Real Reliability
The Value of Virtual Power

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VOLUME I: SUMMARY REPORT

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Brattle

Notice

PLEASE NOTE

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Summary

Overview

Maintaining power system resource adequacy is a major investment.

Over the past decade, the U.S. added over 100 GW of new capacity intended largely to maintain resource adequacy. This amounted to over $120 billion of capital investment, primarily in gas-fired generators and lithium-ion batteries.

Virtual Power Plants (VPPs) are an emerging alternative to conventional resource adequacy options.

A VPP is a portfolio of actively controlled distributed energy resources (DERs). Operation of the DERs is optimized to provide benefits to the power system, consumers, and the environment. Within a decade, analysts forecast an inflection point in the trajectory of DER ownership. VPPs already are beginning to be deployed across the U.S. and internationally.

We explore the ability of VPPs to reliably reduce resource adequacy costs in the coming decade.

We model the economics of a residential VPP for a representative U.S. utility system in 2030. The utility system is 50% renewables, with both summer and winter resource adequacy needs. The VPP in our study is composed of commercially available residential load flexibility technologies. VPP operations are based on actual observed performance of DERs, accounting for operational and behavioral constraints. The net cost of providing resource adequacy from the VPP is compared to that of a gas peaker and utility-scale battery. Net cost accounts for additional value from energy, ancillary services T&D deferral, resilience, and greenhouse gas (GHG) emissions.

Key Findings

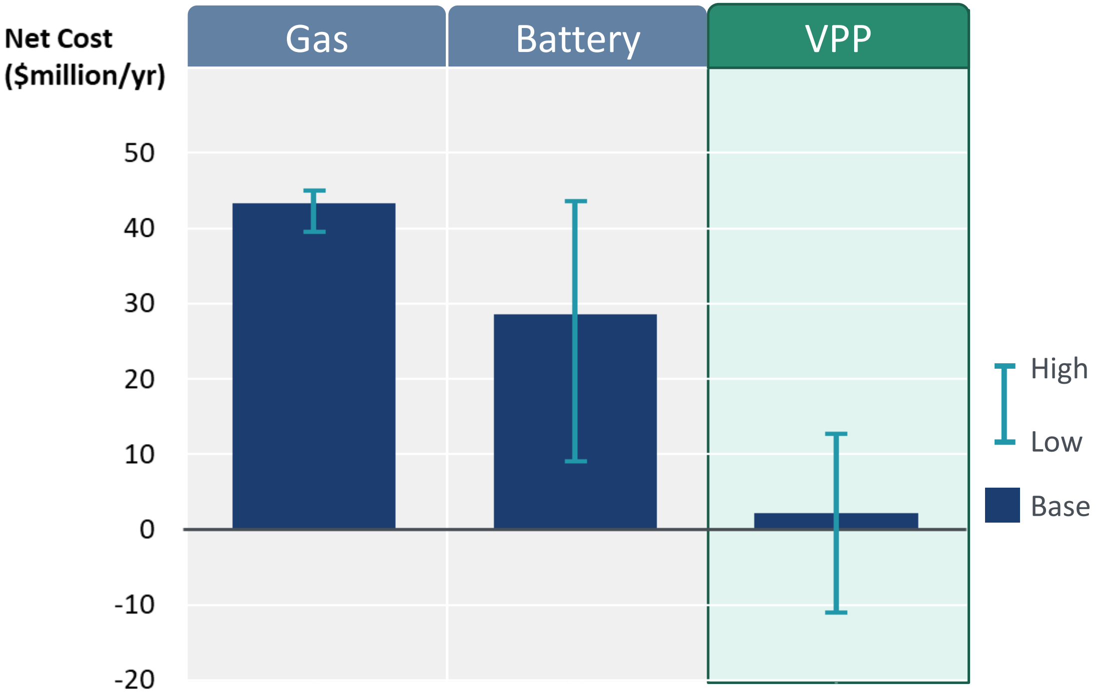
Real reliability: A VPP that leverages residential load flexibility could perform as reliably as conventional resources and contribute to resource adequacy at a similar scale.

Cost savings: Excluding societal benefits (i.e., emissions and resilience), the net cost to the utility of providing resource adequacy from the VPP is only roughly 40% to 60% of the cost of the alternative options. Extrapolating from this observation, a 60 GW VPP deployment could meet future resource adequacy needs at a net cost that is $15 billion to $35 billion lower than the cost of the alternative options over the ensuing decade (undiscounted 2022 dollars).

Additional benefits: When accounting for additional societal benefits, the VPP is the only resource with the potential to provide resource adequacy at negative net cost. 60 GW of VPP could provide over $20 billion in additional societal benefits over a 10-year period.

More work is needed: Key barriers must be addressed to fully unlock this value for consumers and ensure that virtual power plants become more than just virtual reality.

Net Cost of Providing 400 MW of Resource Adequacy
(Range observed across all Sensitivity cases)



Note: Costs shown in 2022 dollars. Costs are net of societal benefits (i.e., GHG emissions avoidance and resilience value) and power system benefits (energy, ancillary services, and T&D deferral value).

An Introduction to VPPs

Introduction

Over 100 GW of capacity was built primarily to provide resource adequacy in the U.S. in the past decade, requiring over $120 billion of investment. More will be needed.

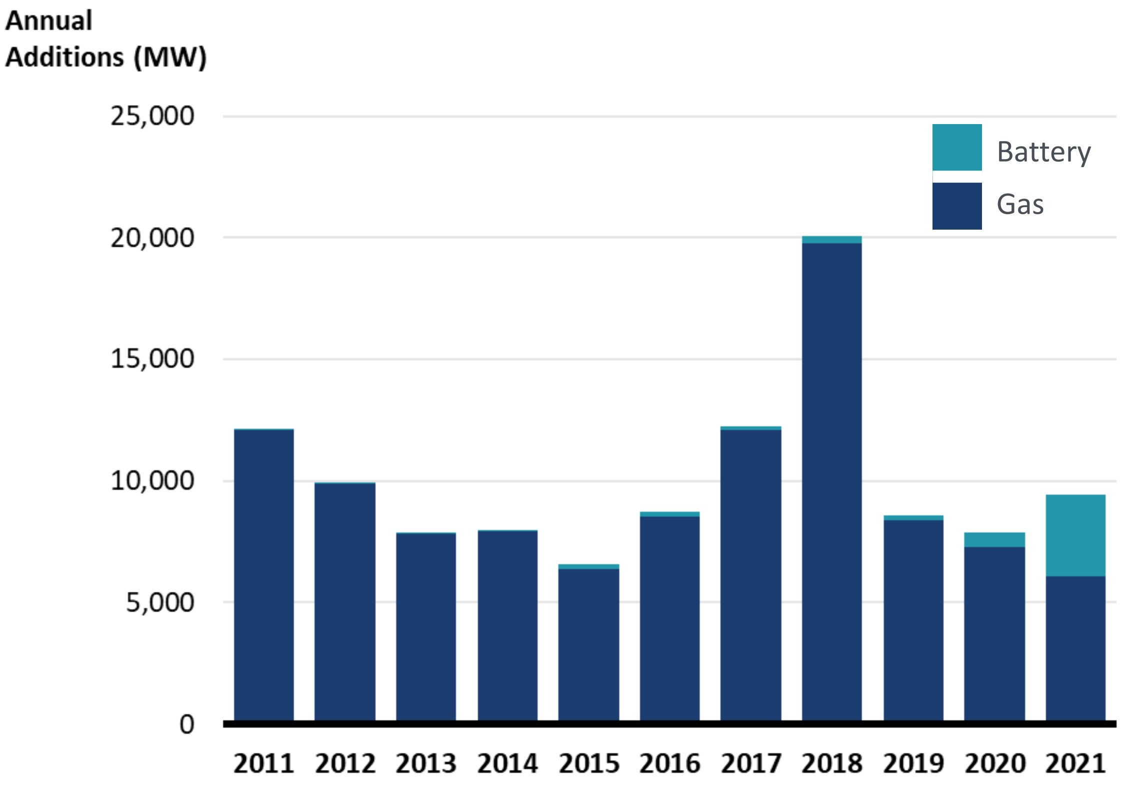
Providing affordable system reliability is the primary objective of utilities and regulators as they make generation resource investment decisions.

