VPP Acceleration Initiative

The ABCs of VPPs

An Introduction to Virtual Power Plants

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ABOUT THIS REPORT

This paper was produced by the Clean Energy States Alliance (CESA) to help state officials, as well as other stakeholders, understand what virtual power plants (VPPs) are and how they can be optimally designed.

This report was produced by CESA as part of the VPP Acceleration Initiative. The Initiative helps states, local governments, communities, and financial institutions deploy and scale VPPs—advancing affordability, strengthening resilience and grid reliability, and supporting decarbonization. This initiative is led by CESA, Clean Energy Group (CEG), and World Resources Institute (WRI). For more information about this effort and to browse related resources, visit www.cesa.org/projects/vpp.

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DISCLAIMER

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GLOSSARY OF TERMS

Advanced distribution management system (ADMS)
Utility software used to monitor and manage distribution grid operations.

Aggregator
An entity that enrolls and coordinates many distributed resources to provide grid services.

Application programming interface (API)
A defined way for software systems to exchange information.

Baseline
An estimate of what electricity use would have been without a VPP event, often used to measure load reduction.

CTA-2045 / EcoPort
A standardized appliance communication interface, often discussed for water heaters and other controllable appliances.

Demand response
An energy management strategy where electricity consumers reduce or shift their power use during periods of high demand or grid stress.

Demand response management system (DRMS)
Software used to manage demand response programs.

Distributed energy resource (DER)
A small-scale resource connected to the distribution system or located behind a customer meter, such as solar, storage, EV charging, or flexible load.

Distributed energy resource management system (DERMS)
Software used to monitor, forecast, dispatch, and measure distributed energy resources.

Dispatch
An instruction to use enrolled devices to provide a grid service at a particular time.

Feeder
A distribution circuit that delivers electricity from a substation to customers.

Gateway
Hardware or software that bridges two systems or networks that do not naturally communicate with each other.

Home energy management system (HEMS)
Hardware or software that coordinates energy devices in a home.

Interoperability
The ability of different devices, platforms, and systems to exchange information and work together.

Measurement and verification
The process of determining what a VPP actually delivered during an event or market interval.

Non-wires alternative
A resource or program, such as storage or demand flexibility, used to defer or avoid traditional wires-based grid upgrades.

OEM cloud
A cloud platform operated by the original equipment manufacturer of a device.

OpenADR
A standard for automated demand response event messaging.

Opt-out
A customer's ability to decline participation in a specific event or withdraw from a program under defined rules.

Override authority
The utility's ability to limit, cancel, or modify a VPP dispatch to protect safety or reliability.

Reserve margin/backup reserve
The portion of a battery kept available for customer backup power rather than discharged during a VPP event.

Supervisory control and data acquisition (SCADA)
Utility systems used to monitor and control grid equipment.

Settlement
The process of calculating payments or credits after performance has been measured.

Site controller
Hardware or software at a site that translates VPP instructions into device-level actions.

Telemetry
Operational data sent from devices or platforms, such as load, output, availability, and state of charge.

Virtual power plant (VPP)
A coordinated portfolio of distributed energy resources that can be operated together to provide grid services.

INTRODUCTION

The electric grid is changing more quickly than it has in decades. Rising demand, rapid electrification, distributed energy adoption, reliability concerns, and cost pressures are forcing states and utilities to look for new ways to expand grid capability. Virtual power plants (VPPs)—aggregations of small, behind-the-meter energy resources—can help support rapid, economic, reliable, and equitable grid growth by coordinating customer-sited resources so they can reduce demand, shift energy use, integrate and optimize renewable energy, and support the grid when needed, all while providing cost savings and backup power to businesses and residences. The U.S. Department of Energy (DOE) has framed VPPs as a near-term resource for meeting load growth and reducing grid costs. Based on the idea that VPPs could serve 10-20 percent of projected future U.S. peak demand, DOE estimates VPP capacity could grow from roughly 33 GW today to 80 to 160 GW by 2030.[1]

A VPP becomes a dependable grid resource when its benefits become visible, dispatchable, measurable, monetizable, secure, customer-protective, and useful to the grid.

This paper explains how VPPs operate and why communications and standards are central to their success. VPPs are not simply collections of distributed energy resources. They are coordinated operating systems for flexible demand, storage, and distributed generation. Their value depends on whether customers, devices, aggregators, utilities, and markets can communicate reliably, protect customer choices, verify performance, and operate under clear rules. For state energy agencies, a central challenge is to help create the technical, regulatory, and programmatic conditions that allow VPPs to develop, access markets, and realize their potential as dependable grid resources.

A VPP helps the grid by coordinating many smaller customer-sited (behind-the-meter) resources so they can act together as a flexible grid resource. These customer-sited resources may include batteries, electric vehicles and chargers, smart thermostats, water heaters, rooftop solar paired with storage, building controls, and flexible commercial loads, among others. These technologies are often called distributed energy resources (DERs) because they are located at homes and businesses rather than at a central power station.

1 Sonali Razdan, Jennifer Downing, and Louise White, *Pathways to Commercial Liftoff: Virtual Power Plants—2025 Update*, U.S. Department of Energy, January 2025, www.smartenergydecisions.com/wp-content/uploads/2025/04/liftoff_doe_virtualpowerplants2025update.pdf.

VPPs can provide valuable services to a utility or wholesale energy market. These services may include reducing peak demand, shifting energy use, discharging stored energy, relieving local grid constraints, providing ancillary market services such as frequency regulation, and deferring traditional grid investments such as poles-and-wires or substation expansion. Importantly, VPPs can benefit the enrolled customers, providing revenue and energy cost savings during business-as-usual conditions, and in many cases, backup power during grid outages; and they reduce costs for ratepayers by providing lower-cost grid services that displace higher-priced resources.

