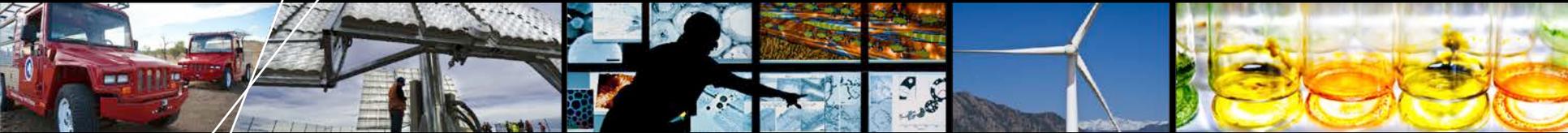


Value of Demand Response: Quantities from Production Cost Modeling



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Background

DOE-led, multiple national laboratory research project investigating the potential of DR to provide services to the grid.

Resolution: Balancing areas (in WECC), hourly data, zonal constrained transmission between BAs

More information (publications and presentations):

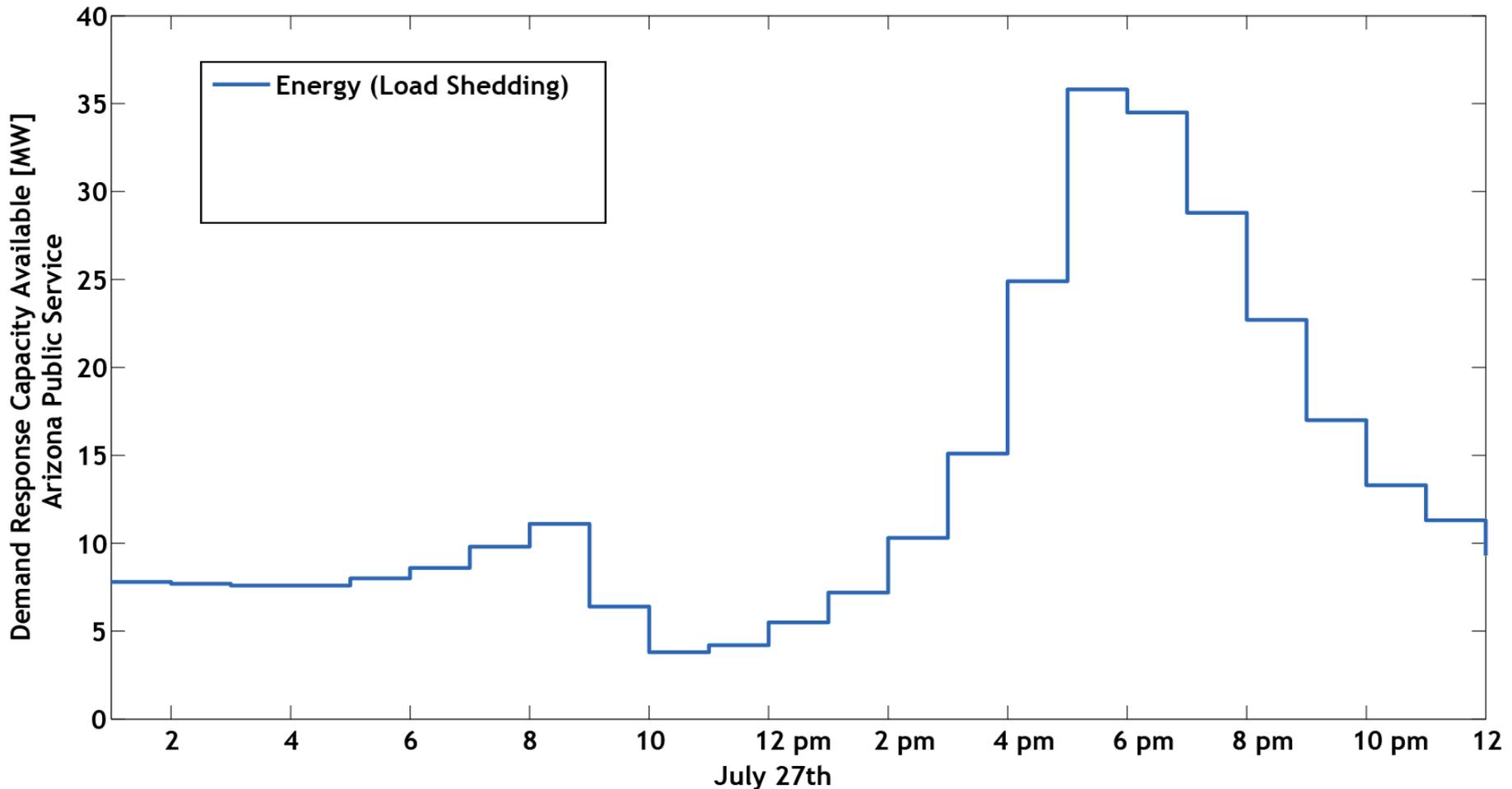
https://www1.eere.energy.gov/analysis/response_storage_study.html

Assess potential of load to provide: energy, regulation, contingency, and load-following