Electrification, coal retirements, and dependence on resources with limited capacity value (wind, solar) will continue to result in a persistent need to maintain sufficient system "resource adequacy" by adding new dispatchable capacity.

Historically, natural gas-fired combustion turbines and combined cycles have served this need. Increasingly, utility-scale battery storage is being deployed for the same reason.

Alternatively, in this study we explore the cost of serving resource adequacy needs from an emerging resource: a virtual power plant (VPP).

Historical U.S. Capacity Additions for Resource Adequacy
~110 GW, 2012-2021



Sources: EIA, Velocity Suite ABB Inc, and NREL.
Note: $120 billion estimate assumes 110 GW at an average installed cost of approximately $1,100/kW in 2022 dollars. "Gas" includes combustion turbines and combined cycles that have been built for a combination of resource adequacy and energy value.

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What Is a VPP?

A VPP is portfolio of distributed energy resources (DERs) that are actively controlled to provide benefits to the power system, consumers, and the environment.

Virtual Power Plant

Examples of potential elements

- Smart thermostats
- Rooftop solar PV
- Electric vehicles (EVs)
- Distributed batteries
- Smart water heaters
- Commercial building automation systems

Note: VPPs can be composed of many distributed technologies. As described later, the VPP modeled in this study is composed of a subset of the options shown here.

1 Customers allow their DERs to be directly managed – subject to operational constraints – by an aggregator or electric utility.

Aggregator or utility with distributed energy resource management system (DERMS)

2 Utilities and aggregators manage the DERs in an orchestrated way to provide grid benefits (e.g., reducing demand during peak load hours to avoid investment in conventional generation capacity).

Power system (distribution grid, transmission grid, power generation)

3 The power system is expanded and operated at a lower total cost, reliability is maintained, and emissions are reduced.

4 The cost savings provided by the VPP are shared between the individual participants, the aggregator, the utility, and society broadly.

An Inflection Point for VPP Deployment

DER ownership is expected to grow by several multiples within the next decade in the United States.

Several forces currently are driving VPP deployment to an inflection point:

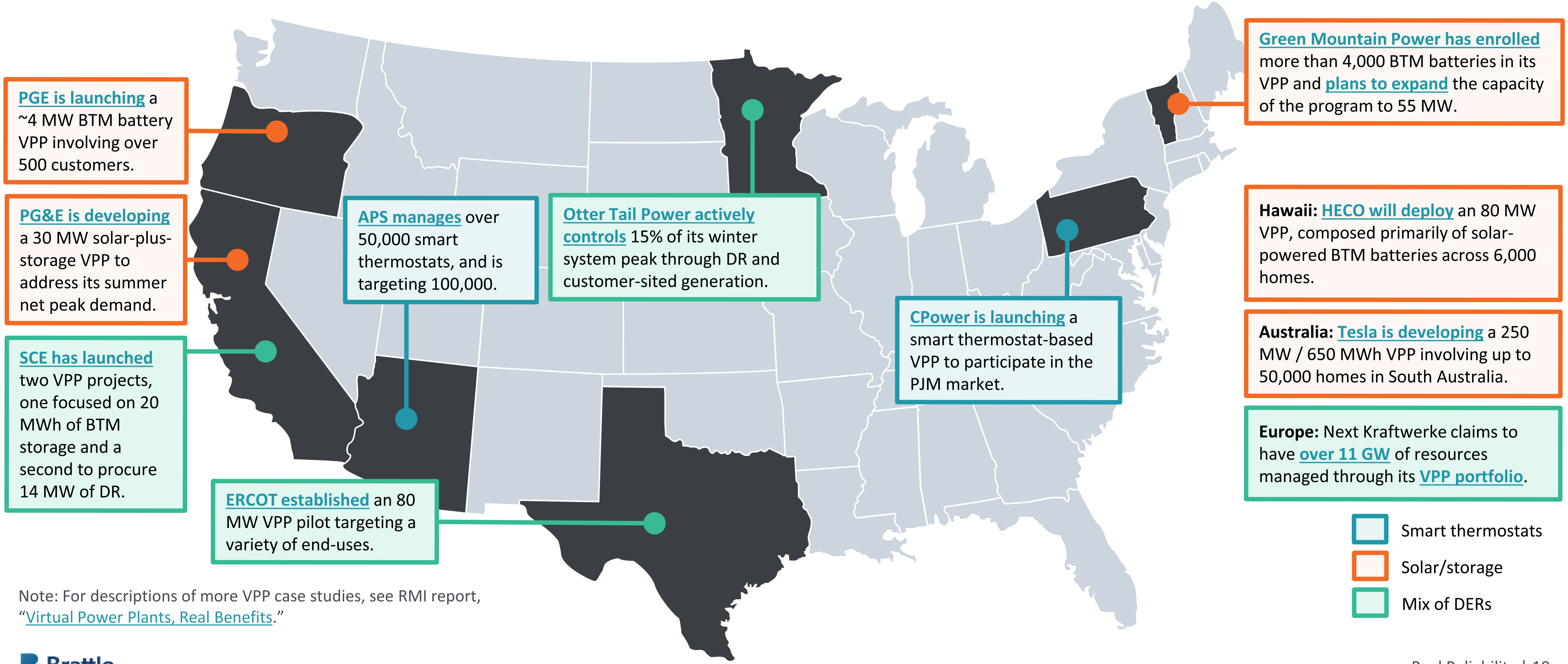
- **Declining DER costs**, particularly EVs and batteries
- **Technological advancement** in algorithms for managing and optimizing the value of DERs
- **Inflation Reduction Act (IRA) incentives** to promote electrification and efficiency
- **FERC Order 2222** and accompanying initiatives to open wholesale markets to VPP participation
- **Growing model availability** of EVs, thermostats, smart panels, and others
- **The decarbonization imperative**, a focus of policymakers, utilities, and consumers

	PRESENT	2030
Homes with Smart Thermostats	10%	34%
Homes with Electric Water Heating	49%	50%
Residential Rooftop Solar	27 GW	83 GW
Behind-the-Meter (BTM) Batteries	2 GW	27 GW
Light-Duty Electric Vehicles	3 mil.	26 mil.

Notes: See technical appendix for details. Modest growth in electric water heating is due to significant existing market saturation and near-term focus of the adoption forecast. The Inflation Reduction Act may further accelerate these adoption forecasts.

Real-World VPPs

To a degree, VPPs have existed for decades as demand response programs. But VPPs are rapidly evolving to leverage the expanding mix of DER technologies.



Note: For descriptions of more VPP case studies, see RMI report, "Virtual Power Plants, Real Benefits."

Modeling VPP Performance

The VPP Modeled in This Study

VPPs can be composed of a variety of technologies.

In this study, we focus on commercially-proven residential demand response applications.

