Demand Response Research Center

BERKELEY LAB

Overview of R&D Related to Grid Interactive Efficient Buildings and Automated Demand Response

Dec 11, 2018

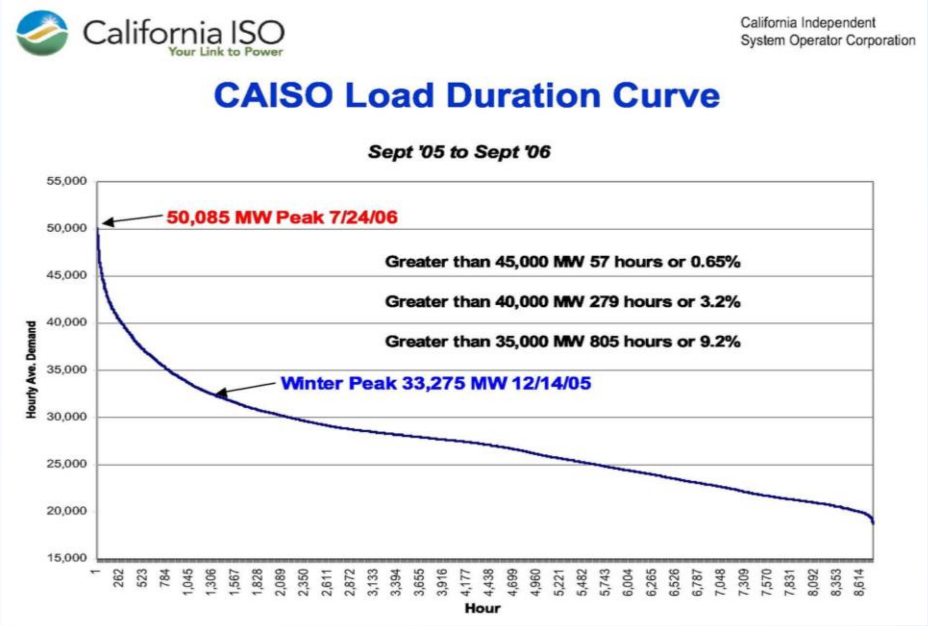
Mary Ann Piette

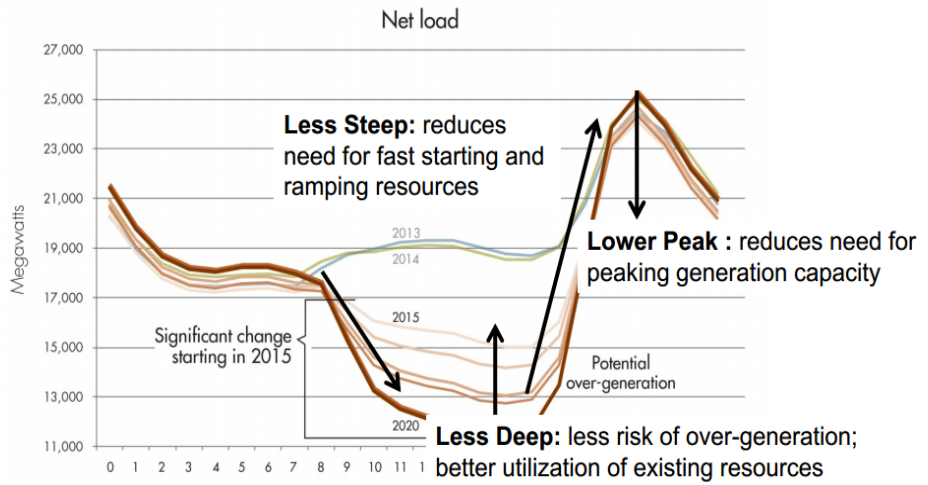
Presentation Outline

- The Need for Grid Services
- Development and Testing of DR Automation
- California DR Potential Study
- Current related and new DOE BTO Projects
  - GMLC 1.4.1 – Interoperability and Responsive Load
  - Four BTO Open Call Projects
- Summary and Future Directions

Challenges with the Grid

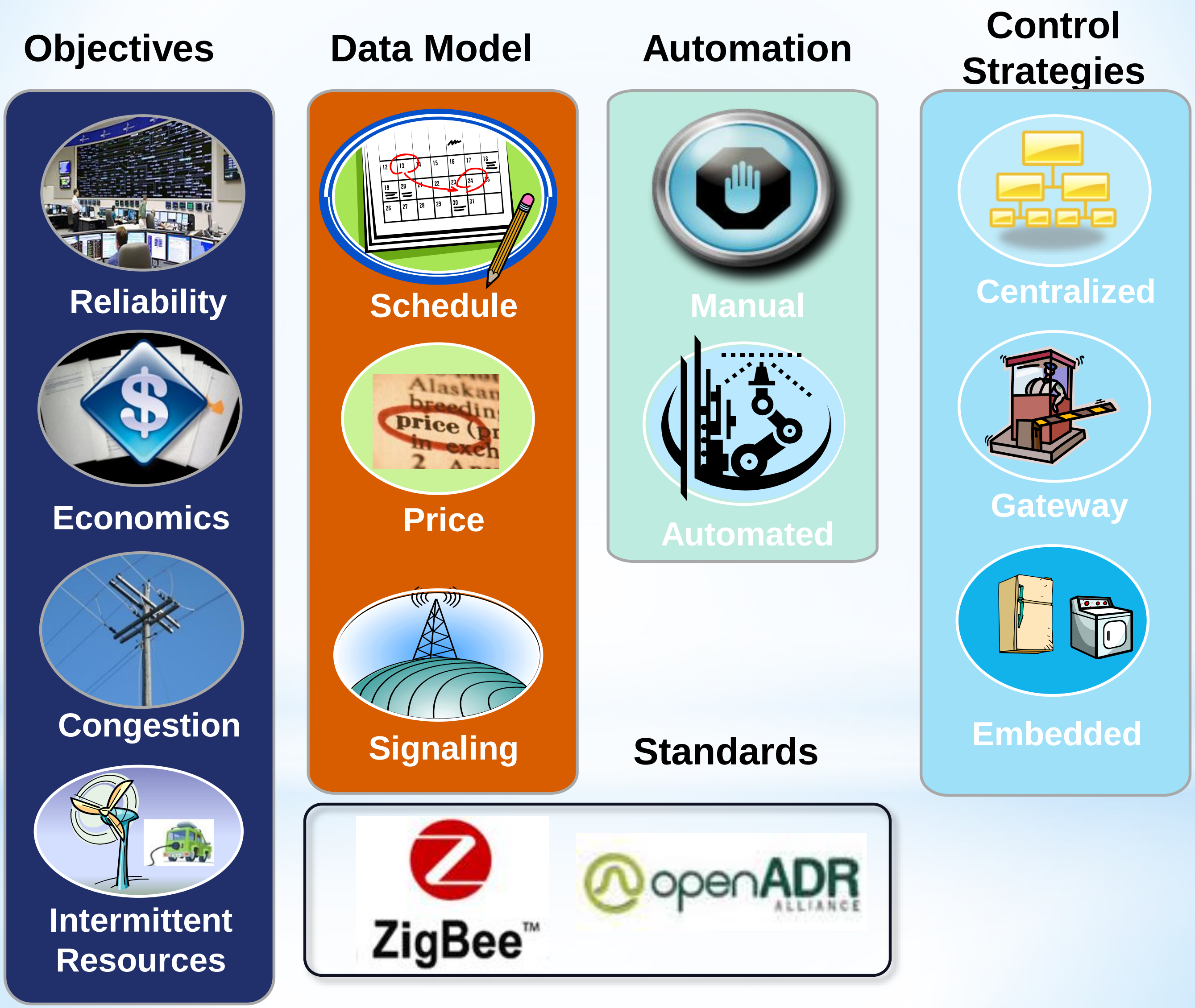
- Manage Peak Capacity During Hot Summer Days
- Improve Affordability of Electricity
- Improve Grid Reliability
- Enable More Renewables on Grid





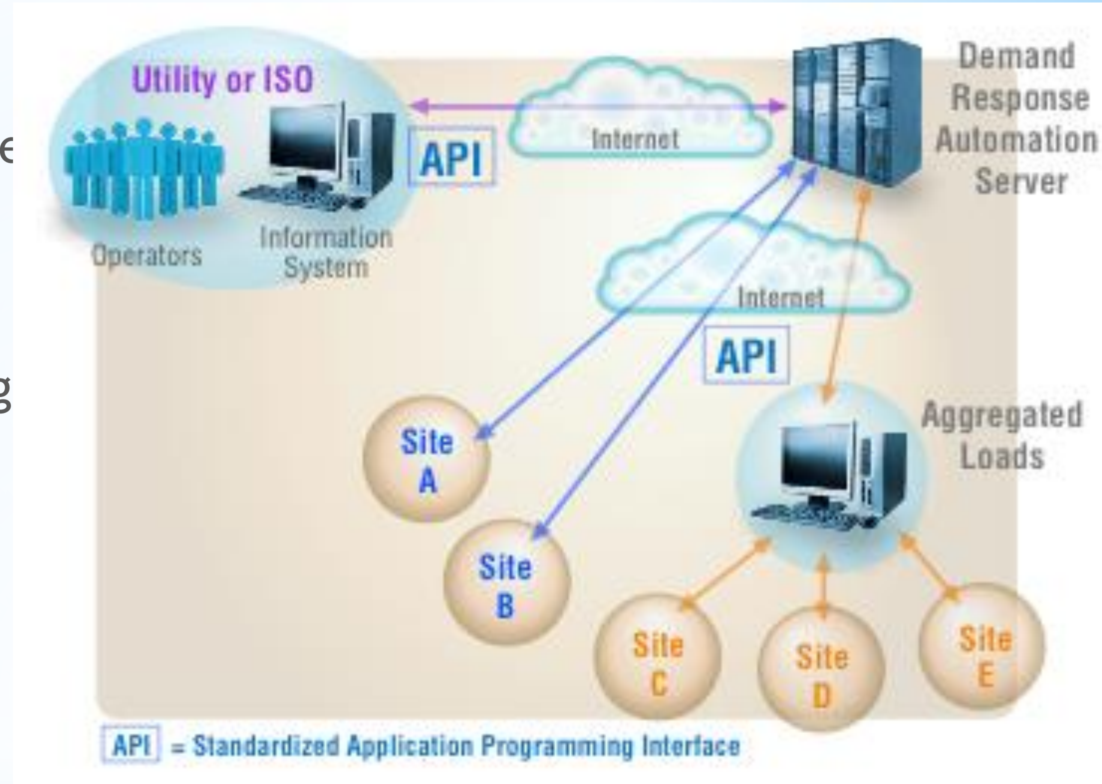
Note, this curve is being updated, it is used here to represent how we should look at what we are trying to accomplish

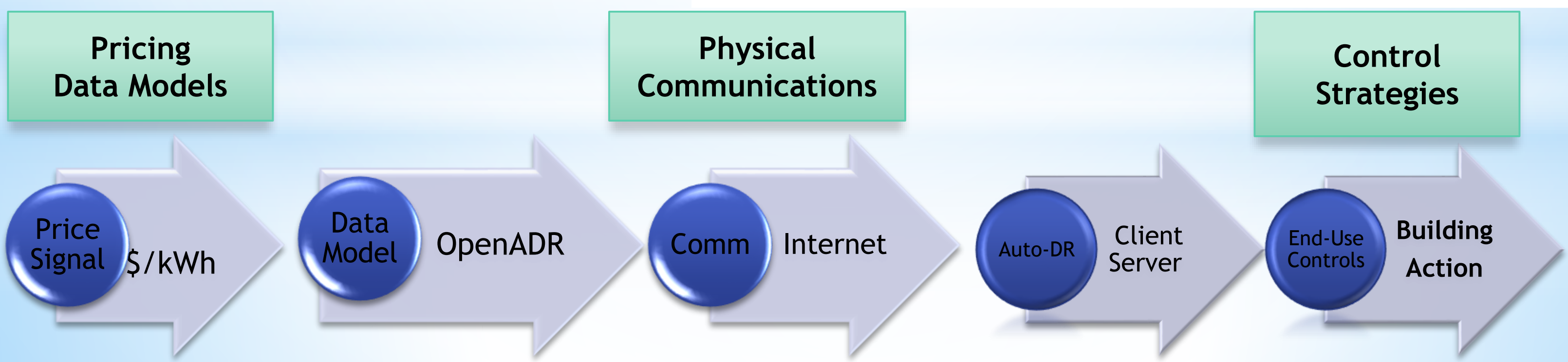
Motivation and Framework for Grid Services



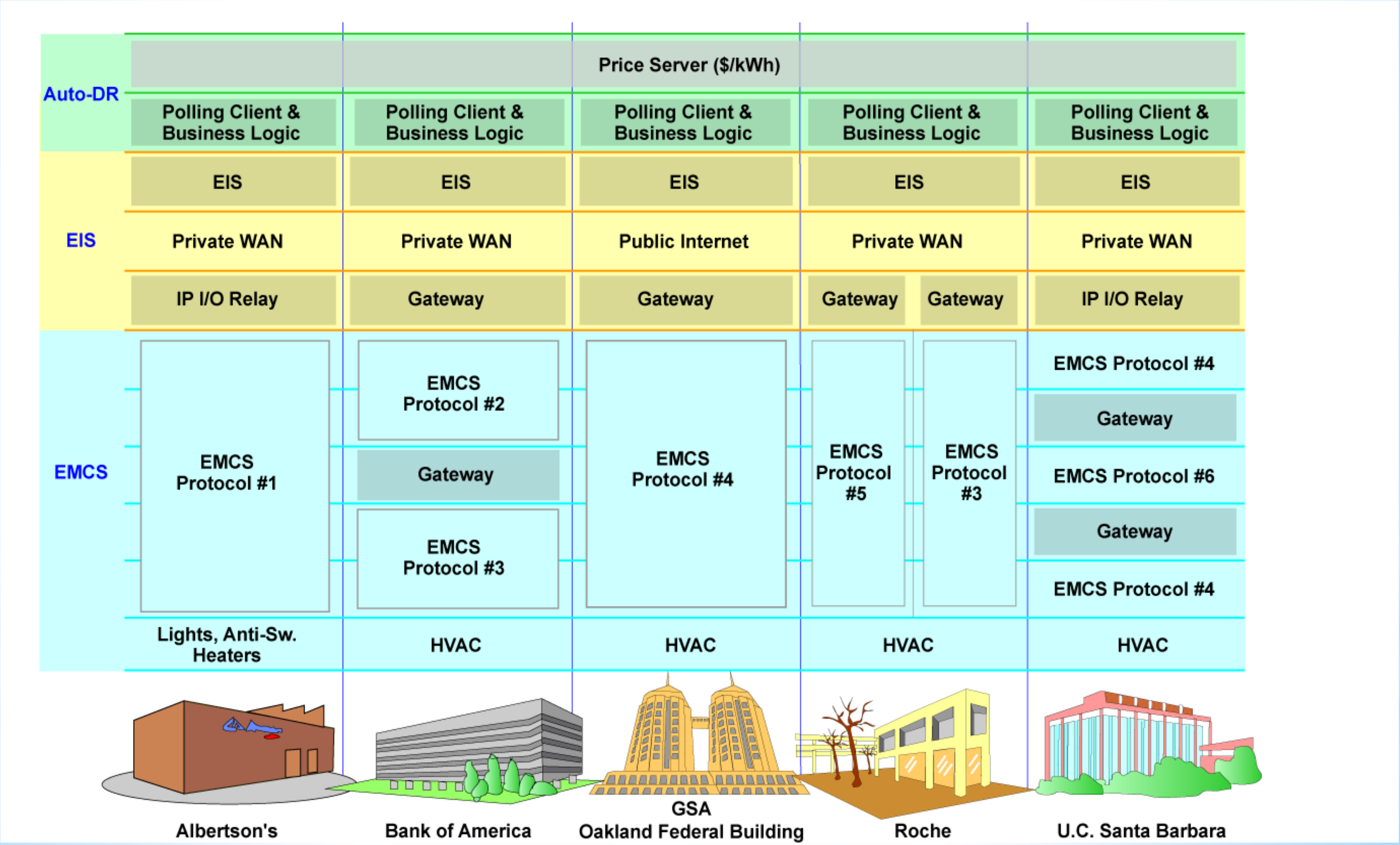
Open Automated Demand Response

- Open standardized DR interface
- Allows elec providers to communicate DR signals directly to customers
- Uses XML language and existing communications e.g., Internet



