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Shift Demand Response: A Primer

Dr. Brian Gerke, Dr. Giulia Gallo, Jingjing Liu, Mary Ann Piette (PI), Peter Schwartz (Co-PI)
Lawrence Berkeley National Laboratory
Dr. Peter Alstone
Schatz Energy Research Center – Humboldt State University

Introduction to *Shift*: What, Why and When

As California approaches a generation portfolio including 50^{+}% renewable resources, there are new and evolving challenges for balancing generation and loads, exemplified by the much-discussed "duck curve." The state already experiences days similar to Figure 1 below, which shows representative generation and load profiles for a high renewables penetration. Through the day we identify four key challenges:

1. **Downward ramping**: Thermal resources must ramp down rapidly (and some shut down) as the Sun rises and solar generation picks up the load on the grid.
2. **Minimum generation**: Dispatchable thermal generators run in the middle of the day at a minimum power level to maintain the reliability of the power system, and "over generation" by renewables in these peak solar generation times is curtailed.
3. **Upward ramping**: Thermal resources must ramp up rapidly in the late afternoon as the sun sets to replace solar generation and carry the evening peak.
4. **Peaking capacity**: The generation portfolio must have sufficient peak capacity to meet the peak.

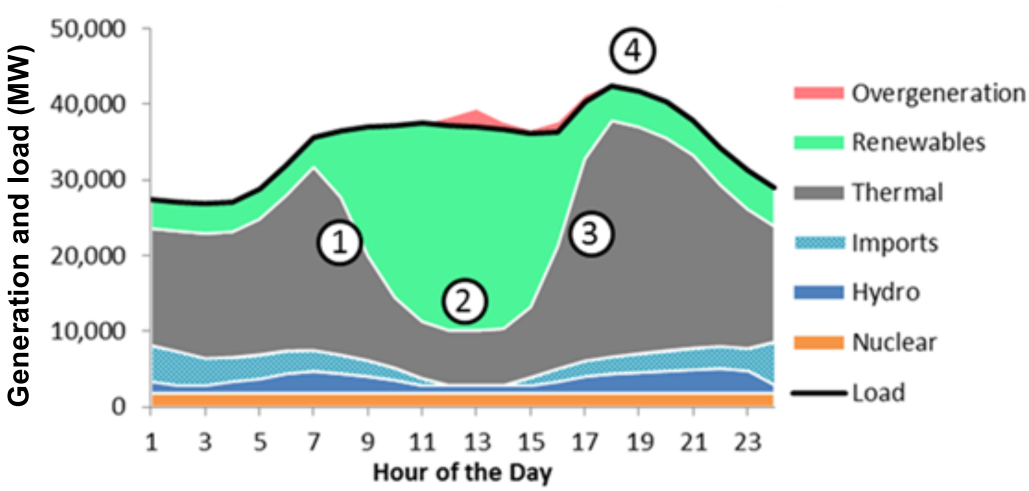

Figure 1: The challenges of a 50% Renewable Portfolio
Source: Alstone, P., et al. ***Final Report on Phase 2 Results, 2025 California Demand Response Potential Study: Charting California's Demand Response Future***, Lawrence Berkeley National Laboratory, 2017.

A key future grid planning tool is likely to be a new approach to demand response (DR), termed *Shift*[1], that motivates customers to *move* the timing of loads from one time to another, to utilize renewable generation when it is available to flatten the duck curve. This is a new and additional service beyond load shedding to reduce the peak, which was the original DR programs' goal.

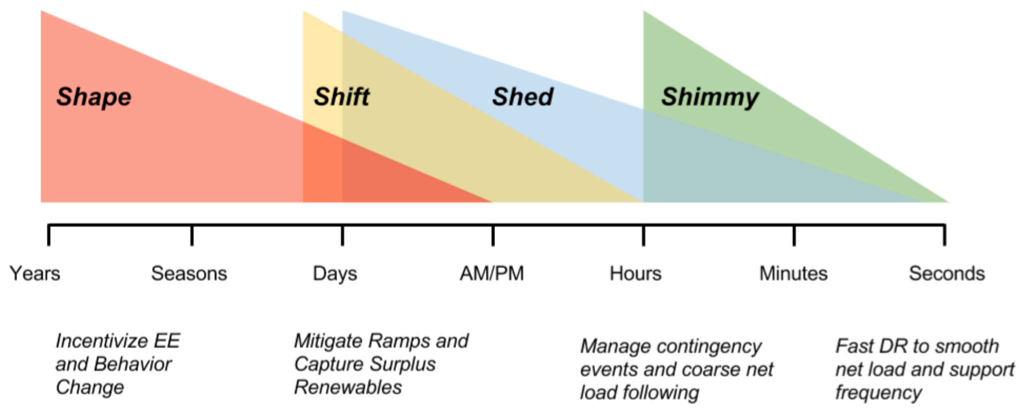

Figure 2: The four broad categories of DR identified in the CPUC DR potential study

The CPUC-commissioned *2025 California DR Potential Study – Phase 2*[2] (hereafter, the DR Potential Study) identified four broad categories of DR resource, summarized in Figure 2, of which *Shift* is one.

- ***Shed*** refers to traditional load-reducing DR, in which consumers curtail specific loads in response to either, a grid operator's or program administrator's DR signal. From a supply-side perspective, *Shed* resembles, and is compensated like, a *generation capacity* resource.
- ***Shift*** refers to a DR approach that involves moving electrical loads from one time to another to better match either, the availability of low-cost power or to "valley fill" grid-level load requirements (i.e., peak-clipping), while providing equivalent energy service to the end user. From a grid perspective, *Shift* resembles a *storage* resource.
- ***Shimmy*** refers to fast-responding DR that can rapidly modulate loads on timescales of seconds to minutes. From the grid perspective, *Shimmy* resembles frequency regulation or 5-minute load-following *ancillary services* resources.
- ***Shape*** refers to long-term, persistent changes in the shape of the daily demand profile, arising from automated or manual changes in demand-side behavior in response to static incentives such as time-of-use (TOU) pricing or dynamic critical peak or real-time pricing. Its impact will

[1] Throughout this document we will use capitalized and italicized terms (*Shift, Shed,* etc.) when referring to categories of DR product, to distinguish between the DR categories and the specific actions taken by participants.
[2] Alstone, P., et al. *Final Report on Phase 2 Results, 2025 California Demand Response Potential Study: Charting California's Demand Response Future*, Lawrence Berkeley National Laboratory, 2017. http://www.cpuc.ca.gov/WorkArea/DownloadAsset.aspx?id=6442452698

generally be equivalent to some combination of *Shift* and *Shed* occurring predictably on a daily basis.