Model the performance of DR in a production cost model

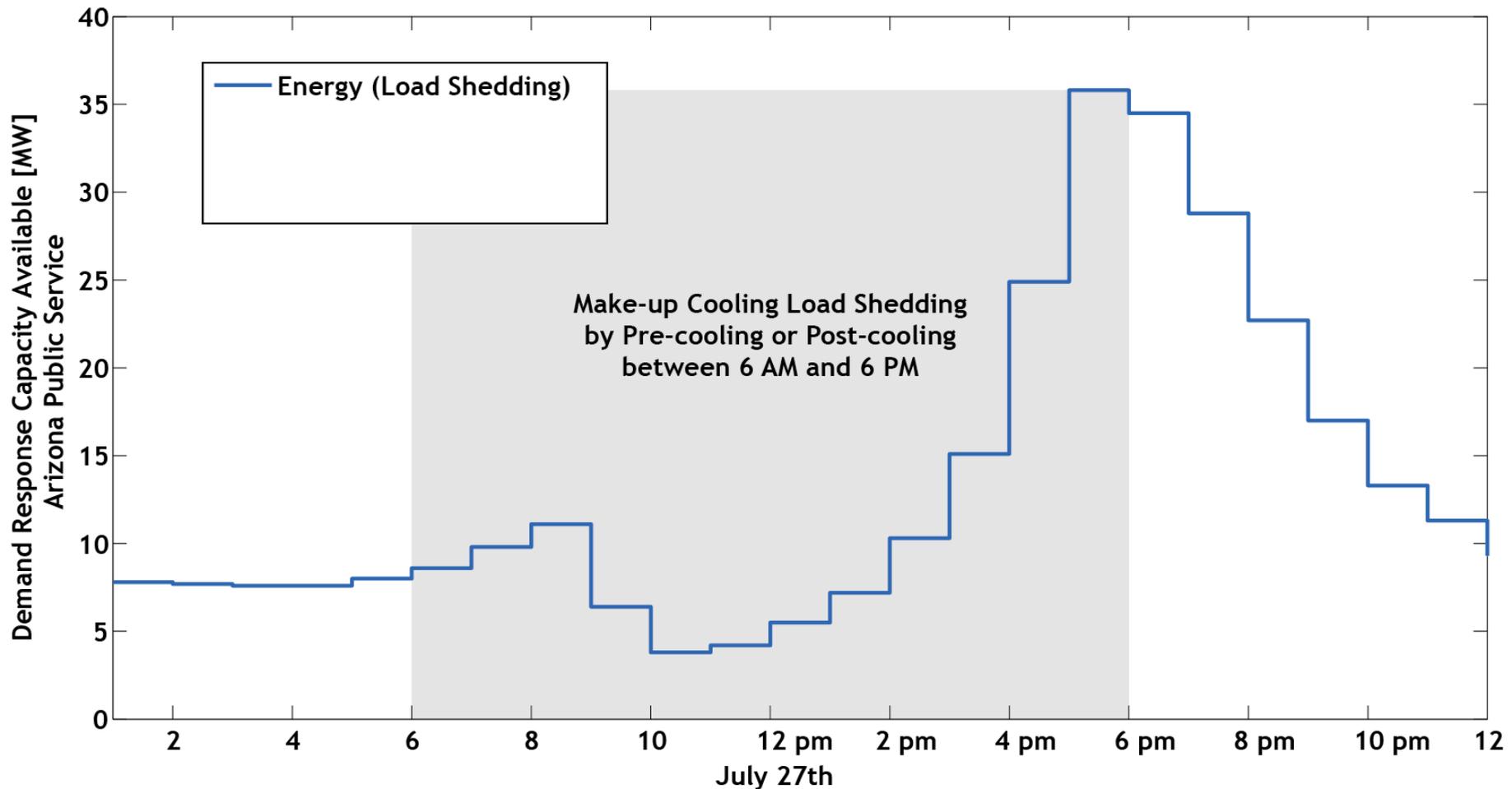
Market & policy barriers to DR entry into wholesale markets

