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Analyzing the Value of Storage and Demand Response in a Wholesale Market

Marissa Hummon

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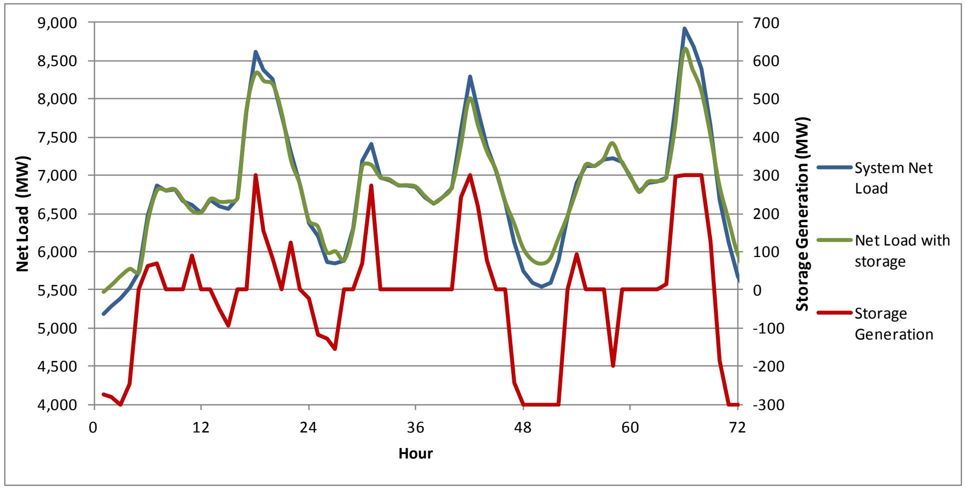
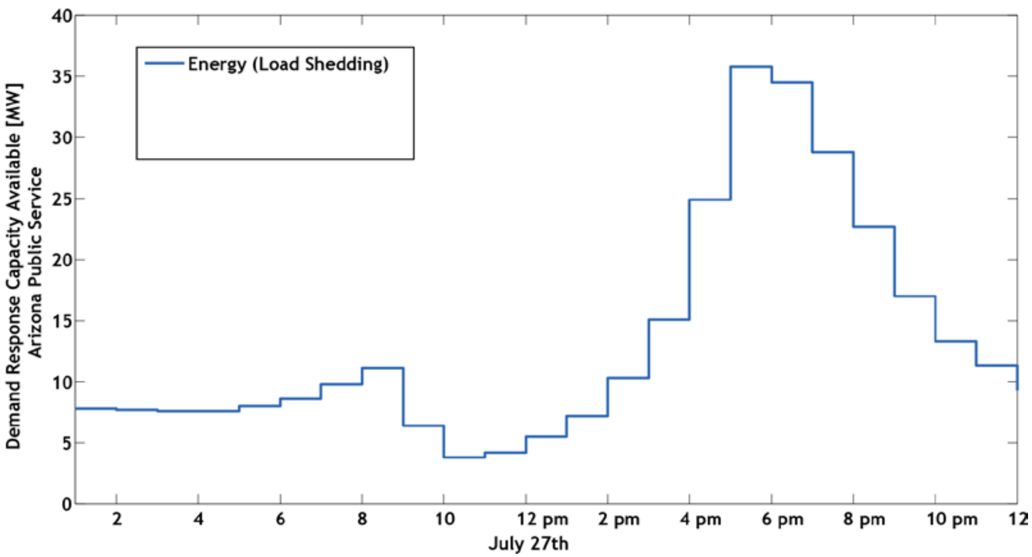
Storage and demand response have unique operational characteristics effecting future value