This document focuses on the *Shift* category: moving electrical loads from one time to another to align electrical loads with available renewable generation. At the site level, *Shift* is manifested as a load reduction (a "shed") at a time when aggregate demand is high relative to available renewable generation, coupled with a load increase (a "take") at a different time beforehand, or afterward, when renewable generation is high relative to demand. Depending on the end uses involved and power system conditions, this shed/take cycle can occur over a period of a few hours, over a diurnal (AM/PM) cycle, or even across several days (e.g., shifting peak weekday loads to the weekend). The CAISO has recently released a straw proposal[3] as part of its Energy Storage and Distributed Energy Resources (ESDER) initiative that includes a potential load-shifting DR product with participation limited to individually, sub-metered, behind-the-meter batteries. Here, we explore the potential for expanding this general concept to a wider set of end uses, without the need individual sub-metering.

It is worth noting that some fraction of the load shedding in traditional *Shed*-type DR is likely to also be offset by a take at a different time to make up the lost energy service, such as by pre-cooling and other strategies to increase load before a *Shed* event, or through so-called "snapback" afterward. This effect is incompletely controlled in typical DR programs and may or may not be well aligned with system needs. One of the *Shift* concept aims is to change the timing of loads in a controlled manner to ensure that the shed/take cycle serves to mitigate, not exacerbate, the duck curve. Furthermore, the opportunity to use *Shift* to mitigate renewables curtailment or fast ramping may occur much more frequently than the need to use traditional *Shed* DR for mitigating extreme peak loads. To this end, *Shift* can either be implemented as a day-to-day dynamic or **dispatchable** resource (e.g., an ISO market product that can be called upon in real time, or a real-time price sent to devices), or as **permanent** load reshaping arising from long-term changes in behavior and structural changes to the installed load base (i.e., achieved through *Shape*, a consumer response to TOU pricing or other incentives, with no day-to-day flexibility). In this discussion, we will often conceptualize *Shift* as a dispatchable resource, but it is worth remembering that some portion of the resource being discussed could be achieved through longer-term, behavior-based or technological approaches – that is, through *Shape*.

[3] http://www.caiso.com/Documents/StrawProposal-EnergyStorageandDistributedEnergyResourcesPhase3.pdf

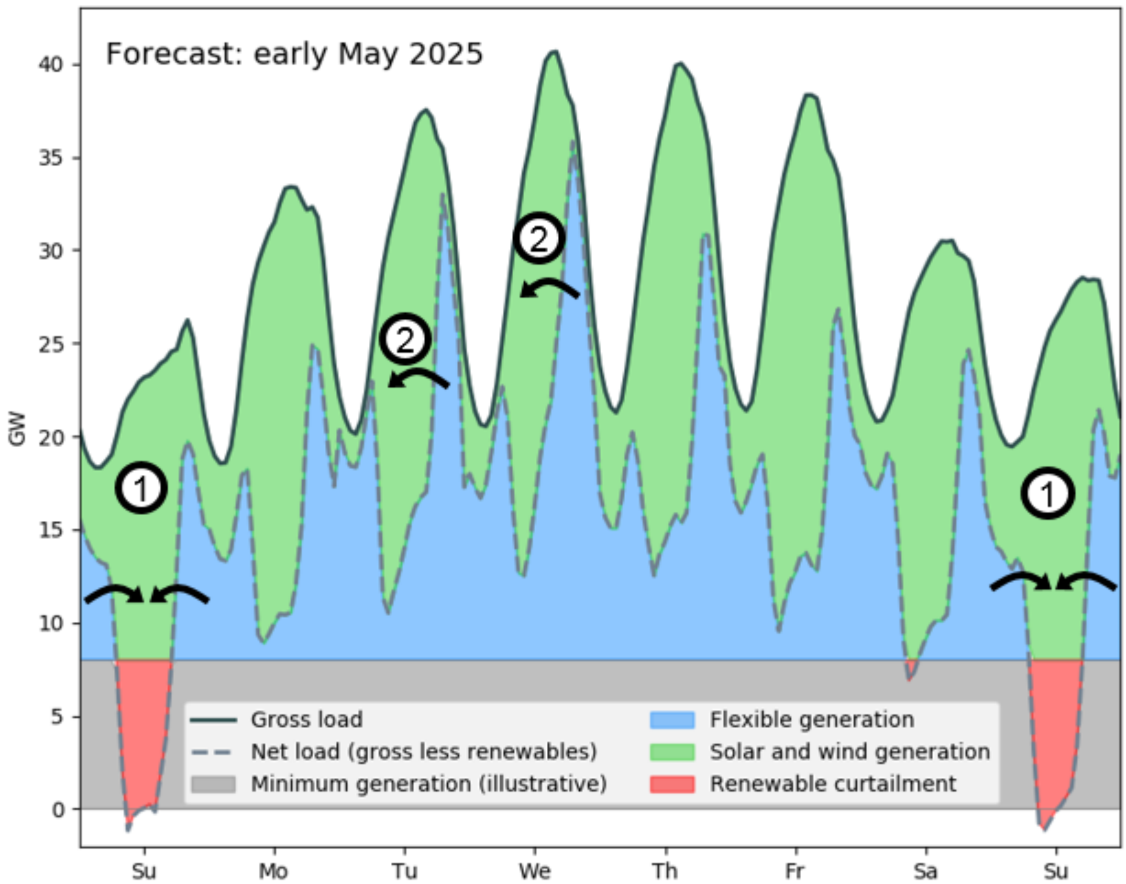

Figure 3: Demand and generation stack for ten days in May 2025, as forecast by the LBNL-LOAD model. Annotations show example periods when *Shift* DR would be valuable for mitigating renewable curtailment (1) and fast ramping (2).