To achieve all this, VPPs require clear operating rules. Before a single customer is enrolled, some basic questions need to be answered. These include who enrolls customers, who sends dispatch instructions, who controls the enrolled devices, who measures performance, who pays whom and on what basis, and who can override dispatch for reliability or safety, or to accommodate resiliency needs. Program design choices such as resource ownership, compensation, eligible technologies, contract duration, dispatch methods, and affordability provisions strongly shape the operating model.[2]

The main takeaways for state energy agencies are straightforward: VPP scale depends less on technology breakthroughs than on trusted communication among devices, customers, aggregators, utilities, markets, and regulators. Standards can reduce integration costs and make programs more repeatable. Embedding equity components in VPP program rollout and design can help ensure public support and widespread adoption. VPPs also need customer protections, cybersecurity plans, performance measurement, data governance, and compensation rules that are clear enough for customers, utilities, aggregators and market operators to rely on.

2 Todd Olinsky-Paul, *Program Design for Battery-Based Virtual Power Plants*, Clean Energy States Alliance, February 2026, www.cesa.org/resource-library/resource/bvpp-program-design.

The basics: what a VPP is and why it matters

WHAT IS A VIRTUAL POWER PLANT?

A virtual power plant is a coordinated group of distributed energy resources that can be operated together to provide grid services. It is “virtual” because the resources are spread across many homes, businesses, buildings, vehicles, and devices rather than located at a single power plant. The word “plant” can be misleading because a VPP is less a physical facility than an operating model: software, communications, customer agreements, and control systems allow many small resources to respond as one coordinated portfolio, a single “virtual power plant.”

VPPs build on the long history of demand response (DR), but they are not limited to traditional DR programs, which typically pay large utility customers to reduce load during a limited number of peak events. A VPP can do that, but it may also provide more active, measured, and coordinated services; in some cases, VPPs export power to the grid. As VPP programs grow in sophistication, they become more automated, more location-responsive, and more tightly integrated with utility operations.[3]

Table 1: **DR, DERs, and VPPs Are Related but Distinct Concepts**

	Demand Response (DR)	Distributed Energy Resources (DERs)	Virtual Power Plants (VPPs)
What is it?	A program, service, or strategy that changes electricity consumption in response to grid conditions or price signals	Physical technologies that generate, store, manage, or shift electricity use at customer sites or on the distribution system	A coordinated aggregation of DERs that can be managed and dispatched as a single grid resource
Examples	Smart thermostat programs, managed electric vehicle (EV) charging, commercial load curtail-ment, peak demand programs	Rooftop solar, battery storage, EVs, smart thermostats, water heaters, backup generators	Networks of batteries, EVs, thermostats, water heaters, and other DERs operating together
Physical asset?	No	Yes	No
Shifts the timing of electricity use?	Yes	Sometimes	Often
Can generate electricity?	No	Sometimes	Sometimes (through participating DERs)

CONTINUED

3 Angela Long, Ryan Long, and Natalie Mins Frick, *Virtual Power Plant Profiles and Inventory*, Lawrence Berkeley National Laboratory, January 2025, https://eta-publications.lbl.gov/sites/default/files/2025-03/vpp_profiles_and_inventory_singl-pgs_fnl_3-25_rev.pdf.

Table 1: **DR, DERs, and VPPs Are Related but Distinct Concepts** (CONTINUED)

	Demand Response (DR)	Distributed Energy Resources (DERs)	Virtual Power Plants (VPPs)
Can reduce or shift demand?	Primary purpose	Sometimes	Common capability
Requires coordination across many customers?	Sometimes	Not necessarily	Yes
Can provide grid services?	Yes	Potentially	Primary purpose
Can participate in wholesale markets?	Limited	Generally not on its own	May be designed to do so
Primary value proposition	Provides flexible demand that can help balance the grid	Produces, stores, or manages energy at a specific location	Combines many distributed resources into a reliable, dispatchable grid resource
What it is NOT	Not a technology or device	Not necessarily coordinated with other resources	Not a single technology or device

DR refers to programs that change electricity consumption; DERs are the underlying technologies that can produce, store, or manage energy; and VPPs coordinate multiple DERs to provide services to customers, utilities, grid operators, and wholesale markets.

WHY DO VPPS MATTER NOW?

A VPP is a coordinated portfolio of customer-sited resources that can reduce, shift, store, or supply electricity when the grid needs help.

States, utilities and grid operators are facing multiple pressures at once: rising electricity demand, electrification, data center growth, distribution system investment needs, reliability concerns, increasing extreme weather events and associated grid outages, and the need to integrate more variable renewable generation. VPPs offer an important way to expand grid capability without relying only on new centralized infrastructure. They can use resources that customers are already installing for bill savings, backup power, mobility, or comfort, and coordinate those resources to provide value to the wider grid. VPPs can support equity goals too, since resource investment and associated savings can support customers and communities experiencing high energy burdens. And investing in VPPs means investing in the community rather than utility- or corporate-owned infrastructure.

Over the past decade, VPP programs have spread rapidly. Battery-based VPPs are now active in the majority of U.S. states and Puerto Rico, and more are being developed by state energy agencies and utilities.[4]

Notable active VPP programs include:[5]

- In Vermont, utility Green Mountain Power has created one of the most successful VPP programs, with more than 10,000 batteries behind residential meters to provide peak demand reduction and frequency regulation.
- The California CalReady program aggregates more than 56,000 residential customers, with 75,000 batteries and solar+storage systems providing peak demand reduction, resource adequacy, and emergency reliability support; this system provides up to 375 MW of peak capacity.
- Also in California, the Peak Power Rewards program aggregates 8,500 residential solar and storage customers of the utility PG&E for peak demand reduction and summer reliability. This program provided 27 MW over more than 90 consecutive days and instantaneous peak output near 32 MW during the first season.
- The North Carolina PowerPair program aggregates up to 6,000 residential solar+storage systems in Duke Energy's territory for peak demand reduction, grid support, and emissions reduction.
- The Arizona SRP Battery Partner program aggregates up to 5,000 residential customers for peak demand reduction and emergency demand response.
- In Texas, the ERCOT Aggregate Distributed Energy Resource Pilot aggregates batteries, solar+storage, electric vehicle (EV) chargers, smart thermostats, flexible commercial loads, and distributed generation for wholesale market participation, energy, ancillary services, and grid support.
- In Massachusetts, the ConnectedSolutions VPP program was recently expanded; in addition to tapping behind-the-meter (BTM) batteries, thermostats, water heaters, EV chargers and other connected devices for peak demand reduction,

VPPs sit at the intersection of technology, utility regulation, customer programs, energy equity, cybersecurity, and market design. State energy agencies can help make those aspects understandable and actionable.