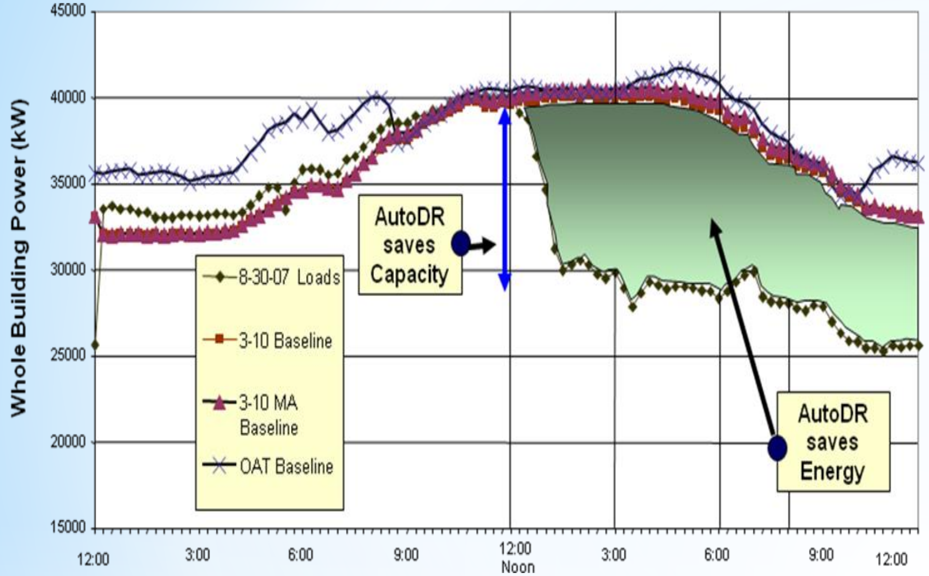


First 5 Auto-DR Tests - 2003

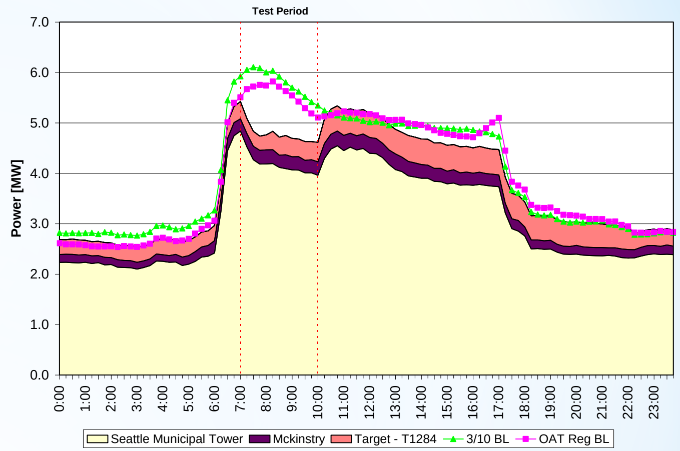


Historic focus on Seasonal Grid Stress

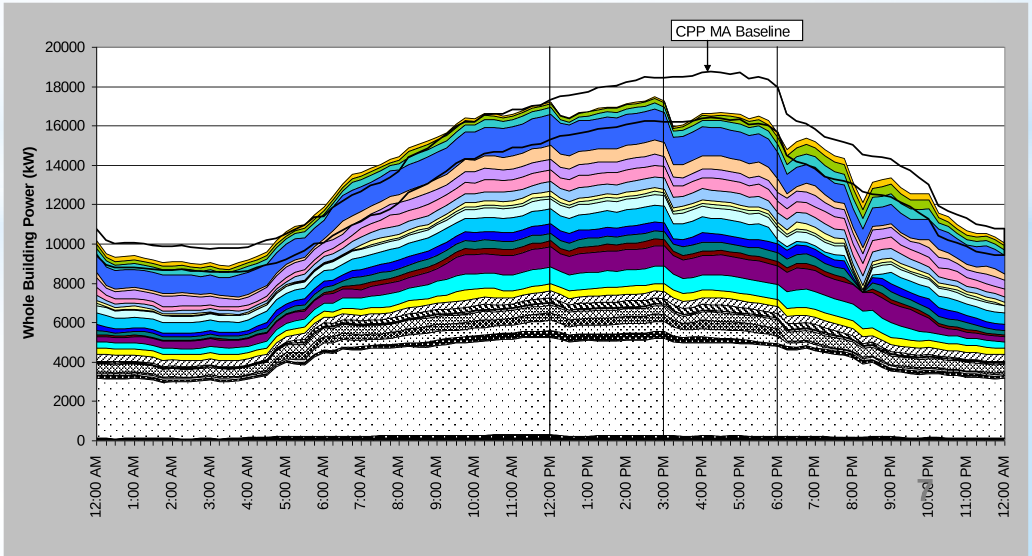
OpenADR PG&E Demand Bid Test Day



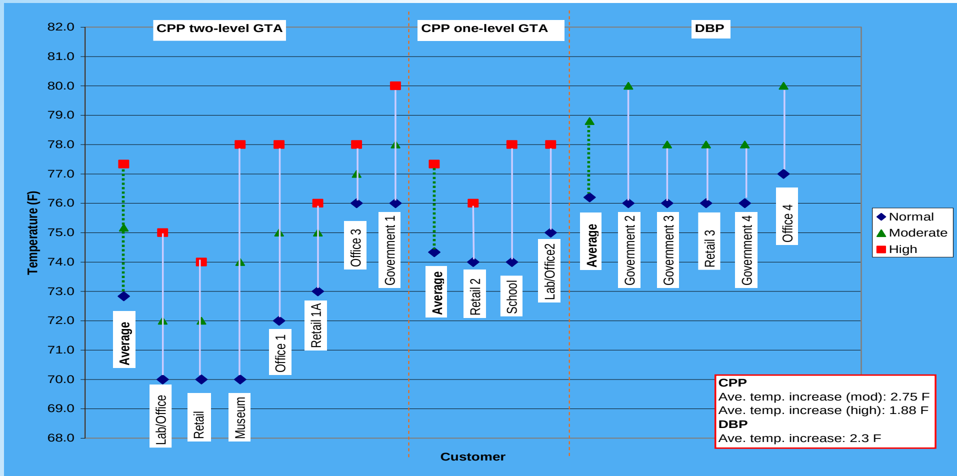
OpenADR Northwest Test on Cold Morning

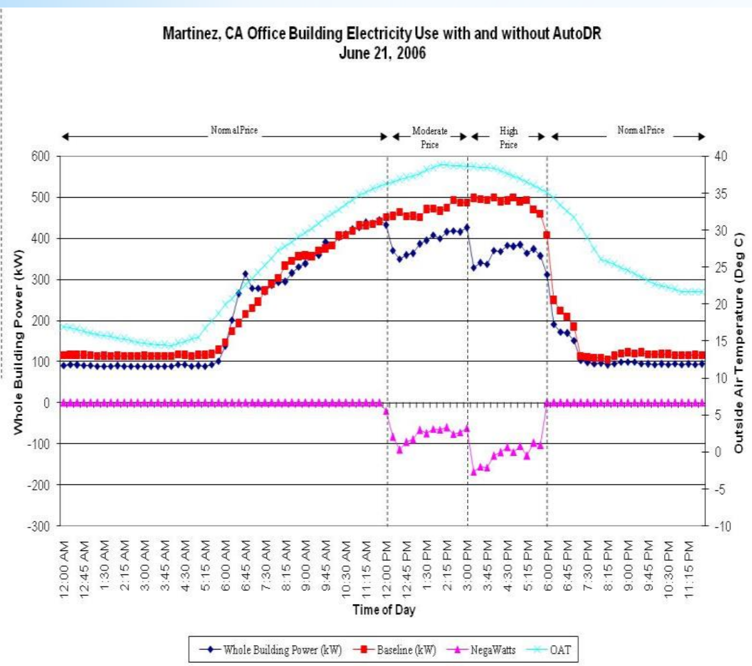


OpenADR Cumulative Shed



Control Strategies Evaluated in Previous Demos





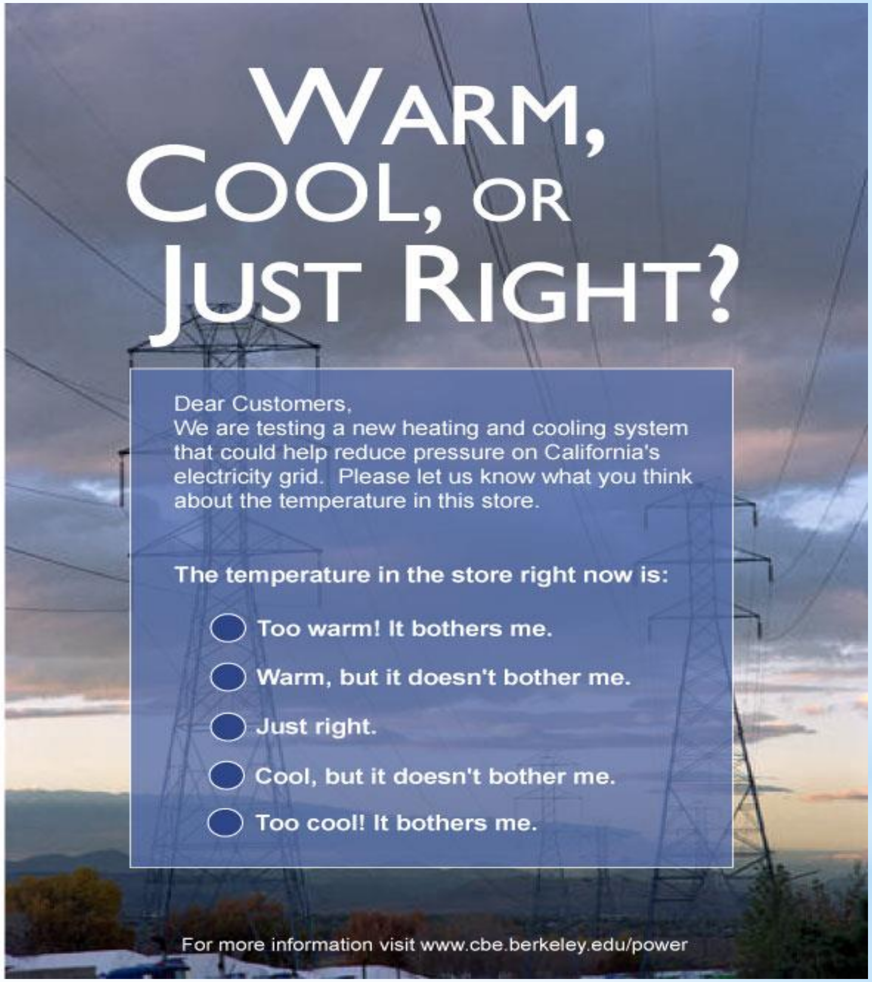
		HVAC											Lighting					Other
	Building use	Global temp. adjustment	Duct static pres. Increase	SAT Increase	Fan VFD limit	CHW temp. Increase	Fan qty. reduction	Pre-cooling	Cooling valve limit	Boiler lockout	Slow recovery	Extended shed period	Common area light dim	Office area light dim	Turn off light	Dimmable ballast	Bi-level switching	Non-critical process shed
ACWD	Office, lab	X	X	X		X			X	X		X						
B of A	Office, data center		X	X	X	X			X									
Chabot	Museum	X						X										
2530 Arnold	Office	X									X							
50 Douglas	Office	X									X							
MDF	Detention facility	X																
Echelon	Hi-tech office	X	X	X			X						X	X	X	X		
Centerville	Junior Highschool	X						X										
Irvington	Highschool	X						X										
Gilead 300	Office			X														
Gilead 342	Office, Lab	X		X														
Gilead 357	Office, Lab	X		X														
IKEA EPaloAlto	Furniture retail	X																
IKEA Emeryville	Furniture retail	X																
IKEA WSacto	Furniture retail																	
Oracle Rocklin	Office	X	X															
Safeway Stockton	Supermarket																X	
Solectron	Office, Manufacture	X													X			
Svenhard's	Bakery																	X
Sybase	Hi-tech office														X			
Target Antioch	Retail	X					X											
Target Bakersfield	Retail	X					X											
Target Hayward	Retail	X					X						X				X	
Walmart Fresno	Retail	X															X	

Demand Shifting with Thermal Mass

* Goal - understand demand shifting with mass & assist in optimal use of new control strategies

* Past Work –commercial building field studies & preliminary simulation study

* Recent Results –2003 Santa Rosa demo shifted afternoon chiller power (2 W/ft^2)