Figure 3 shows an example future load shape that demonstrates the need for *Shift*. The diagram shows the demand profile for ten days in May 2025, as forecast by the LBNL-LOAD model for the DR Potential Study, along with a generation stack broadly categorized into minimum generation (i.e., inflexible base generation) in gray, flexible generation (i.e., resources that can support rapid ramping) in blue, and renewable generation (specifically solar and wind) in green. As shown, when the net load on the grid (defined as gross demand less renewable generation) falls below the minimum generation level (red shaded regions), it is necessary to curtail renewables. The minimum generation level in 2025 is unknown, and the value of 8 GW shown here is for illustrative purposes only. Notably, however, in two instances during the period shown, the net load curve falls below zero; in those cases, curtailment would occur even if all non-renewable generation could be turned off completely.

The numbers in Figure 3 denote the primary reasons why *Shift* DR is likely to be needed in the future:

1. To alleviate renewable curtailment, in essence by "filling in" large troughs in the net load.

2. To ease ramping rates and flatten extremes of demand by reducing load during peak periods (similar to *Shed*) and instead using the same energy during periods of very low net demand (unlike *Shed*).

On a typical day, the load shift that is needed involves a shed during evening and/or morning hours and a take during midday or overnight hours (depending on whether solar or wind dominates renewable generation on a particular day). Importantly, rapid ramping of the flexible resources occurs on every day, in response to changes in renewable generation at sunrise and (especially) sunset, when the drop in solar generation is paired with an increase in demand. Using *Shift* DR to ease these ramps could potentially provide value to the grid on every day of the year, since it can eliminate the need for some peak generation capacity. The value may be greatest, however, on days with substantial renewable curtailment or with especially large evening peaks in the net load, since this impacts the total amount of generation infrastructure that is needed to provide adequate capacity.

For the deepest curtailment periods in Figure 3, or in cases where significant wind generation dominates the generation mix over a multi-day period, there could be added value in shifting energy consumption over multiple days, such as by rescheduling discretionary loads from weekday evenings to weekend mornings. The potential for this kind of long-duration shifting over more than a few hours has not been thoroughly explored to date.

Modeling and Measuring *Shift*

In the DR Potential Study, the DR-Path model estimated the future potential *Shift* resource by modeling it as a DR product that was perfectly **energy neutral** at the site[4], over some defined time window. The model assumed that *Shift* DR resources would be responding to a Shed and Take dispatch signal that is just the inverse of Generation-Up and Generation-Down dispatch. The specific dispatch instructions were estimated using optimization of resources in E3 Consulting's RESOLVE model (see the DR Potential Study Phase 2 report for further details). Figure 4 shows this dispatch signal for the average model day in 2025. *Shed* periods occur during periods of peak net demand in the early morning and late evening, when demand is significant but solar generation is not available; while Take periods occur in the middle of the day, when solar generation is strong, and overnight when loads are minimal but there is often significant wind generation.

[4] In practice, there may be some losses associated with *Shift*, but these were neglected for the purposes of estimating the size of the resource.

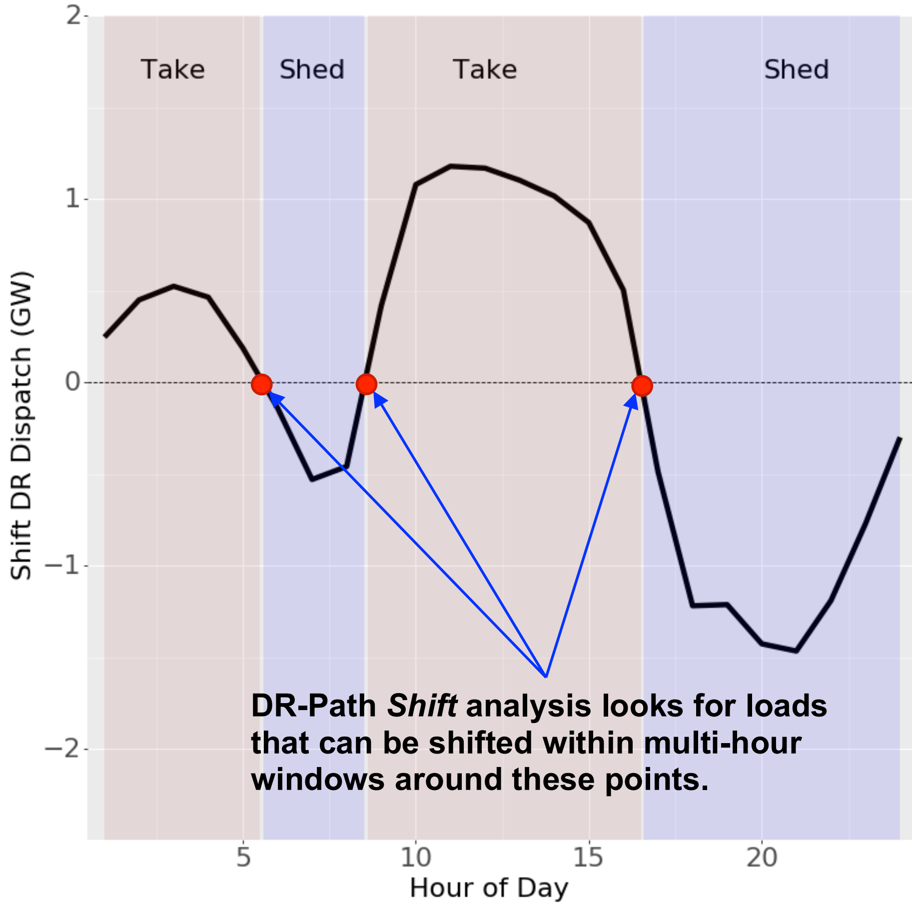

Figure 4: Average daily dispatch signal to which *Shift* DR would respond.
To estimate the *Shift* resource, the DR-Path model identifies loads that could be shifted within symmetrical, multi-hour windows about the zero points (red dots).