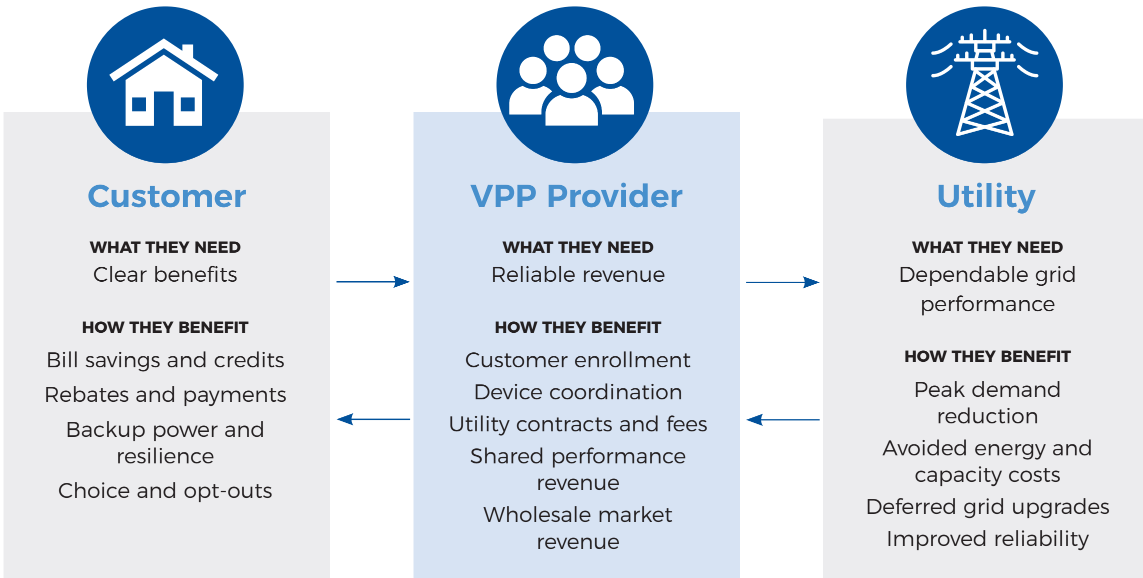
4 "Virtual Power Plant Programs Summary Table," Clean Energy States Alliance, accessed September 2026, www.cesa.org/resource-library/resource/virtual-power-plant-programs-summary-table.

5 Ibid.

the program now includes locational adders for enrollees that can provide local distribution grid benefits (distribution investment deferral).

Clearly, VPPs are no longer theoretical—they're up and running in at least 30 states. Given the rapid spread of VPPs, the questions state energy agencies developing a program need to ask are increasingly concrete: what services should VPPs provide in their state, who will be able to participate, how will participants be compensated, how will performance be measured, and what rules are needed to make the program scalable?[6]

Figure 1: **How VPP Value Can Flow Between Participants**



VPPs create optimal value when benefits and obligations are aligned across customers, providers, and utilities.

6 Olinsky-Paul, *Program Design for Battery-Based Virtual Power Plants*.

Who participates and what happens when a VPP operates

WHO PARTICIPATES IN A VPP?

A working VPP depends on coordinated action among several groups. Customers provide access to BTM energy resources and receive value through payments, bill savings, backup power, resilience, or participation in a community reliability effort. Device manufacturers and installers provide the hardware, software, apps, and cloud interfaces that make devices controllable. Aggregators or VPP providers enroll customers, connect devices, forecast available flexibility, dispatch resources, measure performance, and manage compensation. For some VPP programs, utilities aggregate

Figure 2: **Who is Involved in a VPP and What Do They Do?**

Role	Who They Are	What They Do
VPP Provider/ Aggregator	The entity that coordinates distributed resources into a single, dispatchable resource	• Recruit and enroll resources • Forecast availability and grid needs • Dispatch resources and optimize performance • Settle payments and manages incentives
Resource Owner	The individual or organization that owns the DER (such as solar, storage, EVs, or smart thermostats)	• Own and maintain the DER • Authorize participation of the DER in the VPP • Receive incentives or bill savings in return
Host Customer	The customer site or facility where the DER is located	• Host the DER on their premises (e.g., home business, or community facility) • Agree to allow the VPP to dispatch the DER when needed • Experience reliability and cost benefits from participation
Device/Asset Manufacturers (OEMs)	Companies that design and manufacture DER technologies and equipment	• Build reliable, secure, and interoperable DER devices • Ensure product performance, safety, and standards compliance • Enable integration with VPP platforms and systems
Software/ Platform Providers	Companies that provide the software platforms, controls, and analytics that enable VPPs	• Provide VPP platforms, controls, and data analytics • Ensure secure communication and interoperability • Support operations, optimizations, and reporting
Utility/Grid Operator	Entities responsible for operating the grid and serving customers	• Procure VPP services (e.g., capacity, peak reduction, reliability) • Integrate VPPs into grid operations and planning • Ensure reliability, safety, and compliance

CONTINUED

Figure 2: **Who is Involved in a VPP and What Do They Do?** (CONTINUED)

Role	Who They Are	What They Do
Regulators/ Policymakers	State and federal agencies that set rules, policies, and market frameworks	• Establish rules for participation and compensation • Ensure consumer protection and equitable access • Enable innovation through policy and regulatory frameworks
Financiers/ Investors	Lenders, investors, and financing institutions that fund DERs and VPPs	• Provide capital for DERs and VPP platforms • Assess risk and support bankable project structures • Enable innovative financing models

resources; in other programs, device manufacturers or installers serve as aggregators; in still others, aggregators are third parties.

