Mitigating the Grid Impacts of Electrification: Opportunities to Reduce Barriers to Electrifying our Buildings for Decarbonization.

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ABSTRACT

One promising path towards a zero-carbon future is to electrify all our energy needs within energy-efficient buildings and to generate 100% renewable, carbon-free electricity to meet those needs. A major challenge to this future will be matching variable renewable supply with the increasing future peak demand from electrification.

This paper summarizes research performed by Rewiring America and Linden Clean Energy to understand the grid impacts of electrification and opportunities for mitigating those impacts to reduce barriers to building electrification (Rewiring America 2024). The paper starts by describing the issues with matching variable renewable supply with the increased peak loads from electrification and how this could create a barrier to accelerating the transition from fossil-fueled appliances to efficient electrified appliances. The paper then summarizes the key issues, challenges, and opportunities for three areas critical to the continued growth of electrification: 1) rate reform, 2) grid infrastructure build-out, and 3) the role of load flexibility and virtual power plants. The research takes a national scope but will provide examples of how these challenges and opportunities vary locally across the national landscape.

This research provides electrification advocacy organizations, national and state policy officials, and other industry members with a high-level overview of these issues to enable taking action in support of continuing to accelerate electrification as a key pathway to decarbonization.

Introduction:

There is wide recognition that the world needs to tackle climate change by rapidly electrifying customer loads and transitioning to carbon-free electricity. In the US, the Biden administration has stated a goal of achieving a carbon pollution-free power sector by 2035 and net-zero emissions no later than 2050 (The White House 2023). To decarbonize our electric grid, we will need to rely on a variety of carbon-free electricity sources, including solar, wind, hydro, geothermal, and legacy nuclear. We will also need significant amounts of energy storage and load flexibility to reliably match supply and demand on the electric grid. Energy efficiency will also be key in reducing demand, increasing the thermal storage capacity of buildings for load flexibility and reducing the need for fossil-fueled power generation during this transition.

The quickest path to reaching 100% carbon-free electricity requires a massive increase in electricity generation from clean sources such as solar and wind. While existing nuclear and hydro are also sources of carbon-free electricity generation, it is unlikely that we can count on new generation from these sources to scale up quickly enough to accelerate this transition in the short term.

Overview of the Challenge

According to the National Renewable Energy Laboratory (NREL), to achieve 100% carbon-free electricity in the US in a least-cost scenario, 60 - 80% of electricity generation in 2035 would have to come from wind and solar (NREL 2022a), up from 17% in 2023 (NREL 2023). As a result of decarbonization goals, federal and state incentives, and continued price declines in solar and wind generation, wind and solar energy are expected to make up 84% of new US power generation capacity in 2023 (Spector and Olano 2023).

Previous Rewiring America analysis estimates that to electrify our economy we need to increase electricity production 2 to 3 times over current levels by 2050 (Calisch and Wyent 2023). While doubling or tripling our energy production with renewables is achievable, we also must consider when that energy is produced and when it is needed over the course of a day, a week, a month, or a year.

Figure 1 shows modeled average daily demand curves (in purple) and variable renewable generation from wind and solar (in orange) for 2024, 2035, and 2050 using data from NREL's "mid-case with 100% Decarbonization by 2035" scenario, which has central estimates for most inputs but includes nascent technologies and assumes the national electricity sector linearly approaches zero net emissions by 2035 (NREL 2022b).

These projections show how wind and solar generation will be insufficient to meet peak demand given that variable renewable generation peaks midday while demand peaks in the evening after the sun has gone down. The challenge of meeting these increased loads with 100% carbon-free energy will involve filling in the gaps between these demand and generation curves in the early morning and evening.

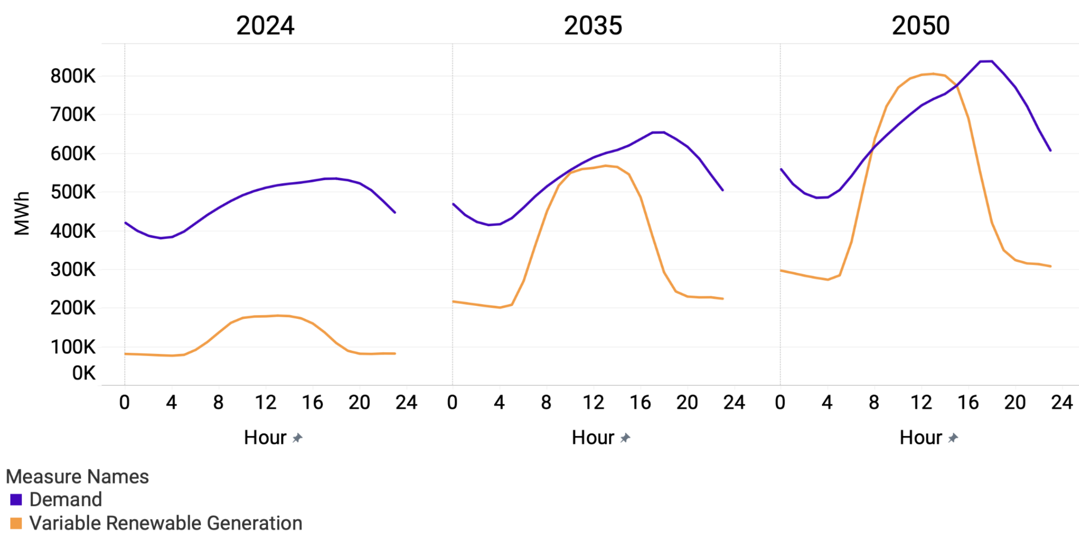

Figure 1. Forecasted Average Hourly Generation and Load by Year. *Source:* NREL 2023.