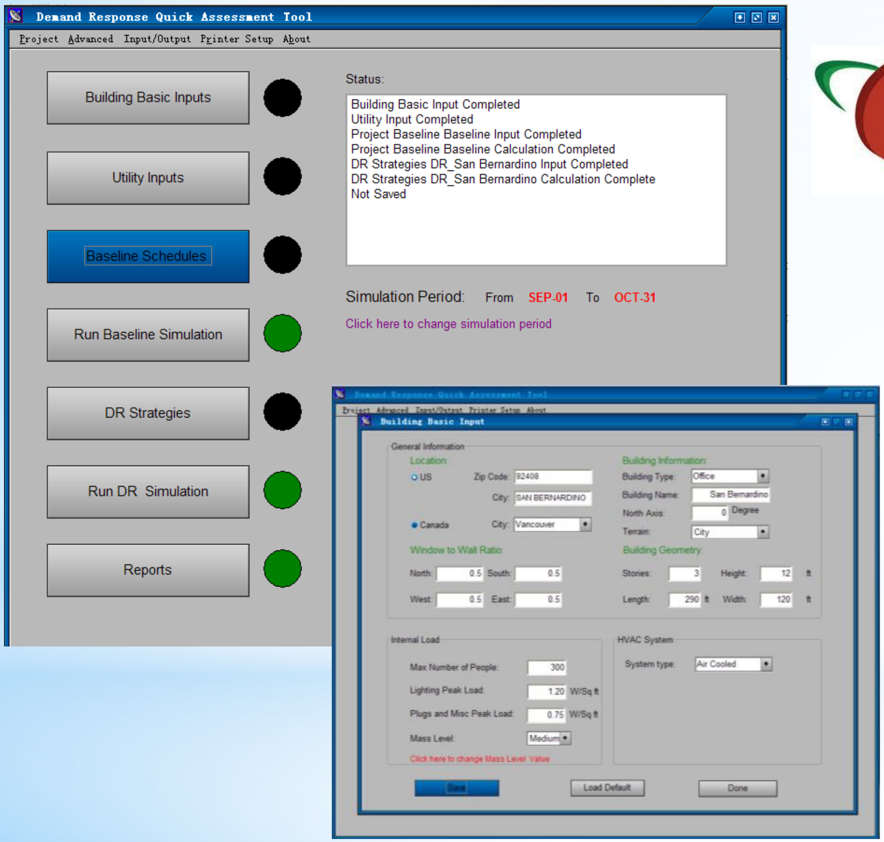


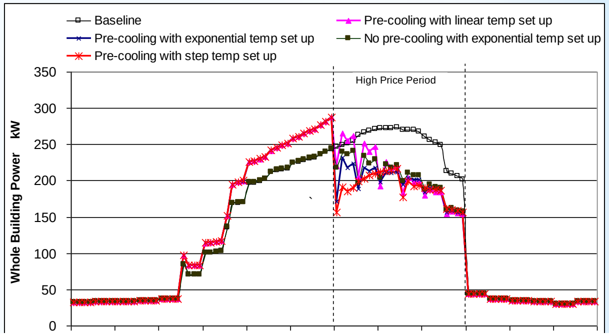
Concrete Floor

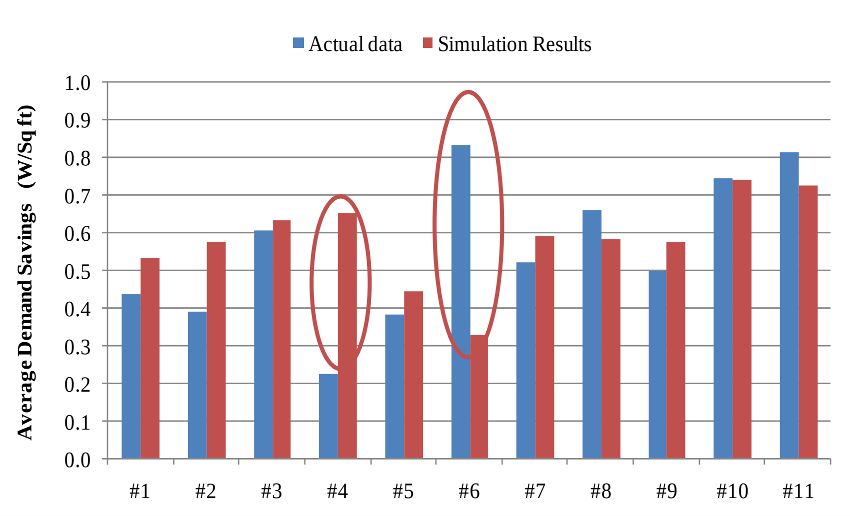
Thermal Capacity
~ 3 Watts-Hours/ft^3 - F

DR Quick Assessment Tool

- EnergyPlus tool with retail and office building prototype
- Initially developed to support **California** utilities to evaluate DR strategies in Commercial buildings
- Expanded to include **Canadian** and **NY** climate data

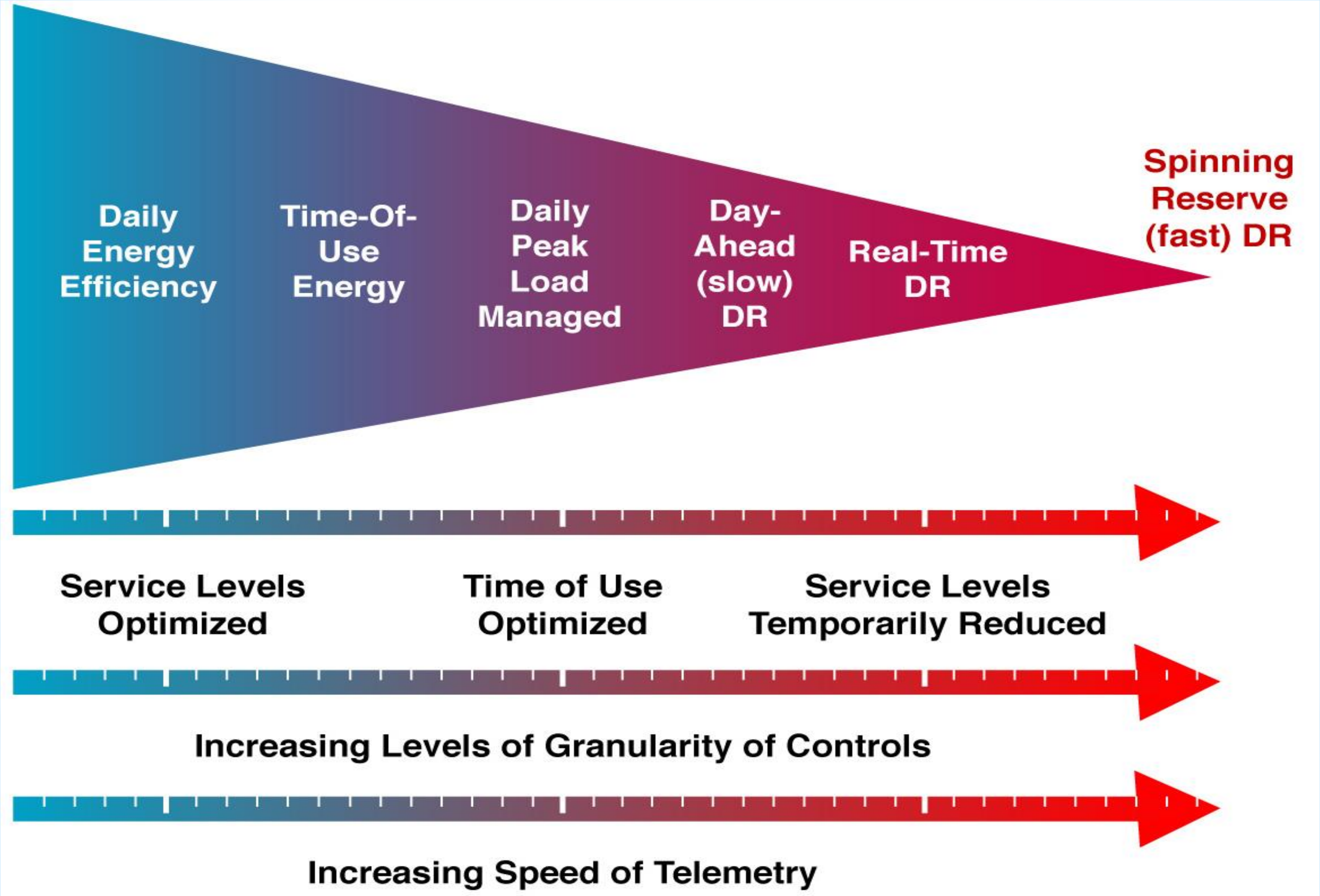






Excellent performance predicting DR in southern Calif. Included modeling pre-cooling strategies

Linking Energy Efficiency and DR



History of OpenADR

Over 250 MW automated in California

Official OpenADR specification (1.0) by LBNL/CEC*

Research initiated by LBNL/ CEC

Fast DR Pilots

National outreach with USGBC

OpenADR 1.0 Commercialization
(PG&E, SCE, and SDG&E)

Pilots and **field trials**
Developments, tests (Utilities)

2002 to 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2018

1. OpenADR Standards Development
   - OASIS (EI TC), UCA, IEC
2. NIST Smart Grid, PAP 09

EI 1.0 standards
- OpenADR profiles

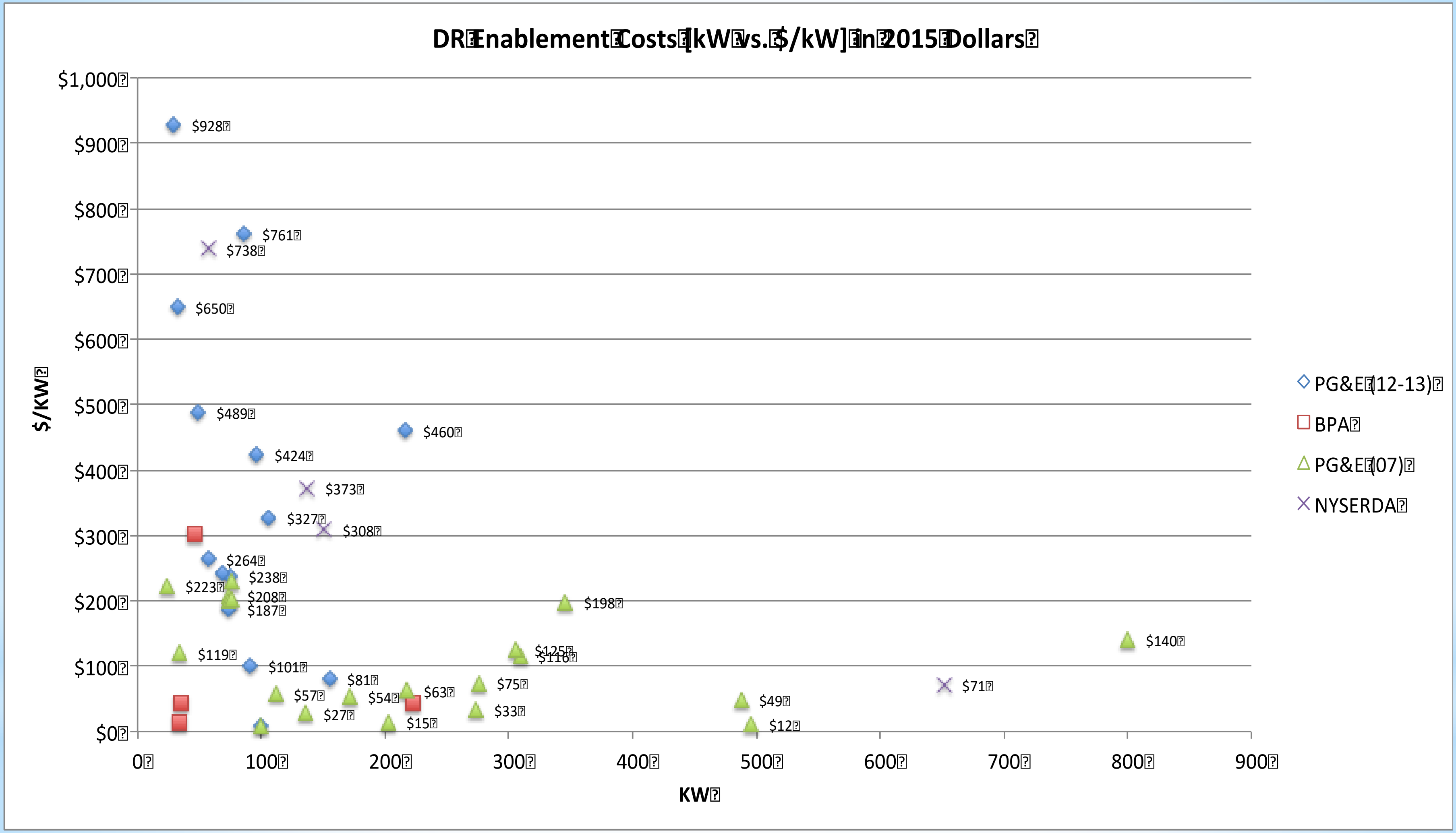
OpenADR 2.0 specification
- Products, commercialization

Certification/Testing (v2.0)

Chinese Standard Based on OpenADR Published in 2017

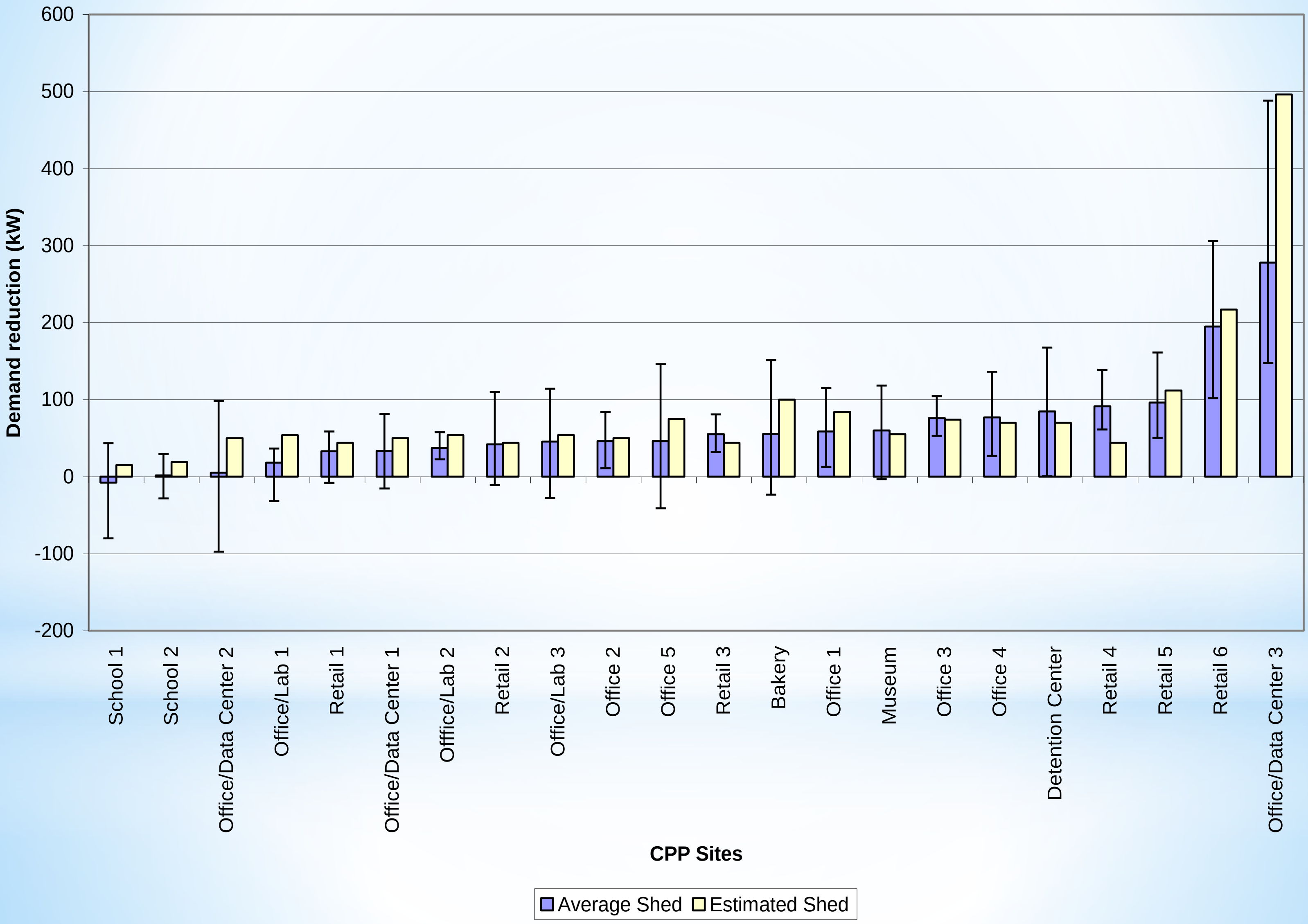
International Electrotechnical Committee – Nov 2018 - IEC TR 62746-2:2015 Systems interface between customer energy management system and the power management system - Part 2: Use cases and requirements