The term "VPP" often is associated with aggregations of behind-the-meter (BTM) solar and storage. However, a VPP can be composed of a much broader range of technologies.

In fact, a VPP does not even need to generate power. Dispatchable demand response (DR), enabled by technologies such as smart thermostats and electric vehicles (EVs), can provide many of the same benefits as distributed generation resources by reducing or shifting load.

Composition of the VPP modeled in this study

Smart Thermostats
A/C and electric heating are controlled to reduce usage during peak times. Customer comfort is managed through pre-cooling/heating.

Smart Water Heating
Electric water heaters act as a grid-interactive thermal battery, providing daily load shifting and even real-time grid balancing.

Home EV Managed Charging
EV charging is a large, flexible source of load that can be shifted overnight.

BTM Battery Demand Response
Customer-sited batteries can be charged and discharged to provide services to the grid for a limited number of events, while providing resilience as backup generation during all other hours.

Analysis Approach Overview

We compare the net cost of providing 400 MW of resource adequacy from three resource types: a natural gas peaker, a transmission-connected utility-scale battery, and a VPP. Our methodology is illustrated below.

1 Define utility system

The prototypical U.S. utility is defined using publicly available data.

We conservatively assume operationally challenging conditions for a VPP.

2 Establish system resource adequacy need

Each resource must provide 400 MW of resource adequacy. This is approximately 7% of the gross system peak for the illustrative utility.

3 Determine MW of each resource type needed

Each resource must be available with sufficient generation or load reduction capability during the top system net load hours of the year.

4 Estimate total cost of each resource type

The all-in cost of each resource type includes CapEx, fuel, and ongoing program costs, and is sourced from publicly available data.

5 Simulate market value of each resource type

We use Brattle's LoadFlex and bSTORE models to simulate the additional (i.e., non-resource adequacy) value that could be provided by each resource.

6 Calculate net cost of each resource type

The value of each resource is subtracted from its all-in cost to arrive an estimate of the net cost of providing 400 MW of resource adequacy from each resource type.

Note: See technical appendix for a complete description of modeling assumptions and data sources.

The Illustrative Utility System

We model an illustrative mid-size utility with 400 MW of new resource adequacy need (7% of gross system peak demand).

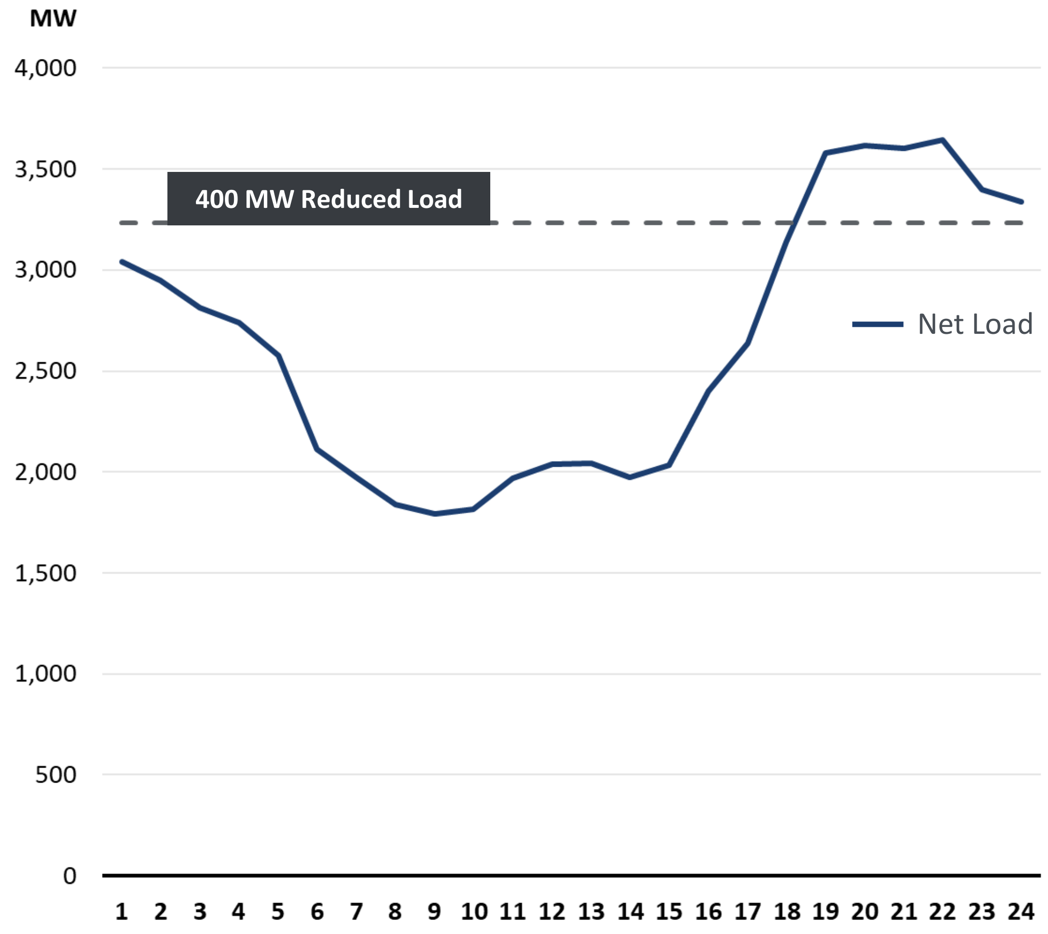
It includes a customer base of 1.7 million residential customers. Other factors in our illustrative utility include:

- 5,700 MW gross peak demand, 3,600 MW peak demand net of expected wind and solar generation
- Power generation is 50% renewable by 2030 (¼ solar, ¾ onshore wind), representing a growing trend toward decarbonized power supply

The illustrative utility is conservatively selected to represent challenging performance requirements for a VPP, such as a need for resource adequacy performance during many hours in both summer and winter

Data on marginal costs, hourly system load, renewable profiles, and customer characteristics are derived from sources such as NREL, EIA, and the U.S. Department of Energy.

Hourly System Net Load on Example Peak Day



Note: See technical appendix for a complete description of modeling assumptions and data sources.

