The California Demand Response Potential Study, Phase 4: Shed and Shift Resources Through 2050

Brian F. Gerke, Sarah J. Smith, Samanvitha Murthy, Sunhee Baik, Shreya Agarwal, Peter Alstone*, Aditya Khandekar, Cong Zhang, Richard E. Brown, Jingjing Liu, and Mary Ann Piette

Lawrence Berkeley National Laboratory

**California Polytechnic University, Humboldt*

ENERGY TECHNOLOGIES AREA
BERKELEY LAB

DR Potential Study Team


Samanvitha Murthy


Aditya Khandekar


Shreya Agarwal


Cong Zhang


Sunhee Baik


Brian Gerke, Co-PI, study lead


Sarah Smith, load modeling lead


Peter Alstone

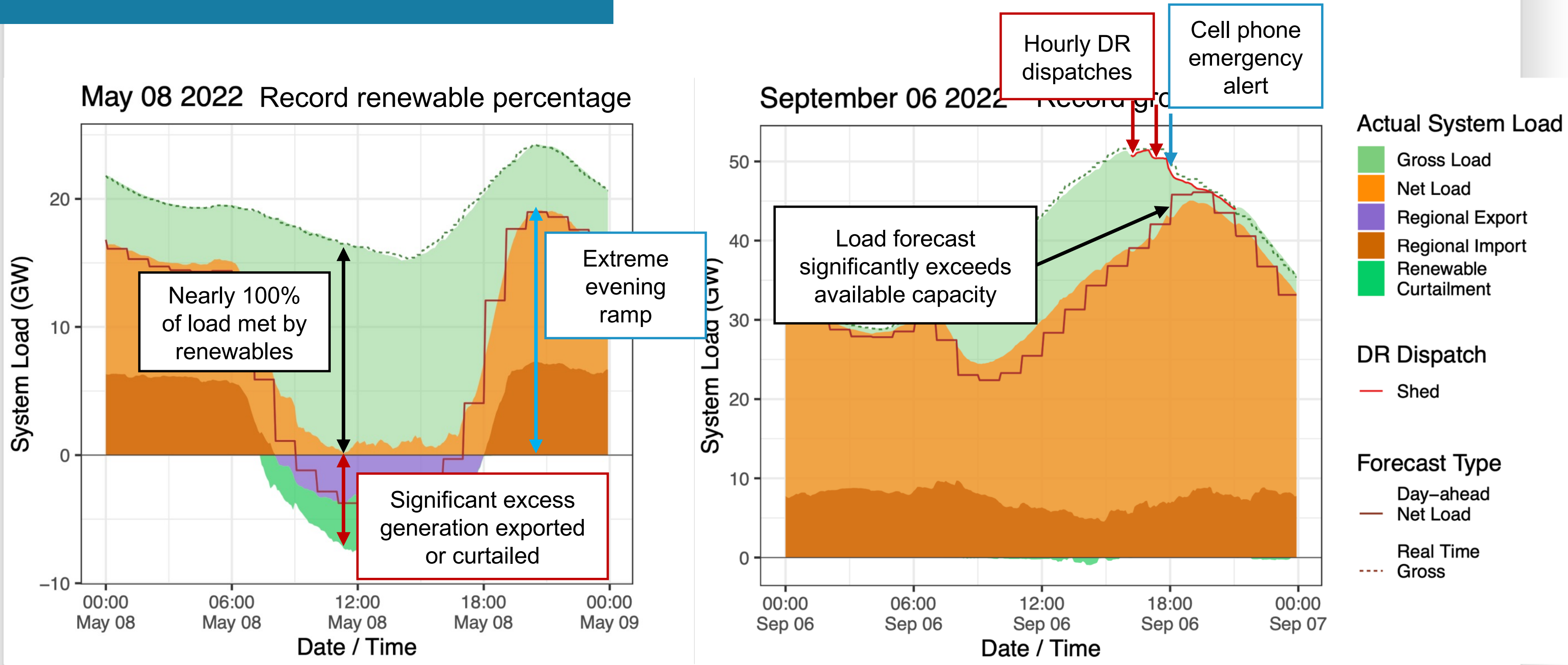

Rich Brown, Co-PI


Mary Ann Piette, PI

Agenda

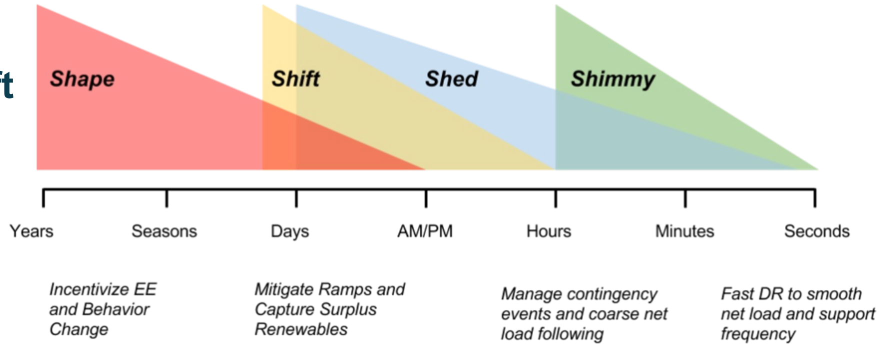
- Overview of the California Demand Response (DR) Potential Study
- Summary of updates to the DR-Futures modeling framework in Phase 4
- Evolution of system loads through 2050: key end-use drivers and changes in the need for DR
- The evolution of Shed and Shift DR potential through 2050
    - Technical, economic, and achievable potential and the gaps between them
    - Key end uses and trends
- Discussion: reaching fuller achievement of DR potential

A tale of two CAISO records



The California DR Potential Study

- The California DR Potential Study is a research effort for the California Public Utilities Commission (CPUC) to estimate future DR resource potential and enhance the role of DR in the state's resource planning
- Previous phases identified four different "flavors" of DR:
  - **Shed**: short-term load reduction to manage peaks
  - **Shift**: changing the timing of load to manage ramping
  - **Shape**: load modification in response to time-of-use or other time-varying pricing
  - **Shimmy**: fast DR for ancillary services
- Phase 4 of the study focuses on **shed** and **shift** resources through 2050, as well as the potential to capture these resources as shape DR via dynamic pricing programs



Phase 4 Report Timeline and Uses

- Study began early 2020; Load data collected for 2018-2019
- Analysis completed late 2022; report review and data release ruling complete April 2024
  - Results and data reflect the time the analysis was conducted
- While under review, results were shared confidentially to support state agency analyses:
  - IRP processes
  - CEC Load Shift Goal
  - California Load Flexibility Research and Development Hub (CalFlexHub)
- Report now publicly available, including datasets
  - Cluster time series (available now)
  - DR Potential Results (coming soon; contact us if you are interested in this data)
- Research projects furthering this work
  - California Load Flexibility Research and Development Hub (CalFlexHub)
  - CPUC Dynamic Pricing studies (1 published, 1 under review, 1 in progress)

Data and modeling methods

Updates for Phase 4

ENERGY TECHNOLOGIES AREA
BERKELEY LAB

The DR-Futures Framework

The Phase 4 study includes significant updates across all parts of the modeling framework

Smart meter data for California IOU customers

- Demographic data for all >13M IOU customers
- Hourly load data for a stratified random sample across sectors, building types, regions, etc.
- >400k hourly customer load shapes

LBNL-Load: Customer and system load forecasts

- Cluster customers based on observable similarities
- Disaggregate load profiles into end uses
- Forecast future loads according to existing statewide forecasts

DR-Path: Build a DR supply curve

- Pair clusters with DR technologies to generate possible future DR pathways
- Select the pathways that maximize the DR resource for a given levelized cost

IOU data request: in two stages

Stage 1: Descriptive data for all accounts that were active in 2019

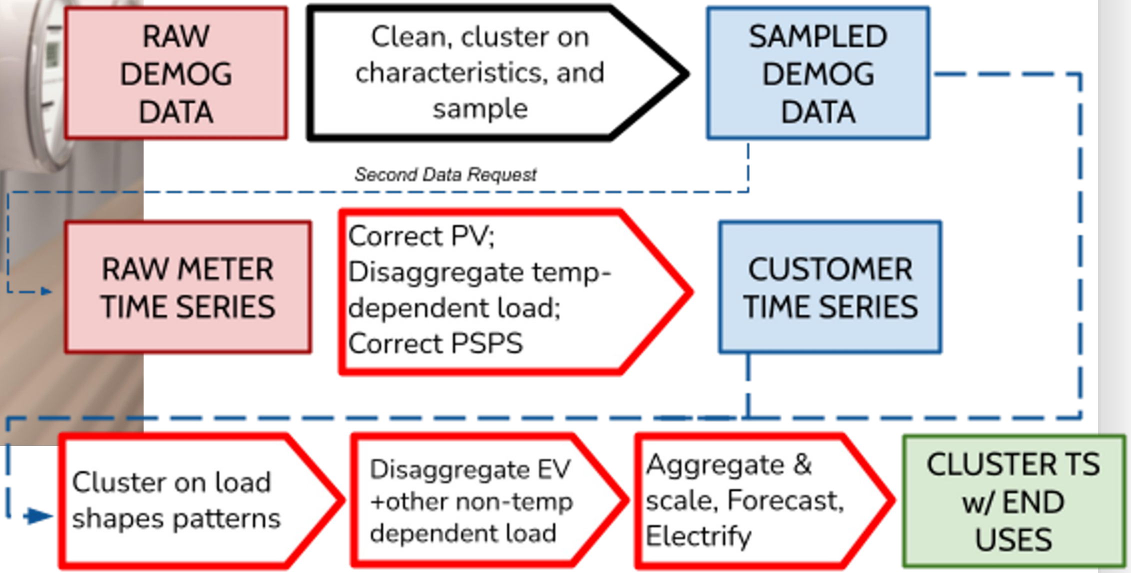
- Demographic information on every service account
  - Sub-LAP, climate zone, zip code, latitude/longitude
  - Energy service provider, and tariff, including indicators for CARE, NEM, and EV tariffs
  - Account start and end date, 2019 peak and total consumption
  - Indicators for all-electric customer and/or electric heating, EV owner, residential type (single family vs. multi family), NAICS code
- A complete list of very large customers (2019 energy use greater than 10 GWh)
- DER data; linking accounts to NEM and SGIP datasets
- EV rebate data
- EE and DR program participation data

Stage 2: Hourly meter data for 2018 and 2019 for a representative sample

- LBNL developed a stratified random sample of the Stage 1 data based on numerous characteristics, including geography, climate, building type, peak demand, annual consumption, and presence of electrified loads
- Total sample size was set at 3% of customers
- Sampled 2% of residential customers and used the remaining “budget” to more thoroughly sample the high diversity of customers in the non-residential sectors
- This approach allowed us to sample 35% of total 2019 load in the IOU service territories, in a sample of only 3% of accounts