Building the Grid of the Future at the Lowest Cost

In assessing how to best match supply and demand on a decarbonized grid, we need to consider which opportunities can meet these needs at the lowest cost. To decarbonize through electrification, for example, we need to create positive feedback loops that lower the cost of electrification over time, so that the penetration of electrified devices will continue to increase over time. This requires policies that incentivize serving increased loads from electrification at the least cost. Using least cost approaches will help keep electric rates low, which will in turn make electrification more attractive and cost effective. Figure 2 provides an illustration of this positive feedback loop to continue and speed up our progress towards a zero-carbon future.

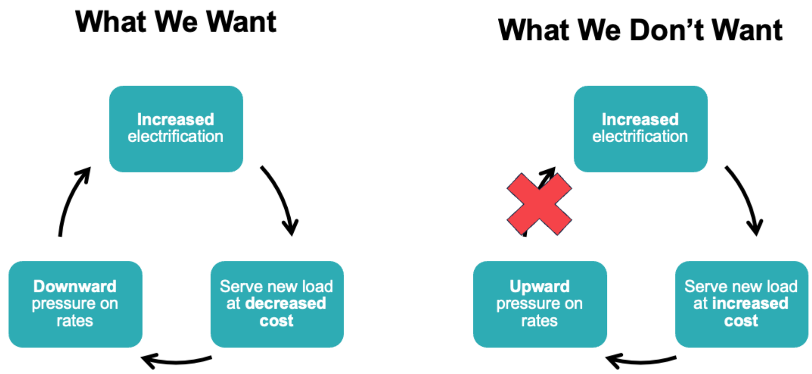

Figure 2. Electrification Rate Feedback Cycles. *Source:* Rewiring America 2024

Research Description and Findings

This paper consolidates findings from a research study funded by Rewiring America to provide electrification advocacy organizations, federal and state policy officials, utilities, and other industry participants with an overview of the grid implications of residential electrification and clean energy, as well as recommended solutions to create a reliable, affordable, and decarbonized grid (Rewiring America 2024). The research described included in-depth interviews with industry experts in these three areas as well as a literature review of available studies. This research identified three critical opportunity areas for helping match supply and demand on the grid to help ensure the increased loads from electrification can be met with carbon-free energy.

- **Opportunity Area 1: Electric Rates –** how electric rate reform can be used to incentivize electrification and help with load shaping.
- **Opportunity Area 2: Grid Infrastructure Upgrades –** what grid infrastructure upgrades are needed to support increases in electrified load and variable renewable generation.
- **Opportunity Area 3: Virtual Power Plants and Load Flexibility –** how electrified homes can participate in virtual power plants (VPPs) to help match supply and demand on the grid.

Opportunity 1: Rate Design

The changing nature of our electrical loads and generation profiles requires rethinking electric utility rate design. Done correctly, rate reform should be used to: 1) create an incentive for electrification, 2) help match supply and demand on the grid, and 3) ensure a more equitable energy transition. This section will discuss some basic concepts of rate design and make recommendations for how Public Utility Commissions (PUCs), utilities, and other policy makers can use these concepts to design effective rates for the future grid.

Reduce Volumetric Rates to Incentivize Electrification

Future rates should create incentives for customers to move away from fossil-fueled machines and towards electrified machines that can be powered by clean energy. New rate designs can create these incentives by reducing volumetric rates ($/kWh) and recovering costs through alternate means.

Examples of utilities implementing rates that incentivize electrification include:

- Central Maine Power (CMP)
    - Electric Technology Rate - includes a higher fixed charge and lower volumetric rates (CMP 2024a)
    - Heat Pump Rate - same as electrified technology rate, but with higher rates in summer and lower rates in winter (CMP 2024b)
- Burbank Water and Power Electric Vehicle TOU rate (Burbank, CA) - A seasonal time of Use (TOU) rate with a high graduated fixed charge based on customer panel size and decreased volumetric rates, especially during winter and off-peak periods (Burbank Water and Power 2024).
- Duke Electric Vehicle (EV) pilot – flat rate for EV charging billed off vehicle telemetry (Duke Energy 2023)

Use Dynamic Rates for Load Shaping

Load shaping and flexibility can help to move electric load outside of peak times, reducing energy supply costs and reliance on fossil-fuel peaker plants. Figures 3 and 4 show examples of dynamic rate structures of varying dynamism and complexity.