Defining Resource Adequacy

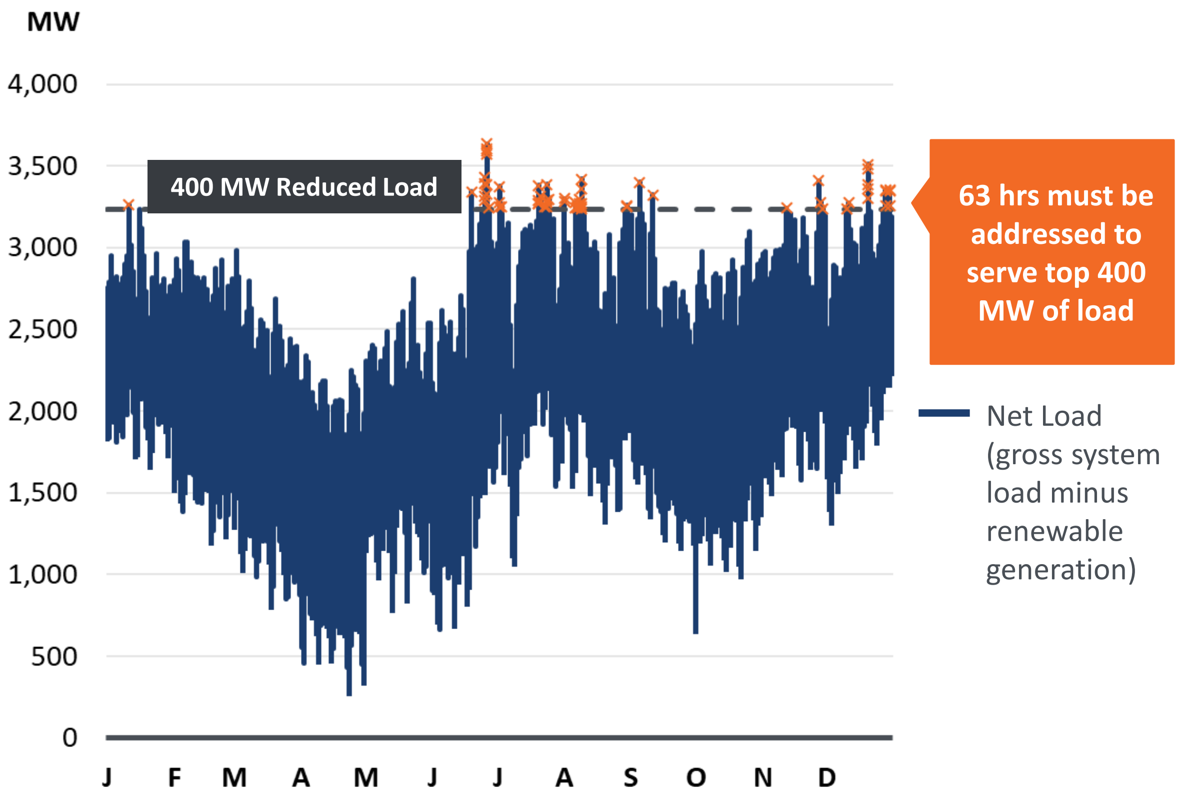
We conduct an hourly reliability assessment to ensure that all three modeled resource types are capable of fully providing 400 MW of resource adequacy to the utility system.

As a proxy for resource adequacy performance requirements, we require that the three resource options each be available to serve all load contributing to the utility's top 400 MW of net peak demand over an entire year (see figure at right).

This means that the resources must be available to perform at the required level for 63 hours of the year, spanning both summer and winter seasons.

One particular summer peak day in our analysis requires resource performance during seven consecutive hours.

Utility Hourly Net Load Profile



Note: See technical appendix for a complete description of modeling assumptions and data sources.

Calculating the Net Cost of Resource Adequacy

Our analysis estimates the cost of providing resource adequacy from each of the three resource types, net of any additional value those resources provide to the system and to society. The result is the "net cost" of providing resource adequacy.

Cost of installing and operating resource

- CapEx
- Fuel
- Operations & Maintenance (O&M)
- Program costs

−

System value of resource[1]

- Energy value
- T&D investment deferral
- Ancillary services value

−

Societal value of resource[1,2]

- GHG emissions reduction
- Resilience value

=

Net cost of resource adequacy

Notes:
[1] Negative "value" indicates that the resource increases cost (e.g., a gas peaker increasing GHG emissions).
[2] Excluding societal value from the calculation results in an estimate of the net resource cost from the perspective of the utility or system operator.

Estimating Additional Market Value

The distributed nature of VPPs allows them to provide a broader range of system benefits than transmission-connected alternatives.

System Impact	Description	Gas Peaker	Utility-Scale Battery	VPP
Energy	Net change in system fuel and variable O&M costs due to the addition of the new resource.	+	+	+
Ancillary Services	Value associated with operating the resource to provide real-time balancing services to the grid.	+	+	+
Emissions	Net change in greenhouse gas (GHG) emissions due to the addition of the resource, valued at a social cost of carbon estimate of $100/metric ton.	–	–	+
T&D Investment Deferral	Deferred cost of investing in the transmission and distribution grid due to strategic siting of distributed resources.	N/A	N/A	+
Resilience	Avoided distribution outage associated with using DERs as backup generation.	N/A	N/A	+

+ = system benefit – = system cost

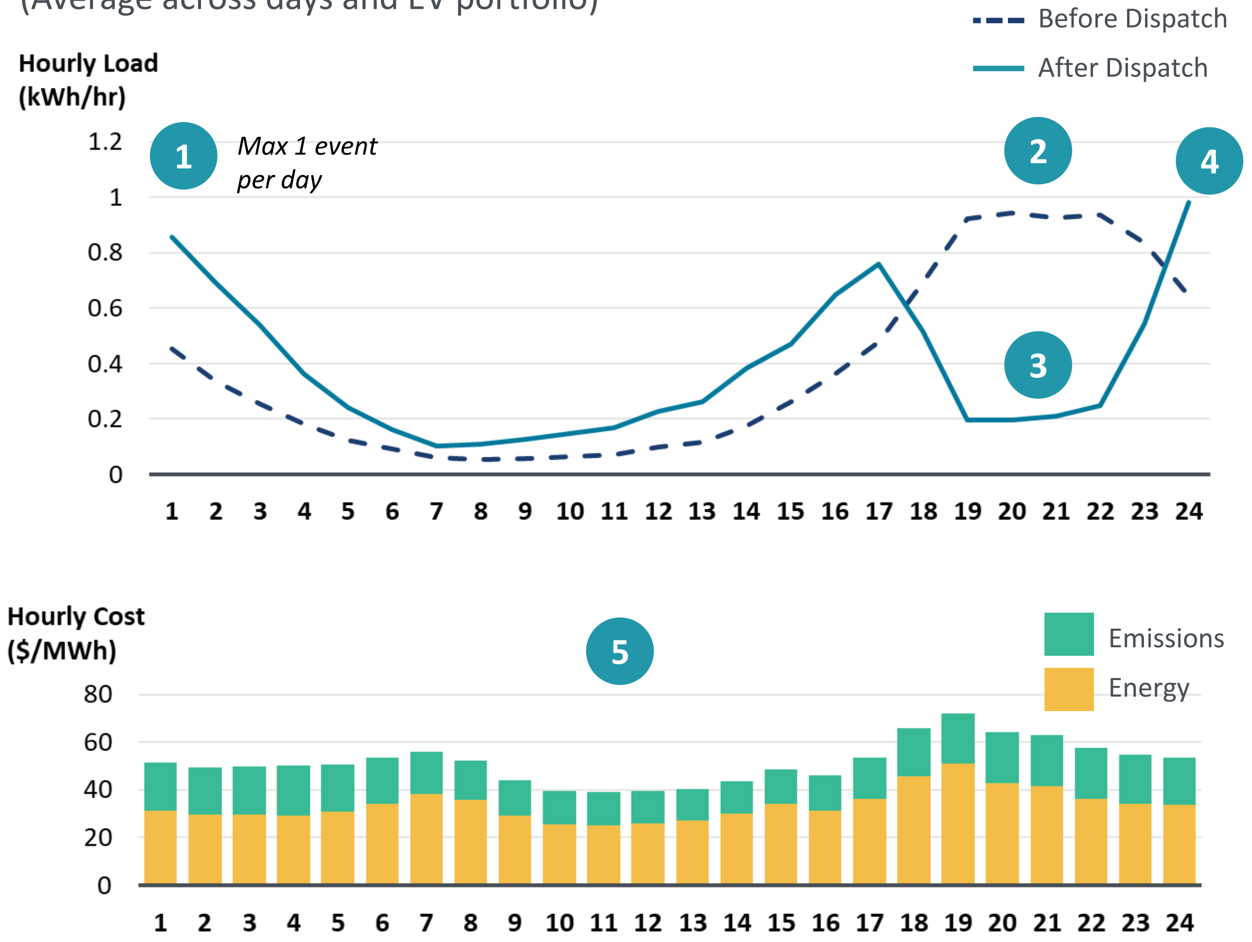
Notes:
Further discussion provided in next section.
Throughout the presentation, “utility-scale battery” refers to transmission-connected lithium-ion batteries.

