Modeling Demand Response for Integration Studies

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Motivation

- Loads can provide multiple services to the grid through selective curtailment or load shifting (e.g., using thermal storage (building structure or water) to optimally shift energy intraday)
- Flexibility of some loads is well correlated to the system, resulting in high value; other loads have limited value.

Demand Response participation in U.S. Electricity Markets (2013)

Table 3-3: Potential Peak Reduction from U.S. ISO and RTO Demand Response Programs

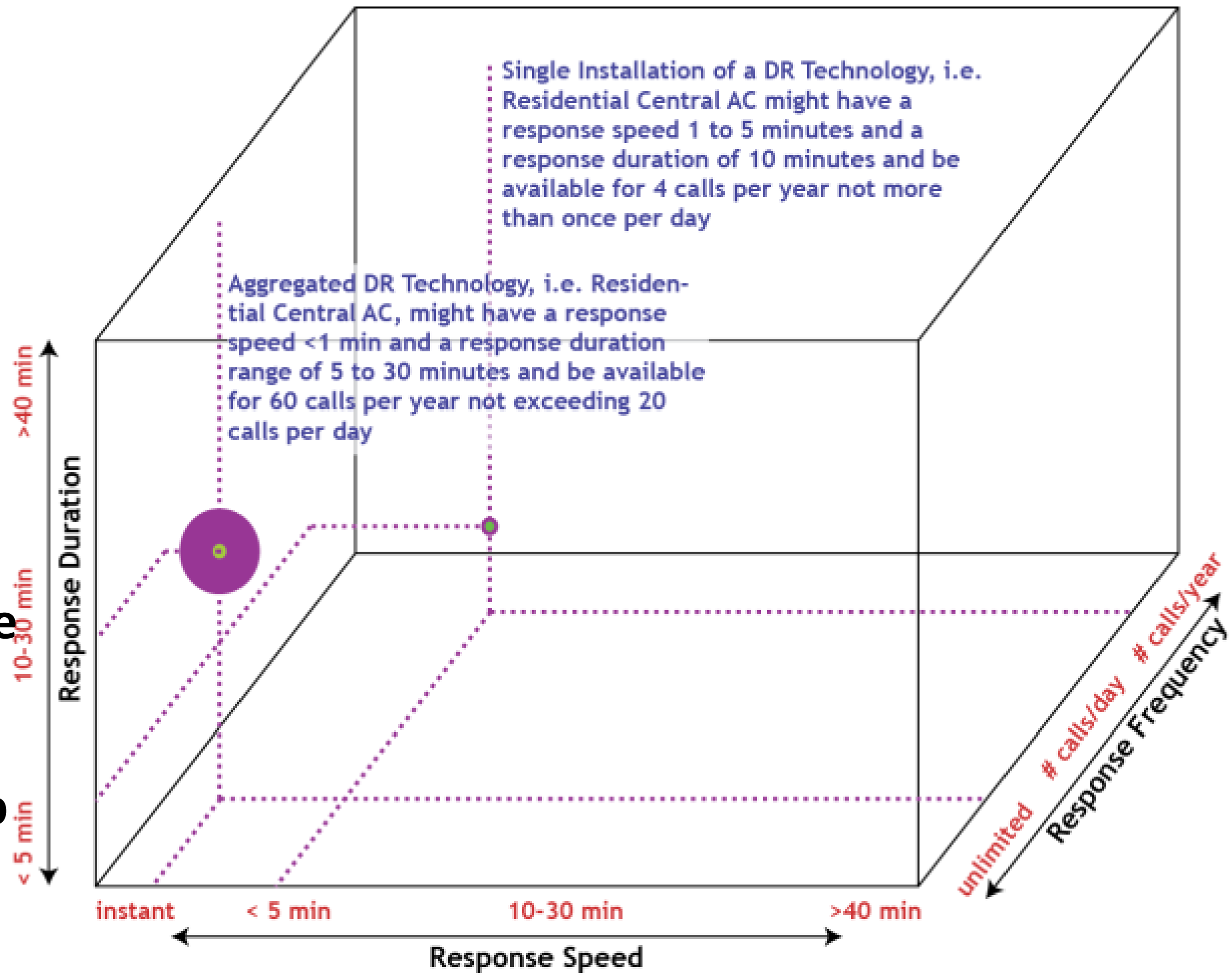
RTO/ISO	2012 Potential Peak Reduction (MW)	2012 Percent of Peak Demand[8]	2013 Potential Peak Reduction (MW)	2013 Percent of Peak Demand[8]
California ISO (CAISO)	2,430 [1]	5.2%	2,180 [9]	4.8%
Electric Reliability Council of Texas (ERCOT)	1,800 [2]	2.7%	1,950 [10]	2.9%
ISO New England, Inc. (ISO-NE)	2,769 [3]	10.7%	2,100 [11]	7.7%
Midcontinent Independent System Operator (MISO)	7,197 [4]	7.3%	9,797 [12]	10.2%
New York Independent System Operator (NYISO)	1,925 [5]	5.9%	1,307 [13]	3.8%
PJM Interconnection, LLC (PJM)	8,781 [6]	5.7%	9,901 [14]	6.3%
Southwest Power Pool, Inc. (SPP)	1,444 [7]	3.1%	1,563 [15]	3.5%
Total ISO/RTO	**26,346**	**5.6%**	**28,798**	**6.1%**

Source: Federal Energy Regulatory Commission (FERC), Assessment of Demand Response and Advanced Metering, December 2014.

Analysis of demand response is complex because end users see DR as an opportunity cost, while the system operator sees DR as a resource with no fuel cost.