LBNL-Load

From a large sample of customer smart meter data, generate thousands of clusters representing sets of similar customers, disaggregate specific end-uses, and build a bottom-up picture of the CAISO system load



Key LBNL-Load updates for Phase 4

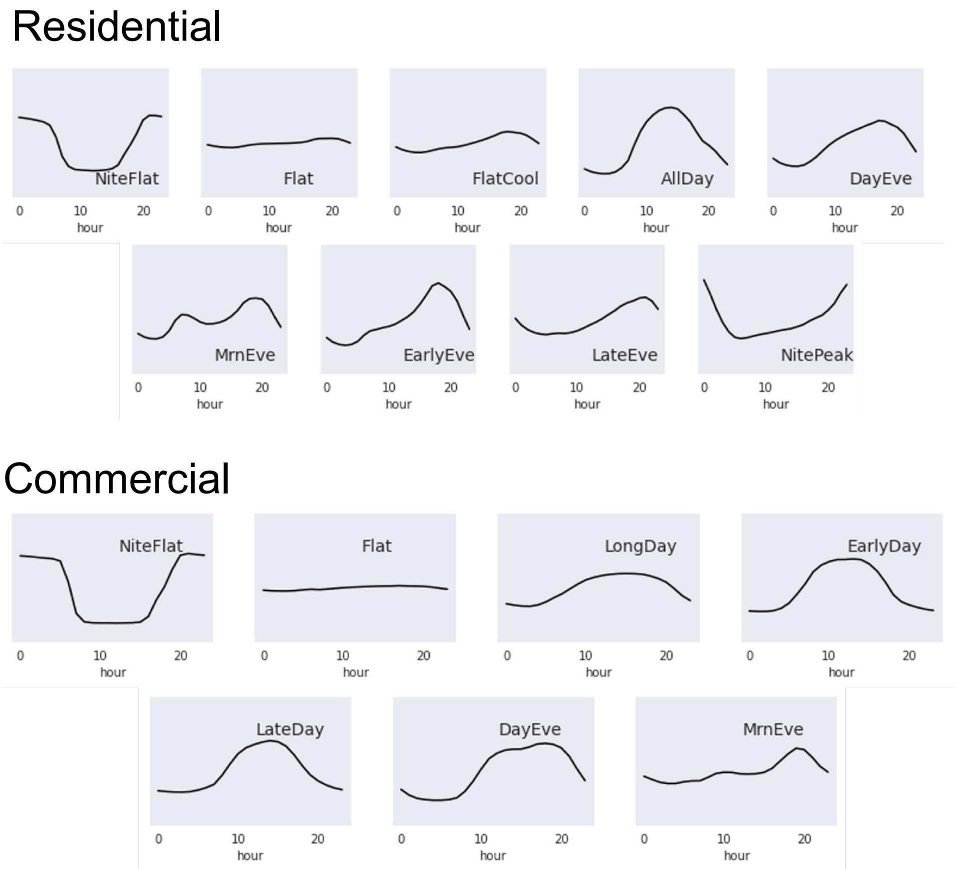
- New customer load data: >400,000 hourly load shapes for 2019
- Modeling customer rooftop PV generation
- Novel approach to clustering customers by load shape
- Drastically expanded coverage of building types and end uses
- Modeling growth of electrified loads, including medium/heavy duty EVs (MHDEV)

Residential Sector		Commercial Sector		Industrial/Ag sector	
Building Types	End Uses	Building Types	End Uses	Building Types	End Uses
• Unknown • Single-family • Multi-family • Master meter	• Cooling • Heating • Ventilation • Indoor Lighting • Outdoor lighting • Cooking • Dishwasher • Clothes Washer • Clothes Dryer • Refrigerator • Freezer • Pool pump • Spa heater • Spa pump • Television • Office equipment • PCs • Water heating • Misc. • EV level 1 • EV level 2 • Rooftop PV	• Office • Retail-food • Retail-other • Dining • Lodging • Medical • Education • Assembly • Datacenter • Warehouse • Refrigerated warehouse	• Cooling • Heating • Ventilation • Indoor lighting • Outdoor lighting • Office equipment • Refrigeration • Water heating • Datacenter IT • Misc. • EV charging • Rooftop PV	• Ag-crop • Ag-animal • Ag-indoor • Ag-other • Chem/petrol • Food/bev • Mfg-equipment • Mfg-goods • Mfg-materials • Military • Water	• Boiler • Process heat • Process cooling • Machine drive • Electrochem. Process • Other process • Non-process • Pumping • Rooftop PV

New modeling in red

Clustering customers by load shape

- We developed a novel approach to clustering customers based on shared load shape features
- We used k-means clustering to identify common daily load shapes in the residential and commercial sectors and grouped these into similar types.
- Then we clustered customers (again using k-means) according to the relative frequency with which they exhibited each typical load shape
- The result is 9 residential and 7 commercial load-shape clusters representing different typical electricity consumption patterns



See ACEEE paper by S. Murthy et al.: https://emp.lbl.gov/publications/multi-level-load-shape-clustering-and

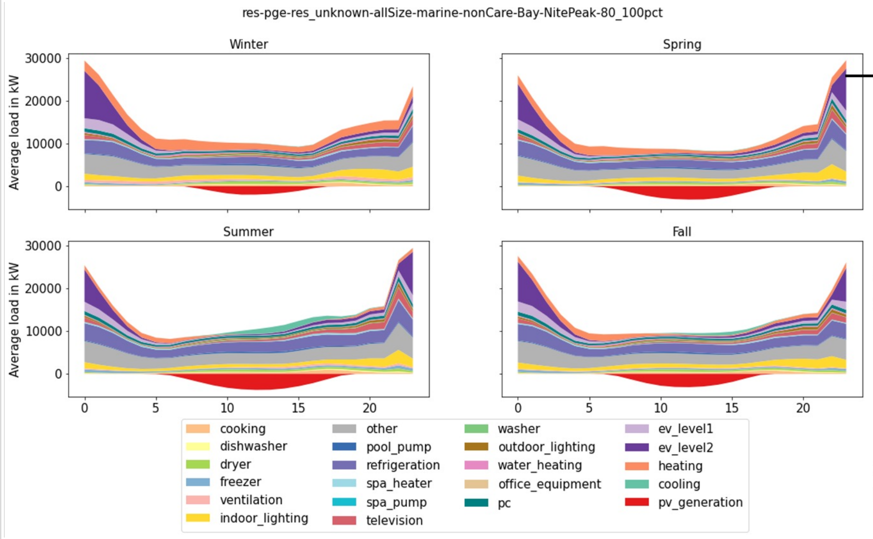
Final customer clustering

- We combined the results of load shape clustering along with other demographic and geographic characteristics to develop a final set of customer clusters:
  - Sector
  - Utility
  - Building Type
  - Building Size (S/M/L)
  - Local Capacity Area
  - Load shape cluster
  - Climate region (marine/hot-dry/cold)
  - Low income indicator (CARE vs. non-CARE)
  - kWh percentile bin

Sector	# of clusters
Residential	*1384*
Commercial	*2786*
Industrial	*801*
Agricultural	*363*
Other	*88*
Total	**5422**

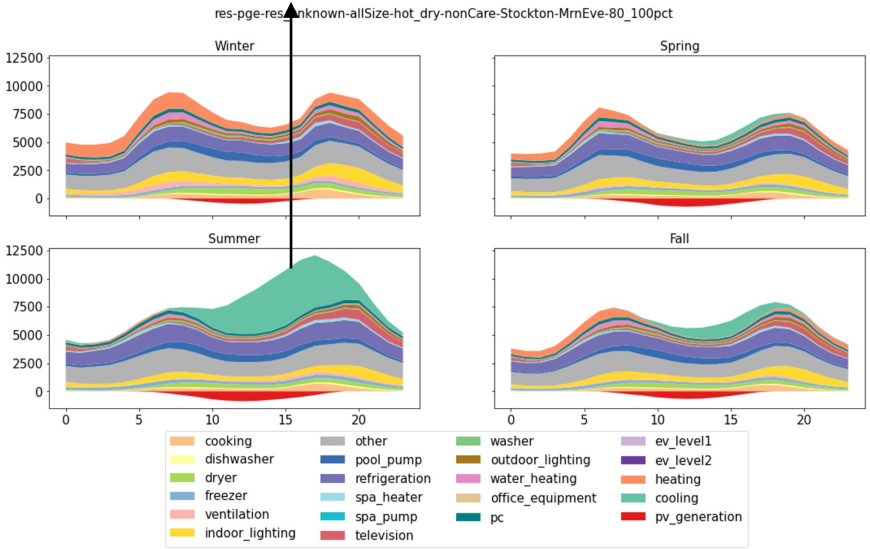
Cluster load results available at https://buildings.lbl.gov/potential-studies

