Virtual Power Plants, Real Benefits

How aggregating distributed energy resources can benefit communities, society, and the grid

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Authors and Acknowledgments

Authors

Kevin Brehm
Mark Dyson
Avery McEvoy
Connor Usry

Authors listed alphabetically. All authors from RMI unless otherwise noted.

Contacts

Kevin Brehm, **kbrehm@rmi.org**
Mark Dyson, **mdyson@rmi.org**
VP3 Information, **vp3@rmi.org**

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About VP3

Virtual Power Plant Partnership, or VP3, is a coalition of nonprofit and industry voices that seeks to shift the necessary policies, regulations, and market rules to unlock the market for virtual power plants (VPPs). Our members span hardware and software technology solution providers, distributed energy resources (DER) aggregators, nonprofits, and others.

A robust VPP market expands the possibilities for all DERs — empowering households, businesses, and communities to play a role in the energy transition alongside technology solution providers. Learn more at vp3.io.

About RMI

RMI is an independent nonprofit founded in 1982 that transforms global energy systems through market-driven solutions to align with a 1.5°C future and secure a clean, prosperous, zero-carbon future for all. We work in the world's most critical geographies and engage businesses, policymakers, communities, and NGOs to identify and scale energy system interventions that will cut greenhouse gas emissions at least 50 percent by 2030. RMI has offices in Basalt and Boulder, Colorado; New York City; Oakland, California; Washington, D.C.; and Beijing.

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Executive Summary

Virtual power plants (VPPs) — grid-integrated aggregations of distributed energy resources — are providing benefits to households, businesses, and society today. Moreover, they are on the cusp of significant market growth due to recent federal legislation and the ongoing technology- and market-driven transformation of the electricity grid.

- By 2030, VPPs could reduce peak demand in the United States by 60 gigawatts (GW). That number could grow to more than 200 GW by 2050. By avoiding generation build-out, decreasing wholesale energy costs, and avoiding or deferring transmission and distribution investments, VPPs can help reduce annual power sector expenditure by $17 billion in 2030.
- VPPs are also a key resource to meet climate goals — VPPs can reduce greenhouse gas emissions by decreasing reliance on the most polluting fossil fuel–fired power plants, incentivizing build-out of clean generation, and enabling economy-wide electrification.
- To access the full benefits of VPPs, there remains a need to understand and communicate VPP benefits, advance best practices, and shift policy and regulation to put VPPs on a level playing field with traditional grid investments.
- The next few years are a critical window for VPP market development. Coordinated and collective action over this time can set the VPP market on a path to delivering long-term benefits.

RMI's new coalition

To accelerate the growth of the VPP market and deliver the reliability, affordability, and climate benefits of VPPs at scale, RMI is launching the Virtual Power Plant Partnership (VP3): a coalition of nonprofit and industry voices dedicated to growing a vibrant VPP market. VP3 will publish technical resources, provide direct support in key venues, convene across stakeholders, and communicate to targeted and mass-market audiences to raise awareness of the VPP opportunity. For more information, please contact **vp3@rmi.org**.

Virtual Power Plants: An Overlooked Resource

The coming decade will be a period of rapid change for the US electric grid. Policy, climate change, geopolitics, and consumer preferences will push the grid to evolve at unprecedented speeds. Grid planners, regulators, and operators have the challenge of managing these changes while simultaneously advancing power system performance across seven objectives:

1. **Reliability:** increasing system reliability and resilience even as extreme weather and cybersecurity threats increase
2. **Affordability:** driving down household energy burden in the face of rising inflation and global energy supply chain disruption
3. **Decarbonization:** reducing greenhouse gas emissions to meet national, state, and corporate climate targets
4. **Electrification:** enabling rapid electrification of homes, transportation, and industry to reduce economy-wide emissions and avoid the worst impacts of climate change
5. **Health:** reducing or eliminating early deaths and other health damages resulting from power plant pollution
6. **Equity:** addressing inequitable health and community impacts embedded in the current energy system
7. **Consumer empowerment:** providing energy consumers choice and a voice in shaping the power system in which they participate

Virtual power plants (VPPs) — grid-integrated aggregations of distributed energy resources — are a resource to help advance performance across each of these objectives in the coming years.

Unfortunately, VPPs are often overlooked by policymakers, utilities, and consumers. This brief defines VPPs in the context of emerging challenges and opportunities, discusses their benefits, and provides a set of recommendations for growing the VPP market in ways that help communities and society.

VPPs are not new. This paper draws on data from a decade of successful VPP pilots and programs to demonstrate how VPPs help the grid meet pressing challenges. This paper also summarizes power system modeling to show VPPs can grow in scale and impact — with the potential to offset or provide 14% of US peak electric power demand in 2050.[1]

Although VPPs are not new, they are at an inflection point. Consumer adoption of flexible devices such as heat pumps, electric vehicles (EVs), and battery storage is accelerating just as the Infrastructure Investment and Jobs Act and Inflation Reduction Act will pump billions of dollars into the electric grid. At the same time, regulators and utilities are looking for short- and long-term solutions to reliability and affordability challenges.