Utilities identify grid needs, define operating limits, request events, verify performance, and may require visibility or override authority to protect the distribution system. Depending on the market and regulatory structure, utilities may procure VPP services, operate or coordinate with VPP aggregators, and integrate VPP resources into distribution system planning and operations. They can manage peak demand, provide capacity and other grid services, defer or avoid infrastructure investments, and improve system reliability and resilience with VPPs. Market operators may enable qualified aggregations to participate in energy, capacity, ancillary service, or other markets. State energy offices, regulators, and program administrators shape program design, customer protections, eligibility rules, incentives, reporting, and equity requirements.

The more clearly the different roles are defined, the easier it is for VPP programs to succeed and grow.

WHAT HAPPENS WHEN A VPP IS DISPATCHED?

A VPP becomes useful to the grid when it can respond to a specific need. That need may be a summer peak, a winter reliability concern, a local distribution constraint, a high wholesale price period, or an emergency generation shortfall. Dispatch is the process of activating the VPP to respond to a grid need through coordinated action across many enrolled devices.[7]

A typical event begins when a utility, market operator, program administrator, or VPP provider identifies a system or market need and sends a request to the VPP provider

7 VPPs can also add grid value when they are not being dispatched. For example, some VPPs compensate enrolled customers for maintaining devices in a “ready” state. This is similar to a traditional peaking generator that is paid for capacity, even if it is not called upon to deliver electricity.

or aggregator. Depending on the VPP program, these events may be predefined and automated or up to the discretion of the utility or market operator. The VPP platform then checks which devices are available and applies practical limits: customer opt-outs, battery reserve settings, thermostat comfort bands, electric vehicle charging needs,

Figure 3: **What Happens During a VPP Event?**

	What Happens	When Does This Happen
1 **Forecast and Planning**	The utility identifies an upcoming grid event, such as a summer peak, local reliability issue, or emergency shortage, which means the grid needs support.	Days or hours ahead of the grid event
2 **Event Call**	The utility or grid operator sends a dispatch request to the VPP aggregator, with details about the timing, location duration, and requested response.	Pre-dispatch
3 **Availability Check**	The VPP aggregator checks which devices are available, with regard to customer opt-outs, device settings, and comfort settings.	Pre-dispatch
4 **Device Response**	Devices support the grid by reducing demand or providing power during the grid event (e.g., batteries discharge, EV charging shifts, thermostats adjust, water heaters pause).	During the grid event (high demand, grid instability)
5 **Telemetry and Monitoring**	Operational data shows whether the portfolio is responding as expected.	During and after grid event
6 **Measurement and Verification**	Performance is measured and results are tracked, reported, and used to determine payments.	After event
7 **Settlement Period**	Participating customers, aggregators, or providers receive payments, bill credits, or other compensation.	After event
8 **Program Review**	Program administrators review outcomes, customer experience, equity metrics, and operational lessons.	After event

A VPP event is a step-by-step process of coordinating customer-hosted devices to respond to grid needs while ensuring consumer protections and performance verification.

and device operating constraints. Dispatch instructions move through the communication chain to devices. This can mean discharging batteries, slowing the charging of EVs, adjusting thermostats, pausing water heating, or shifting flexible building loads. After the event, telemetry and meter data are used to verify performance and settle payments.

A VPP dispatch event is a chain of actions: request, availability check, customer protections, device control, telemetry, verification, and payment.

Most VPPs follow a similar sequence of activities before, during, and after a dispatch event. The timeline in Figure 3 illustrates the typical operational flow, from customer enrollment and event forecasting through dispatch, performance verification, compensation, and program evaluation.

VPP CASE STUDY

Puerto Rico's Customer Battery Energy Sharing Program

Puerto Rico's Customer Battery Energy Sharing program provides a concrete example of how dispatch works. LUMA, the company responsible for operating Puerto Rico's electric grid, forecasts grid events based on expected capacity shortfalls, notifies aggregators, and participating customer batteries discharge stored energy first to the customer's home or business to reduce demand, and then to the grid to supplement supply. Aggregators manage customer enrollment and event communications, and customers retain important choices such as backup reserve settings and the ability to opt out of individual events. Participating customers are compensated through their aggregator. LUMA pays each aggregator $1.25 per kilowatt-hour based on the amount of energy delivered during a grid event, but each aggregator determines customer compensation. LUMA tries to provide day-ahead dispatch, but sometimes the dispatch signal is sent only hours or minutes ahead; fast and accurate communications are essential to allow the VPP to respond.[8] The Customer Battery Energy Sharing program grew from 3,440 customers in March 2024 to more than 90,000 customers providing an average of 75 MWs of grid support during events two years later. Currently, seven aggregators have been approved by LUMA to participate in the program.[9] This case study shows why customer communication is part of VPP operations, not an optional add-on.

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8 Hanna Jones, *Lessons Learned from Puerto Rico's First Virtual Power Plant*, Clean Energy States Alliance, February 2026, www.cesa.org/resource-library/resource/puerto-rico-virtual-power-plant.

9 "Customer Battery Energy Sharing," LUMA Energy, accessed August 2026, https://lumapr.com/battery-demand-response/?lang=en.

The VPP technology stack

WHAT ARE THE MAIN TECHNOLOGY LAYERS IN A VPP?

VPPs are easier to understand when they are broken into layers. Although not all programs use exactly the same architecture, most include four basic layers: the grid-edge asset layer, the site or gateway layer, the aggregation and orchestration layer, and the utility or market interface layer.

Grid-edge or asset layer

The grid-edge layer is made up of the physical resources that actually change electricity use, generate or store energy, or export power. Examples include home batteries, EV chargers, smart thermostats, water heaters, solar inverters, building controls, and flexible commercial or industrial loads. This is where value is created: a battery discharges, an EV charger slows, a thermostat adjusts, or a building reduces demand.

