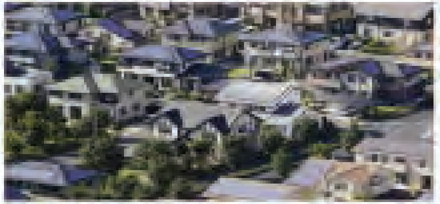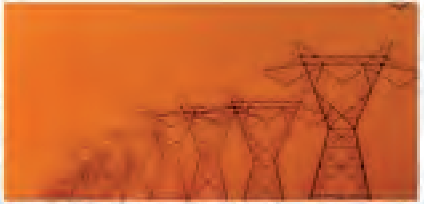

2025 California DR Potential Study:

Data-driven modeling of distributed energy resources to inform public policy

October 9th 2017

Peter Alstone

Schatz Energy Research Center

Humboldt State University

Study Team:

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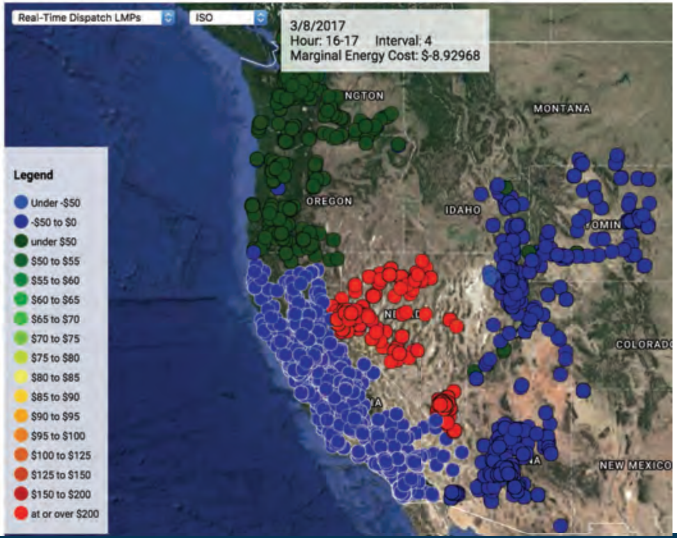
Nexant: Josh Bode, Adriana Ciccone, Ankit Jain

2025 California DR Potential Study

Assess Demand Response (DR) Potential to facilitate long-term clean energy goals with reliable and cost-effective support for the grid.



Context: CPUC Rulemaking 13-09-011

ALJ/KHY/NIL/avs PROPOSED DECISION Agenda ID #15995
Alternate to Agenda ID# 15996
Ratesetting

Decision PROPOSED DECISION OF ALJ HYMES and ALJ ATAMTURK
(Mailed 9/15/2017)

BEFORE THE PUBLIC UTILITIES COMMISSION OF THE STATE OF CALIFORNIA

Order Instituting Rulemaking to Enhance the Role of Demand Response in Meeting the State's Resource Planning Needs and Operational Requirements. | Rulemaking 13-09-011

DECISION ADOPTING STEPS FOR IMPLEMENTING THE COMPETITIVE NEUTRALITY COST CAUSATION PRINCIPLE, DECLINING TO HOLD AN AUCTION IN 2018 FOR THE DEMAND RESPONSE AUCTION MECHANISM, AND ESTABLISHING A WORKING GROUP FOR THE CREATION OF NEW MODELS OF DEMAND RESPONSE

DR Potential Study Timeline:

Summer 2015: Initiate work with CPUC

April 2016: Phase 1 "Interim" Report describing load shed DR

November 2016: Draft Phase 2 Results Public workshop with Stakeholders

March 2017: Final Report

April 2017: Public workshop on "pathways to new models of DR"

full proposed decision: http://docs.cpuc.ca.gov/SearchRes.aspx?docformat=ALL&docid=195586659

"DR Futures" Framework & Model

- **Public interest research led by LBNL 2015-2017** leveraging SmartMeter datasets for end-use DR estimates**.**
- **Focused on <u>2 linked questions</u>:**
  1. What **DR service types** will meet California's future grid needs as it moves towards clean energy & advanced infrastructure?
  2. What is **expected resource base size & cost** for DR service types?

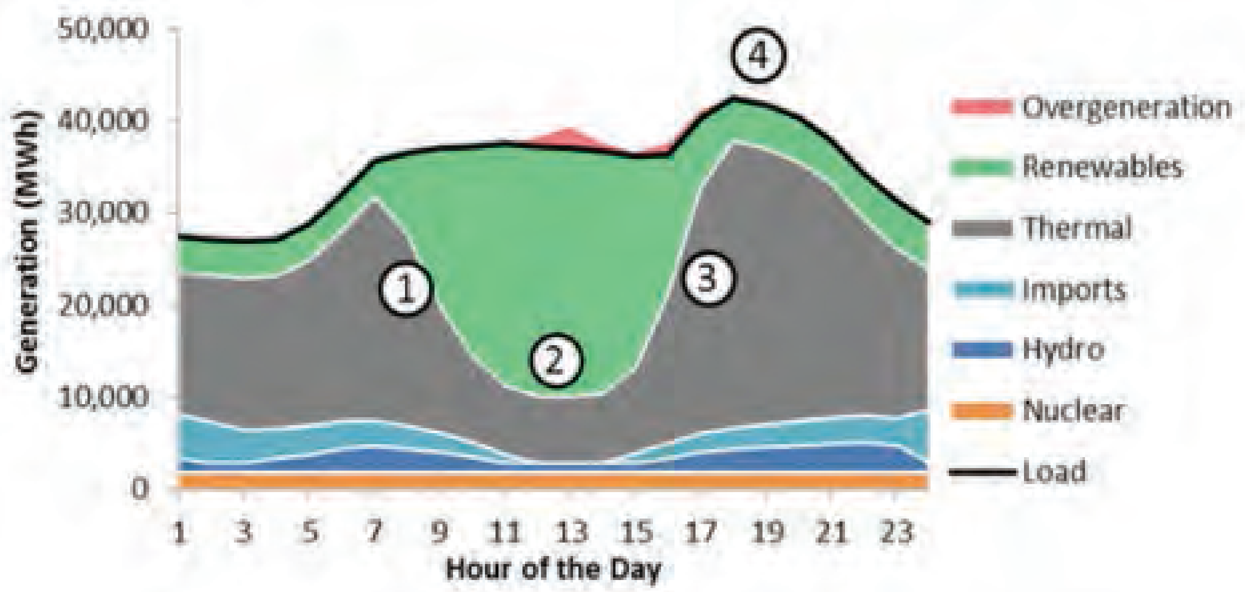
Driven by the Challenges of a 50% RPS

Ramping ① ③

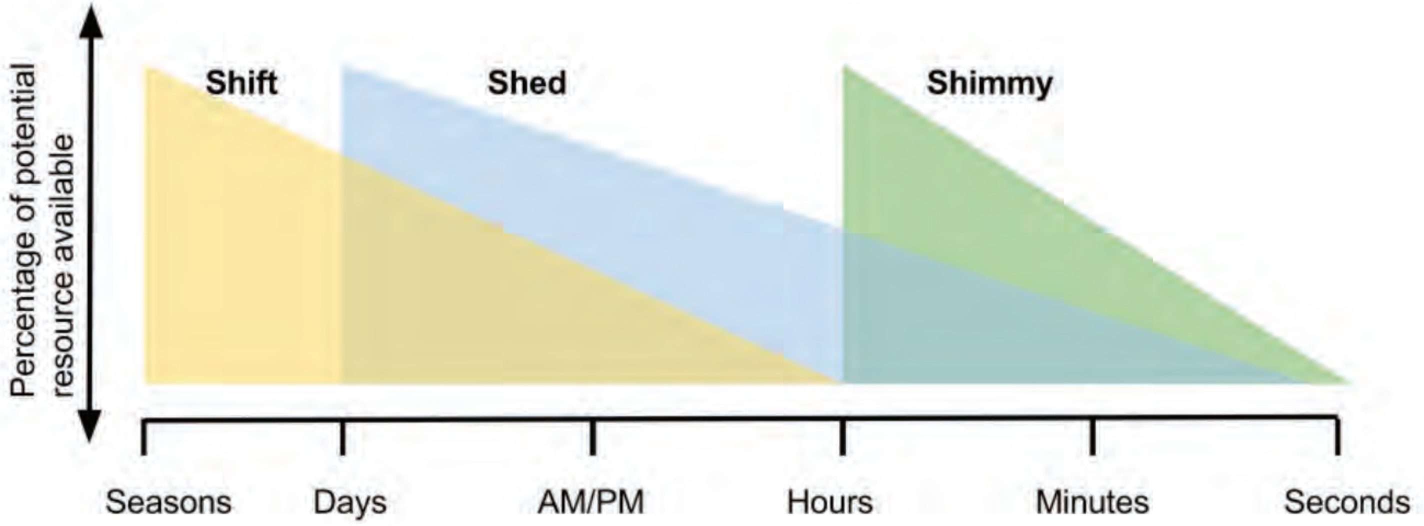
Minimum Generation
& **Curtailment** ②

Evening **Peak** ④

Intra-hour **Variability**
& Short-duration Ramps
① ② ③ ④ (All day)



DR Service Across Timescales to Meet Future Grid Needs



Mitigate Ramps and Capture Surplus Renewables

Manage contingency events and coarse net load following

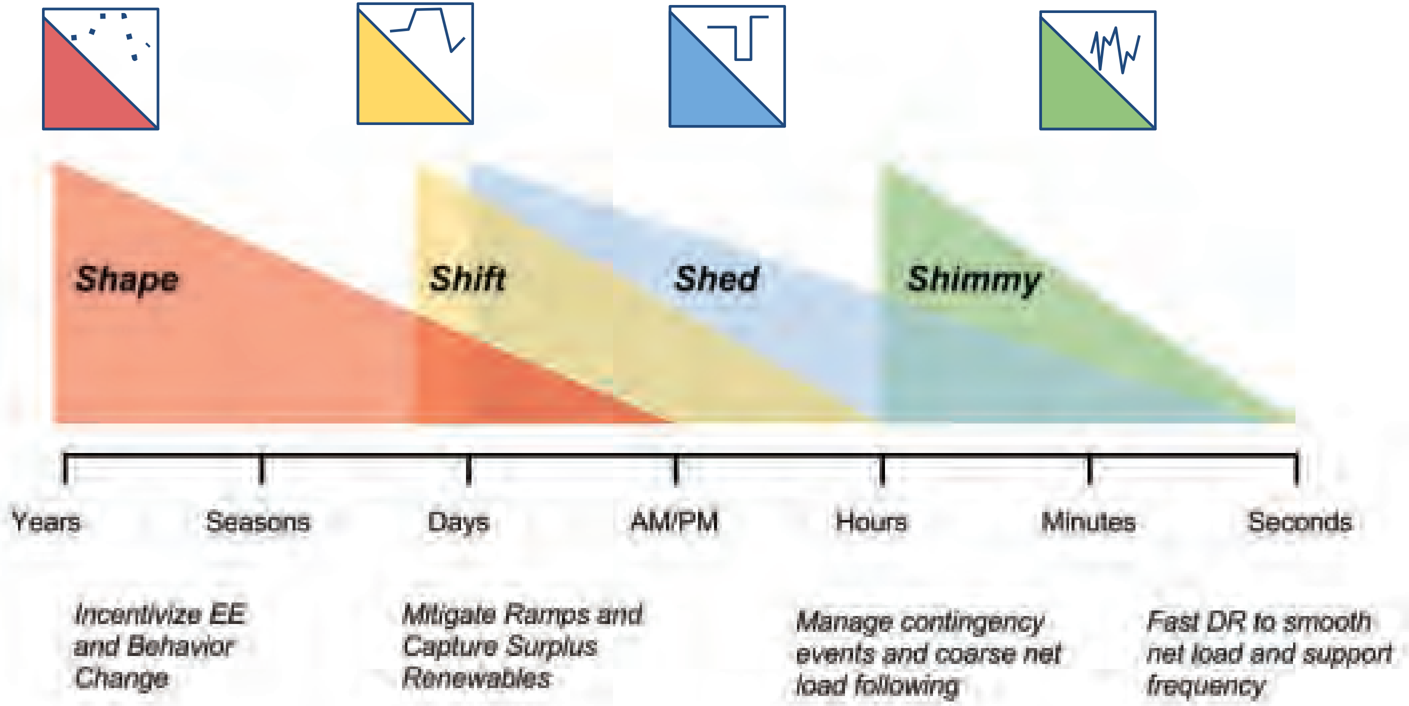
Fast DR to smooth net load and support frequency

DR Service Across Timescales to Meet Future Grid Needs

"Shape" is how we described price-based response that results in shifting and load shed.