Cost to Automate DR vs Power Reduction



Note- Some projects include efficiency technology and not just DR systems

DR Data from 22 Commercial Buildings



PG&E EE-DR Measures in 2012-2013

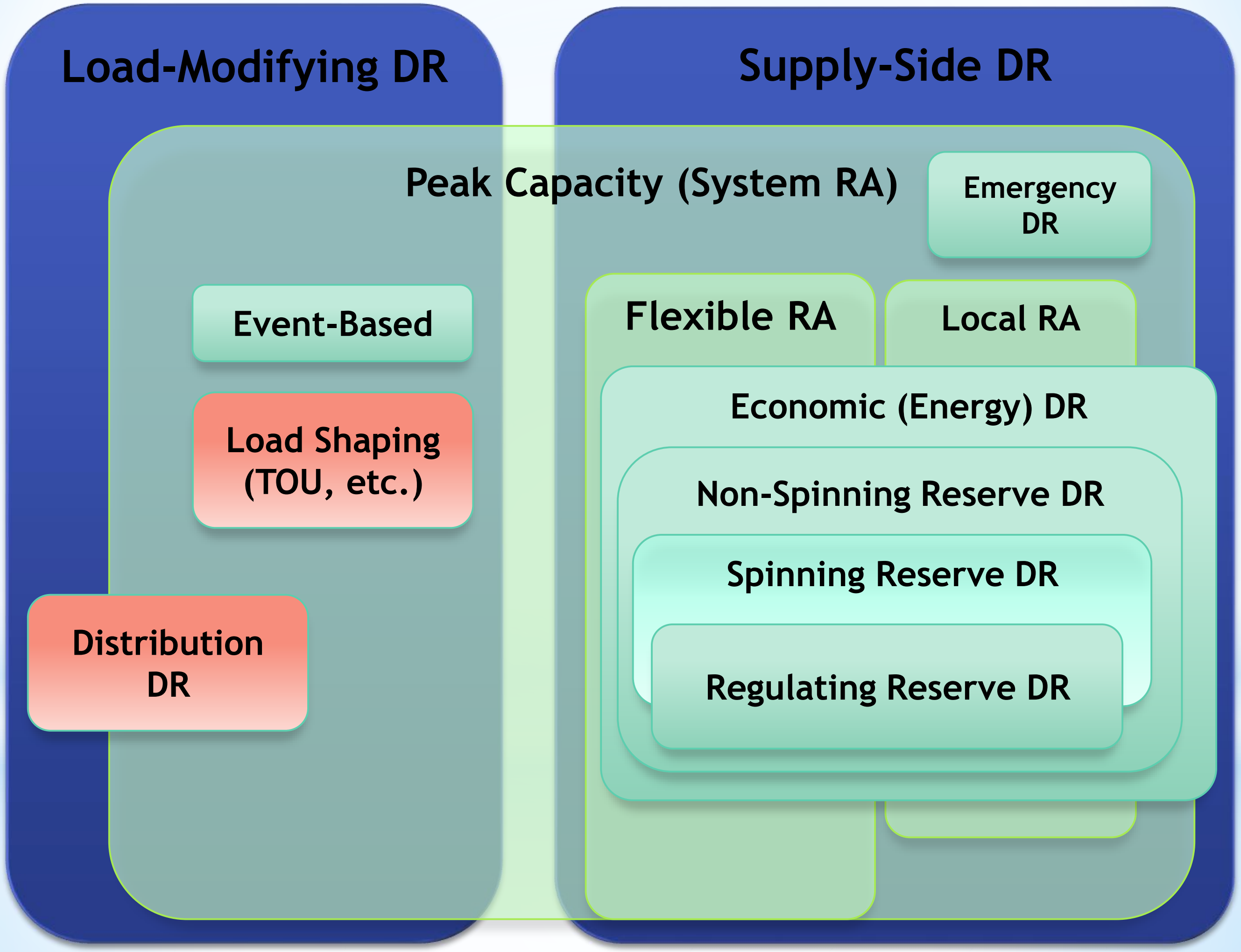
Facility	DR Program	DR kW	Project Cost $	Eligible ADR Incentive	Ratio of DR Incentive to project cost	$/kW	Measures	Options
College	PDP	57	16,400	19,950	1.00	288	EMS, cut duty cycles	EE&DR
Restaurant and Bar	CBP	75	29,210	26,250	0.90	389	EMS, cut duty cycles	EE&DR
Hotel	CBP	32	34,025	6,400	0.19	1063	Shut off ancillary plug load	EE&DR
Hotel	CBP	69	27,290	13,800	0.51	396	Shut off ancillary plug loads	EE&DR
Big Box	CBP	2003	720,691	701,050	0.97	360	EMS, cut duty cycles	EE&DR
Office	AMP	264	2,032,326	94,200	0.05	7698	Duty cycles, turn off & dim lights, reset deadband of temp setpoints	EE&DR
Cinema	PDP	49	26,130	17,150	0.66	533	EMS, cut duty cycles	EE&DR
Shopping Mall	PDP	106	37,820	37,100	0.98	357	EMS, cut duty cycles	EE&DR
Office	CBP	216	162,626	75,600	0.46	753	EMS, cut duty cycles	EE&DR
Office	CBP	86	107,157	30,100	0.28	1246	EMS, cut duty cycles	EE&DR
Family Bowl	PDP	32	11,400	11,200	0.98	356	EMS, cut duty cycles	EE&DR

OpenADR in California in 2014

Utility	Enabled Load Shed kilowatts (MW)[a]	Cost of Enablement ($M)	Enrolled Service Accounts	Enrolled Load Shed (MW)[b]
Pacific Gas and Electric	81	14	347	71
Southern California Edison	158	37	747	155
San Diego Gas & Electric	11	3	126	8
TOTAL	**250**	**54**	**1,220**	**234**

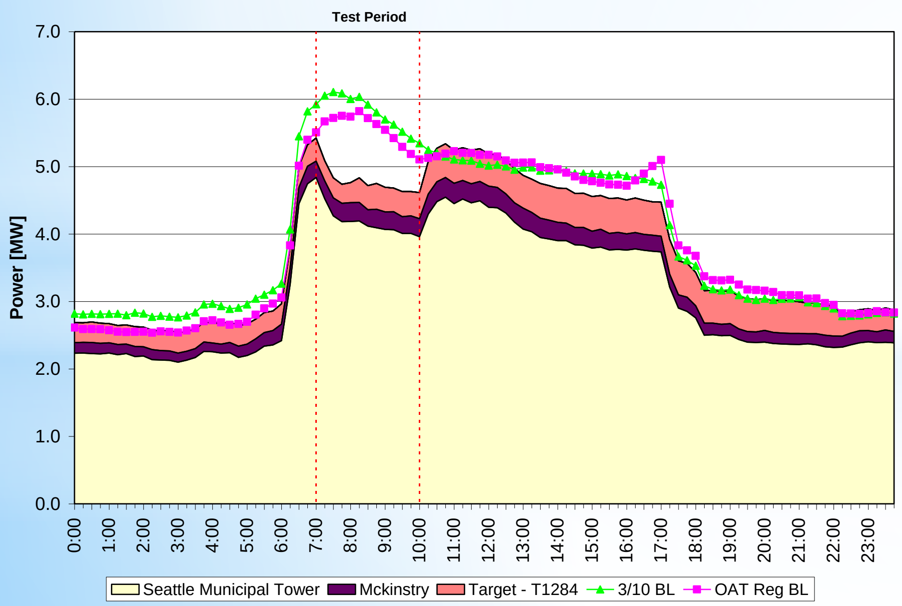
- As of summer, 2014, 234 MW, 1200 accounts currently enrolled
- ~$215/kW statewide average enablement cost
- Now over 5000 sites with Residential WIFI Communicating Thermostats (*Bring Your Own Thermostat Program)*

Nested Grid Support Products



5 Grid Service Studies Beyond Hot Summer Days

- Cold mornings for winter peak regions (Seattle)
- Non-spin reserve ancillary services (No. Cal)
- Regulation ancillary services (No. Cal)
- Economic dispatch - integrated price signals (NY NY)
- Fast telemetry for small commercial (No. Cal.)

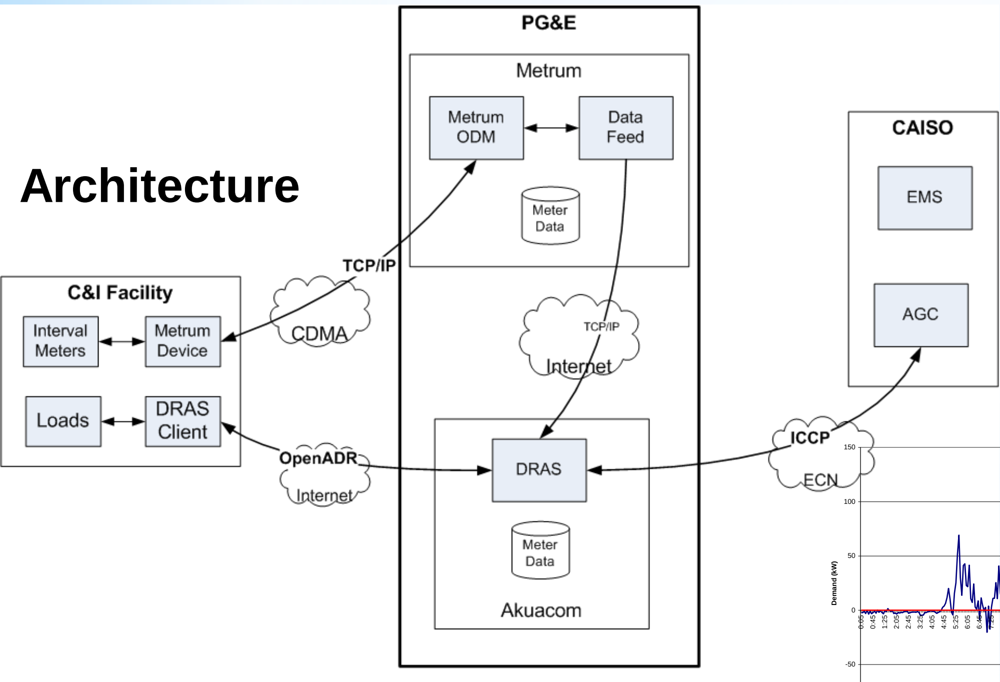


	HVAC													Lighting					Other		
Site	Global temp. adjustment	Duct static pres. decrease	SAT decrease	Fan VFD limit	RTU Shut off	Duty Cycling RTUs	Pre-heating	Pre-cooling	Fan-coil unit off	Cycle electric heaters	Cycle AHU Fans	Cycle VAVs	Set up CO2 Setpoints	Common area light dim	Office area light dim	Turn off light	Dimmable ballast	Bi-level switching	Non-critical process shed	Elevator cycling	Slow Recovery
McKinstry	S					W		S								S					W
Target - T1284	WS				WS													WS			
Seattle Municiple Tower	WS										W	W									WS
Seattle University	WS					W	W	S		W	W	W	W								W

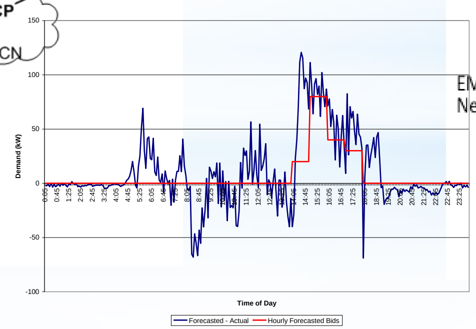
Advanced Applications- Using Demand-side Resources for Grid Reliability with DR and Microgrids

- Fast DR – Evaluating how loads can act like generators
  - Development of communication, control and telemetry requirements
  - Understanding markets and market participation rules
  - Research concepts supported with field tests