Results of load disaggregation: Residential sector



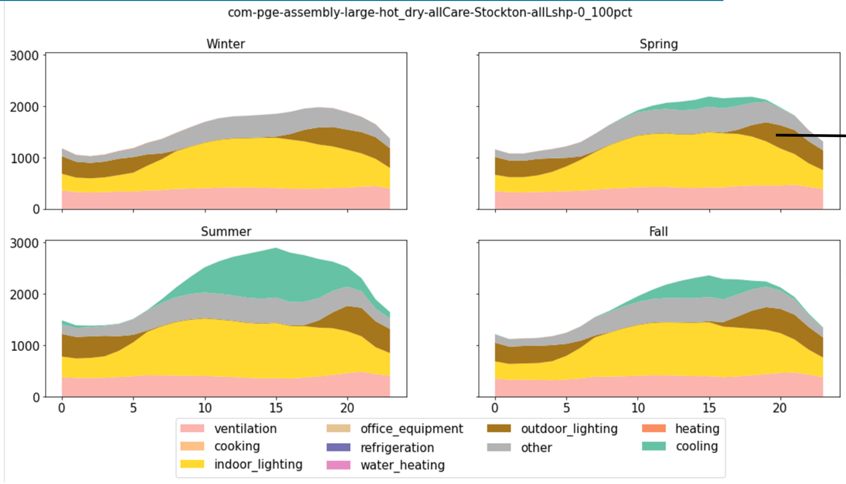
EV charging load driving the load shape

Space cooling driving the load shape



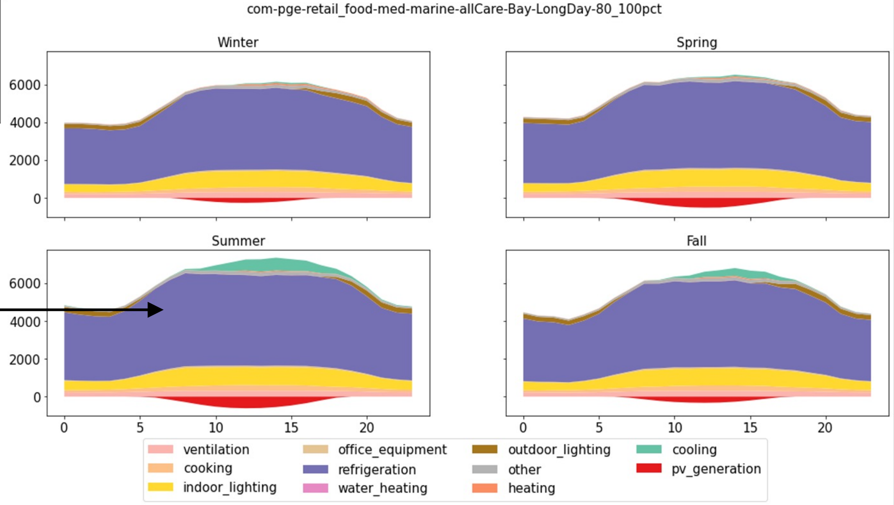
22 residential end-uses

Results of load disaggregation: Commercial sector



Lighting loads being turned on/off

Significant refrigeration load in a grocery store cluster



Forecasting load growth

Baseline load growth

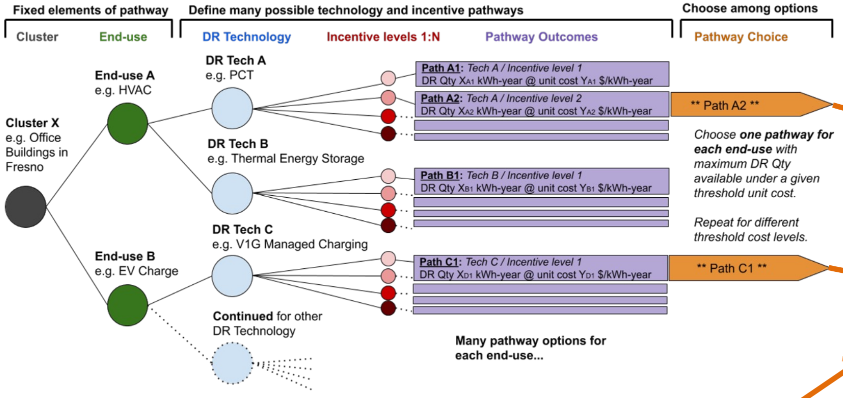
- Through 2030 from IEPR forecast (2021 Mid-case, including EV charging)
- Through 2050 using E3 PATHWAYS model for SB100 study (consistent with CPUC IRP forecast)

Additional EE adoption

- Through 2030 based on energy savings from EE Potential & Goals Study
- Fractional savings in 2030 extended to 2050

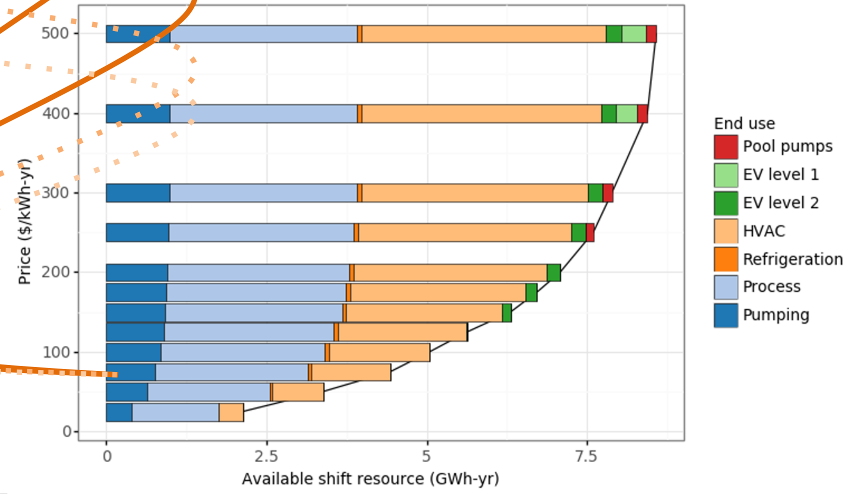
Growth of electrified loads

- Through 2030 based on Fuel Substitution measures from EE P&G Study
- Through 2050 using SB100 PATHWAYS model
- M/HDEV loads from LBNL HEVI-Load modeling for CEC



DR-Path

Pair cluster load shapes with DR technologies to generate a large number of DR-Pathways. Select pathways at increasing cost levels to build a DR supply curve.



Key DR-Path updates for Phase 4

- Updated model for **customer enrollment** in DR programs in response to incentives
- Thoroughly updated **DR technology characterization**
- Modeling different **types of DR Potential**: Technical, Economic, Achievable
- Modeling effective DR resources as shape DR from **dynamic electricity tariffs**
- Accounting for the **existing saturation** of DR-enabling technologies in the building stock (e.g., BYO thermostat programs)
- Improved modeling of DR **dispatch probability** informed by CPUC avoided cost calculator (ACC)
- Estimation of **avoided costs and GHG emissions** from DR using the ACC
- Integration with CPUC's EE potential and goals study: technology saturation growth for technologies that provide both EE and DR
- Integration with CPUC's Integrated Resource Planning (IRP) process: generate outputs that can be used in capacity expansion modeling

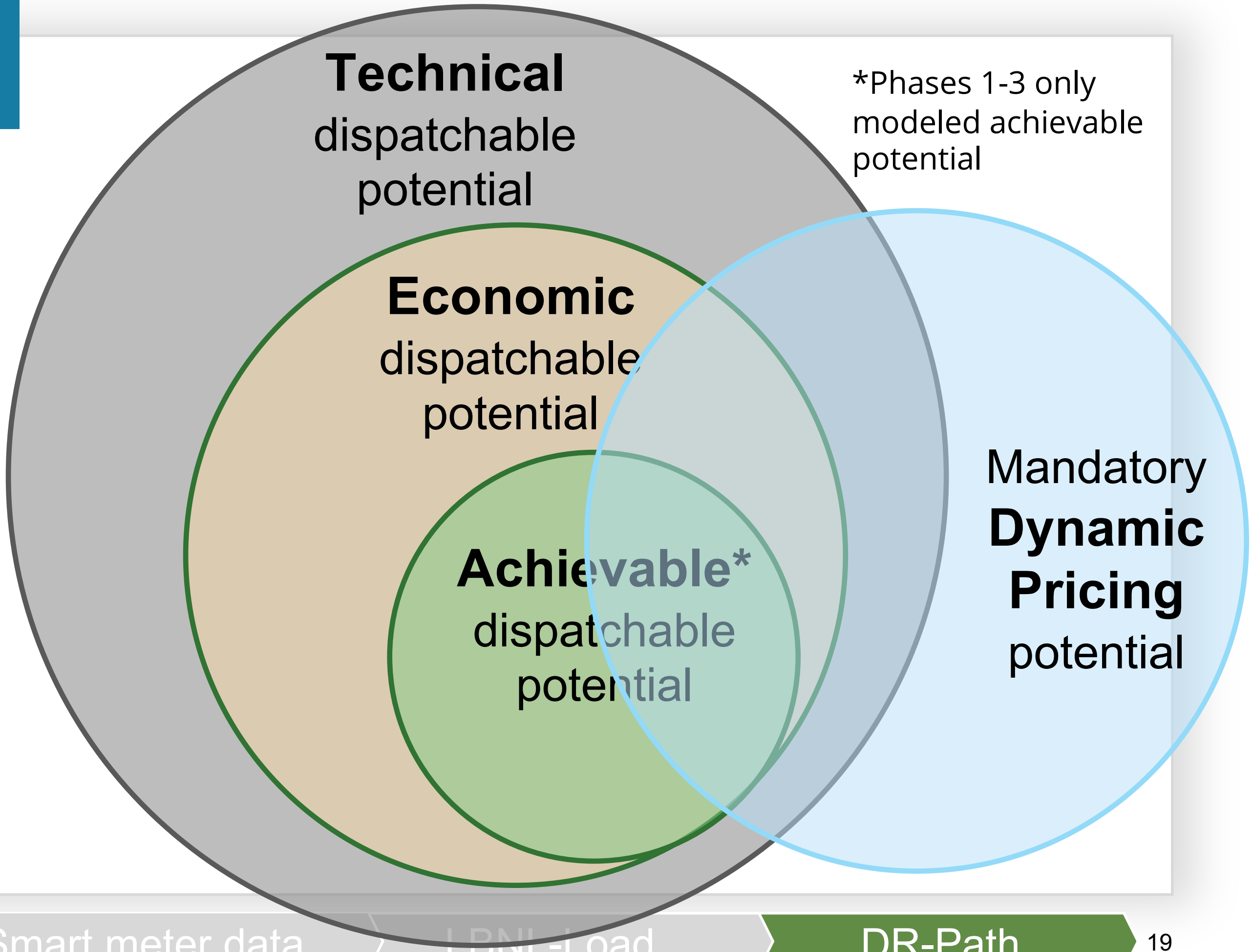
Modeling multiple types of DR Potential

Technical: The maximum that can be achieved with the best available technology

Economic: The maximum that can be achieved with cost-effective technologies

Achievable*: What can be achieved considering program costs and enrollment

Dynamic Pricing: Potential from dynamic pricing programs, which may include behavioral/manual measures that would not be used in a dispatchable program