Site, gateway, or device-cloud layer

The site or gateway layer translates VPP instructions into device-specific actions. This layer may include a home energy management system, a building energy management system, an inverter platform, a charger management system, a communications gateway, or a manufacturer's cloud platform. It is also where customer preferences are often enforced, including thermostat comfort bands, battery backup reserve settings, charging needs, and opt-out choices.

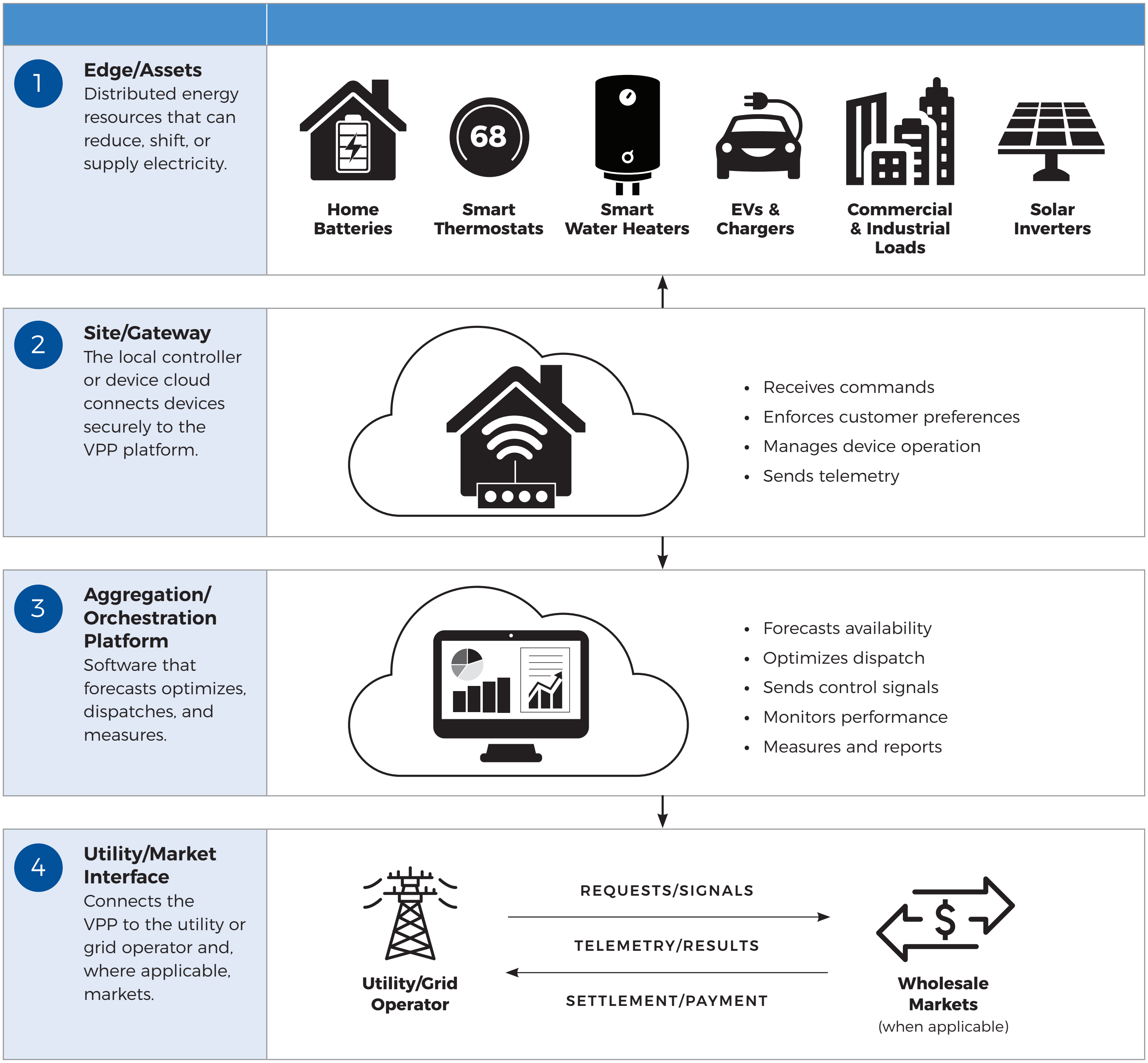
Aggregation and orchestration layer

The aggregation and orchestration layer is the software layer that turns many separate devices into a coordinated portfolio. It forecasts availability, estimates response uncertainty, decides which resources to dispatch, sends control signals, monitors performance, and performs measurement and verification. This layer is often called a VPP platform or a distributed energy resource management system (DERMS).

Utility and market interface layer

The utility and market interface layer is where the VPP interacts with the utility or aggregator. Utility-facing functions may include managing distribution constraints, issuing event calls, exercising override authority, providing operational visibility, and reporting performance. Market-facing functions may include submitting bids, receiving dispatch instructions, exchanging telemetry and metering data, and supporting settlement.

Figure 4: **What Are the Main Components of a VPP?**



Most VPPs can be explained as four connected layers, supported by cybersecurity, privacy, and interoperability.

WHAT INFORMATION IS SHARED IN A VPP?

VPPs depend on trusted information exchange. Customer and enrollment information establishes who is participating, which devices are enrolled, what the customer has agreed to, and how the customer can withdraw or opt out. Device information may include battery state of charge, inverter status, charger availability, thermostat settings, water heater status, reserve preferences, or other operating data. Grid and market information may include event calls, price signals, feeder constraints, dispatch instructions, operating limits, telemetry requirements, and settlement rules.

Performance and financial information are also essential. Utilities, aggregators, and market operators need to know how much load was reduced, how much energy was exported, whether the resource followed the dispatch instruction, and whether customers opted out. Settlement then depends on the terms of the customer contract or tariff, and the performance of the enrolled resources.

Different parties need different data. Customer data should be shared only with the parties that need it, and only to the degree necessary for them to perform their defined role. A utility may need enough visibility to operate safely and verify performance, but that does not mean every party needs full customer-level data.

Communications, standards, and trust

HOW DO DEVICES ENROLLED IN VPPS COMMUNICATE?