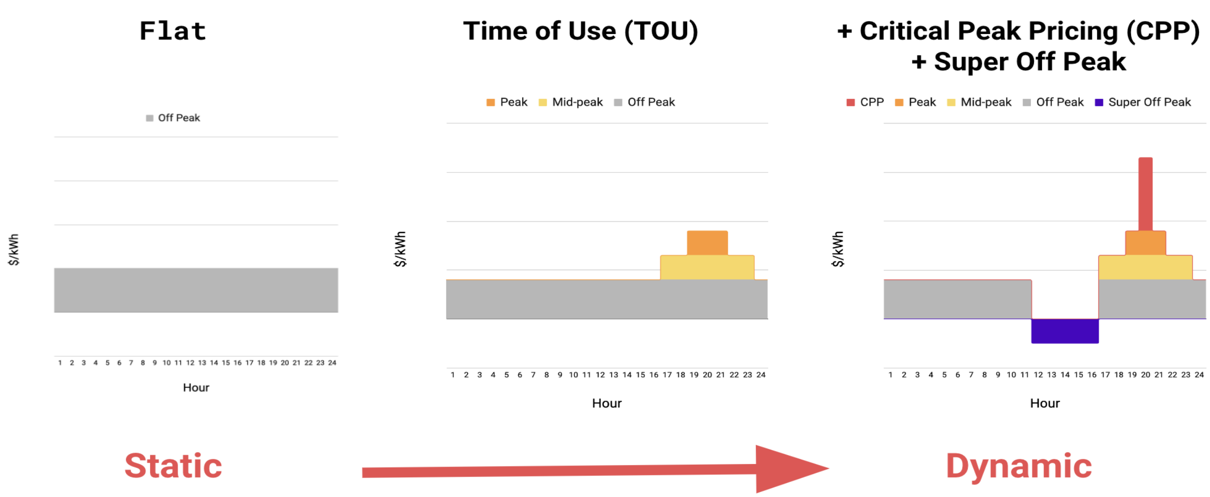

Figure 3. Illustration of Static and Dynamic Rate Types. *Source:* Rewiring America 2024.

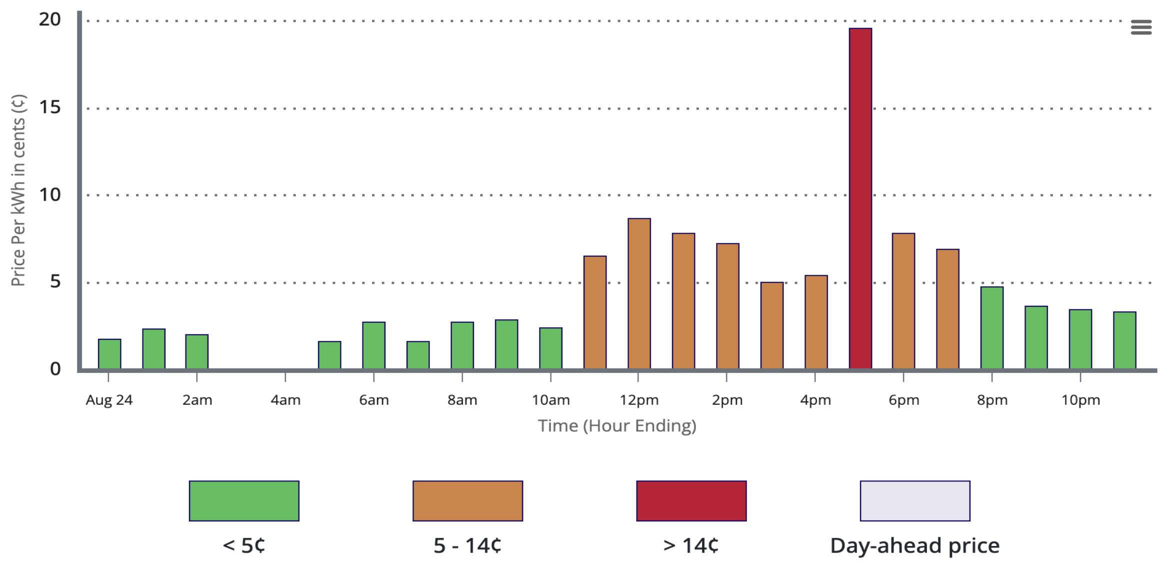

Figure 4. ComEd Real Time Prices for August 24th, 2023 During a Heat Wave. *Source:* ComEd 2023.

According to data published by EIA, just under 10% of residential utility customers were on dynamic rates in 2022, and 48% of those customers are in California, where default TOU rates were rolled out in 2020. Of the available dynamic rate options in 2022, 80% were TOU rates[1].

Examples of utilities implementing dynamic rates include the Burbank Water and Power rate and CMP rates (mentioned above), Oklahoma Gas and Electric Smart Hours (OG&E), and the ComEd real time rate illustrated in Figure 4. The ComEd real time rate allows residential customers to buy energy supply at the real-time wholesale market rate from the PJM interconnection with no markup. Since the real-time energy price does not include the capacity costs, this rate is is paired with a capacity charge, which is also a pass through for customers with no markup. The rate also includes other fixed fees and distribution charges. ComEd indicates that enrolled customers have saved an average of 15% on their energy supply costs compared to the default fixed residential rate.