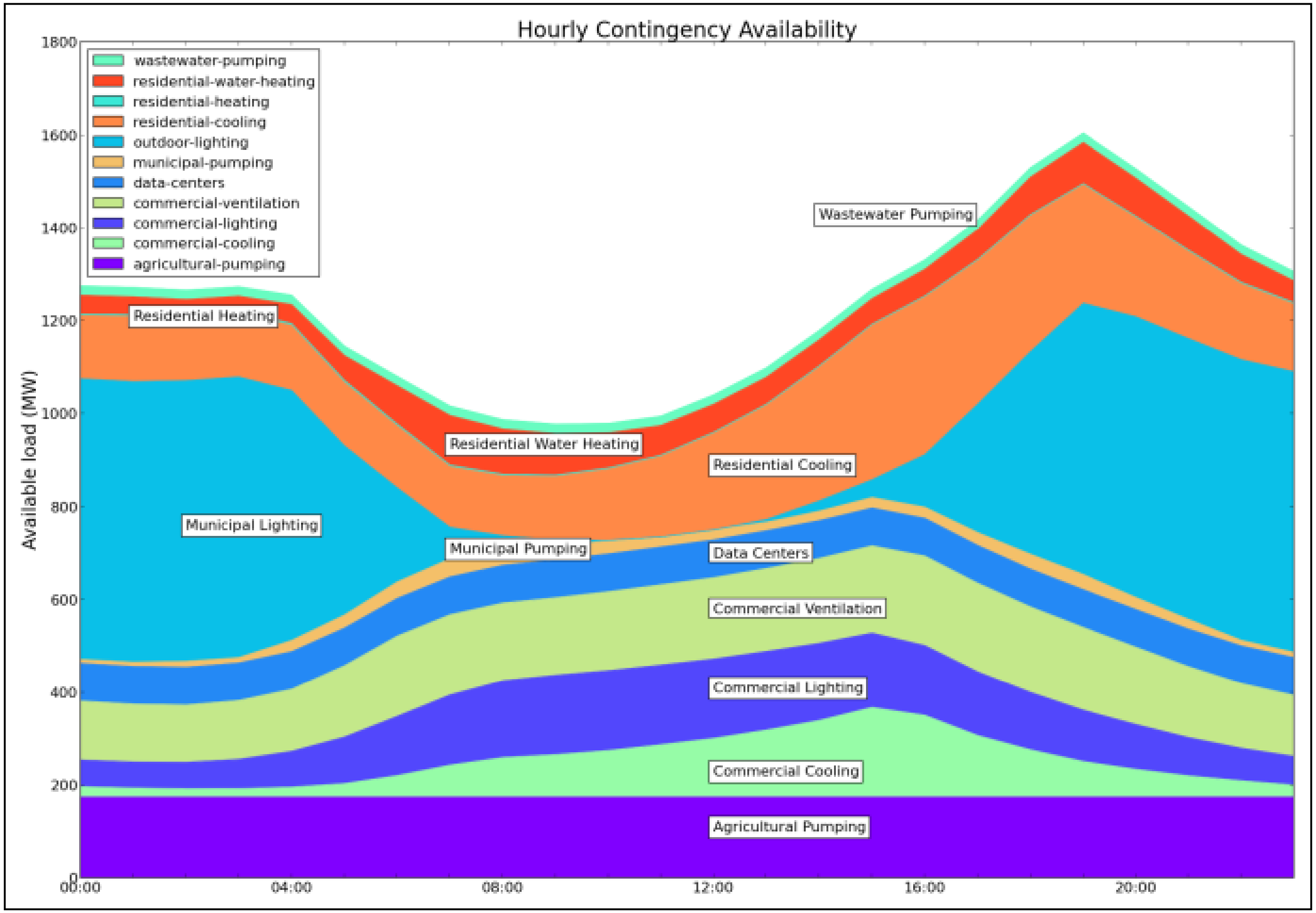
These characteristics change the opportunity cost and system value:

1. **Discrete DR events versus continuous resource operation**
2. **Small loads versus large loads**
3. **Single responsive loads versus aggregated response**
4. **Schedulable loads versus service interruption/disturbance**



Demand response end uses

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



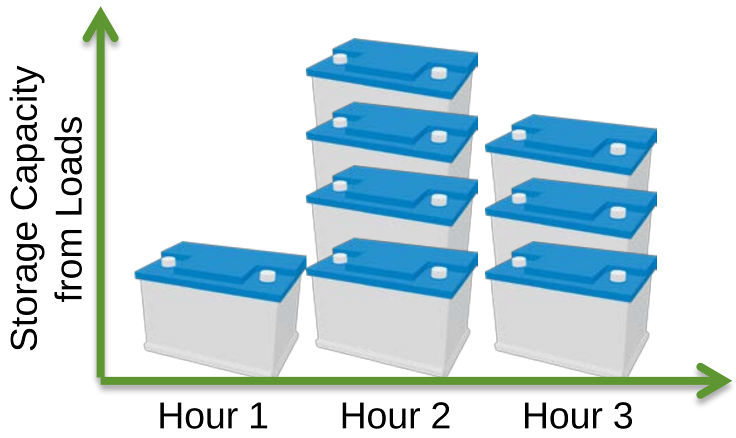
Olsen, D. J.; Kiliccote, S.; Matson, N.; Sohn, M.; Rose, C.; Dudley, J.; Goli, S.; Hummon, M.; Palchak, D.; Denholm, P.; Jorgenson, J.; Ma, O. (2013). [Grid Integration of Aggregated Demand Response, Part 1: Load Availability Profiles and Constraints for the Western Interconnection. 92 pp.; Lawrence Berkeley National Laboratory; Demand Response Research Center Report No. LBNL-6417E]