VPP communication is layered and often hybrid. A device may communicate through a manufacturer app or cloud, a site controller, a gateway, a charger network, an aggregator platform, a utility demand response system, or a DERMS. Some communication is direct, but much of it passes through vendor clouds or aggregators.

The utility usually does not send a command directly to every enrolled thermostat, battery, or EV charger in a VPP. Instead, the utility or market signal moves through a chain of systems that translate the grid need into device-level action. Performance data then flows back through the chain for monitoring, measurement, verification, and settlement.

Effective device communication enables a VPP to respond quickly and accurately during emergencies, allows performance to be measured, and is key to making the VPP a reliable and responsive resource for the utility, aggregator or grid operator to call upon.

WHAT ARE STANDARDS, AND WHY DO THEY MATTER?

A standard is a shared specification for how technologies or organizations interact. Standards do not make every device the same; they make it easier for different devices, platforms, utilities, and markets to work together. They also enable competition, allow for a variety of products to enter the marketplace, simplify troubleshooting, and reduce administrative burdens. A simple analogy is a common phone charger. The charger does not make every phone identical, but it reduces friction by making connection safer, more predictable, and less expensive.

Similarly, VPP communications benefit from standardization. A VPP may include batteries, EV chargers, thermostats, water heaters, inverters, commercial building systems, manufacturer clouds, aggregator platforms, utility systems, and wholesale market systems. If every connection is custom, costs go up, reliability goes down, and the program becomes harder to replicate. Standards can reduce integration costs, improve interoperability, support cybersecurity, make performance easier to verify, and allow more vendors to participate. With standards, VPPs become more repeatable, financeable, interoperable, and scalable.

The standards landscape is not a single solution; it is a mix of interconnection rules, communications protocols, information models, EV charging standards, distribution services contracts, certification efforts, and cybersecurity frameworks.

No single standard governs the full VPP stack. Instead, near-term VPP deployment depends on a layered standards ecosystem. Some standards govern DER behavior at the grid edge. Some structure communications between utilities, aggregators, gateways, and devices. Some support demand response or EV charging. Others address the operating and commercial relationship between utilities and aggregators. The most important standards and coordination efforts are summarized in Figure 5 (p. 20).

WHAT MAKES A VPP LOOK LESS RISKY TO UTILITIES?

Because utilities are charged with the very important job of providing safe, reliable power to millions of customers—and because blackouts can be costly and life-threatening—utility managers tend to be risk-averse. New technologies, especially those not under the utility's direct ownership and control, can seem risky. Utilities may also have financial concerns about resources such as rooftop solar, which can reduce demand for utility-supplied electricity and alter traditional revenue and investment patterns. For these reasons and others, utilities have historically been slow to embrace innovative DERs such as DR, rooftop solar, and combined-heat-and-power (CHP) as solutions to grid constraints. Because VPPs have historically needed utility participation in order to function, a risk-averse utility posture can be a significant impediment to VPP development.[10]

To reduce utility perception of VPP risk, three concepts are especially important:

- **Visibility:** Can the utility see what the VPP is doing before, during, and after dispatch? This depends on telemetry quality, reporting speed, and integration with utility systems.
- **Schedulability:** Can the VPP respond when and how it is asked? A more mature VPP can follow shaped schedules, not just simple start-and-stop events.
- **Availability:** Can the VPP be counted on often enough to matter for planning and operations? A resource limited to a few hours on summer afternoons has less value than one available across seasons and longer event windows.

10 With the implementation of FERC Order 2222, which requires ISOs and RTOs to open wholesale energy markets to DER participation, VPP aggregators will increasingly be able to bypass utilities and bid VPP services directly into wholesale energy markets. However, much of the country operates outside of regional wholesale markets; and even within such markets, a utility contract for services may be a better deal for VPP participants than a wholesale market contract. Therefore, de-risking VPPs for utilities remains critical to VPP scale-up.

Figure 5: **The VPP Standards Mix**

Standard/Framework	Where It Applies	What It Does/Why It Matters for VPPs
IEEE 1547	**Grid interconnection point**	Sets functional requirements for **how DERs behave at the distribution grid interface**, including voltage, frequency, ride-through, and interoperability. It helps ensure resources behave predictably when connected to the grid.
IEEE 2030.5	**DER communications**	Provides a **standardized internet-based communications protocol between utilities and DERs**, especially smart inverters and gateways. It can reduce reliance on one-off integrations, though implementation still varies by utility and vendor.
OpenADR	**Demand response communications**	Standardizes **automated demand-response event messages from electricity providers to customers**, including event timing, duration, and requested response. It is useful for event-based VPP programs, but is typically one part of a broader technology stack.
IEC 61850-7-420	**Utility operational systems**	Provides **standardized communication and information models** for DERs, controllable loads, and energy-management systems. It is an international standard especially relevant to more complex, utility-grade integration.
OCPP	**EV charger network communications**	Standardizes **communication between EV chargers and charging-management systems**. It supports managed EV charging and can reduce vendor lock-in at the charger-to-network interface.
ISO/IEC 15118	**EV-to-charger communications**	Governs **communication between the EV and charging equipment**, including Plug & Charge and capabilities relevant to bidirectional charging. Unlike OCPP, it focuses on the vehicle-to-charger interface. This is an international standard.
DOE/NAESB contract work	**Utility/market contracting and coordination**	Helps standardize **contractual and business arrangements among aggregators, utilities, and other parties**. It complements technical standards by addressing the commercial rules needed for VPP participation. Standardized contracting can help reduce soft costs.

VPPs rely on a variety of standards, which create a common language that lets different devices, aggregators, utilities, and markets work to communicate in different ways.

De-risking VPPs requires cybersecurity, performance verification, customer protections, operational testing, and clear rules for utility override authority. Aggregators can further reduce risk for the utility by bringing proprietary DERMS and experience with VPP operations. VPP value increases as programs move from simple event-based demand response toward more visible, schedulable, and grid-aware resources. Within the VPP technology stack, some technologies may be lower risk than others. For example, thermostats may carry relatively more risk because customer behavior is related to comfort.

