Power Shift

How Virtual Power Plants Unlock Cleaner, More Affordable Electricity Systems

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About RMI

RMI is an independent nonprofit, founded in 1982 as Rocky Mountain Institute, 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 climate pollution at least 50 percent by 2030. RMI has offices in Basalt and Boulder, Colorado; New York City; Oakland, California; Washington, D.C.; Abuja, Nigeria; and Beijing.

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.

Acknowledgements

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Executive Summary

As multiple grid challenges emerge, virtual power plants (VPPs) present a flexible, deployable solution for managing grid needs.

Today's grid operators and planners face interrelated challenges to delivering reliable, affordable electricity to ratepayers, from growing projected loads and retiring generation capacity to clogged interconnection queues and increasing high-impact, low-probability weather events. VPPs, which could constitute over 20% of US peak capacity by 2030,[1] are uniquely suited to meet these challenges by leveraging existing grid assets to deploy quickly and provide distribution and resilience benefits.

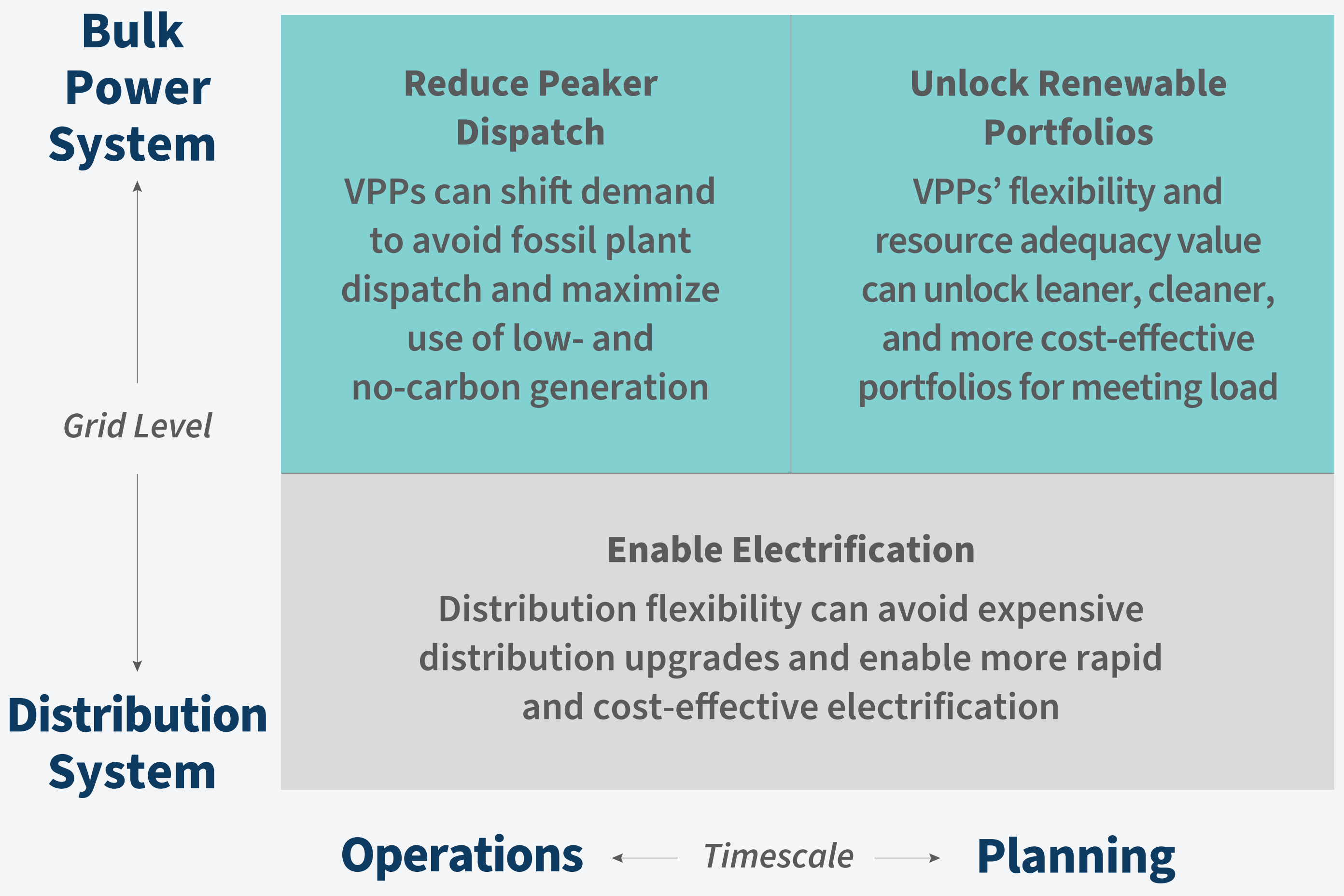
VPPs are providing a variety of benefits to the grid today. Updated grid planning and operations can unlock their full potential.

VPPs can provide multiple services to the grid, but conventional practices have not fully integrated VPPs into grid planning and operations. Grid planning and operations that proactively plan for, deploy, and use VPPs can realize more of their potential benefits.

This report examines the potential role that VPPs could play in evolving, decarbonizing grid systems.

We examine the role of VPPs in delivering affordable, reliable, and low-carbon power, with a special focus on VPPs' role in reducing emissions from power systems. We identify three pathways (*see Exhibit ES1*) where VPPs can drive decarbonization, across timescales and system levels.[i]

Exhibit ES1: Virtual Power Plant Decarbonization Pathways



Bulk Power System

Grid Level

Distribution System

Reduce Peaker Dispatch
VPPs can shift demand to avoid fossil plant dispatch and maximize use of low- and no-carbon generation

Unlock Renewable Portfolios
VPPs' flexibility and resource adequacy value can unlock leaner, cleaner, and more cost-effective portfolios for meeting load

Enable Electrification
Distribution flexibility can avoid expensive distribution upgrades and enable more rapid and cost-effective electrification

Operations ← *Timescale* → **Planning**

RMI Graphic. Source: RMI analysis

In this report, we use a detailed model of an example power system in 2035 and a nationwide simulation of VPP dispatch to better understand the role of VPPs in a transitioning energy system. We find that VPPs can reduce costs and carbon while maintaining reliable grid operations.

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[i] This report evaluates VPPs' role on the bulk power system and does not directly quantify the emissions benefits of VPPs' impact on the distribution system.

Key Findings

VPPs unlock a reliable, lower-cost, and cleaner resource mix compared with portfolios without VPPs in our detailed power system model.

Using a case study power system in 2035 in the Mountain West, a portfolio of resources that includes VPPs reliably meets demand and, compared with a baseline portfolio without VPPs *(see Exhibit ES2)*:

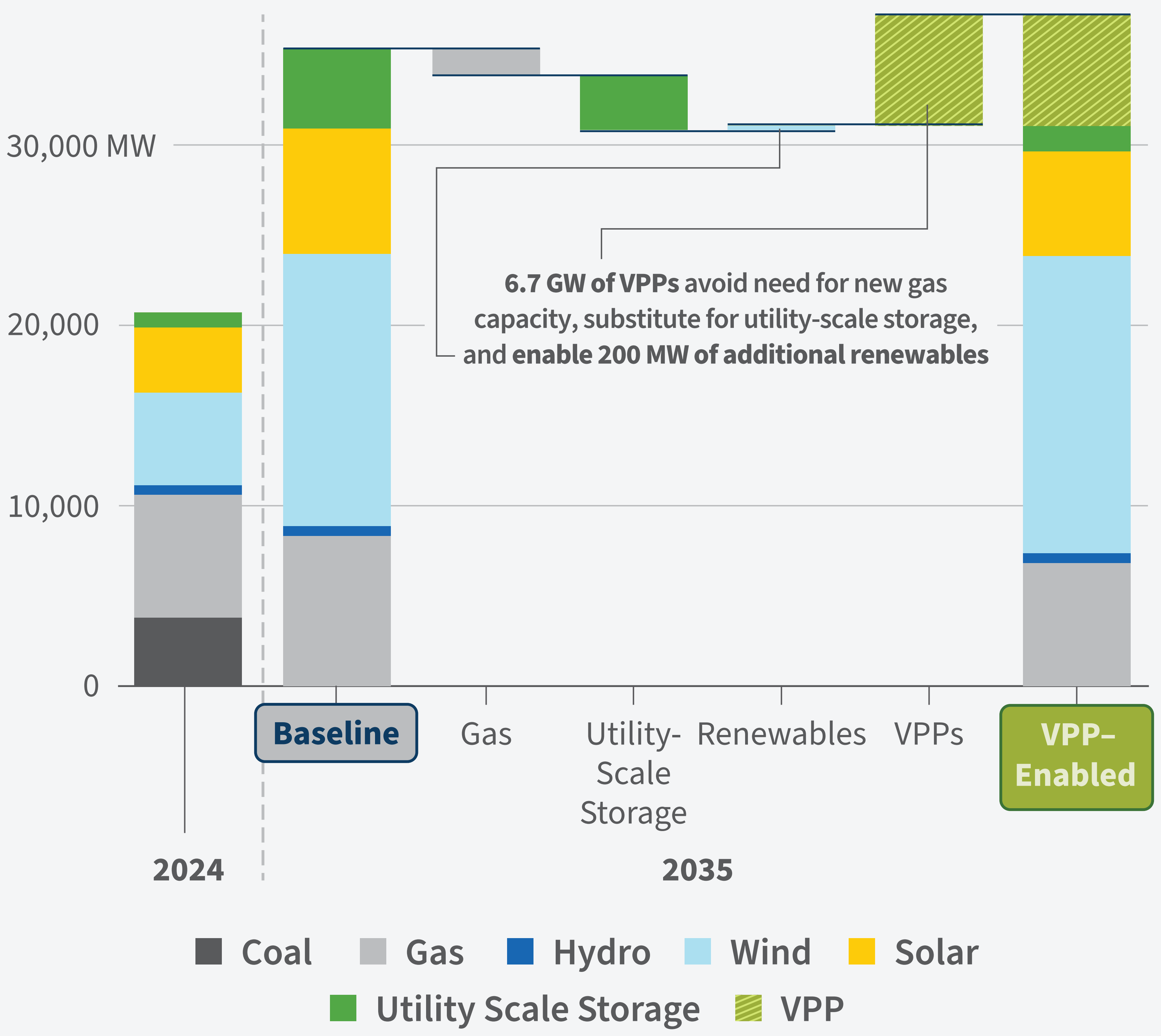
- Reduces the need for new gas by 75% or 1.5 gigawatts (GW)
- Enables 200 MW of additional renewables
- Reduces net generation costs by 20% or $140 per household annually
- Reduces carbon emissions by 7%.

We also evaluate the role of VPPs on a power system with a carbon reduction policy in place. In the system with a carbon reduction policy, we find a 17% reduction in net generation costs alongside a 47% reduction in carbon emissions compared with a no-policy, no-VPP baseline.

Nationwide, VPPs could avoid 12 million to 28 million tons of carbon dioxide emissions by 2035, or 2% to 4% of projected US power sector emissions.

We also estimate the potential for VPPs to reduce power sector carbon emissions by shifting demand across the continental United States through 2035. VPPs avoid emissions by shifting demand from high-emissions periods when demand is met by expensive, high-emissions generators to low-emissions periods when demand is met by renewable energy.[ii]

Exhibit ES2: Total Resource Capacity by Case Study Portfolio, 2024 and 2035 (Baseline and VPP-Enabled)



RMI Graphic. Sources: US Energy Information Administration (EIA) Form 860; and RMI analysis

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[ii] Emissions-reducing demand shifts by VPPs vary depending on the technology, season, and geography.

Key Priorities for Maximizing VPP Impacts

We identify four key conditions for realizing VPPs' grid benefits:

1. **Distributed energy resources (DERs) continue to be deployed and VPP enrollment accelerates across the country.**
VPP grid impacts scale directly with total capacity enrolled in VPPs, which depends on deployment of VPP-enabled technologies and easy enrollment in VPP programs. Utilities, regulators, and VPP developers can provide financing options and build a seamless enrollment experience to address customer cost and acquisition barriers.

2. **VPP capabilities, program design, and customer experience support regular, responsive VPP dispatch.**
Although some key grid services (e.g., generation capacity, resilience) can be provided by dispatching at key times, others maximize their impact with regular VPP dispatch (e.g., fuel savings, reducing emissions). When VPP platforms can choose which grid services they participate in and VPP participants can choose their level of participation, VPPs can deliver high-value operations and positive participant experiences.

3. **VPPs have accurate, timely signals about grid conditions and carbon emissions.**
VPP operations that are most effective for reducing emissions vary depending on the weather, season, and geography. VPP platforms can integrate grid emissions signals into participant interfaces and operational decision-making to ensure VPP dispatch is aligned with avoiding carbon emissions.

4. **Grid decision makers evaluate, plan for, and realize the full value of VPPs, including avoided transmission and distribution (T&D) costs.**
Although VPPs were cost-effective in our analysis without considering T&D benefits, avoided T&D costs are a critical savings opportunity for ratepayers. Utilities, regulators, and VPP developers can use emerging integrated distribution system planning methods to ensure all VPP benefits are captured.

Background

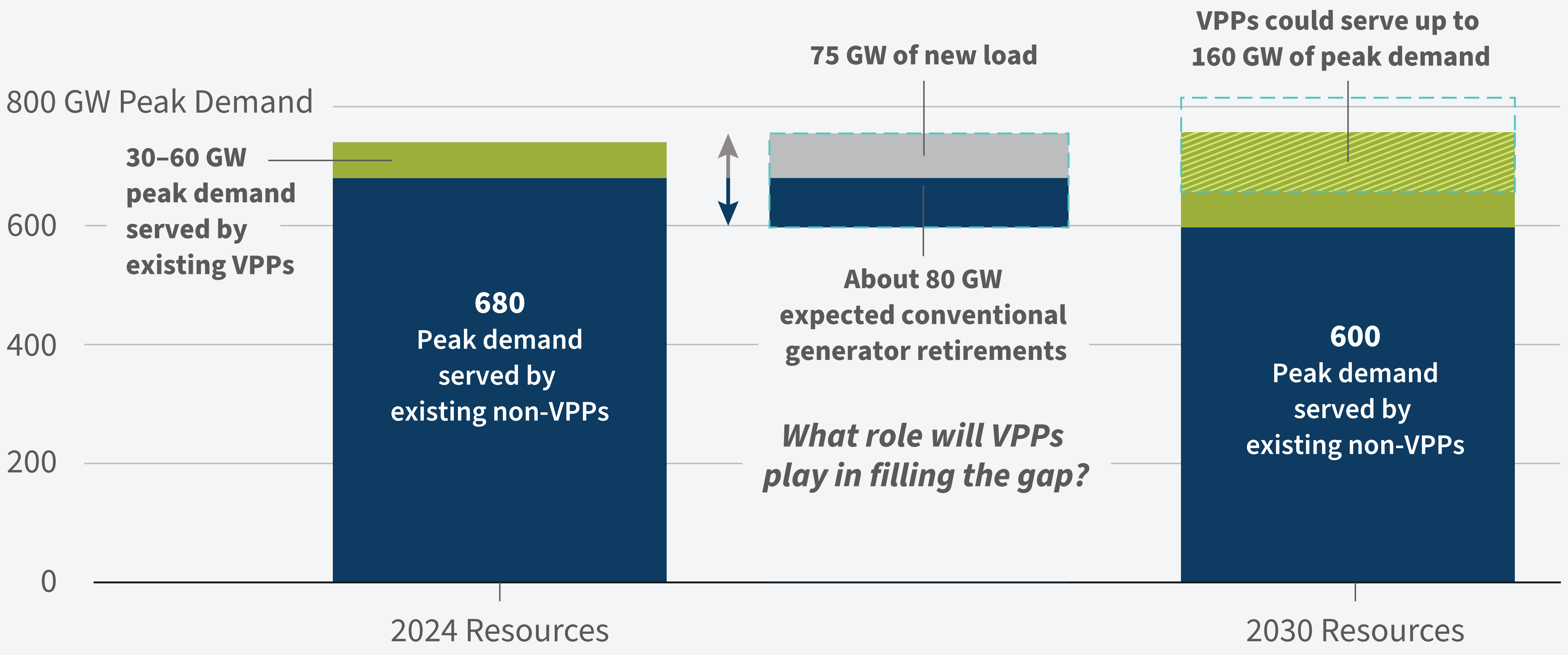
Virtual Power Plants: VPPs are grid-integrated aggregations of distributed energy resources, such as batteries, electric vehicles, smart thermostats, and other connected devices.

New Trends across the Power Sector: VPPs are uniquely suited to meet grid needs.