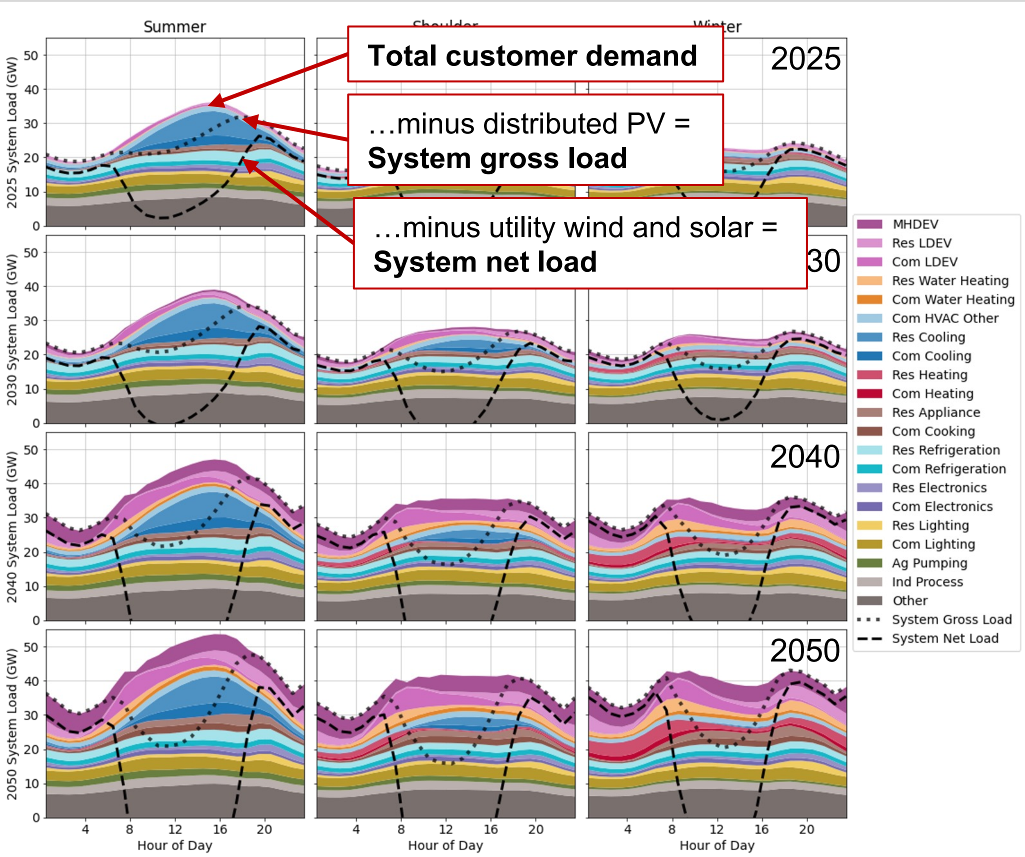


*Phases 1-3 only modeled achievable potential

Findings

1. Changes in system load shapes and the need for DR

System load forecasts: seasonal average days

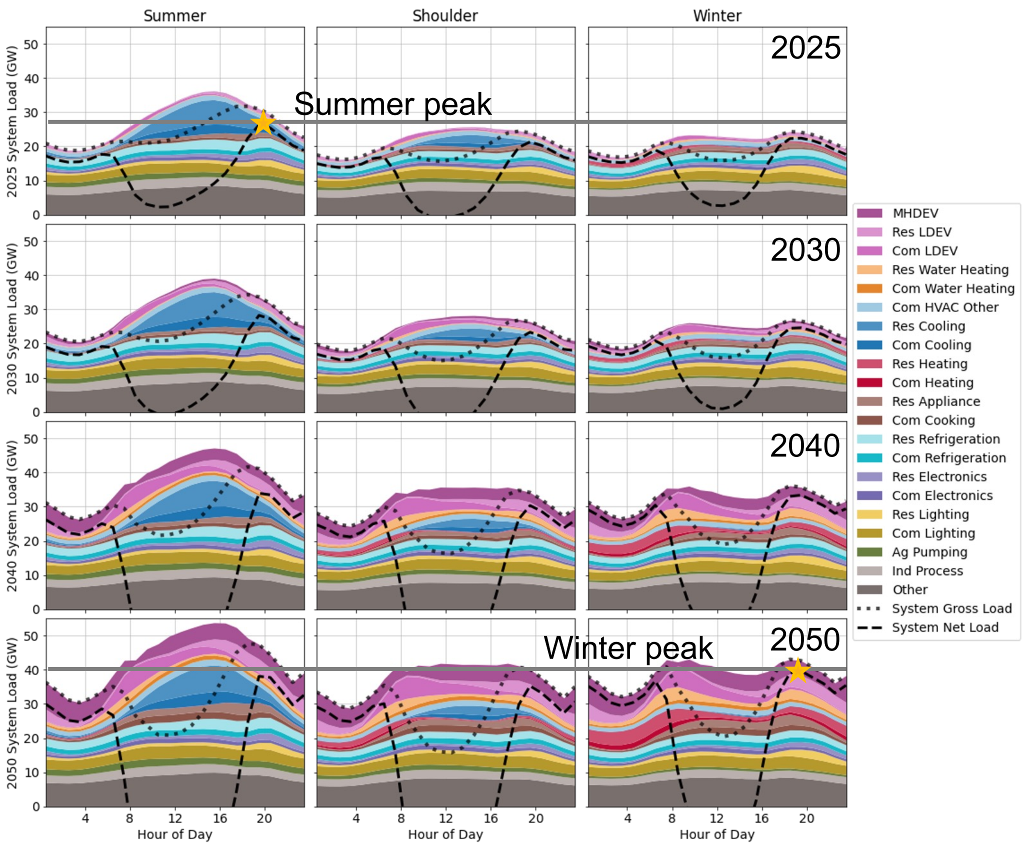


System load forecasts: seasonal average days

Growth in electrified loads—especially EV charging—drastically reshapes customer demand

Growth in renewables—especially solar—yields dramatic changes in the net load on the grid

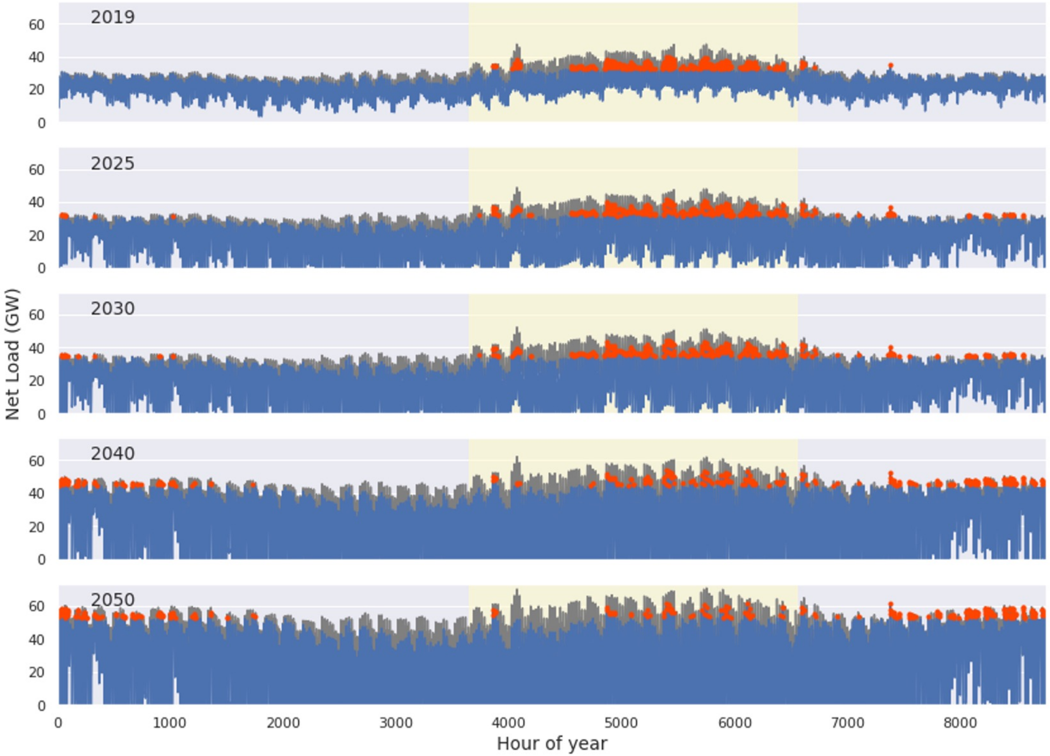
By 2050 the combined effect has shifted the net load peak into the winter



System peak hour distribution throughout the year

Peak net-load hours, currently clustered in the summer months, migrate significantly to the winter.

Coupled with periods of limited winter renewable generation, these changes will pose new challenges for managing the grid and may enhance the importance of the demand side.



Findings

2. Shed and Shift DR Potential in California 2025-2050

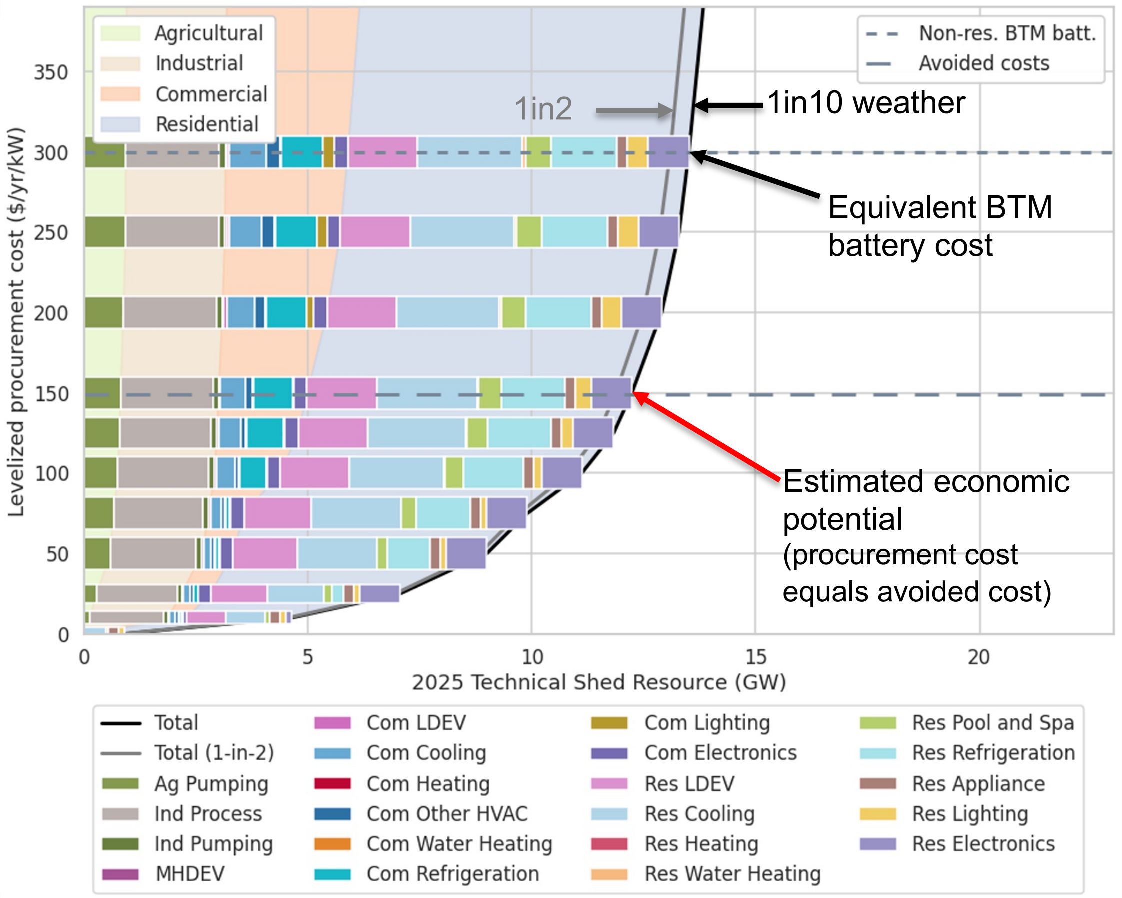
Shed Technical Potential Supply Curve: 2025

Biggest potential resources, 2025:

- Cooling and refrigeration (res and com)
- LDEV charging (res)
- Ind. Process
- Ag pumping