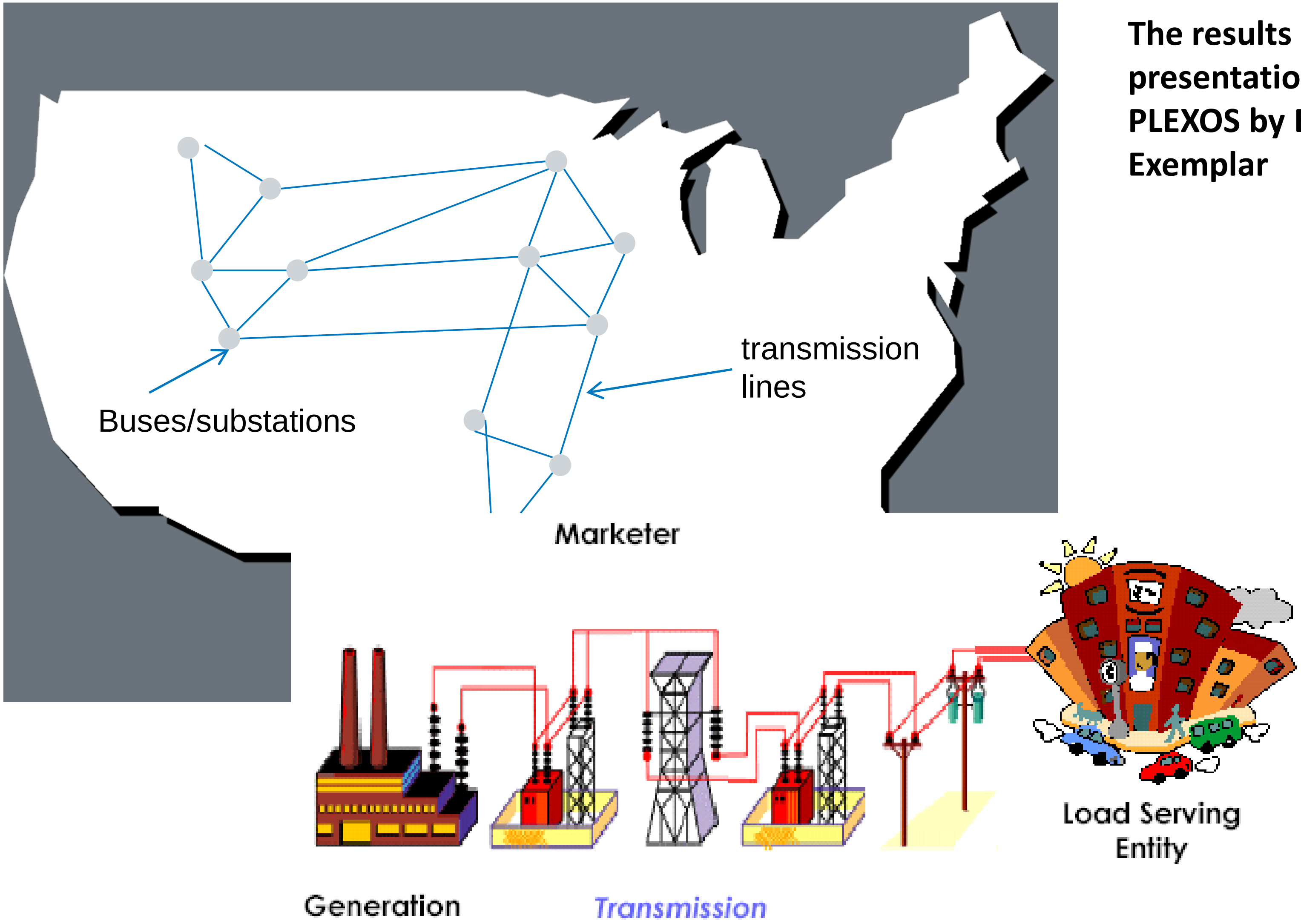
Storage and some demand response: **Charge and discharge cycle**



Demand response: **Time varying availability of charge/discharge capacity**



Unit commitment and economic dispatch optimization captures the operational constraints



The results in this presentation use PLEXOS by Energy Exemplar

To study a wide variety of system conditions, we isolated a region – Rocky Mountain Power Pool

Western Electric Coordinating Council (WECC) Transmission Expansion Policy Planning Committee (TEPPC)

Simulation year: 2020
Meteorological year: 2006

Isolated Rocky Mountain Power Pool (RMPP): PSC and WACM

“turned off” generation and load outside of RMPP and aggregated transmission outside of RMPP

Increased capacity to planning reserve margin of 9%

Zonal transmission

The change in the production cost of electricity can estimate the operational value of a technology