To estimate the available *Shift* resource, DR-Path examines a large set of forecasted load profiles, disaggregated by end use and grouped by customer type into representative clusters. The model identifies end uses whose load can be shifted within a window of a given duration (e.g., 4 hours), and it estimates, within that window, the amount of shiftable load that is available to be moved across each of the zero-points of the *Shift* dispatch curve (red dots in Figure 4).

Given this total, DR-Path then generates a supply curve for *Shift* by calculating the fraction of the total theoretically available *Shift* resource that could be enabled for a given cost, based on a cost model for the DR-enabling technology and a behavioral model for DR participation at a given incentive level. By comparing this supply curve to a demand curve derived from the RESOLVE model for resource procurement, it is possible to forecast the amount of *Shift* DR that will be economical in different scenarios.

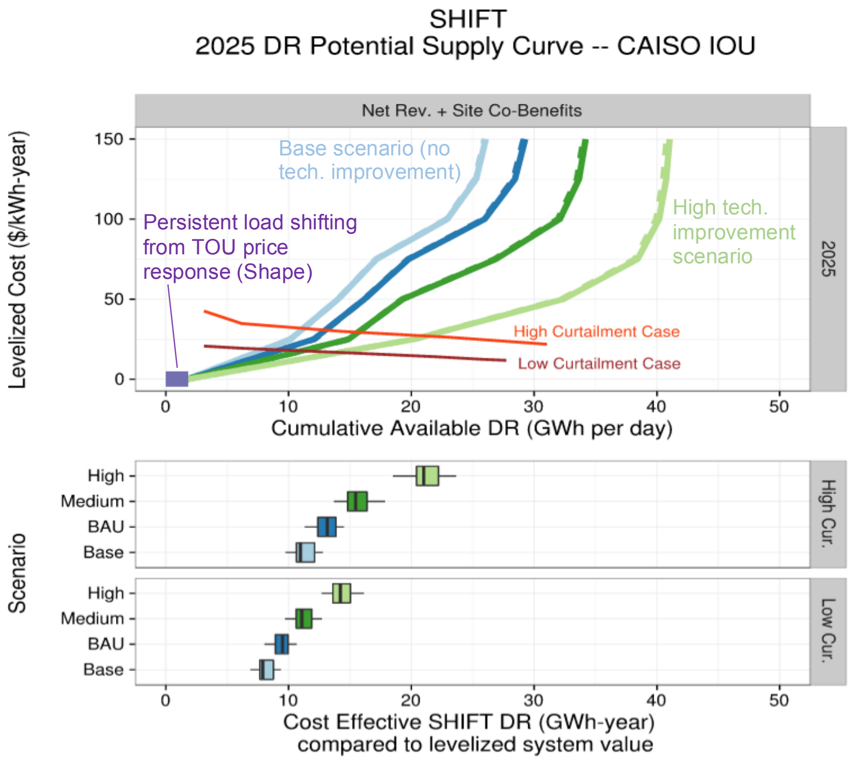

Figure 5: Top: Supply and demand curves for *Shift* DR resources in 2025, under various different technology improvement scenarios. Bottom: Economical *Shift* DR amounts in each scenario, with estimated uncertainties.

Figure 5 shows the 2025 forecast of available *Shift* from the DR potential study. The upper panel shows the supply and demand curves for *Shift*, including both persistent load shifting that is enabled by adoption of TOU retail prices similar to those slated for deployment in 2019 (purple bar), as well as the average daily *Shift* that would be enabled for a given total cost of procurement under various different scenarios for future improvement trends in DR technology (from left to right these are the Base, Business-as-Usual, Medium, and High improvement scenarios). As shown, the California power system circa 2025 is expected to have 10-20 GWh of load that can participate cost-effectively in Shift DR.

To fully understand Figure 5, it is important to briefly describe the units of measure for the *Shift* resource. In traditional procurement of generation capacity (or *Shed* DR), because different resources and contracts can have different lifetimes, the resources procured are often reported in units of *kW-year*, which represents a kilowatt of power generating capacity that is available over a period of a year[5]. Because *Shift* is modeled as an energy-neutral resource similar to energy storage, which simply moves energy consumption from one time to another without impacting aggregate demand, the analogous unit is the *kWh-year.* In Figure 5, then, a procurement cost of $100/kWh-year means that a marginal investment of

[5] Importantly, the kW-year should be read as a unit of generation *capacity* available over a given period of time and NOT a unit of energy, as a naïve dimensional analysis would suggest, since the resource will be available, but will not be used for generation constantly throughout the year. Indeed, the *Shed* resource is only used at peak times.

$100 will one kWh to be shifted on a daily basis, on average throughout the year, during periods of system need (i.e., at times near the zero crossings in Figure 4).

Shiftable End Uses and the timing of *Shift*

A wide variety of electrical end uses can provide *Shift* DR. The DR Potential Study considered a subset of these, limited by the ability to disaggregate those loads from the historical meter data that supports the model and by the available information at the time related to end-use technology. Figure 6 shows the contribution of each of these sector-specific end uses to the *Shift* supply curve. It is notable that residential behind-the-meter batteries may be a significant source of *Shift*, especially if prices fall further than was assumed in the DR Potential Study. However, the future adoption of battery technology remains highly uncertain, and it is notable that there are many other end uses already in use that provide comparable potential.