We modeled TOU and CPP in the study.

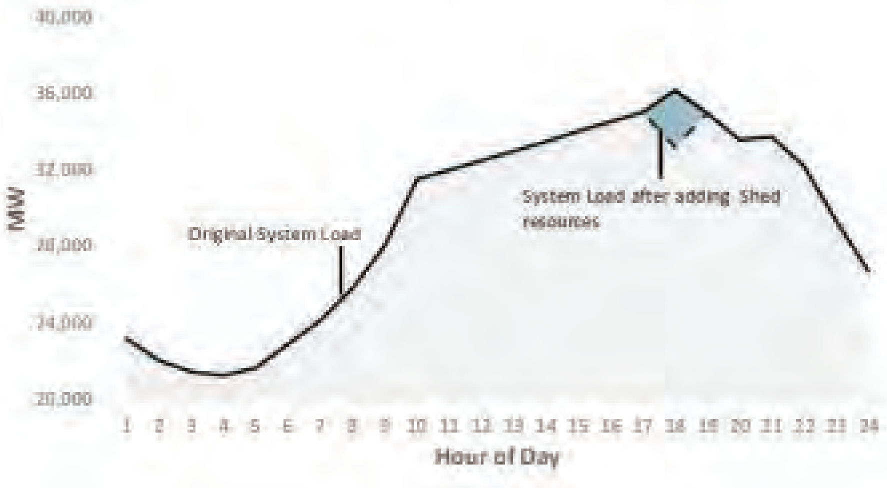
The term is from the parlance of DR intervenors and stakeholders.

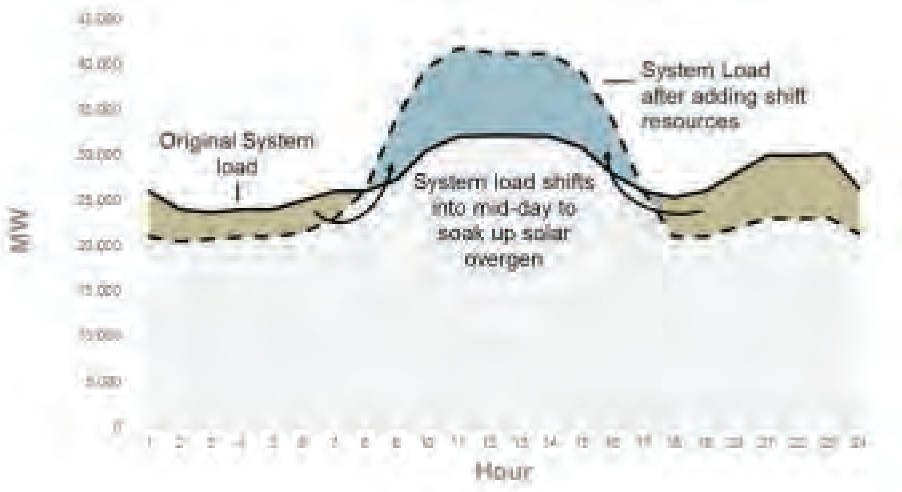


Shed and Shift

Shed Service Type: Peak Shed DR

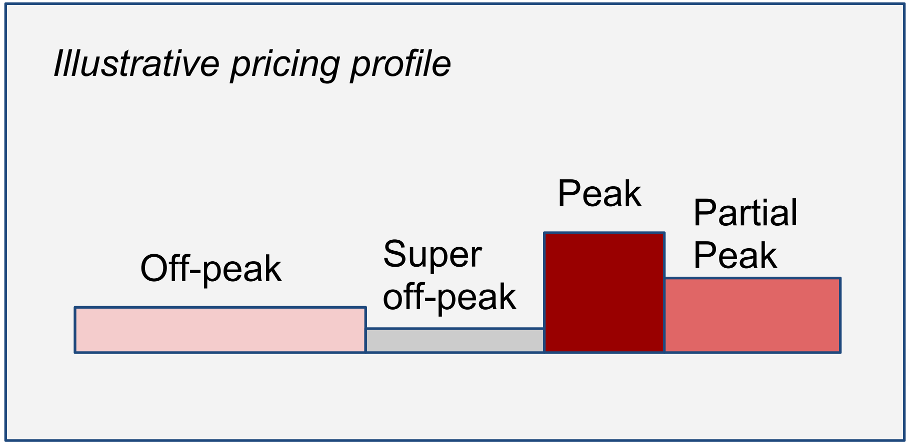
Shift Service Type: Shifting load from hour to hour to alleviate curtailment/ overgeneration



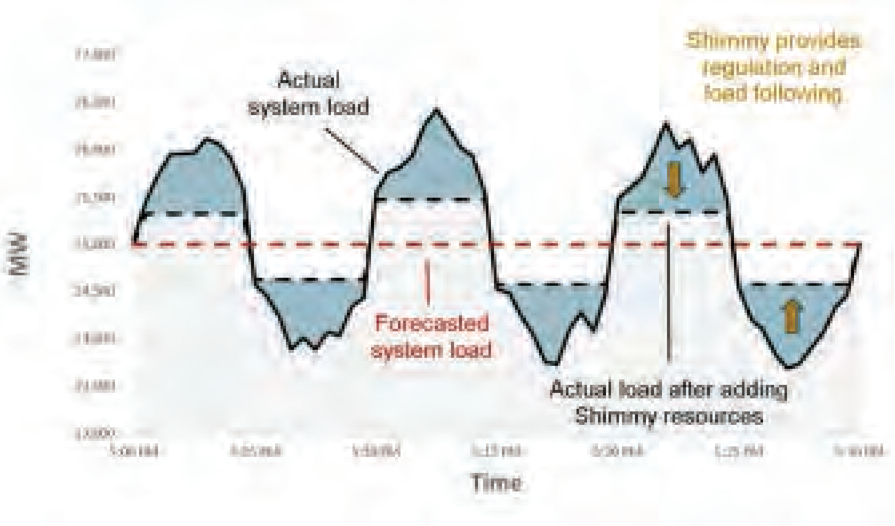


Shape and Shimmy

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



Shimmy Service Type: Load Following & Regulation DR



Why a Simplified Framework?

Shape, Shift, Shed, Shimmy

Generalized, friendly nomenclature enables **clear conversations about DR beyond peak capacity DR, with less jargon.** The goal was to develop generalized system modeling frameworks.

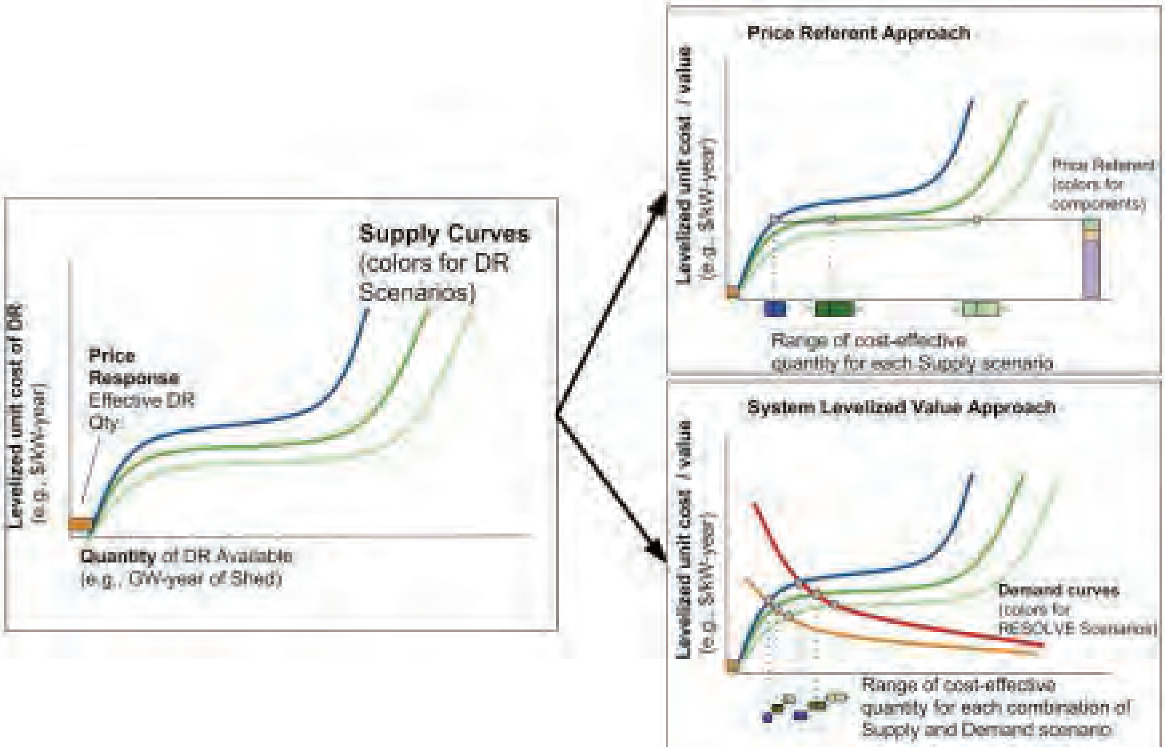
The **policymaking challenge** is translating generalized results to specific programs and market structures.

	DR Service Product	California Market
Shed	Peak Capacity	System and Local RA Credit
	Economic DR	Economic DR / Proxy Demand Resource
	Contingency Reserve Capacity	AS- spinning
	Contingency Reserve Capacity	AS- non-spin reserves
	Emergency DR	Emergency DR / Reliability DR Resource
	DR for Distribution System	Distribution
Shift	Economic DR	Combination of Energy Market Participation
	Flexible Ramping Capacity	Flexible RA -- energy market participation w/ ramping response availability
Shimmy	Load Following	Flexible Ramping Product (similar)
	Regulating Reserve Capacity	AS- Regulation
Shape	Load modifying DR - Event-based	CPP
	Load Modifying DR - Load shaping	TOU

Two DR Valuation Approaches

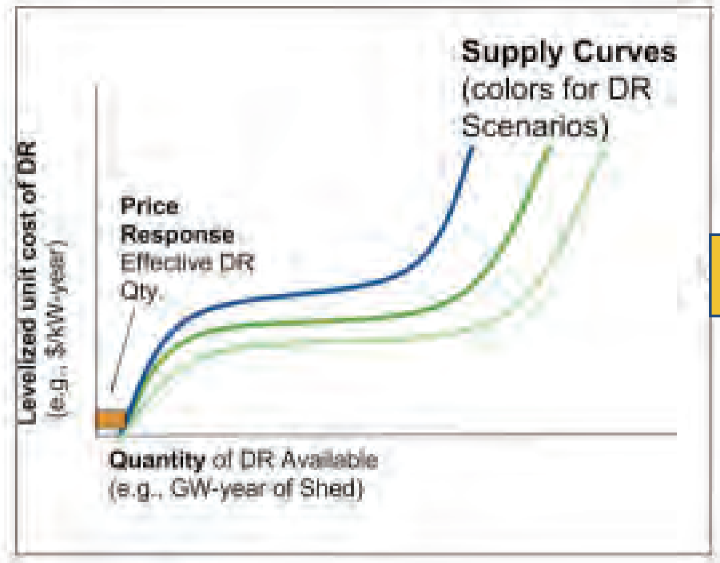
Supply & demand Intersections represent a procurement target or expected market outcome assuming business models & markets reflect estimates in model.

