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Rate Design for Beneficial Electrification

Transcendent Energy for the Building Decarbonization Coalition

ALEJANDRA MEJIA CUNNINGHAM • MICHELLE VIGEN RALSTON • KATIE WU

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Rate Design for Beneficial Electrification

The rates that gas and electricity utilities charge customers are a product of a complex, negotiated process that inherently involves policy choices. Those choices are made to align with the principles of cost-causation, address the needs of individual customer groups, balance cost burdens across different groups, or support other policy goals.[1] Under the traditional cost-of-service approach to ratemaking, the process is intended to produce rates that are just and reasonable for consumers, reflect the cost of procuring and distributing regulated fuels,[2] and ensure cost recovery for utility investments.

In California, residential energy rates are generally a combination of minimal fixed charges (or "minimum" bills) and largely volumetric rates that may vary by usage tiers and/or baseline allowances.[3] California's default volumetric electric rates will also soon depend on the time of day that electricity is used. Economic theory posits that customers can respond to price signals, and that aligning customer prices with electricity costs can improve outcomes. This suggests that if all of these rate design elements are balanced so that they collectively reflect the real costs of using different fuels, rate design can convey price signals to support building electrification where it is societally beneficial. This paper explores how these goals could be achieved in practice.

Contents

RESIDENTIAL RATE REFORM: California committed to residential electric rate reform in 2013. The state's vision for ongoing improvements to rate design, as defined by the CPUC in collaboration with a large number of interested stakeholders, is well aligned with helping customers switch to clean heat. The CPUC's rate design principles for this new era emphasize cost-reflective rates that communicate the time-dependent costs of generating and distributing electricity. Successfully implementing residential rate reform can be an important step towards supporting building decarbonization, as exposing customers to improved price signals allows them to share in the economic benefits of load shifting technology investments, such as electric heat pumps that can store cheap solar energy by preheating spaces and water.

Rates that meet these goals can empower customers to electrify their buildings and use their electric equipment in a way that minimizes GHG emissions and lowers the cost of energy service. Accurate retail rates could reveal opportunities for increasing benefits both to customers and to the system by adjusting when and how much energy is consumed, especially with the help of automation technologies.[4] Yet, conveying price signals that are better aligned with both cost causation principles and policy goals is a challenging and often contradictory task. Rate design goes beyond setting time-dependent volumetric rates. Electric rates must be designed so customers are not punished by legacy assumptions of what fuels satisfy basic household needs. In the absence of widespread automation technology adoption, rates must also be simple enough so that the average customer can easily understand and act on them. They must also be rolled out with enough accompanying customer education and protections for the most vulnerable customers.

Rate designs that are aligned with cost causation and policy goals can ensure that early adopters of building decarbonization technologies do not incur counterproductive costs after investing in new building electrification technology. Keeping electricity rates low, predictable, and stable will help customers view electricity as a preferred fuel and help drive near-term decarbonization adoption that is consistent with long-term policy goals.

This paper discusses key rate design levers to be used to align electric rates with California's short- and mid-term climate goals. That section is followed by a set of criteria that can be used to evaluate proposed electric rates. Finally, the chapter concludes with a discussion about more innovative rate designs to be explored in order to set California on the right path to complete building decarbonization. Gas rates are also relevant to building decarbonization, but are not discussed in this paper.

RATE DESIGN LEVERS FOR BENEFICIAL ELECTRIFICATION

There are a handful of rate design elements that are central to creating a rate that supports beneficial building electrification. This section examines the most traditional of these elements: baseline allowances;[5] peak to off-peak differentials in volumetric rates; high usage, demand, and fixed charges; and solar export prices. Addressing each of these key levers should help design rates that support California's near- and mid-term building decarbonization goals. A rate design vision for the state's long-term goals will likely involve more sophisticated, dynamic rates coupled with controllable loads. These long-term needs are discussed in the paper's conclusion section.