In addition, California, an early adopter of TOU rates, is interested in moving toward fully dynamic real-time rates for all customers in California to advance demand flexibility (CPUC 2022).

Update Net Energy Metering for Rooftop Solar

In areas of high solar penetration, customers should be incentivized to install energy storage, or utilize EV batteries for their storage capacity. Rates that compensate solar energy

[1] EIA Form 861 data indicates that 13 million residential customers were on dynamic rates in 2022 (EIA 2023a) out of 140M total residential customers from EIA's electric sales data (EIA 2023b). The Form 861 data indicates that 347 of the 429 dynamic rates offered by utilities were TOU rates (EIA 2023a).

export near wholesale market costs incentivize customers to store solar energy during high solar output hours, and to use that energy to offset usage or export to the grid during peak demand hours with high wholesale market prices. States which have implemented or are considering net energy metering (NEM) reforms include California, Hawaii, Arizona, and Utah. While reform of net metering policies is important for the integration of more renewables onto our grid, these policies must be designed carefully to ensure that the installation of renewable distributed generation is still cost-effective for customers and that there is equitable access to these technologies for disadvantaged customers. Design considerations for cost effective and equitable NEM policy that is good for the grid should include:

- Current and future estimates of solar penetration
- Differential between retail rates and wholesale market prices/utility avoided costs of energy during peak solar hours
- Technology prices for solar and energy storage
- Available incentives for these technologies
  - For standard customers
  - For disadvantaged customers
- Available low-cost financing
- Payback period for solar and energy storage technologies

Develop More Innovative Approaches to Rate Setting

The approaches listed above mostly involve refining, tweaking and expanding the penetration of existing rate setting mechanisms, but there are other innovative and novel approaches to rate setting and cost recovery that include more drastic changes to the existing paradigm. Some of these other opportunities for innovation in rate setting for electrification include:

- Provide innovative electrification-specific rates such as giving fuel switchers a marginal cost of energy (kWh) budget to account for the increased load, or multi-year fixed bills that share the risks of electrification with utilities.
- Improve equitability of electricity costs by varying increased fixed costs by customer size (e.g., maximum demand or electrical panel size) or income.
- Recovering fixed costs of service, such as costs for wildfire mitigation, stranded assets, or low-income assistance, through progressive tax structures instead of electrical rates.

Align Utility Incentives with Societal Goals

Policy efforts could also focus on better regulation by legislatures and PUCs to ensure that utilities are incentivized to meet societal goals such as decarbonization and reducing electricity bills.

Utilities should be incentivized to meet the challenges of decarbonization with the lowest-cost solutions. For example, in Performance-Based Regulation (PBR) models, the allowed utility rate of return can be adjusted based on performance measured by predefined metrics. These adjustment mechanisms are known as Performance Incentive Mechanisms (PIMs). Current areas of focus for these PIMs include (Shea 2023):

- Meeting renewable, clean energy or emissions-reduction goals
- Encouraging new technologies, including DERs and smart grid technologies
- Improving peak-load management
- Enhancing reliability and resilience
- Addressing issues related to energy equity
- Accommodating electric vehicles or other forms of beneficial electrification

Table 2 provides some examples of PIMs and relevant incentives for several states implementing PBR.

Table 2. Examples of PIMs for strategic demand reduction (SDR) under a PBR framework (Shea 2023)

State	**Key Design Features**	**Maximum Available Incentive**
Hawaii	Initial, one-time incentive based on achievement of peak demand reduction target through direct procurement	Lesser of 5% of aggregate annual contract value or $500,000
Michigan	Up to 15% of demand response costs on a sliding scale based on demand response capacity, growth rate achieved, and NWA assessment costs	15% of demand response spending
Texas	1% of net benefits for every 2% of demand reduction goal exceeded	10% of net benefits
Vermont	Percentage of total approved budget based on performance on several outcomes, including winter / summer peak demand reduction	2.5% of total approved budget
Rhode Island	Cash reward (exempt from utility ROE cap) based on achievement of peak demand reduction, structured as a shared savings mechanism	45% of net benefits

PBR and PIMs can help ensure that utility incentives are aligned with those of ratepayers and the public, while advancing decarbonization and equity objectives. In this way, utilities that help meet societal targets based on predefined metrics would earn higher rates of return on equity, and thereby increase their allowed profit. If they miss their targets, they would get a lower allowable rate of return, which would result in a lower allowed revenue requirement from rates and thereby reduce customer rates.

Opportunity 2: Grid Upgrades

One of the most straightforward technical solutions to the issues described in this report is the additional buildout of traditional grid infrastructure on the distribution and transmission grids. Distribution infrastructure will help ease congestion on a local level, while interregional transmission will help move wind and solar energy long distances to even out regional variations in weather and load. Unfortunately, there are many barriers to building out this infrastructure, and building additional “poles and wires" is not always the fastest or cheapest solution because of the high costs and long lead times of many of these projects. Other NWAs that ease congestion on the grid can often be implemented faster, and in many cases more cost-effectively, than traditional poles and wires.