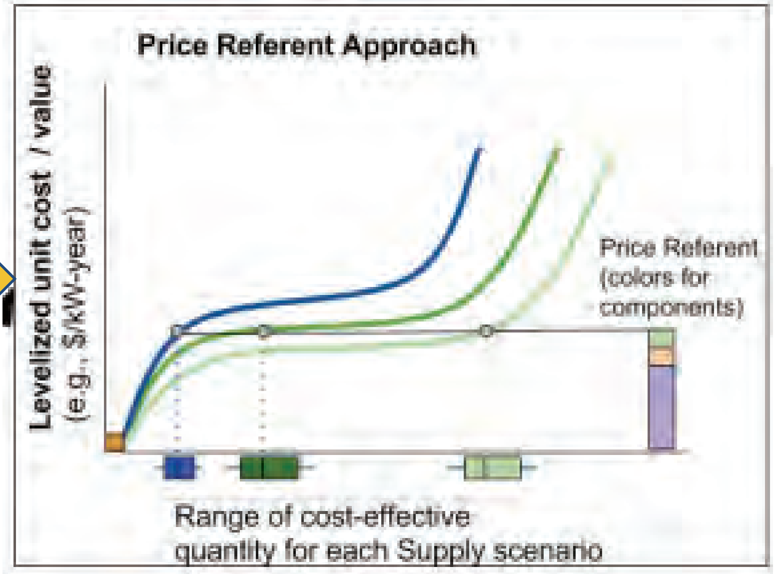
Two methods for estimating "demand curves."



1. Price Referent Approach

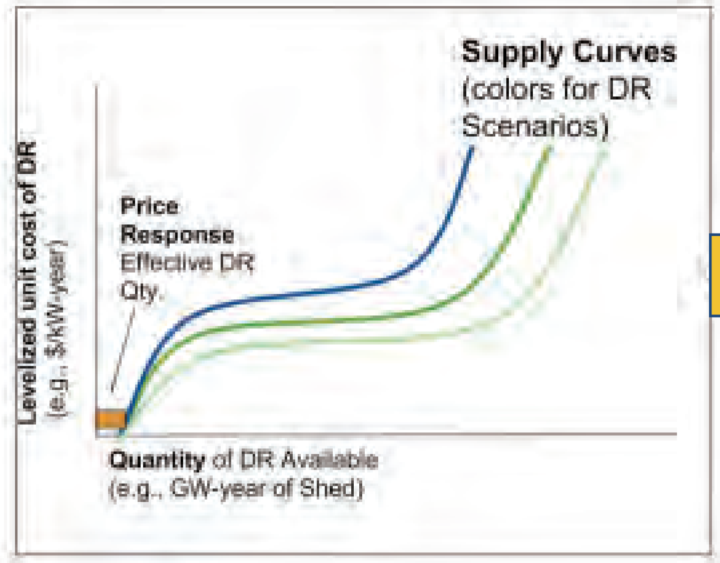
Price Referent Approach: Compares DR Supply to cost of procuring an alternative resource (e.g., NG combustion turbine for peak load). A "horizontal" demand curve. **This is only used for "Shed" in our study.**

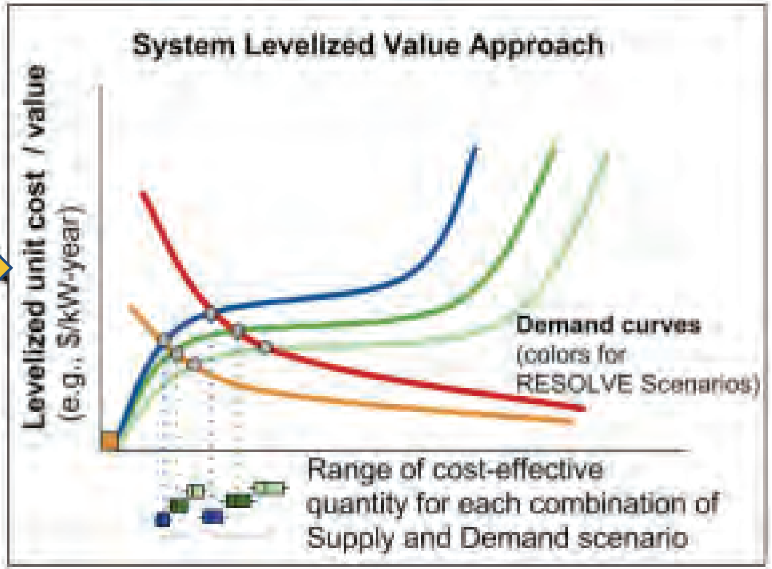




2. System Levelized Value Approach

System Levelized Value Approach: Compare DR supply with estimated "levelized value" to grid. Levelized value could be thought of as effective annual demand curves. This is used for all resources in our study.





Methodology

LBNL-Load analysis groups IOU-provided customer load (~220,000 customers) & demographic data (~11 million customers) into 3,500 "clusters," based on observable similarities. We developed **characteristic load profiles** for total & end use-specific load clusters. **LBNL-Load** forecasts loads for years 2020 & 2025 according to 2015 Integrated Energy Policy Report.

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

Renewable Energy Solutions (RESOLVE) model estimates a set of value benchmarks for each DR type based on avoided investment & operation costs when DR is available for use. DR availability scenario ranges are run to establish DR's value for two benchmark cases: **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

We used **Technology Advancement Scenarios** to compare a range of trajectories in the DR Market.

Parameter	Parameter Description	Scenario	2014 Value	2020 Value	2025 Value
Cost	Full DR enabling technology cost relative to the base cost (lower is better)	BAU	1.00	1.00	1.00
		Medium	1.00	0.95	0.90
		High	1.00	0.85	0.70
Performance	DR service quantity (kW or end-use load fraction) available relative to base performance (higher is better)	BAU	1.00	1.05	1.10
		Medium	1.00	1.10	1.20
		High	1.00	1.20	1.40
Propensity	Likelihood to enroll and participate in DR relative to base propensity (higher is better)	BAU	1.00	1.05	1.10
		Medium	1.00	1.15	1.30
		High	1.00	1.25	1.50

BAU:
Business-as-Usual Progress

"Medium"
Accelerated Progress

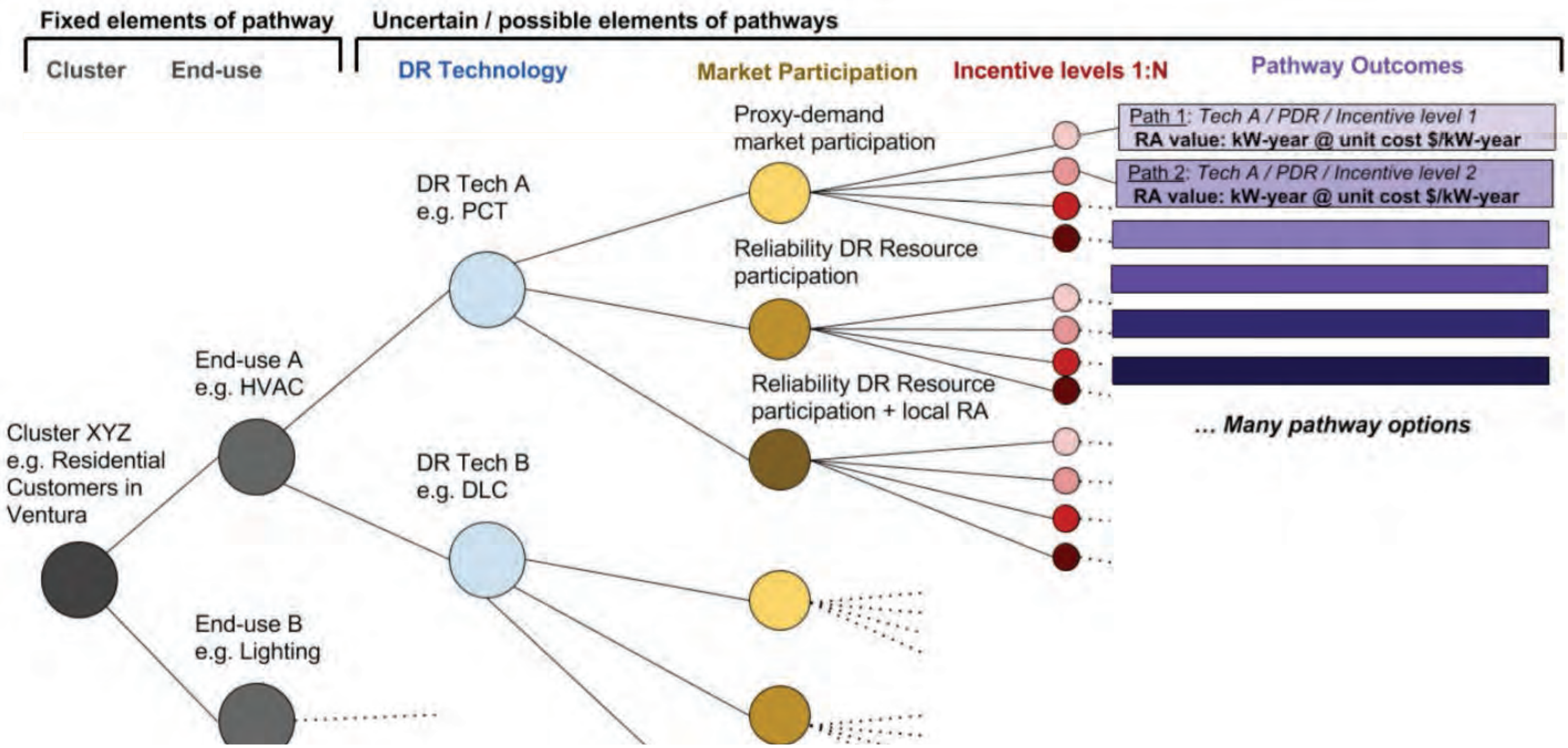
"High"
Faster Progress (NOT a ceiling)