DR Grid Service Availability



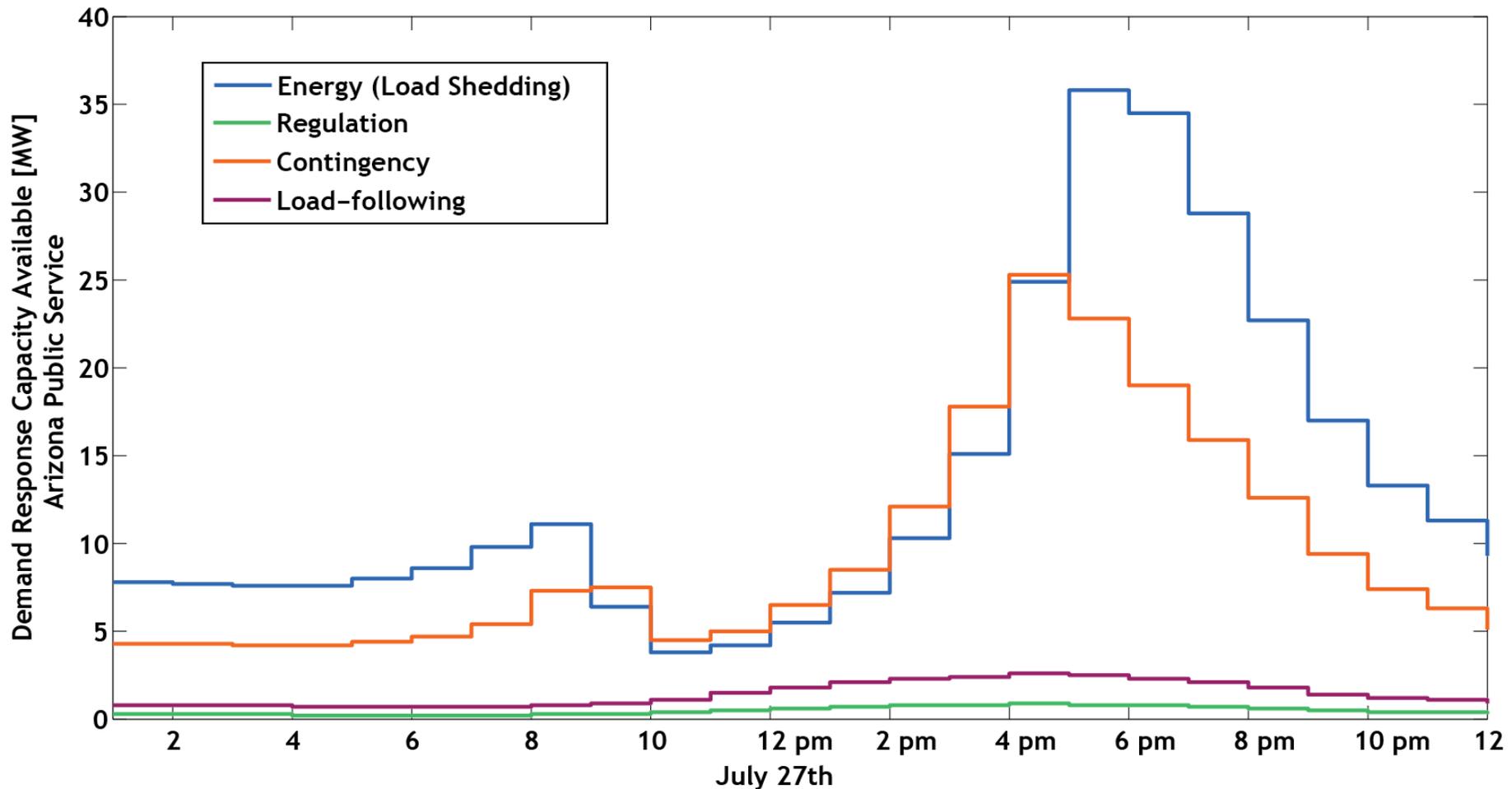
DR availability for energy is constrained by a hourly profile that is a fraction of the total end use load. Example: Commercial Space Cooling has a peak “sheddability” that is acceptable and controllable of 12.5% of the total commercial cooling load. [see Olsen, et al. 2013]

DR Grid Service Availability



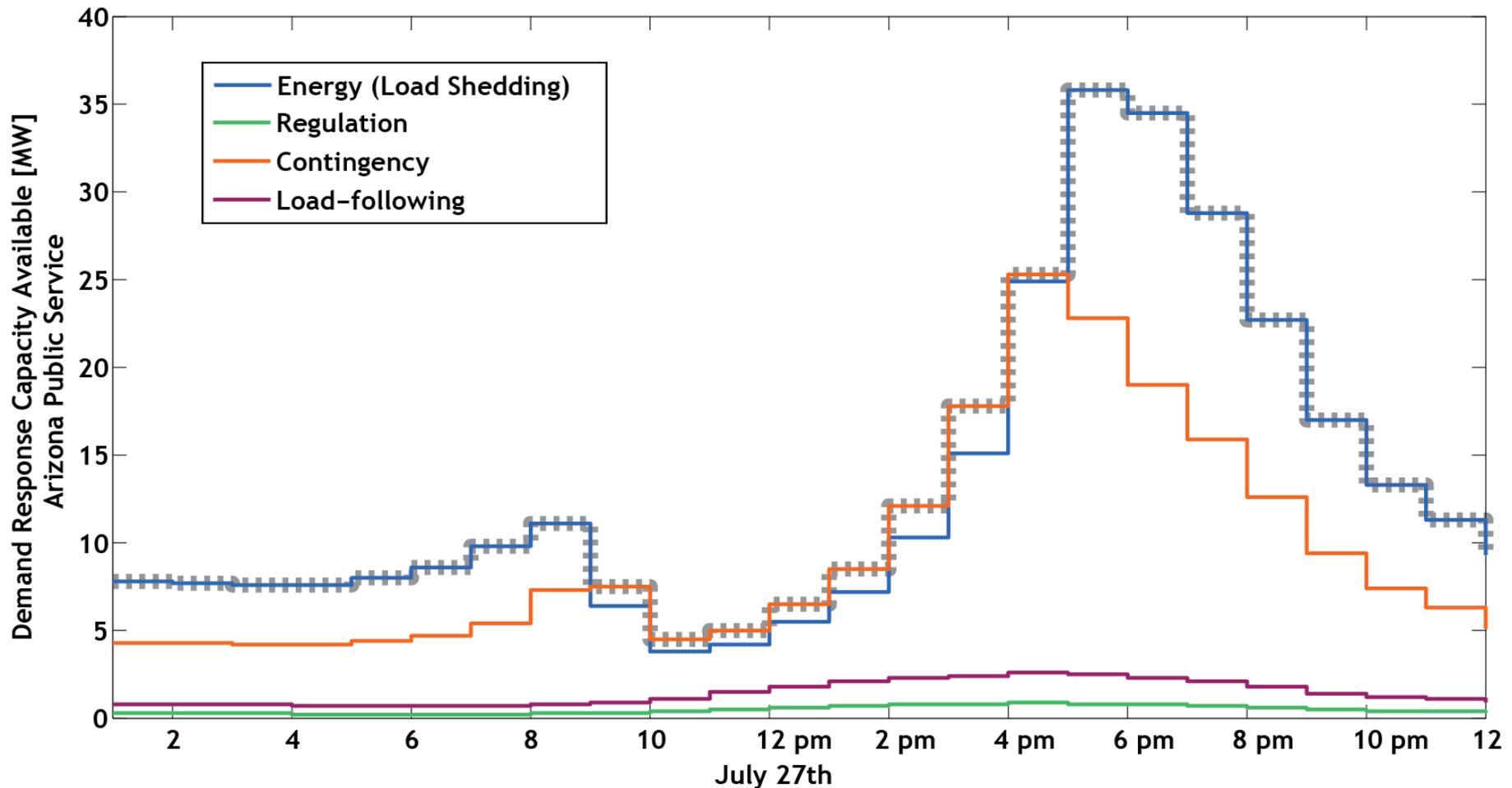
Load shedding, in some types of DR, results in a shift of load. We expect commercial buildings to primarily use a pre-cooling strategy between the hours of 6 am and 6 pm. The system operator optimizes the load shedding and shifting to minimize the overall system cost.