BASELINE ALLOWANCES AND TIERS

California law requires that the CPUC:

> Designate a baseline quantity of gas and electricity which is necessary to supply a significant portion of the reasonable energy needs of the average residential customer. In estimating those quantities […] the commission shall develop a separate baseline quantity for all-electric residential customers. For these purposes, "all-electric residential customers" are residential customers having electrical service only or whose space heating is provided by electricity, or both.[6]

Per this mandate, customers are charged a lower volumetric rate for that baseline quantity of gas or electricity and a higher rate for any use beyond the baseline amount. The difference between the baseline and non-baseline rate depends on customer profile and climate zone, but it is roughly 39%.[7] However, baseline allowances that do not account for other electrified end uses disadvantage customers that choose to electrify other equipment. This creates a disincentive for decarbonization.

Because space heating is an energy-intensive basic necessity, per statute, electric baseline quantities are more generous for customers that use electricity for their primary space heating fuel than for those who do not. However, electric space heating is the only electric end use that triggers an increase in baseline allowances. Electric baseline allowances are not higher for customers who use electricity for other basic needs, such as cooking and water heating, than for customers who use gas for those needs.[8]

Electric water heaters and other electric end uses are currently excluded from all-electric baseline estimates, and therefore customers who use heat pump water heaters (HPWHs) are charged a higher electric rate for water heating than customers who also use electric space heating. Adjusting a customer's baseline allowance to account for electrified end uses would remove this disincentive. This could reduce annual energy bills of customers who switch to electric water heating equipment by about $90.[9]

Related to baselines is the High Usage Charge (HUC), which is a recently implemented component of California Investor Owned Utility residential rates that increases volumetric rate prices when customers use over 400% of their baseline allowance. It was intended to discourage excessive electricity consumption. While most residential customers in California will soon be shifted to a Time of Use without the HUC (potentially making the issue moot), this type of rate design is at odds with the longer-term vision of increased electricity usage being a desired outcome. To this end, the CPUC and utilities have implemented residential electric rates that do not use tiers or baselines as a means to encourage transportation electrification. Allowing the same for customers undertaking building electrification may be appropriate as well.

PEAK TO OFF-PEAK DIFFERENTIALS IN VOLUMETRIC RATES

The volumetric rate is the price that a customer is charged for each unit of electricity they use from the grid. It is usually expressed in terms of dollars per kilowatt hour ($/kWh). Residential electric bills are usually determined almost entirely by the volumetric rate, which incorporates the costs of generating and delivering electricity, as well as other grid investment and public policy costs.

The cost of generating and distributing electricity varies greatly throughout the seasons of a year and hours of a day. Historically, this variation has been largely due to changes in demand for electricity: for example, when air conditioning use spikes in the summer months, the system must use more expensive generators to serve increasing demand. Higher demand hours also tax the transmission and distribution grid, which increases the cost of delivering electricity. More recently, the cost of electricity in California has also been affected by widely available low-cost solar power in the middle of the day, and the need to quickly ramp up fossil fuel generation after sunset, especially during the spring and fall seasons. The availability of low-cost solar power in the middle of the day and inflexible demand in the evening has led to even greater variations in the demand and supply of electricity within single days.[10]

There are significant benefits to rate designs that incentivize customers to reduce use during the few hours each day that electricity is most expensive and carbon intensive. Time of use (TOU) rates can do this by setting different volumetric rates for electricity consumed during the most and least expensive times of day. This signals to customers to shift some or all of their use away from the higher price (peak) hours to the lower price (off-peak) periods. This shift can be accomplished either by changing behavior or by programing appliances to avoid running during the most expensive hours.

Optional rates can be designed with an increased TOU differential, to better reflect time-dependent generation and distribution costs, including the costs of GHG emissions.[12] An analogous cost-based rate available today is SCE's TOU-D-Prime rate, which has larger TOU differentials than the utility's proposed default residential TOU rates. More dynamic rate options that feature peak periods designed for each season would also improve the accuracy of the cost and GHG signals that can be revealed to consumers via rates.[13]

DEMAND CHARGES

Demand charges are based on the measurement of a customer's demand for power (such as kW), as opposed to their demand for energy (such as kWh). Demand charges bill customers for the highest instantaneous electricity demand (typically measured as peak demand over fifteen minutes) in a predetermined period of time (such as a monthly billing period). Demand charges are not often used in residential rate design, but they are a key component of rates for commercial and industrial customers.[14] Most demand charges fall into one of two categories: coincident demand charges that apply only when the electric grid is most heavily loaded (aka "peak" hours); and non-coincident demand charges that apply during all hours. Traditionally, coincident demand charges are used to collect costs associated with generation capacity and time-dependent distribution costs (such as substation capacity upgrades), while non-coincident demand charges are used to collect costs that do not vary with time (such as the cost of extending the distribution system to serve new customers).