Expand Interregional Transmission

Additional interregional transmission infrastructure is needed to even out the variability of clean energy over a larger area, and thereby increase the resiliency and efficiency of the grid without building more localized generation resources. NREL has estimated that the United States needs to build between 1.3 and 2.9 times our current transmission capacity to meet our target of 100% clean electricity by 2035 (NREL 2022), but the recent annual growth rate of transmission infrastructure has only been 1% a year (Energy Central 2023). Unfortunately, most new transmission planning and deployment happens at the regional or utility level. The specific barriers and solutions to building more interregional transmission are described with the five 'P's (CATF 2021):

- **Planning -** The Department of Energy (DOE) or FERC could mandate transmission be built where needed to help surmount the obstacles to interregional transmission, and plan for lines that will actually be built. New planning requirements should include conditions of the future grid, rather than current conditions (e.g., increased electrification, buildout of variable renewable energy, and increasingly extreme weather).
- **Permitting -** FERC could assert responsibility for permitting of interregional lines like their authority for natural gas pipelines and/or Congress could explicitly grant them this authority. In 2021 Congress amended FERC's backstop siting authority that should help approval of future interregional lines in cases where states are holding up approvals.
- **Paying -** FERC could provide further guidance on cost allocation for interregional lines and include a wider range of benefits in the cost allocation framework such as lower costs, reduced risk of grid outages, and greater resilience in extreme weather.
- **Participation -** Stakeholders should be engaged early and often to identify issues early, and to consider alternative approaches for projects that are identified as problematic from an environment or equity perspective. Stakeholders could also be provided with financial resources to participate.
- **Process -** There is no standard process for developing these projects. A federal agency could study existing processes and provide best practices or standardize a process for these projects.

Utilize Grid Enhancing Technologies (GETs)

Grid Enhancing Technologies (GETs) are one of the approaches to increase the capacity of the current transmission system without building new poles and wires. GETs are technology solutions that use advanced sensors and control algorithms to move more power through the existing grid safely and efficiently. A recent report from the Brattle Group found that the use of GETs could double the capacity for new resources to interconnect to the grid (Brattle 2021). While these technologies are not new, they have not yet been used extensively in the US.
The Brattle report referenced above defines the three main GET technologies as follows:

- **Advanced Power Flow Control:** Injects voltage in series with a facility to increase or decrease effective reactance, thereby pushing power off overloaded facilities or pulling power on to under-utilized facilities.
- **Dynamic Line Ratings (DLR):** Adjusts thermal ratings based on actual weather conditions including, at a minimum, ambient temperature and wind, in conjunction with real-time monitoring of resulting line behavior.
- **Topology Optimization:** Automatically finds reconfiguration to re-route flow around congested or overloaded facilities while meeting reliability criteria.

A recent DOE report has also highlighted the potential for GETs (DOE 2022) and the organization Working for Advanced Transmission Technologies (WATT) promotes these technologies and tracks case studies on their website (WATT 2023).

Implement Other Alternatives to New Transmission

We can also improve the capacity of the current grid by upgrading the lines themselves with higher capacity wires, a process called reconductoring. This increases the capacity of the system without the time-consuming process of permitting new transmission corridors.

Another potential NWA is Storage as Transmission, which uses strategically located energy storage like batteries instead of building new transmission lines. One example of how storage as transmission could work is in helping with “N+1” redundancy on the transmission system. N+1 redundancy is meant to ensure that the system will not fail if a single transmission line is abruptly taken out of service. By locating energy storage at each end of a long-distance line, the storage could temporarily act in place of the transmission line while power is rerouted, allowing time for the lost line to be brought back online. NY-BEST has published a white paper on storage as a transmission asset and includes case studies (NY-BEST).

Invest in Comprehensive Distribution Grid Planning

Utilities should take a longer-term planning approach to achieve the lowest long-term costs of distribution infrastructure upgrades. This should include a focus on NWAs, VPPs (discussed under Opportunity 3), and other low-cost approaches to serving load. In some cases, this may require PUCs to reconsider how IOUs are incentivized, and consider alternative approaches to existing revenue requirement calculations, such as performance-based regulation (discussed under Opportunity 1).

PUCs and utilities should also consider more comprehensive distribution system planning, such as Integrated Distribution Planning (IDP). IDP involves longer-term planning, which coordinates planning of transmission, distribution and generation. It also considers all solutions, including VPPs and other NWAs that could be lower cost than traditional upgrades. For more information on IDP, Lawrence Berkeley Labs Energy Markets and Policy has compiled an extensive list of training materials and presentations on their website (LBNL 2024).

Opportunity 3: Virtual Power Plants and Load Flexibility

Grid operators on both the transmission and distribution systems should consider managing peak demand and grid congestion by utilizing VPPs and other forms of load flexibility. This approach can both reduce peak demand by reducing load during peak times (e.g., summer evenings, and winter mornings) and reduce curtailment of renewable energy by increasing load during times of peak renewable generation (e.g., the middle of the day for solar). In these ways, VPPs and load flexibility can provide an alternative to building more dispatchable, carbon-fueled generation or long-distance transmission, and can also increase the utilization of renewable energy on the grid.

Table 3 provides a summary of load flexibility models and device flexibility levels.