DR Grid Service Availability



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.

DR Grid Service Availability



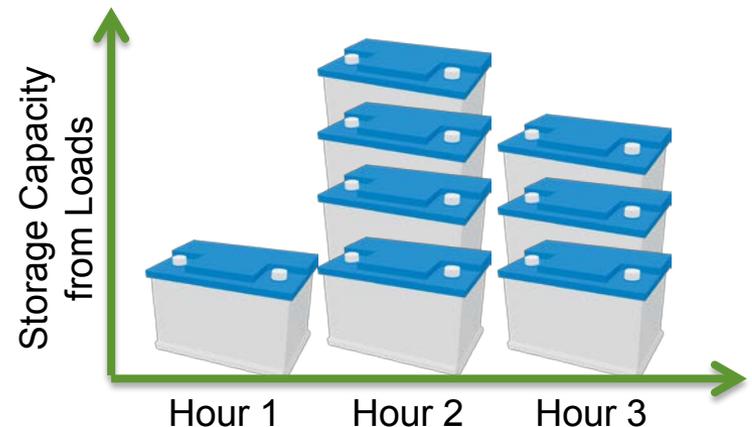
The sum of the DR allocations across energy and ancillary services is constrained by the maximum availability of end use load. All services were bid at \$0/MW-h, and thus were preferentially selected to be “first” in the dispatch/service stack.

DR Modeling

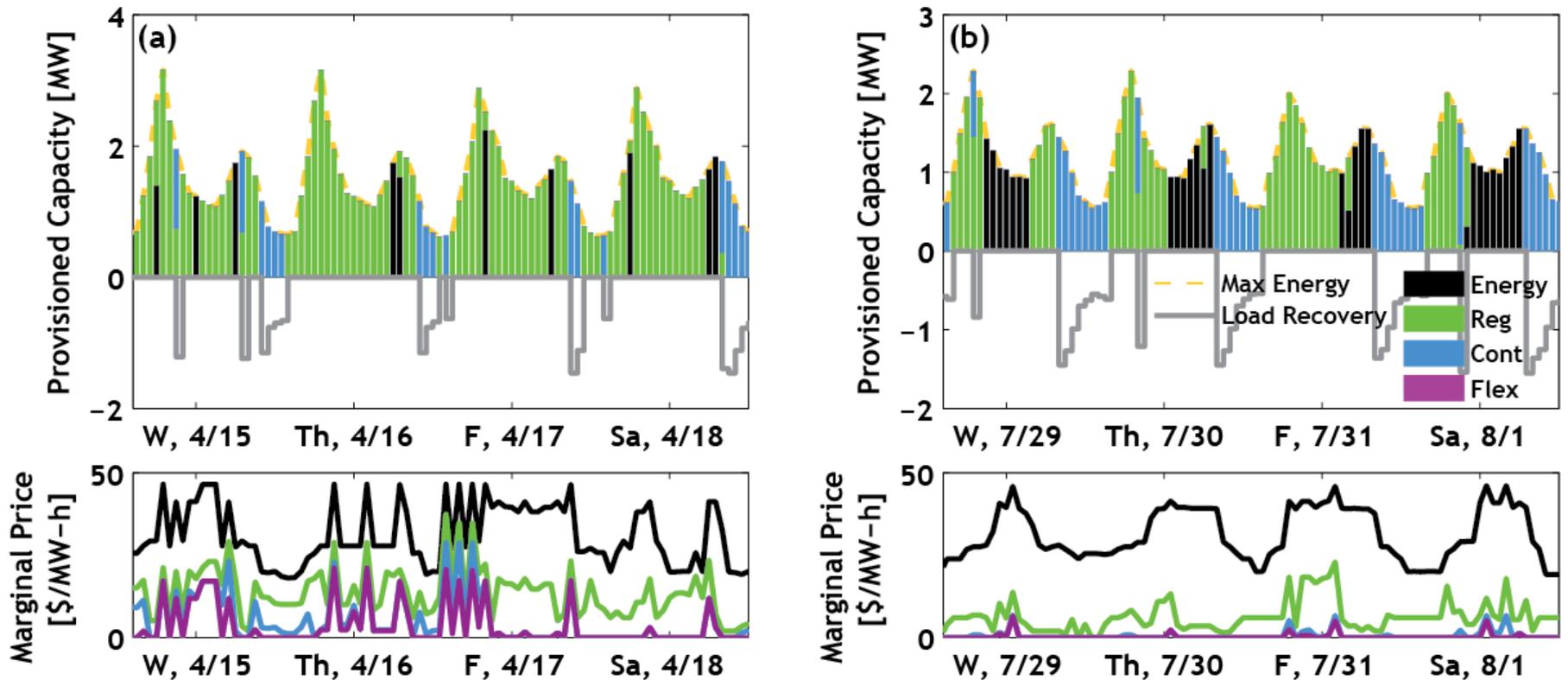
- **Commercial**
 - Space cooling, space heating, lighting, ventilation
- **Residential**
 - Space cooling, space heating, water heating
- **Municipal**
 - Freshwater pumping, highway lighting, wastewater pumping
- **Industrial**
 - Agricultural irrigation pumping, data centers, refrigerated warehouses