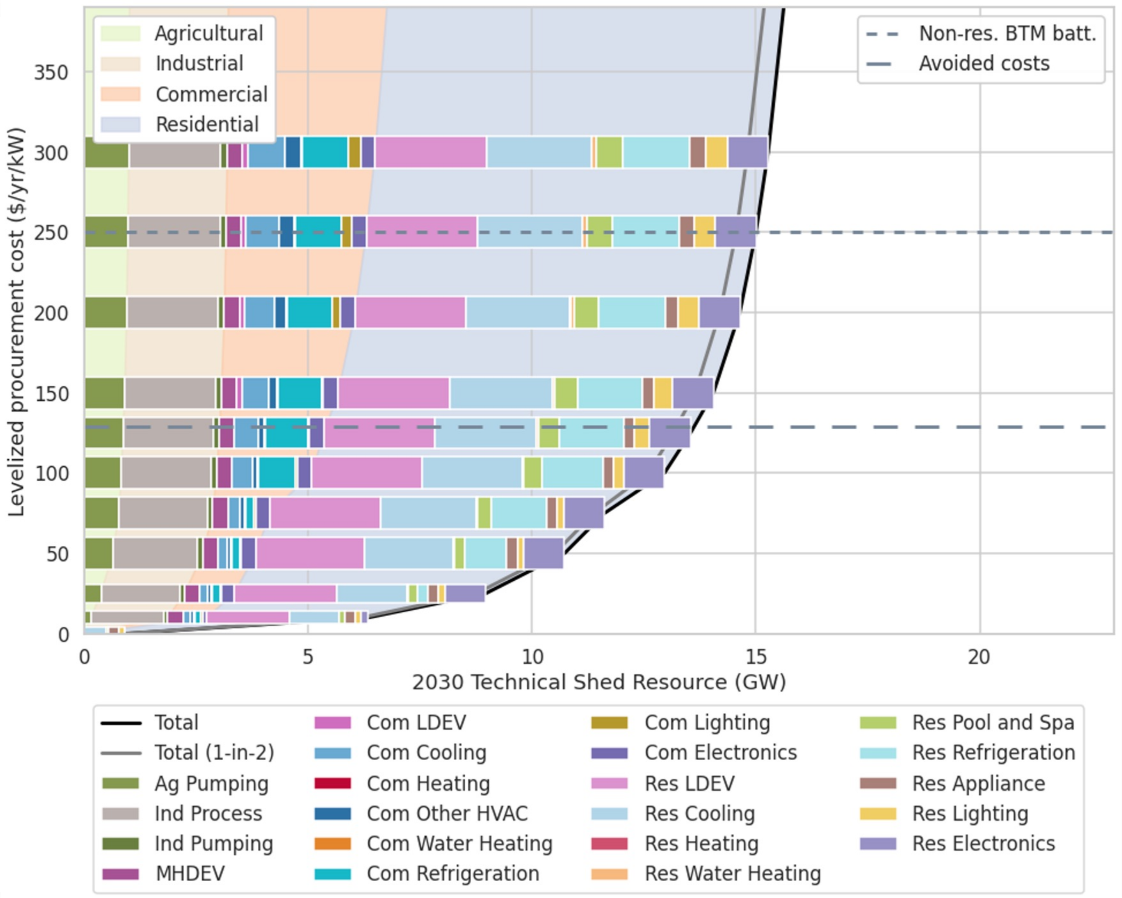
Also notable:

- Res. pool and spa
- Res. electronics (TVs, PCs)
- Res. appliances



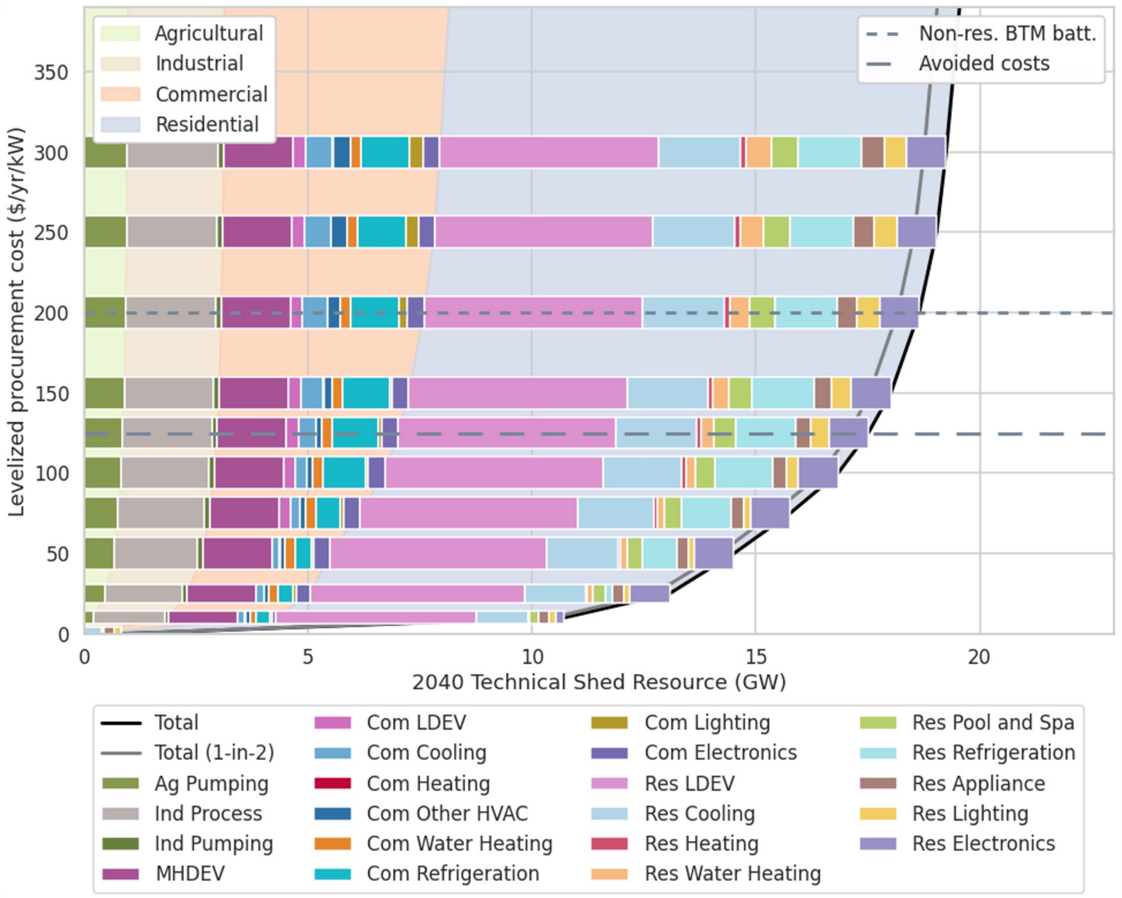
Shed Technical Potential Supply Curve: 2030

- LDEV charging grows
- MHDEV charging appears



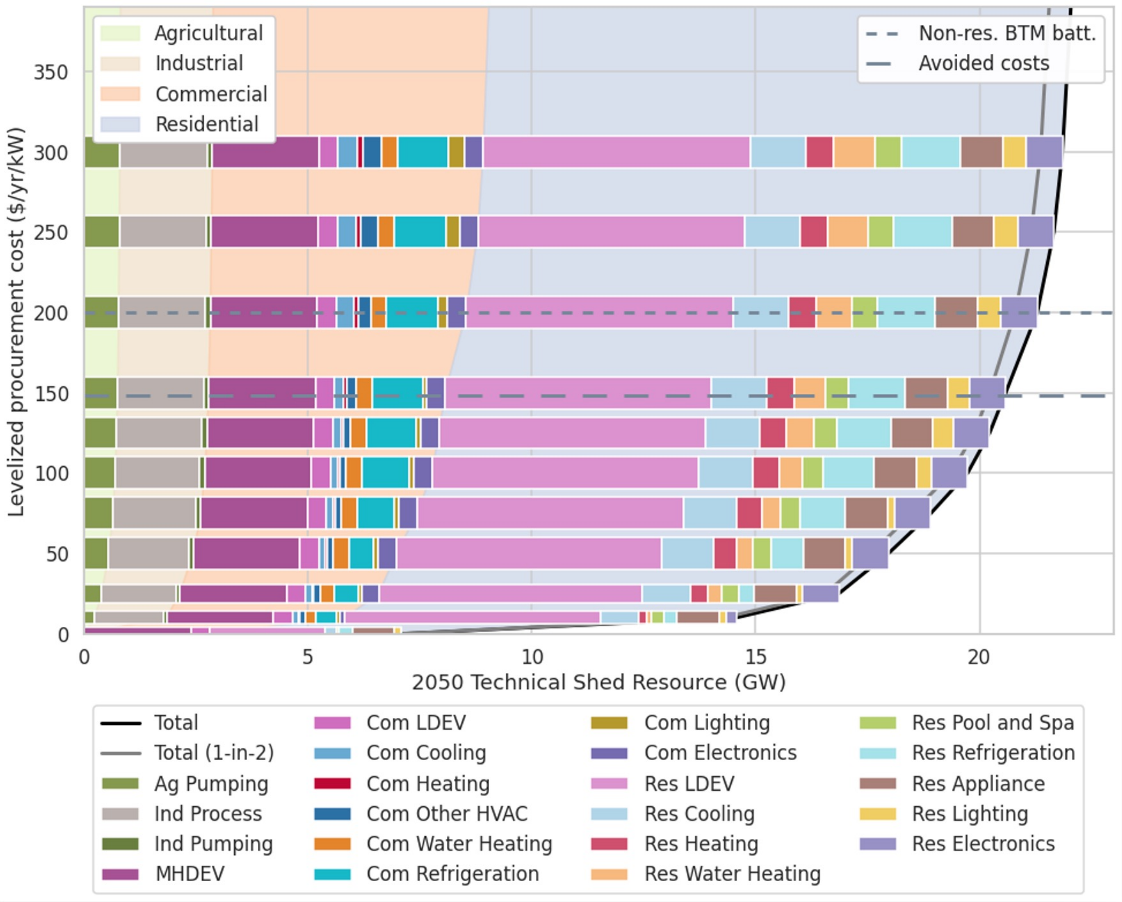
Shed Technical Potential Supply Curve: 2040

- LDEV charging grows
- MHDEV charging grows
- Water heating appears
- Meanwhile, average cooling resource declines (because it is not available to serve winter peaks)