Non-coincident demand charges can charge customers for using electricity at times when the overall costs are near zero. In other words, non-coincident demand charges could disincentivize energy use when the grid is lightly loaded. For example, during spring months when solar generation is being curtailed, customers may be inappropriately discouraged from increasing energy usage to avoid triggering a higher demand charge. Any rate design that uses these rate elements could be counterproductive to the state's energy affordability and GHG reduction goals.[15]

FIXED CHARGES

Fixed charges are bill components that do not vary depending on a customer's volumetric energy use. The CPUC has a long history of avoiding fixed charges in IOU residential electric rates, though some California municipalities, such as the Sacramento Municipal Utility District (SMUD), include fixed charges in their residential rates. This means that all residential electric costs—energy, infrastructure, and explicit policy costs—are collected through volumetric rates. However, in recent years, there has been an increase in the use of fixed charges for residential rates nationwide. The reasoning for using fixed charges is that they recover fixed infrastructure costs independent of a customer's volumetric use; they can ensure cost recovery for infrastructure that would be needed even if a customer minimizes their energy use. Fixed charges can also ensure that infrastructure cost recovery does not inflate volumetric rates more than necessary. One of California's gas utilities already uses fixed charges in their residential rates, but the CPUC has not approved this approach for electric rates.

By allowing more infrastructure cost recovery via fixed charges, the CPUC could lower the volumetric rate for electricity used, which if combined with time-varying rates could encourage beneficial electrification. Care must be taken, however, to avoid unnecessary and inefficient consumption of electricity. Other tools, such as minimum bills, can also be used to address some of the issues with recovering costs when customers are reducing their use of grid-provided electricity.

SOLAR EXPORT PRICES

A key benefit of some building electrification technologies is their thermal storage capacity. Heat pump equipment with sufficient storage capacity can use the cheapest and cleanest electricity to prepare for household needs at other times of day. For example, HPWHs can heat water at times of high solar energy production and store that energy in the form of hot water for use later in the evening, when electricity is dirtier and more expensive. In homes with distributed solar generation, using a controllable HPWH has two complementary benefits: less surplus solar power has to be sold to the grid during the middle of the day, when energy prices are lower, and expensive electricity does not have to be purchased to heat water for evening use. Using thermal storage this way also reduces costs for all electricity consumers by reducing the cost of operating the electric grid during high usage times. However, current Net Energy Metering policy does not provide the kind of solar export price that would reward thermal storage capacity, because customers receive largely time-independent retail-value credits for generation.[16]

> **THERMAL STORAGE** is the capability of some building electrification technologies to store energy in the form of heat for use at a later time. Like any other storage technology, it can reduce electricity costs for all electric customers.

When water is preheated with the home's own solar PV-based electricity, the opportunity cost of energy is the export price of surplus solar at the time the water is heated. In other words, the opportunity cost of electricity at that time—what the homeowner is giving up to preheat the water—is the foregone income from selling surplus solar to the grid. This income is determined by the 'export price of solar,' which is currently set by CPUC policy to be equal to the average 12-month rolling market rate for electricity, but is not time-dependent.[17]

The following two figures use idealized electricity consumption and solar generation curves to illustrate the accounting that would determine a household's daily 'electric bill' with and without a managed HPWH.