Demand response, from a modeling perspective, is very similar to storage.

Implemented in PLEXOS – production cost model – DR is modeled as a virtual, co-optimized storage device (dis-charge, charge) with hourly profiles defined for energy and each ancillary service.

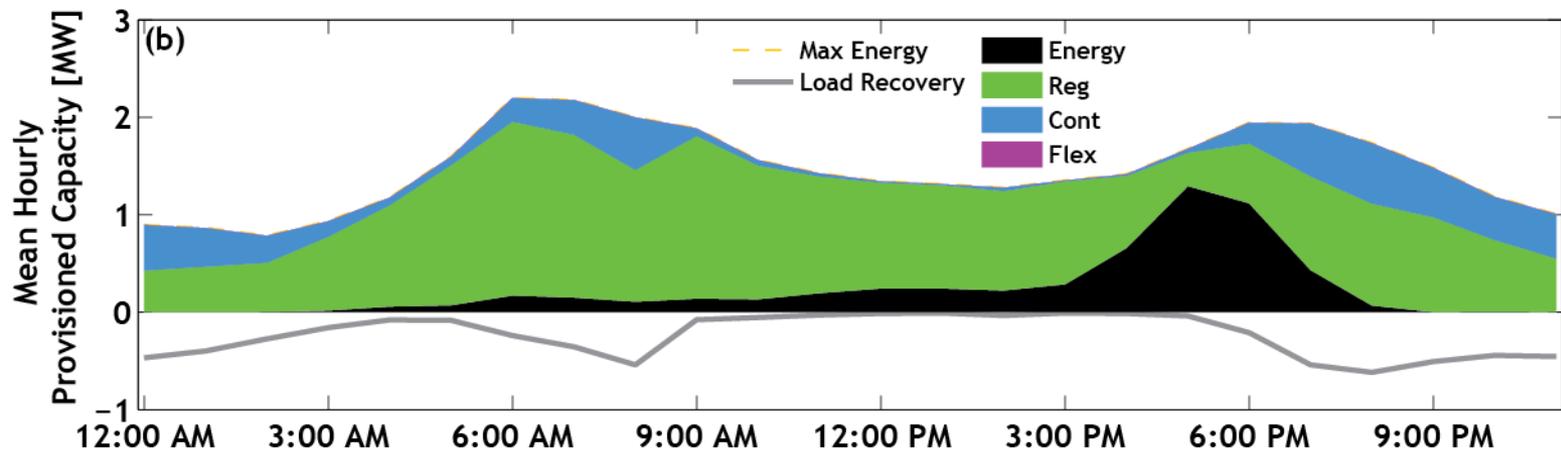
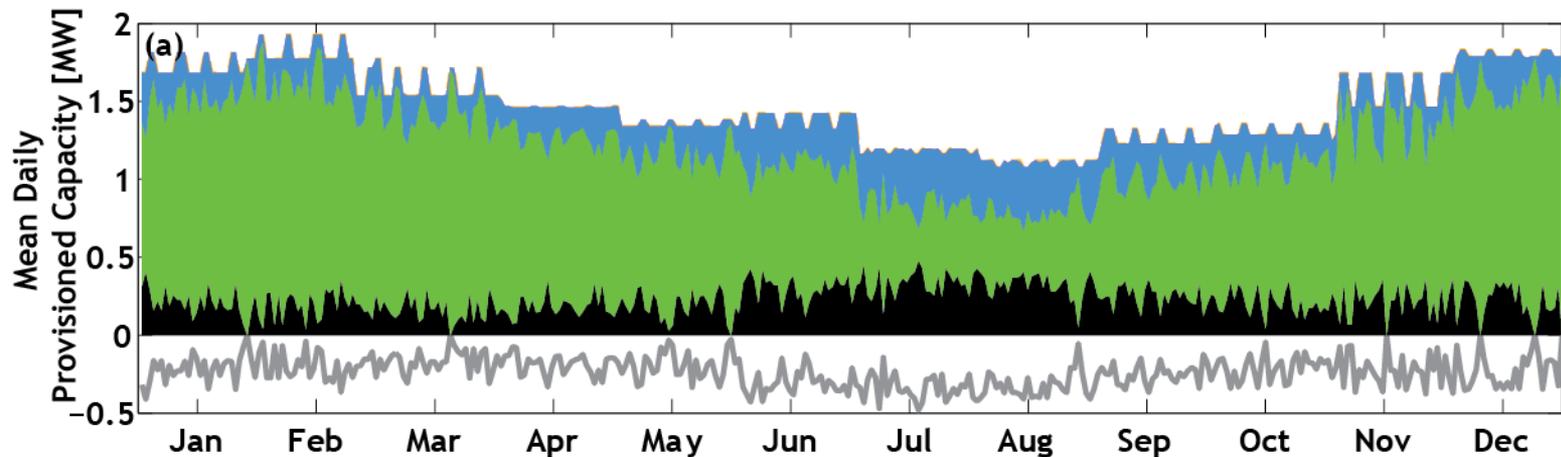


Modeling Results: Residential Water Heating



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.