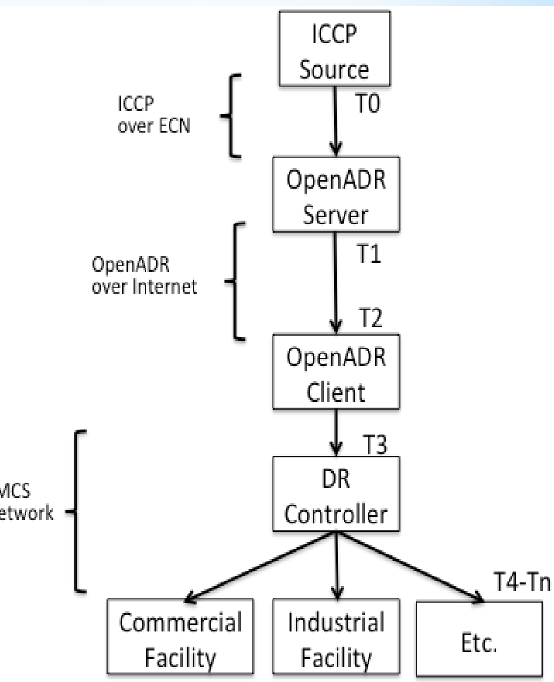
Architecture



Loads

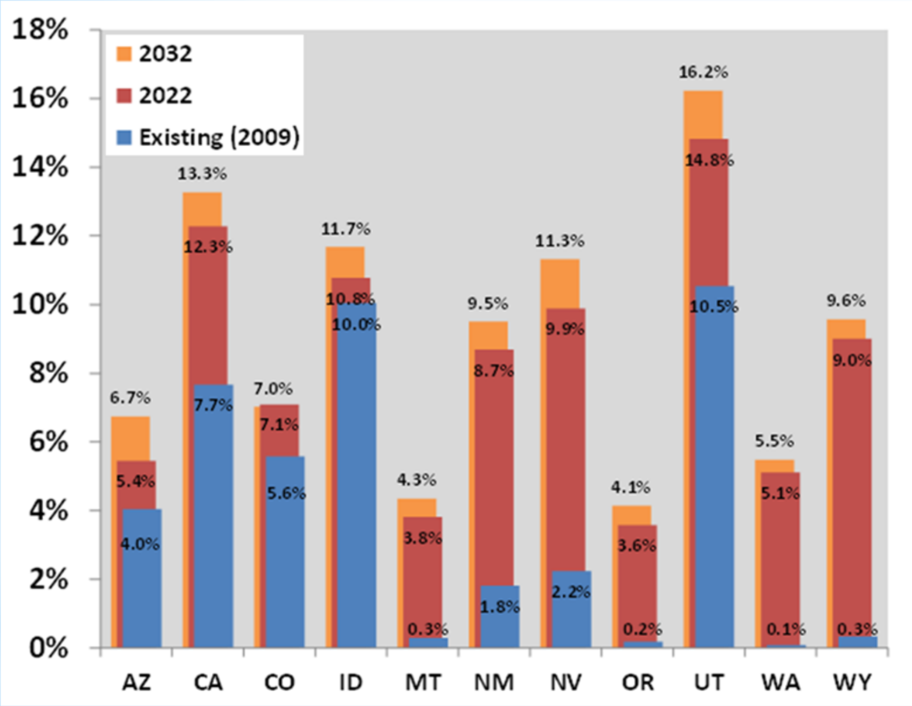


Communication Latency

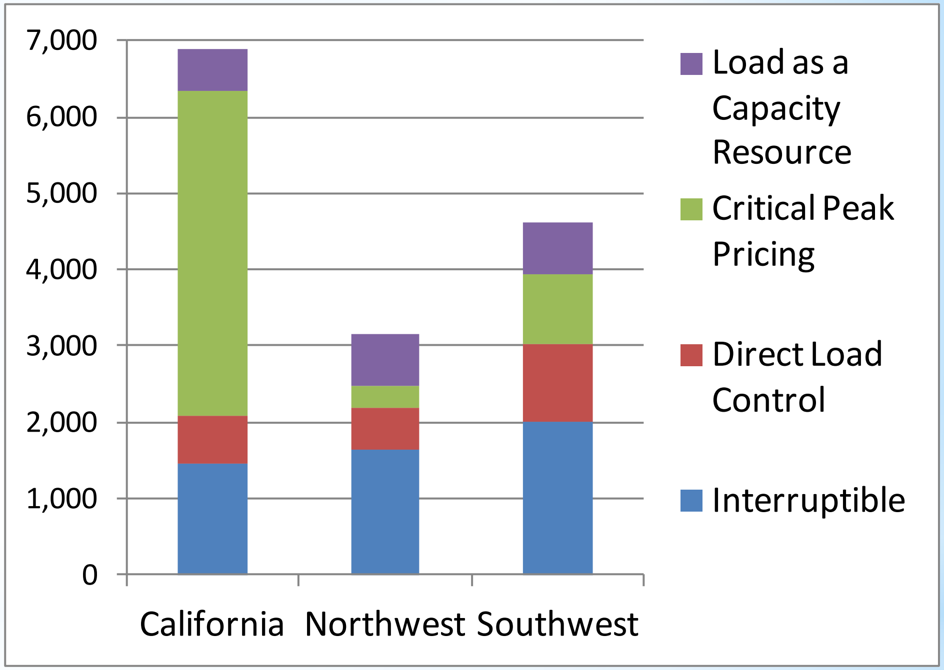


DR Potential Estimates for Western U.S. States

DR Capability (% of Peak Demand) in High DSM Case

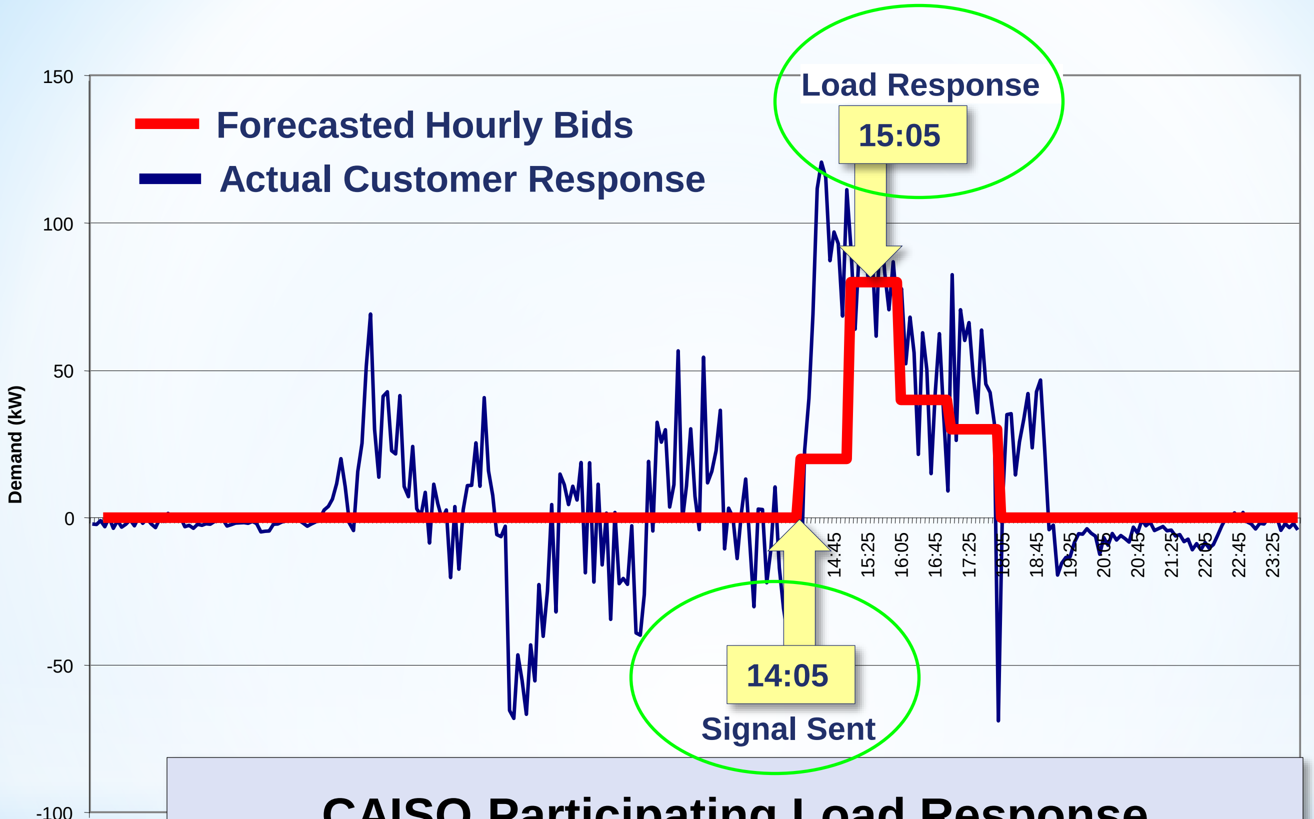


2032 DR Capability by Program Type



LBNL worked with Brattle Group to update and extend DR potential estimates from 2009 FERC National Assessment

OpenADR with Ancillary Services

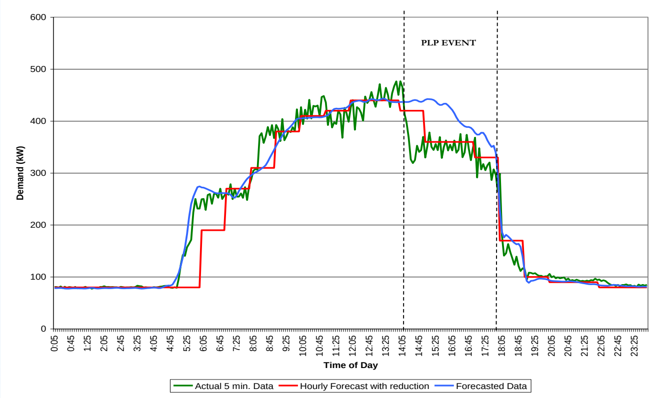


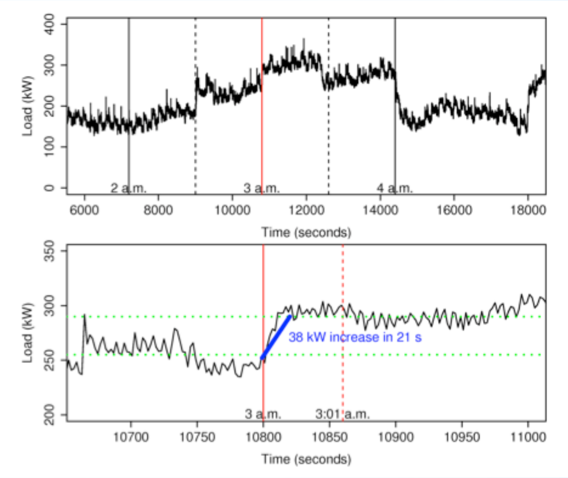
CAISO Participating Load Response

Forecasted vs Actual Ramp Time (MW/ min)	Forecasted vs. Actual Average Hourly Shed (kW)			
	HE 15:00	HE 16:00	HE 17:00	HE 18:00
0.002/ 0.006	20 / 72	80 / 86	40 / 51	30 / 49

Fast DR in Commercial Buildings

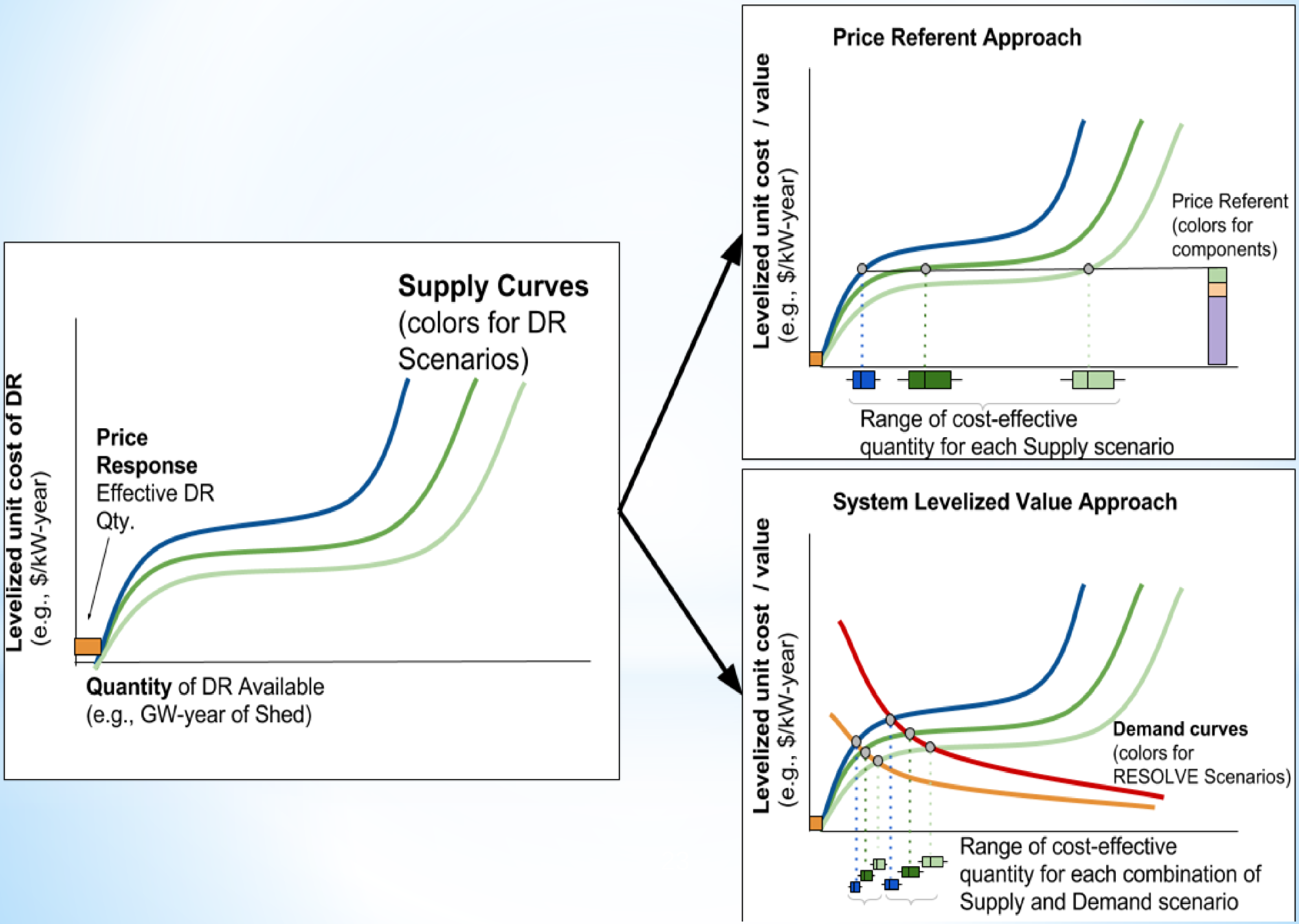
* Buildings can provide ramping
* - Costs will be lower if used in many DR programs
* - How often can load be called?



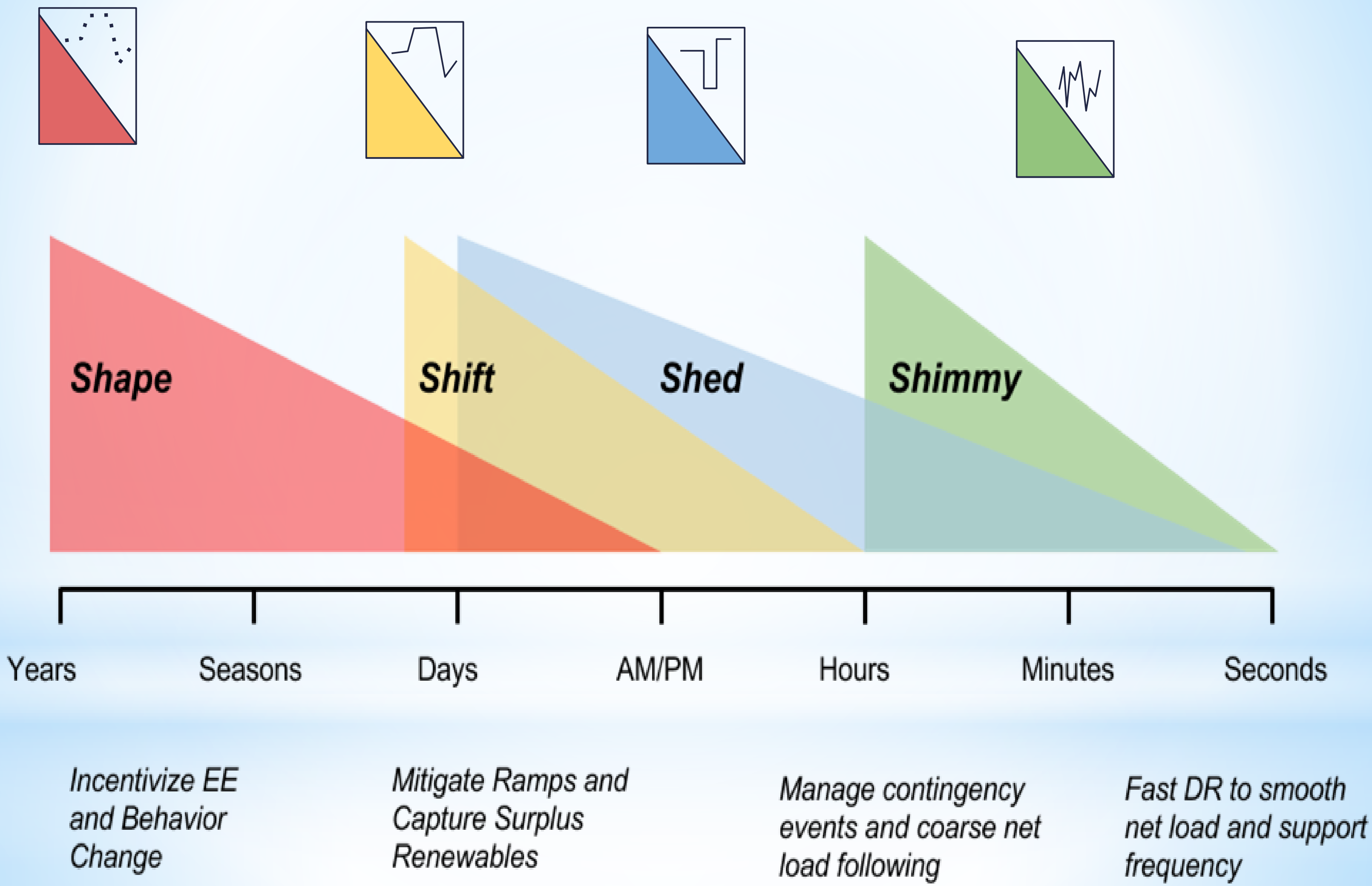


Site	Available Capacity (MW)	Min. Operating Limit (MW)	Max. Operating Limit (MW)	Ramp Rate (MW/min.)
UC Merced	0.16	0	0.17	Reg up: 0.022 Reg down: 0.022
West Hill Farms	0.03	0	0.16	Reg up/down:0.03
SMCC	0.2	0	0.2	Reg up: 0.05 Reg down_1: 0.066 Reg down_2: 0.134