DR Supply Curve Estimation

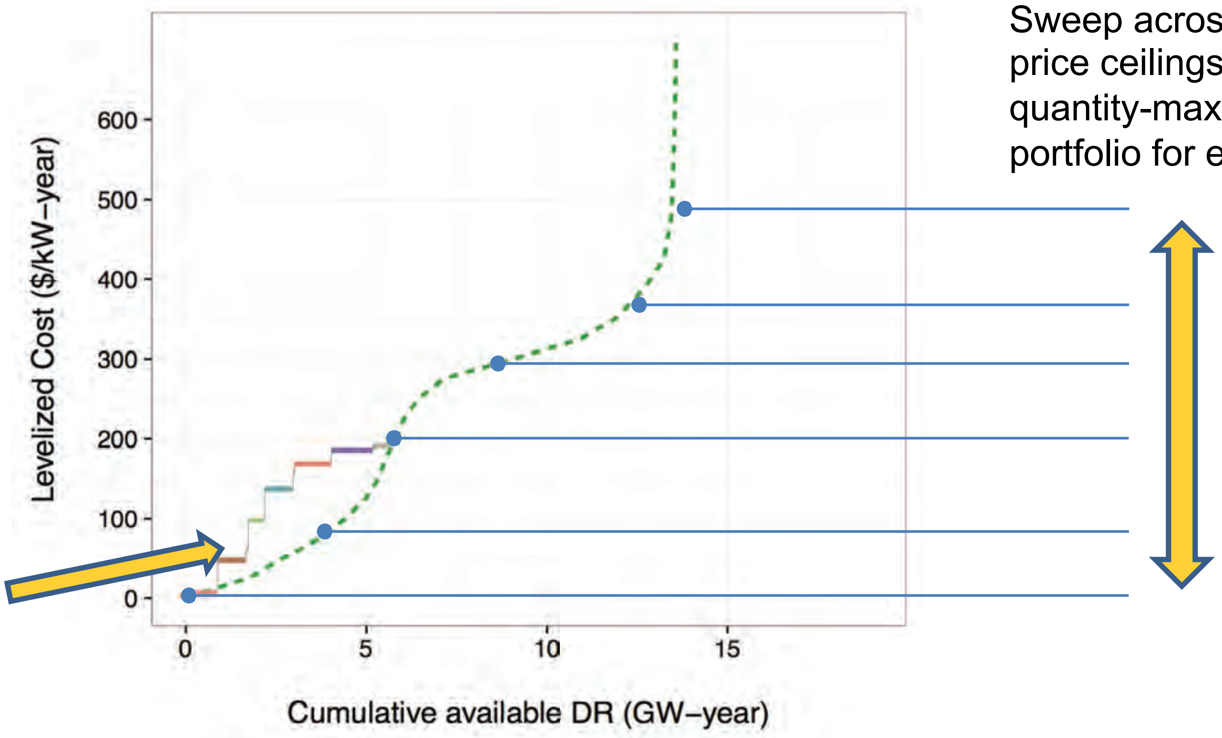
Unit of analysis is **at the cluster level, for each end use...**

1. **Estimate quantity and cost of DR service for many options**, including possible combinations of:
   - ❑ DR control and communications technology
   - ❑ Market participation
   - ❑ Incentives / payments offered, changing propensity to adopt

2. **Sweep through a range of price ceilings**, and for each choose the highest quantity of DR at each cluster based on the options available below each price.


Fixed elements of pathway
Uncertain / possible elements of pathways
Cluster
End-use
DR Technology
Market Participation
Incentive levels 1:N
Pathway Outcomes
Proxy-demand market participation
Path 1: Tech A / PDR / Incentive level 1
RA value: kW-year @ unit cost $/kW-year
Path 2: Tech A / PDR / Incentive level 2
RA value: kW-year @ unit cost $/kW-year
DR Tech A e.g. PCT
Reliability DR Resource participation
Reliability DR Resource participation + local RA
... Many pathway options
End-use A e.g. HVAC
Cluster XYZ e.g. Residential Customers in Ventura
DR Tech B e.g. DLC
End-use B e.g. Lighting

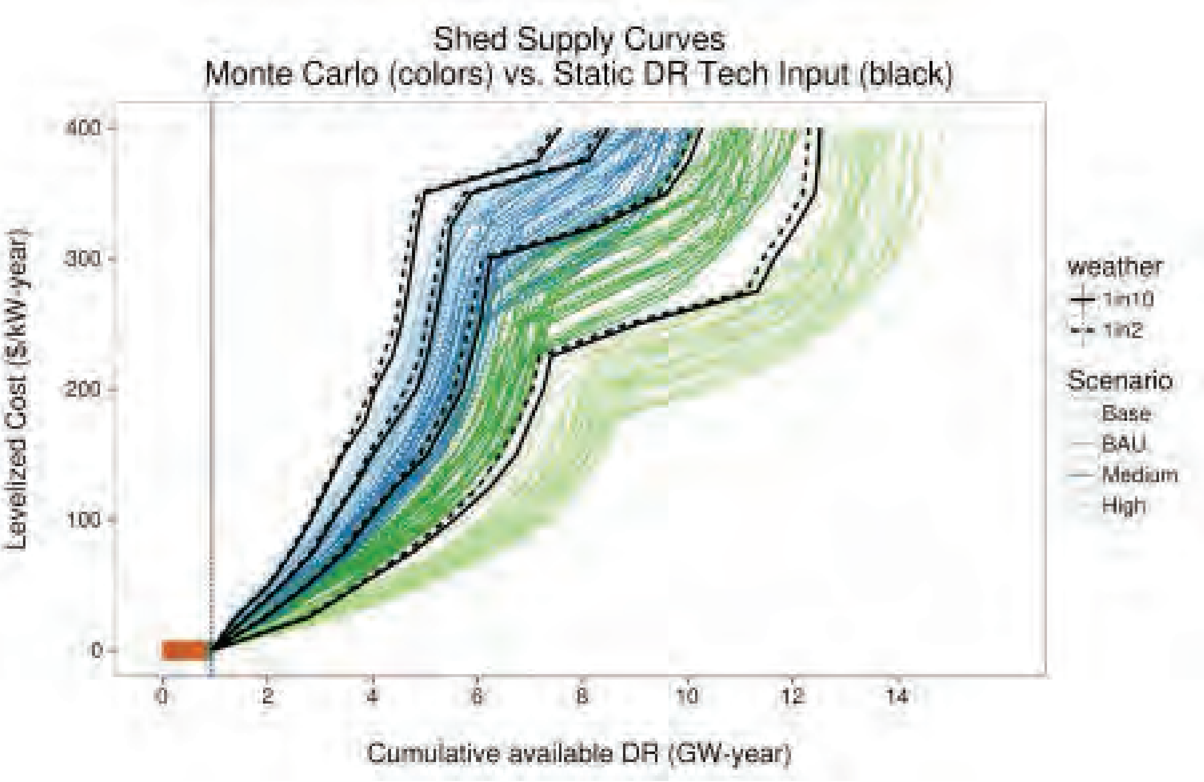
Trace potential estimates over many cost options



Sweep across a range of price ceilings and find a quantity-maximizing portfolio for each.

At each price ceiling, **a portfolio of DR that maximizes the quantity available**

Many Possible Supply Curves for Each Resource:
Weather, DR Market Scenarios, Forecast Year and Monte Carlo

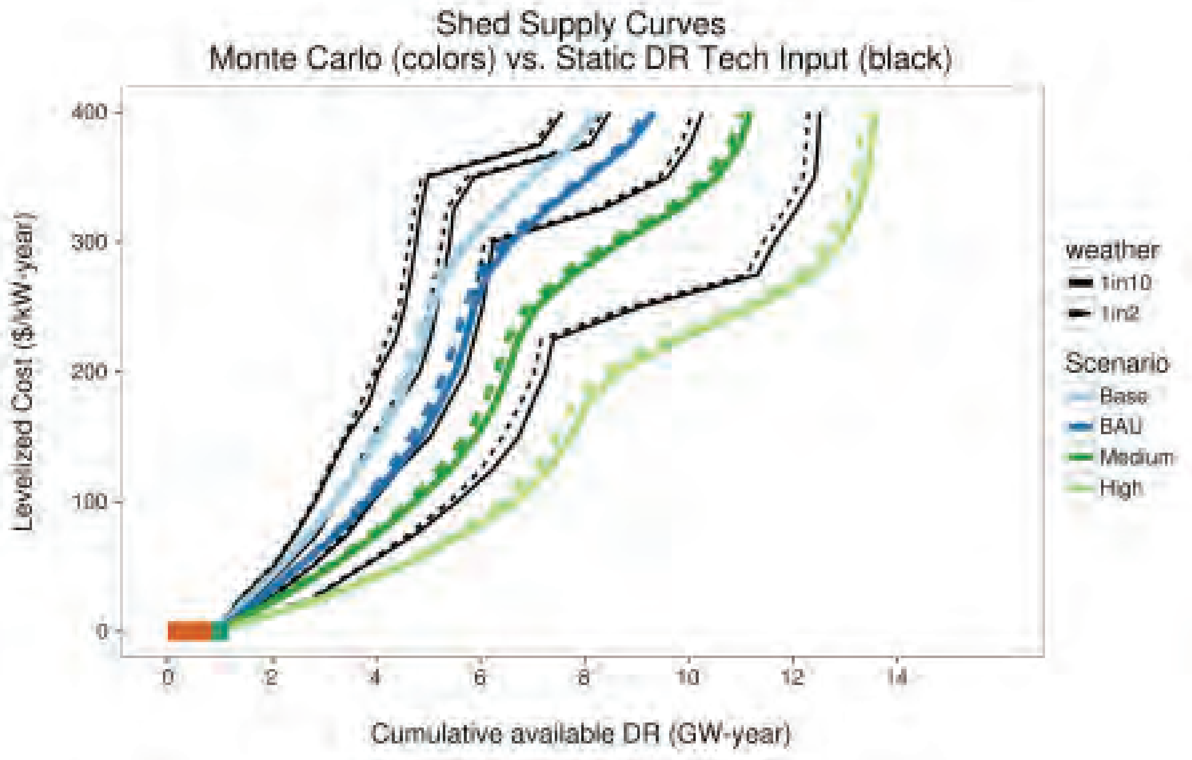


- **Monte Carlo analysis introduces variability** in technology advances & site-to-site variability trajectory.

- **DR potential can be increased <u>if</u> market participants can identify & target highest-value sites & technology.**

*** Phase 2 focuses on results that include variability, NOT static technology runs ***

Mean Monte Carlo Results are Shown on Supply Curve Plots



- **Mean of Monte Carlo results (bold colored lines)** are expected "average" quantity/cost supply curves.
- **Black lines** represent what expected supply curve would be without site-to-site variation.