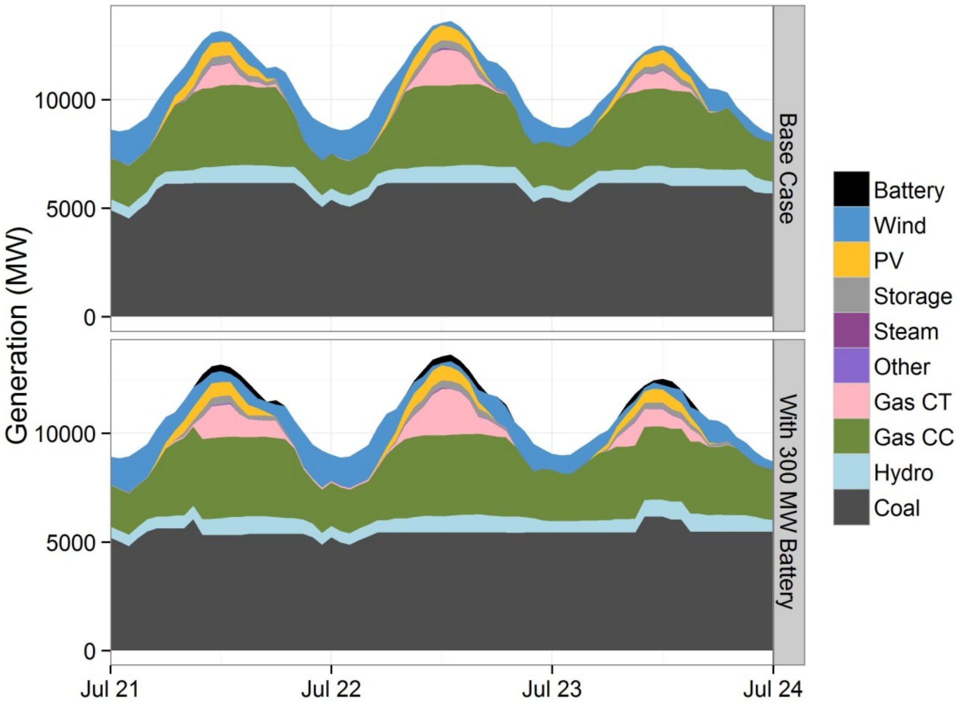
	Base Case	With Storage (300 MW)	Increase with Storage
Total Fuel Cost (M$)	1,210.5	1,204.7	-5.8
Total O&M Cost (M$)	152.1	152.8	0.7
Total Start Cost (M$)	58.2	52.8	-5.5
Total Regulation “Adder” Cost (M$)	4.7	4.8	0.1
Total Production Cost (M$)	1,425.6	1,415.1	-10.5

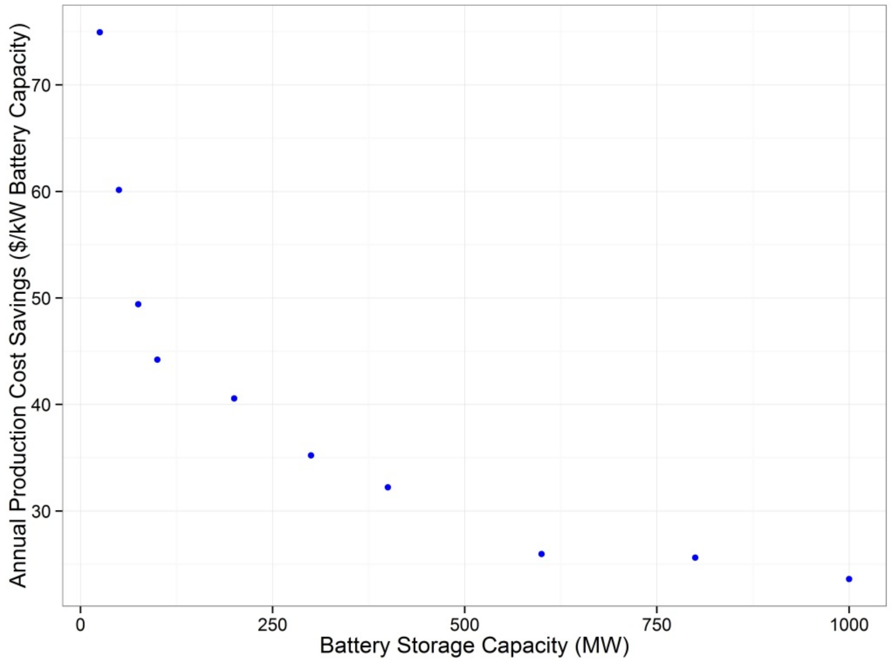
“The difference in production costs can be translated into an annualized benefit. For example, in the base case the difference of $10.5 million is divided by 300 MW to produce an annual benefit of about $35/kW-year.”