Table 3. Load Flexibility Participation Models

Flexibility Level	**Examples**	**Participation Models**
High - can be moved with little effect on the customer	• Water heating with oversized tanks and/or preheating • EV charging • Energy storage for solar self-consumption	• Address through TOU rates to consistently move loads (permanent load shift) • Otherwise can participate in VPPs
Medium - can be moved occasionally with some effect on the customer	• Space conditioning (A/C, electric heat, heat pumps) • Energy storage for backup power	• Participate in demand response programs through VPPs • Address through dynamic rates like Critical Peak Pricing or Real-Time prices
Low - cannot easily be moved without affecting the customer	• Baseload appliances (always on) • Electric cooking (often on at peak times) • Other plug loads	• Participation is difficult • Can possibly be included in emergency demand response programs

The appropriate approach to load flexibility will depend on the technologies being used and the use case or value proposition for flexing load. There is also a tradeoff between dynamic utility rates and dispatchable VPPs, as effective TOU rates will permanently push loads outside of peak periods and then those loads will not be available during peak times for demand response programs.

Expand Value Streams for VPPs

To achieve the full potential of VPPs, we must continue to open up new value streams to ensure they are cost-effective across multiple regions. These value streams include:

- **Wholesale market revenues –** FERC Order 2222 requires that all ISOs and RTOs in the US provide access to wholesale markets for load flexibility (FERC 2023). This is important, as it allows independent third parties to earn revenue for VPPs instead of having only utilities be able to use VPPs to generate value.

- **Capacity/resource adequacy payments –** These are payments for a resource to be available when dispatched, typically paid in $/kW-month. Utilities will pay for available capacity to meet resource adequacy requirements set by the North American Electric Reliability Corporation (NERC). For resources to get capacity payments they must have a firm capacity value, or a measure of the kWs that they can guarantee are available when dispatched. Capacity payments can be a lucrative value stream for energy producers.
- **Distribution value –** In a Distribution System Operator (DSO) model, VPPs could get payments for offering distribution value by strategically shifting load at the feeder/secondary transformer level to avoid local blackouts and/or the need for costly upgrades to existing equipment at the distribution level. These DSO models could act similarly to how ISOs and RTOs work for transmission systems but at a more granular and local level. One example of a state pursuing this model is Maine, which has signed legislation to study the feasibility of a DSO model for the state (Runyon 2023).
- **GHG reduction value –** VPPs can have environmental benefits by reducing reliance on fossil fuel generation and decreasing curtailments of carbon-free renewable generation. Robust carbon markets with carbon prices that more closely match the social cost of carbon would help VPPs monetize their services. In addition, a standardized way to calculate the secondary carbon impacts of VPPs (e.g., the ability of VPPs to allow for a higher penetration of renewables, and for renewables to operate at higher load factors over time) would help boost the value of these resources.

Include VPPs in Grid Planning

As the market for VPPs continues to develop, they should be evaluated with traditional upgrades as a part of comprehensive grid planning. For example, IDP (discussed under Opportunity 2) has the promise of including VPPs as a solution to distribution constraints. In addition, utilizing PBR (discussed under Opportunity 1) to incentivize utilities to fix grid constraints with lower cost solutions would help incentivize investments in VPPs over costly new infrastructure.

Standardizing VPP Operations

On the flip side of increasing the value of VPPs, we can also seek to reduce the costs of developing and deploying VPPs. As noted above, the deployment of a VPP involves a number of complex steps. Each of these steps can have multiple unique and often proprietary solutions from different technology vendors and VPP aggregators. One way to lower the barrier to entry of new VPP providers, and to ensure cost-effectiveness at scale, is to standardize VPP operations to lower costs and provide program flexibility between vendors. Some examples of operations to be standardized include:

- **Resource management –** Standardization of some of the operations, data flows and formats that these systems rely on could help streamline the development of VPPs at scale. One example to be considered is automatic enrollment (with an opt-out provision) to maximize customer participation.

- **Performance measurement –** VPPs must rely on counterfactual baselines to determine resource performance. The methodologies for determining these baselines can vary widely. A more standardized approach to measuring VPP performance would help VPP developers more easily scale programs between regions/utilities. In addition, standardized methodologies for forecasting VPP performance would help integrate VPPs into grid planning.
- **Utility data authorizations –** the requirement for third party VPP providers to get customer authorization for meter data release can create a barrier to enrollment. Methods to get this authorization vary from signed paper forms to online forms or APIs. Standardization of these authorizations would streamline customer enrollment.
- **Data security –** much of the data needed to run VPP operations can include sensitive customer data, including Personal Identifiable Information (PII) and usage data. Robust data security standards for VPPs could help mitigate concerns about unauthorized access to data. VPPs should be protected so that unauthorized third parties cannot gain access to VPP controls and adversely affect customers or the grid.

For more information on opportunities to build VPPs at scale, the U.S. Department of Energy (DOE) Load Program Office released a Commercial Liftoff report in the fall of 2023 (DOE 2023).