Modeling Realistic VPP Operations

We simulate VPP dispatch to account for real-world operational limitations, based on observed performance in actual deployments.

1. Limits on customer tolerance for number of interruptions
2. Load impacts limited to actual available load during system peak hours
3. Load impacts account for event opt-outs, remain within customer tolerance range
4. Pre- and post-event load building to ensure customer usage ability
5. Dispatch is simulated to maximize avoided power system costs, in addition to providing resource adequacy

EV Home Charging Load Profile Relative to Hourly System Costs
(Average across days and EV portfolio)



Note: Dispatch and costs are shown as averages across event days. See technical appendix for a compete description of modeling assumptions and data sources.

Defining the VPP

The VPP modeled for this study is composed of load flexibility from four home energy technologies.

This is just one of many potential configurations of VPPs. Eligibility reflects potential technology adoption within the next decade. We assume achievable levels of customer participation in each component of the VPP.

Modeled costs are those that would be incurred by the utility. Costs are based on market studies, review of actual deployments, and expert interviews.

Note: Controllable demand sums to more than 400 MW across technologies to ensure sufficient capacity is available during all hours required for resource adequacy. Costs shown in 2022$. Smart water heating is the only option modeled as providing ancillary services (modeled as spinning reserves), as this is an existing commercial offering from grid-interactive electric resistance water heaters in PJM and other markets.

	Smart Thermostat DR	Smart Water Heating	Home Managed EV Charging	BTM Battery DR
Eligibility (% of residential customer base)	67% summer; 35% winter	50%	15%	1%
Participation (% of eligible customers)	30%	30%	40%	20%
Total Controllable Demand at Peak (MW)	204 MW	114 MW	79 MW	26 MW
Participation Incentive ($ per participant per year)	$25 per season	$30	$100	$500
Other Implementation Costs, including marketing and DERMS ($ per participant per year)	$43	$55	$80	$140
VPP Operational Constraints	15 five-hour events per season, plus 100 hrs of minor setpoint adjustments per year	Daily load shifting of water heating load, ancillary services	Daily load shifting of vehicle charging load	15 demand response events per year

The Value of VPPs

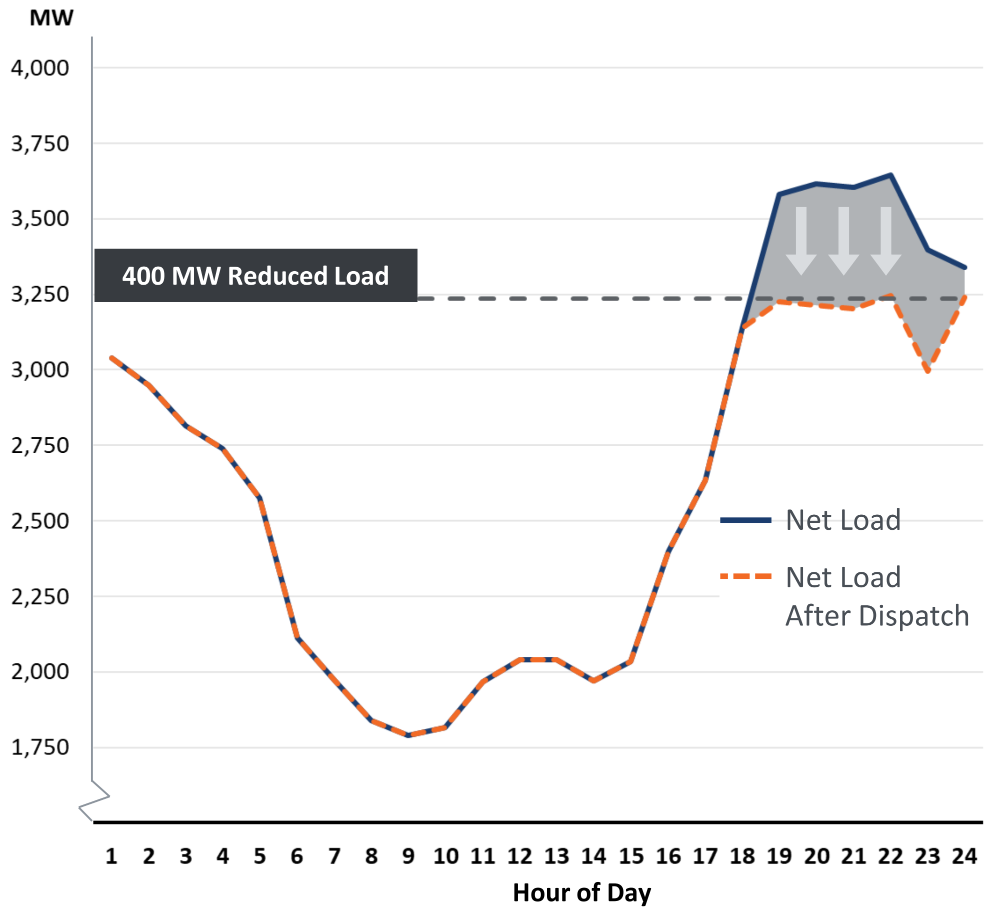
Gas Peaker Operations

The gas peaker provides resource adequacy by being available to generate when needed for system reliability reasons.

	System Impact	Discussion
Energy	+	The peaker runs in any hour when its variable cost is lower than that of the marginal resource (or the energy price in wholesale energy markets)
Ancillary Services	+	The peaker quickly ramps up and down in real-time to balance the grid
Emissions	–	When the peaker runs, it burns natural gas and emits GHGs but also displaces emissions from the marginal unit
T&D Investment Deferral	N/A	Not a distributed resource
Resilience	N/A	Not a distributed resource

+ = system benefit – = system cost

Peak Net Load Day



Note: We assume that 440 MW of gas peaker capacity needs to be built in order to account for an expected forced outage rate of 10%.