Denholm, P.; Jorgenson, J.; Hummon, M.; Jenkin, T.; Palchak, D.; Kirby, B.; Ma, O.; O'Malley, M. (2013). Value of Energy Storage for Grid Applications. 45 pp.; NREL Report No. TP-6A20-58465.

Smaller devices have higher value per unit of capacity

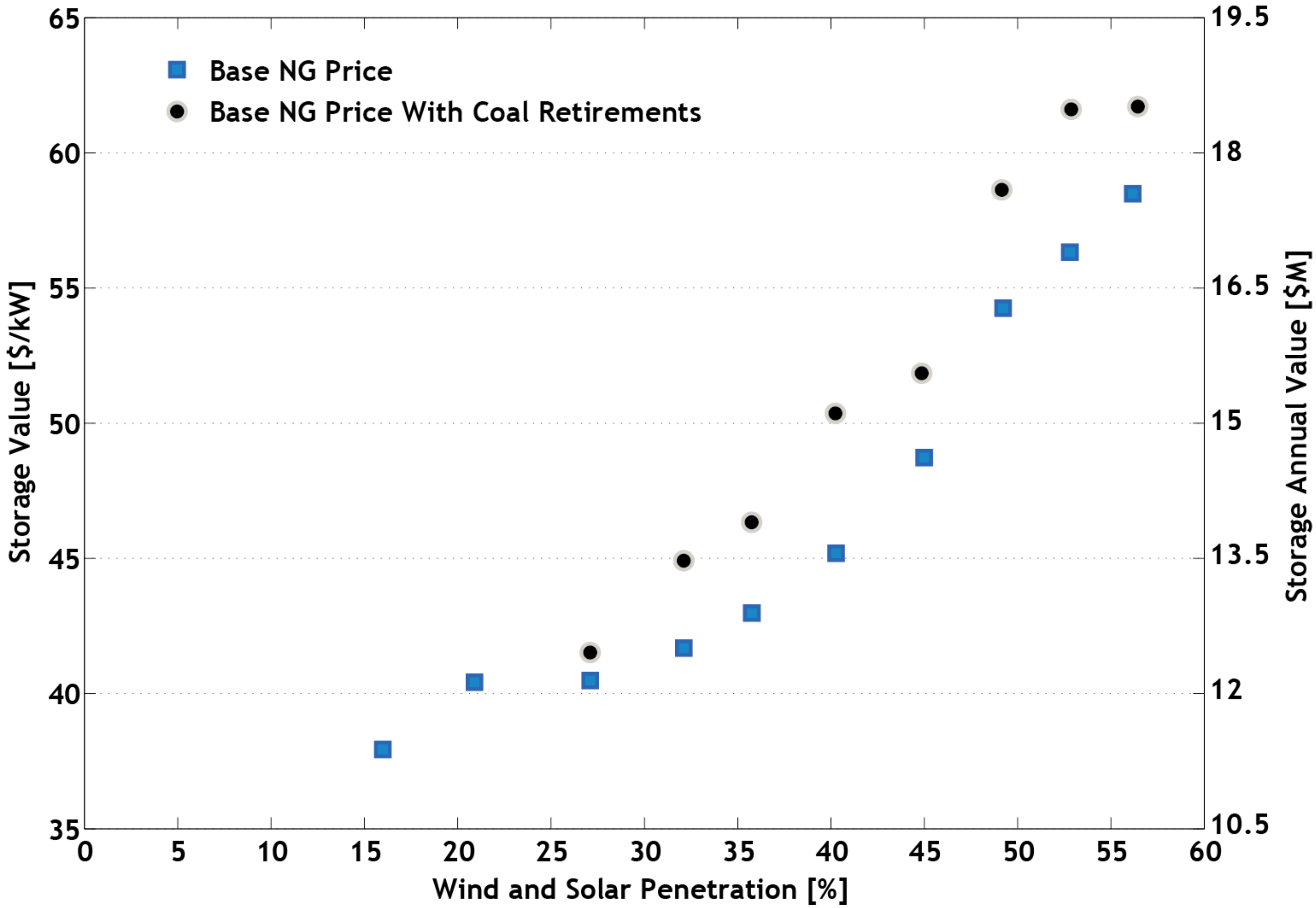
- Long-duration storage device: Can only shift energy
- Represents a battery or CAES or other storage technology, with 8 hours of storage and 75% round trip efficiency
- Generally: Charges at night, generates during periods of high net system load
- Measured value by the change in total generation cost:
  - For a 300 MW, energy-only device: $10.5M reduction in annual total production cost (0.7%)