DR modeling approach

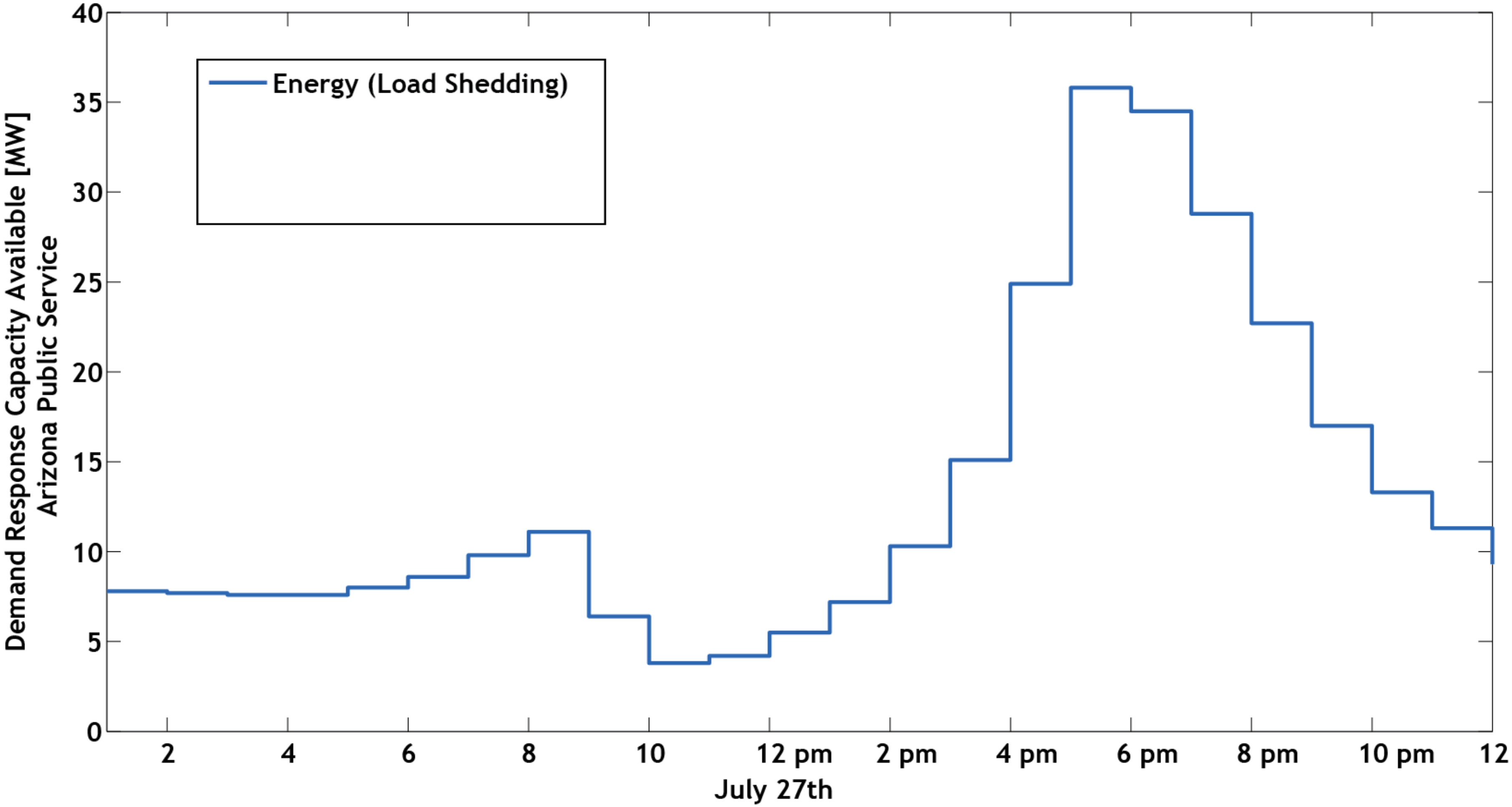
- We modeled the co-optimization of *aggregated* flexible load providing multiple grid services
- Using an hourly production cost model we evaluate the total system value and the revenue to flexible load for energy and ancillary services

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

DR is modeled as a virtual, co-optimized storage device (dis-charge, charge) with hourly profiles defined for energy and each ancillary service.