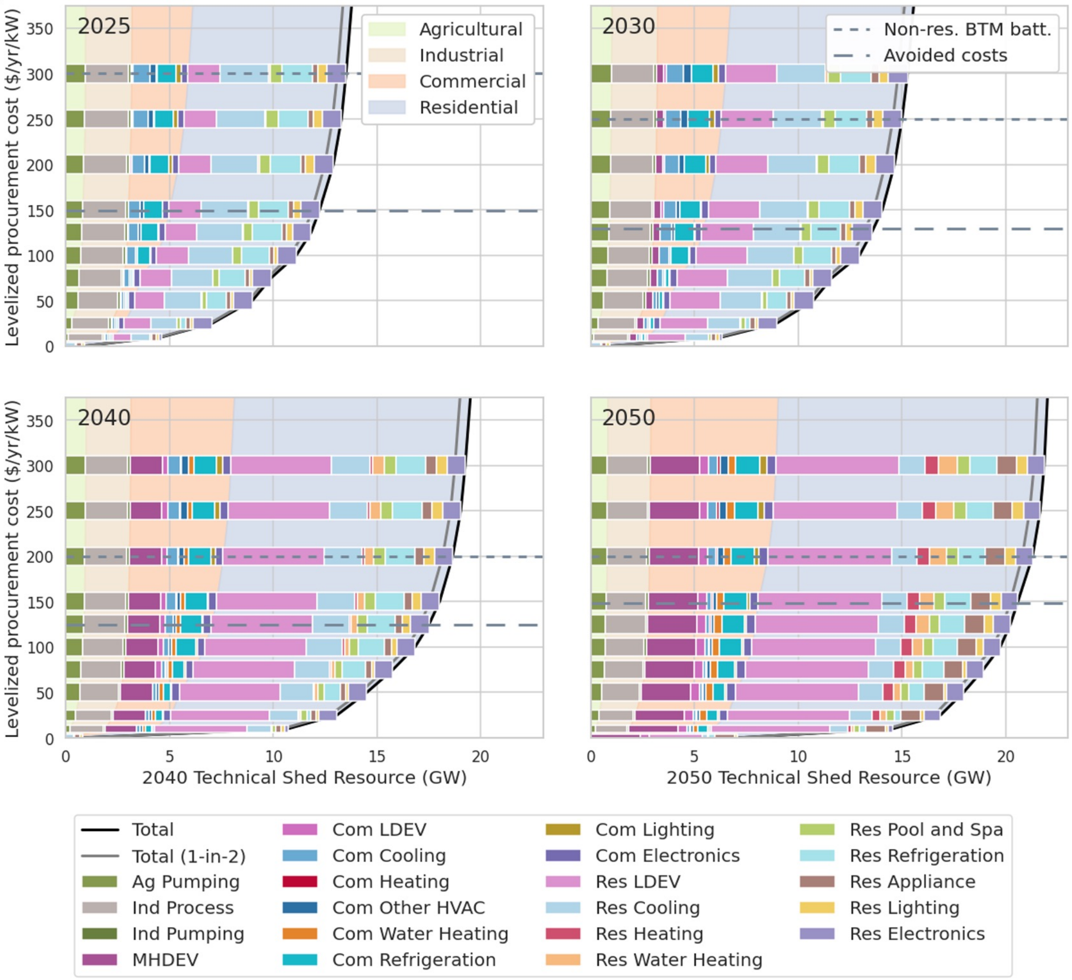


Shed Technical Potential Supply Curve: 2050

- EV charging and water heating both grow
- Space heating becomes important
- Residential appliances grow (clothes dryer electrification)
- Cooling resource declines further



Shed Technical Potential Supply Curve: All Years

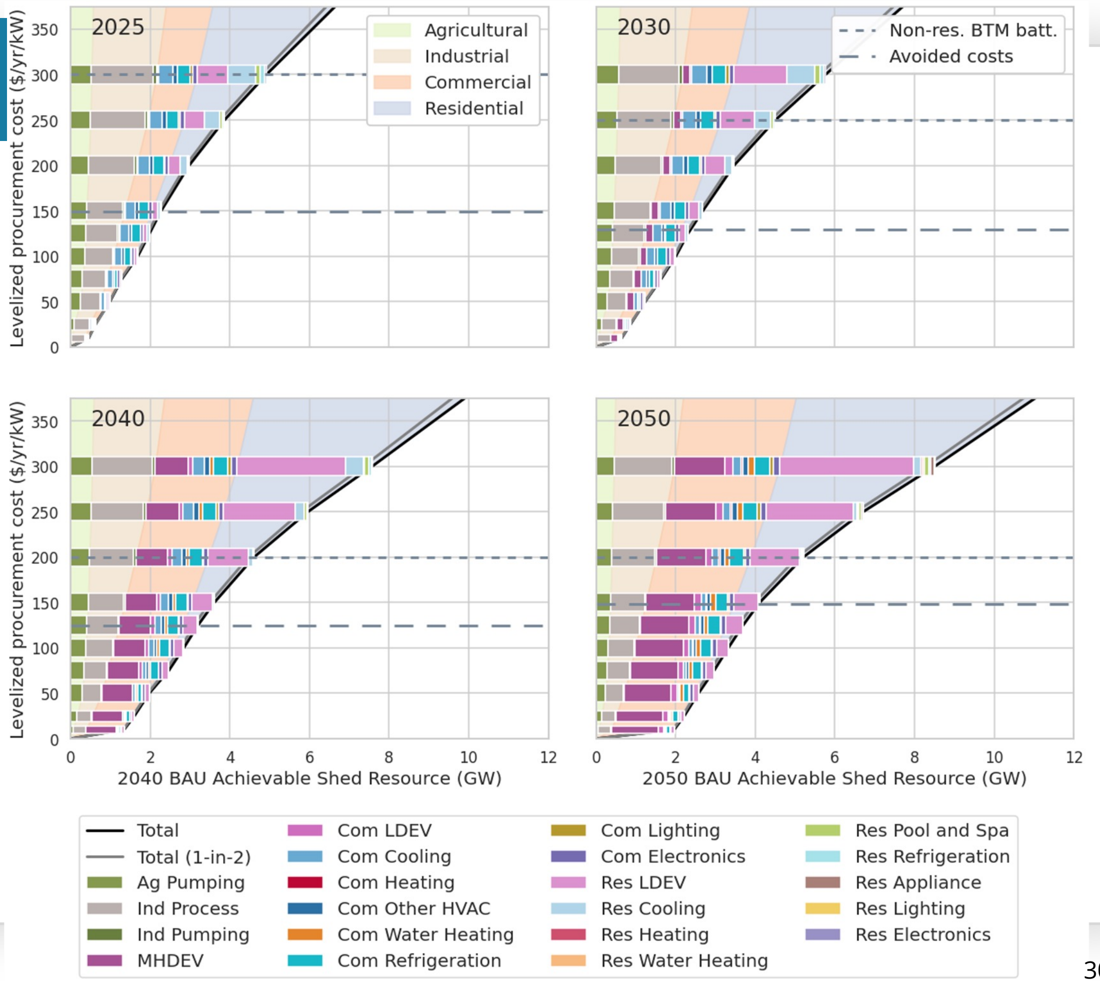


Shed Achievable Potential Supply Curve: All Years

Applying the customer enrollment model sharply reduces the amount of potential, especially in the residential sector, reflecting low historical enrollment rates

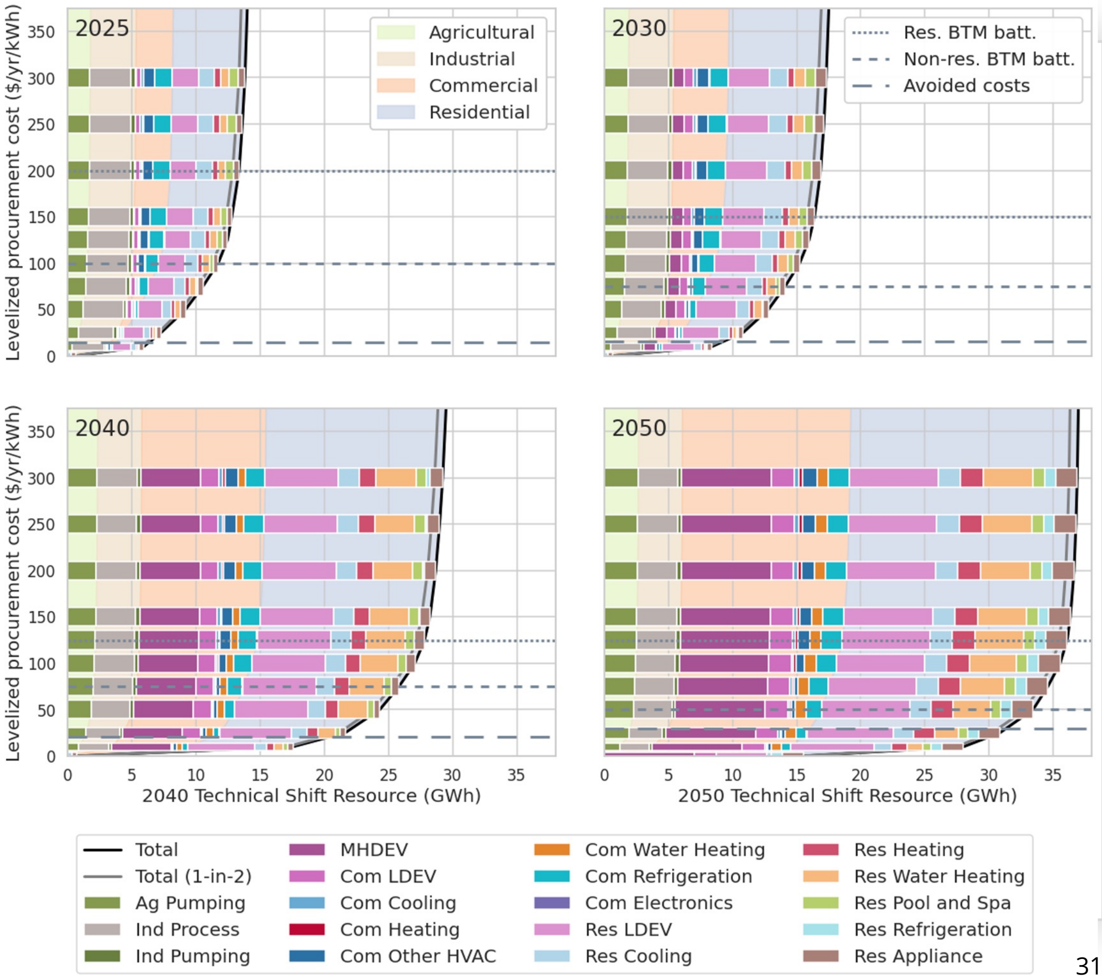
This achievable potential estimate relies on historical program enrollment, so we refer to it as the “Business-as-usual (**BAU**) achievable” potential

Future improvements in customer outreach and engagement may be able to achieve more



Shift Technical Potential Supply Curve: All Years

Shift DR technical potential shows similarly strong growth to what we saw for shed, with somewhat larger growth in space and water heating end uses and a more steady contribution from space cooling