Today's grid operators and planners face interrelated challenges to delivering reliable, affordable, and clean electricity to ratepayers:

- **Projected load growth.** Across the United States, load growth projections are rising higher than they have in decades, driven by electrification, advanced manufacturing, and expected data center demand. Peak demand is projected to grow by 60 gigawatts (GW) by 2030, reaching 800 gigawatts (GW) across the country.[2]
- **Existing generator retirements.** At the same time, aging infrastructure, economics, and public policy are putting pressure on existing generators. Generation resources serving approximately 80 GW of peak demand in the United States are expected to retire by 2030.[3] Load growth and retiring resources leave a 155 GW gap to meet peak capacity in 2030.
- **Growing interconnection queues.** Although nearly 2,600 GW of new grid-scale resources are in the process of connecting to the grid, costs and delays associated with interconnecting these resources continue to grow.[4] Meanwhile, transmission infrastructure is not being built rapidly enough. The US Department of Energy estimates that additional transmission is needed today, and that need will increase significantly in future years.[5]
- **Extreme weather events.** High-impact, low-probability events are growing in intensity and frequency, underscoring the need for a resilient power grid.[6]

Exhibit 1: Virtual US Power Sector Peak Demand Resource Transition, 2024-30



RMI Graphic. Sources: Downing et al., *Pathways to Commercial Liftoff*, 2023; and *2023 Long-Term Reliability Assessment*, North American Electric Reliability Corporation (NERC), 2023

VPPs can play a key role in meeting emerging challenges on an evolving grid. VPPs provide unique benefits over grid-scale resources: they are rapidly deployable, meet load where it exists, and offer local economic, reliability, and resilience benefits.[7] There are already 500 VPP programs in operation, providing between 30 and 60 GW of peak-coincident capacity in the US.[8] By 2030, hundreds of gigawatts of new distributed resources (DERs) are expected to be added to the grid.[9] Aggregated and orchestrated as VPPs, these resources could serve a substantial portion of the emerging need for 155 GW of new peak demand *(see Exhibit 1)*.

Existing Processes Don't Integrate the Full Benefits of VPPs

VPPs provide a range of benefits to grid operators and customers *(see Exhibit 2)*, including conventional grid services and advantages unique to distributed resources.

Below are a few examples of VPPs that are delivering benefits to grid stakeholders today:

Resource Adequacy:

- Pacific Gas & Electric Company and Sunrun's Peak Power Rewards program provided daily peak demand reductions for 90 days in summer 2023.[10]
- Arizona's three largest utilities have enrolled over 100,000 customers in smart thermostat programs, providing over 300 megawatts (MW) of peak demand reduction capacity.[11]

T&D Infrastructure Relief

- New York's Value of Distributed Energy Resources evaluates Locational System Relief Value for all DERs.[12]
- Colorado legislators have included VPPs as part of a comprehensive approach to distribution system planning.[13]

Affordability:

- In Utah, the Public Service Commission determined VPPs to be cost-effective utility investments compared with traditional solutions.[14]
- Green Mountain Power (GMP)'s Energy Storage System lease program gives customers financial support for installing home battery systems in exchange for allowing GMP to dispatch the battery to reduce system costs for all customers.[15]

Although VPPs are already delivering benefits to the grid today, fully realizing VPPs' potential to serve the grid will require updated approaches to grid planning and operations.[16] Benefits such as resource adequacy and T&D infrastructure relief can best be realized when VPPs are fully integrated into grid planning and operations.[17] This will include modeling a full range of VPP benefits and considering VPP investments alongside utility-scale resources.

Exhibit 2. VPP Grid Benefits

Resource Adequacy	Increasing system reliability by providing dispatchable power on peak
T&D Infrastructure Relief	Increasing T&D efficiency, alleviating congestion, and potentially avoiding or deferring additional network investments
Reliability & Resilience	Integrating backup power and avoiding a single point of failure for key loads
Versatility & Flexibility	Acting as a modular, quick-deploying option for meeting specific grid needs
Affordability	Driving down household energy burden by deferring grid investments, avoiding fuel costs, and compensating VPP participants
Community Empowerment	Providing control to customers in how they generate and use energy, creating good local jobs
Decarbonization	Reducing greenhouse gas emissions to meet national, state, and corporate climate targets

Source: Downing et al., *Pathways to Commercial Liftoff*, 2023

VPPs are a Versatile Tool for Low-Carbon Power Systems: VPPs can reduce emissions across system levels and over multiple timescales.

VPPs will support decarbonization in at least three distinct ways, at varying timescales and system levels *(see Exhibit 3)*.

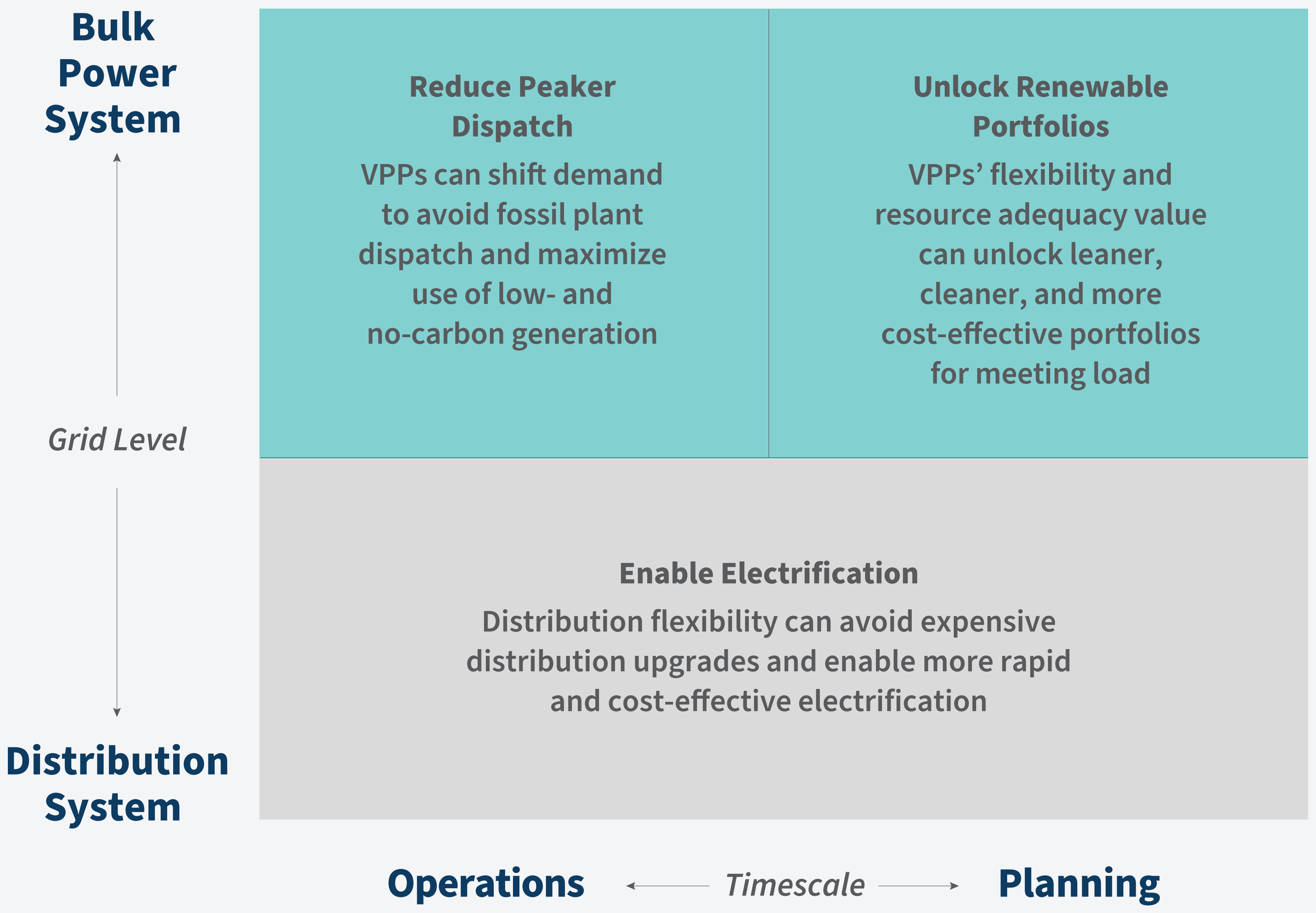
VPPs can reduce fossil peaker dispatch by shifting load away from peak demand periods, which often correlate to times when the most expensive and polluting units are brought online.[iii]

VPPs can unlock new renewable portfolios by shifting demand to coincide with renewable generation and contributing to resource adequacy.

VPPs can enable electrification for end-users by managing demands on distribution infrastructure, allowing additional electrified demand to interconnect before creating the need for distribution upgrades.

VPPs' potential to reduce power sector carbon emissions has yet to be estimated.[iv] Although VPPs can support decarbonizing grids through the above pathways, there isn't yet a clear understanding of the magnitude of potential VPP impacts. A clear understanding of VPPs' potential as a decarbonization tool could shed light on the importance of VPPs in an affordable energy transition and point toward changes to policy, planning and operations that realize VPP benefits.

Exhibit 3: Virtual Power Plant Decarbonization Pathways



Reduce Peaker Dispatch
VPPs can shift demand to avoid fossil plant dispatch and maximize use of low- and no-carbon generation

Unlock Renewable Portfolios
VPPs' flexibility and resource adequacy value can unlock leaner, cleaner, and more cost-effective portfolios for meeting load

Enable Electrification
Distribution flexibility can avoid expensive distribution upgrades and enable more rapid and cost-effective electrification

RMI Graphic. Source: RMI analysis

[iii] "Peaker" generators are fossil-fueled power plants that generate only during times of peak demand. They tend to be less efficient and emit more air pollutants than other fossil-fueled generators. For more information, see: *Electricity: Information on Peak Demand Power Plants*, US Government Accountability Office, May 2024, **https://www.gao.gov/assets/gao-24-106145.pdf**.

[iv] Although VPPs are expected to enable decarbonization on the distribution system by reducing stress on distribution infrastructure and enabling beneficial electrification across transportation, industry, and buildings, this report only evaluates VPPs' role on the bulk power system.

Our Approach: We explore how VPPs can support affordable, reliable decarbonization across the US power sector.

To better understand VPPs' role in decarbonizing systems and the potential scale of their impact, we conduct two analyses:

- In ***VPPs' Role in Affordable, Reliable Decarbonization***, we conduct a utility planning exercise for a stylized Mountain West power system, putting VPPs on a level playing field with conventional grid resources. We demonstrate the benefits VPPs can provide across reliability, affordability, and emissions reductions.

- In ***VPPs' Nationwide Decarbonization Potential***, we model the first nationwide estimate of the emissions reduction potential of VPPs through 2035.

In both analyses, we model VPPs as a diverse set of demand-side technologies, aggregated and operated together *(see Exhibit 4)*.

Exhibit 4: Virtual Power Plant Technologies Evaluated in Power Shift Analyses

Managed Electric Vehicle Charging
Electric vehicles (EVs) and charging infrastructure can shift EV charge timing.

Heating, Ventilation, and Air Conditioning (HVAC)
HVAC loads can shift set points or preheat or cool spaces.

Distributed Storage
Storage installed by residential, commercial, and industrial customers charge and discharge to shift aggregate load.

Water Heating
Water heating units can preheat or shift set points.

Industrial Demand Flexibility
Industrial processes can shift production times or, in some cases, preheat and store process heat.

Other Flexible Loads
Other flexible loads consisting of residential and commercial appliances (e.g., refrigeration, computers) with VPP-enabled technologies can also shift usage and demand.

RMI Graphic. Source: Sun et al., *Electrification Futures Study*, National Renewable Energy Laboratory (NREL), 2020

Grid operators, utilities, regulators, and policymakers can work together to update existing grid planning and operations practices and maximize VPPs' impacts.

The conclusion of this report, ***Maximizing the VPP Power Shift***, illustrates the key conditions for realizing potential VPP benefits and outlines actions grid decision makers can take to address barriers to meeting that potential.

VPPs' Role in Affordable, Reliable Decarbonization

Overview: Including VPPs in planning unlocks a reliable, low-cost, and clean resource mix.

A VPP-enabled resource portfolio achieves a 20% reduction in net generation costs and a 7% reduction in emissions compared with the Baseline portfolio without VPPs.

Analysis

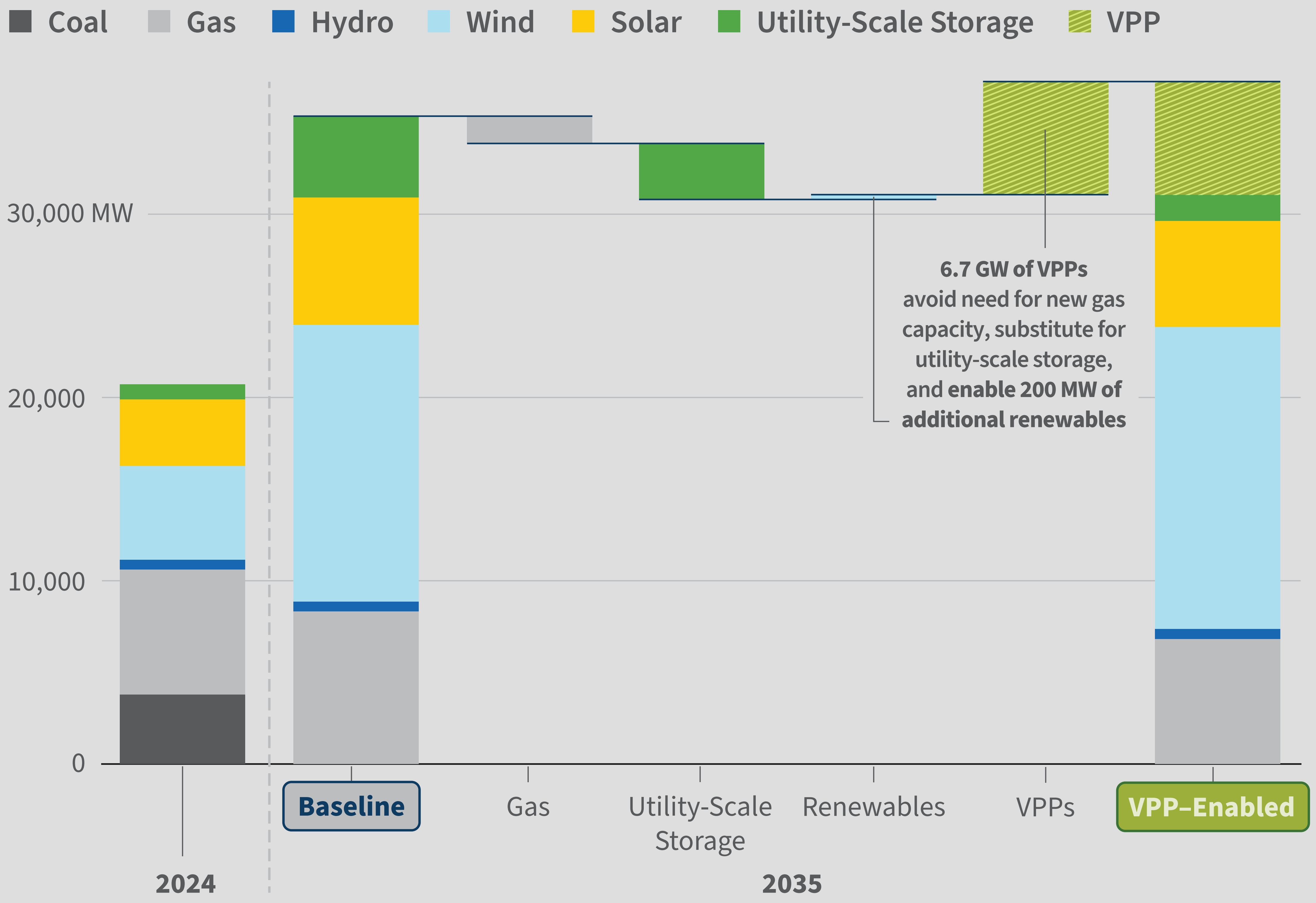
Using a power system in the Mountain West as a case study, we conduct capacity expansion planning to identify two cost-effective resource portfolios in 2035. The Baseline portfolio does not have access to VPPs as a resource; the VPP-Enabled portfolio is able to procure and operate VPPs.

Results

When VPPs' full benefits are included in grid planning, they can play a key role in delivering reliable, lower-cost, low-carbon power. In the VPP-Enabled portfolio:

- VPPs dispatch to use more variable renewable energy and avoid the need for peaking gas units, avoiding 75% of new gas capacity and enabling 200 MW of additional renewables *(see Exhibit 5)*.
- Emissions are reduced by 7%.
- Avoided capital costs, operating savings, and avoided T&D costs save all households an average of $140 per year.
- In a sensitivity where the region implements a clean energy transition through an ambitious carbon policy, VPPs deliver cost savings while enhancing carbon reduction.