If a house gets too hot, residents may turn up the air conditioning even though the utility has called a peak demand event. By comparison, batteries do not reduce customer comfort when they discharge, so customers are usually indifferent to whether the utility is discharging the battery.[11]

What makes a VPP look less risky to participants and other ratepayers?

Utility customers may also have a perception of risk when considering a VPP program. Customers may be hesitant to enroll for several reasons. Here are questions potential customers may have:

- **Economic risk:** What assurance is there that promised VPP program revenues will really materialize? Will revenues and cost savings add up to pay back my initial investment?
- **Trust and control issues:** If I enroll in a VPP, am I giving up control of my enrolled devices to the utility or aggregator? Will I really be able to opt out of events if I want to?
- **Knowledge gaps:** How does the VPP work? Are there hidden risks?

De-risking VPPs for participants requires information and transparency. Utilities, aggregators and developers all have a role to play, as do state policymakers and regulators, who are in a position to require consumer protections as part of VPP program development. Making enrollment contracts clear and easy to understand, providing examples of program economics, and answering customer questions can help reduce the perception of risk. In addition, utility regulators should ensure customers are getting a fair shake economically from VPP programs—both customers who enroll, and other ratepayers, who should not bear additional costs.

To reduce ratepayer risk perception, it is important to ensure the VPP will be cost-effective, and to identify and mitigate potential cost shifts from one group of ratepayers to another. Among the common cost-effectiveness tests used by states, the Ratepayer Impact Measure (RIM) test is useful to identify cost shifts between participating and non-participating customers.[12]

11 An exception to this is when a natural disaster, such as a winter storm, is anticipated and may cause grid power outages. In these cases, most VPP programs avoid calling on customer batteries, since customers will want fully charged batteries to help them ride through a grid outage.

12 For more information on cost-effectiveness tests, see: *Energy Storage Benefit-Cost Analysis: A Framework for State Energy Programs*, Applied Economics Clinic for the Clean Energy States Alliance, December 2022, www.cesa.org/resource-library/resource/energy-storage-benefit-cost-analysis-a-framework-for-state-energy-programs.

Program development implications for states

WHAT SHOULD STATE ENERGY AGENCIES ASK WHEN REVIEWING OR DEVELOPING A VPP PROGRAM?

VPP program development involves both technical and program design choices. Technical choices determine how efficiently and cost-effectively the VPP will function, how well it integrates with or supplements other resources, and how it minimizes risk. Program design choices determine what benefits and services the VPP provides, who participates, and how it interacts with other state energy programs. There will inevitably be some overlap between the technical and program design choices.

To make **technical choices**, state energy policymakers and regulators do not need to become protocol engineers. But they do need to ensure that a proposed VPP will meet minimum standards of performance, cost effectiveness, safety and security. Program design choices, such as device ownership, may have practical considerations for participants and other ratepayers. Some useful questions to ask include:

- How will cost-effectiveness be measured?
- Which resources and customers will be eligible to enroll?
- How will the system be dispatched?
- What telemetry will be used?
- What measurement & verification and settlement data are required?
- Are interfaces standards-based?
- Who is responsible for authentication, encryption, updates and incident response?
- What compensation/settlement mechanisms will be used?

Generally, **program design choices** depend on what the VPP is intended to accomplish. For this reason, CESA recommends that state agencies first set policy goals the VPP will support. Program design will then follow from those goals.

This is important because VPP programs will look different depending on what they are supposed to achieve. For example, if the policy goal is grid modernization and resilience, the VPP program may include proactive distribution grid planning, locational incentives to advance non-wires solutions, and an emphasis on back-up power and community resilience hubs. If the goal is peak demand reduction, the program may include peak demand dispatch and incentives for longer-duration discharge. If the goal is decarbonization, the dispatch signal may be based on emissions peaks rather than demand peaks, may be coordinated with electrification programs, and may include mechanisms to support retirement of fossil fueled peaker plants.

Once the goals are clear, VPP program design involves answering a set of practical questions. These include:

- What grid services will the VPP provide?
- How will customer incentives be structured?
- How will customer contracts be structured?
- Who should own VPP assets, and who should have a voice in how they are used?
- How will equity/affordability be ensured?
- How will the economic and environmental benefits and burdens be shared across communities?
- What will be the role of third-party aggregators?
- Will the VPP export power to the grid, or just reduce load behind the meter?

These and other VPP program design elements, and emerging best practices, are discussed in CESA's publications *Program Design for Battery-Based Virtual Power Plants*[13] and *Energy Storage Program Design for Peak Demand Reduction*.[14] A summary table of VPP programs across the nation, with links to program pages and documents, can be found on CESA's website.[15]

VPP program design should flow from state policy goals, incorporating emerging best practices from existing programs.

13 Olinsky-Paul, *Program Design for Battery-Based Virtual Power Plants*.

14 Todd Olinsky-Paul and Olivia Tym, *Energy Storage Program Design for Peak Demand Reduction*, Clean Energy States Alliance, December 2024, www.cesa.org/resource-library/resource/energy-storage-program-design-for-peak-demand-reduction.

15 "Virtual Power Plant Programs Summary Table," Clean Energy States Alliance, accessed September 2026, www.cesa.org/resource-library/resource/virtual-power-plant-programs-summary-table.

Barriers and what comes next

WHAT TECHNICAL AND INSTITUTIONAL BARRIERS STILL SLOW VPP DEPLOYMENT?

Although VPP deployment is no longer limited by whether flexible devices exist, it remains limited by whether the ecosystem can operate them reliably at scale. Persistent barriers include fragmented device interfaces, proprietary application programming interfaces, inconsistent telemetry, limited distribution-system visibility, bespoke utility-aggregator contracts, unclear performance measurement and settlement rules, cybersecurity and data governance gaps, customer enrollment and retention challenges, equity and affordability barriers, gaps in institutional coordination, and uncertain rules for value stacking.

