Electricity Market Visions

TO SUPPORT A RELIABLE AND AFFORDABLE ELECTRIC GRID UNDER ELECTRICITY DECARBONIZATION

March 2025

ESIG
ENERGY SYSTEMS INTEGRATION GROUP

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Electricity Market Visions to Support a Reliable and Affordable Electric Grid Under Electricity Decarbonization

A Report by the Energy Systems Integration Group's Electricity Markets Under 100% Clean Electricity Task Force

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Disclaimer

This report was produced by a task force made up of diverse members with diverse viewpoints and levels of participation. Specific statements may not necessarily represent a consensus among all participants or the views of participants' employers.

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Executive Summary

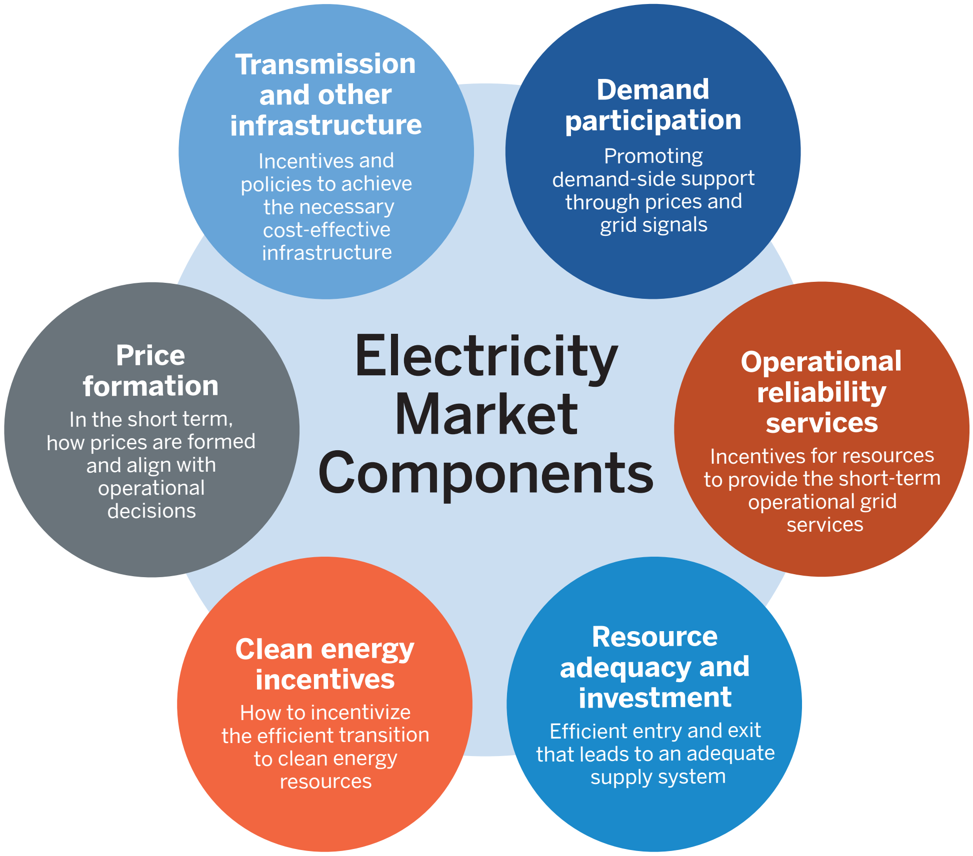
As the electricity grid continues to evolve and the mix of electricity suppliers moves toward one where there are clean, emissions-free suppliers, opportunities and challenges arise. With these changes, organized electricity markets can play a key role in the future in achieving a system that maintains the goals of affordability and reliability and fosters further innovation. The Energy Systems Integration Group convened the Electricity Markets Under 100% Clean Electricity Task Force to evaluate the potential design of electricity markets under a system in which all electricity is supplied from clean, zero-emitting supply resources. Task force participants included experts from independent system operators and regional transmission organizations, expert practitioners, developers, and other key stakeholder groups. The primary goal was to determine what kind of design will be beneficial to society while also considering future structures, institutions, and policies. It was a collaborative effort to describe a coherent vision of how a future electricity market can provide efficient signals such that meeting electricity demand with all zero-emitting clean energy resources leads to a reliable and affordable system that is fair and equitable. This report presents a collective vision regarding particular goals and core fundamentals as well as highlights areas still under active debate.

Organized electricity markets can play a key role in the future in achieving a system that maintains the goals of affordability and reliability and fosters further innovation.

Figure ES-1 (p. viii) shows six key categories that need consideration for future markets.

The electricity market can achieve many goals, but it cannot do everything. In some cases the incentives that are built into the market design can be changed by designers or regulators based on what the challenges are and where solutions are needed. We focus on four key principles for what a market needs to do today and in the future (Figure ES-2, p. ix): (1) to enable innovation such that market designs are not fixed to the current set of technologies but rather show the right signals to improve upon the existing technology when cost-effective, (2) to incentivize investment decisions (entry and exit) when they are needed to meet reliability needs and maximize efficiency, (3) to allow for hedging from suppliers and consumers alike when uncertainty or variability can increase risk, and (4) to provide an incentive for the existing participants in the market to operate in a way to maximize efficiency and to contribute to reliability.

FIGURE ES-1
Categories of Change for Future Market Design Vision



Several categories were discussed as part of the workshops and task force discussion that need consideration when sharing the future market design vision. These included price formation, clean energy incentives, resource adequacy and investment, operational reliability services, demand participation, and transmission and other infrastructure.