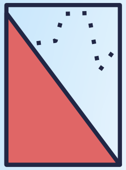
California DR Potential Study- 2 Reference Methods



California DR Potential Study Evaluated Four DR Grid Needs

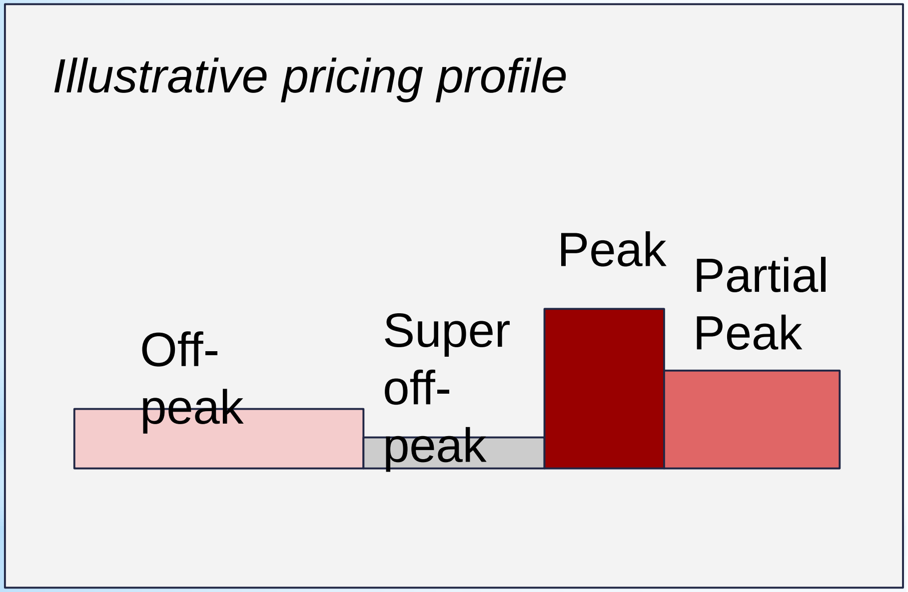


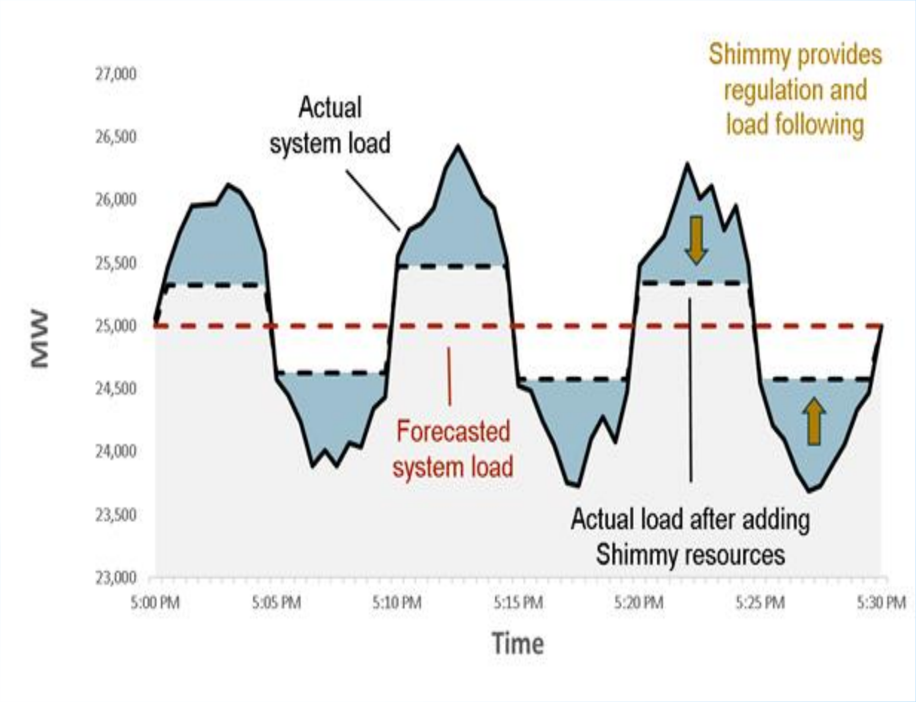
Shape and Shimmy



Shape Service Type as modeled: Accomplishes Shed & Shift with prices & behavioral DR.

Shimmy Service Type: Load Following & Regulation DR



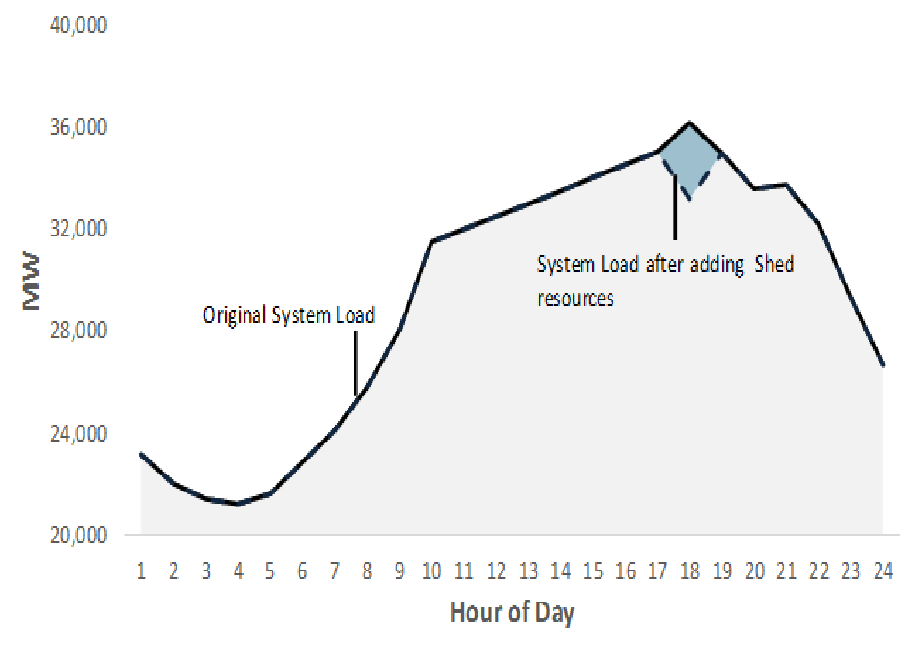


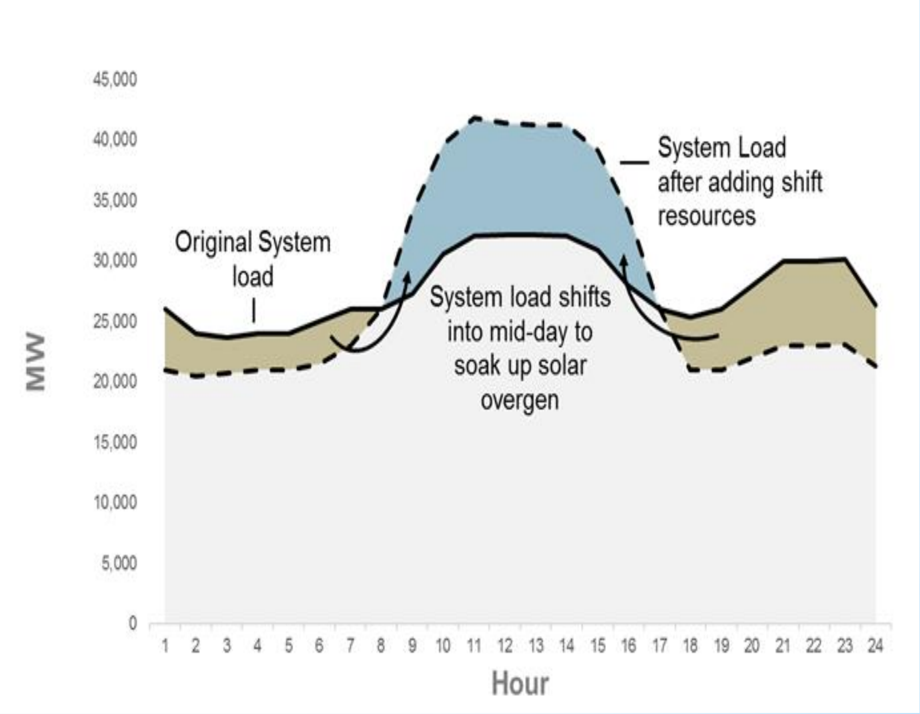
Energy+Environmental Economics

Shed and Shift

Shed Service Type: Peak Shed DR

Shift Service Type: Shifting load from hour to hour to alleviate curtailment/ overgeneration





Energy+Environmental Economics

Methodology

LBNL-Load - IOU-provided load (~220,000 customers) & demographic data (~11 million customers) in 3,500 "clusters," based on observable similarities. **Load profiles** for total & end use-specific clusters. Forecasts to 2025.

DR-Path - estimates DR pathways based on load shape and forecasts from LBNL-Load. Pathways represent future DR supply potential, given assumptions on **technology adoption**, **participation** & **cost** for existing & emerging technologies.

Renewable Energy Solutions (RESOLVE) estimates set of benchmarks for each DR type based on avoided investment & operation costs when DR is available. DR availability evaluated for **low & high** renewable energy curtailment levels.

End Uses and Enabling Technologies

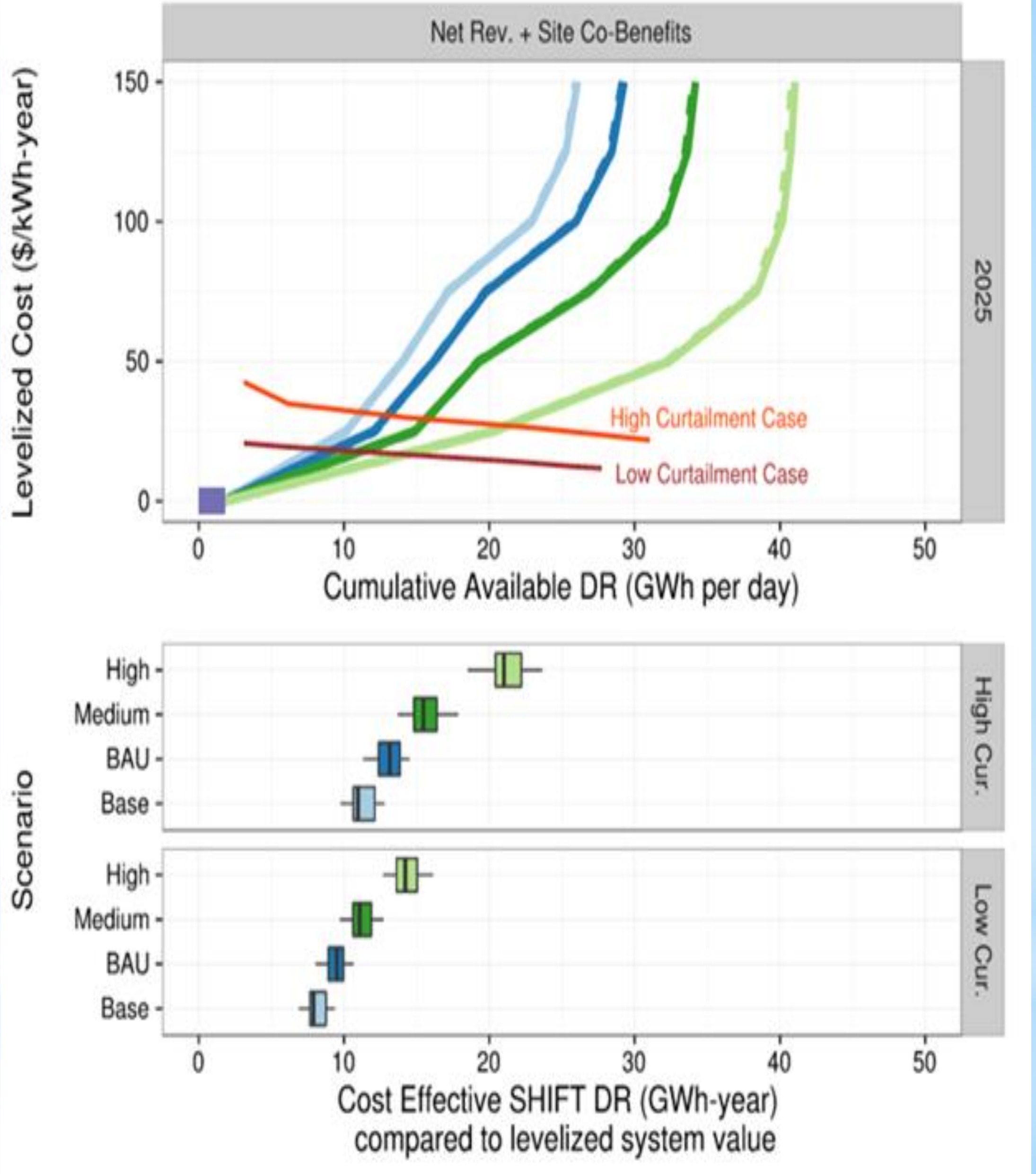
Sector	End Use	Enabling Technology Summary
All	Battery-electric and plug-in hybrid vehicles	Level 1 and Level 2 charging interruption
	Behind-the-meter batteries	Automated DR (Auto-DR)
Residential	Air conditioning	Direct load control (DLC) and Smart communicating thermostats (Smart T-Stats)
	Pool pumps	DLC
Commercial	HVAC	Depending on site size, energy management system Auto-DR, DLC, and/or Smart T-Stats
	Lighting	A range of luminaire-level, zonal and standard control options
	Refrigerated warehouses	Auto-DR
Industrial	Processes and large facilities	Automated and manual load shedding and process interruption
	Agricultural pumping	Manual, DLC, and Auto-DR
	Data centers	Manual DR
	Wastewater treatment and pumping	Automated and manual DR

Shift Supply Curves

2025 Supply + Demand
(Net ISO Rev and Co-Benefits)

Shown with *~2 GWh Shape-Shift*

10-20 GWh cost-effective supply
(~ 2-5% of daily load shifted)



Phase 2 DR Quantity Findings: By 2025, Medium DR Scenario Suggests...