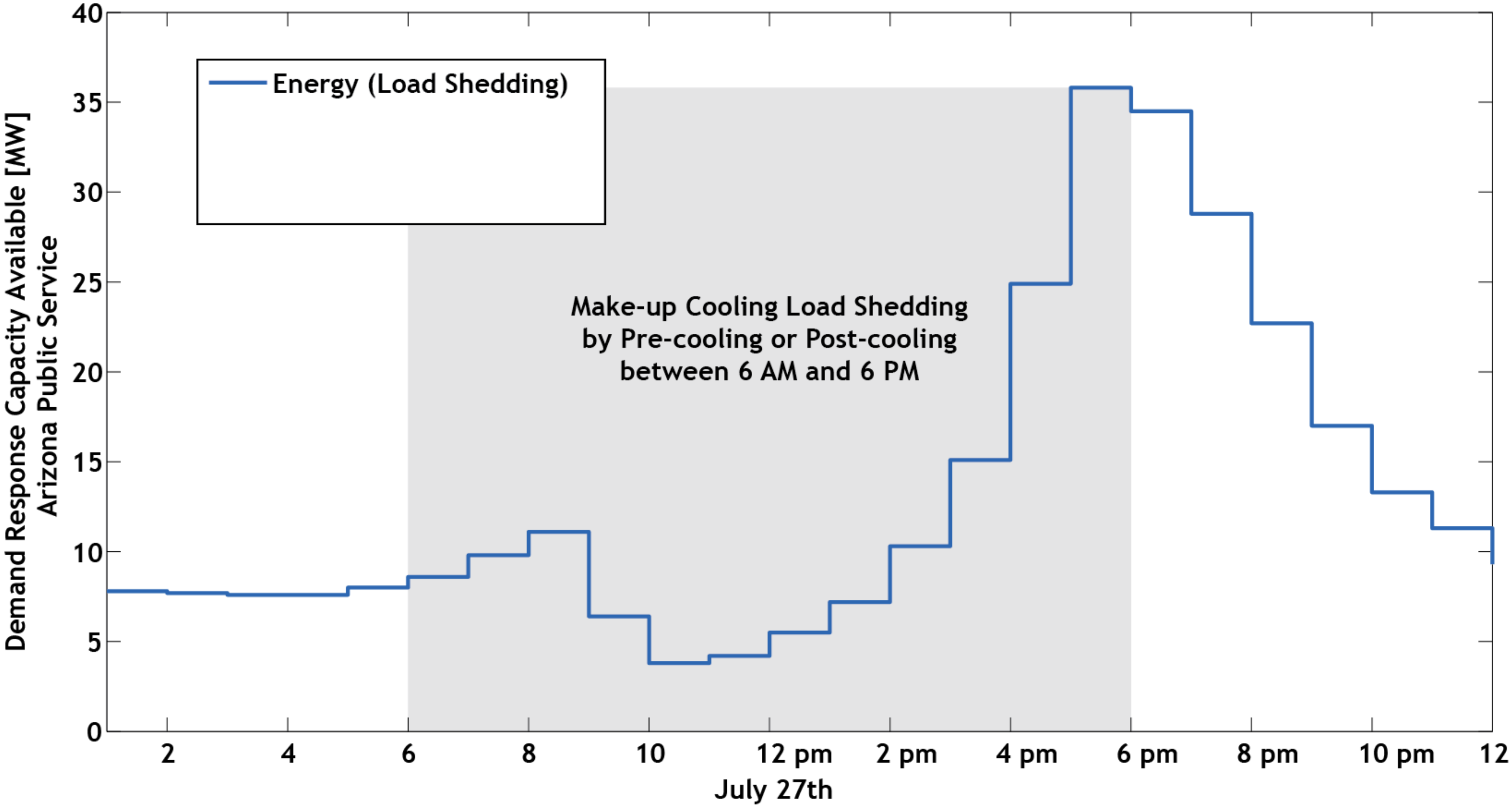


DR Grid Service Availability



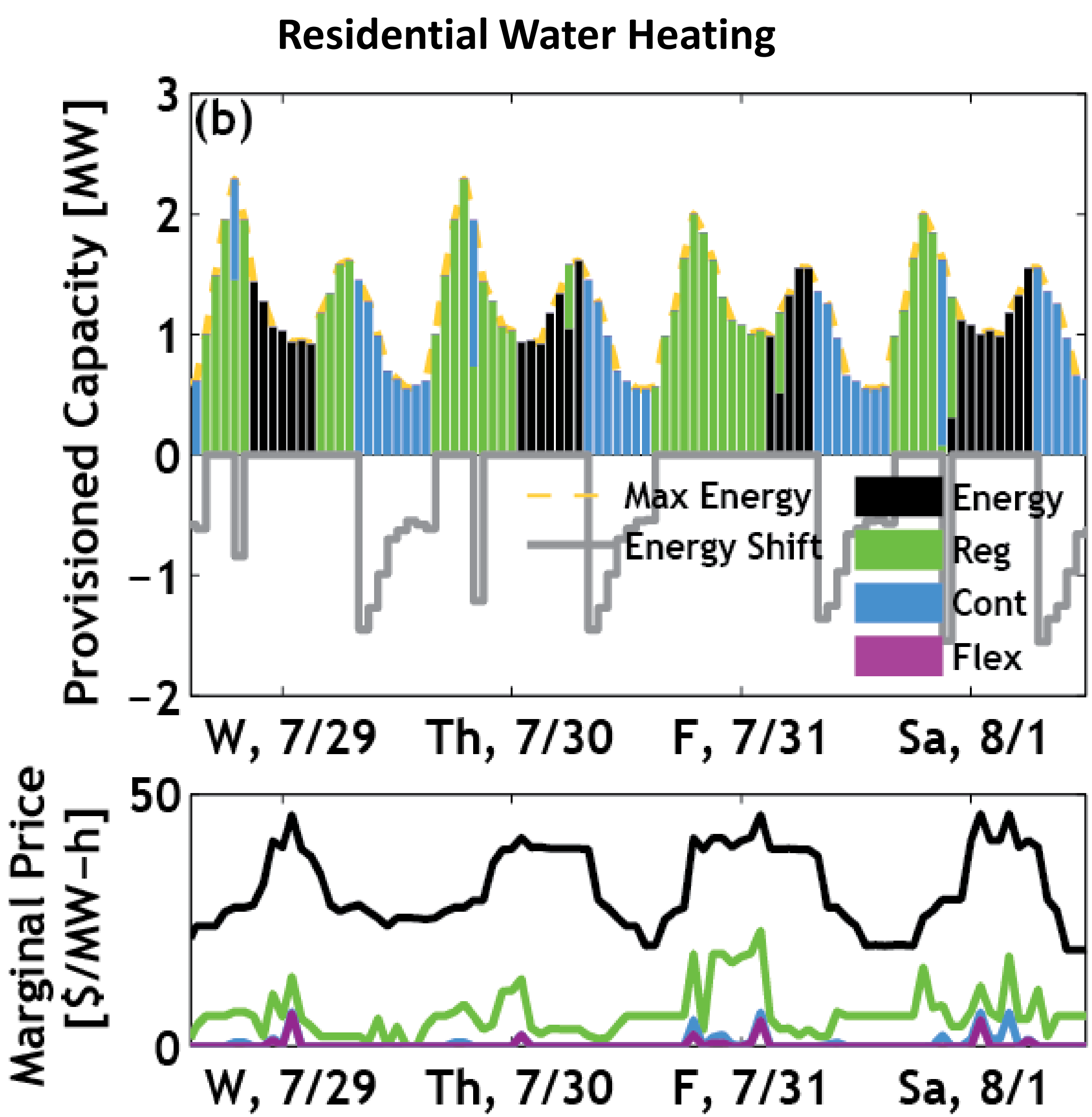
DR availability for energy is constrained by a hourly profile that is a fraction of the total end use load. Example: Commercial Space Cooling has a peak "sheddability" that is acceptable and controllable of 12.5% of the total commercial cooling load. [see Olsen, et al. 2013]

DR Grid Service Availability



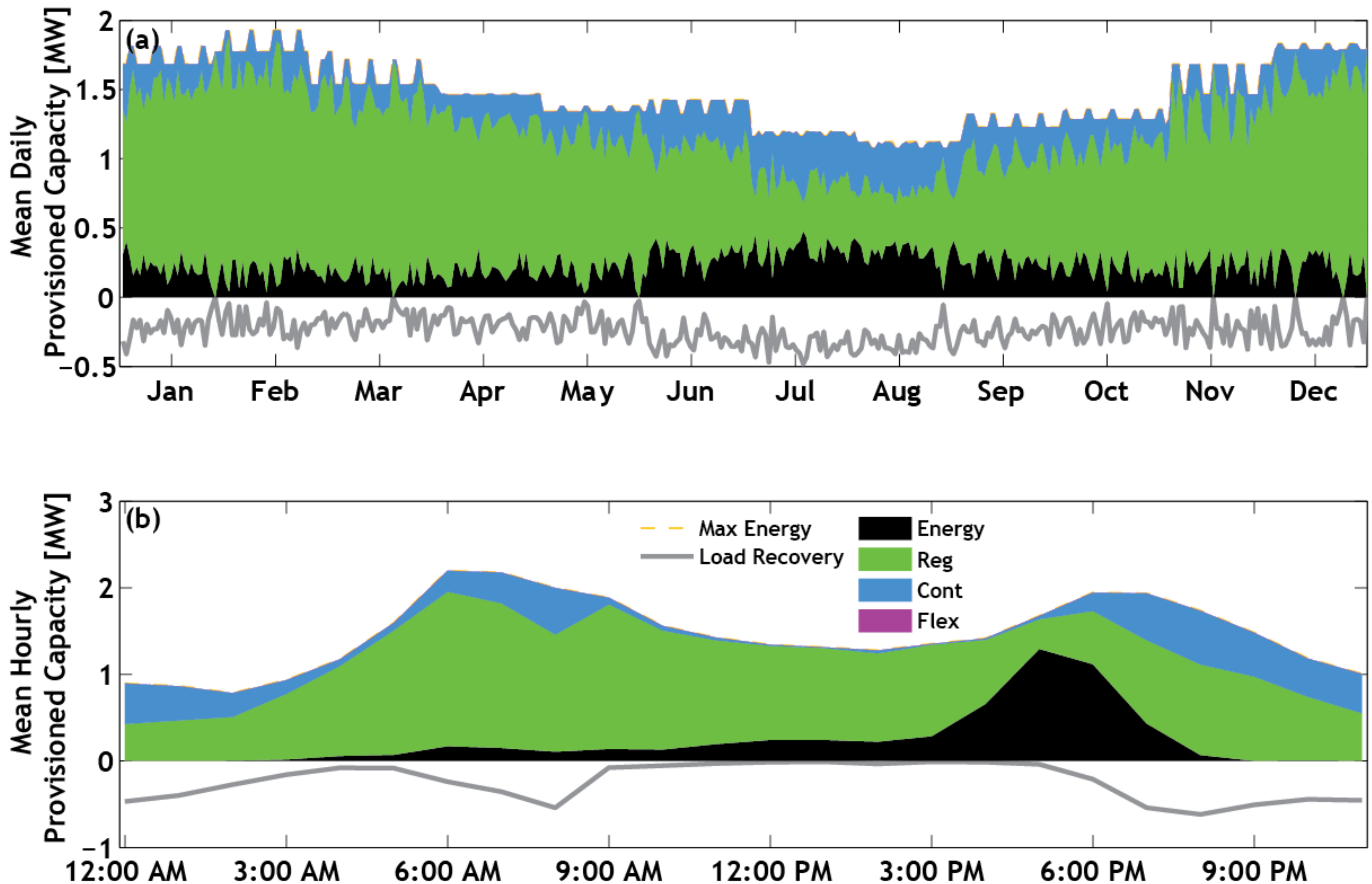
Load shedding, in some types of DR, results in a shift of load. We expect commercial buildings to primarily use a pre-cooling strategy between the hours of 6 am and 6 pm. The system operator optimizes the load shedding and shifting to minimize the overall system cost.