Figure 1. Solar Home Electricity Calculus without a Managed HPWH

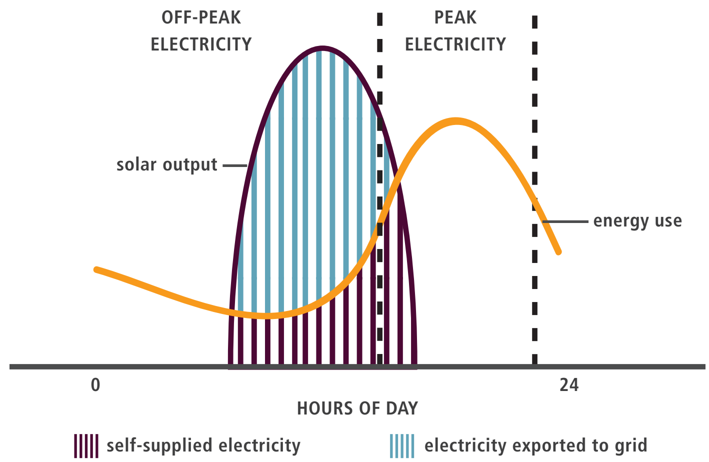
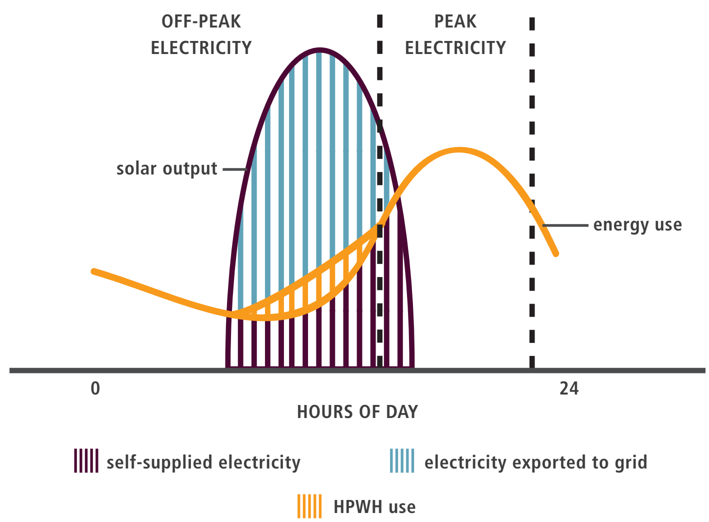


Figure 2. Solar Home Electricity Calculus with a Managed HPWH



The green area in Figure 2 represents the electricity that would be used to preheat water with a HPWH. As the figure shows, the electricity for the HPWH would be taken from the surplus solar power that would otherwise have been exported to the grid. Therefore, absent any policy intervention, the cost to the customer of that energy is the foregone income from exporting surplus solar power into the grid. This underscores the importance of setting the solar export price correctly. The solar export price should align the customers' economic incentives with the costs of operating the electricity grid, including both generation and distribution elements. Otherwise, non-solar customers may end up overpaying for solar power in the middle of the day.

Distributed generation, like all generation, is more or less valuable depending on the time of day and year it is produced, the amount of load on the system, and other factors. On many days of the year, the opportunity cost of using solar self-generation for thermal storage is very low. However, solar export prices are not currently set in a way that reflects the time-dependent costs of distributed solar and therefore do not encourage the use of thermal storage for self-generation systems. This is a missed opportunity to reduce grid operation costs for all customers.

CRITERIA FOR EVALUATING RATES FOR BUILDING ELECTRIFICATION SUPPORT

While any rate design that would support building electrification must address the elements discussed above, not all rate proposals that feature those elements will be equally beneficial to the state's emissions reductions goals. For that reason, the Commission will need to set standard criteria to consistently evaluate all subsequent rate design proposals. The evaluation criteria described below were designed to be consistent with California's rate design principles and GHG reduction goals.

VALUES EMISSIONS REDUCTIONS: ***The rate design approach reflects the societal benefit of using the cleanest fuel available in california, including self-utilization of clean power for homes with distributed generation systems.***

Electricity is the cleanest space and water heating fuel that is currently available in California.[18] A rate that supports building decarbonization is one that allows customers access to clean electricity at a price that is more economic than the next dirtiest fuel, while still allowing recovery of utility costs. Tapping in to low-cost and low-GHG emission electricity is a key strategy for achieving this cost parity without subsidizing energy use. This would involve reflecting the time-dependent costs and benefits of GHG emissions from electricity use in a way that is compelling to customers.