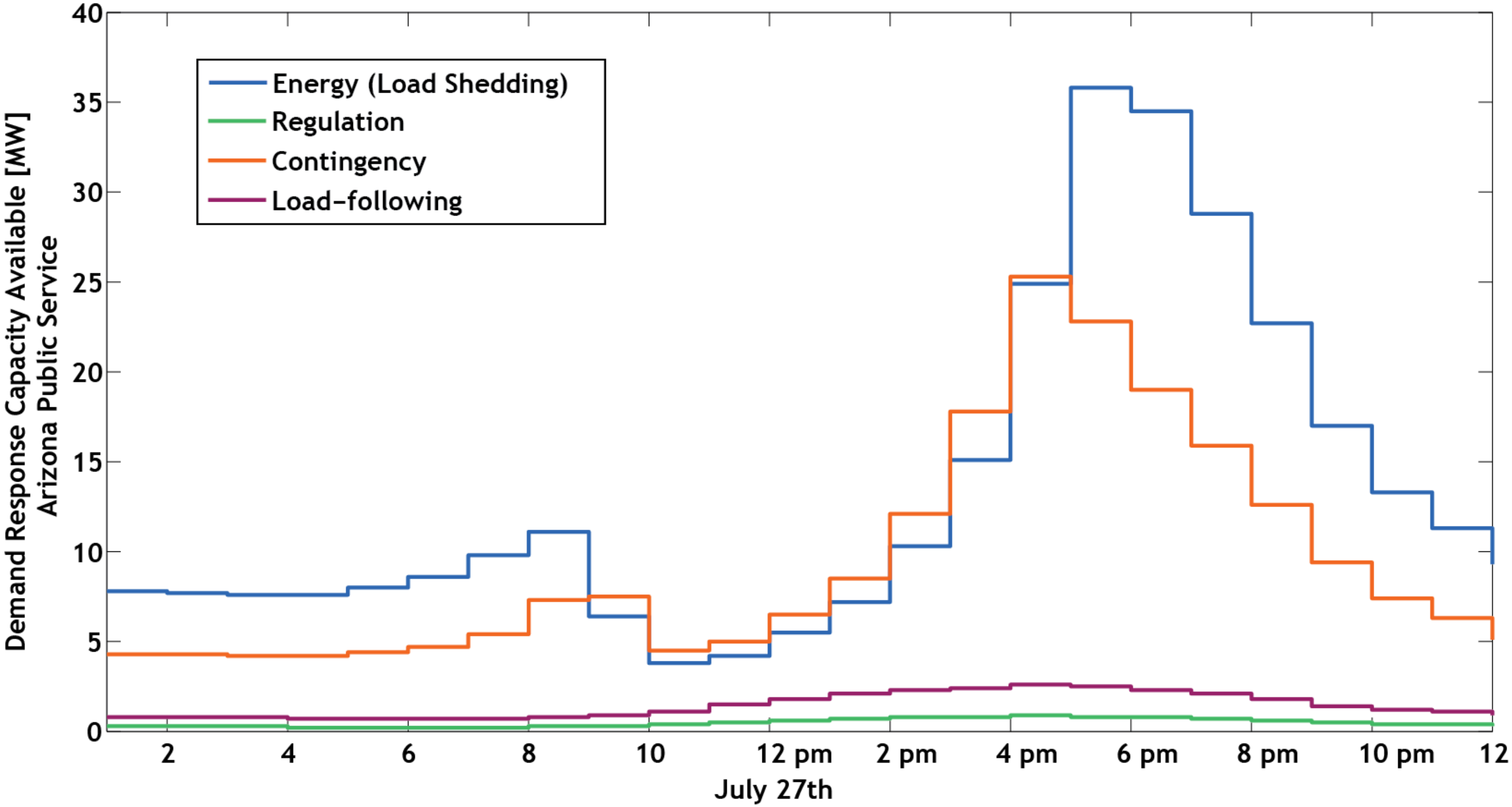
Value of storage increases with renewable penetration due to decreasing off-peak energy price