Exhibit 5: Total Resource Capacity by Portfolio, 2024 and 2035 (Baseline and VPP-Enabled)



6.7 GW of VPPs avoid need for new gas capacity, substitute for utility-scale storage, and **enable 200 MW of additional renewables**

RMI Graphic. Sources: EIA Form 860; and RMI analysis

Analysis: We compare resource portfolios to understand the impact of VPPs.

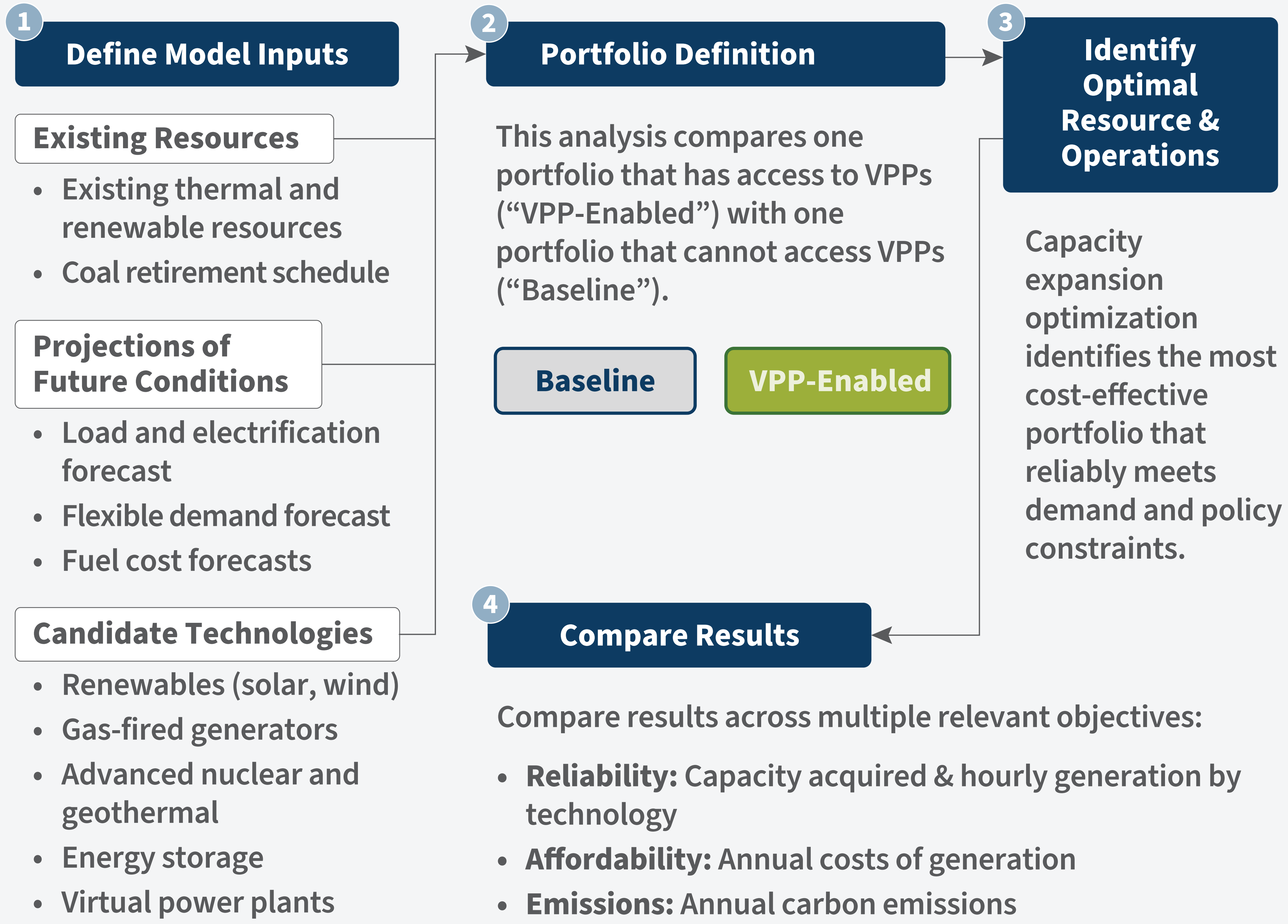
This analysis mimics the planning process undertaken by vertically integrated utilities in the United States *(see Exhibit 6)*. We construct a forward-looking model of an example power system in the Mountain West of the United States in 2035. Then, we identify the optimal portfolio of energy resources that reliably meets demand at the lowest cost to ratepayers. Although the results from this case study are not meant to inform any specific utility's resource plan, they provide insights into what utilities across the country can expect as they integrate VPPs into system planning.

To assess the effects of including VPPs in planning, we construct and compare two portfolios in 2035: a Baseline portfolio without VPPs and a VPP-Enabled portfolio that can procure and operate VPPs. We evaluate them on the following outcomes:

- **Reliability:** What resources are needed to maintain an equivalent level of resource adequacy with and without VPPs?
- **Affordability:** How do VPPs affect the magnitude and composition of costs to ratepayers?
- **Emissions:** How do VPPs affect total portfolio emissions? How do VPP-enabled portfolios interact with existing public policy goals?

Additional details on methods, assumptions, and data sources for the national VPP dispatch study are provided in a separate technical appendix.

Exhibit 6: Analytical Approach, VPPs' Role in Affordable, Reliable Decarbonization



1 **Define Model Inputs**

Existing Resources

- Existing thermal and renewable resources
- Coal retirement schedule

Projections of Future Conditions

- Load and electrification forecast
- Flexible demand forecast
- Fuel cost forecasts

Candidate Technologies

- Renewables (solar, wind)
- Gas-fired generators
- Advanced nuclear and geothermal
- Energy storage
- Virtual power plants

2 **Portfolio Definition**

This analysis compares one portfolio that has access to VPPs ("VPP-Enabled") with one portfolio that cannot access VPPs ("Baseline").

Baseline **VPP-Enabled**

3 **Identify Optimal Resource & Operations**

Capacity expansion optimization identifies the most cost-effective portfolio that reliably meets demand and policy constraints.

4 **Compare Results**

Compare results across multiple relevant objectives:

- **Reliability:** Capacity acquired & hourly generation by technology
- **Affordability:** Annual costs of generation
- **Emissions:** Annual carbon emissions

RMI Graphic. Source: RMI analysis

Analysis: Power systems will build a combination of low-cost variable renewable and flexible, dispatchable resources.

Power system planners will balance a combination of new low-cost, zero-emissions variable renewable energy and flexible, dispatchable resources to meet demand and replace retiring capacity in the next decade. This analysis focuses on three flexible resources that are widely available today: gas-fired turbines, battery storage resources, and virtual power plant resources *(see Exhibit 7)*.

Each technology has a unique profile of benefits and limitations. When the resilience and T&D benefits of VPPs are included in cost-benefit analysis, VPPs can provide the same system values at 40%–60% of the cost of a gas-fired turbine or energy storage installation.[18]

Flexible technologies also have different impacts on the optimal overall portfolio of energy resources. Storage and VPP resources can shift energy demand to better use renewable generation, supporting greater deployment of solar and wind capacity.

Exhibit 7. Annual Costs, Portfolio Availability, Benefits, and Limitations by Flexible Dispatch Technology

Technology	Annual Costs	Portfolio Availability	Benefits	Limitations
Gas-Fired Turbine	Capital costs, operations and maintenance, fuel costs	Baseline VPP-Enabled	• Can dispatch for long durations, pending fuel availability	• Fuel cost and volatility • Dispatch dependent on fuel availability • Carbon and local air pollutant emissions • Does not enhance value of variable renewable energy
Utility-Scale Battery Storage	Capital costs (minus clean energy tax credits), operations and maintenance	Baseline VPP-Enabled	• Enhances value of variable renewable energy • Instant dispatch, not dependent on time of day • Eligible for clean energy tax credits	• Limited duration • Battery must be charged to be available at peak times
Virtual Power Plants	Program management costs, participant incentives	VPP-Enabled	• Uses existing assets on the grid • Quickly scalable and deployable • Can support managing T&D constraints • Enhances value of variable renewable energy • Can provide resiliency benefits for VPP participants	• Limited dispatch duration for each individual device • Availability depends on VPP program characteristics

RMI Graphic. Source: RMI analysis

Results (Portfolios): The VPP-Enabled portfolio avoids gas and substitutes with energy storage while integrating additional renewables.

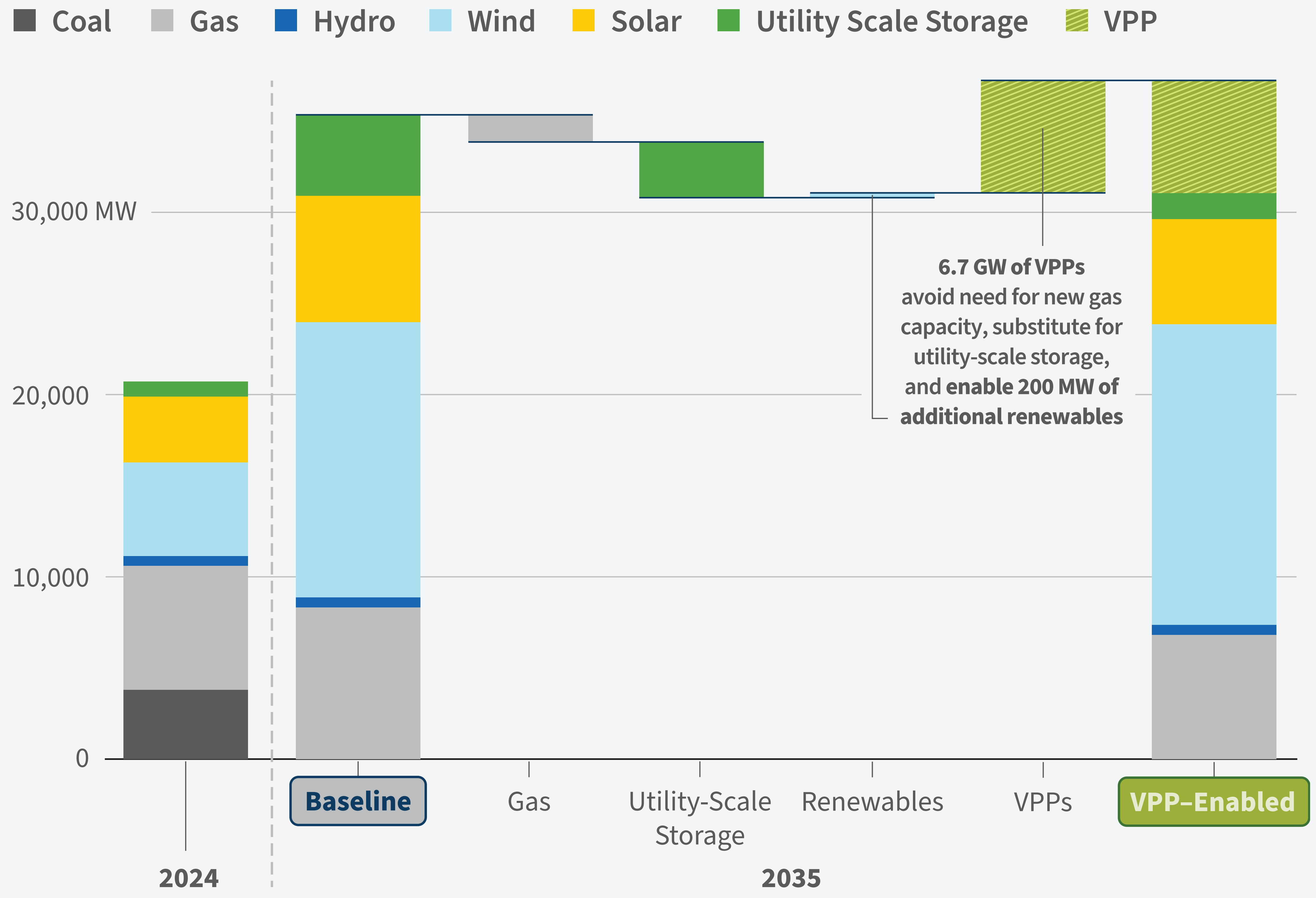
The capacity expansion model builds and operates two portfolios: the Baseline portfolio does not have access to VPPs as a resource; the VPP-Enabled portfolio is able to procure and operate VPPs.

In both cases, cost-optimal portfolios include a combination of resources to meet electrifying demand in 2035 *(see Exhibit 8)*:

- Portfolios with access to **VPPs procure all available capacity** (6.7 GW) across VPP technologies. This represents VPP participation of about a third of households and businesses in the example power system.
- VPPs almost eliminate the need for **new gas capacity**, with a 75% (1.5 GW) reduction compared with the Baseline case.
- VPPs relax the need to procure additional **utility-scale storage**, although storage plays a complementary role, and there are still hundreds of megawatts of incremental storage in 2035 compared with the 2024 system.
- Technologies across the VPP portfolio are dispatched regularly (up to two shifts per day) to integrate renewables and maintain reliability.

Overall, the VPP-Enabled portfolio includes incremental variable renewable capacity and a greater total amount of flexible capacity (including VPP demand flexibility and distributed storage), with less gas-fired capacity and less utility-scale storage.

Exhibit 8: Total Resource Capacity by Portfolio, 2024 and 2035 (Baseline and VPP-Enabled)



RMI Graphic. Sources: EIA Form 860; and RMI analysis

Results (Reliability): VPPs reduce the need for future gas.

The VPP-Enabled portfolio meets annual reserve margin requirements and load in every modeled hour, using substantially less gas and utility-scale storage capacity.

Portfolios with VPPs are also better able to use variable renewable generation to avoid the need for gas dispatch at peak hours. In Exhibits 9 and 10, we show average hourly generation and load shift by technology type on the peak demand day in 2035 for our example Mountain West system. The dotted Gross Load line, representing system load before any demand shifting from VPPs or battery storage, is the same across portfolios. The VPP-Enabled portfolio uses multiple VPP technologies to shift load from evening hours to mid-day, when more solar power is available, and early morning hours, when wind generation is high compared to load.

Exhibit 9: Generation by Technology, 2035 Peak Demand Day (Baseline)