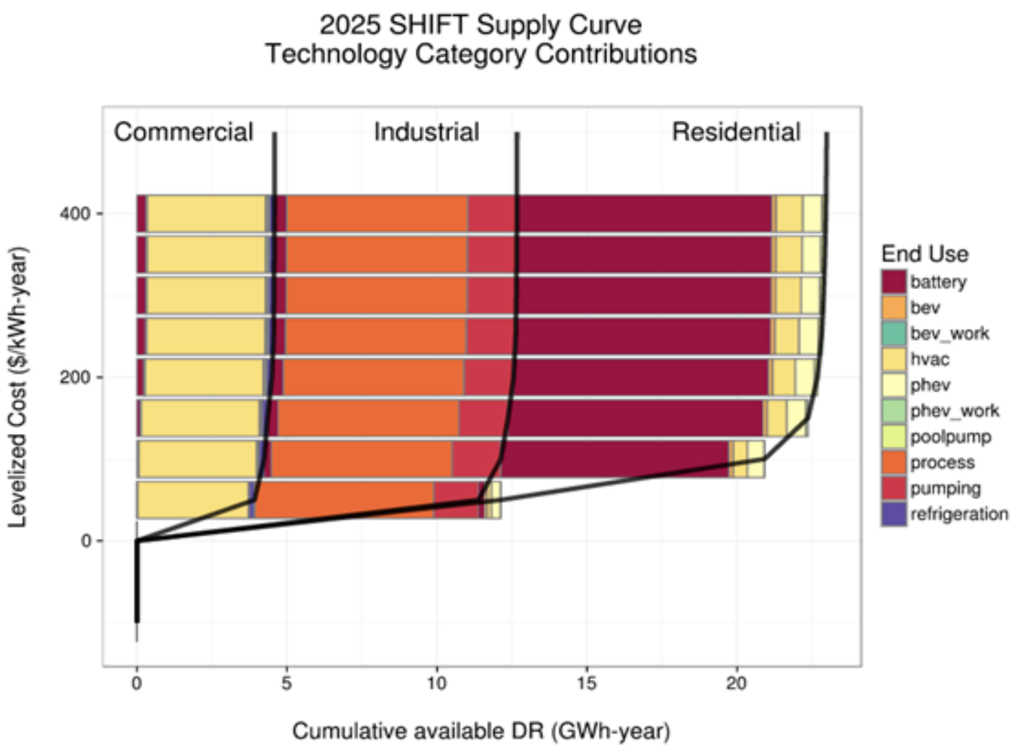

Figure 6: Contributions to the *Shift* supply curve, by sector and end-use. Note: electric vehicle (EV) charging has been divided into battery-only (BEV) and plug-in hybrid (PHEV) vehicles, with charging occurring both at home and at work.

Table 1 lists a broader set of end uses for which *Shift* DR may be technically feasible; shaded cells indicate end uses or technical pathways that were not considered in the DR Potential Study. This table is intended to be comprehensive given existing technology, though new and emerging technologies could potentially enable load shifting for additional end uses in the future. For the purposes of developing potential *Shift* products in the near term, it will be important to analyze which end uses have significant load-shifting potential and address any barriers to participation.

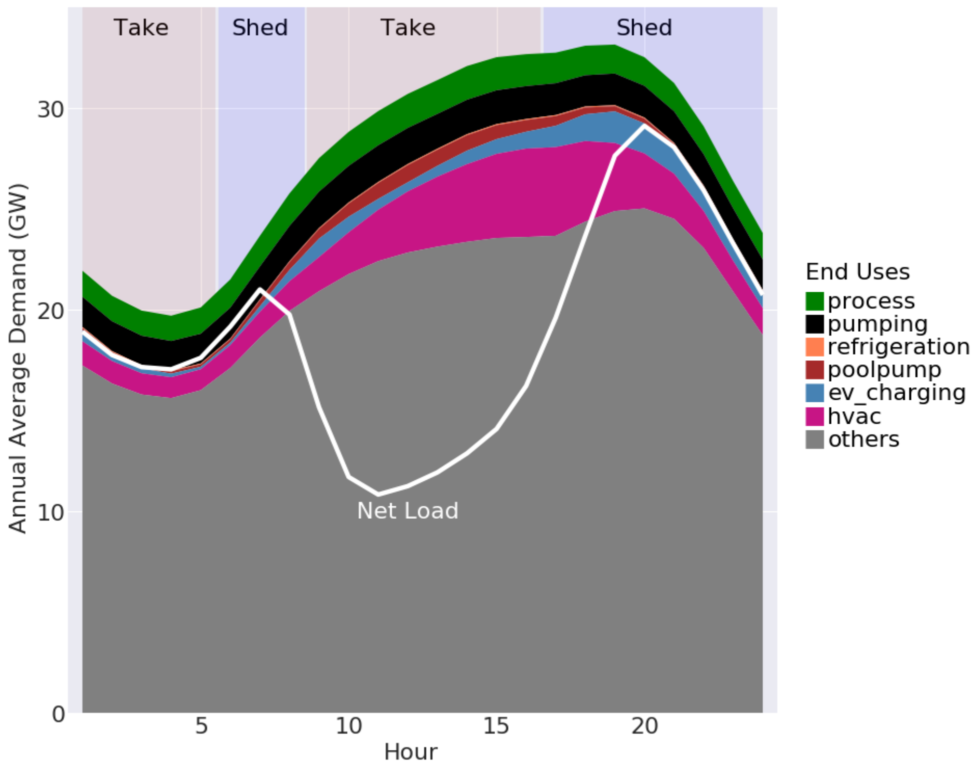

Figure 7: Annual average daily load shape in 2025, as forecast by LBNL-LOAD, with analyzed Shiftable end uses disaggregated (colored bands) and set in the context of the daily Take/Shed cycle from Figure 4. Other loads that were not considered for *Shift* participation are shown in gray, and the average daily net load is also shown for reference.

To serve as a significant source of *Shift*, a given end use must meet two criteria: it must have an inherent flexibility in timing, and it must have a significant amount of load that would typically occur during times when there is need to reduce the system load, along with an ability to increase load at times when there are significant renewables available. Figure 7 shows the annual average daily statewide load shapes, projected in 2025 for the various different shiftable end uses considered in the DR Potential Study (with the exception of batteries, whose expected load shapes are not well constrained). As mentioned above, the study considered shifting within defined multi-hour windows centered on the daily Shed/Take transitions, and these are labeled as shaded regions in the figure. A visual assessment can uncover alignment of an end use's load shape with the Shed/Take transitions that suggest either a strong or weak opportunity for *Shift* DR. As seen in Figure 7, HVAC and electric vehicle (EV) charging loads have natural peaks near the transition periods; hence they are likely to have a high *Shift* potential. By contrast, pool pump loads have their peak during the middle of the day, where it is already largely aligned with system needs. Industrial process and pumping have flatter profiles, suggesting that they may have potential to shift a portion of their load. In essence, the opportunity to participate in *Shift* comes from a misalignment between the "natural" timing of loads that is incumbent in the power system and the emerging dynamics of renewable generation. It is also potentially interesting to look at shiftable load shapes by sector or geographic region, to gain insight into targeting strategy for future *Shift* programs. In the appendix to this document, we consider load shapes broken down by sector as an example.