Over the next decade, VPPs could play a central role in meeting grid and societal needs. However, barriers related to wholesale market value, retail offerings, and consumer awareness must be addressed to unlock the full potential of VPPs.

Over the next decade, VPPs could play a central role in meeting grid and societal needs. However, barriers related to wholesale market value, retail offerings, and consumer awareness must be addressed to unlock the full potential of VPPs. Planning and policy choices over the coming years will set the path for VPP market development over the coming decade.

Understanding VPPs

What Is a Virtual Power Plant?

We define virtual power plants (VPPs) as grid-integrated aggregations of distributed energy resources. There are three key parts to that definition:

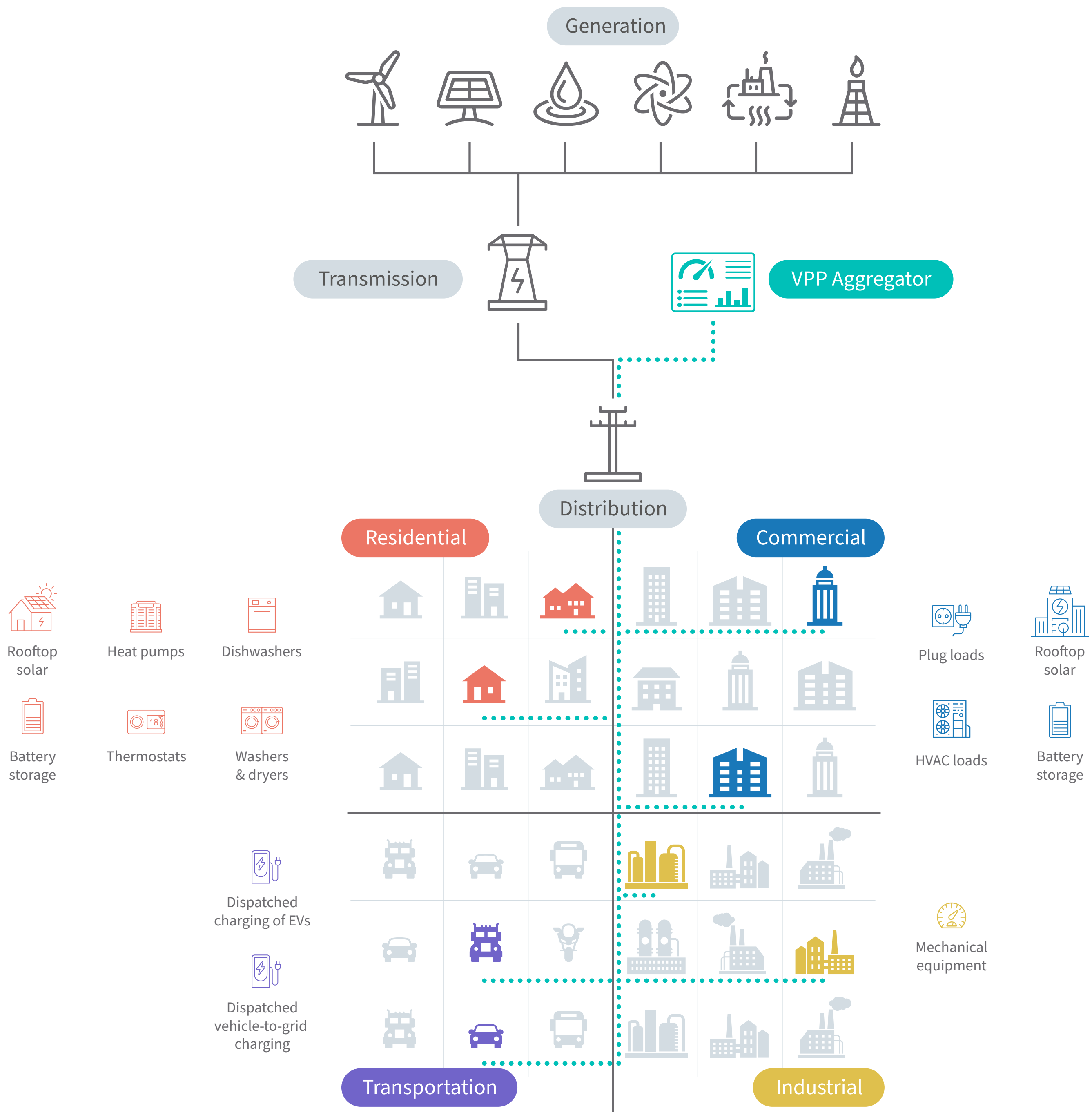
- **Distributed energy resources (DERs):** At its core, a VPP is comprised of hundreds or thousands of devices located at or near homes and businesses. Some of these assets (e.g., behind-the-meter batteries) are readily dispatchable. Other assets (e.g., solar photovoltaic [PV], or passive energy efficiency investments) are less likely to be flexibly dispatched but still can be aggregated and provide value to the grid.