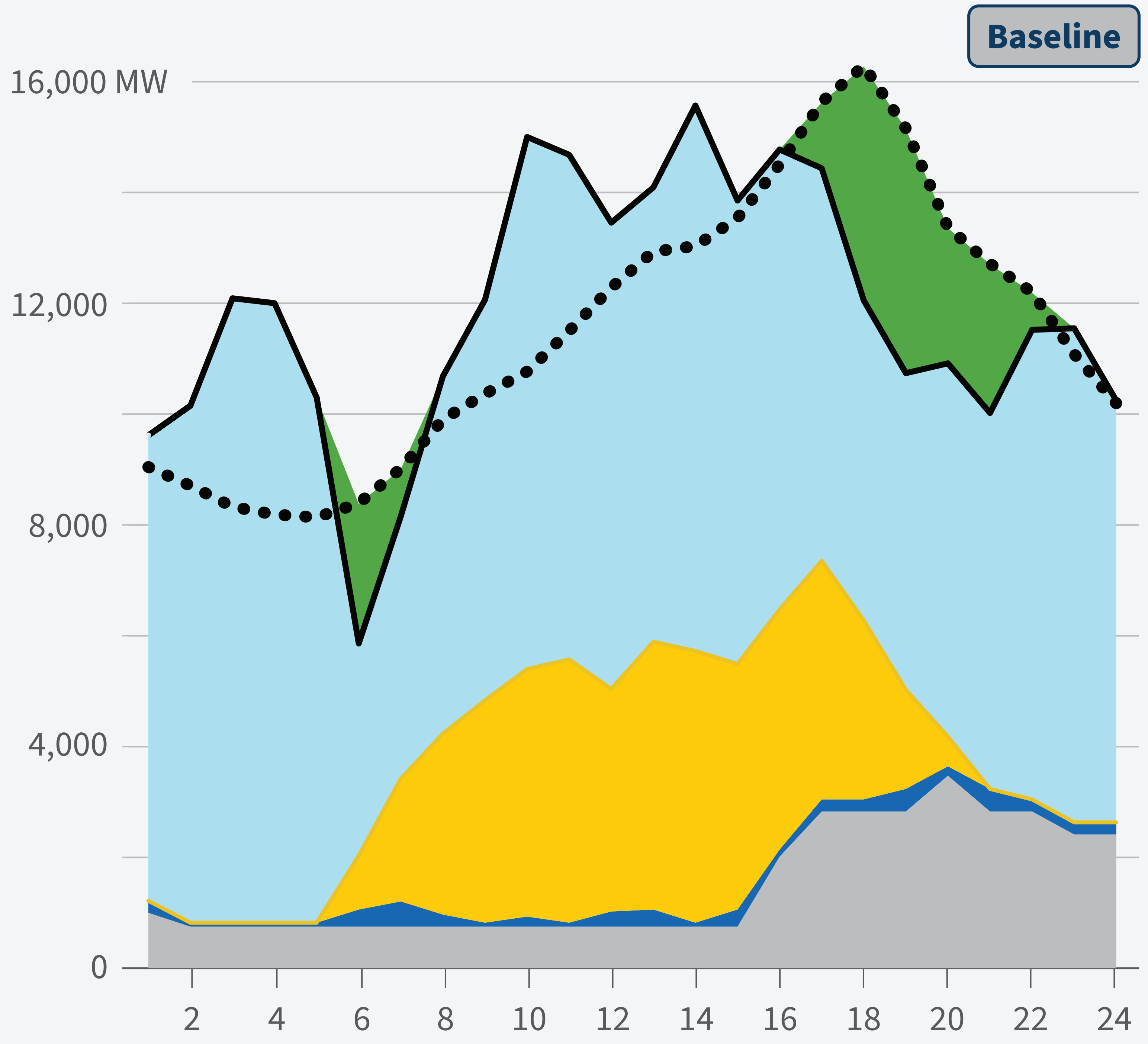
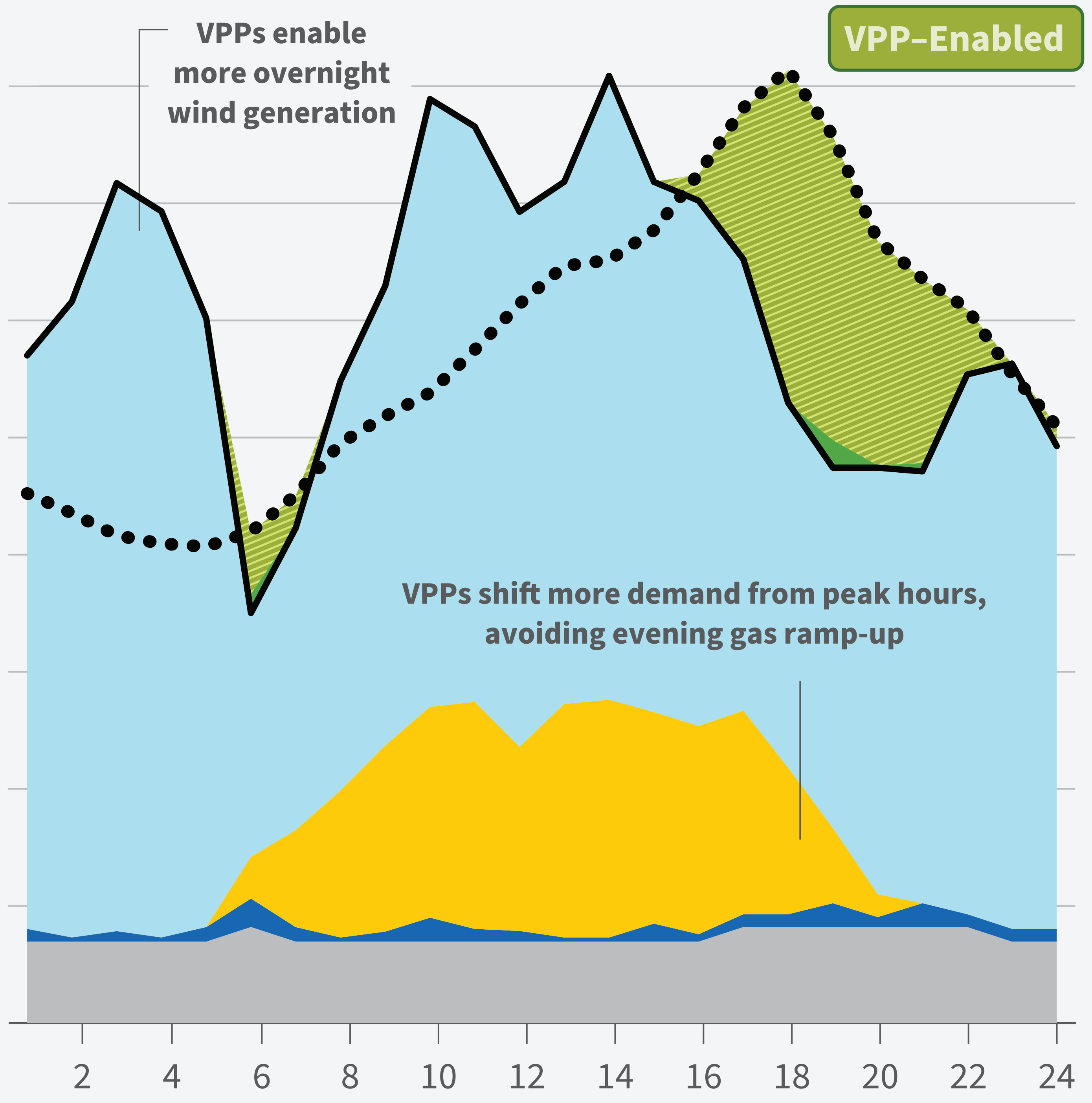


Exhibit 10: Generation by Technology, 2035 Peak Demand Day (VPP-Enabled)



VPPs enable more overnight wind generation

VPPs shift more demand from peak hours, avoiding evening gas ramp-up

RMI Graphics. Source: RMI analysis

Results (Affordability): VPPs reduce net generation costs by 20%, saving households $140 per year.

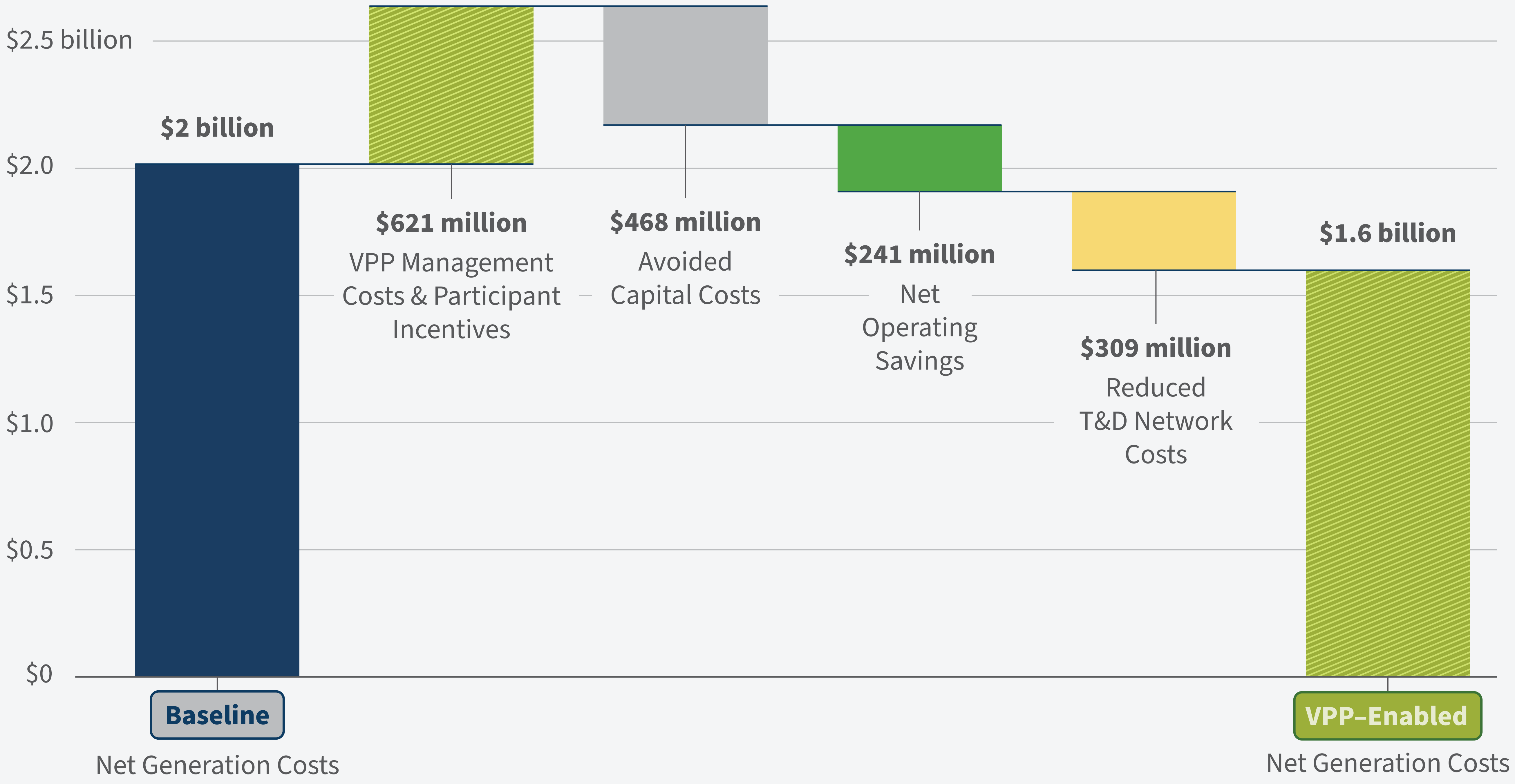
Total portfolio VPP costs include customer incentives, marketing, program management, and control software. In the VPP-Enabled portfolio, these costs total $621 million per year, or about $90 per kilowatt of peak load reduction per year.

The VPP-Enabled portfolio also realizes over $1 billion in benefits each year compared with the Baseline portfolio, including *(see Exhibit 11)*:

- $468 million per year in **avoided capital costs** from new gas and battery storage capacity
- $241 million per year in **net operating savings**, including reduced startup and operations and maintenance costs, additional production tax credit benefits, and reduced use of traditional demand response
- $309 million per year in **reduced T&D network costs**

In total, the VPP-Enabled portfolio reduces net power generation costs by 20%, or about $140 per household (including nonparticipants in VPPs) each year.

Exhibit 11: Net Generation Costs and Benefits, VPP-Enabled versus Baseline Portfolio



Note: "Generation costs" only include net generation costs for the example power system. They do not include costs of depreciation for existing generators or T&D assets, operations, and maintenance for existing T&D assets, or other costs not directly associated with new grid-scale generation.

RMI Graphic. Source: RMI analysis

Results (Emissions): VPPs reduce emissions and costs by providing cost-effective flexibility, avoiding gas capacity, and substituting for energy storage.

VPPs reliably and cost-effectively substitute substantial amounts of utility-scale gas and battery storage. In the example Mountain West system, all 6.7 GW of VPPs are economically selected, reducing the need for 1.5 GW of new gas and 3.0 GW of new utility-scale storage *(see Exhibit 12)*.

The resulting system is not only lower cost, but also lower emissions. In a status quo environment, without any carbon policy, we find that including VPPs in planning reduces emissions 7%, alongside a 20% reduction in net generation costs *(see Exhibit 13)*.

Combining VPPs with carbon policy drives deep emissions and cost savings

We also evaluate the carbon and cost impacts of VPPs in systems with carbon policies. The **Baseline portfolio with carbon policy**, which applies a carbon price to operations and planning, offers large cuts to emissions (42%), with a slight increase in costs (5%).[19] The **VPP-Enabled portfolio with carbon policy** offers a win-win: enabling even greater cuts to emissions (47%) alongside substantial reductions in costs (17% compared with a no-carbon-policy baseline).

Exhibit 12: Net Procured Capacity of Flexible Grid Resources in 2035, by Portfolio

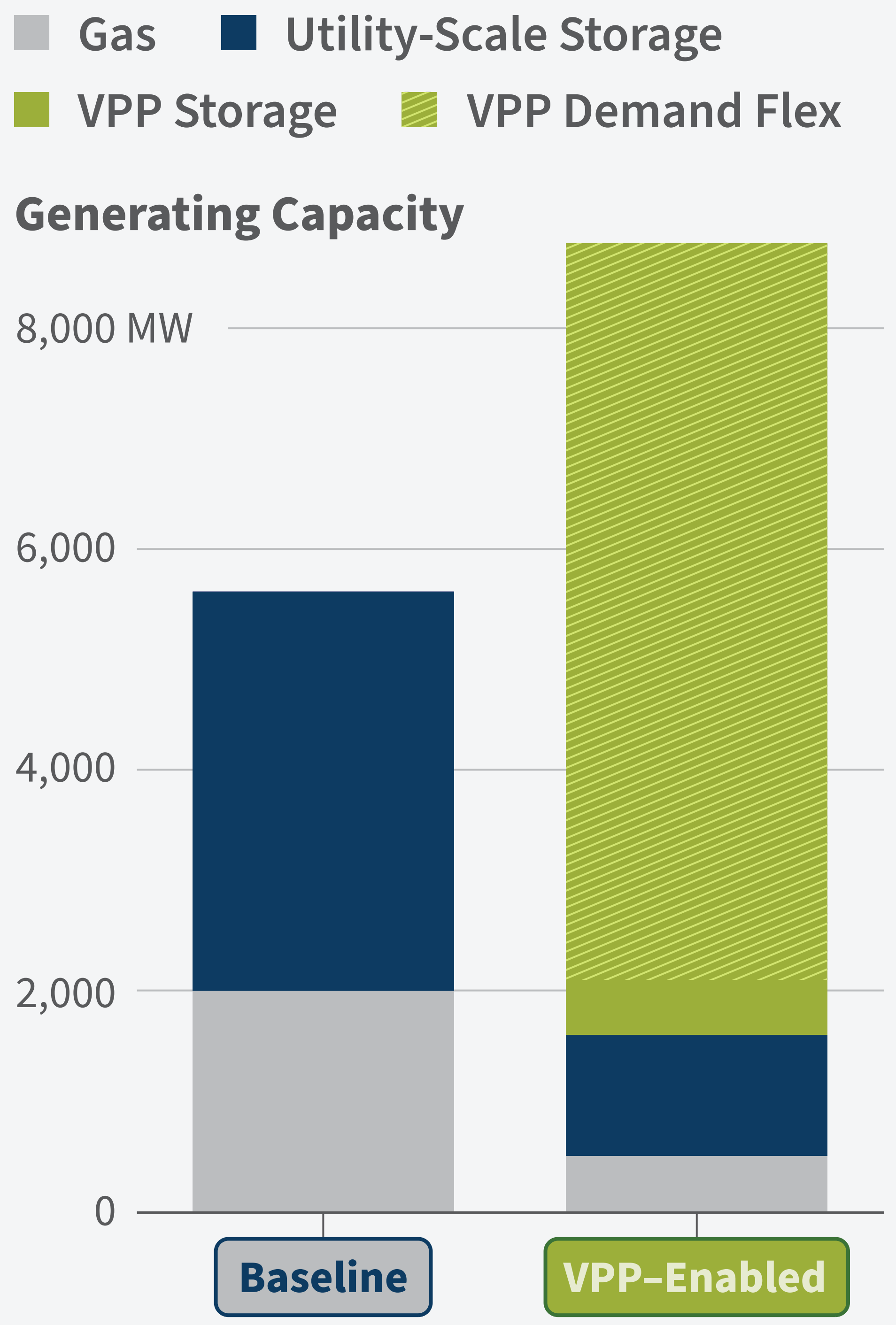
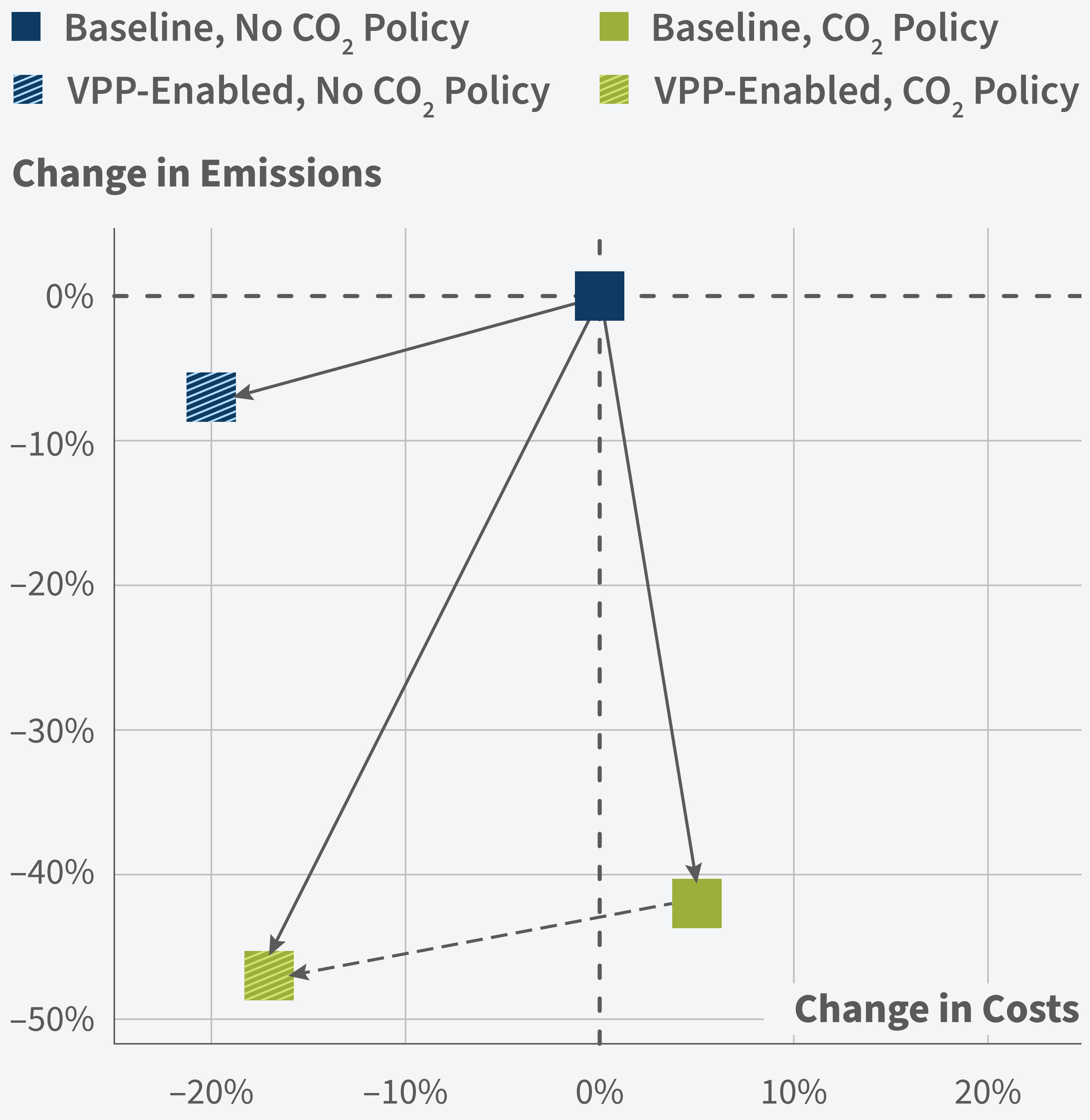


Exhibit 13: Impacts of VPPs and CO_2 Policy on 2035 Emissions and Costs



RMI Graphics. Source: RMI analysis

VPPs' Nationwide Carbon Savings Potential

Overview: VPPs can shift demand to reduce power sector emissions by millions of tons per year.