Standardize Device Control Capability

To bring down the cost of implementing VPPs, advocates should focus on the use of open standards whenever possible. They should also encourage free access to the control APIs for devices, as the connection fees many device manufacturers charge can take a significant portion of the value of the connected device in the VPP. Progress on this has begun with CTA-2045 becoming required for water heaters in Washington and Oregon. California is also considering standards in this area as part of the California Flexible Appliance Rulemaking (CEC 2023). At a national level, EPA's ENERGY STAR program has voluntary requirements for connected functionality for grid communications (EPA 2024).

Further Expand the Deployment of Smart Grid Infrastructure

Smart meters/AMI may be required for effective VPP deployment, and other smart grid components can contribute to the management of the grid. For example, most line transformers, which provide the final step down of voltage on the distribution grid and serve a handful of customers, lack the ability to measure usage in real-time. Utilities worry that multiple new EVs on a single line transformer could overwhelm the circuit with concurrent charging. Smart transformers could allow utilities to monitor transformer capacity, and moderate EV charging on the circuit to avoid overuse or the need for another transformer upgrade.

A similar approach could be taken within a household utilizing a smart panel to manage the load, keeping the peak demand under the threshold that would trigger a costly utility service upgrade.

Example VPP Programs

A small sample of existing VPP programs that demonstrate the ability of VPPs to provide assets to the grid include:

- Green Mountain Power runs a Bring Your Own Device Battery Energy Storage Program to reduce load during peak times. (Green Mountain Power 2024)
- The Aggregate Distributed Energy Resource (ADER) pilots for ERCOT (Electric Reliability Council of Texas) are aggregating distributed resources for the wholesale market. (ERCOT 2024)
- Sunrun has bid a VPP consisting of residential solar and batteries into the NE-ISO wholesale market. (Sunrun 2022)
- In response to rolling grid outages in 2020, the California Emergency Load Reduction Program (ELRP) was established to help avoid rotating outages during peak summer electricity usage periods. (CPUC 2024)

Conclusion

This research has identified several promising, low-cost solutions to help match supply and demand on the future grid to enable meeting our decarbonization goals through electrification and clean energy. Utilizing the lowest cost solutions to solve these problems is essential to accelerate the switch from fossil-fueled machines to electrified machines which are carbon-free when powered by clean energy. If the expansion of electrified loads is satisfied with business as usual – electrical utilities building out expensive infrastructure that results in increased rates for customers – then the transition to electrified machines will be threatened by high electrical rates.

This research identified three key areas of focus for low-cost solutions: 1) electrical rate reform, 2) grid infrastructure, and 3) virtual power plants. The common thread among these solutions is that they have the potential to both reduce electrical rates and help match increased electrical load and increased electrical supply.

While the solutions listed in this paper show great promise, they are novel solutions in that they have not yet been deployed widely across the country. Like anything new, adoption of these solutions will create risk in an industry that is necessarily risk adverse – where reliability of electrical power has long been the sole metric of success. While many of these solutions seem common-sense for immediate pilots and/or full implementation, in many cases there are significant barriers to wider adoption. These barriers include federal and state-level regulation, public perception of new technologies, and large utility business models which can favor the build out of expensive grid infrastructure within their own service territories over linking service territories with interregional transmission or investing in lower cost solutions like VPPs, GETs and other NWAs.

To take action to enable these solutions, it is important to both pilot new technologies and work with regulators to create conditions for wider adoption of these technologies. Reducing these barriers and setting a path for adoption of these solutions will set us on the best path for meeting our decarbonization goals in the near future while maintaining the reliability of the future grid.

References

Brattle. 2021. "Unlocking the Queue with Grid-Enhancing Technologies". February. https://www.brattle.com/insights-events/publications/grid-enhancing-technologies-shown-to-double-regional-renewable-energy-capacity-according-to-study-by-brattle-consultants/

Burbank Water and Power. 2024. "Optional Time of Use Rates for Electric Vehicle Owners." Accessed May 28th. https://www.burbankwaterandpower.com/electric/rates-and-charges

California Energy Commission (CEC). 2024. "Flexible Demand Appliances." Accessed March 4. https://www.energy.ca.gov/proceedings/active-proceedings/flexible-demand-appliances

California Public Utilities Commission (CPUC). 2022. "Order Instituting Rulemaking to Advance Demand Flexibility Through Electric Rates." July 22. https://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M496/K285/496285639.PDF

_____ 2024. "Emergency Load Reduction Program." Accessed May 29th. https://www.cpuc.ca.gov/industries-and-topics/electrical-energy/electric-costs/demand-response-dr/emergency-load-reduction-program

Calisch, S., C. Wyent. 2023. "Electrification won't break the grid, it will make it smarter." *Rewiring America*, Accessed September 1. https://www.rewiringamerica.org/circuit-breakers-the-grid#1

Clean Air Task Force (CAFT). 2022. "How are we going to build all that clean energy infrastructure?" August 25. https://www.catf.us/resource/clean-electricity-transmission/

Central Maine Power Company (CMP). 2024a. "Electric Deliver Rate Schedule: Optional Rate A Residential Service – Electric Technology Rate." January 1. https://www.cmpco.com/documents/40117/115962041/aelectech+02.28.24.pdf/1490cd99-fe39-6a76-e784-0a2f03ef9461?t=1709126315721