E3 RESOLVE model to estimate DR Value for two "Futures" of Renewable Integration

RESOLVE is an E3 model that selects least-cost portfolios of renewable resources and integration solutions within the CAISO region between 2015 – 2030. We investigated two "Futures" based on CPUC's 2016 LTPP Assumption scenarios**:**

High Curtailment Future

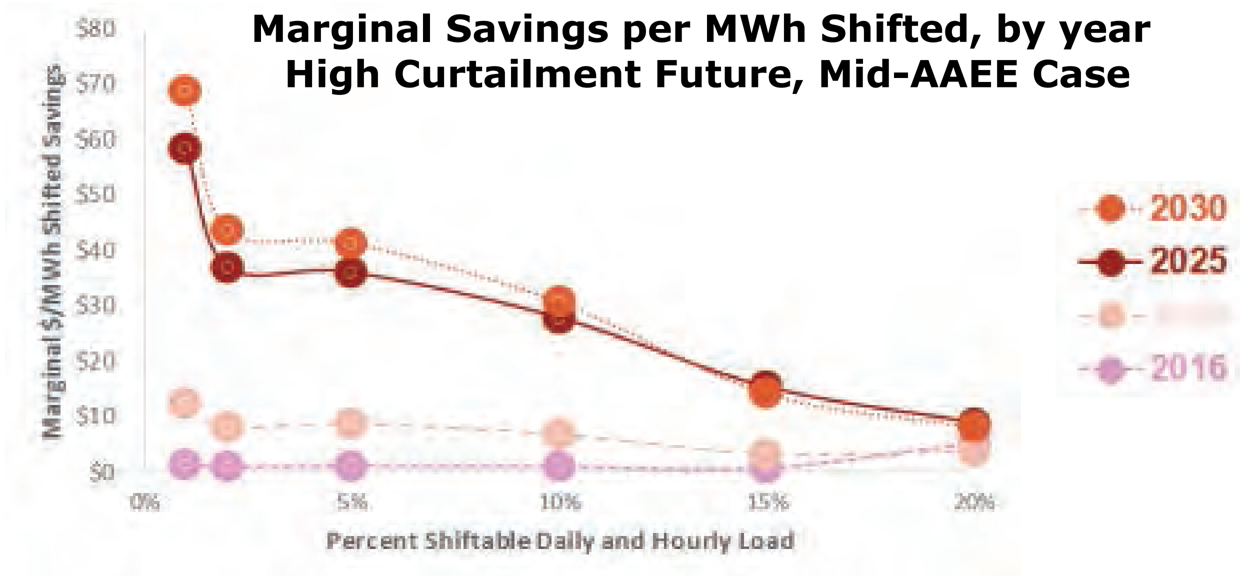
- More utility-scale and BTM PV, which would *increase curtailment* & thus DR value
- Represented by High BTM PV Scenario in 2016 LTPP

Low Curtailment Future

- More regionalization, more wind, & less behind-the-meter PV. Leads to *less curtailment* than High Curtailment Future, thus lower DR value
- Represented by Out of State Wind Scenario in LTPP

Savings from *Shifted* Load Increase As Over Time as Renewables Come Online

- Diminishing marginal value as additional load is shifted in each day & hour – saturation is reached at ~20% shift in 2025+
- Value increases significantly between 2020 & 2025 as large increase in renewable build takes advantage of expiring federal tax credits

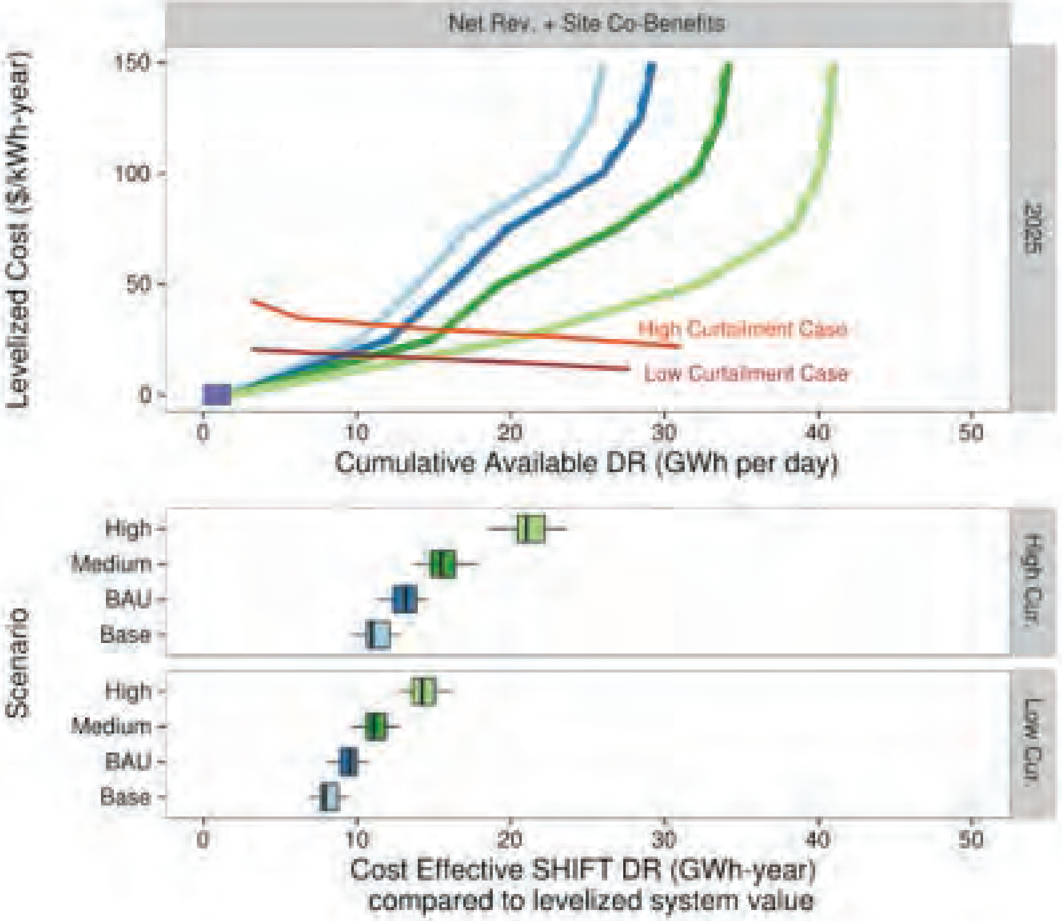


Shift Supply Curves

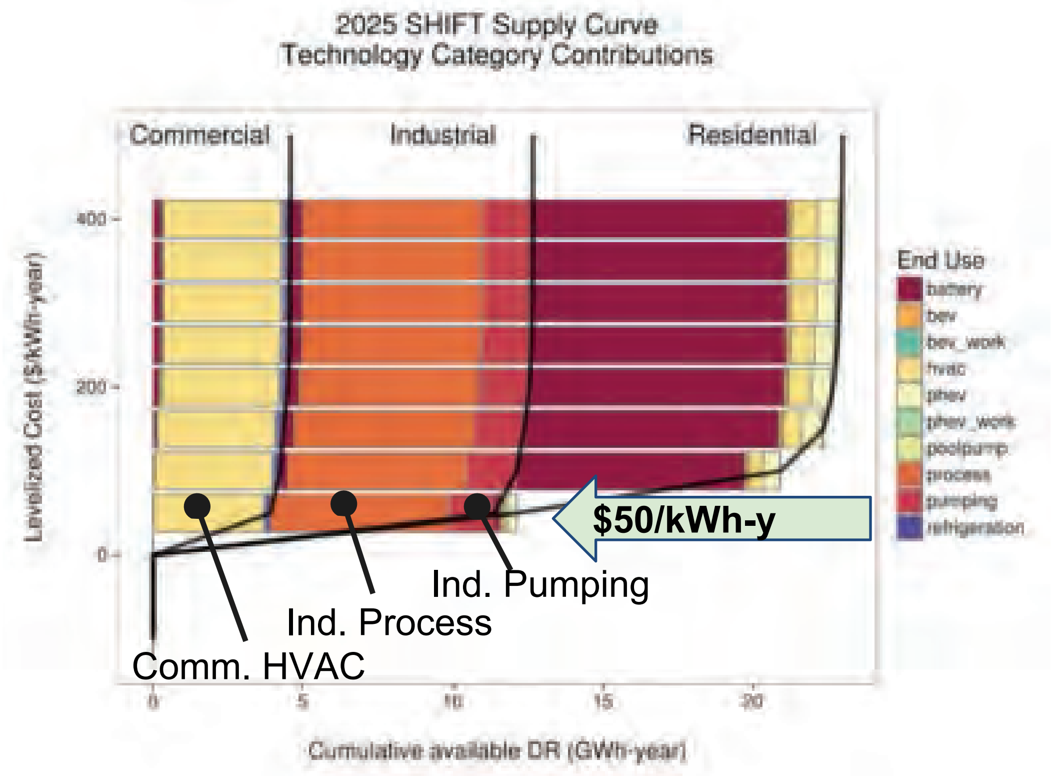
2025 Supply + Demand
(Net ISO Rev and Co-Benefits)

Shown with *~2 GWh Shape-Shift*

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



Shift Technologies



Key Technology Options at $50 /kWh-year cost:

- Industrial process & pumping
- Commercial HVAC Loads

Electric Vehicles & Batteries could be significant if prices fall.

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.

Opportunities for Local Shed

50% of Shed located in currently constrained "local capacity areas"
(⚡ in photos and map)

Santa Barbara (Photo: John Wiley)

San Bernardino Basin (Photo: USGS)

San Diego (Photo: Dole Frost)

Advanced Shift DR and Ongoing Activity

Shift could also be framed as a combination of (separate) load building and shed events, or a price response. Some current work streams to highlight:

- **CAISO: ESDER 3 Straw Proposal** (Oct 2017) includes bi-directional DR that would expose participating customers to real-time energy prices through bids. The **Baseline Analysis Working Group** is exploring more robust baselines through statistical regression and control group methods.

- **Utilities: Excess Supply Pilots** are developing lessons learned in dispatch of load to consume. **Modified TOU rates** to fill mid-day solar peak.

- **CPUC: Load Consumption Working Group:** Starting in January 2018, convened by CPUC to inform the design of new models for DR

Challenges for achieving Shift in both Market and Price-based approaches

- **Shift** is likely a frequently dispatched resource (the value to the system is through accumulated dispatch), thus **baseline measurement** is inherently challenging.

- **Interactive effects between retail and wholesale** market jurisdiction mean that customers effective price for consumed electricity is the retail price minus wholesale payments. This may reduce the price ratio experienced by customers compared to a true dynamic price.

DR Going Forward

- Behind the meter storage, electric vehicles, new automation technology (”IoT”), and monetized distribution system service are all **wild cards** for future DR potential and role.
- **Shift is fundamentally different from Shed** – frequently dispatched, accumulating value, and could require bidirectional communication and control.
- **Shimmy markets are thin**, but if energy neutral could be key elements of combined portfolios with other DER/DR resources.

Keys to Achieving DR Potential

Opportunities for Each Resource

Shape: Could there be deeper potential for energy shift with more aggressive rates & dynamic pricing, combined with automated DR? ***Design pricing to Shift*** rather than Shed.

Shed: ***Targeted Shed*** for local capacity & distribution system service, which may require faster DR technology. Half of statewide Shed resources are in a locally constrained capacity area.

Shift: Explore ***transitioning conventional DR*** automation to Shift. ISO integration presents baseline & settlement challenges for daily resources – consider retail price pathways (“Shape”).

Shimmy: Ancillary services markets are “thin” but high value for grid. ***Explore portfolios*** with Shimmy & other services that can be provided with fast-responding automation technology.

Transitioning from Conventional to Advanced DR

Policy Considerations:

- **Integration between policy at the CPUC and CAISO** to ensure that market designs are matched with most cost-effective pathways for DR services.
- Continued work on how integrated energy efficiency (EE), behind-the-meter storage & DR can amplify value – **integrated demand-side management (IDSM).**
- Continued work to build portfolios of value streams at the system scale, on the distribution system, and at the site level—**distributed resource planning (DRP)**.
    - Our model included first-order estimates for **distribution system service**.
    - With distribution system service, the result is an increase of about 4 GW of additional Shed DR capacity compared to a model run without portfolio approach

Thank you!