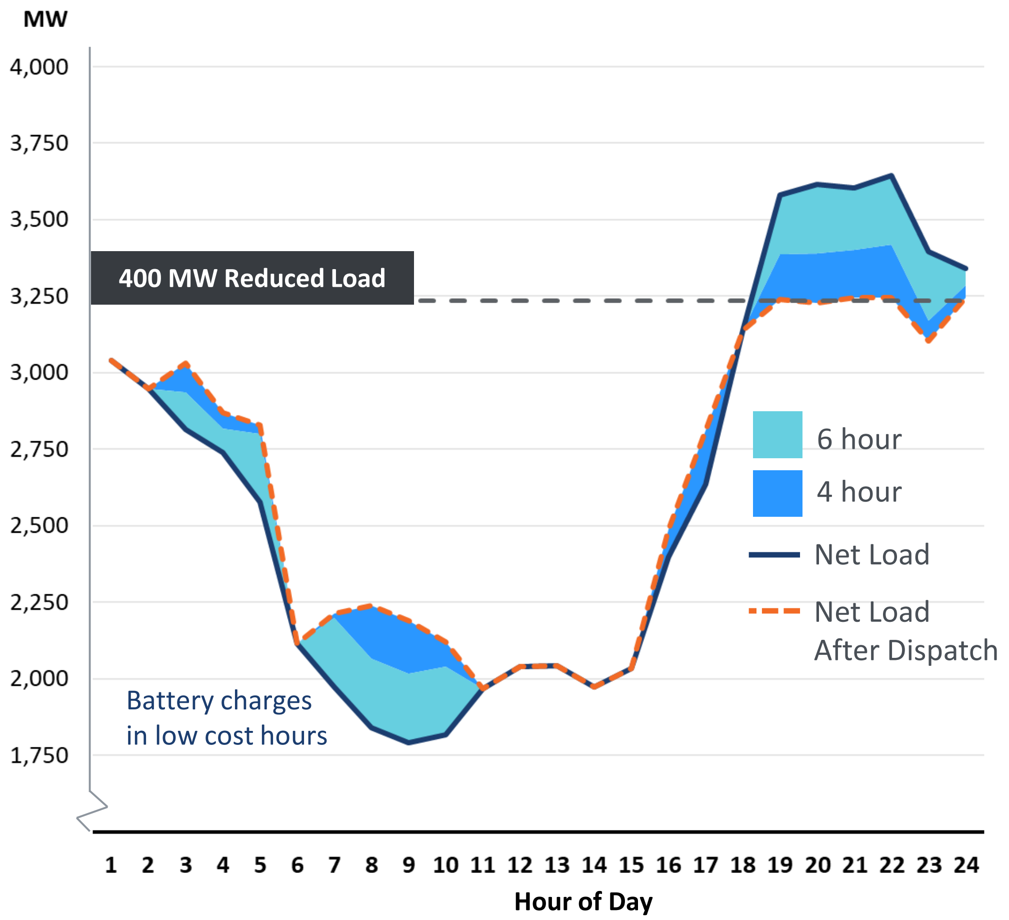
Utility-Scale Battery Operations

Batteries provide resource adequacy by charging during low cost hours and being available to discharge when needed for system reliability.

	System Impact	Discussion
Energy	+	The battery charges during the lowest cost hours of the day, and discharges during the highest cost hours of the day, displacing higher cost units
Ancillary Services	+	Batteries have the flexibility to quickly ramp up and down in real-time to balance the grid
Emissions	–	In our simulations batteries slightly increase GHG emissions, primarily because they consume more energy than they discharge (i.e., due to roundtrip losses)
T&D investment deferral	N/A	Not a distributed resource
Resilience	N/A	Not a distributed resource

+ = system benefit   – = system cost

Peak Net Load Day



Note: We model a portfolio of 4-hour and 6-hour batteries; there are days when more than 4 hours of energy discharge is needed to provide full resource adequacy.

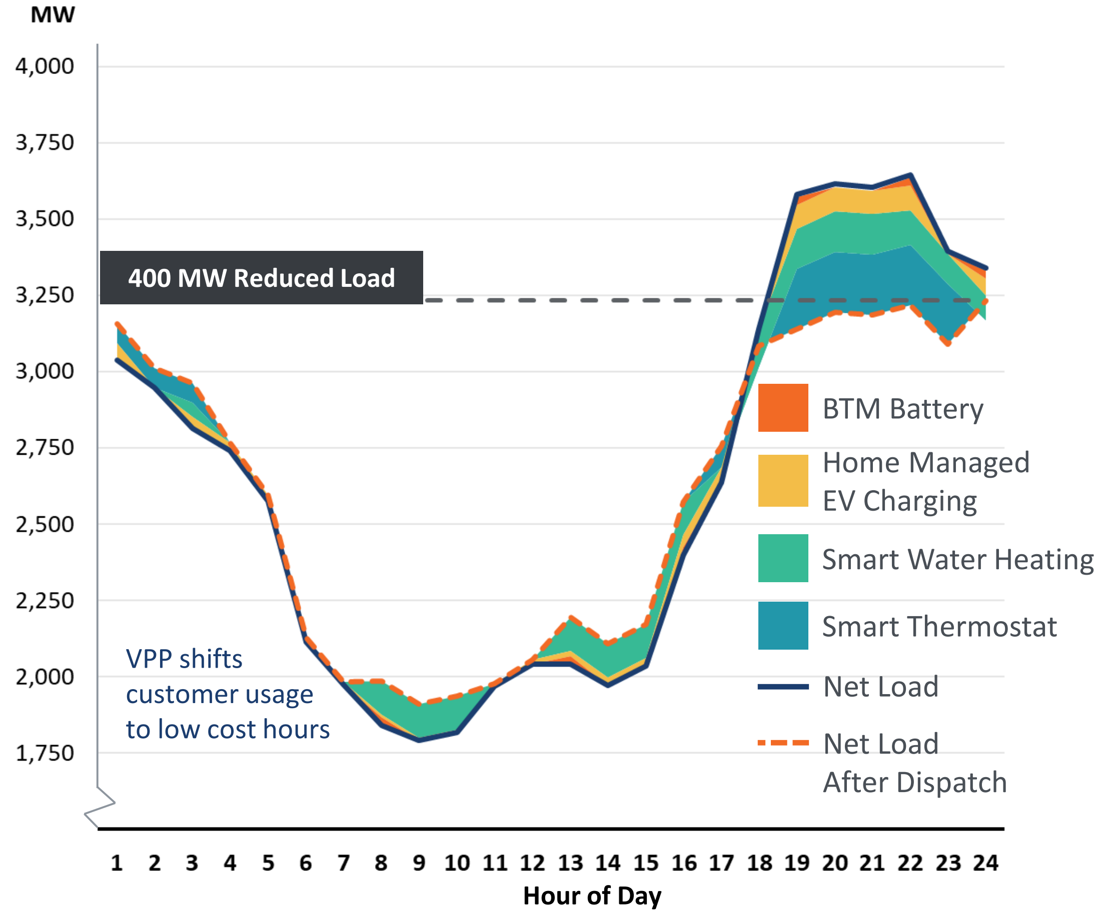
VPP Operations

The modeled VPP can fully provide 400 MW of resource adequacy, curtailing load across multiple hours of the day during summer and winter.

	System Impact	Discussion
Energy	+	The VPP curtails load during the highest cost hours of the day, and shifts load to lower hours
Ancillary Services	+	The heating element of smart electric water heaters can be managed to provide ancillary services
Emissions	+	The VPP reduces GHG emissions through an overall reduction in electricity consumption due primarily to the energy efficiency benefits of the smart thermostat
T&D Investment Deferral	+	Reductions in demand will delay the need for peak-related capacity upgrades to the T&D system
Resilience	+	Behind-the-meter batteries provide backup generation during distribution outages