Table 1: List of end uses for which participation in *Shift* DR may be technically feasible

End use	Sector	Approach/technology
Space cooling	Res/Com	Pre-cooling with PCT or EMS
	Com	Thermal storage
Ventilation	Res/Com	Advanced controls
Pool pumps	Res	Dynamic scheduling
Irrigation pumping	Ind (Ag)	Dynamic scheduling
Wastewater pumping	Ind	Dynamic scheduling
Water supply pumping	Ind	Dynamic scheduling/pumped storage
Industrial process	Ind	Dynamic scheduling
Refrigeration	Com	Warehouse pre-cooling
	Res/Com	On-board thermal storage
EV charging	Res/Com	Dynamic scheduling
	Res/Com	Two-way charging
Battery (whole building)	All	Storage, two-way charging
Battery (distributed/ point of use)	All	Storage, two-way charging
Cooking	Res/Com	Scheduled electric cookers
Water heating	Res/Com	Pre-heating and scheduling
Space heating	Res/Com	Pre-heating with PCT or EMS
Cleaning Appliances (dishes, clothes, dryer)	Res/Com	Dynamic scheduling
Lighting	Ind (Ag)	Indoor photoperiod shifting (grow lights)

Next Steps for Analyzing *Shift* DR

Exploring seasonality in *Shift*

Just as the potential for a given end use to provide *Shift* depends on its daily load profile, there is also a strong seasonal component to each end use's value as a *Shift* resource. Figure 8 shows the daily statewide load shapes in 2025 by season, disaggregated into estimated end use contributions, similar to the annual average load shapes in Figure 7. A strong seasonal variation is apparent in the amount of shiftable load, driven primarily by seasonal variation in HVAC load. The DR Potential Study reported annual averages when estimating the supply curve for *Shift* that reflected the accumulated opportunity and value to shift loads. When planning for the deployment of *Shift* resources, it will be essential to also account for seasonal variation, since the largest available end uses may not align with times of critical system need. For example, solar curtailment may be most problematic in the spring, when there is relatively high daily insolation but low temperatures limit the total mid-day HVAC load; however, the reduced HVAC load also means there is less load-shifting resource available to offset curtailment.

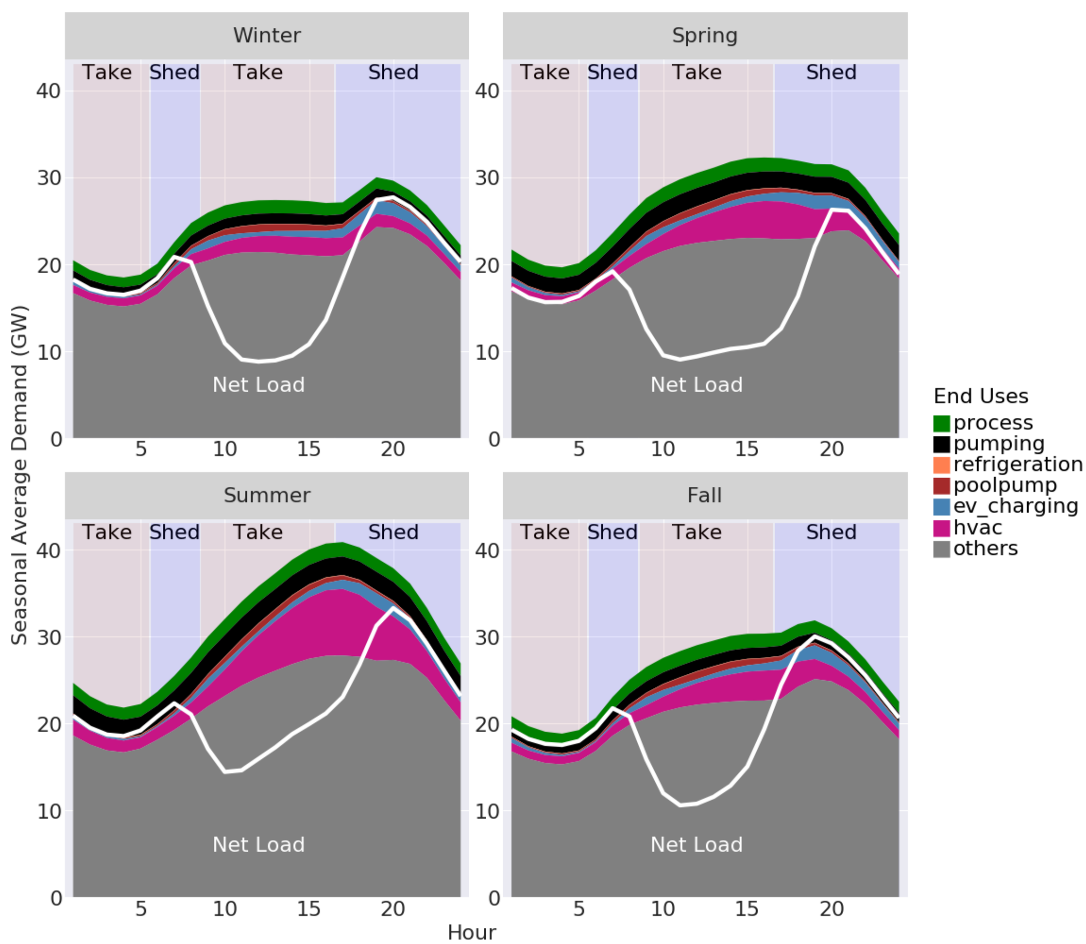

Figure 8: Seasonal average daily load shapes in 2025, as forecast by the LBNL-LOAD model. The loads are broken down by end use and set in the context of the daily net load and Shed/Take periods, as in Figure 7.

Where is the *Shift* resource?