Shape: Conventional TOU / CPP rates effectively provide **1 GW Shed & 2 GWh Shift** at ~zero cost. Deeper potential?

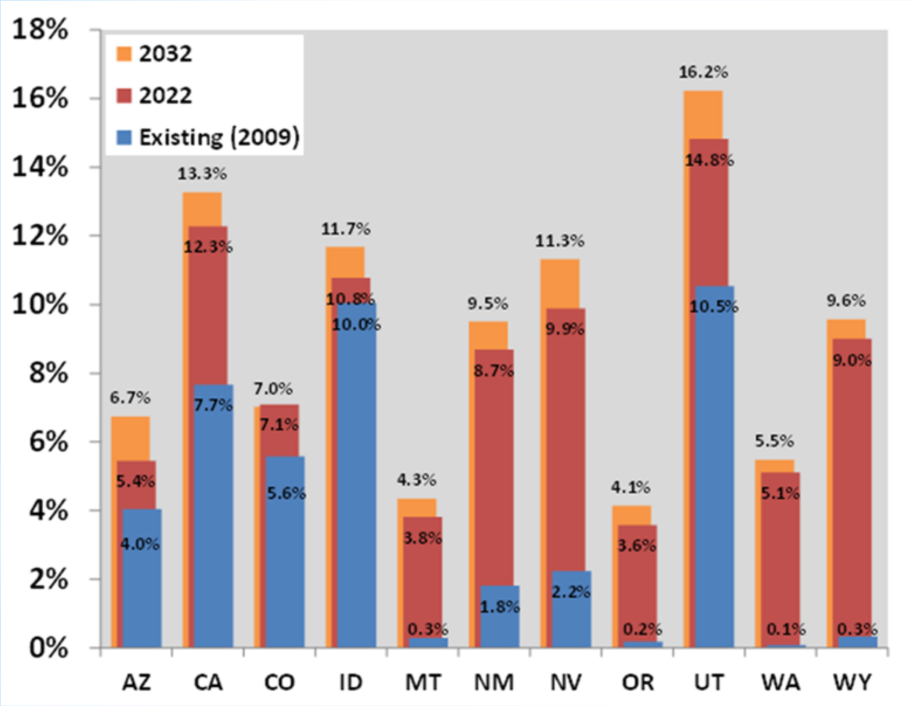
Shed: Generation overbuild means ~zero need for system-level shed, but **2-10 GW** in cost-effective local Shed & distribution system service.

Shift: **10-20 GWh** of cost-effective daily Shift (2-5% of daily load), with opportunity for system value at ~$200-500+M/year.

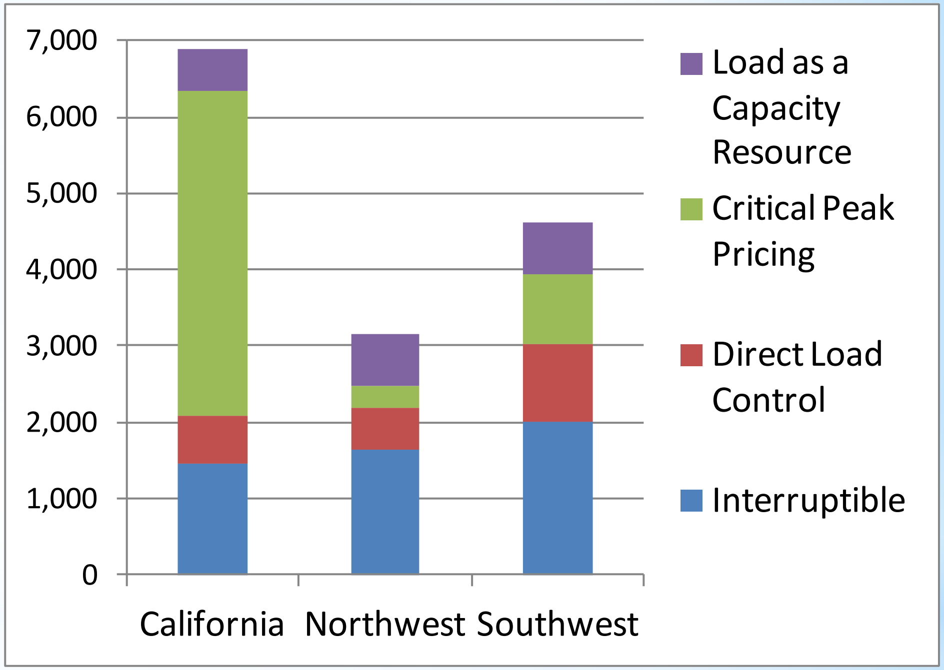
Shimmy: **300 MW** Load-following & **300 MW** Regulation. Opportunity for system-level total value is ~$25 M/year.

DR Potential Estimates for Western U.S. States

DR Capability (% of Peak Demand) in High DSM Case



2032 DR Capability by Program Type

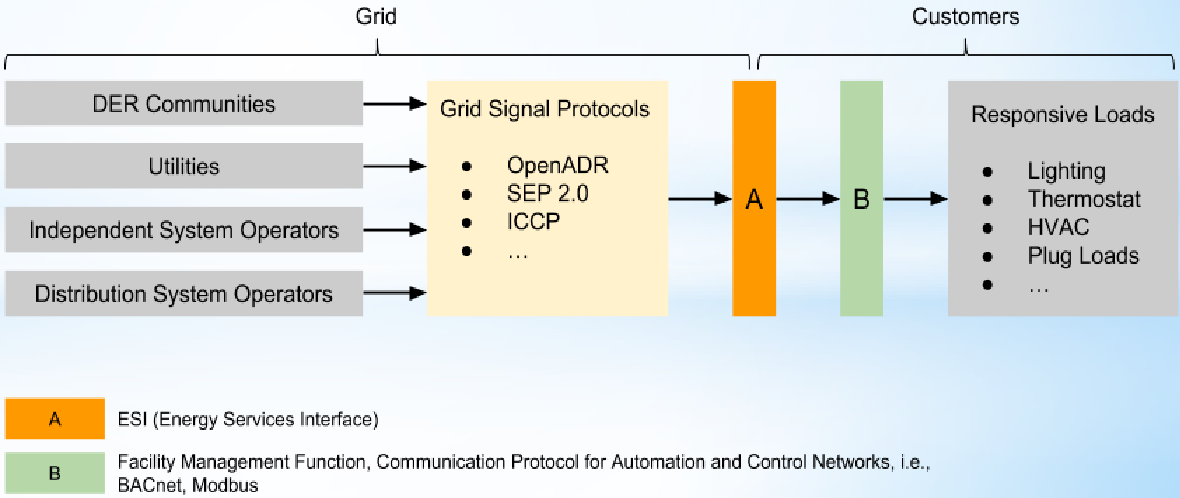


LBNL worked with Brattle Group to update and extend DR potential estimates from 2009 FERC National Assessment

GMLC 1.4.1 Interoperability between the Grid and Customers

* Background
  * Energy Services Interface (ESI) proposed as a standard, interoperable way for grid operators to request services from responsive loads
  * OpenADR has been developed as a protocol for grid-to-customer communication, but has only been deployed for simple demand response programs, not advanced grid services.
* Objectives
  * Demonstrate test method to assess use of an interoperable, standard grid signal to implement the ESI functionality for advanced grid services
  * Evaluate speed of DR and controls latency of system architectures for responsive loads

- 2 types of grid services
  - 5-min real-time energy market
  - Ancillary service (AS) – freq regulation (up and down).



ICCP: Inter-Control Center Communications Protocol
SEP: Smart Energy Profile

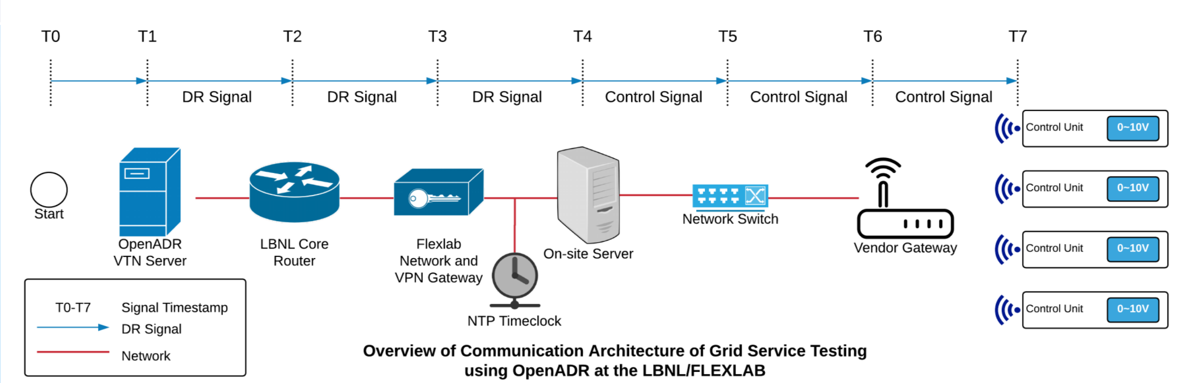
Examples of Open Standards for DR and Controls

Domain/Function	End Use	Applicable Standards
Grid/ Grid Signaling	All	**OpenADR (2.0), IEEE 2030.5 (SEP 1 and 2), Multi-Speak**
Customer/ End-use Control	Heating, ventilation, air conditioning	**ASHRAE 135/ISO 16484 (BACnet), IEC 14908-1 (LonTalk)**
	Lighting	**DALI, ZigBee SEP 1 and 2, BACnet**
	Water Heaters & other devices	**BACnet, CTA-2045**

GMLC 1.4.1 - Testing Procedure Development

- Demonstrate a test method to assess interoperable, standard grid signal for Energy Services Interface functionality for advanced grid services:
  - 5-minute Real-time Energy
  - Ancillary Service (i.e., AS – Frequency Regulation [up and down])
- Performance metrics: Accuracy of Information Exchange & Communication Latency

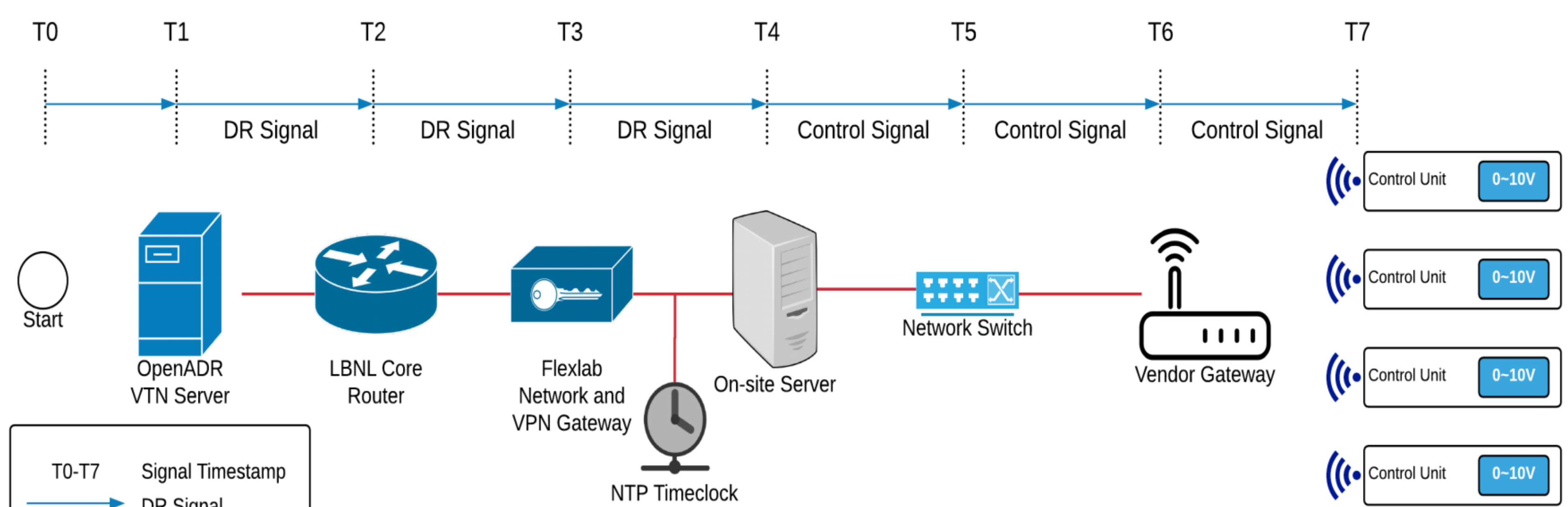
Vendor	OpenADR VEN Location	OpenADR Certified?
Daintree Networks (Current by GE)	On-site server	Yes
Enlighted	On-site server	Yes
Lutron	Cloud	No
Wattstopper	On-site server	No



Overview of Communication Architecture of Grid Service Testing using OpenADR at the LBNL/FLEXLAB

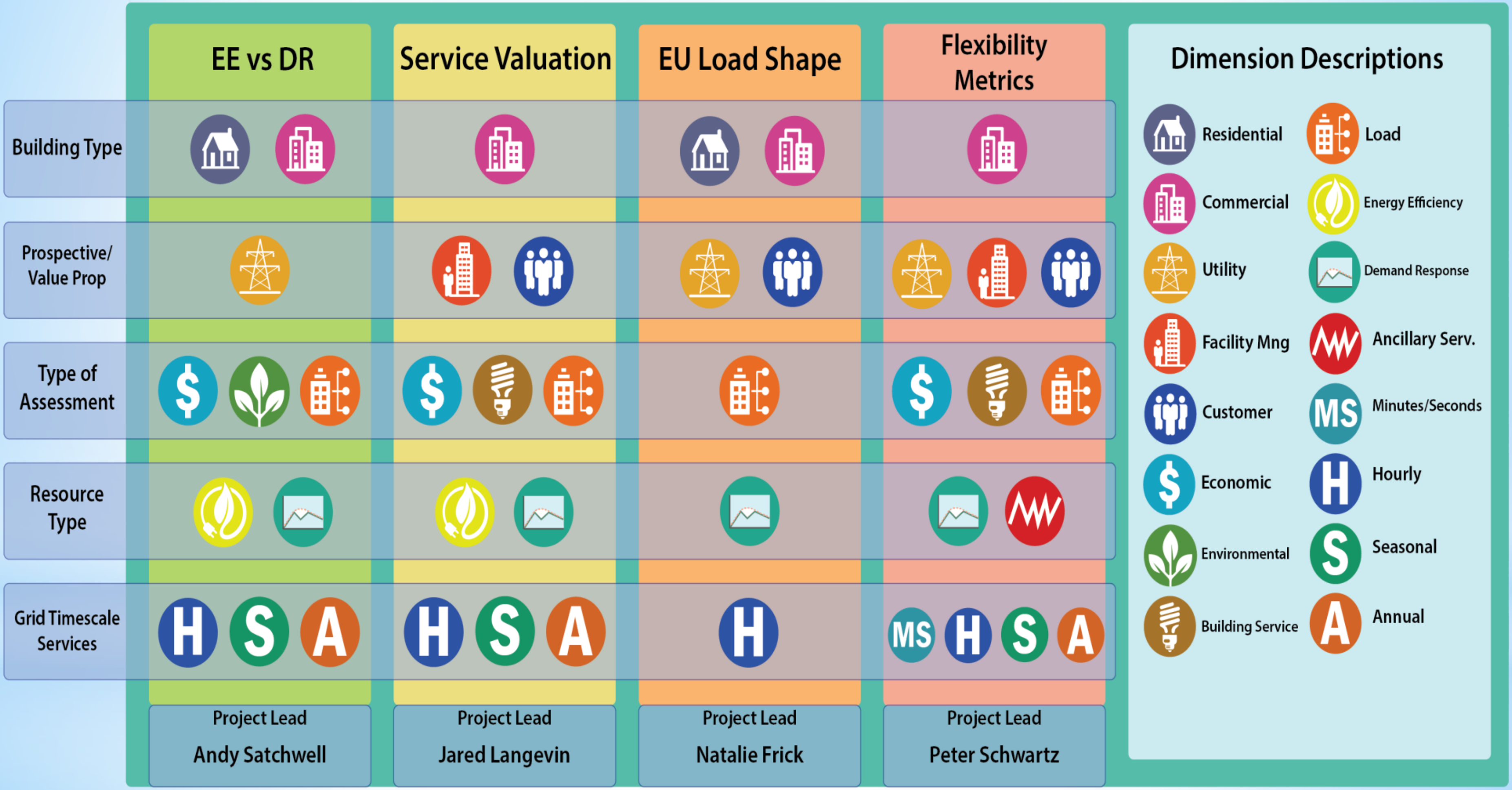
GMLC 1.4.1 - Testing Framework

- Evaluation of communication latency, time calculated as delay between timestamp T1 when DRAS-VTN sends DR signal and timestamp T7 when load response observed
- Lighting communication and control architectures
  - via on-site server (Daintree Networks, Enlighted) below
  - via vendor cloud (Lutron).