+ = system benefit — = system cost

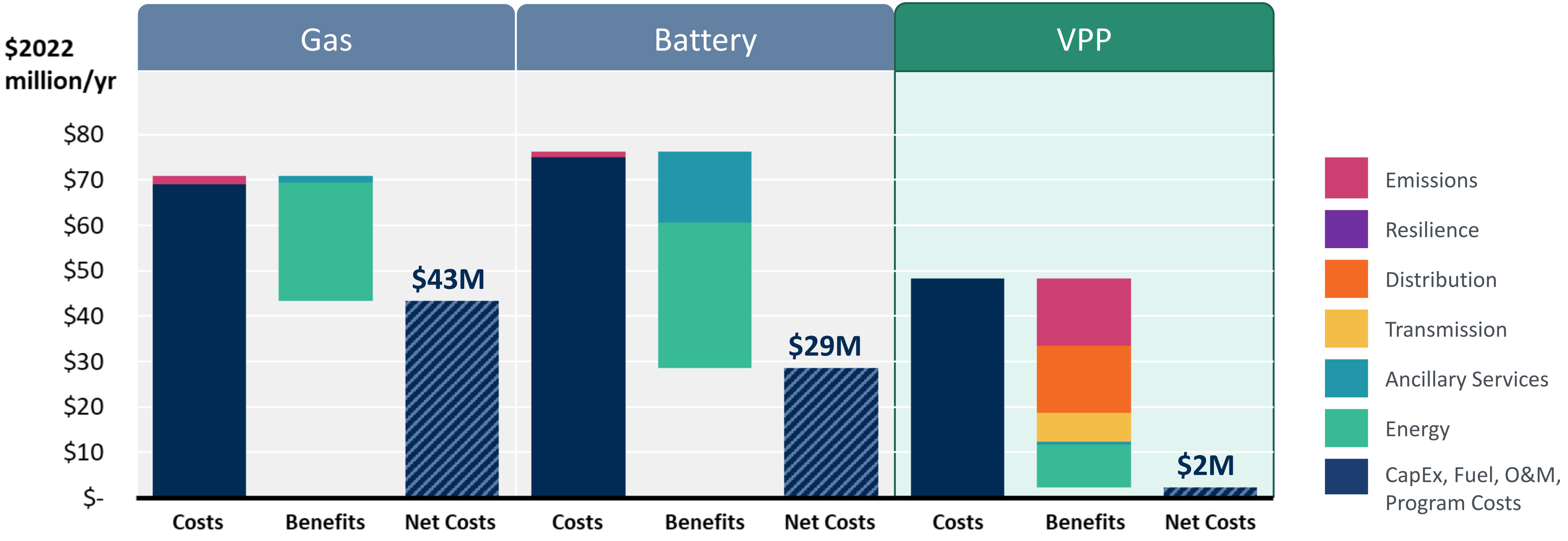
Peak Net Load Day



Resource Adequacy… For Cheap

The VPP could provide the same resource adequacy at a significant cost discount relative to the alternatives.

Annualized Net Cost of Providing 400 MW of Resource Adequacy



The Cost of 60 GW of U.S. Resource Adequacy

VPPs could save U.S. utilities $15 to $35 billion in capacity investment over 10 years.

Focusing only on utility system costs and benefits, and ignoring societal benefits (i.e., emissions, resilience), the VPP could provide resource adequacy at a net utility system cost that is only roughly 40% of the net cost of a gas peaker, and 60% of the net cost of a battery.

According to RMI, 60 GW of VPPs could be deployed in the U.S. by 2030. Extrapolating from the findings for our illustrative utility, a 60 GW VPP deployment could meet future resource adequacy needs at a net cost that is $15 billion to $35 billion lower than the cost of the alternative options over the ensuing decade.

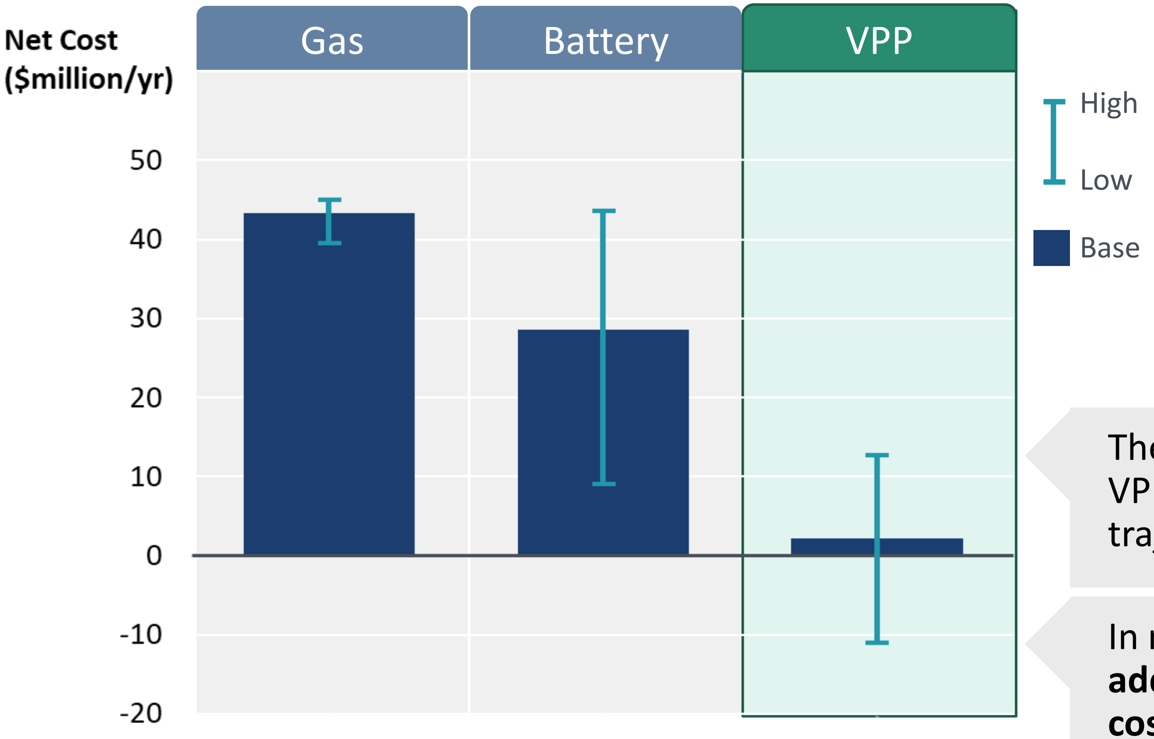
Decarbonization and resilience benefits are incremental to those resource cost savings. Consumers would experience an additional $20 billion in societal benefits over that 10-year period.

Notes: Assumes 60 GW of resource adequacy is procured for 10 years from each resource type at an annualized per-kW net cost that is based on the base case findings from this study. The VPP provides incremental societal value of approximately $37/kW-yr. Values are presented as an undiscounted sum over a 10-year period in real 2022 dollars.

Sensitivity Analysis

The VPP is the only resource with the potential to provide resource adequacy at a negative net cost to society.

Net Cost of Providing 400 MW of Resource Adequacy
(Range observed across all sensitivity cases)



Note: See technical appendix for a complete description of modeling assumptions and data sources. Costs shown in 2022$.

Sensitivity cases modeled:

- Higher carbon price
- Lower carbon price
- Higher T&D cost
- Lower T&D cost
- 2030 technology cost trends
- Business-as-usual renewables deployment
- Alternative battery configuration
- Energy only (no ancillary services benefit)

The economic competitiveness of battery storage and VPPs **will vary from one market to the next,** and also will depend on the trajectory of future cost declines.

In markets with higher T&D costs or higher GHG emissions costs, **the additional (i.e., non-resource adequacy) value of a VPP can outweigh its costs,** thus providing resource adequacy at a negative net cost to society.

Additional Unquantified Benefits of VPPs

VPPs can provide several additional major benefits not modeled in this study.

INCREASED RENEWABLES DEPLOYMENT

By shifting load to hours when excess solar and wind generation otherwise would be curtailed, VPPs can increase the capacity factor of wind and solar generation. In turn, the cost-effectiveness and economic deployment of those resources could increase.

BETTER POWER SYSTEM INTEGRATION OF ELECTRIFICATION

VPPs can facilitate cost-effective deployment of electrification measures by reducing load impacts and associated infrastructure investment needs.

FASTER GRID CONNECTION

The highly distributed nature of VPPs means they are not limited by the same interconnection delays currently facing many large-scale resources.