VPPs can shift demand from high-cost, high-emissions times to low-cost, low-emissions periods, avoiding millions of tons of carbon emissions annually.

Analysis

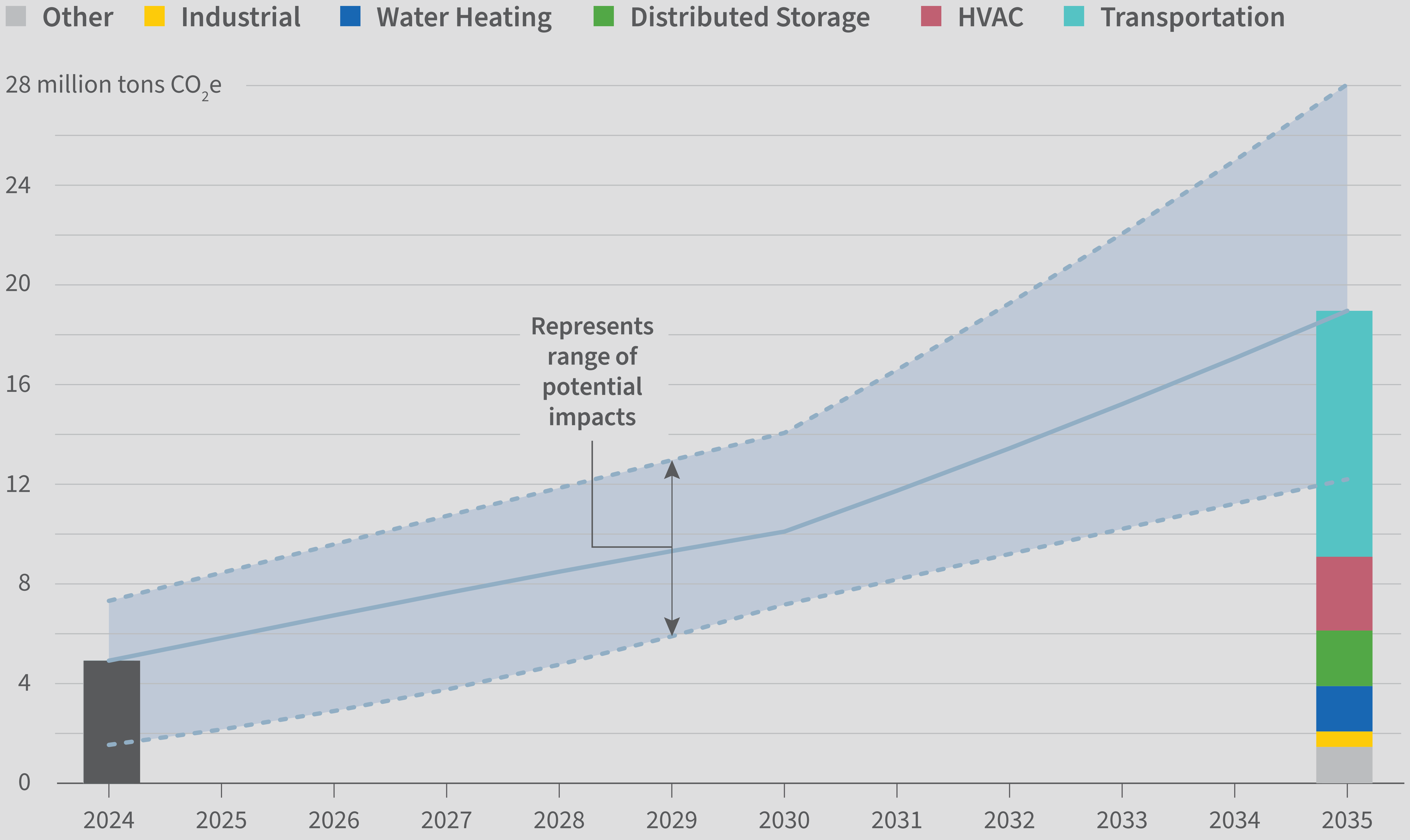
Using projections of electrified load, VPPs, and future US power sector emissions, we simulate the impact of VPPs shifting and shaping demand to avoid carbon emissions.

Results

- We project that over 50 GW of VPPs are online today and over 200 GW could be online by 2035.
- In 2024, VPPs could avoid 1.5 million to 7.3 million tons of carbon emissions, or the equivalent of over 1 million internal combustion vehicles' annual emissions *(see Exhibit 14)*.
- By 2035, VPPs could avoid 12 million to 28 million tons of carbon emissions, or 2% to 4% of projected US power sector emissions.[20]

If VPP enrollment is sustained from 2024 to 2035 and VPPs are operated to avoid emissions from the dirtiest generators on the grid, they can reshape bulk grid demand and meaningfully reduce carbon emissions.

Exhibit 14: Annual VPP Emissions Reduction Potential for the United States, 2024-35



RMI Graphic. Source: RMI analysis

Analysis: We simulate VPP operations to estimate VPPs' potential for avoiding carbon emissions, 2024-35.

Exhibit 15 shows the analytical approach for the ***VPPs' Nationwide Carbon Savings Potential*** study. First, we project electric sector DER deployment, VPP adoption, and hourly grid emissions based on projections from the National Renewable Energy Laboratory (NREL) and Wood Mackenzie.[21] Then, we simulate VPPs across technologies and US states, shifting demand to reduce power sector carbon emissions as much as possible within technical constraints and without exceeding existing system peak demand.

We estimate a range of carbon impacts, based on multiple metrics for calculating grid emissions intensity.

Exhibit 15: Analytical Approach, VPPs' Nationwide Decarbonization Potential

1 Project VPP Capacity

We use NREL Electrification Futures Study (EFS) projections for electrified and technically flexible load in the United States, 2024–35. We use Wood Mackenzie energy storage market forecasts to project distributed storage capacity.

2 Define VPP Potential

Based on NREL EFS characterization of flexible demand technical capabilities and projected pace of VPP adoption, we define VPP potential at the state level, 2024–35.

3 Project Grid Emissions Signals

We use NREL projections scenarios of future US power sector operations and emissions to generate hourly grid emissions factors. This analysis uses an NREL mid-case scenario that projects 95% decarbonization by 2050.

We evaluate VPP dispatch across multiple emissions factors:

- Average emissions rate (AER)
- Long-run marginal emissions rate (LMER)
- Short-run marginal emissions rates (SMER)

4 Identify Demand Shift that Maximizes Avoided Emissions

Based on hourly demand, VPP flexibility, and emissions rates, we dispatch demand flexibility to reduce emissions by shifting load from high-emissions times to low-emissions times.

Demand shifts are subject to technical constraints at the device and system level. Shifts do not exceed previous system peak demand and are subject to technology-specific dispatch constraints.

5 Calculate Total Emissions Reduction

We calculate total emissions savings from VPP demand flexibility dispatch for each month and state, 2024–35.

Note: Additional details on methods, assumptions, and data sources for the national VPP dispatch study are provided in a separate technical appendix.

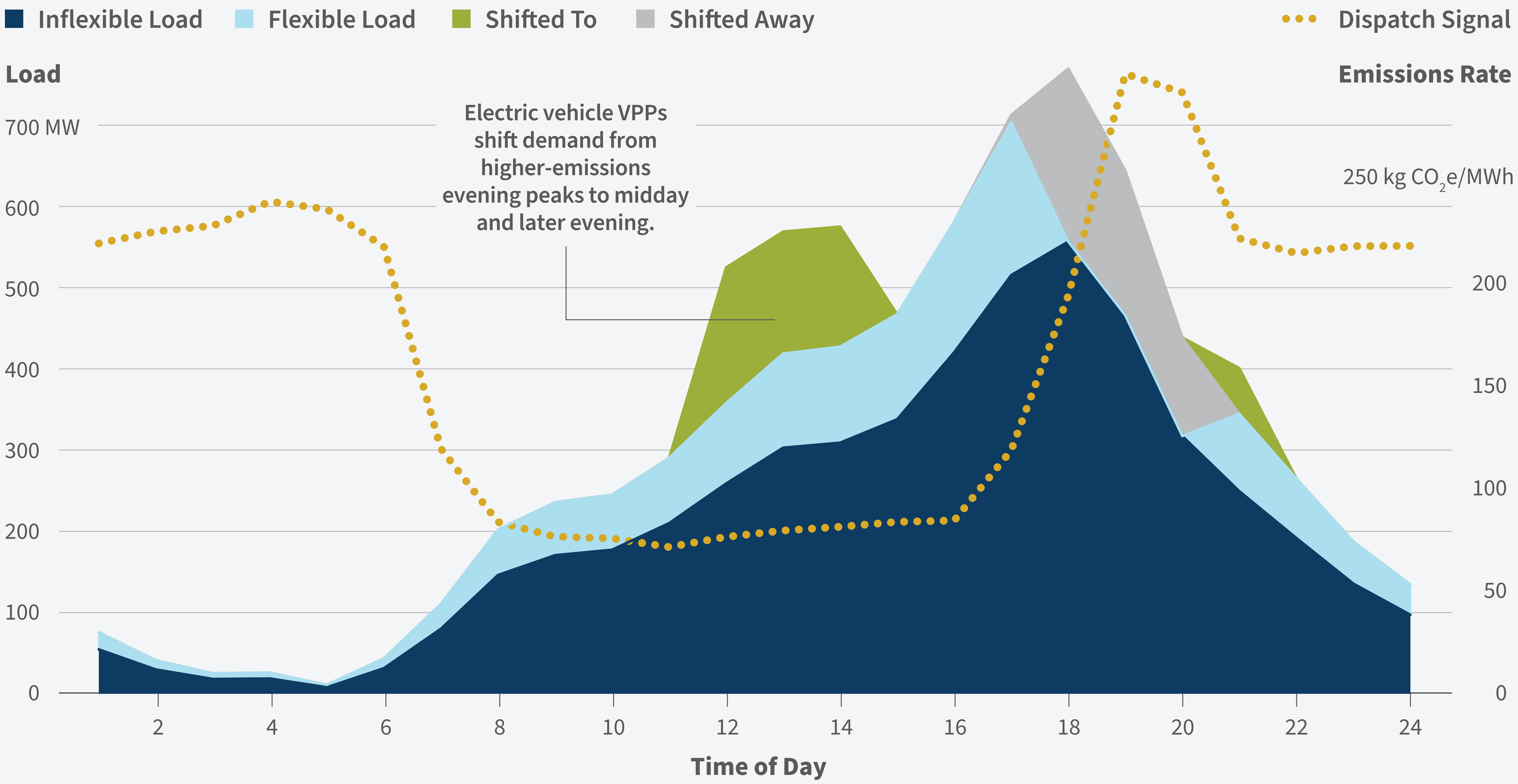
RMI Graphic. Sources: Sun et al., *Electrification Futures Study*, NREL, 2020; *U.S. Energy Storage Monitor 2024 Q1*, Wood Mackenzie, 2024; Pieter Gagnon, Brady Cowiestoll, and Marty Schwartz, *Cambium 2022 Data*, NREL, 2023; and RMI analysis.

Analysis: VPPs shift demand to minimize carbon emissions.

This study estimates total demand and VPP-enrolled demand by technology for each state in each analysis year. Projections of grid emissions intensity act as a "dispatch signal" for the VPP, providing information about which demand shifts would avoid the most carbon emissions. VPPs use the dispatch signal to shift demand to avoid the most carbon emissions without causing an increase to system peak demand or exceeding technology-specific limitations.

Exhibit 16 shows an example of VPP dispatch of light-duty electric vehicle charging demand in New Mexico in August 2030. VPP-enrolled electric vehicles shift charging from the high-emissions peak in the evening toward midday, when emissions are lowest, with a small amount of charging deferred until later in the evening. The VPP shifts a portion of flexible load to simulate real-world limits on changes to charging behavior.

Exhibit 16: Light-Duty Electric Vehicle Charging Load and Average VPP Dispatch (New Mexico, August 2030)



Electric vehicle VPPs shift demand from higher-emissions evening peaks to midday and later evening.

RMI Graphic. Source: RMI analysis

Analysis: VPP enrollment and economy-wide electrification could reach over 100 GW of VPP capacity by 2030 and accelerate to over 200 GW by 2035.

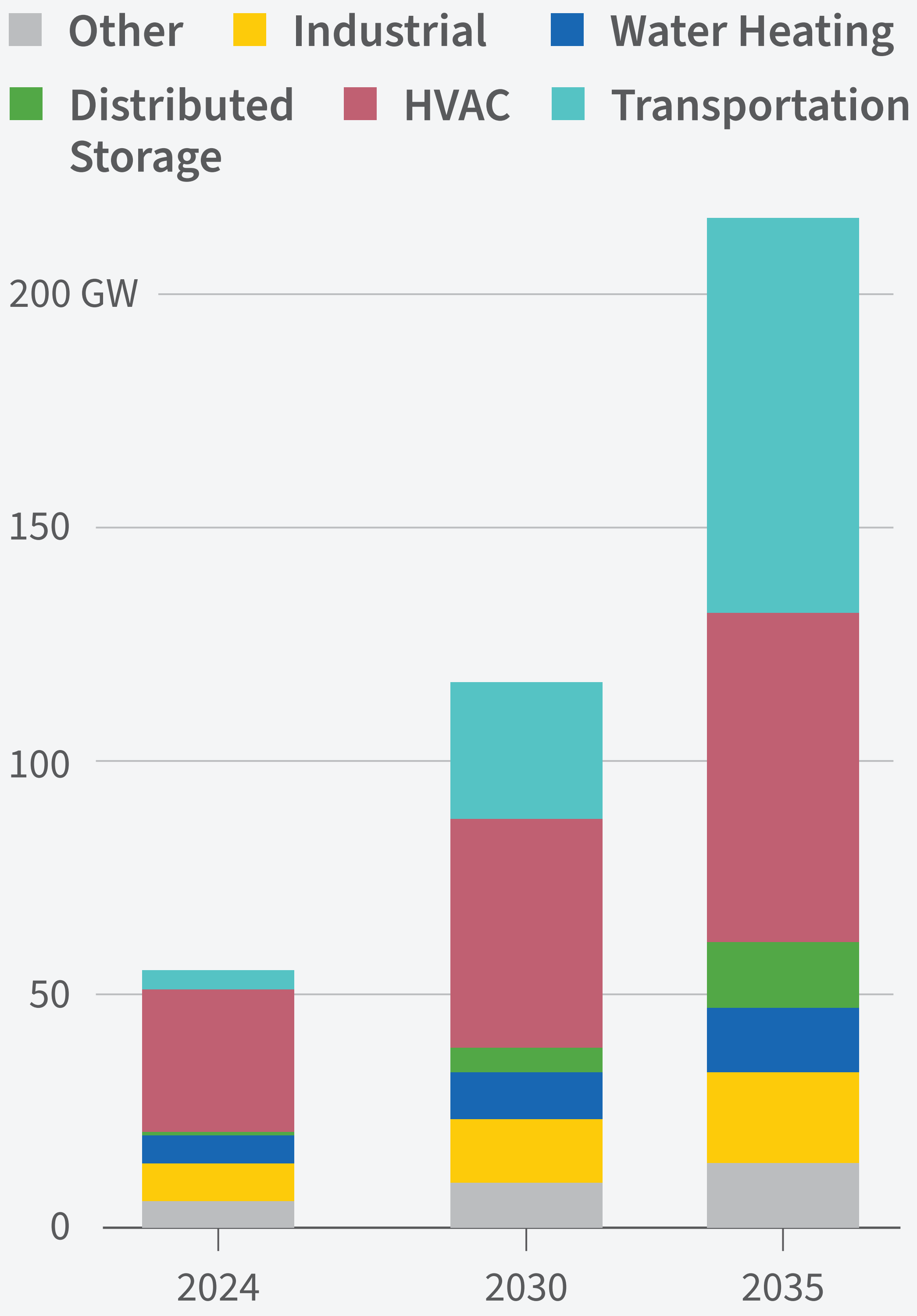
Using forecasts from NREL and Wood Mackenzie, this study projects that total VPP capacity could reach over 100 GW in 2030 and 220 GW by 2035 *(see Exhibit 17)*.