REFLECTS TIME VALUE: ***The rate design approach conveys the differences in cost of using energy at different times of day.***

The price of electricity varies according to time of day and season of year. Fuel, transmission, and distribution costs at one hour of the day can be an order of magnitude higher than on a different hour in the same day, and varying demand contributes to fluctuating prices.[19] Furthermore, the GHG intensity of California's electricity falls and rises along with generation and distribution costs. Signaling these hourly variations to the end customer and encouraging the use of electricity during lower-cost periods can help reduce unnecessary electricity and environmental costs. The long-term rate objective should be to set TOU rates based on their full cost differential, including societal GHG costs.

PROMOTES CUSTOMER ACCEPTANCE: ***Customers are able to understand and benefit from the rate design approach.***

The effectiveness of any rate is limited by how easily it can be understood by its target customer sector. A customer that cannot understand a rate will do one of two things: not alter their behavior in the ways intended by the rate and absorb the higher costs; or, not alter their behavior and opt out of the rate. Either way, the rate would fail to deliver the desired costs and GHG savings. It could also magnify the energy burden of households that cannot or do not know how to manage their energy use.

A successful residential rate must consider the limitations and preferences of residential customers. In addition to understanding the rate, residential customers must be able to easily incorporate the rate's price signals into their electricity use patterns by using either control technology or behavior change to avoid adverse impacts.[20] Ideally, customers' propensity to act on a rate should be assessed before the rate is rolled out.

NO ONE-SIZE-FITS-ALL RATE: Many building electrification end uses are well suited to provide GHG reduction and grid services without disturbing building occupant comfort or operations. However, some specialized customers, like residential customers with medical equipment and some commercial kitchens, will have a more difficult time adjusting their consumption patterns to fit the needs of the grid. Those customers may need specialized rates and/or increased financial incentives to couple electrification investments with battery storage. The Commission's DER Action Plan Vision Elements for Rates and Tariffs should guide rate design for specialized customer groups.

SUPPORTS CUSTOMER FINANCING OPTIONS: ***The rate design approach provides enough cost/benefit certainty to support financing of technologies on the customer side of the meter.***

Customers are much more likely to invest in these technologies if they can leverage external financing, the availability of which will hinge on well-defined, certain revenue streams and pay-back periods.

COMPENSATING OTHER BENEFITS OF ELECTRIFICATION: GHG REDUCTIONS AND RAMP SMOOTHING GRID SERVICES

Programming building electrification equipment to use electricity during the cleanest times of day—whenever possible—can significantly reduce the GHG emissions associated with space and water heating in California's buildings.[21] Electricity generated at noon on a sunny spring day will have a smaller carbon footprint than electricity produced after sunset that same day.[22] This is because solar power is abundant in the middle of the day, but more fossil fuel plants are needed once the sun goes down. This is why the thermal storage capability of many building electrification technologies can be so valuable in helping the state meet its GHG reduction goals: it allows consumers to use affordable, 100% GHG-free solar energy to power end uses that previously could only have been powered by fossil fuels.

Furthermore, the load shifting capabilities of building electrification technologies can also produce valuable electric grid management services, which would help reduce costs for all customers.[23] These grid benefits are manifold, but in general are well summarized by the term 'ramp smoothing.'[24] By using clean electricity that is plentiful in the middle of the day, programmed electric equipment can reduce the difference between off-peak and on-peak net demand for electricity. This translates to less strain on the transmission and distribution infrastructure, as well as reduced GHG emissions and costs related to the afternoon ramp.[25] For example, a HPWH that is programed to preheat water in the middle of the day helps reduce the evening peak demand and, therefore, the number of fossil fuel generators that have to be kept generating and ready to ramp up once solar output falls and electricity demand rises. In 2016, the Regulatory Assistance Project (RAP) estimated that using programmable electric water heaters in only a fraction of California homes could ameliorate 10% or more of the state's expected evening ramp needs:

> Implementation of water heater controls on one million electric water heaters would enable a utility to add about 4,400 MW as needed, shed up to 1,000 MW of water heating load as needed, and to shift a total of about 10,000 MWh of energy between periods of the day.[26]

Similar load shift effects can also be created by popular smart home controls, such as Nest and Ecobee systems. These systems can program other home appliances to use power during peak solar production hours and curtail load during the evening ramp.