Another essential component to maximizing the cost-effective *Shift* resource is efficient targeting for participation in *Shift* DR programs to those customers having a high potential. Interval meter data may be valuable for this purpose: one might expect, for example, that promising sites would be those with large evening peaks that could be shifted slightly earlier to utilize solar generation. A challenge arises, though, because this data represents only the total load for the site and does not distinguish between shiftable and non-shiftable end-uses, with the result that the overall site-level load shape can mask (or mimic) a significant shiftable resource. Figure 9 shows several example load shapes that illustrate the challenge. Each of the load shapes shown is the average daily load shape for a cohort of similar customers that has a potential *Shift* resource (as a fraction of the cohort's total load) that among the very highest in each sector. But, particularly for the commercial and industrial sectors, there is a large qualitative variability among the load shapes, with some sites having the expected large evening peaks, others with a minimum in the evening, and still others with more erratic or complex average load shapes. (In the residential sector, by contrast, the load shapes are fairly self-similar.) More research is needed to determine metrics and statistics that can identify the highest-leverage sites to help drive rapid deployment of *Shift* DR.

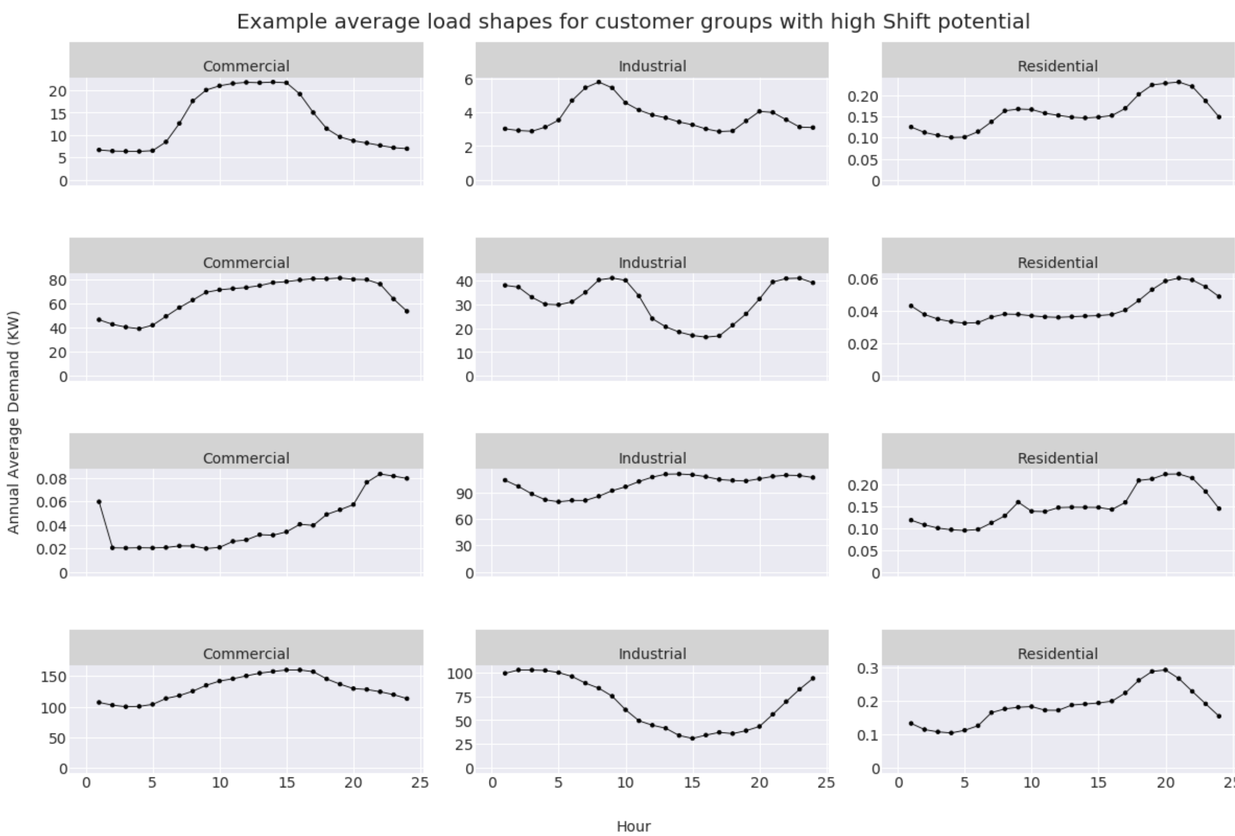

Figure 9: Annual average daily load shapes for selected customer groups that have a large fractional *Shift* potential.

Open questions for deployment: How do we get *Shift* on the grid?

Finally, there are several crucial questions that must be addressed on the way to implementing *Shift* DR. First, as illustrated in Figure 1 and Figure 3, a grid with high renewables penetration has a fairly consistent need to shift load away from morning and evening hours and toward the middle of the day, owing to the regularity of solar generation.

For this reason, it may be desirable to achieve a large fraction of this shift by incentivizing persistent behavioral changes and structural investments in price responsive loads (i.e., through more aggressive TOU, predictable dynamic prices, and other means combined with enabling technology), rather than solely through a dispatchable market product. As shown in Figure 5, though, the effective permanent *Shift* resource (purple bar) arising from currently planned TOU pricing incentives (assuming past behavior changes are a good predictor for response) is relatively low compared to the total expected available resource. Thus, it may be fruitful to explore additional means of driving long-term behavioral change, beyond TOU pricing. However, measuring such changes may be a challenge. If *Shift* is incentivized with TOU pricing, it can be measured with control group data for buildings having similar size, demographics and climate. If TOU pricing varies by season, it may also be possible to use weather regression to assess impacts for individual buildings. Developing better data on demand elasticity will also help to estimate permanent forms of *Shift.* In any case, measuring *Shift* will require a careful evaluation of hourly load shapes during Take and Shed hours.

A more vexing set of questions arises when considering how to design an ISO market for dispatchable *Shift* and facilitate market settlement. Key issues to be addressed through future research include the following.