Results: Arbitrage and Co-optimization



The residential water heating profile represents a fraction of the total water heating load. The model is constrained to using approximately 8 hours of DR from the water heaters profile, per day. The DR allocated for energy use corresponds with the high price hours, and during the "payback" hours, the water heater is also allowed to provide contingency reserves. Regulation, the highest cost ancillary service, is provisioned during the remaining hours.

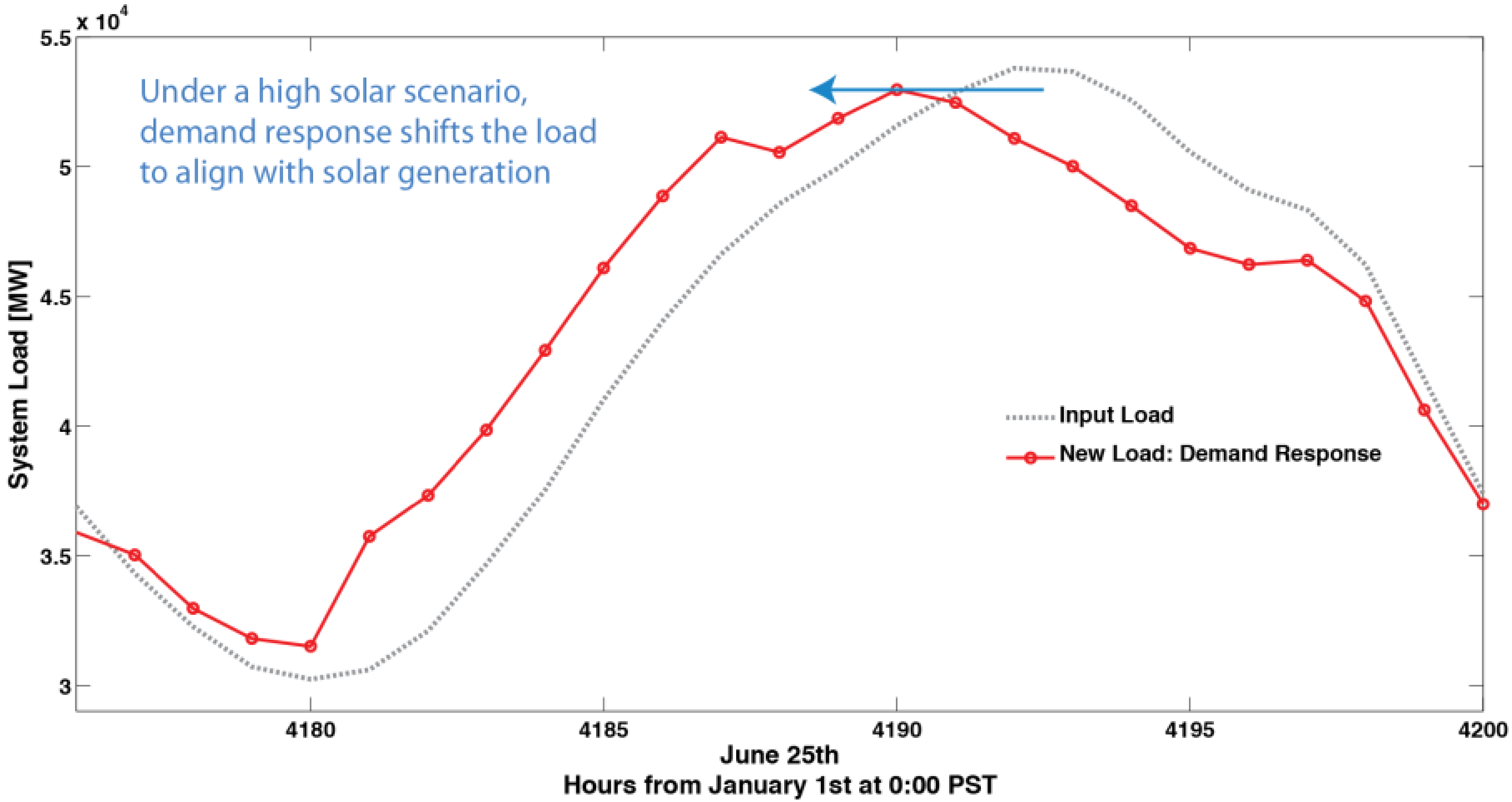
Modeling Results: Residential Water Heating



Scenario: 12% wind, 2% solar.

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 changes.

High renewable scenario (24% solar, 22% wind): New net load shape due to demand response



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.