"The increase in storage value is driven largely by the decrease in off-peak energy price used for charging…At low VG penetration, natural gas is the marginal fuel for most hours of the year, despite the very large contribution of coal to the overall generation mix."



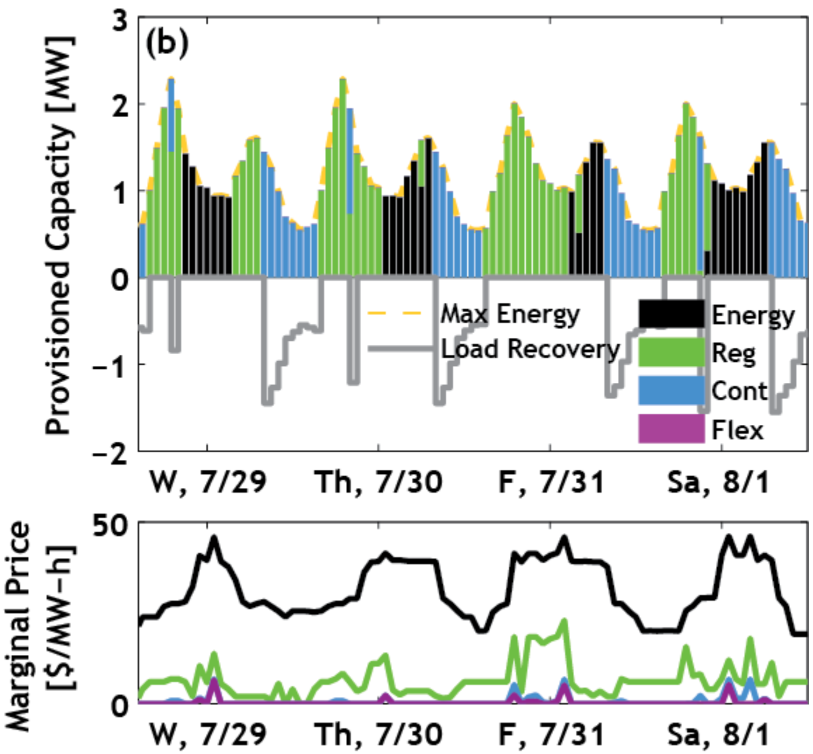
Denholm, P.; Jorgenson, J.; Hummon, M.; Palchak, D.; Kirby, B.; Ma, O.; O'Malley, M. (2013). Impact of Wind and Solar on the Value of Energy Storage. 40 pp.; NREL Report No. TP-6A20-60568.