Yet, as valuable as this load shifting is to the environment and the grid, it is not fully compensated in residential rates. A recent study that modeled the economic benefits of managed HPWHs found that a sophisticated algorithm controlling the technology could reduce a utility's marginal costs related to operating the electric distribution grid by as much as 60%;[27] however, optimizing the HPWH according to a two-season TOU rate with high peak to off-peak price differentials could only reduce the customer's water heating cost by about half of the reduction seen in a utility's costs.[28] These results point to the limitations of traditional TOU rate designs: the usual two-season construct leads to peak periods that can miss cost variations in spring and fall seasons, and the absence of negative rates keeps customers from seeing times of negative energy prices. Furthermore, electric rates may not fully incorporate the GHG-related costs.[29] In other words, the relatively simple TOU rate designs (that are, admittedly, more easily understood by customers) cannot capture the full value available from more dynamic and granular pricing coupled with control algorithms.

Until rates can incorporate negative price signals and peak periods that appropriately reflect GHG and cost peaks in each season, traditional rate design alone may not accurately compensate the benefits of building electrification technology. More dynamic and granular rates should help provide the necessary price signals, but more field validation is needed to demonstrate that those rates will be sufficient to achieve the level of decarbonization that California needs. In the meantime, given the urgent need to inspire customers to invest in building electrification technology and the economic, market, and logistical barriers to customer adoption, the Commission might want to consider layering additional "programmatic" incentives on to end use rates. Some of these incentives should be distributed through traditional customer-facing programs, but others can be layered directly over electric rates.

One option for compensating the ramp smoothing benefits of smart electric technologies is to add a positive incentive that is built into the rate. The incentive could take the form of a bill credit. This credit would provide a year-round price signal that would be easier for residential customers to internalize and act on by simply programing their equipment once. The bill credit could be made contingent on participation in a remote equipment control program or other confirmation that the electric equipment would be managed to provide the ramp smoothing services. However, equipment verification and/or program participation requirements should be structured so that they do not become a barrier to customer participation. Compensation for GHG and grid benefits needs to layer on top of rates as seamlessly as possible. This seamless layering will become increasingly important as further locational and time-dependent attributes become more valuable on the grid.

NEXT STEPS: RATE DESIGN FOR CALIFORNIA'S NEAR- AND LONG-TERM GRID

NEAR-TERM RATE DESIGN NEEDS

This paper discussed the most important building blocks for near-term building electrification-friendly rate design: adjustable baseline allowances, volumetric rates with meaningful peak to off-peak differentials, time differentiated solar export prices, and seamless compensation for GHG reductions and grid services. Electric rates that feature all of those elements are needed so that early building electrification customers can reap the economic rewards of helping the state meet its clean air goals. Favorable customer economics for early adopters will slowly increase demand for electrification technologies, helping manufacturers reach economies of scale, and further reducing installation costs as trade professionals learn through doing and become more comfortable with the equipment. This should make the technologies more easily available to a wider population.

In order to kick-start this virtuous cycle of technology adoption and falling prices, early adopters will need rate designs that:

- Adjust baseline allowances to avoid penalizing new beneficial electrification loads[30]
- Offer cost-based TOU volumetric rates with larger TOU peak to off-peak price differentials that accurately reflect grid costs and GHG emissions, possibly with the use of minimum bills or fixed charges
- Revisit and review the HUC for residential customers and non-coincident demand charges for other customer types to avoid dampening the incentive to shift loads during the day

Each of these elements should be considered carefully so as to not negatively impact the state's most vulnerable populations, including customers eligible for CARE and FERA rates. However, vulnerable customers should not simply be left out of innovative rate design policy; policy should specifically address their needs and constraints so they too can share in the potential benefits of building electrification.