Value to the System Operator

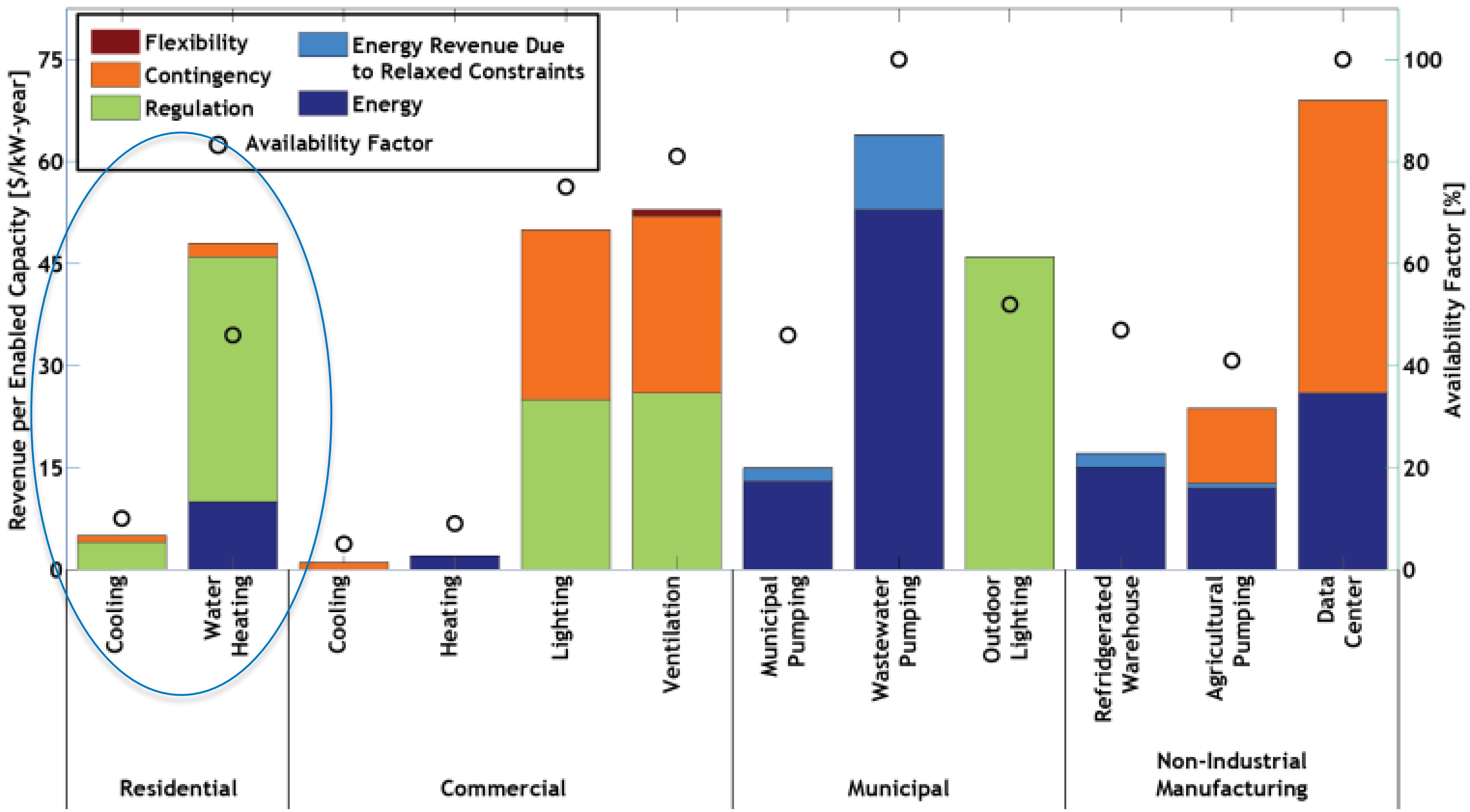
Production Cost [M$]	Base Case	Base Case with DR	Decrease in Cost with DR
Fuel Cost	1215.0	1208.0	-7 / -0.6%
Variable O&M Cost	151.8	152.2	0.4 / 0.3%
Start & Shutdown Cost	58.4	58.7	0.4 / 0.6%
Regulation Reserve Bid Price	4.5	2.9	-1.7 / -36.8%
Total Generation Cost	**1429.7**	**1421.8**	**-7.9 / -0.6%**

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.

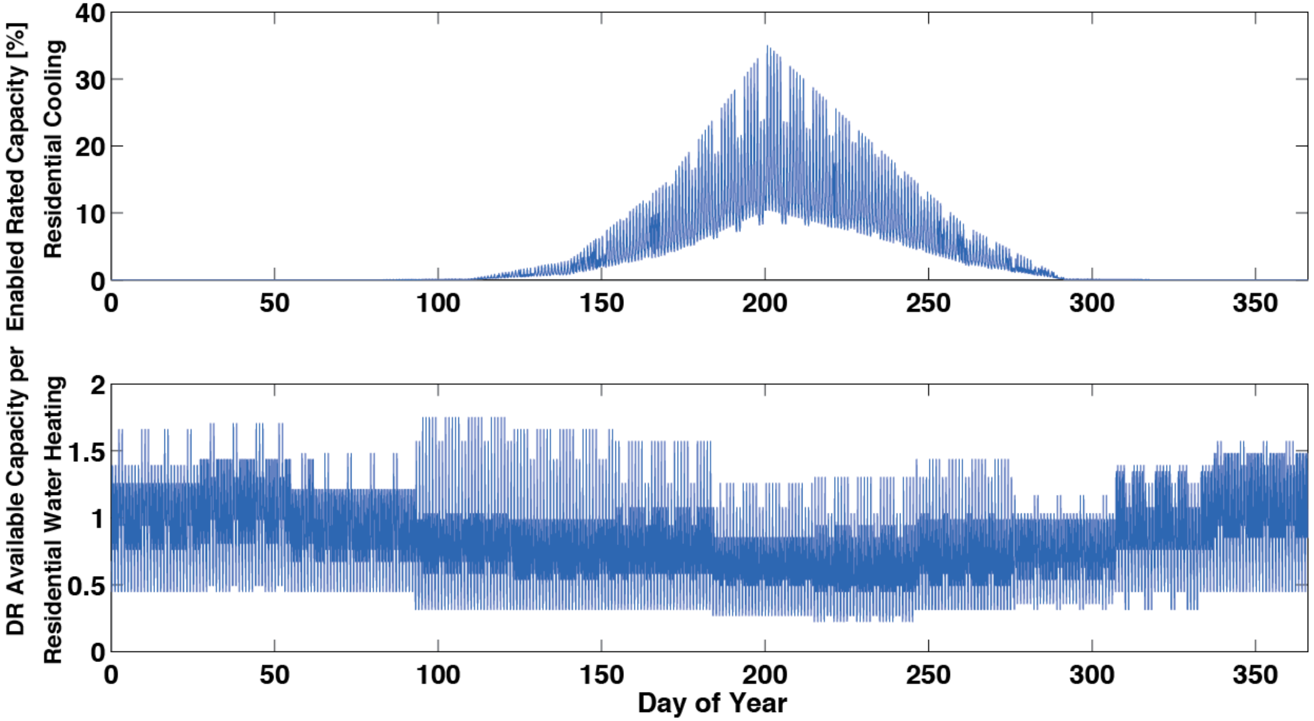
Value to Load



- 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.