_____ 2024b. "Electric Deliver Rate Schedule: Rate A- Seasonal Residential Service." January 1. https://www.cmpco.com/documents/40117/115962041/a-seasonal+02.28.24.pdf/13c3d872-e9d9-48f3-030d-f261ba6b8456?t=1709126369895

ComEd. 2023. "Real-Time Hourly Prices." Accessed November. https://hourlypricing.comed.com/live-prices/

DOE. 2022. "Grid-Enhancing Technologies: A Case Study on Ratepayer Impact". February. https://www.energy.gov/sites/default/files/2022-04/Grid%20Enhancing%20Technologies%20-%20A%20Case%20Study%20on%20Ratepayer%20Impact%20-%20February%202022%20CLEAN%20as%20of%20032322.pdf

DOE. 2023. "The Pathway to Virtual Power Plants Commercial Liftoff." September. https://liftoff.energy.gov/wp-content/uploads/2023/10/LIFTOFF_DOE_VVP_10062023_v4.pdf

Duke Energy. 2023. "Duke Energy to Pilot EV Charging Subscription Service in North Carolina." August 28. https://news.duke-energy.com/releases/duke-energy-to-pilot-ev-charging-subscription-service-in-north-carolina

Energy Central. 2023. "Why It's So Hard to build New Electrical Transmission Lines in the U.S." February 22. https://energycentral.com/news/why-its-so-hard-build-new-electrical-transmission-lines-us

Energy Information Administration (EIA). 2023. "Annual Electric Power Industry Report, Form EIA-861 detailed data files, 2022 final data." October 5. https://www.eia.gov/electricity/data/eia861/

____ 2023. "Electric Sales, Revenue, and Average Price." October 5. https://www.eia.gov/electricity/sales_revenue_price/

Environmental Protection Agency (EPA). 2024. "Connected Criteria for Partners." Accessed March 4. https://www.energystar.gov/products/smart_home_tips/about_products_connected_functionality/connected_criteria_partners

Electric Reliability Council of Texas (ERCOT). 2024. "Aggregate Distributed Energy Resource (ADER) Pilot Project." Accessed May 29th. https://www.ercot.com/mktrules/pilots/ader

Federal Energy Regulatory Commission (FERC). 2023. "FERC Order No. 2222 Explainer: Facilitating Participation in Electricity Markets by Distributed Energy Resources." June 24. https://www.ferc.gov/ferc-order-no-2222-explainer-facilitating-participation-electricity-markets-distributed-energy

Green Mountain Power. 2024. "Bring Your Own Device." Accessed May 29th. https://greenmountainpower.com/rebates-programs/home-energy-storage/bring-your-own-device/

Lawrence Berkeley National Laboratory (LBNL). 2024. "Integrated Distribution System Planning." Accessed March 4. https://emp.lbl.gov/projects/integrated-distribution-system-planning

National Renewable Energy Laboratory (NREL). 2022a. "Examining Supply-Side Options to Achieve 100% Clean Electricity by 2035." https://www.nrel.gov/docs/fy22osti/81644.pdf

____ 2022b. "Cambium 2022 Scenario Descriptions and Documentation." https://www.nrel.gov/docs/fy23osti/84916.pdf

____ 2023. Cambium Data Sets. Accessed November 30. https://www.nrel.gov/analysis/cambium.html

NY-BEST. 2023. Storage as Transmission Asset Market Study: White Paper on the Value and Opportunity for Storage as Transmission Asset in New York. January.https://cdn.ymaws.com/ny-best.org/resource/resmgr/reports/SATA_White_Paper_Final_01092.pdf

Rewiring America. 2024. "Electrification and the Grid - Implementing Rate Design, Grid Upgrades, and Load Flexibility to Support Electrification." https://www.rewiringamerica.org/policy/electrification-and-the-grid

Runyon, Jennifer. 2023. "Maine rivaling California in progressive thinking about the future of the grid." July 7. https://www.power-grid.com/der-grid-edge/maine-rivaling-california-in-progressive-thinking-about-the-future-of-the-grid/#gref

Shea, Daniel. 2023. "Performance-Based Regulation - Harmonizing Electric Utility Priorities and State Policy." National Conference of State Legislatures (NCSL). April. https://documents.ncsl.org/wwwncsl/Energy/Performance-Based-Regulation-Primer-f01.pdf

Spector, J., M.V. Olano. 2023. "Chart: Clean energy to make up 84% of new US power capacity in 2023." *Canary Media*, March 10.

Sunrun. 2022. "Sunrun Activates Nation's First Residential Virtual Power Plant in Wholesale Market." October 11. https://investors.sunrun.com/news-events/press-releases/detail/273/sunrun-activates-nations-first-residential-virtual-power

Working for Advanced Transmission Technologies (WATT). 2023. "Global Deployments of Grid-Enhancing Technologies." Accessed November. https://watt-transmission.org

White House. 2023. "FACT SHEET: President Biden to Catalyze Global Climate Action through the Major Economies Forum on Energy and Climate." https://www.whitehouse.gov/briefing-room/statements-releases/2023/04/20/fact-sheet-president-biden-to-catalyze-global-climate-action-through-the-major-economies-forum-on-energy-and-climate/