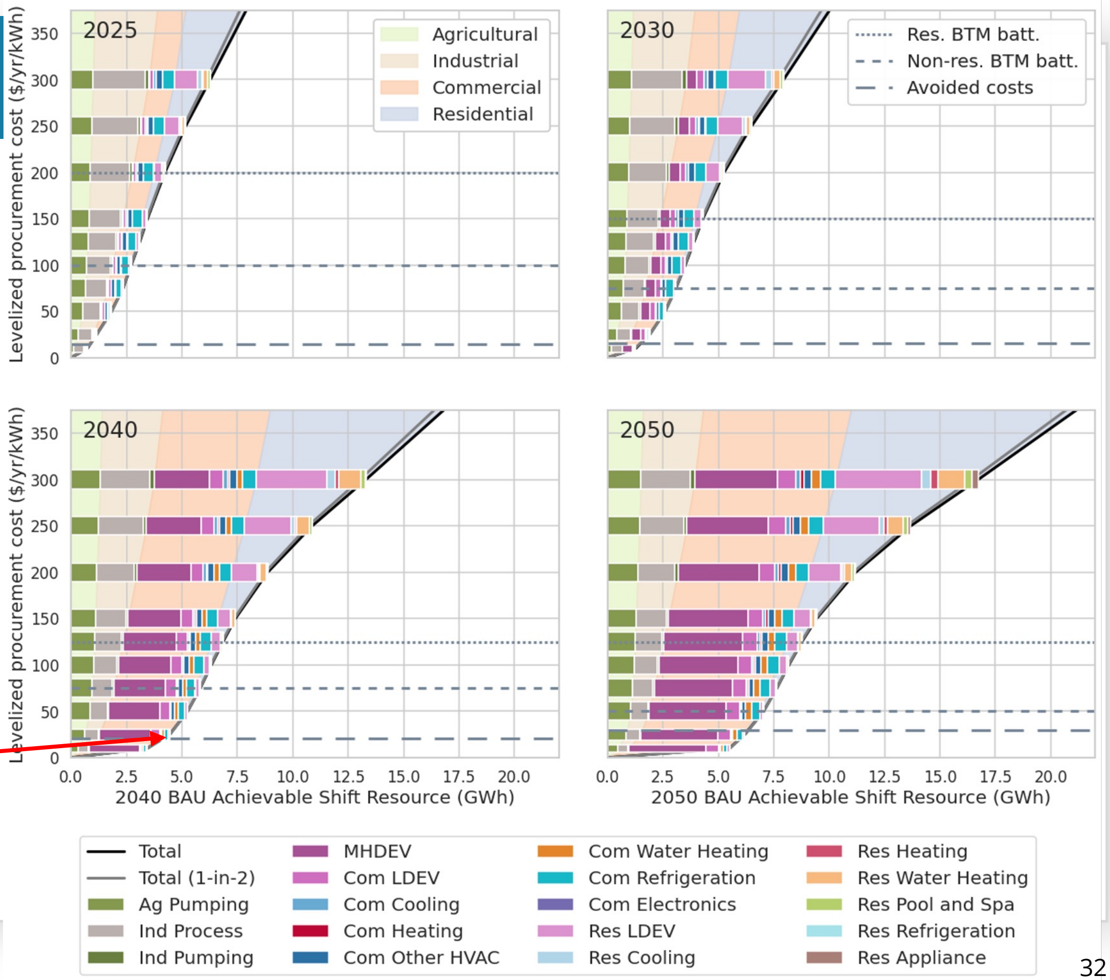


Shift Achievable Potential Supply Curve: All Years

Shift DR technical potential shows similarly strong growth to what we saw for shed, with somewhat larger growth in space and water heating end uses and a more steady contribution from space cooling

The enrollment model again sharply constrains the BAU achievable potential

Low avoided cost estimates from the ACC further restrict the cost-effective potential



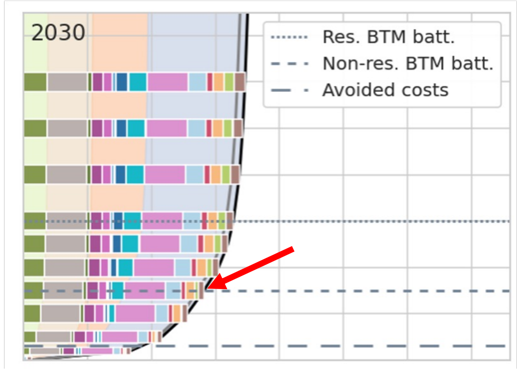
The value of shift DR

Shift DR can provide value by offsetting the need for **flexible** generation capacity to manage steep ramps

California utilities have flexible resource adequacy requirements, but there is no value stream for this in the ACC (instead all capacity value is assigned to peak hours)

Adding this source of value could significantly boost the estimated avoided costs from shift DR

We calculate alternative resource estimates at the equivalent cost of BTM batteries, as an upper bound on the cost-effective shift resource



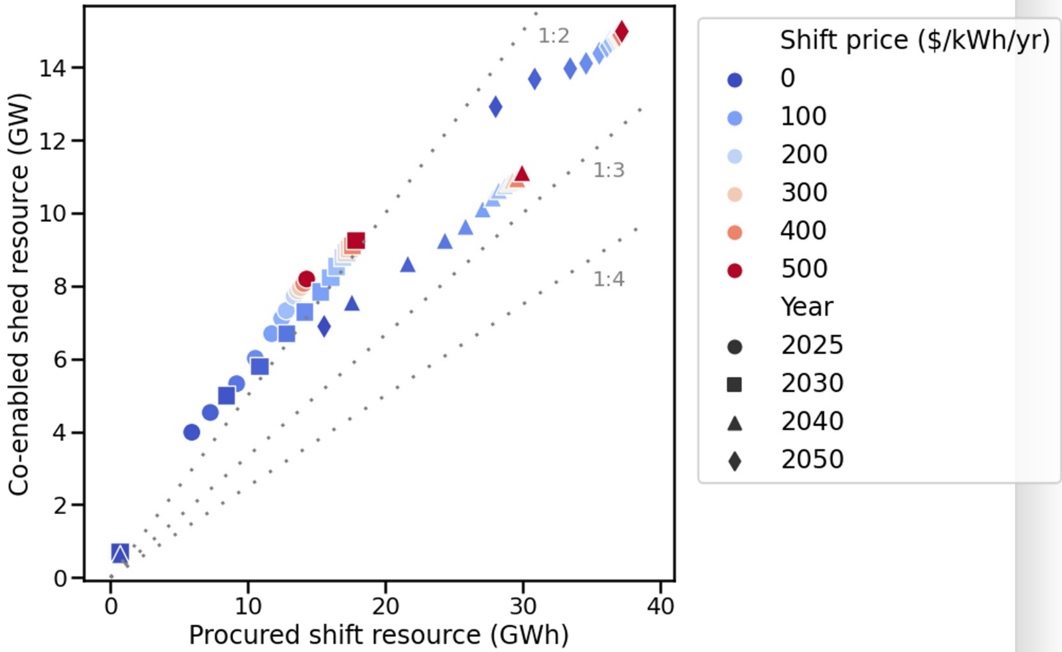
The shed implications of shift

Any resource that can **shift** can also **shed**, by definition

We can estimate the shed potential of a shift resource by computing the shed resource for all technology-cluster combinations in the shift supply curve

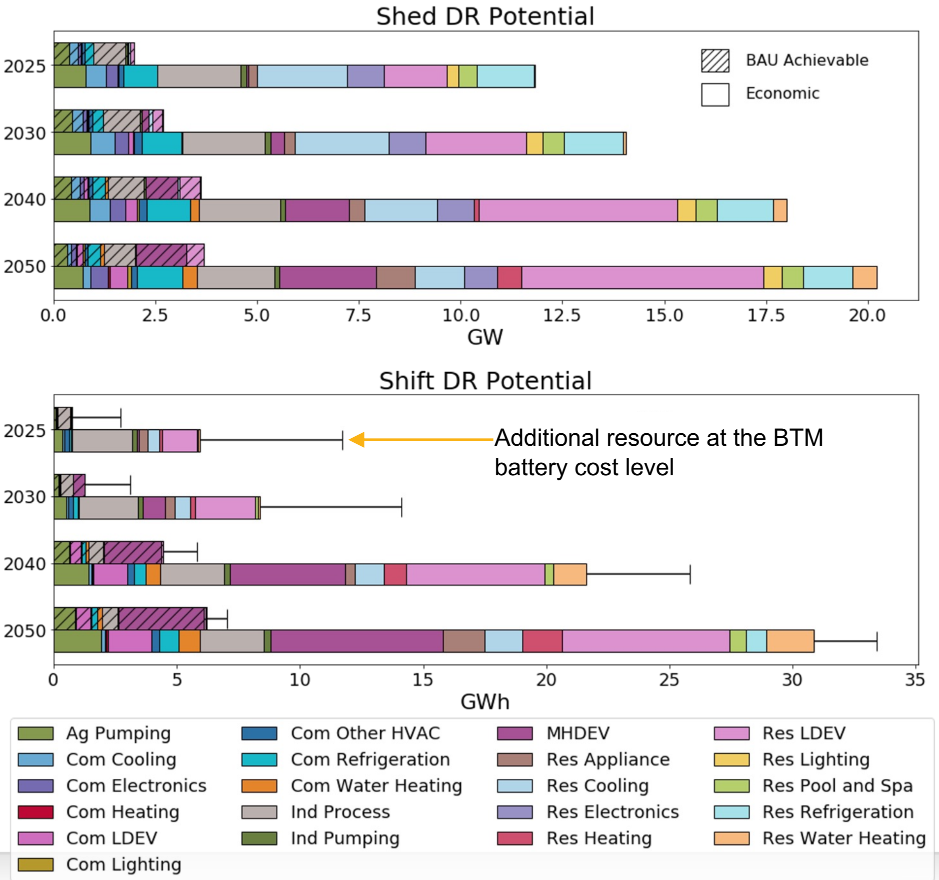
Roughly speaking, there is 1 kW of shed resource enabled for every 2-3 kWh of shift DR

Accounting for the value of this shed resource can boost the cost-effectiveness of shift