Electrification and load growth trends drive changes in VPP capacity across technologies:

- Heating, ventilation, and air conditioning loads represent the greatest source of flexible load into the early 2030s.
- Electrified transportation grows through the 2020s and 2030s, becoming the highest-capacity technology for VPPs in 2032.
- Industrial and water heating flexible capacity steadily increases through the 2020s and 2030s but represents a fraction of available flexible capacity by 2035.
- Although total electric load grows by 25% from 2024 to 2035, VPP capacity quadruples in the same period because of changes in technology, electrification, and VPP adoption.

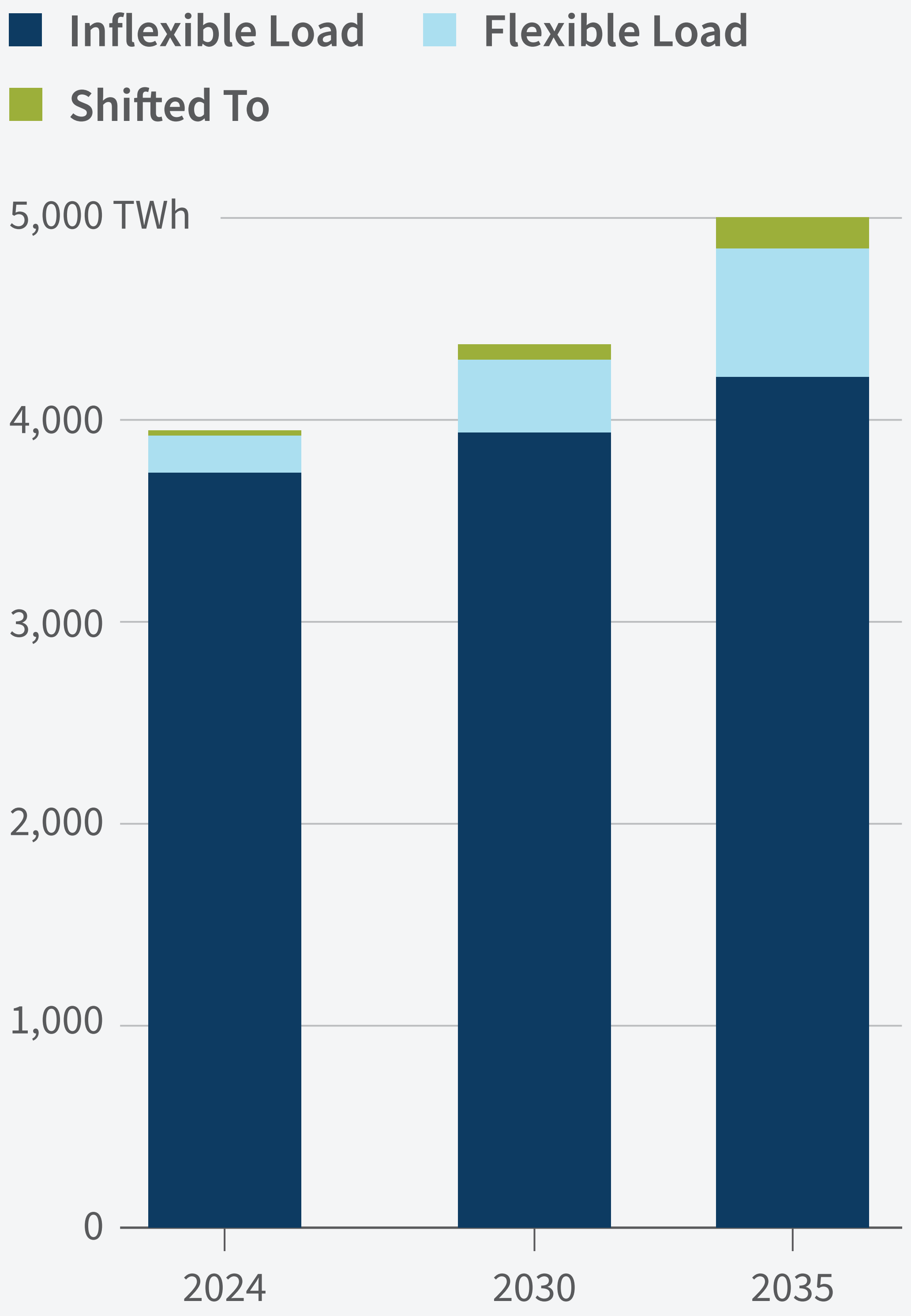
In total, over 14% of total US power sector load could be enrolled in a VPP by 2035. Because VPPs are not constantly dispatched, however, the actual portion of total US load that is shifted by VPP dispatch is much lower. This analysis projects that VPPs could shift up to 0.5% of US power sector load in 2024 and up to 3% of total power sector load in 2035 *(see Exhibit 18)*.

Exhibit 17: VPP Capacity Potential by Type, 2024, 2030, and 2035



RMI Graphic. Sources: Sun et al., *Electrification Futures Study*, 2020; and *U.S. Energy Storage Monitor 2024 Q1*, Wood Mackenzie, 2024

Exhibit 18: Total Annual Load Flexibility, 2024, 2030, and 2035



RMI Graphic. Source: RMI analysis

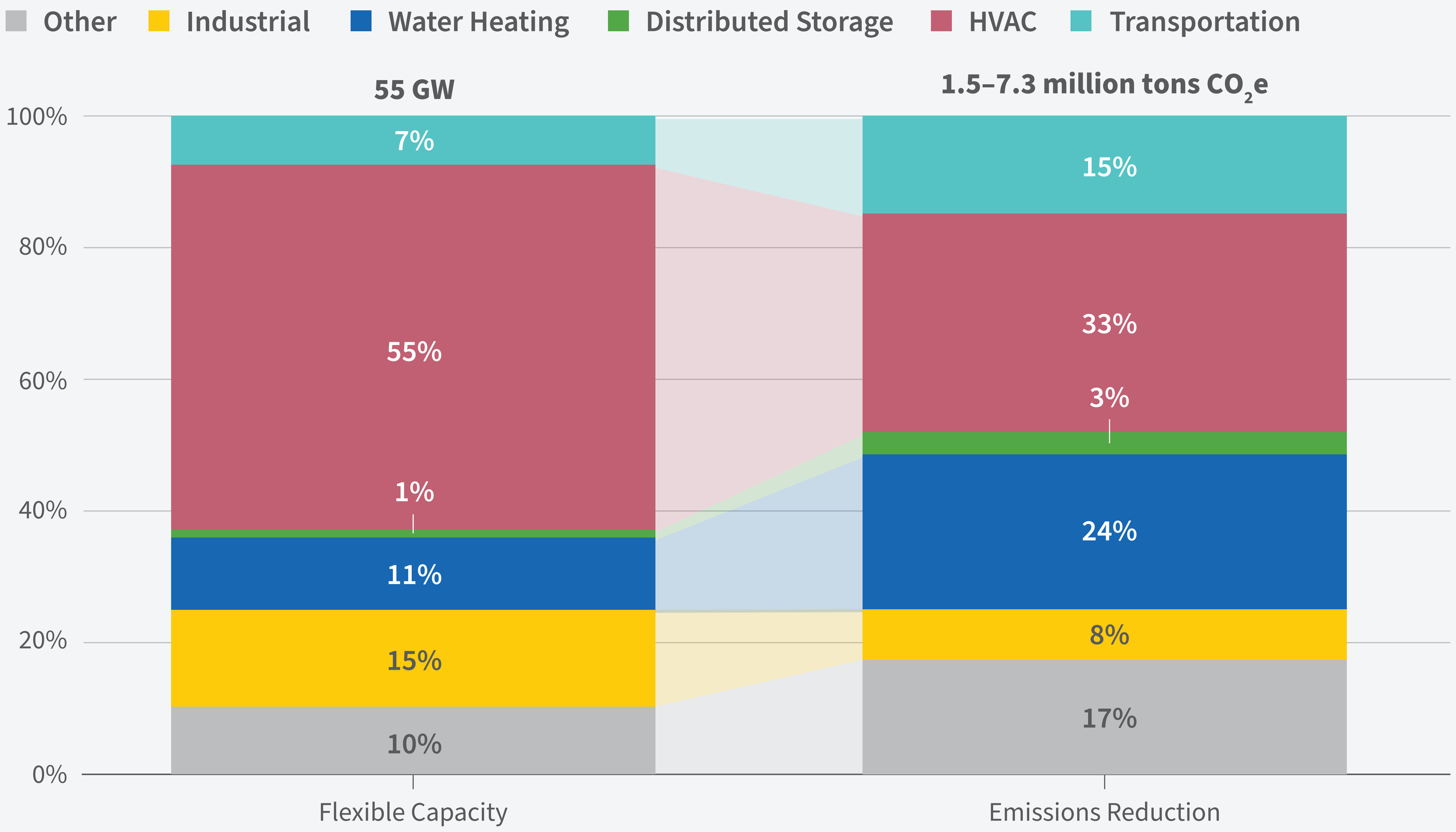
Results: VPPs avoid 1.5 million to 7.3 million tons of carbon emissions in 2024, or up to the equivalent of 1.7 million internal combustion vehicles.

In 2024, over 50 GW of potential VPP capacity could avoid 1.5 million to 7.3 million tons of carbon dioxide emissions across the United States *(see Exhibit 19)*. HVAC technologies represent the greatest capacity of VPPs deployed in 2024 with over 30 GW of capacity.

Emissions reduction varies from 1.5 million tons to 7.3 million tons, based on the grid carbon emissions factors used.

The low end of the range is informed by grid-average emissions rates, which assume that all sources of generation adjust equally in response to changes in load. The high end of the range is informed by marginal emissions rates, which assume that only the highest-cost generator (which may be a less-efficient, more emissions-intensive generator) shifts generation in response to changes in load.[v]

Exhibit 19: VPP Flexible Demand Capacity and Potential Emissions Reduction, 2024



RMI Graphic. Sources: Sun et al., *Electrification Futures Study*, 2020; *U.S. Energy Storage Monitor 2024 Q1*, Wood Mackenzie, 2024; and RMI analysis

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[v] This report analyzes a range of grid emissions factors to generate a reasonable range of emissions reduction estimates. For more information, see Pieter Gagnon and Wesley Cole, "Planning for the Evolution of the Electric Grid with a Long-Run Marginal Emissions Rate," *iScience* 25, no. 3 (March 2022): 103915, **https://doi.org/10.1016/j.isci.2022.103915**.

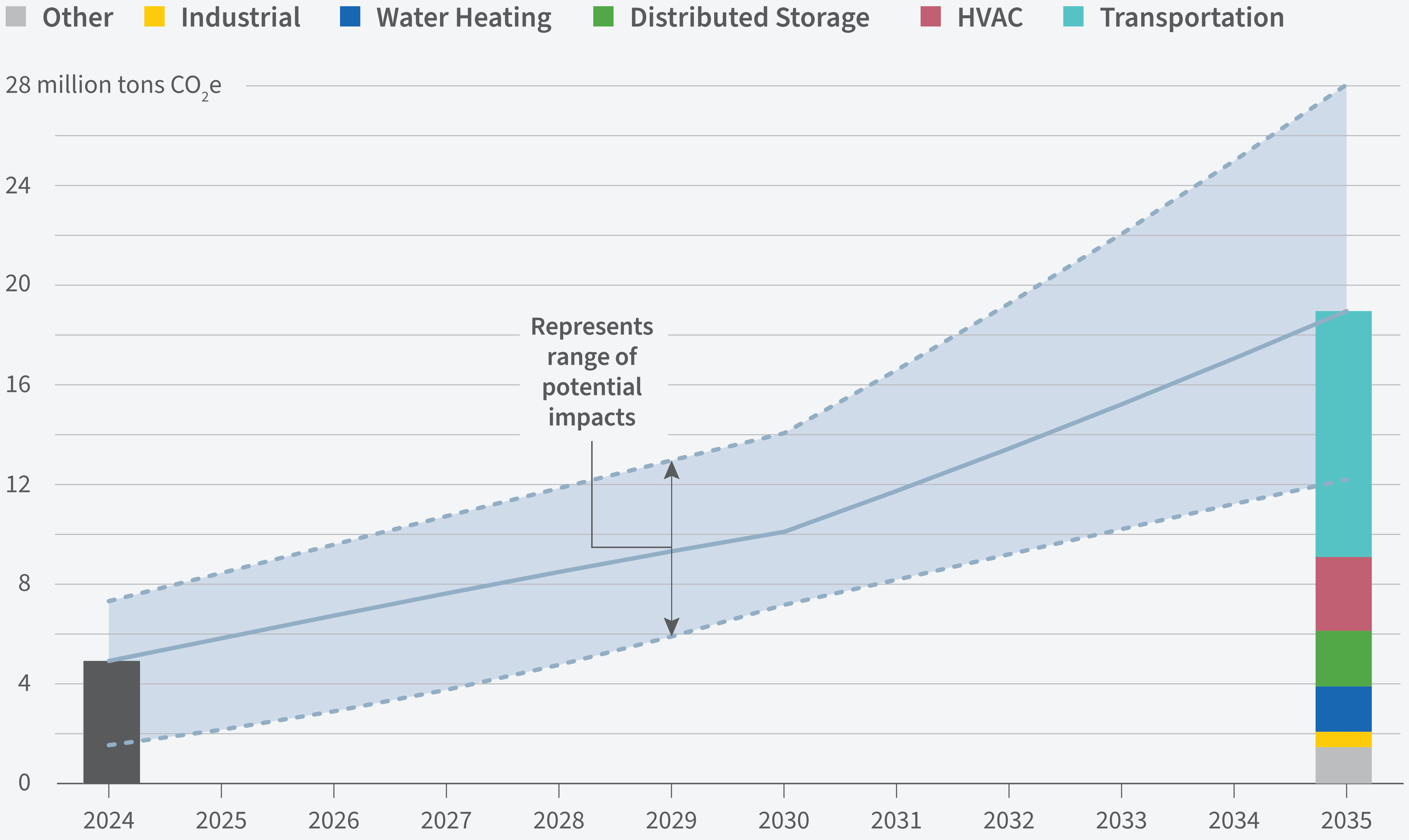
Results: Nationally, VPPs can avoid 12 million to 28 million tons of carbon emissions in 2035, reaching 2% to 4% of projected US power sector emissions.

Electrification, changes to power sector generation technologies, and increased VPP enrollment drive increases in VPPs' emissions impact over time.

VPP carbon impacts expand in the 2020s. Emissions reduction potential from VPPs grow to 7 million to 14 million tons by 2030, driven by increases in VPP enrollment through 2030 *(see Exhibit 20)*.

In the 2030s, accelerating electrification drives increases in carbon savings. Projected electrification trends accelerate in the 2030s, which increases the asset base and decarbonization potential for VPPs. VPPs could avoid 12 million to 28 million tons of carbon emissions by 2035, or 2% to 4% of projected total US power sector emissions.[vi]

Exhibit 20: Annual VPP Emissions Reduction Potential for the United States, 2024-35



RMI Graphic. Source: RMI analysis

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vi This analysis uses US power sector emissions projections from NREL Cambium's Mid-Case with 95% Decarbonization by 2050. See: Pieter Gagnon, Brady Cowiestoll, and Marty Schwartz, *Cambium 2022 Data*, NREL, 2023, **https://scenarioviewer.nrel.gov**.