- **Aggregation:** A VPP brings these DER assets together into aggregations. In some instances, these aggregations can be collectively and directly controlled by a grid operator. At other times, the aggregation is much looser, with less direct control by a grid operator.

- **Grid-integrated:** Finally, VPPs provide value to the grid, and they are compensated for the value they provide. Properly integrated into long-term grid planning and real-time operations processes and/or markets, VPPs can add value alongside other, traditional grid assets like large-scale generating facilities.

Exhibit 1 (next page) shows possible components of a VPP. VPPs can include EVs and chargers; heat pumps; home appliances; heating, ventilating, and air conditioning (HVAC) equipment; batteries; plug loads; solar PV; or industrial mechanical equipment. Single-family homes, multifamily homes, offices, stores, factories, cars, trucks, and buses can all participate in a VPP.

Exhibit 1 **VPPs Aggregate Distributed, Grid-Interactive Electric Devices**



How Do VPPs Work?

There is no standard design for a VPP. Broadly, however, there are two channels through which VPPs can provide value and be compensated:

1. **Market-participant VPPs** provide services to and are compensated by wholesale electricity markets.
2. **Retail VPPs** provide services to and are compensated by utilities.

Market-participant VPP

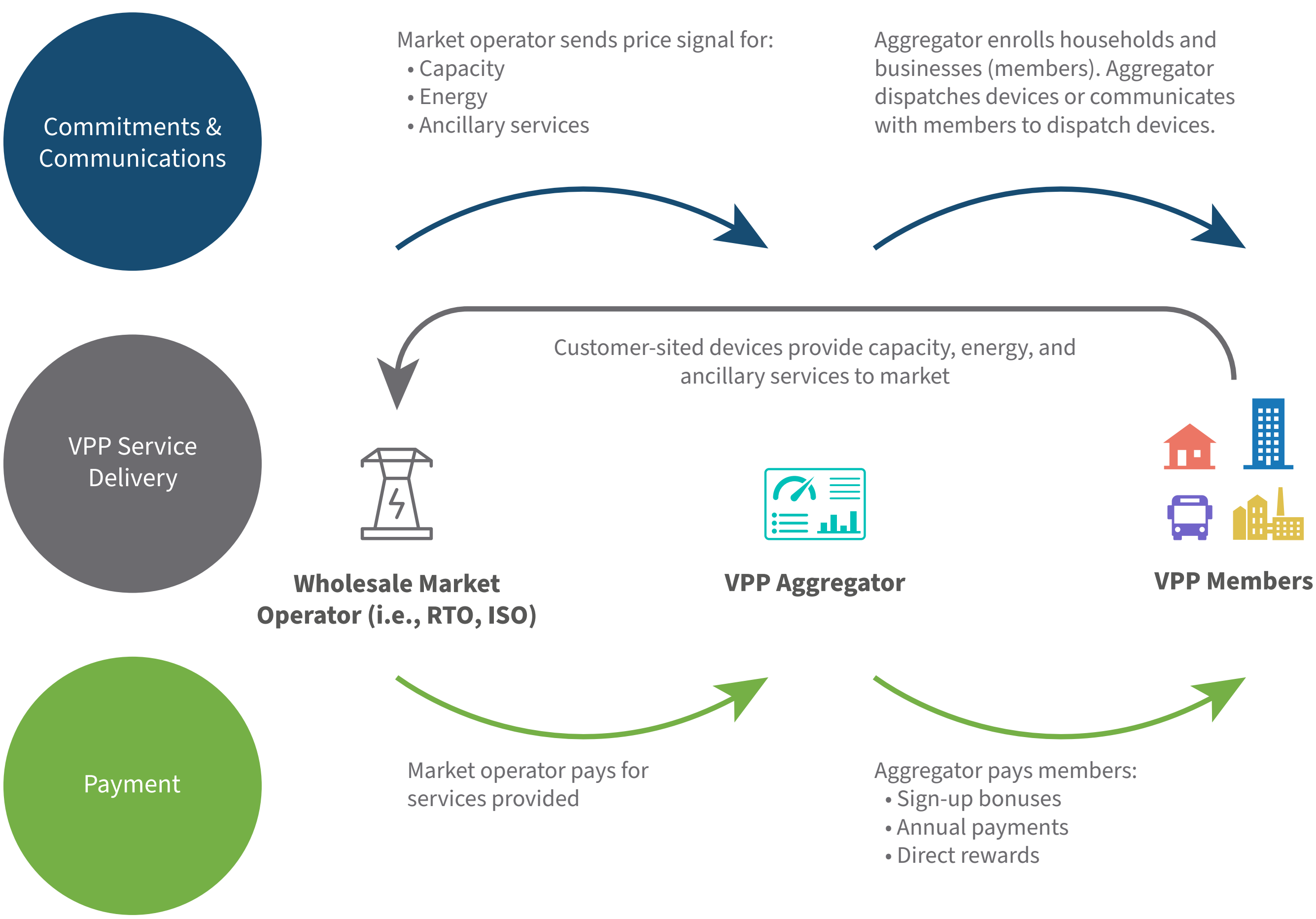
OhmConnect operates a market-participant VPP in California's wholesale electricity market. OhmConnect's VPP is comprised of more than 200,000 members with 250,000 dispatchable smart devices.[2]