Modeling Results: Residential Water Heating



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 of Demand Response

Value to Generation System

Production cost savings

- Avoided Fuel Off take
- Avoided Generator Startups and Shutdowns
- Avoided Generator Ramping

Production cost models optimize the total cost (fuel, starts, VO&M, and wear & tear bids) of producing energy under transmission, generator operation, and other defined constraints.

Value to Load

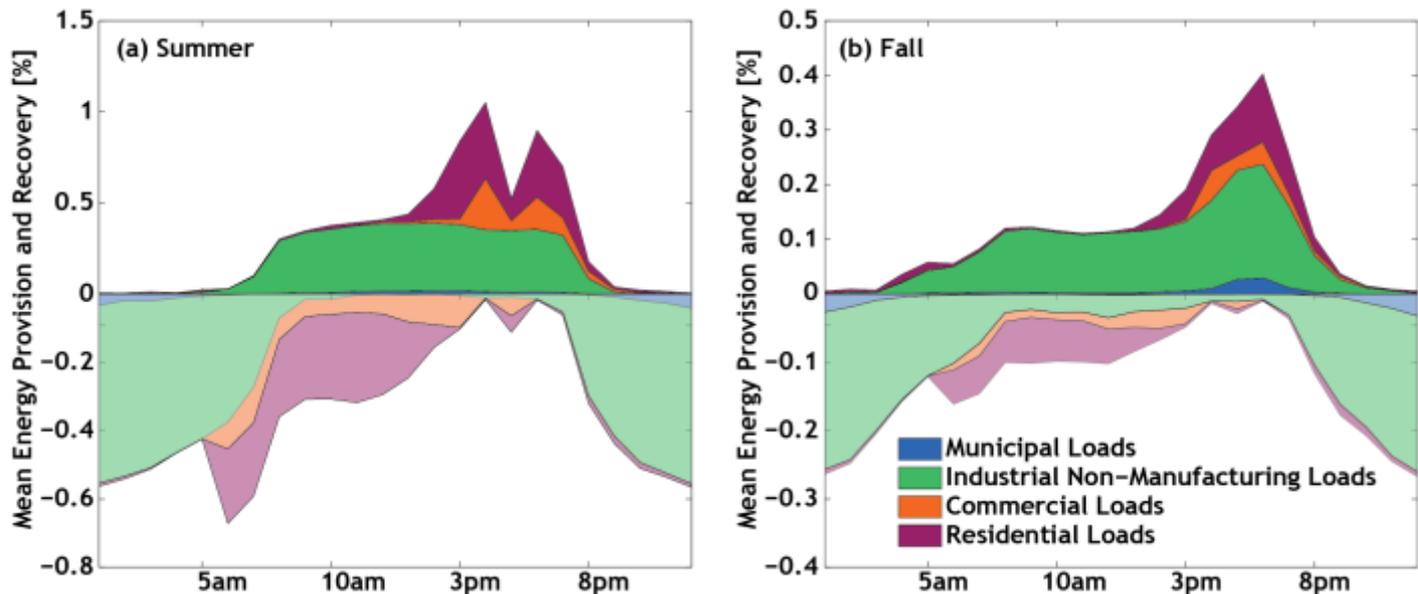
Revenue:

- \$/kW (peak capacity) of end use offered to system
- \$/end use enabled
- \$/MW-h of grid service provided

Revenue is based on the marginal cost of the grid service (during each hour) multiplied by the provision of that service. Marginal costs represent the production cost of providing the next unit of energy/reserves – and therefore are generally an overestimate of the total production cost.