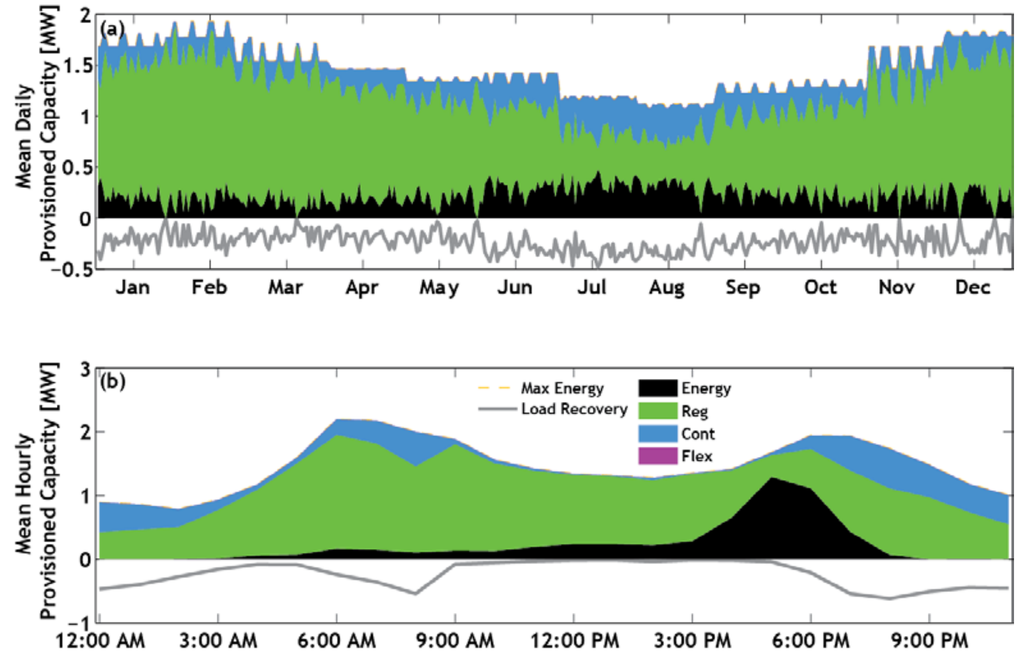
Loads can provide multiple grid services



End use loads can provide ancillary services, depending on the control technologies. We use these four profiles to define the maximum availability of DR to provide each grid service: energy, regulation, contingency, and load-following.

Modeling Results: Residential Water Heating





The allocation of residential water heating demand response for all grid services (top) always uses the full capacity of the DR resource. The marginal cost of each service (bottom) explains the hour(s) of energy provision from water heaters and the majority of the remaining hours is allocated to regulation reserves.

Average daily and hourly allocation is optimized by the model against the net load of the system (load minus solar and wind generation). As the renewable penetration increases, or the ratio of solar to wind generation changes, the daily and seasonal use of DR will change.

Value to the System Operator

Production Cost [M$]	Base Case	Base Case with DR	Decrease in Cost with DR
Fuel Cost	1215.0	1208.0	-7 / -0.6%
Variable O&M Cost	151.8	152.2	0.4 / 0.3%
Start & Shutdown Cost	58.4	58.7	0.4 / 0.6%
Regulation Reserve Bid Price	4.5	2.9	-1.7 / -36.8%
Total Generation Cost	**1429.7**	**1421.8**	**-7.9 / -0.6%**