During an extreme heat wave that lasted from August 31 to September 8, 2022, California's wholesale market operator, California Independent System Operator (CAISO), called on all available resources to match supply and demand. These resources included VPPs managed by OhmConnect, Tesla, Sunrun, Leap Voltus, AutoGrid, and others.[3]

Over the nine-day heat wave, OhmConnect's VPP automatically dispatched member devices 1.3 million times in response to real-time signals from CAISO. CAISO paid OhmConnect for services delivered. OhmConnect in turn paid $2.7 million in rewards to its members.[4]

Exhibit 2 illustrates how a market-participant VPP works.

Exhibit 2 **A Market-Participant VPP Calls on Customer-Sited Devices to Provide Services to Wholesale Electricity Markets**



Retail VPP

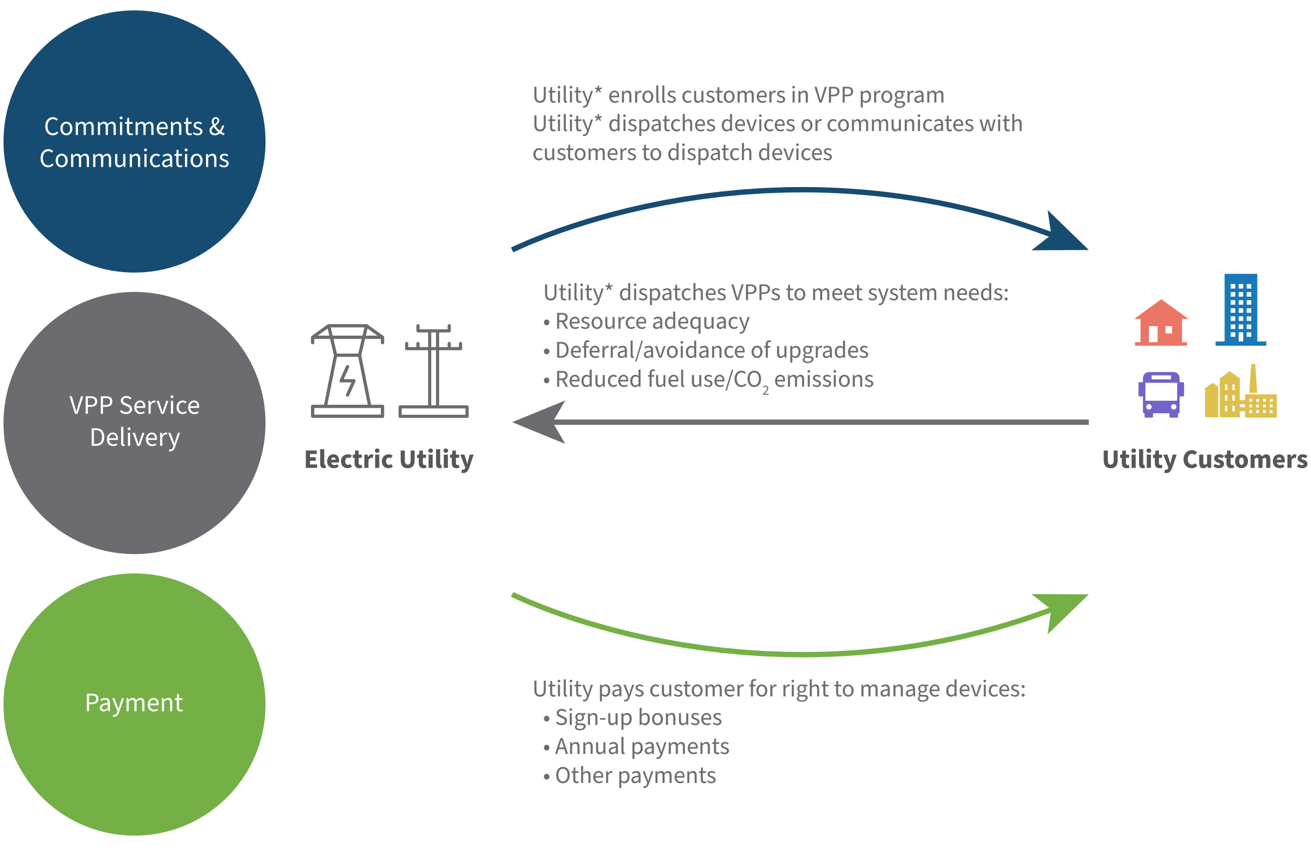
National Grid's ConnectedSolutions is an example of a retail VPP.