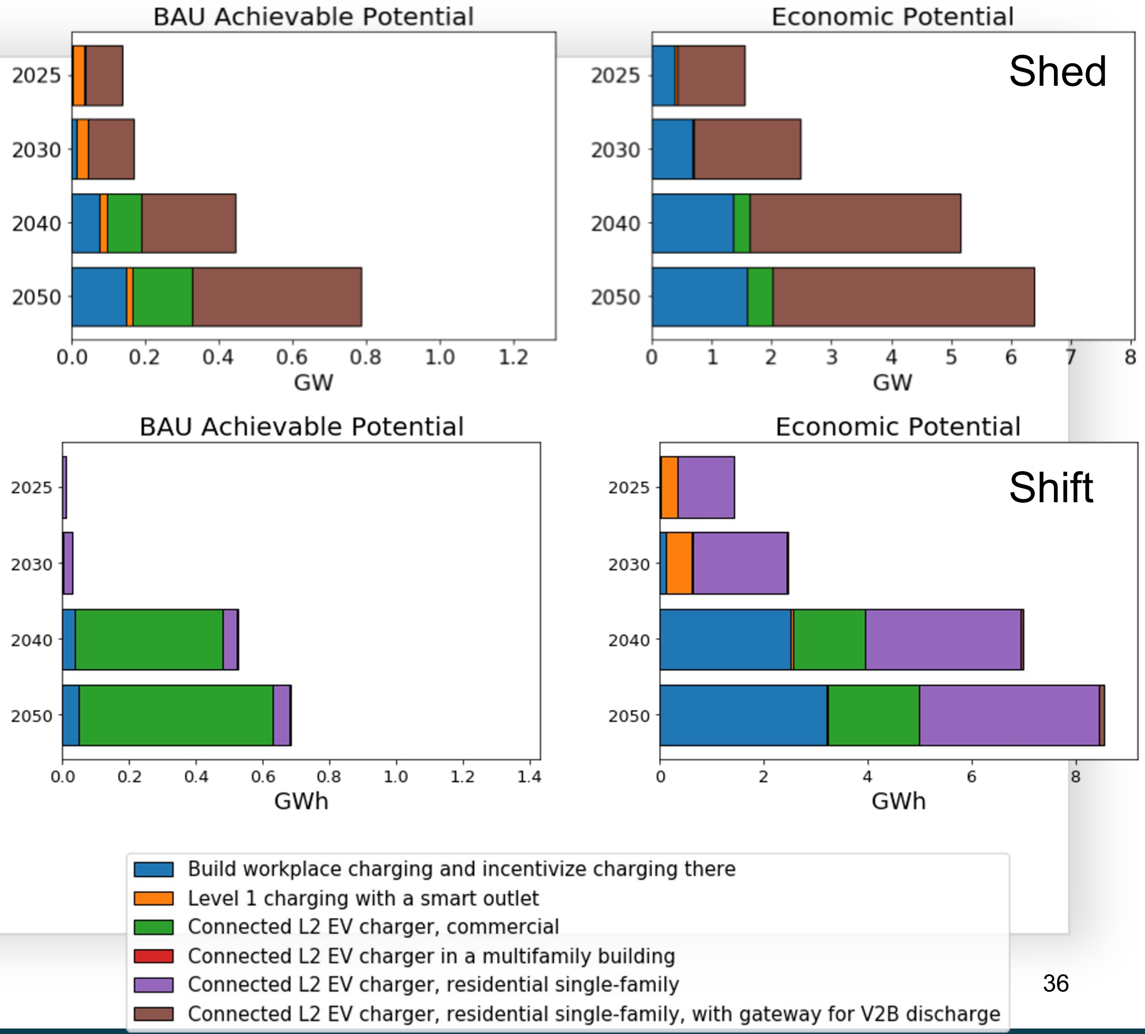
Summary of Shed and Shift potential through 2050

- Rapid growth in load leads EV charging to become the dominant resource by 2050
- There is also significant growth from electrified space and water heating
- Industrial and ag loads are steady contributors
- Significant shed potential also exists from refrigeration and electronics
- A large gap (~5x) exists between the economic potential for DR and what would be captured with circa 2019 enrollment rates



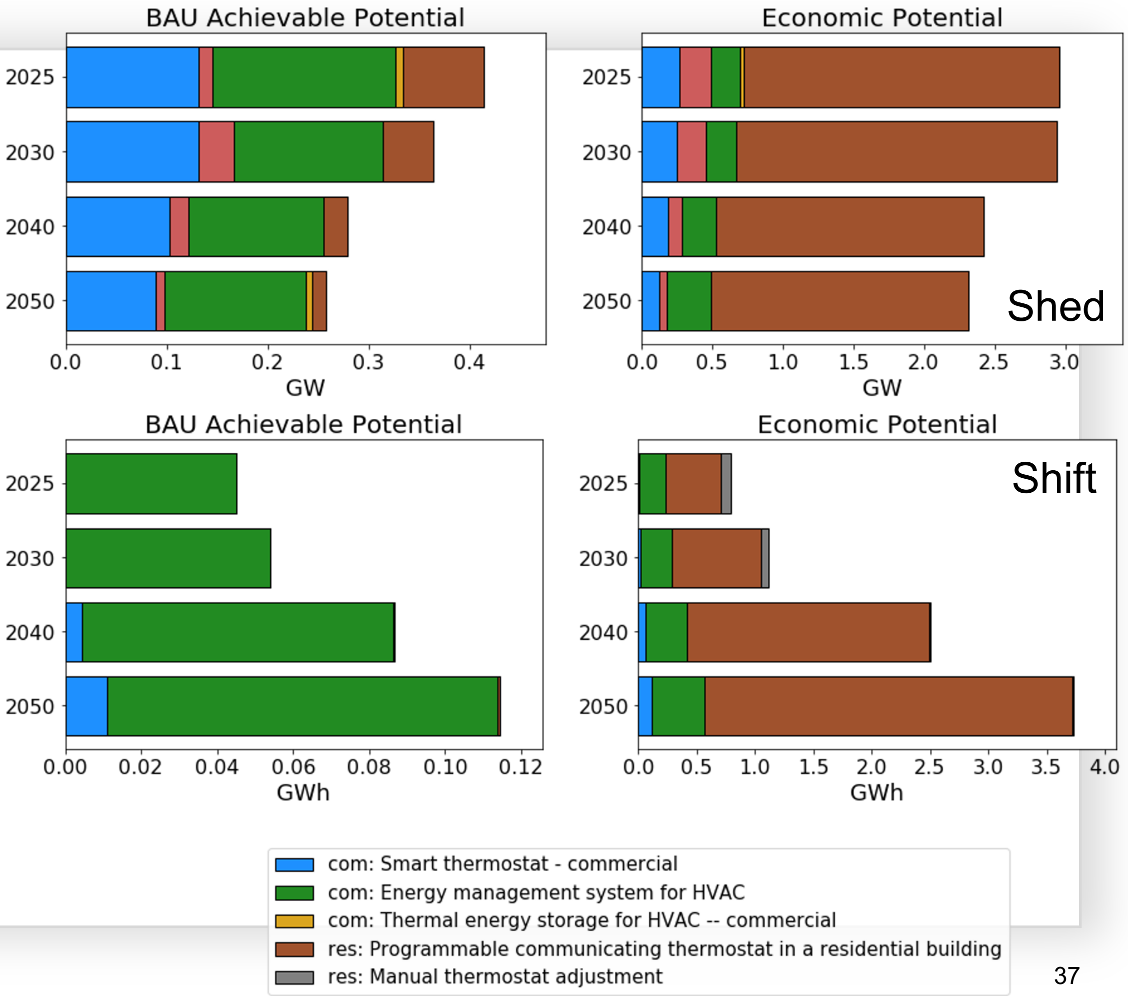
Example enabling technologies: LDEV charging

- As one might expect, connected charging infrastructure are an important part of enabling EV charging flexibility
- But we find that more costly options are also often cost-effective, given the large loads they can enable:
  - Building new workplace charging infrastructure can shift loads off peak
  - Adding gateways for vehicle-to-building charging can provide substantial shed resources



Example enabling technologies: space conditioning

- Although we saw that the shed resource from cooling declines significantly, smart thermostats and energy management systems remain important due to the growth in potential from space heating
- These technologies are also a rapidly growing source of shift potential.



Discussion

Notable demand-responsive end-use

Steady Workhorses	Rising Stars	Emerging Performers	Declining Resources	Development Opportunities
Significant across all years	Rapid growth to dominance	Also growing in importance	Less important over time	New tech may enable large loads
• Ind Process • Ag Pumping • Com Refrigeration • Res cooling (for shift) • Res refrigeration (for shed) • Electronics (for shed) • Res lighting (for shed) • Pool/spa • Commercial air handling	• MHDEV charging • Res LDEV charging • Res water heating (for shift)	• Com LDEV charging • Res water heating (for shed) • Res space heating • Res appliances • Com water heating • Com space heating	• Space cooling (for shed)	• Lighting • Electronics • Res refrigeration (for shift)

Notable DR-enabling technologies

Flexible EV chargers

- Even costly options may be cost-effective

Connected water heaters

- Both integrated and add-on controls

Connected outlets

- Enable a wide variety of plug loads

Smart thermostats

- For both heating and cooling

Energy mgmt. systems

- For both heating and cooling

Thermal energy storage

- For commercial refrigeration

Remote ag pumping controls

Connected appliances

- Especially dryers
- SB 49

Barriers to DR realization and paths to overcoming them

Customer incentives	• Current financial incentives may not be worth the effort • Explore new engagement strategies and non-financial incentives
Complex DR program landscape	• Many program options, complex rules for eligibility • Streamline program structures (e.g., dynamic pricing)
Customer structural barriers	• Technical and organizational constraints on flexing certain loads • Develop new technologies; provide organizational support
Access to automation technology	• Adopting and utilizing technology may be challenging • R&D to improve cost and ease of use; SB 49 standards
Measurement methodologies	• Current baselining methods can underestimate response • Improved baseline estimation using AMI data modeling
Valuation of shift DR	• Lack of flex-capacity value may under-compensate shift DR • Develop frameworks for valuing flexibility specifically

Summary

- Phase 4 of the California DR Potential Study provides an updated view of future DR resources in California with a dramatically expanded scope including expanded modeling of electrification, forecasts through 2050, and analysis of technical, economic, and achievable potential
- Growth in renewables and electrified loads will drastically alter the DR landscape by 2050, with major shifts in the seasonality of system peaks and extreme growth in the need for flexible generation
- Loads with year-round availability will provide stable DR resources, while the value of seasonal loads like cooling may diminish, especially for shed DR
- EV charging and other electrified loads will rapidly grow to become dominant sources of DR potential by midcentury
  - Significant investment in flexible EV charging infrastructure will pay dividends
- There is a significant (~5x) gap between the available potential and what is achieved by programs with current enrollment rates; improving on this is a key area for development
- Developing a framework to appropriately value shift DR is another important challenge
- Dynamic electricity pricing shows promise as an alternative pathway to capturing DR

Contact

Sarah Smith sjsmith@lbl.gov

Acknowledgements

Lawrence Berkeley National Laboratory is supported by the U.S. Department of Energy under Contract No. DE-AC02-05CH11231. The work described in this report was funded by the California Institute for Energy and Environment (CIEE), which is funded by the California Public Utilities Commission (CPUC) under State of California Interagency Agreement 18NS0496, UC-CIEE Subaward Nos. POCP06-L01.

Resources

- DR Potential Study Website (all reports and data download pages):
  – https://buildings.lbl.gov/potential-studies
- CEC Load Shift Goal:
  – https://www.energy.ca.gov/publications/2023/senate-bill-846-load-shift-goal-report
- CalFlexHub
  – https://calflexhub.lbl.gov/
- Dynamic Pricing Bill Impacts Study
  – https://eta-publications.lbl.gov/publications/potential-bill-impacts-dynamic
- Load Shape Clustering Paper
  – https://emp.lbl.gov/publications/multi-level-load-shape-clustering-and

- Contact
  – Sarah Smith, sjsmith@lbl.gov