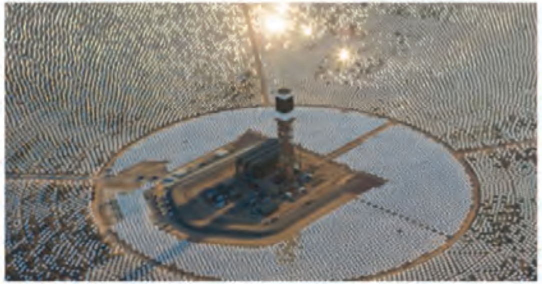
BERKELEY LAB

Energy+Environmental Economics

Nexant

SCHATZ ENERGY RESEARCH CENTER



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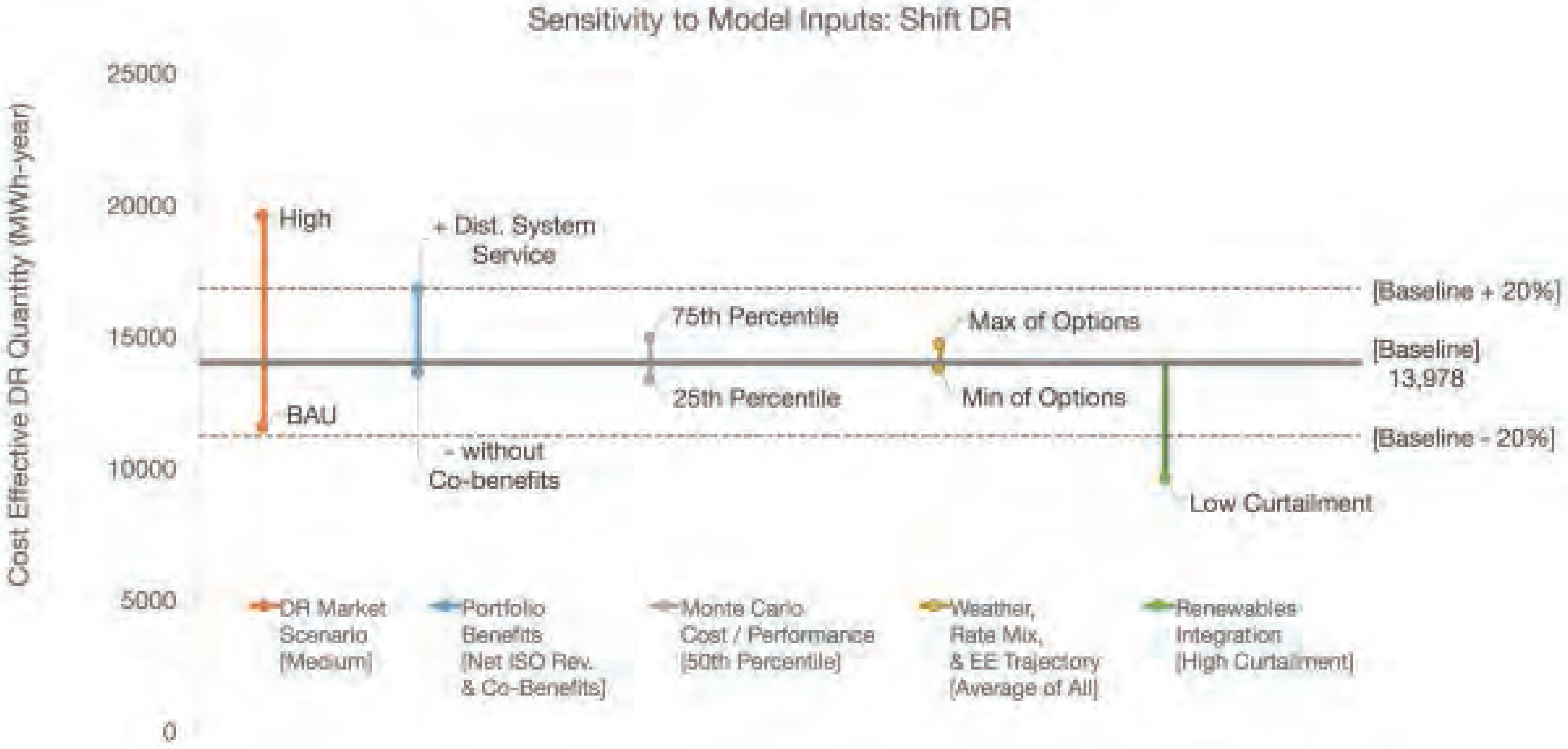
- Sam Piell, PG&E
- Jill Powers, CAISO
- Heather Sanders, SCE
- Heather Sanders, SCE
- Nora Sheriff, CLECA
- Mike Ting, Itron
- Greg Wikler, Navigant
- Gil Wong, PG&E

Shift:
Most Sensitive to Tech. Advances & Renewable Integration

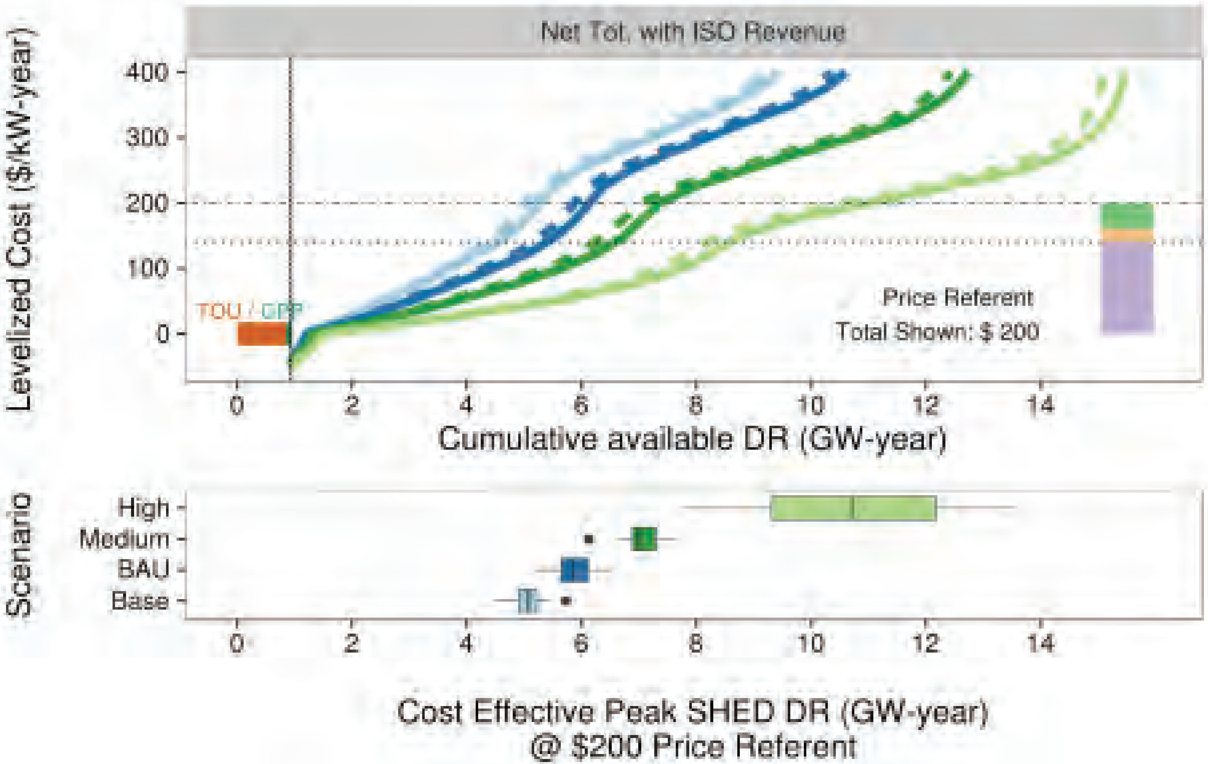


2025 Shed DR Potential Supply Curve vs. Price Referent

Supply Curves compared to **conventional price referent** suggest 6-10 GW of cost-effective Shed.

- **Take Home:** Significant Shed potential with price referent approach that assumes capacity investments are offset.

Supply Curve Notes: Rate Mix 3, Mid AAEE, Net Revenue + Site Co-Benefits

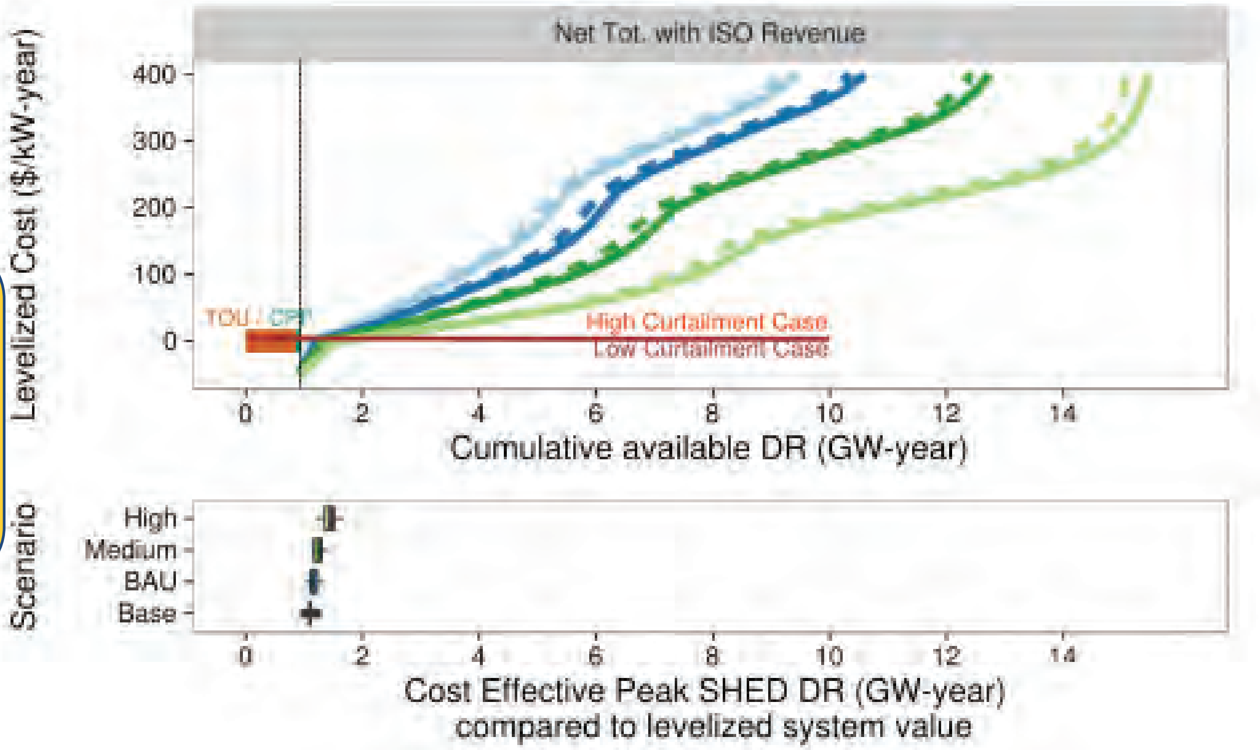


2025 Shed DR Potential Supply Curve Vs. Levelized System Value

Supply Curves compared to **levelized system value** suggest 0-1 GW of cost-effective Shed.