In the ConnectedSolutions program, National Grid — an electric utility serving customers in New York and Massachusetts — pays customers both upfront and annual incentives to enroll their smart thermostats, home batteries, and EVs in the VPP program. National Grid dispatches these devices to balance summer peak demand.

In 2020, the VPP helped reduce summer peak demand by 0.9%.[5] This helps National Grid avoid costs it would otherwise need to spend on wholesale power costs, transmission and distribution infrastructure upgrades, fuel, and other expenditures.

Exhibit 3 illustrates a retail VPP.

Exhibit 3 A Retail VPP Can Help a Utility Meet Demand and Reduce Costs for Both the Utility and Its Ratepayers



**Utility may partner with third-party service provider*

A specific, but important, category of retail VPP is a VPP in which aggregations of DERs respond, either actively or passively, to rate designs set by power providers — usually retail utilities or load-serving entities, but in some cases wholesale market operators. In the examples above, OhmConnect and National Grid actively aggregated households and businesses into VPPs and have technology to directly control devices' operations. In contrast, tariffs (rates) paid by electric customers can also induce DER build-out and demand flexibility. These include time-of-use pricing, real-time pricing, critical peak pricing, and participation incentives, which all can achieve some level of demand flexibility but differ in their level of responsiveness and ability to dynamically adjust incentives in real time.

How Are VPPs Different than Other Demand-Side Solutions?

Our definition of VPPs is intentionally broad. It encompasses a wide range of solutions that harness and compensate DERs to meet the needs of the grid. Demand response, demand flexibility, demand-side management, DER aggregations, bring-your-own-device programs, and grid-interactive efficient buildings are all examples of programs and technologies that can contribute to VPPs.

VPPs build on the success of decades of progress in demand-side management programs and participation models for DERs. Given the current landscape of rapidly shifting technology and emergent challenges to reliability, affordability, and other priorities, we use a broad definition of VPPs to characterize how, with renewed attention and targeted interventions, aggregated demand-side resources and programs can address these challenges at a scale rarely contemplated in previous decades.

Though our definition is broad, not all programs that shape customer behavior are VPPs. For example, calls for voluntary conservation in a time of crisis do not compensate customers for the benefits they provide to the grid and thus do not transact value in the same way as commercially viable VPPs.

How VPPs Can Address Key Grid Challenges

VPPs are a powerful tool to help regulators, utility planners or operators, and other grid stakeholders address key challenges facing the grid. This section looks backward to see how VPPs have already provided value, as well as forward to project how VPPs can further address grid challenges in the coming years and decades, if policies and markets are structured to enable this.

Reliability

VPPs are key solutions to enhance grid reliability and resilience

Grid planners and regulators want to know if they can count on VPPs to show up during the days, hours, and minutes when the grid needs them most. VPPs are showing they can be trusted to support grid reliability.

Each year there are more examples of how VPPs have contributed to grid reliability. A few are described below:

- **Sunrun's** VPP reduced more than 1.8 gigawatt hours (GWh) of energy demand over the summer in ISO New England.[6]
- **Arizona Public Service's** Cool Rewards Program has enrolled 60,000 thermostats and helped shed nearly 100 megawatts (MW) during the hot summer months in 2022.[7]
- **South Australia's** VPP stabilized the grid in October 2019 when a coal-fired power plant tripped offline and left a supply gap of 748 MW.[8] The VPP has also provided critical support during November 2019 and January 2020 grid disruptions between South Australia and Victoria.[9]
- **VPPs managed by AutoGrid's platform** collectively represented 5 GW of capacity and 37 GWh of energy across 15 countries as of summer 2021. These assets were dispatched 1,500 times to meet grid needs in summer 2021.[10]

These examples demonstrate how VPPs are ensuring reliable operation of the bulk power system by reducing demand or injecting power into the system during times of critical demand. VPPs also provide three reliability-related benefits that traditional power plants do not:

1. **Rapid and flexible deployment:** Whereas a fossil fuel–powered thermal energy plant (such as coal or gas) needs on average over four years to be developed and built,[11] some VPPs can be developed in as little as months. Furthermore, while traditional power plant investments tie utilities to a single asset for decades, VPPs can be more flexibly reconfigured or scaled back in response to changing grid needs.
2. **Sited near load:** VPPs can bypass transmission or distribution constraints or congestion by providing capacity close to load.
3. **Community energy resilience:** Solar, batteries, and EVs can participate in VPPs when the grid is up or provide resilient power supply to homes and critical facilities when the grid is down. For example, General Motors, Ford, and others are piloting bidirectional charging programs in which EVs become backup home power sources.[12]