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

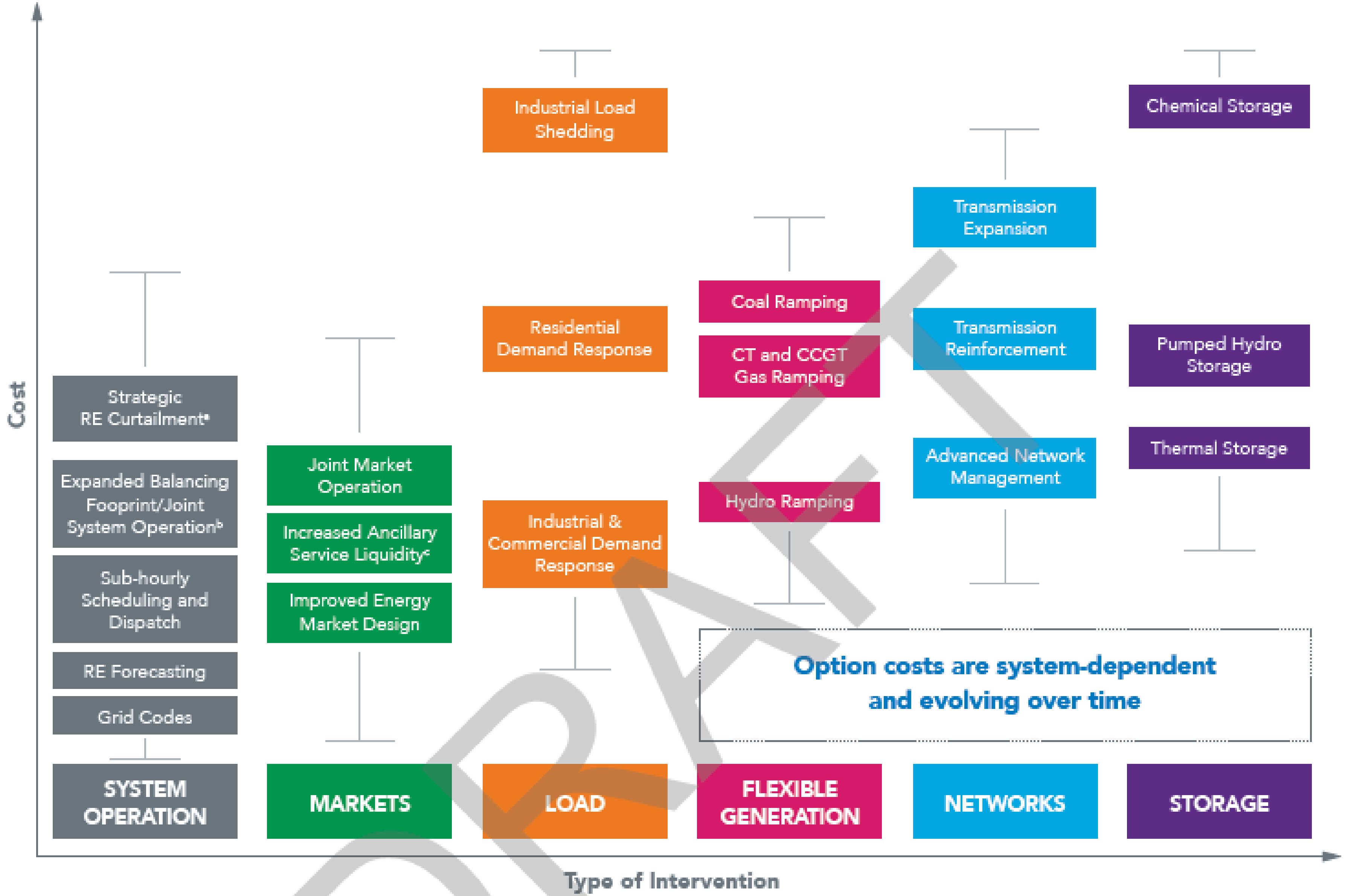
Modeling the hourly optimization of DR resources with transmission-level assets yields three insights:

- **Revenue per kilowatt of enabled DR capacity varies significantly across the resources from less than $1/kW-year to more than $65/kW-year**
- **DR availability is shaped by temperature (time of day) and season**
- **Use of DR for intraday energy shifting is directly affected by the opportunity for price arbitrage**

Considerations for IAM Frameworks

- **Incorporating DR**
  - Flexibility Attribute
  - Net Load Duration Curve
  - Supply Curve
- **What's needed**
  - Parameterized studies
    - f(weather, load, buildings…)
  - Economic potential estimates in various geographies
  - "Techno/economic" change
    - Learning?
    - Forecasts to 2100?
  - Incorporating institutional and occupant behavior?
  - Technical potential for demand response with high energy efficiency

Relative Economics of Integration Options



Thank you and questions

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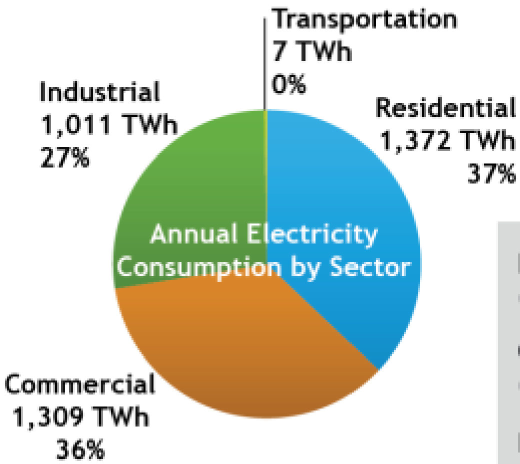
Types of Demand Response



2012 United States

	# of sites	peak capacity per site (approx.)
Industrial (facilities)	350,000	593.7 kW
Commercial (buildings)	4,600,000	58.5 kW
Residential (households)	113,000,000	2.5 kW

Direct load control:

- End use loads under the direct, remote control of the system operator or aggregator, e.g. Xcel Energy Saver Switch on residential air conditioners.
- Counts as firm capacity if the DLC device controls a peak load contributor

Interruptible Loads:

- Large loads (e.g. industrial) have historically supplied emergency load reduction in response to system operators request (typically a phone call).
- Annual and per event payments, or a better rate structure.
- Communication is person-to-person; control is supplied by the load operator; verification of performance is “obvious” to the system operator.