- What is the baseline against which dispatchable *Shift* occurs? If *Shift* is intended to be approximately energy neutral over some period, it will be necessary to define a counterfactual load shape or other metric that represents what would have occurred in the absence of a *Shift* dispatch, so that the energy-neutral load shift can be measured and verified. In the context of an individual site with many different end uses, only some of which are shiftable, and all of which may have varying day-to-day utilization, defining such a counterfactual baseline is a significant challenge, especially if *Shift* is dispatched frequently.
- If *Shift* DR is implemented as an approximately energy-neutral product, it will be necessary to define a time window over which the neutrality is enforced—i.e., each *Shed* must be offset by a counterbalancing take within some number of hours or days. Since *Shift* can operate by moving loads either earlier or later, and since it is easy to imagine cases where temporal shifts occur in both directions within a single day, it will be important to carefully consider how energy neutrality is defined and enforced.
- Similarly, since some amount of losses (or savings) may be expected in both energy storage and load shifting, it will be important to define the tolerance within which energy neutrality should be maintained for *Shift* products.

- Because *Shift* DR involves a load increase (take), during which the participating site will be paying for consumed energy, it will be important to consider the gap between retail electricity prices and wholesale market payments, to limit opportunities for demand-side price arbitrage.

Summary

This document has provided an introduction to the *Shift* grid service that is being developed in California. We have included grid service and data definitions, a description of how we model and measure *Shift*, a description of end-uses that can provide *Shift,* and a description of seasonal needs for *Shift.* We also describe next steps for developing shift and the some of the development needs and topics for future study.

Appendix: Load shapes by end use and sector

Figure 10 shows the daily statewide load shapes in 2025 by season and sector, disaggregated into estimated end use contributions, similar to the all-sector seasonal load shapes in Figure 8. There is a strong variation across sector in the amount of shiftable load, as well as in its daily and seasonal timing. For instance, there is a very large potential HVAC resource in the residential sector during the summer, but this resource is dramatically smaller in other seasons. By contrast, the shiftable loads in the commercial sector and (especially) the industrial sector are available more consistently throughout the year. The appropriate approach to enrolling Shift participants by sector will depend on when during the year the need for *Shift* is greatest. Similar considerations are likely to arise for different geographic regions, especially if *Shift* is used to help mitigate local system constraints.

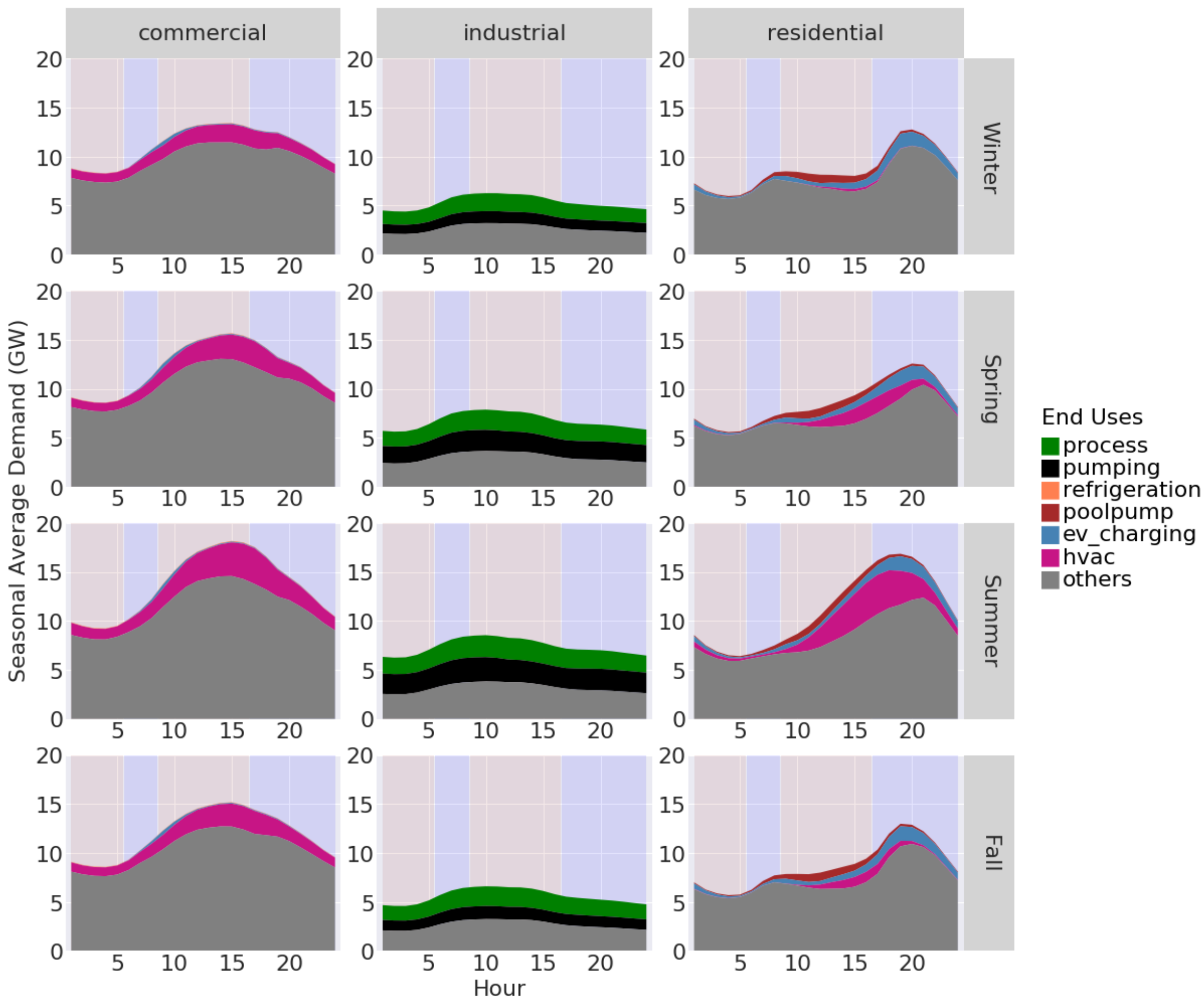

Figure 10: Seasonal average load profiles, broken down by sector.
Shiftable end uses analyzed in the 2025 CA DR Potential Study – Phase 2 are color-coded.