LONG-TERM RATE DESIGN NEEDS

However, there is more that can be done through rate design.[31] As California progresses in its building and transportation electrification goals, the electric grid will be responsible for powering a much larger portion of California's economy. In planning for that growth in demand, the state will need to invest in new carbon-free generation resources, but it should also leverage the demand-side assets that will be connected to the electric grid in the coming years. Instead of simply sizing the system up to meet a new, larger peak demand, the state should first invest in shaping some of the more controllable demand to use the existing system better. Many building electrification technologies are well suited to provide this kind of load shaping, and advanced rate design will be key to maximizing this potential.[32]

Building electrification technologies with thermal storage capabilities can be programed to avoid using electricity during the highest cost, most GHG-intensive hours of the day,[33] as prescribed by a cost-based TOU rate. Yet, in reality, electricity prices and the immediate needs of the grid can vary significantly within TOU periods, and even in much smaller time increments. More dynamic and granular rates would be needed to transmit the ensuing price signals to controllable equipment—for example, to signal to a water heater when to soak up excess power and when to "shed load" at times of peak demand. Smart control technologies, two-way communications, and successful customer education should enable much more responsive loads. Load management controls would allow customers or third parties to program technologies to respond in certain ways to different price signals, making the demand-side technology dependable assets for grid management, and allowing customers to benefit from very low rates without having to personally respond to dynamic price signals.

Incentives that compensate for the grid and GHG benefits of electrification technologies are a great way to encourage early adopters and begin reducing technology costs. However, for building electrification to be sustainable in the long run independent of programmatic incentives, it is likely that more dynamic, granular rates and load management will be needed. Advanced grid harmonization rates with active load management can be key to achieving California's long-term GHG reduction goals with the lowest costs possible. This is why it is so important to begin learning how to layer dynamic compensation for GHG and grid benefits seamlessly over initial TOU rates. If we don't get the rate design building blocks right today, we're going to struggle to operate the grid we'll need in twenty years.