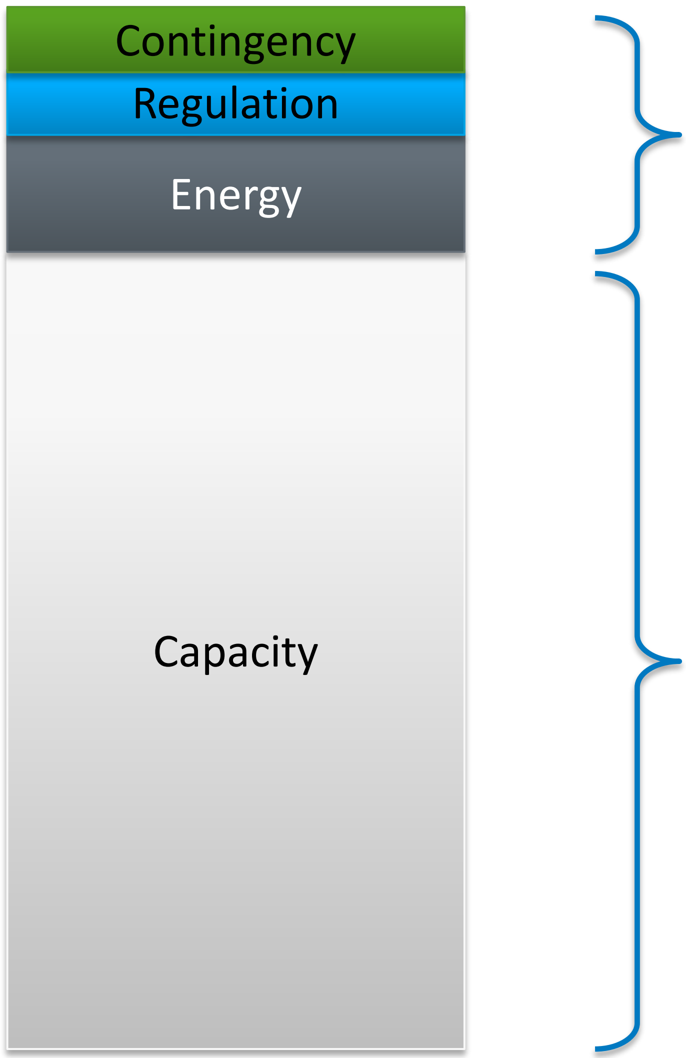
Price responsive:

- **Price responsive demand** is the ability of consumers to control their energy expenditures by changing their electricity use in **response** to wholesale electricity **prices**.

Scheduled load:

- Selectively schedule loads based on forecasted prices, agreement with system operator or utility, etc.
- For example, charging electric vehicles could be a slow, low power event or a fast, high power event, and either way the vehicle must be fully charged by the time the vehicle needs to perform a task.

Increasing DR participation in the electricity market hinges on the total value proposition



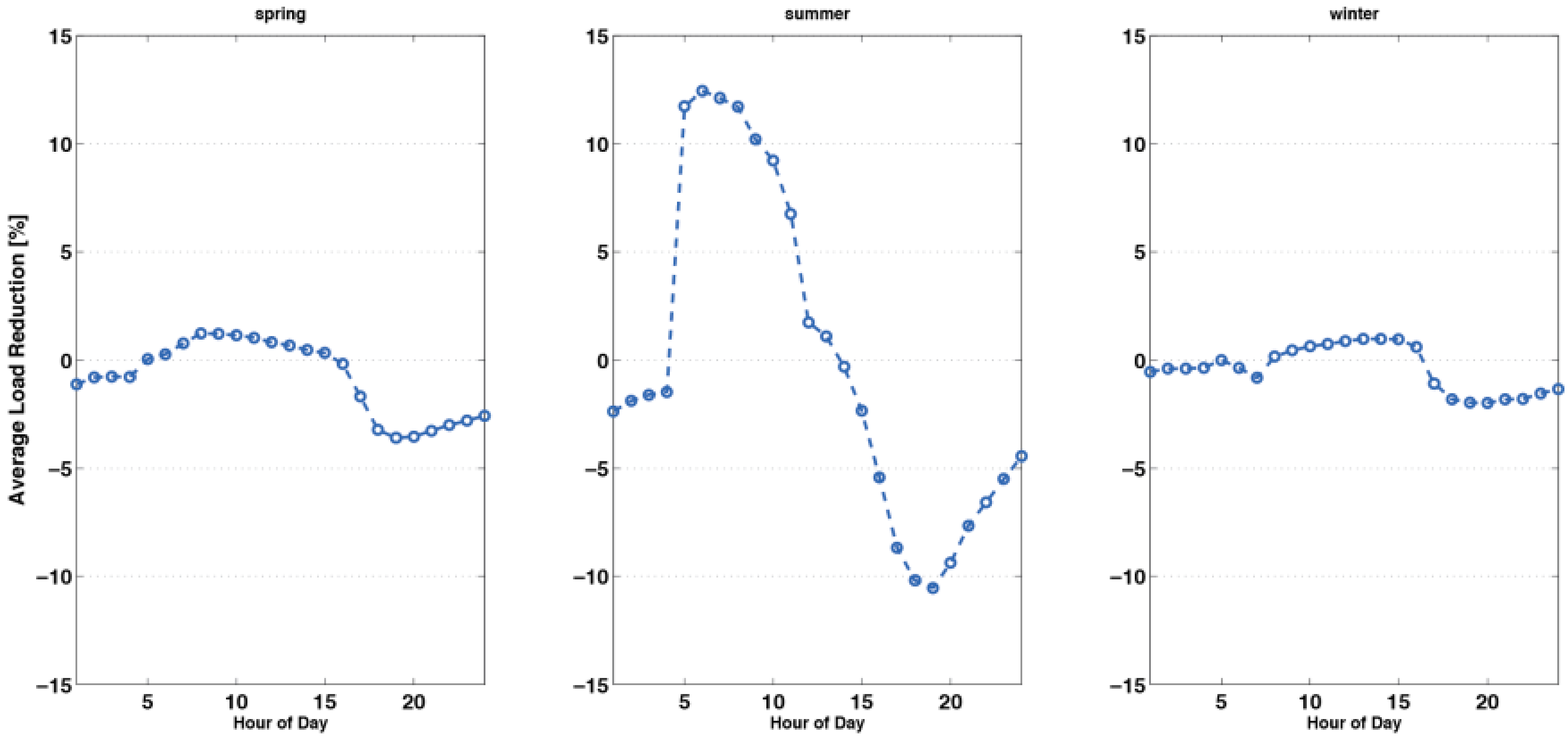
We can answer these questions under a wide variety of system conditions

Need new data, math, tools

Complicated calculation: energy limited, dynamic response, and varies by time/type/location

Location changes alternative capacity investments

Change in load shape: Loads available for demand response, arbitrage opportunity



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