Looking forward, VPPs can play a large role in supporting grid reliability in this decade and beyond. RMI analysis (detailed in the Appendix) estimates that VPPs could provide 62 GW of peak coincident dispatchable capacity by 2030. This is comprised of 17 GW flexible EV load, 10 GW behind-the-meter battery storage, 20 GW flexible residential demand, and 15 GW flexible commercial demand. Analysis from the National Renewable Energy Lab (NREL) found that by 2050, demand flexibility could reduce system-wide peak demand by roughly 200 GW.[13,i]

Exhibit 4 **Peak Coincident VPP Capacity — 2030**

Source: See Appendix

i This is the impact of demand flexibility on a modeled peak load day. It corresponds to the high electrification scenario, in which load grows 81% by 2050 compared with 2019. The figure from NREL does not include behind-the-meter storage, distributed solar, or energy efficiency.

Affordability

VPPs are a cost-effective resource to improve electricity affordability

The average price of electricity is projected to increase 7.5% in 2022 compared with 2021.[14] This is an inconvenience for many but an acute hardship for the 30.6 million energy-burdened households in the United States — households paying more than 6% of their gross annual household income on energy bills.[15] VPPs can make electricity more affordable both for customers who participate in VPPs and for homes and businesses that do not.

VPPs directly compensate participating households and businesses through bill savings, cash payments, or rewards programs:

- **OhmConnect's California VPP,** which includes 40% of their consumers qualifying as low income, saves customers on average $250–$300 per year.[16]
- In **South Australia,** customers save $200 per year by participating in the state's VPP.[17]

VPPs also help drive down bills for nonparticipating customers by reducing the total cost to operate the electric grid. VPPs do this in a few ways:

1. **Avoid or defer generation capacity investments** by reducing peak demand.
2. **Avoid or defer distribution and transmission system investments** by reducing peak demand.
3. **Reduce wholesale energy and fuel costs** by shifting demand away from high-cost peaking resources and toward low- or no-marginal cost resources. This also provides decarbonization benefits.

Looking into the future, NREL's electrification futures study found that demand flexibility could avoid or defer $120 billion (net present value [NPV]) worth of generation capacity investments through 2050.[18,ii] Efficient operation could avoid $10 billion in annual bulk system fuel and maintenance costs in 2050.[19] Those studies do not include the potential impact of deferred or avoided distribution system upgrades, which further increase the economic value of VPPs.

According to Brattle Group analysis, by 2030, demand flexibility could avoid generation capacity worth $9.7 billion, wholesale energy costs worth $4.8 billion, ancillary service charges worth $0.3 billion, and transmission and distribution costs worth $1.9 billion.[20]

ii 2019–50 NPV of bulk system savings from enhanced flexibility as compared with current flexibility (Murphy et al. 2021).

Decarbonization

VPPs accelerate power sector decarbonization

VPPs can help regulators, policymakers, businesses, and households reduce CO_2 pollution. VPPs do this in three ways:

1. **Decrease dispatch of highly polluting power plants:** VPPs can directly impact emissions by shifting demand away from times when the grid relies on the most highly polluting coal- and gas-fired power plants and toward times when carbon-free resources are available. This is the direct and near-term emissions impact of VPPs.

2. **Drive build-out of carbon-free power supply:** VPPs provide flexibility and capacity that will be critically important in a future carbon-free power system. By shifting demand, VPPs can reduce solar and wind curtailment. This enhances the value of solar and wind in a region and can indirectly lead to more solar and wind build-out in the future. VPPs also can help avoid the need to build new fossil fuel–fired power plants and help accelerate closure of some existing fossil fuel–fired plants.

3. **Enable economy-wide electrification:** VPPs can facilitate economy-wide electrification of other end uses, further reducing economy-wide emissions outside the power sector. This is discussed in the next section on electrification.

VPPs have already shown how they can help enable retirement of some fossil fuel peaker plants:

- **Green Mountain Power's VPP** attributed part of the retirement of two diesel generators with 4 MW of peaker capacity to the ability to call on its VPP participants' residential home battery systems while maintaining system-ramping capabilities and reliability.[21]

- **The City of Redondo Beach, California,** is working with OhmConnect to develop a community VPP that eliminates reliance on AES's 68-year-old gas peaker plant in Redondo Beach. Over 20,000 people live within 1 mile of the gas peaker plant, which emits harmful nitrogen oxides and particulate matter.[22]

The climate benefits of VPPs will increase over time as the United States deploys more electric devices, brings online more renewable energy, and retires coal generation.[iii] By 2050, VPPs could avoid 44 million–59 million tons of CO_2 in 2050.[23,iv] This could go a long way toward helping the United States close the gap between current policy and commitments made in the Paris Climate Agreement.