- **Take Home:** Essentially zero potential with RESOLVE model approach that incorporates expected capacity surplus

Supply Curve Notes: Rate Mix 3, Mid AAEE, Net Revenue + Site Co-Benefits



RESOLVE: Renewable Energy Solutions Model

RESOLVE is an E3 model that selects least-cost portfolios of renewable resources and integration solutions within the CAISO region between 2015 – 2030

- Selects portfolio of solar, wind, geothermal, biomass, and small hydro
- Adds cost-effective integration solutions such as energy storage and flexible conventional resources, in combination with the renewable portfolio, to minimize total cost over the analysis period
- Meets energy, capacity, RPS, GHG and other constraints
- RESOLVE performs capacity expansion modeling function to support IRP

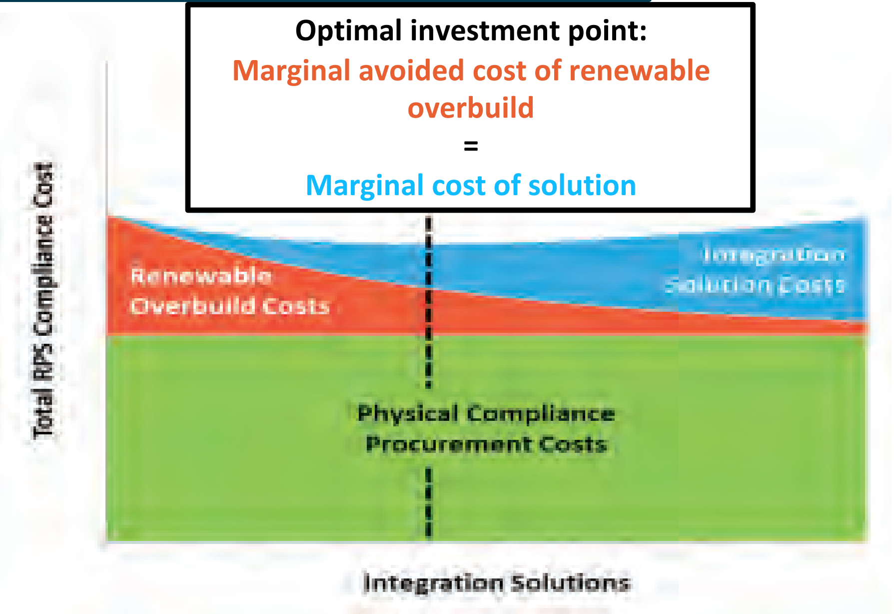
Resources are added to meet RPS target, overbuilding renewable portfolio if necessary

- Renewables are curtailed if the output cannot be consumed in California or exported due to oversupply or insufficient flexibility
- Resources added if necessary to replace curtailed output; replacement cost increases geometrically with curtailment

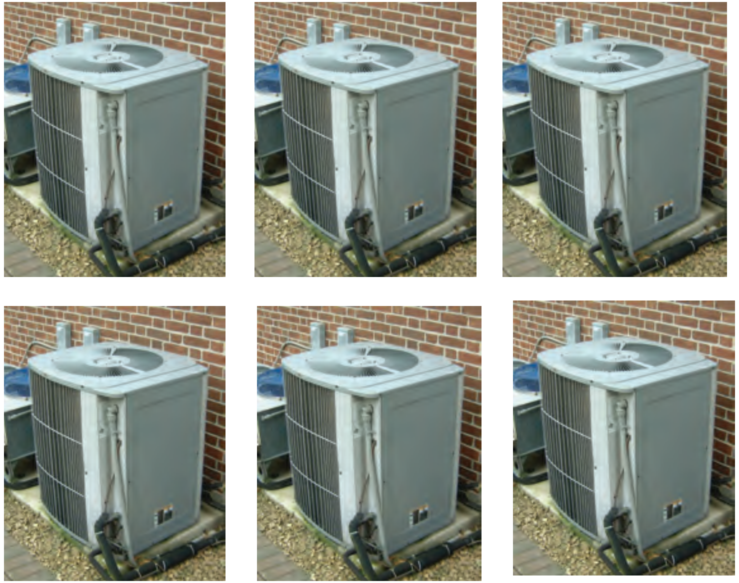
RESOLVE Provides a Framework for Valuation of Flexible Resources

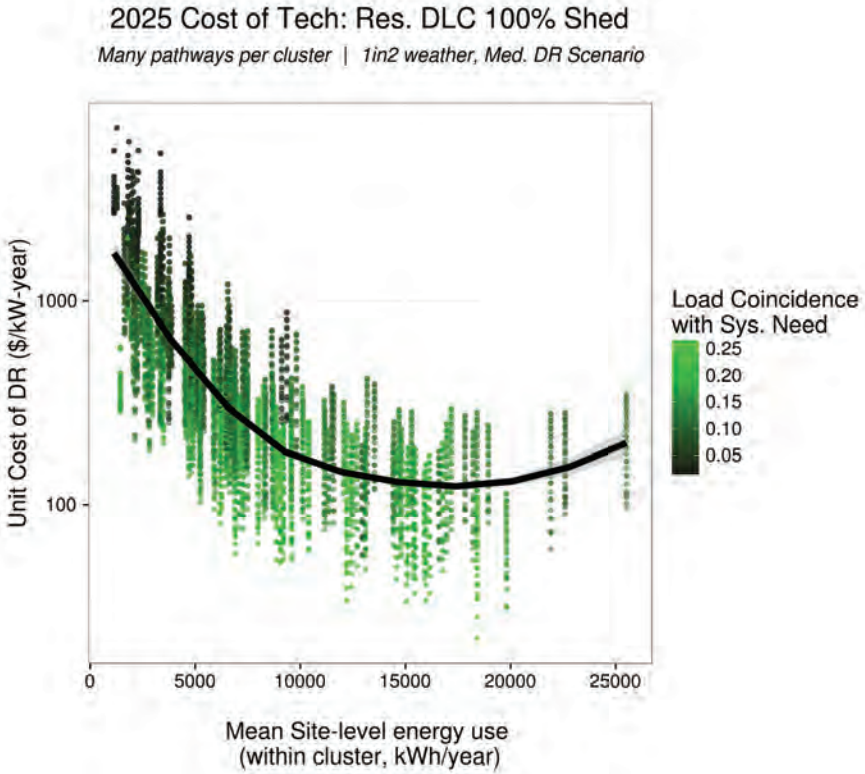
Economic curtailment & renewable overbuild are default solution to flexibility challenges, & form "avoided cost" of power system inflexibility

- Sizing electric system to deliver every MWh of renewable generation is cost-prohibitive
- Reduction of renewable curtailment & overbuild provide value to ratepayers
- Flexible resources are selected when their benefits—primarily reduced renewable overbuild—are greater than their costs



Smart Meters enable high-resolution potential estimates and targeting best sites





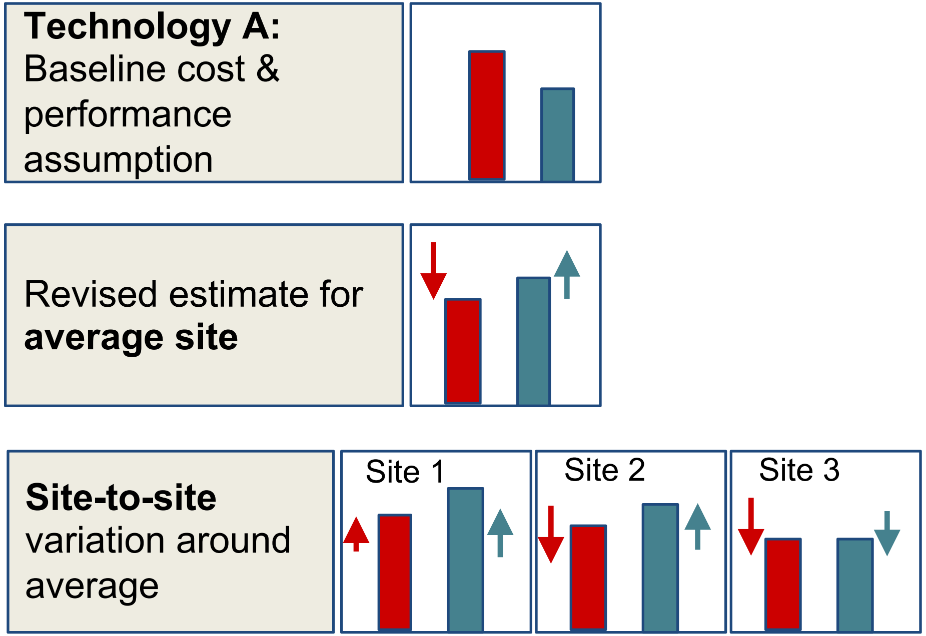
Modeled Uncertainty in Technology Assumptions

Monte Carlo Analysis starts with Baseline Assumption

Looks at two uncertainty levels:

(1) Expected market-wide cost & emerging DR technologies' performance

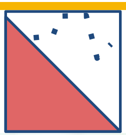
(2) Site-specific variation in technology cost & performance

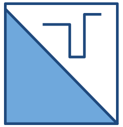


Cluster Summary

Sector	Clusters (Quantity)	Customer Count			Avg. Number of Time Series per Cluster
		(5th Percentile)	(Median)	(95th Percentile)	
Residential	493	1,450	11,148	56,530	201
Commercial	1,402	9	247	2,639	55
Industrial	1,614	4	43	619	15
Other	68	345	831	2,308	23
Total	3,577				

DR Service Type Table



 Service Type	Description	Grid Service Products/Related Terms	Analysis Unit	Shape (TOU/CPP) Included in service type analysis?
 **Shift**	Demand timing shift (day-to-day)	Flexible ramping DR (avoid/reduce ramps), Energy market price smoothing	kWh-year	Yes
 **Shed**	Peak load curtailment (occasional)	CAISO Proxy Demand Resources/Reliability DR Resources; Conventional DR, Local Capacity DR, Distribution System DR, RA Capacity, Operating Reserves	kW-year	Yes
Shimmy	Fast demand response	Regulation, load following, ancillary services	kW-year	No

Phase 2 built on Phase 1

The Phase 1 scope was expanded and enhanced in Phase 2

Phase 2 also included:

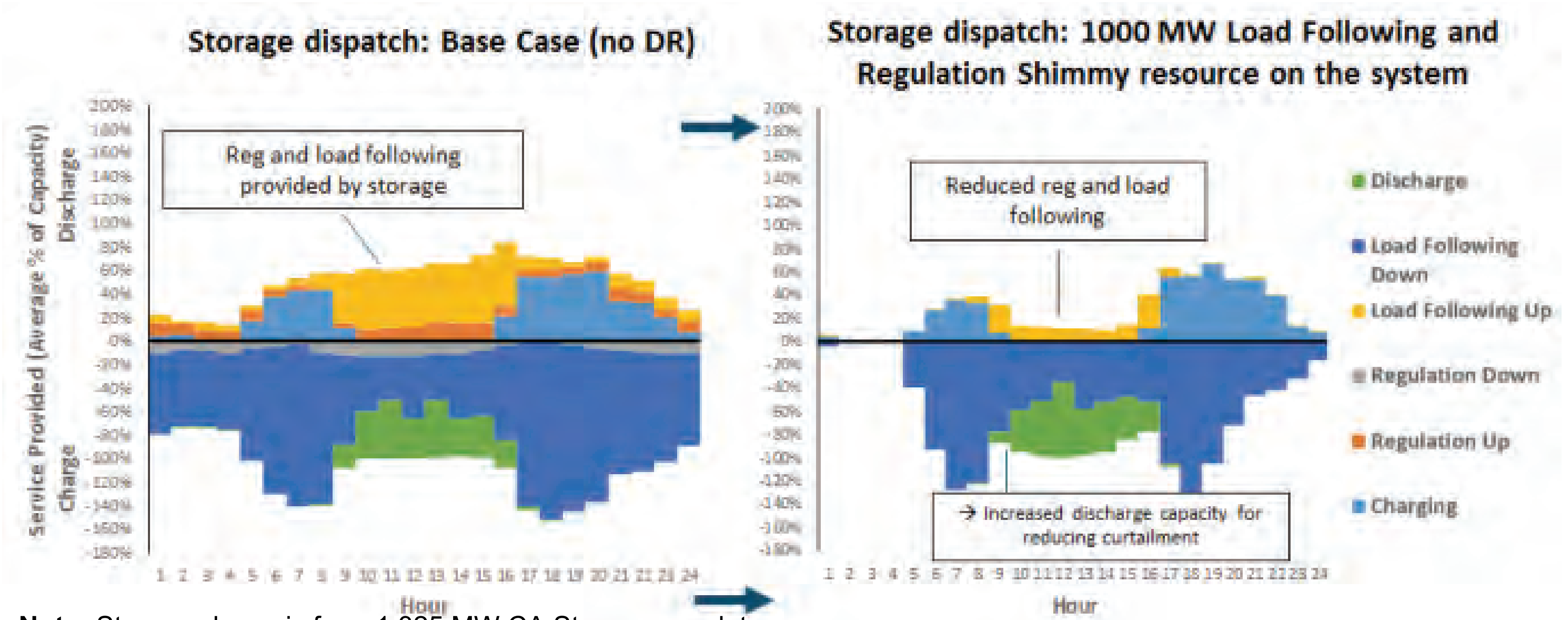
- **Improved input** estimates
- **Expanded TOU** analysis – 3 Rates
- **Monte Carlo** error analysis approach.