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%



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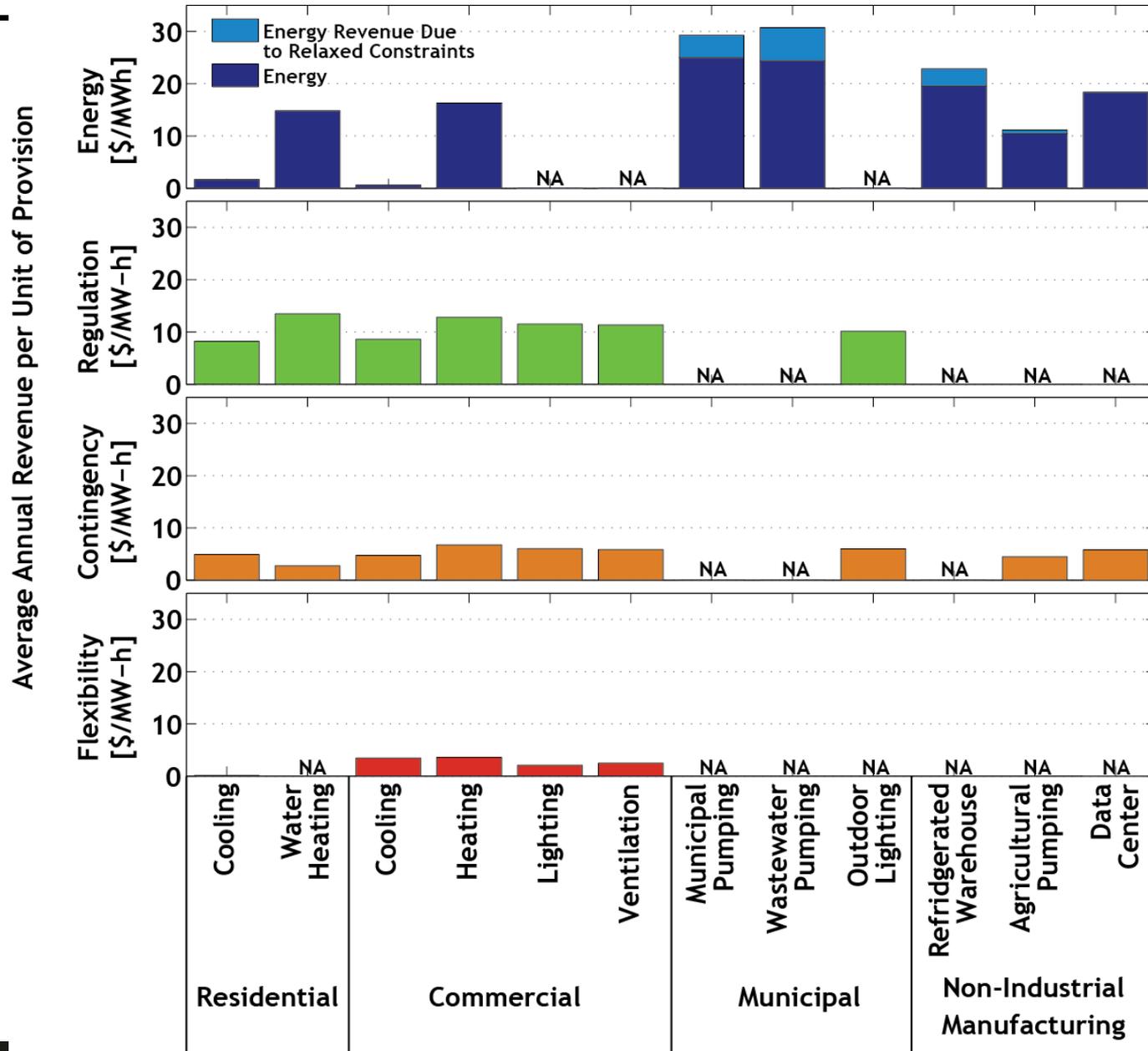
Dividing \$7.9M in production cost savings by the **peak DR capacity** enabled, 293 MW, yields a value of \$26.91/kW-yr of DR capacity.

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.