FLEXIBLE SCALING

A gas peaker is a multi-decade commitment with risks of becoming a stranded asset. Alternatively, the capacity of VPPs can be increased or decreased flexibly over time to align with the needs of a rapidly changing power system.

ENHANCED CUSTOMER SATISFACTION

The opportunity to participate in a VPP unlocks a new feature of customer-owned DERs, improving the overall consumer value proposition of the technologies.

IMPROVED BEHIND-THE-METER GRID INTELLIGENCE

Improved visibility into a portfolio of energy technologies that are connected to the distribution grid can enhance the operator’s ability to detect and respond to local changes in system conditions.

Moving Forward with VPPs

The Ideal Conditions for VPP Deployment

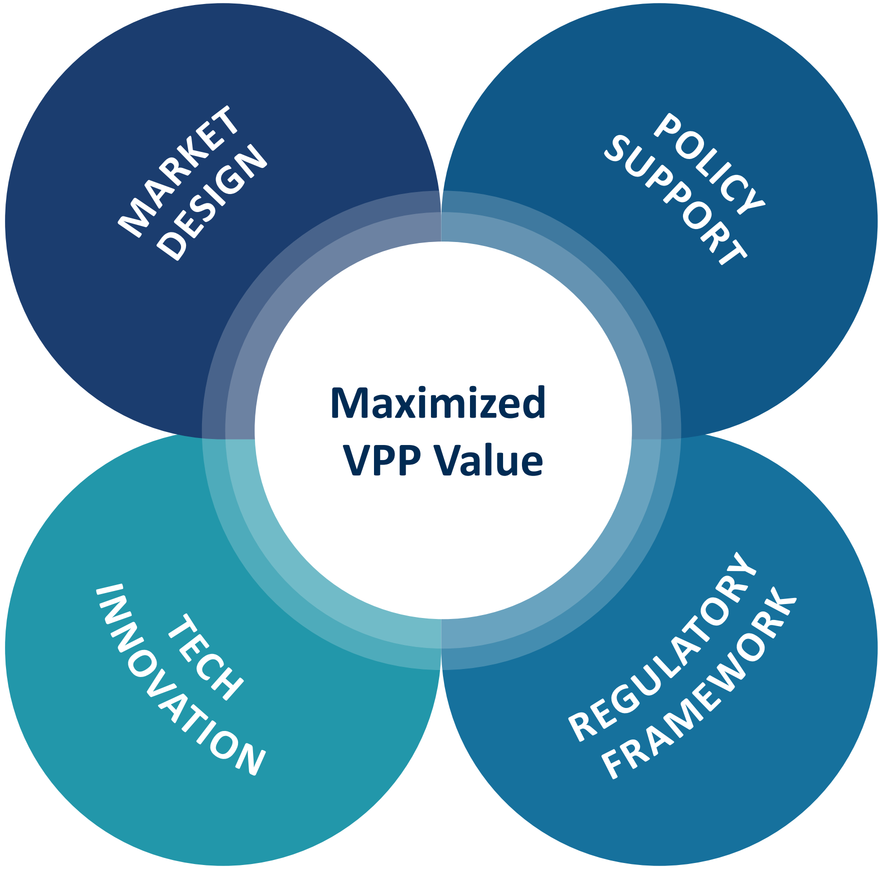
Innovation in technology, markets, policy, and regulation can enable VPP deployment.

MARKET DESIGN

- Wholesale markets provide a level playing field for demand-side resources
- Retail rates and programs incentivize participation in innovative, customer-centric ways

TECHNOLOGY INNOVATION

- DERs are widely available and affordable. DERs can communicate with each other and the system operator
- Algorithms effectively optimize DER use while maintaining customer comfort and convenience



POLICY SUPPORT

- Codes and standards promote deployment of flexible end-uses
- R&D funding supports removal of key technical barriers

REGULATORY FRAMEWORK

- Utility business model incentivizes deployment of VPPs wherever cost-effective
- Utility resource planning and evaluation accounts for the full value of VPPs

Overcoming Barriers to VPP Deployment

Barriers are preventing VPP potential from being realized. With work, they can be overcome.

	Key VPP Barriers	Possible Solutions	Examples
Technology	Lack of communications standards (between devices, with grid)	Initiatives to create coordination and standardization among product developers	The Connected Home over IP (CHIP) working group, Matter, the VP3 initiative
	Uncertain consumer DER adoption trajectory	R&D / implementation funding to improve products and reduce costs	Inflation Reduction Act tax credits for DERs and smart buildings
Markets	Prohibitive/complex wholesale market participation rules	Market products that explicitly recognize VPP characteristics	ERCOT's 80 MW Aggregated DER (ADER) Pilot Program
	Retail rates and program design that do not incentivize DER management	Subscription pricing coupled with load flexibility offerings; time-varying rates	Duke Energy pilot coupling subscription pricing with thermostat management
Regulation	Utility regulatory model that does not financially incentivize VPPs	Performance incentive mechanisms, shared savings models	At least 12 states with utility financial incentives for demand reduction
	Full value of VPPs not considered in policy/planning decisions	Regulatory targets for VPP development	Minnesota PUC 400 MW demand response expansion requirement

Note: For further discussion of barriers and solutions, see the U.S. DOE's A National Roadmap for Grid-Interactive Efficient Buildings.

Quick Wins

Among many options for enabling VPP deployment, here are three low-risk actions utilities and regulators can take in the near-term.

Conduct a jurisdiction-specific VPP market potential study. Then establish VPP procurement targets.

This is a common approach to promoting the deployment of renewables, energy efficiency, and storage.

Potential studies should account for achievable adoption rates and cost-effective deployment levels.

Establish a VPP pilot. Test innovative utility financial incentive mechanisms.

An inflection point in DER adoption is rapidly approaching; pilots will provide critical experience before it's too late.

Technology demonstration is not enough; regulatory models that allow utilities to share in the benefits also must be tested.

Review and update existing policies to comprehensively account for VPP value.

Methods for evaluating VPP cost-effectiveness often consider only a portion of the value they can create.

Evaluation of VPP proposals will need to account for benefits created by the full range of services VPPs provide, including energy savings, load shifting, peak clipping, real-time flexibility, and exports to the grid.

Conclusion

As decarbonization initiatives ramp up across the U.S., **affordability and reliability** are in the spotlight as the top priorities of policymakers, regulators, and utilities.

This study demonstrated that VPPs have the potential to provide the same reliability as conventional alternatives, with **significantly greater** affordability and decarbonization benefits.

While VPPs are beginning to be deployed across the U.S. and internationally, achieving the scale of impacts described in this study will require a **collective industry effort** to place VPPs on a level playing field with other resources.

A renewed focus on innovation in technology development, wholesale and retail market design, utility regulation, system planning, and customer engagement will be **key to ensuring that virtual power plants become more than just virtual reality.**

UNIQUE FEATURES OF THIS STUDY

Hourly reliability assessment, to ensure VPPs are evaluated on a level playing field with alternatives.

Realistic representation of VPP performance characteristics and achievable levels of adoption.

Analysis of net benefits, with comprehensive accounting for VPP costs

Focus on commercially-proven residential demand flexibility

Additional Reading

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Kate focuses her research on resource planning in decarbonized electric markets and economic analysis of distributed energy resources. She has supported utilities, renewable developers, research organizations, technology companies, and other private sector clients in a variety of energy regulatory and strategy engagements. Kate received her B.S. in Environmental Economics from Middlebury College.

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