators

- CAISO: Data, models, requirements
- National Center for Atmospheric Research: WRF/DART
- EPRI & California Energy Storage Alliance: data

Tools

- IBM: CPLEX optimizer implementation on HPC
- Energy Exemplar: PLEXOS support, implementation on HPC
- NREL: System analysis model, datasets

LLNL study builds upon previous work by DNV-KEMA

	DNV KEMA recommendation	LLNL study
1	Better geographic and temporal diversity of renewables	High resolution weather (>4 million grid cells) and renewable generation (5,494 grid cells)
2	Sub-hourly dispatch (< 15 minutes)	Five minute economic dispatch
3	Analyze more than 3 days	3,000 days analyzed
4	Conduct a cost analysis	Using PLEXOS production simulation software with cost parameters for generators
5	Analyze demand response	Demand response is one of the resources in the PLEXOS model

Table 1-1

AB1325 storage procurement targets

Table 1 – Initial Proposed Energy Storage Procurement Targets (in MW)

Use case category, by utility	2014	2016	2018	2020	Total
Southern California Edison					
Transmission	50	65	85	110	310
Distribution	30	40	50	65	185
Customer	10	15	25	35	85
Subtotal SCE	**90**	**120**	**160**	**210**	**580**
Pacific Gas and Electric					
Transmission	50	65	85	110	310
Distribution	30	40	50	65	185
Customer	10	15	25	35	85
Subtotal PG&E	**90**	**120**	**160**	**210**	**580**
San Diego Gas & Electric					
Transmission	10	15	22	33	80
Distribution	7	10	15	23	55
Customer	3	5	8	14	30
Subtotal SDG&E	**20**	**30**	**45**	**70**	**165**
Total - all 3 utilities	**200**	**270**	**365**	**490**	**1,325**