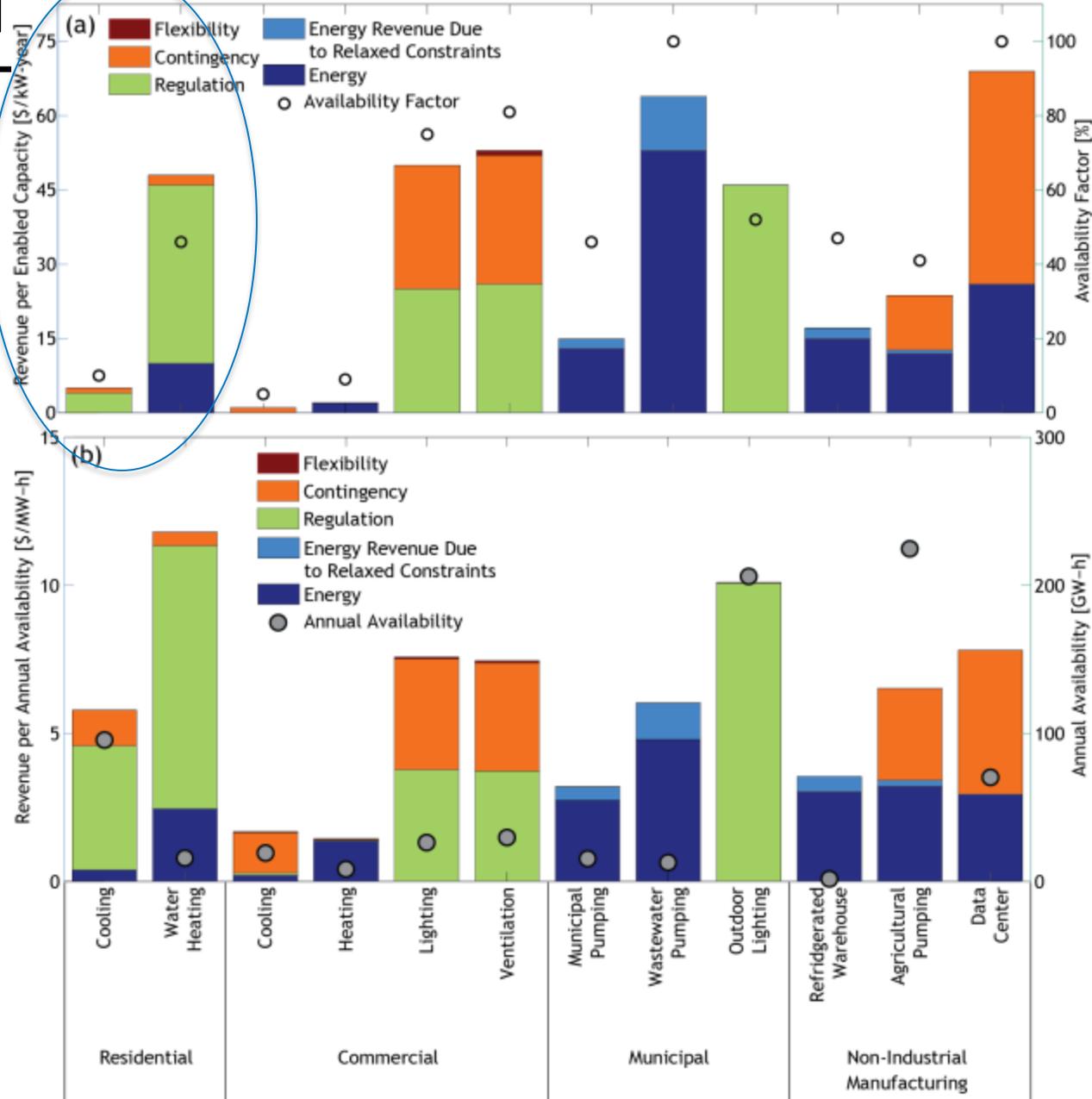
Value to Load

- Revenue is based on the marginal cost of the grid service (during each hour) multiplied by the provision of that service. Marginal costs represent the production cost of providing the next unit of energy/reserves – and therefore are generally an overestimate of the total production cost.
- The annual revenue per unit of grid service provided by DR is fairly constant because the marginal cost for each grid service is fairly constant.



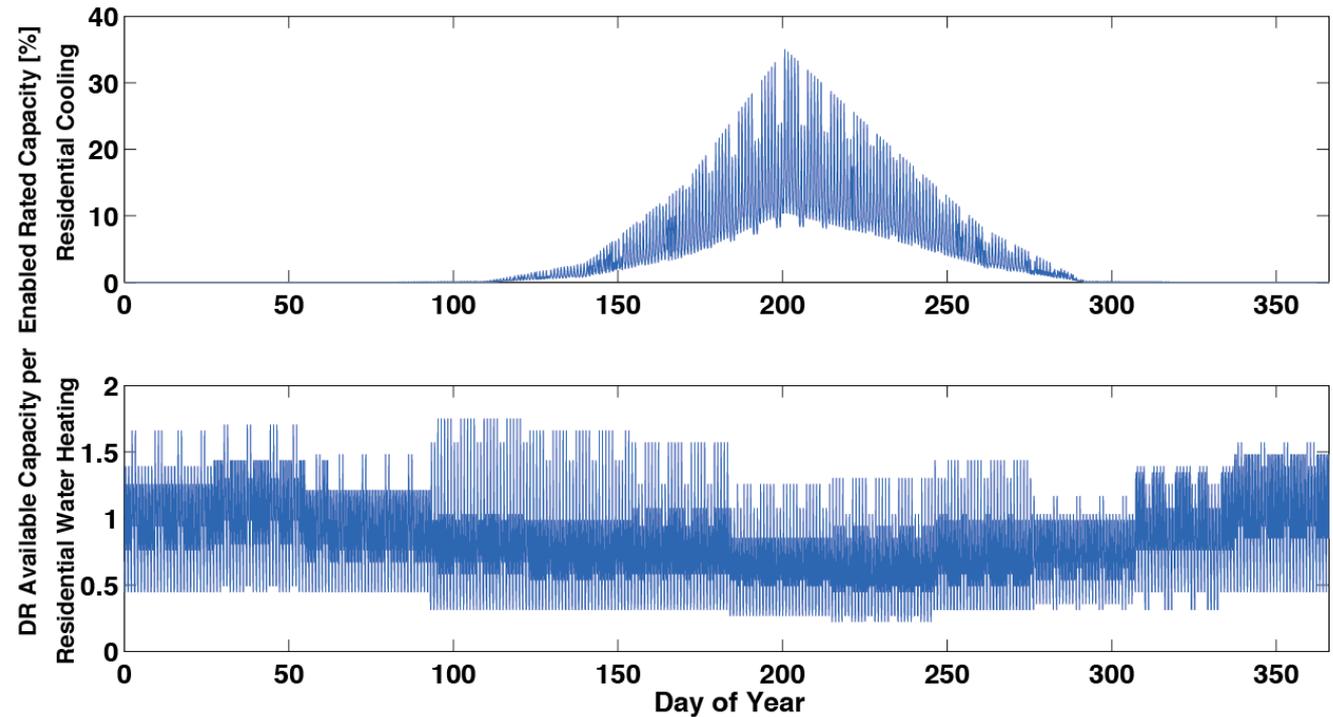
Value to Load

- 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.



Value to Load

- Cost – benefit analysis requires understanding the cost of enabling the service to the grid and the benefit accrued by providing the service.
- Example: residential space cooling has a higher value per unit enabled, while water heating has a higher value per annual availability.



Value Metric	Residential Cooling	Residential Water Heating
Revenue per peak capacity	\$5/kW-year	\$45/kW-year
Revenue per annual availability	\$15/MW-h	\$31/MW-h
Revenue per enabled capacity	\$3.1/kW-year	\$0.7/kW-year
Revenue per unit	\$7.4/unit-year	\$3.3/unit-year

Conclusions

- **DR benefits:**
 - The system benefits by reducing production cost – mainly avoided fuel costs
 - Loads providing DR have potential for multiple revenue streams
- **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
- **Modeling DR with increased fidelity paves the way for sensitivity analysis across renewable penetration, grid operation, and evolution of load**

Thank you!

Questions/comments:

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