	Valuation Approaches		
	Price Referent (typ. $200/kW)	**Levelized Demand Curve** (RESOLVE)	**Limited evidence,** using notional value.
Systemwide Service			
Shift		2	-
Shimmy		2	-
Shed (systemwide capacity)	1 2	2	-
Shed (spin/non-spin reserves)	-	-	-
Local Service			
Shed (local capacity)	1 2	-	-
Shed (distribution system)	-	-	2

From Load Modifying to Load Consumption

TABLE 2 Load Consumption Working Group Tasks
Development of a proposal that defines new load consumption and bi-directional products.
Development of a proposal of whether and how to pay a capacity value for ramping to provide to the resource adequacy proceeding prior to January 31, 2019.
Development of a proposal on how to better coordinate the efforts of the CAISO and the Commission to integrate new models of demand response.
Development of a proposal to identify the value of new products to provide to resource adequacy proceeding prior to January 31, 2019.

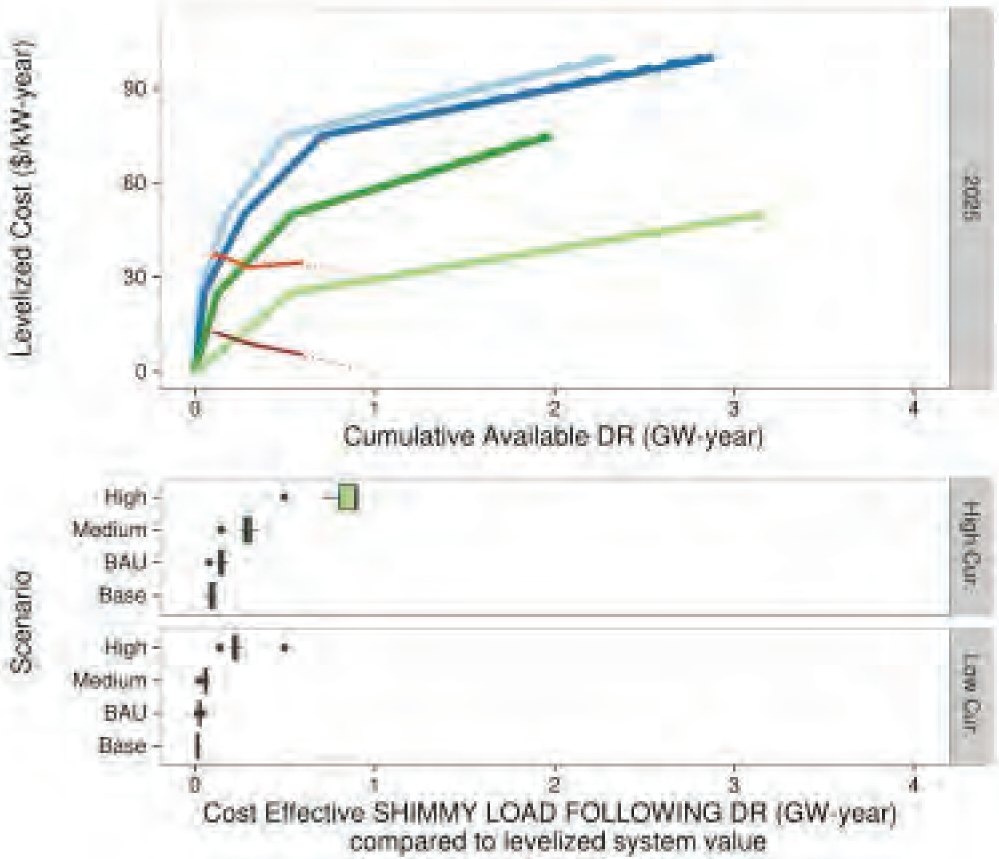
Shimmy Resources Create Savings by Freeing Storage to Dispatch for Shift



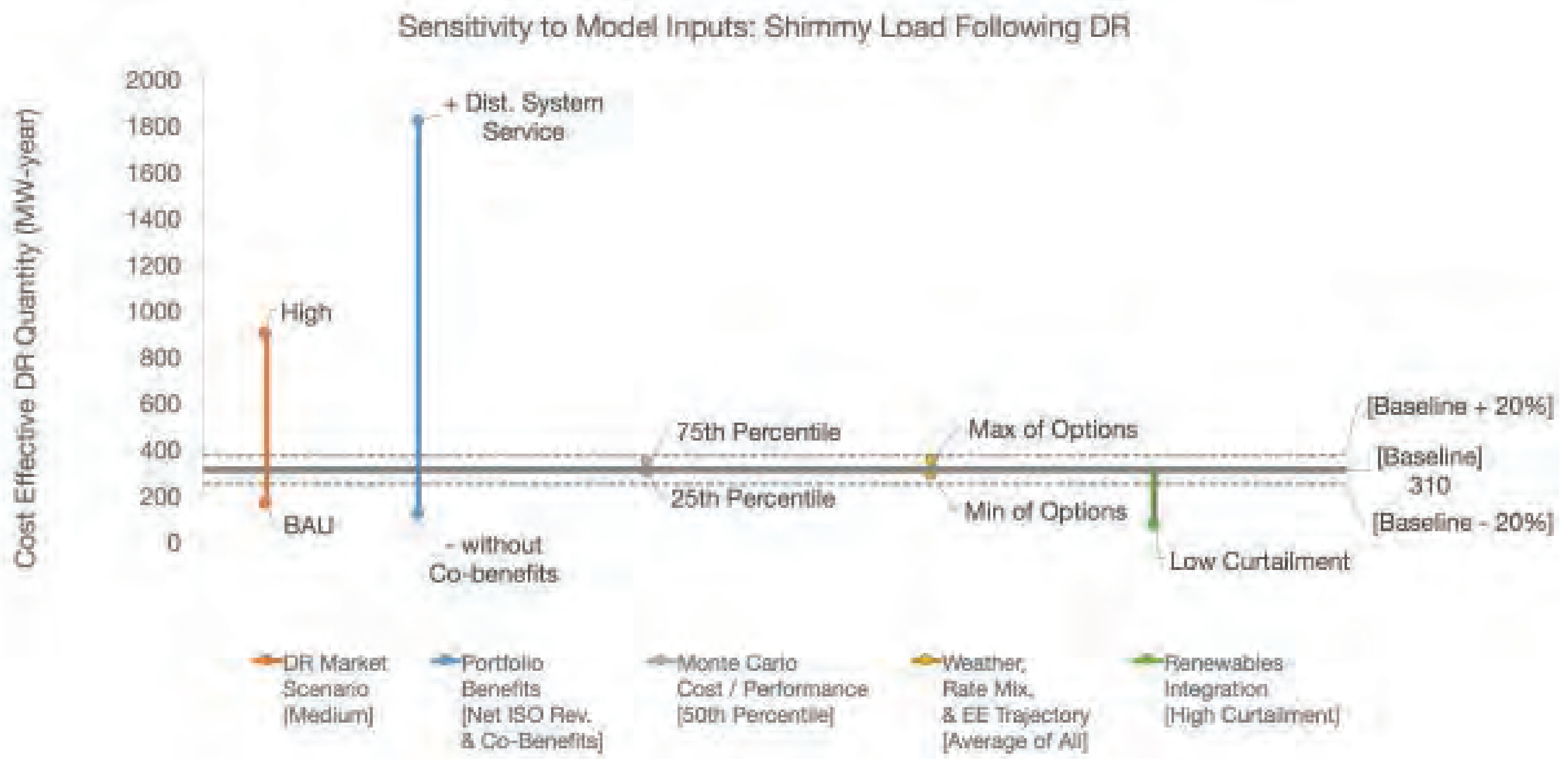
Note: Storage shown is from 1,325 MW CA Storage mandate

Shimmy Results

- **<u>Load following</u> supply curves & system value**
  - Many DR technology scenarios with zero cost-effective resource.
  - Medium & High DR Scenario combined with High Curtailment leads to 100's - 1000 MW potential.

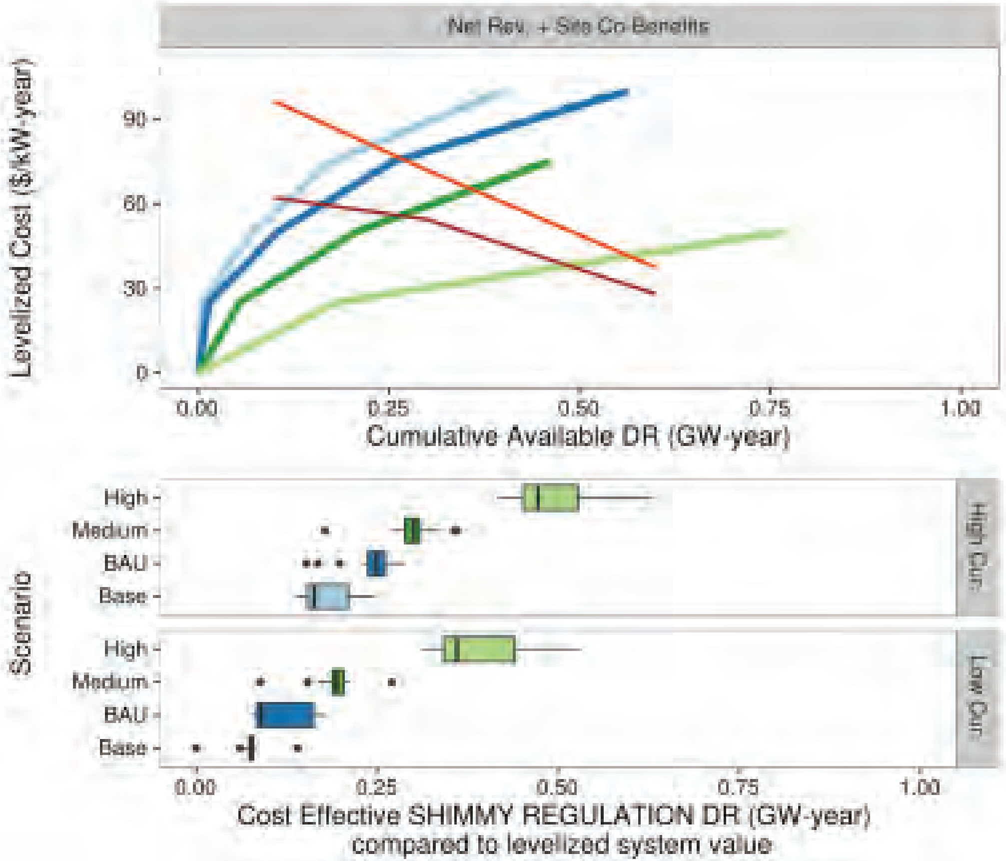


Shimmy Load Following:
Sensitive to Portfolio Options & Technology Advances



Shimmy Results

- **<u>Regulation</u>** supply curves & system value
  - Higher value resource leads to non-zero potential for every expected DR technology scenario.
  - Range in potential from 100-500 MW.



Shimmy Regulation:
Sensitive to Portfolio Options & Technology Advances