Overview of Communication Architecture of Grid Service Testing using OpenADR at the LBNL/FLEXLAB

New LBNL BTO GEB Projects

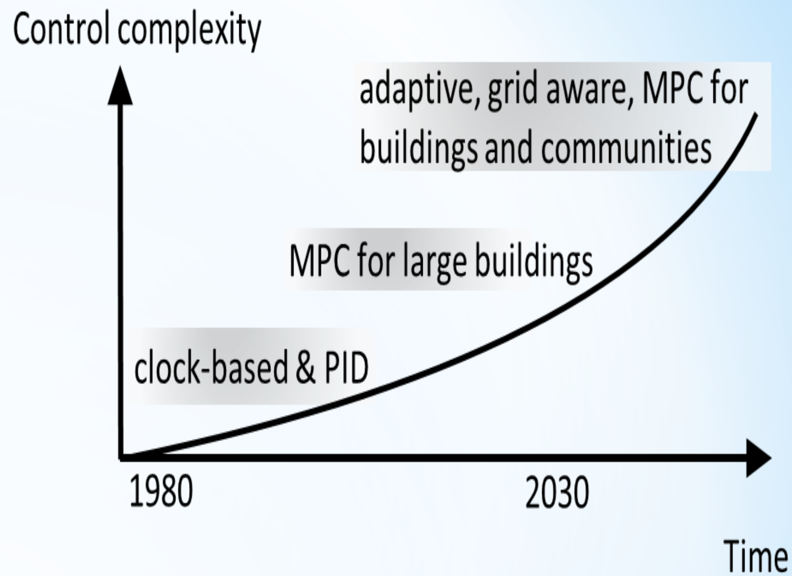


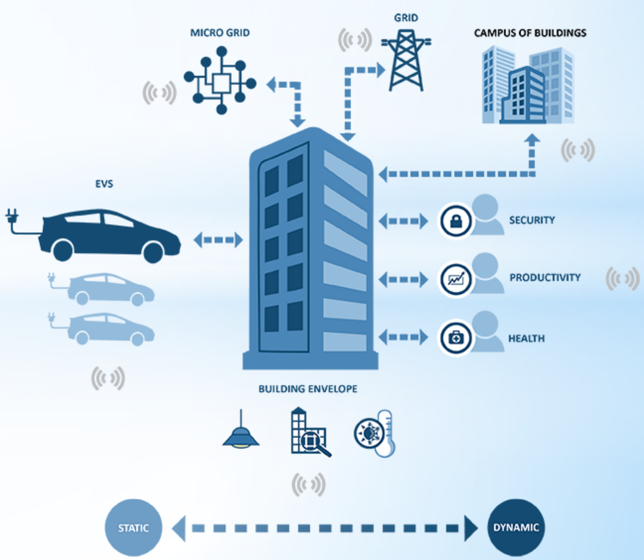
Example of GEB Component, System and End-Use Capabilities

Lighting	Component	System	Whole Building	Aggregator /Utility
Category of functionality	**(driver, lamp or fixture)**	**(lighting control system)**	**(BMS/EMCS)**	**Remote System**
Communicate and receive commands (1 way)	Ability to receive control signals from a lighting control system (via a specific protocol, message format, and data content)	Ability to receive control signal from BMS, aggregator or grid operator	Ability to receive signals from aggregator or grid operator	Ability to send signals to building
Communicate and send response (2 way)	Provide status on lighting component and energy use	Provide status information to BMS or aggregator. Monitor energy use	Provide grid service data to aggregator or utility. Monitor energy use.	Ability to receive signals from building
Inteligent control and optimization	Manage operational efficiency and grid services, (e.g., daylighting, occupancy) or receive a direct control signal from a higher-level controller	Manage efficiency and grid services, (e.g., daylighting, occupancy) or receive a signal	Whole building optimiation, MPC	Multi-building MPC, aggretate modeling
Communication system latency	Speed of receipt of signals and response	Speed control signals be sent through the system	Speed control signals get from the BMS to the light fixtures	Round trip signal latency
Physical system latency	Speed of change in dimming or bi-level control	Speed of total lighting system response	Whole building lighting power response	Aggregated total power response (kW)
Duration of response	Seconds, minutes, hours	Seconds, minutes, hours	Seconds, minutes, hours	Seconds, minutes, hours
Lifetime impact, maintenance issues	Fatigue from frequent actuation (problem may be related to lighting type)	Fatigue from frequent actuation (problem may be related to lighting type)	Persistence of Savings	Persistence of Savings
Response capability	Component power reduction or voltage change	System power reduction or voltage change	Whole buidling power reduction or voltage change	Aggregated power reduction or voltage change
Impact on building services	Perception of change by occupants, frequent change or low light levels	Same	Same	NA

Summary and Future Directions

- Demonstrated capability of building end-uses to provide numerous types of grid services
- Research needed on
  - *modeling and capabilities*
  - *field measurement*
  - *cost-benefits*
  - *commissioning, controls, automation, interoperability*
  - *persistence of savings*
- Linking efficiency and DR is synergistic in many cases





APPENDIX

Elements of Costs for

		Price	Qty	Cost
System Evaluation, Design, Commissioning				
	Labor	$x/hr	y - hrs	xy
Communication				
	Hardware (Gateway)	$x	y	xy
	Software (Client)	$x	y	xy
	Configuration Labor	$x/hr	y - hrs	xy
Controls				
	Equipment	$x	y	xy
	Installation Labor	$x	y	xy
	Controls Programming	$x/hr	y - hrs	xy
Telemetry				
	Hardware (meters, meter comm.)	$x	y	xy
	Installation Labor	$x/hr	y - hrs	xy
	Configuration Labor	$x/hr	y - hrs	xy

Code Official Challenged by Title 24 –DR Controls for Space Conditioning

(h) Automatic Demand Shed Controls.

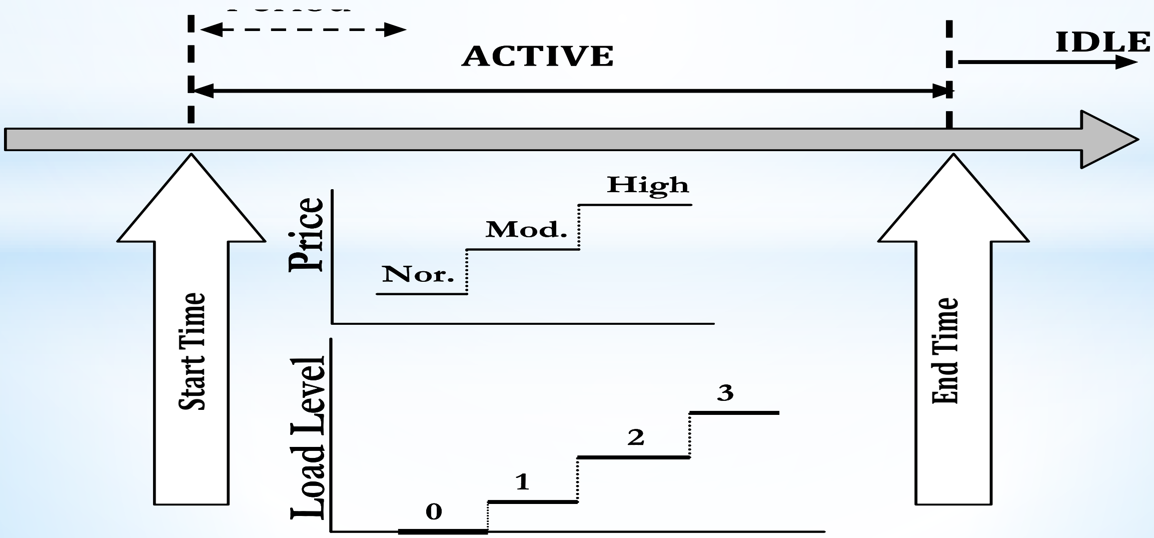
DDC to Zone level be programmed to allow centralized demand shed for non-critical zones:

Controls have capability to

- remotely setup cooling temp by 4 F or more in non-critical zones with EMCS

Controls require following features:

- Manual control. Manual control by authorized facility operators to allow adjustment of heating and cooling set points globally from a single point in the EMCS; and
- Automatic Demand Shed Control. Upon receipt of a DR signal, space-conditioning systems conduct a centralized demand shed, as specified in Sections 120.2(h)1 and 120.2(h)2.



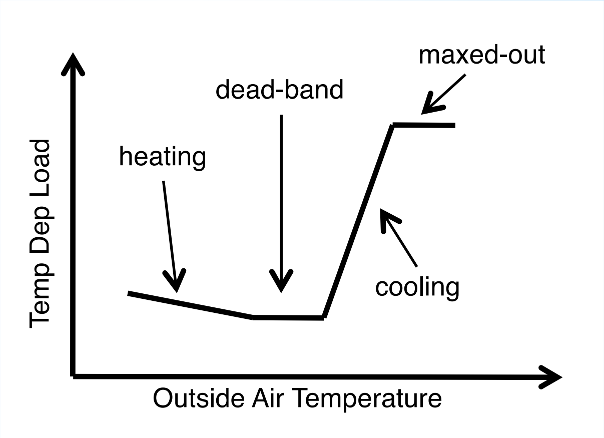
Demand Response and Baseline Model

Utilities use 10 previous days as baseline

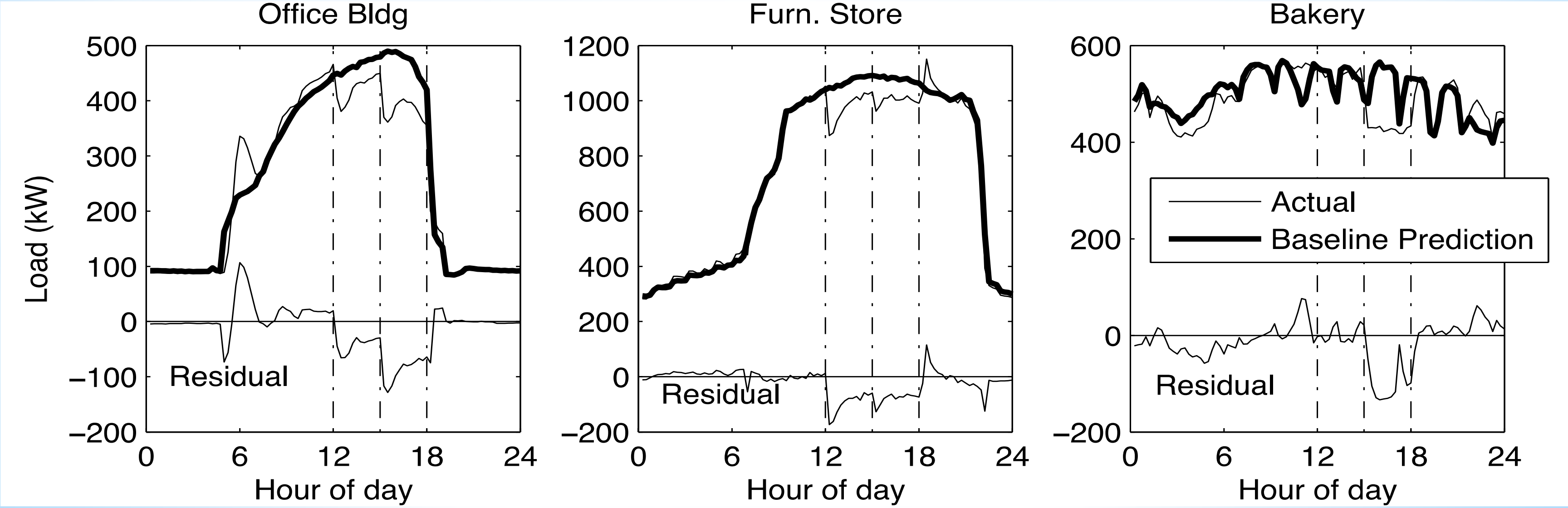
May use a morning adjustment

Regression, built from baseline

- Time-of-week indicator variables
- Piecewise linear temperature dependence



[Mathieu, Price, Kiliccote, and Piette, 2011. *IEEE Transactions on Smart Grid*]



* Grid service products definitions for load participation in the retail and wholesale electricity markets (updated from O. Ma et al.)
* Two grid products will be tested:
  * 5-minute Real-time Energy market (i.e., PDR in the CAISO energy market)
  * Ancillary Service (i.e., AS – Frequency Regulation [up and down])

Electricity market	Product Type	General description	How fast to respond	Length of response	Time to fully respond	How often called
Retail market	Capacity	Response when generation resources or electric system capacity may not be adequate	n/a	1-8 hours	n/a	Maximum of 30 event hours per month (day-of and day-ahead)
	Energy price	High time-of-use energy price	n/a	4-6 hours	n/a	4-6 hours on weekdays (day-ahead)
Wholesale market	Regulation	Response to random unscheduled deviations in scheduled net load	4 seconds	≥ 10 minutes	1 minute	Continuous within the specified bid period
	Contingency (spinning & non-spinning reserves)	Rapid and immediate response to a loss in supply	1 minute	≤30 minutes (≥ 2 hours)	≤ 10 minutes	≤ Once per day
	Flexibility	Load following reserve for large un-forecasted wind/solar ramps	5 minutes	1 hour	15 minutes	Continuous within the specified bid period
	Energy	Shed or shift energy consumption over time	5 minutes	≥ 1 hour	10 minutes	1-2 times per day with 4-8 hour ahead notification
	Capacity	Ability to serve as an alternative to generation	Top 20 hours coincident with balancing authority area system peak			

O. Ma *et al.*, "Demand Response for Ancillary Services," *IEEE Trans. Smart Grid*, vol. 4, no. 4, pp. 1988–1995, 2013.