Distribution visibility is especially important. Many VPPs can reduce system peak, but fewer can reliably deliver distribution-level value on a specific feeder, substation, or transformer because locational mapping and real-time constraint data may be limited. This is one reason the field is moving from simple event-based portfolios toward more grid-aware VPPs.[16]

WHAT NEW DEVELOPMENTS SHOULD STATES MONITOR?

Several developments suggest that the field is becoming more mature. DOE's VPP Liftoff work frames VPPs as a near-term resource for load growth and grid cost management. Berkeley Lab's VPP profiles and inventory work provides a useful vocabulary for distinguishing basic, integrated, and more orchestrated VPP models. DOE and North American Energy Standards Board (NAESB) distribution services contract work is moving standardization beyond device protocols and into the utility-aggregator operating relationship.[17]

New technologies are also emerging. Key among these are plug-in solar, permissionless batteries, bidirectional EVs, and more sophisticated EV chargers. These technologies help to expand access to VPP participation—for example, by getting around the need for participants to own a home in order to install rooftop solar and residential-scale

16 Long et al, *Virtual Power Plant Profiles and Inventory*.

17 Razdan et al, *Pathways to Commercial Liftoff: Virtual Power Plants - 2025 Update*; Saumil Patel and Paul De Martini, *Standard Distribution Services Contract*, U.S. Department of Energy, November 2023, www.energy.gov/sites/default/files/2023-11/2023-11-15%20Standard%20Distribution%20Services%20Contract_optimized.pdf; Long et al, *Virtual Power Plant Profiles and Inventory*.

batteries—and also offer other benefits, such as portability and lower capital costs. As distributed energy technologies continue to advance, states should remain alert to opportunities to expand the VPP technology stack.

States should also watch the Mercury Consortium, IEEE P2030.14, OpenADR 3 and broader distributed energy coordination efforts; EV standards such as OCPP and ISO/IEC 15118; and stronger cybersecurity expectations. The common theme is that standardization is moving from device-level communication toward whole-program coordination: enrollment, consent, dispatch, telemetry, measurement, cybersecurity, contracts, and settlement.[18]

One big change underway in the VPP space is the implementation of Federal Energy Regulatory Commission (FERC) Order 2222 in ISO and RTO markets. Issued by FERC on September 17, 2020, Order 2222 requires regional grid operators to revise their market rules so that aggregated DERs can participate alongside traditional power plants in wholesale energy, capacity, and ancillary services markets. The primary goal of the order is open wholesale markets to DERs by removing longstanding participation barriers and enabling them to earn revenue through market participation, often as part of a VPP. While all ISOs and RTOs have submitted compliance filings to FERC, implementation remains uneven across regions, with market rules still being refined and rollout timelines extending over several years. Some regions have already begun opening wholesale market participation pathways for DERs, while others are still developing the market rules and processes needed to comply with Order 2222.

States should understand that, although Order 2222 is intended to open wholesale energy markets to aggregated distributed resources, this is not necessarily a sufficient replacement for state-designed and regulated VPPs. State-designed VPPs may provide a different set of benefits than DERs enrolled in wholesale market programs (for example, distribution grid support), may enroll a different set of technologies, and may offer different types of incentives and support to participating customers. From the customer perspective, contracting to provide services to their utility may be more beneficial and offer more protections than contracting to provide services in a regional market. Most importantly, wholesale energy markets are not designed to support state policy goals. For these reasons, when developing a VPP within a wholesale market, it will be important for state policymakers and regulators to determine how the program design should (or should not) align with changing wholesale market rules.

18 "FERC Order No. 2222: Fact Sheet," Federal Energy Regulatory Commission, September 2020, www.ferc.gov/media/ferc-order-no-2222-fact-sheet; "Mercury Consortium," Electric Power Research Institute, accessed August 2026, https://msites.epri.com/mercury-consortium.

CONCLUSION

Virtual power plants will scale faster when technical standardization and policy best practices combine to streamline program development and de-risk program operations. The decisive challenge is whether utilities, aggregators, device manufacturers, customers, regulators, and market operators can rely on repeatable technical and operational rules.

The goal is not just to enroll more devices. The goal is to make those devices visible, dispatchable, measurable, secure, customer-protective, and useful to the grid. This goal is advanced by the development and adoption of standards, certification profiles, emerging coordination efforts, emerging best practices, and DOE and NAESB utility-aggregator contract work. The next phase of VPP deployment will depend on connecting these pieces into a coherent model that is adoptable and adaptable to meet the needs of state policymakers, utilities, aggregators, and customers.

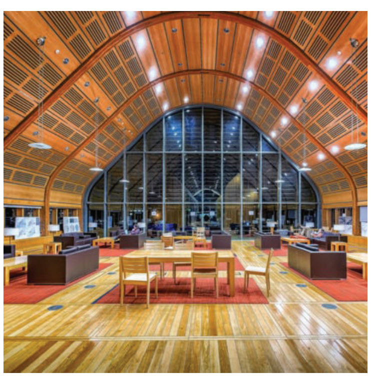












Row 1 (L-R): CESA; Resonant Energy; CESA; Bigstockphoto/DavidM199. Row 2 (L-R): Portland General Electric; CESA; Murray Carpenter/Maine Public.
Row 3 (L-R): Orsted (US Offshore Wind; CESA; Solara/California Energy Commission; iStockphoto/Fotomax. Row 4 (L-R): Tom Piorkowski; CESA; Shutterstock/Soonthorn Wongsaita

ABOUT CESA

The Clean Energy States Alliance (CESA) is a national, nonprofit coalition of public agencies and organizations working together to advance clean energy. CESA members—mostly state agencies—include many of the most innovative, successful, and influential public funders of clean energy initiatives in the country. CESA works with state leaders, federal agencies, and other stakeholders to develop and promote clean energy programs and markets, with an emphasis on renewable energy, energy equity, financing strategies, and economic development. CESA facilitates information-sharing, provides technical assistance, coordinates multi-state collaborative projects, and communicates the views and achievements of its members.

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