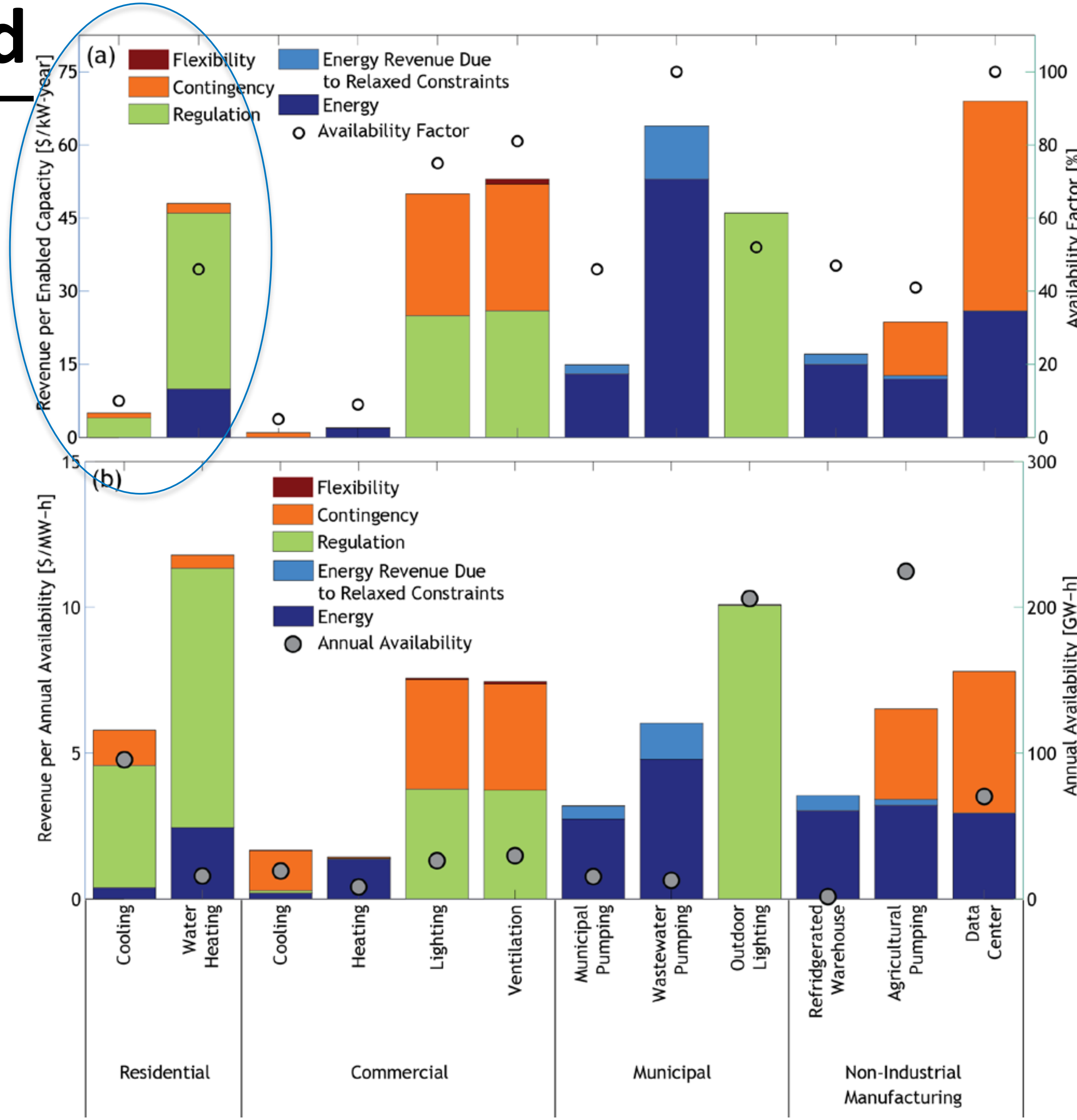
Dividing $7.9M in production cost savings by the *peak DR capacity* enabled, 293 MW, yields a value of $26.91/kW-yr of DR capacity.

Dividing $7.9M in production cost savings by the *total DR* provided to the system, 682 GW-h, yields a value of $0.01/kWh.

Dividing $7.9M in production cost savings by the *total energy DR* provided to the system, 116 GWh, yields a value of $0.07/kWh.

Value to Load

- Revenue can be attributed to a particular grid service. Energy service revenue include pre- or re-charge costs.
- Revenue per peak kW of capacity is closely related to the availability factor – equivalent to the capacity factor of a generator.
- Some DR resources are more flexible or better correlated with system requirements.
- Revenue per annual availability demonstrates the "premium" of such resources.



Conclusions

- **Modeling Storage and DR in a production cost model enables:**
  - Investigation of source of value: fuel, ancillary services, etc.
  - Future value based on changes to system composition or operation

- **Modeling DR with increased fidelity enables more detailed observations, such as:**
  - revenue per kilowatt of enabled DR capacity varies significantly across the resources from less than $1/kW-year to more than $65/kW-year
  - across all DR resources, only 20% of the revenue came from the energy market, while more than 50% of revenue came from the regulation reserve market and the remainder from the contingency reserve market

Thank you!

Questions/comments:

Marissa Hummon
marissa.hummon@nrel.gov

NREL team:
Paul Denholm, Marissa Hummon, Jennie Jorgenson, and David Palchak

LBNL team:
Sila Kiliccote, Daniel Olsen, Nance Matson, Cody Rose, Michael Sohn

DOE: Ookie Ma