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iii Multiple studies (including Zhou and Mai 2021) have shown that economic dispatch of demand flexibility could lead to increased utilization of coal generation. This is particularly the case if natural gas prices are high, in which case demand-side flexibility can lead to increased coal dispatch at the expense of natural gas–fired generation. This finding points to a potential need to co-optimize VPP dispatch for both economics and emissions.

iv Based on analysis in Zhou and Mai (2021). Fifty-nine million tons (Mt) is the annual emissions reduction from flexibility in the high-electrification scenario. Forty-four Mt of emissions are avoided through demand flexibility in the high-electrification, high-renewables scenario. As context, 2021 power sector emissions were 1,551 Mt, according to the Energy Information Administration.

Electrification

VPPs enable economy-wide electrification

Over the coming decades, homes and businesses will increasingly adopt heat pumps, EVs, and other electric devices. The electricity system will need to grow and adapt to accommodate sustained load growth. VPPs enable cost-effective electrification in two ways:

1. **Avoided bottlenecks:** By shifting demand, VPPs can avoid bottlenecks in transmission, distribution, or generation capacity, which could otherwise constrain electrification.

2. **Provide electrification revenue streams:** VPPs provide additional revenue streams for flexibility from electric devices, helping encourage consumers to adopt them over nonelectric alternatives.

Demand flexibility significantly eases the challenges associated with sustained load growth from EVs and heat pumps. For example, in a study of electrification strategies for a Colorado utility,[24] RMI found that simple managed charging for EVs could reduce peak load growth by 20% relative to unmanaged demand from newly electrified devices. In this way, VPPs can accelerate a transition to a future in which electrified devices can help the grid be more resilient without incurring unneeded costs of infrastructure required to deliver energy to inflexible electric loads.

Health, Equity, and Consumer Empowerment

The examples in the preceding sections show how VPPs can also help advance health, equity, and consumer empowerment objectives.

One way VPPs drive positive health outcomes is by decreasing reliance on natural gas-fired peaker plants. The examples in the decarbonization section show how the need for some peaker plants can be avoided through VPPs.

These health benefits will disproportionately flow to people of color and low-income communities. Black, low-income populations are 1.2 times more likely than the average person in the United States to die prematurely from exposure to particulate matter from fossil fuel plants.[25] Furthermore, as discussed in the affordability section, VPPs can advance equity outcomes by providing revenue- and cost-reduction opportunities for low-income households.

Finally, VPPs empower consumers — all consumers — to play a more active role in shaping the way energy is used and consumed in society and within their homes and businesses.

Unlocking the VPP Opportunity

Barriers to Scaling VPPs

For VPPs to grow in the long term, more customers need access to attractive VPP offerings. Three core barriers stand in the way of VPP long-term growth: wholesale market rules, retail utility offerings, and consumer and policymaker awareness.[26] Once these core barriers are addressed, more VPP businesses will have access to reliable revenue streams from utilities or wholesale markets, and customer-acquisition and grid-integration costs will fall. VPP businesses, in turn, will be able to provide highly compelling offerings to households and businesses.

Wholesale market rules

Federal Energy Regulatory Commission (FERC) Order 2222 (2020) requires regional transmission organizations (RTOs) and independent system operators (ISOs) to allow DERs to participate alongside traditional resources in the regional organized wholesale markets through aggregations. In theory, this decision allows the two-thirds of US businesses and households served by utilities and retail electricity providers within RTOs and ISOs to participate in VPPs.

DER integration into wholesale markets is complex, and FERC is relying on RTOs to make rules that efficiently integrate and fairly compensate DER aggregations. The rules RTOs make in at least six areas will impact whether VPPs are able to thrive in those markets:[27]

1. Order 2222 implementation timing
2. Limits on eligible aggregations
   - Minimum aggregation size
   - Technologies involved
   - Location of devices
3. Metering and telemetry requirements
4. Interconnection processes and aggregation reviews
5. Dispatch override by electric distribution companies
6. Customer data access

Retail utility offerings

In areas not served by wholesale electricity markets, retail programs and retail rates are the only option for customers who want to be compensated for the services their devices can provide. Additionally, in areas served by wholesale markets, retail programs and rates will remain an important channel for VPPs.

Unfortunately, in many areas retail programs are not available, or if they are available they are not yet compelling. Utilities may not yet provide compelling offerings for a few reasons:

- Operators at utilities do not yet trust VPPs to show up and provide services when critically needed.

- Necessary infrastructure (e.g., smart meters) and software systems are not yet in place.

- Utilities are required (by law or regulation) to provide multiple technology-specific programs such as smart thermostat programs, managed charging programs, and battery storage programs instead of integrated multi-technology programs.

- Through the cost-of-service regulatory model, most utilities are financially incentivized to make capital investments, not to promote demand-side solutions.

- Legacy planning and resource procurement models and processes fail to consider or adequately consider demand-side resources.[28]

Public utility commissions are responsible for regulating utilities' VPP-related efforts. Unfortunately, VPPs cut across several topic areas — energy efficiency, demand response, EVs, resource planning, procurement, and so on — that have traditionally been handled through separate processes within commissions, making it unclear how to regulate them within existing dockets and proceedings. Furthermore, VPPs touch on complex planning- and cost-recovery issues for which regulatory best practice is still evolving.