Endnotes

1. Less than half of the amount of electric bills are represented by energy costs that vary volumetrically. The remaining costs consist of customer access, grid services, and public goods charges which are typically considered fixed costs.
2. D.15-07-001, pg. 26-27.
3. Residential rate reform, discussed in the call-out box in this page, will transition most residential customers to time-dependent TOU rates that will only have two (baseline and non-baseline) usage tiers.
4. Rocky Mountain Institute, Rate Design for the Distribution Edge, August 2014. Regulatory Assistance Project, Smart Non-Residential Rate Design, December 2017, pg. 7.
5. California's residential rate reform will transition most customers to TOU rates that only feature two usage tiers: baseline and non-baseline. This paper focuses on rates that have these limited rates. However, since inclining tiers can have a detrimental effect on beneficial electrification, the CPUC should continue to educate and enable all remaining residential customers to transition away from the remaining tiered rates.
6. California Public Utilities Code 739(b)
7. Weighted average of Southern California Edison's (SCE) tier two rates and the High Usage Charge compared to the tier one (baseline) rate.
8. Ibid. A recent settlement filed in SCE's 2018 GRC Phase 2 proceeding (A.17-06-030) agrees to study electric water heating baseline allowances. Additionally, on Page 49 of the Proposed Decision in that proceeding, the CPUC orders SCE to conduct an "essential use study" that includes attributes such as household size, building features, and appliances across weather zones and seasons. This was also ordered in PG&E's recent General Rae Case decision (D.18-08-013).
9. This assumes a HPWH uses 1317 kWh per year (DEER 2018) and that all of that electricity is charged at a 39% premium over baseline rates (7 cents for SCE, see footnote 7): 1317*.07=90.
10. California ISO, Fast Facts: What the Duck Curve Tells Us About Managing a Green Grid, 2016.
11. The CPUC's residential rate reform process will result in default TOU rates for most California homes by 2020. However, per CPUC direction, those initial TOU rates will not have peak-to-off-peak differentials that truly reflect the real cost of electricity at peak times (CPUC D.15-07-001, pg. 135).
12. CPUC, Proposed Decision of ALJ Doherty on Southern California Edison Company's Proposed Rate Designs and Related Issues, A. 17-06-030, mailed October 19, 2018, pg. 43-46.
13. California's electric rates already carry some GHG pricing as a result of the AB 32 cap and trade carbon auctions. However, those cap and trade prices likely do not reflect the full societal cost of GHGs, see CPUC D.17-08-022, Decision Adopting Interim Greenhouse Gas Adder, August 31, 2017, pg. 6.
14. No California utility currently uses demand charges in their residential rate design. However, non-coincident demand charges are rate design lever that can be a significant barrier against beneficial electrification. They are included in this section because of the importance of avoiding non-time-dependent rate design elements.
15. It should be noted that some fixed grid costs are non-time dependent and the appropriateness of non-time differentiated demand charges to recover these costs is the subject of on-going analysis and debate.
16. New Net Energy Metering customers in California must enroll in TOU rates, which does introduce some time-varying components to the compensation they receive for solar exports. However, the off peak TOU rates that are available to these customers do not fully reflect the low cost of energy during peak solar production times.
17. In this case, "income" is not a revenue stream. It is a reduction of expenses for the customer, since the solar revenue is netted from a customer's yearly electricity bill at the non-time-dependent rate set by the CPUC.
18. Current heat pump equipment efficiencies make up for the electric energy lost in transmission and distribution. Therefore, in California, heat pump space and water heating equipment emit fewer GHG emissions than any other available technology. See A Path Forward for the Three Prong Test: Recommended Updates to the CPUC's Test for Fuel Substitution, Transcendent Energy, filed by the Natural Resources Defense Council in R.13-11-005, July 27, 2018.
19. California ISO, Q1 2018 Report on Market Issues and Performance, July 10, 2018, Figures 1.5 and 1.7, see March bars.
20. California's utilities have demonstrated the effectiveness of various customer communications and education strategies during the roll-out of the residential rate reform TOU pilots.
21. Energy and Environmental Economics (E3), Appendix A of Deep Decarbonization in a High Renewables Future, Prepared for the California Energy Commission, June 2018. Ecotope, Heat Pump Water Heater Electric Load Shifting: A Modeling Study, June 8, 2018.

Endnotes, cont.

22. See California ISO's monthly Greenhouse Gas Emissions Tracking Reports, Hourly GHG Emissions to Serve Load tables, available at http://www.caiso.com/market/Pages/ReportsBulletins/RenewablesReporting.aspx#ghgreport.
23. Electric resistance technology has been used for decades to shift load and avoid extreme ramps and peaks (see footnote 18). Heat pump technology has the same theoretical capabilities, but these capabilities need further field validation.
24. For a comprehensive list of the grid benefits of energy storage (many of which also apply to thermal storage), see Rocky Mountain Institute, The Economics of Battery Energy Storage, October 2015, pg. 3.
25. Ecotope, 2018, see utility marginal cost results.
26. Lazar, Jim, Teaching the "Duck" to Fly, Second Edition, Montpelier, VT: The Regulatory Assistance Project, page 21, February 2016. The RAP analysis is based on controlling electric resistance water heaters. Other analyses have also found ramp mitigation potential from HPWHs (see footnote 13).
27. This reduction is off the cost of serving the same customer for electric resistance water heating load.
28. Ecotope 2018, pg. 23. The study found that TOU rates could only reduce water heating-related electricity bills by 15-20%. The differences involving the trade-offs between relatively simple rates whose costs are aggregated across fixed TOU periods and the more highly dynamic (and more precise) hourly cost profiles.
29. CPUC D.17-08-022, Decision Adopting Interim Greenhouse Gas Adder, August 31, 2017, pg. 6.
30. These adjustments should be informed by new usage studies.
31. E3, Full Value Tariff Design and Retail Rate Choices, prepared for New York State Energy Research and Development Authority and New York State Department of Public Service, April 2016.
32. Rocky Mountain Institute, 2014.
33. Regulatory Assistance Project, 2016. The Brattle Group, The Hidden Battery, January 2016.