Maximizing the VPP Power Shift

Four Key Conditions for Realizing VPPs' Grid Potential

Based on these analyses, we identify four key conditions that are critical for VPPs to reach their potential to deliver reliability, affordability, and decarbonization benefits.

1. **Distributed energy resources (DERs) continue to be deployed and VPP enrollment accelerates across the country.**
   VPP grid impacts scale directly with total capacity enrolled in VPPs, which depends on deployment of VPP-enabled technologies and easy enrollment in VPP programs. Utilities, regulators, and VPP developers can provide financing options and build a seamless enrollment experience to address customer cost and acquisition barriers.

2. **VPP capabilities, program design, and customer experience support regular, responsive VPP dispatch.**
   Although some key grid services (e.g., generation capacity, resilience) can be provided by dispatching at key times, others maximize their impact with regular VPP dispatch (e.g., fuel savings, reducing emissions). When VPP platforms can choose which grid services they participate in and VPP participants can choose their level of participation, VPPs can deliver high-value operations and positive participant experiences.

3. **VPPs have accurate, timely signals about grid conditions and carbon emissions.**
   VPP operations that are most effective for reducing emissions vary depending on the weather, season, and geography. VPP platforms can integrate grid emissions signals into participant interfaces and operational decision-making to ensure VPP dispatch is aligned with avoiding carbon emissions.

4. **Grid decision makers evaluate, plan for, and realize the full value of VPPs, including avoided transmission and distribution (T&D) costs.**
   Although VPPs were cost-effective in our analysis without considering T&D benefits, avoided T&D costs are a critical savings opportunity for ratepayers. Utilities, regulators, and VPP developers can use emerging integrated distribution system planning methods to ensure all VPP benefits are captured.

Key Condition 1. DERs continue to deploy and VPP enrollment accelerates across the country.

Unlike other grid-scale resources, which require construction of a new facility to meet grid demands, VPPs can aggregate DERs that may already be connected to the grid. This flexibility enables VPPs to rapidly deploy and adapt to meet grid needs.

In the *VPPs' Nationwide Carbon Savings Potential* analysis, VPPs' emissions impact scales with enrollment. The Slow Enrollment sensitivity tests a VPP enrollment ceiling of 20% of all DERs in 2050, versus the 60%–90% enrollment target by 2050 in our main Sustained Enrollment case.[22] In the Slow Enrollment sensitivity, VPPs avoid 6 million to 13 million tons of carbon emissions by 2035 *(see Exhibit 21)* — less than half of the 12 million to 28 million tons of emissions reduction reached in our accelerated enrollment case *(see Exhibit 22)*.

DER deployment and VPP enrollment face unique challenges because each individual device's enrollment is subject to a series of decisions by VPP participants. Prohibitive costs or delays for DER installation, for example, or unintuitive VPP enrollment processes could significantly affect total VPP enrollment. Grid decision makers, including utilities, regulators, and VPP developers, can address these barriers by simplifying VPP enrollment, developing open-ended VPP programs with opt-out provisions, and providing financing resources for procuring DERs.

Exhibit 21: Emissions Reductions over Time (Slow Enrollment), 2024-2035

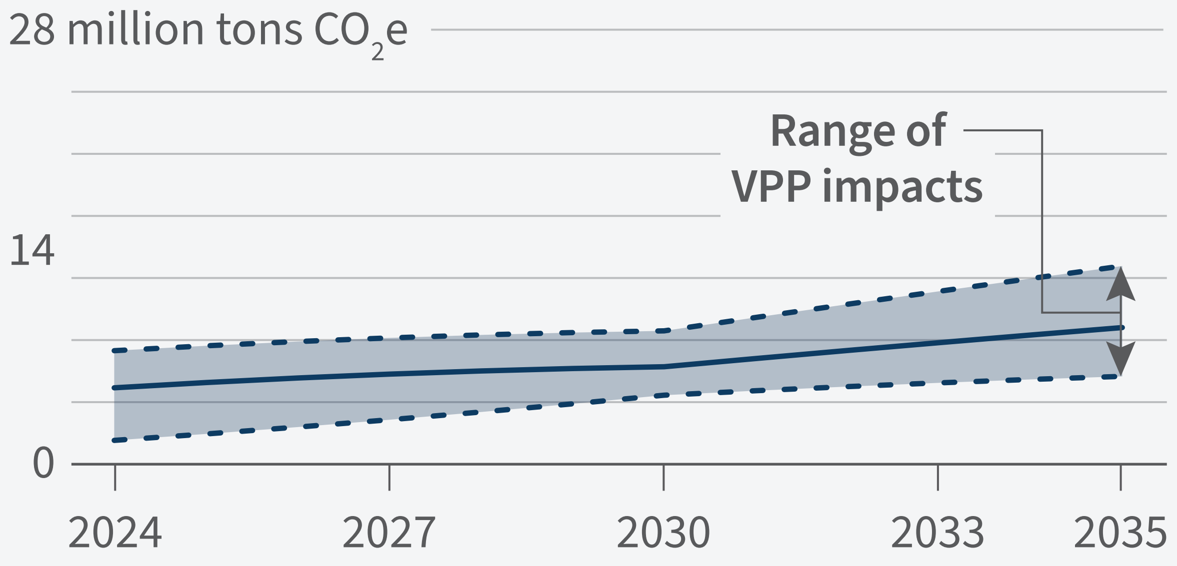
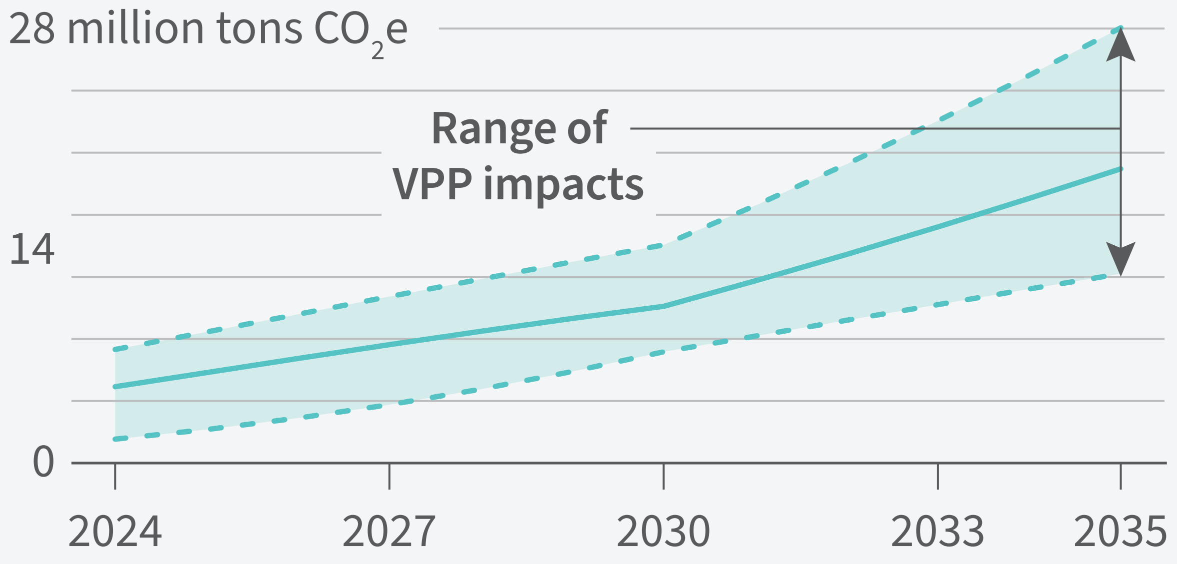


Exhibit 22: Emissions Reductions over Time (Sustained Enrollment), 2024-2035



RMI Graphics. Source: RMI analysis

Emerging Options

- **Simplify VPP enrollment** with opt-out mechanisms and simple, understandable programs and materials.
- **Empower customers to use the device and provider of their choice** through regulator- and utility-led programs that welcome a variety of technologies and providers.
- **Offer financing that removes up-front hurdles** through utility, VPP, or third-party financing for DERs and fair, regular compensation.

Leading Examples

- **Utility:** Arizona Public Service enrolled approximately 6.5% of residential customers in its SmartRewards thermostat program in just five years.
- **Regulator:** The California Public Utility Commission's Demand-Side Grid Support program offers open access to compensation for customers that provide grid services.

Sources: Brehm and Tobin, *Virtual Power Plant Flipbook*, 2024; St. John, "Smart Thermostats," 2023; *2022 Annual Electric Power Industry Report, Form 861*, EIA, 2023; and "Demand Side Grid Program," California Energy Commission, March 12, 2024, **https://www.energy.ca.gov/programs-and-topics/programs/demand-side-grid-support-program**

Key Condition 2. VPP capabilities, program design, and customer experience support regular, responsive VPP dispatch.

VPPs provide a range of services to the electricity grid, which each carry different implications for VPP operations and dispatch *(see Exhibit 23, next page)*. Using VPPs to provide capacity during system peaks, for example, may require several dozen or fewer dispatches per year.[23] Other VPP services, including reducing fuel costs and emissions, provide incremental benefits each time VPPs are dispatched.

At the same time, VPP participant experience is a critical element of sustainable VPP program design. The customer experience of regular VPP dispatch will vary by grid service, technology, and VPP program design. Some VPP operations, like distributed storage management for ancillary services may cause little discernible impact on participants; other participants may voluntarily shift load regularly in response to compensation.[24]

In both analyses of this report, VPP technologies are allowed to maximize benefits by dispatching regularly. Although key VPP services, such as peaking capacity, are met with VPP operations in just the highest-demand hours, regular VPP dispatch consistently manages demand to maximize the value of variable renewable energy and avoid fuel costs.

Successful VPP programs with daily dispatch frequencies already exist on the grid.[25] For many VPP participants and grid operators, however, regular dispatch of VPPs to provide grid services may be new terrain. Grid operators can ensure that VPPs are compensated for a range of grid services, and VPP developers can pass compensation to customers and manage operations to ensure positive customer experiences.

Key Condition 2. VPP capabilities, program design, and customer experience support regular, responsive VPP dispatch.

Exhibit 23. VPP Services, System Benefits, and Typical Frequency of Dispatch

VPP Service	System Benefit	Frequency of Dispatch
Capacity	Avoid, reduce, or defer investment in generation capacity (e.g., gas turbines)	10–35 dispatches annually, based on times of peak demand
	Avoid, reduce, or defer investment in distribution or transmission capacity (e.g., transmission or distribution upgrades)	Variable, depending on specific grid needs
Energy	Reduce system fuel costs and emissions by shifting demand toward low-emissions periods	Daily
Ancillary Services	Cost-effectively provide grid services such as frequency response	Variable, up to daily
Resilience	Provide energy or reduce grid needs during resiliency events	Infrequently, during grid resilience events

RMI Graphic. Source: RMI analysis

Emerging Options

- **Ensure VPPs have access to the full value stack** of services and can provide multiple grid services over multiple timescales.
- **Offer multiple dispatch options to VPP participants** and compensate them for services provided.

Leading Examples

- **Utility:** Hawaiian Energy's Battery Bonus program dispatches to meet system peak demand daily.
- **Market:** The Electric Reliability Council of Texas's aggregated DER pilot allows VPPs to participate in and respond to a range of wholesale market signals.

Sources: Brehm and Tobin, Virtual Power Plant Flipbook, 2024; and Robert Walton, "Texas Moves Ahead with Expanded 80 MW Distributed Energy Resource Pilot Designed to Boost Grid Reliability," UtilityDive, November 4, 2022, **https://www.utilitydive.com/news/texas-puc-aggregated-distributed-energy-resource-ader-pilot/635784/**

Key Condition 3. VPPs have accurate, timely signals about grid conditions and carbon emissions.

The VPPs' Nationwide Carbon Savings Potential analysis shows grid emissions patterns that vary widely across geographies and seasons. The two examples in Exhibits 24 and 25 *(see next page)* show average hourly load, emissions intensity, and VPP dispatch for VPPs in New Mexico in August 2040 and North Dakota in December 2040. Grid emissions intensity, represented as the yellow dotted line, shows low emissions midday in New Mexico, when solar generation is highest. By contrast, the lowest-emissions periods in North Dakota are overnight, when demand is low and wind generation may be highest.

Although overnight demand is lower in the New Mexico example, emissions in the overnight period are higher than the midday period, when there's plentiful solar generation. Time-of-use rates that incentivize overnight versus midday charging, for example, may not reduce carbon emissions in this case.

To effectively reduce emissions in real time, VPPs need accurate, timely signals about grid conditions, and reasonable expectations about how grid conditions will change in the future. VPP developers and grid operators can collaborate with third parties to provide grid emissions data and ensure it is understandable and actionable by VPPs and participants.

Emerging Options

- **Provide information about grid emissions** in an accessible way to VPP participants.
- **Manage VPP operations** to align service provision and carbon reduction.

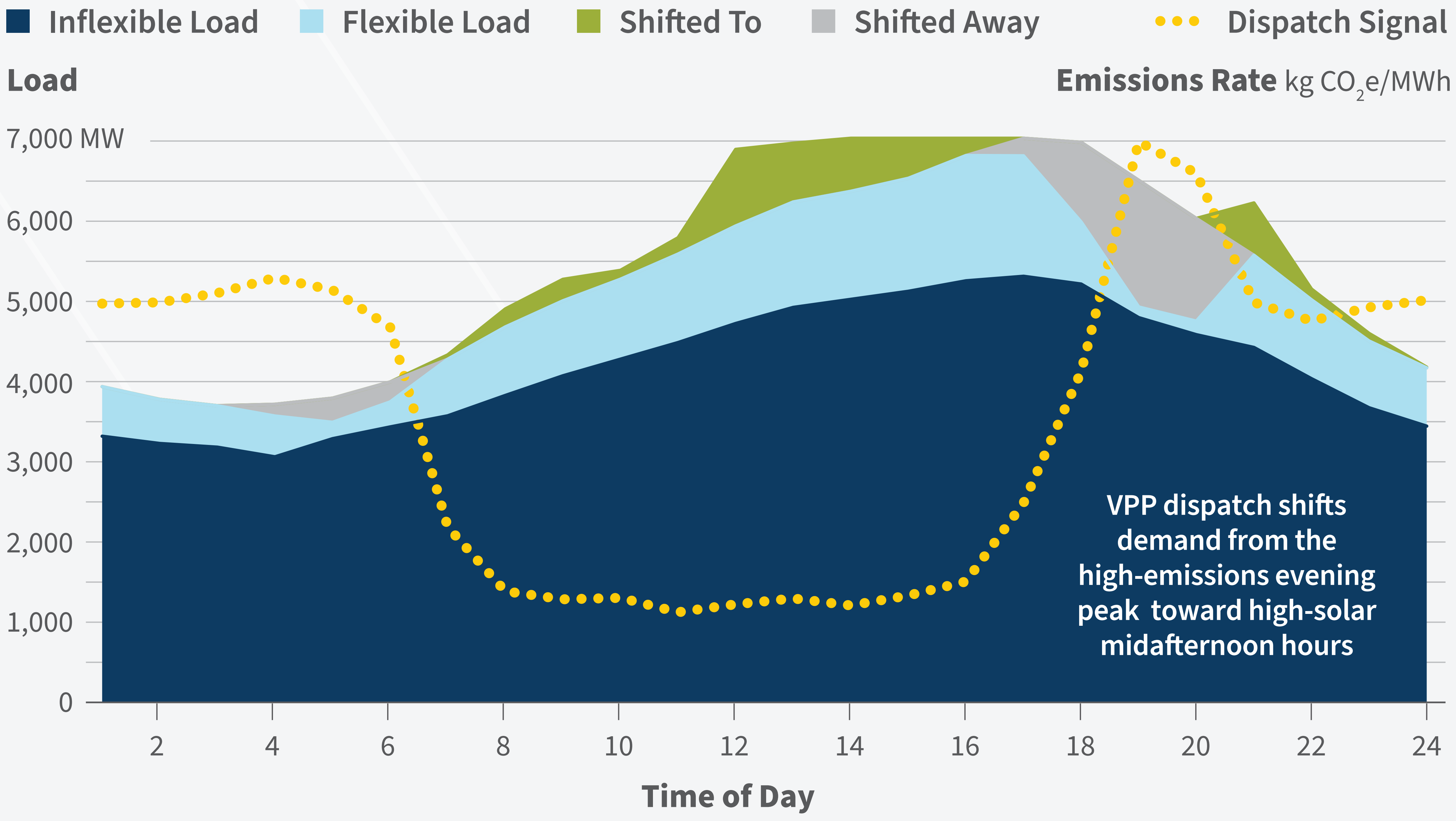
Leading Examples

- **VPP:** WattTime Electricity Maps, and REsurety each provide grid emissions signals and partner with multiple technology manufacturers to integrate grid emissions signals into its operations.