Consumer and policymaker awareness

Although VPPs are not new, awareness of them and their potential remains relatively low among customers and policymakers. As a result, VPP technology and service providers need to spend significant time and resources educating customers about VPP benefits, adding cost to the customer-acquisition process.

Similarly, solutions providers and industry organizations need to educate elected officials and energy offices on VPPs. Without high levels of awareness and understanding, these policymakers may not be developing policies that capture the full benefits of VPPs.

Interventions to Scale a Vibrant VPP Market

To enable a vibrant VPP market that can unlock projects at the hundreds of gigawatts scale in the next decade, and the benefits associated with them, there is a need to work on three priorities in the next two to three years:

1. **Catalog, research, and communicate VPP benefits.** This insight brief and the research referenced in this report attempt to describe and quantify the benefits of VPPs, but more work must be done to understand and communicate the full benefits of VPPs. For example, more work is needed to comprehensively characterize the current VPP market and the benefits VPPs are already providing. More research is needed to model mid-term (i.e., 2030) state-specific impacts of VPPs on reliability, affordability, decarbonization, and other key policy objectives. This research must be translated and communicated in ways that are useful to technical audiences (e.g., utility planners and regulators) as well as less technical audiences (e.g., elected officials, households, and businesses).

2. **Develop industry-wide best practices, standards, and roadmaps.** Once the potential benefits are better understood, industry stakeholders must work together to develop efficient and effective ways to unlock those benefits. As things stand, the VPP market is characterized by nonstandard regulatory approaches, wholesale market rules, retail program structures, technology interoperability protocols, and finance approaches.

   To remove friction from the VPP market, service providers, utilities, regulators, and technology providers need to develop and advance a set of best practices, standards, and roadmaps. This work is complex and will not necessarily result in a one-size-fits-all approach to VPPs, but it will help to unlock VPP benefits by showcasing proven approaches to effective market integration and delivery of customer value.

3. **Inform and shape policy development.** The two activities above are critical, but they will not be sufficient to drive market growth. Stakeholders who have an interest in the growth of the VPP market, including consumer advocates, large energy users, technology developers, and service providers, need to ensure that their voice is heard and listened to in federal, state, and RTO policy venues. Through collaboration across a wide variety of interested businesses and other groups, VPP advocates can marshal the resources and organizational force to effect change in policy and regulation that can put VPPs on a level playing field with traditional electricity system investments.

Appendix

Peak Coincident VPP Capacity Methodology

VPP Resource	RMI Capacity Assumption	Approach
Total	**61.9 GW**	**See below**
Electric Vehicles (Light-Duty Vehicles [LDVs])	**17.3 GW**	***17.3 GW = [26.4 million light-duty EVs] × [0.654 kWh/unit-hour]*** *[# vehicles] × [hourly energy use assumed per unit during system-wide peak day/hour of the year]* **Number of Vehicles** • Based on Edison Electric Institute analysis: 26.4 million light-duty EVs[29] **Energy Use per Vehicle** • Representative annual hourly demand for typical LDV based on modeling from RMI • Peak hourly demand for June 30 at 5 p.m. (**0.654 kWh/unit**)[30] **Notes/Conservatisms** • Based on light-duty EV load shape. Medium- and heavy-duty EV load shapes will be different. • Does not account for shift in load shape over time. • Peak demand and EV load profile will vary by region. As such, this is approximate only.
Behind-the-Meter (BTM) Battery Storage	**9.9 GW**	• Global projections for BTM storage in 2030: **57 GWh**[31] • The United States will have 40% of 2030 BTM storage: **22.8 GWh**[32] • Average system can reasonably assume ~2.3 watts per watt-hour of capacity. *"Typically, residential consumers' batteries can reach 5 kW/13.5 kWh, whereas a battery for a commercial or industrial system is typically 2 MW/4 MWh."*[33] • 22.8 GWh/2.3 hours = **9.9 GW**
Residential Demand Flexibility	**19.8 GW**	**Midpoint between:** • Mid-adoption: **14.2 GW**[34] • High adoption: **25.3 GW**[35] • Peak demand reductions are computed as the sum of impacts during each region's coincident peak hour[36]
Commercial Demand Flexibility	**14.9 GW**	**Midpoint between:** • Mid-adoption: **11.6 GW**[37] • High adoption: **18.2 GW**[38] • Peak demand reductions are computed as the sum of impacts during each region's coincident peak hour
Residential-, Commercial-, and Community-Scale Solar	**N/A**	Ignore "solar" contribution to the capacity and reliability value of VPPs.
Energy Efficiency	**N/A**	Ignore "energy efficiency" contribution to the capacity and reliability value of VPPs.

Endnotes

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RMI Innovation Center
22830 Two Rivers Road
Basalt, CO 81621

www.rmi.org