Sources: Guide to Sourcing Marginal Emissions Sourcing Data, Clean Energy Buyers Institute, 2022, **https://cebi.org/wp-content/uploads/2022/11/Guide-to-Sourcing-Marginal-Emissions-Factor-Data.pdf**

Key Condition 3. VPPs have accurate, timely signals about grid conditions and carbon emissions.

Exhibit 24: Projected System Average Hourly Load and VPP Dispatch (New Mexico, August 2040)

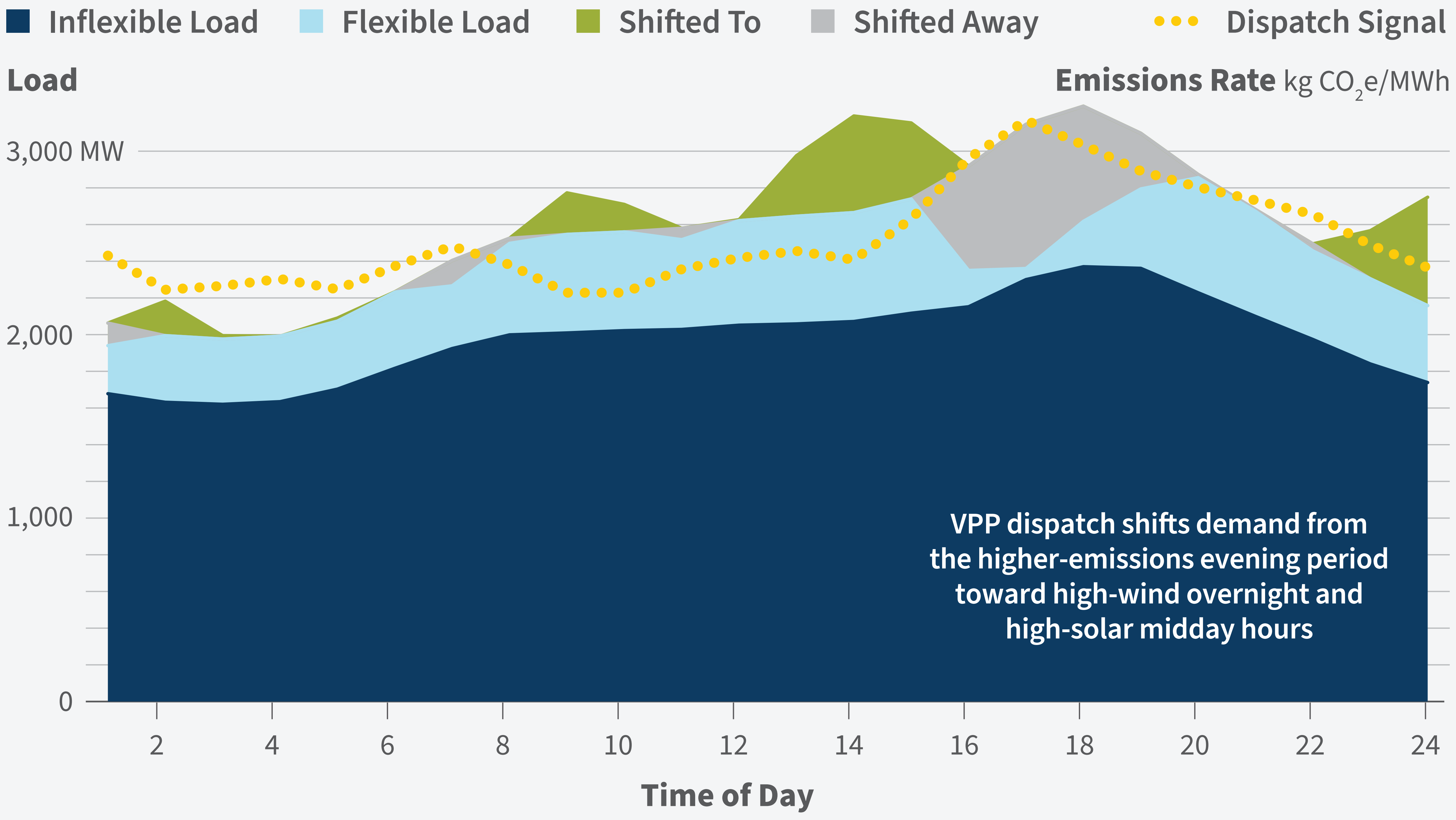


VPP dispatch shifts demand from the high-emissions evening peak toward high-solar midafternoon hours

Note: The VPP dispatch signal shown is the long-run marginal emissions rate; we also evaluated average and short-run marginal emissions rates.

RMI Graphic. Sources Pieter Gagnon, Brady Cowiestoll, and Marty Schwartz, *Cambium 2022 Data*, NREL, 2023; and RMI analysis

Exhibit 25: Projected System Average Hourly Load and VPP Dispatch (North Dakota, December 2040)



VPP dispatch shifts demand from the higher-emissions evening period toward high-wind overnight and high-solar midday hours

Note: The VPP dispatch signal shown is the long-run marginal emissions rate; we also evaluated average and short-run marginal emissions rates.

RMI Graphic. Source: Pieter Gagnon, Brady Cowiestoll, and Marty Schwartz, *Cambium 2022 Data*, NREL, 2023; and RMI analysis.

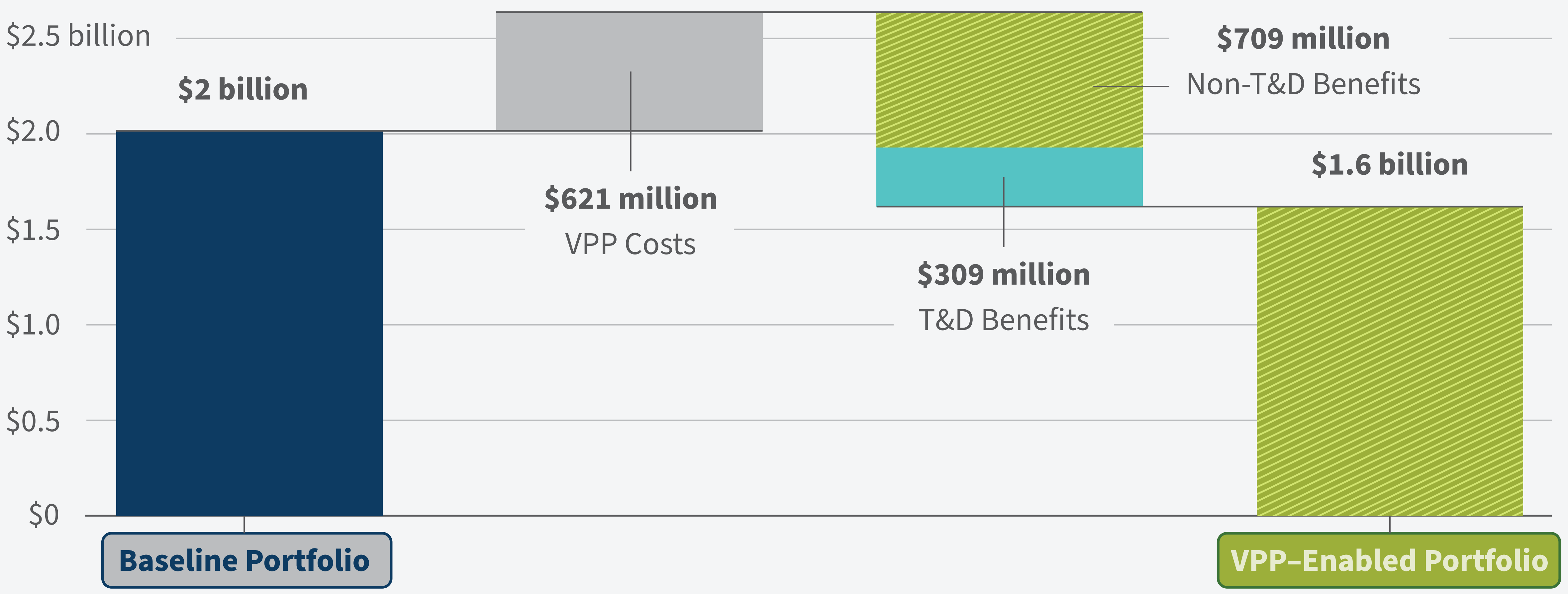
Key Condition 4. Grid decision makers evaluate, plan for, and realize the full value of VPPs, including avoided T&D costs.

Unlike traditional utility-scale resources, VPPs provide benefits at virtually all levels of the electricity system, from the bulk power system down to the distribution system and individual customers. Studies from across the country have found that distribution-connected resources can significantly reduce T&D costs.[26] VPPs realize these benefits by managing voltage, reducing losses across the T&D grid, and avoiding new capital investments in transmission or distribution infrastructure.

T&D benefits represent a substantial portion of VPP-driven benefits. In the study of the role of VPPs, system benefits from VPPs exceed their annual costs without accounting for T&D benefits *(see Exhibit 26)*. If these benefits are not accounted for in utility planning, VPPs continue to be cost-effective. But when these benefits are accounted for and achieved, they drive additional benefits of over $100 per household per year.

Although grid planners may not have enough visibility into the distribution system to identify potential VPP benefits, planning and operating capabilities are changing.[27] Twenty states require utilities to file their plans for meeting distribution needs, and many also publish public information on distribution system conditions and constraints.[28] Continued integration of distribution, transmission, and generation planning, along with increased data accessibility, can unlock additional value for VPPs.

Exhibit 26: Net Costs and Benefits, Baseline vs. VPP-Enabled Portfolios



RMI Graphic. Source: RMI analysis

Emerging Options

- **Integrate distribution system planning** into broader power system planning.
- **Provide public information** on distribution system constraints and the potential for VPPs to avoid distribution costs through capacity maps or non-wires alternative procurements.

Leading Examples

- **Regulator:** New York's Value of Distributed Energy Resources framework includes a transparent locational system relief value metric.
- **Regulator:** Minnesota utilities file biannual integrated distribution plans, which interact with system-wide planning.

Sources: Natalie Mims Frick and Lisa Schwartz, *A National Perspective on State Practices for Integrated Distribution System Planning*, Lawrence Berkeley National Laboratory, 2024, **https://live-etabiblio.pantheonsite.io/sites/default/files/frick_dsp_md_final.pdf**; "Value Stack Resources," New York State Energy Research & Development Authority (NYSERDA), 2024, **https://www.nyserda.ny.gov/All-Programs/NY-Sun/Contractors/Value-of-Distributed-Energy-Resources/Value-Stack-Resources**; and RMI analysis

Directions for Future Analysis: Emerging topics for evaluating the VPP opportunity

These analyses point toward emerging topics that could shed light on an even more comprehensive understanding of VPPs' potential value and inform key actions needed to maximize that potential.

Emerging Topic	Details on Research Need	First Steps Toward Exploration
Refining VPP operations and resource adequacy assumptions with real-world data	Compared to traditional utility-scale resources, VPPs have a shorter track record for providing firm power at high-stress times. Operations data from VPPs can build a track record for firm resource adequacy value and help update planning assumptions accordingly.	• Real-world data from existing deployments (such as Olivine's Fresno Energy Program) can shed light on resource adequacy value of VPPs. • Sunrun and PG&E's Peak Power Rewards program provided consistent peak capacity in summer 2023.
Evaluating distribution system relief opportunities and integrating VPP solutions into distribution and system planning	Utility planners may not have the visibility into the distribution system or processes in place that they need to identify VPP opportunities to reduce distribution costs. Standardized methodologies for evaluating these opportunities are still in development.	• Lawrence Berkeley National Laboratory and the US Department of Energy are developing a broad set of resources to support integrated distribution system planning. • Colorado legislators have included VPPs as part of a comprehensive approach to distribution system planning.
Defining precise, real-time estimates of emissions rates for VPP dispatch and emissions accounting	VPPs can best serve grid needs when they respond to real-time operations data. Future analyses can ensure that emissions metrics for VPP dispatch and emissions evaluation accurately represent VPP dispatch abilities and power system responses to VPP dispatch.	• WattTime has developed a Marginal Operating Emissions Rate for estimating real-time emissions rates and convened the Validating Emissions Rates for Accurate Consequential Impact Taskforce (VERACI-T) for refining understanding of real-time power system emissions impacts.

RMI Graphic. Sources: Vasudha Lathey et al., *Olivine Community: Fresno Energy Program Final Report*, Olivine Inc., November 2021, **https://www.fresnoenergyprogram.com/wp-content/uploads/sites/3/2021/12/Fresno-Energy-Program_Final-Report_121421_clean.pdf**; Jeff St. John, "California's Patchwork Push to Scale up Virtual Power Plants," Canary Media, February 22, 2024, **https://www.canarymedia.com/articles/grid-edge/californias-patchwork-push-to-scale-up-virtual-power-plants**; Hledik and Peters, *Real Reliability*, 2023; "Integrated Distribution System Planning," Lawrence Berkeley National Laboratory, **https://emp.lbl.gov/projects/integrated-distribution-system-planning**; Grace, "Clean Energy Businesses Celebrate," 2024; and "Methodology + Validation," WattTime, 2024, **https://watttime.org/data-science/methodology-validation/**.

Directions for Future Analysis: Characterizing future VPP attributes, technologies, and behaviors

This report evaluates VPPs at the outset of their maturity as energy resources. Over time, our understanding of VPP technologies, behaviors, and optimal operations will continue to evolve as grid-scale VPPs mature.

Emerging Topic	Details on Research Need	First Steps Toward Exploration
Identifying evolving VPP technologies and end-uses	This analysis includes projected VPP technologies that are mature today, and may not include changes in technology and energy use that shape VPPs in the future. Future analyses should continue to evaluate how VPP portfolios might change as end-uses and technologies evolve.	• Exploration of demand flexibility and DER potential for data centers and clean manufacturing • Public research and data sets on load projections and demand flexibility from independent institutions such as NREL • High-precision forecasts of data center load
Understanding key enablers of regular VPP dispatch	With a better understanding of the lived experience and technical implications of regular VPP dispatch, VPP program designers and energy infrastructure planners can ensure cutting-edge VPP programs deliver grid value and high-quality customer experiences.	• Learning from VPP engagements with regular dispatch frequencies • Assessing differential impacts and opportunities of workplace versus residential public EV charging infrastructure
Developing VPP programs that seamlessly integrate across multiple priorities	Devices integrated into VPPs may serve multiple purposes, some of which may compete with VPP aggregation and dispatch. Better understanding of how these competing priorities intersect, and how VPP programs can reconcile these priorities, will lead to more sustainable and effective VPP programs.	• More sophisticated inputs in power sector models that fully characterize VPP customer behaviors and priorities, including but not limited to decarbonization, economic value, comfort, and resiliency

RMI Graphic. Sources: Amy Daniell, “Data Centers’ Role in Providing Resilience and Flexibility in Power Grids,” Data Center Dynamics, July 2, 2024, **https://www.datacenterdynamics.com/en/opinions/data-centers-role-in-providing-resilience-and-flexibility-to-power-grids/**; Sun et al., *Electrification Futures Study*, 2020; Sean Morash, *Charging Ahead: Grid Planning for Vehicle Electrification*, Energy Systems Integration Group, January 2024, **https://www.esig.energy/wp-content/uploads/2024/01/ESIG-Grid-Planning-Vehicle-Electrification-report-2024.pdf**

Learn More about VPPs

To learn more about VPPs, consider the following resources:

- Ryan Hledik and Kate Peters, ***Real Reliability: The Value of Virtual Power***, The Brattle Group, 2023.
- Ryan Hledik, Kate Peters, and Sophie Edelman, ***California's Virtual Power Potential***, The Brattle Group, 2024.
- ***Aggregated Distributed Energy Resources in 2024: The Fundamentals***, National Association of Regulatory Utility Commissioners (NARUC) and RMI, 2024.
- Jennifer Downing et al., ***Pathways to Commercial Liftoff: Virtual Power Plants***, US Department of Energy, 2023.
- Kevin Brehm and Mary Tobin, ***Virtual Power Plant Flipbook***, RMI and VP3 2024.
- Kevin Brehm et al., ***Meeting Summer Peaks: The Need for Virtual Power Plants***, RMI and VP3, 2024.
- ***VPP Policy Principles***, VP3 Regulatory and Policy Strategy Working Group, 2024.
- Kevin Brehm et al., ***Virtual Power Plants, Real Benefits***, RMI and VP3, 2023.
- Liza Martin and Kevin Brehm, "**Clean Energy 101: Virtual Power Plants**," RMI, 2023.

Endnotes

1. Jennifer Downing et al., *Pathways to Commercial Liftoff: Virtual Power Plants*, US Department of Energy, 2023, **https://liftoff.energy.gov/wp-content/uploads/2023/10/LIFTOFF_DOE_VVP_10062023_v4.pdf**.

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