Source: Energy Systems Integration Group.

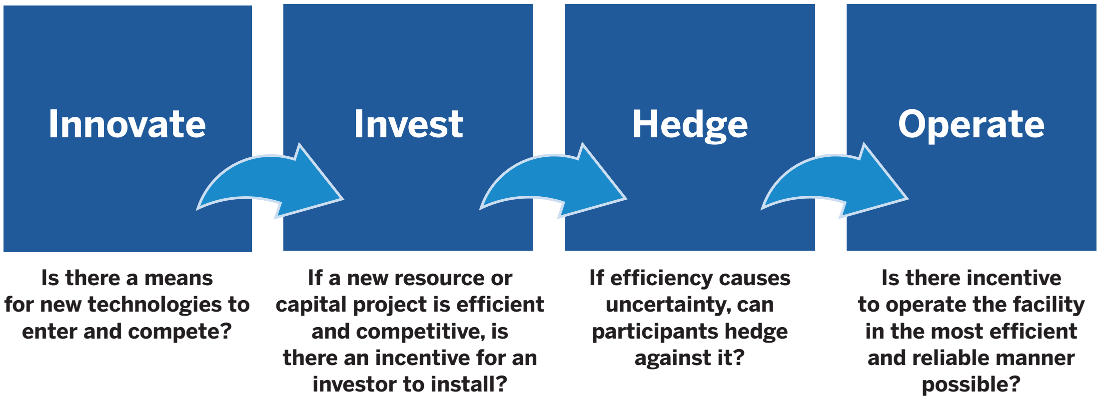
All four principles were kept in mind for any future market design proposal and were leveraged throughout the report.

Keeping all four principles in mind for any future market design proposal is key and leveraged throughout the report.

To develop the future market design vision, several assumptions were made about the power system and its associated characteristics. No time frame or specific mix was laid out, as regions will vary in this regard. But it was assumed that this future system would contain substantial amounts of variable renewable energy such as wind and solar, with a substantial amount of energy storage resources. It may be likely that these technologies are built primarily at the transmission scale, where large-scale transmission expansion and innovative transmission technologies allow for delivery of their energy to load centers. But the technologies could also have a greater presence on the distribution network as distributed energy resources, thereby potentially lessening the transmission need. It was also assumed that a reasonable amount of capacity that is zero-emitting but also with firm and long-duration availability would be present to maintain reliability during critical time periods. The

FIGURE ES-2

Four Key Principles That Markets Aim to Accomplish



Successful markets must incentivize innovation, investment in capital, hedging against risk, and behavior to operate in ways that lead to reliable and economically efficient outcomes.

Source: Energy Systems Integration Group.

amount of this type of resource will depend in part on how much of the demand is responsive to prices and grid needs.

Certain challenges exist in today's systems but are amplified on a system with this make-up of resources. This system leads to challenges to reliability and resource adequacy, and affects the distribution of the resulting wholesale prices. Depending on the system's make-up, there could be additional challenges of building sufficient infrastructure or meeting the control and visibility necessary for reliability. It is also confronted with the lack of direct competitive clean energy incentives within the market to naturally bring clean energy resources to the mix.

Given these assumptions and challenges, the task force looked at market designs that could enable an affordable and reliable system as society transitions to that future. The report shares details of future electricity markets discussed by the task force. It considers the many proposals and reviews in the literature and provides a shared—but not consensus—vision of future markets with a focus on the six components in Figure ES-1. The fundamentals of the future market vision described in the report generally were agreed on by many task force participants, although alternative paths were also proposed and supported by the group. For example, some participants recommended substantial coordination between policymakers and grid planners as a way to achieve resource adequacy with a feasible resource mix and infrastructure investments in place.

Elements of the Market Design Vision

While market structure—the make-up of the market and the responsibilities of different entities—is important, the task force primarily focused on the market design for its vision. The following eleven design elements encapsulate the future market design vision. Some are more concrete and with broader agreement among task force participants, while for others only the general objective was agreed upon and implementation proposals varied. Some are on a "business as usual" path, while others, though not necessarily suggesting major redesigns, do show substantial changes from the status quo.

Price Formation—Incentivize to Operate

A majority of the task force agreed that the existing large regional energy markets with bid-based economic dispatch and nodal marginal cost pricing with sufficient locational and temporal granularity would remain largely in place as a way to incentivize operational behavior and provide signals that can help investment decisionmaking.

Price Formation—Incentivize to Operate and to Invest

Task force participants agreed that shortage or scarcity pricing would be used that drives prices high when conditions warrant. Extended reserve demand curves could be used that would allow for less volatile shortage prices before the actual scarcity condition becomes apparent, while providing beneficial operational incentives.

Price Formation—Incentivize to Operate

While participants believed that existing energy market design should largely continue, they also thought that some incremental changes could continue to be considered such as improved sector coordination, regional seams management and efficiency improvements, market power mitigation procedures, and exploration of whether the unit commitment tool for market clearing is still necessary and what might replace it. Stakeholders and researchers should continue to explore the feasibility of further granularity of pricing, such as distribution network pricing, to determine whether it is practical and whether it provides benefits that outweigh the complexity and administrative costs.

Price Formation—Incentivize to Innovate and to Operate

To incentivize innovation in energy and grid service supply technologies, the task force favored participation models that are preemptive and prioritized for reliability, but that do not prevent or stall new technologies that are competitive from participating in the electricity market. Participants believed that market design should strive for technology neutrality but not attribute neutrality.

Demand Participation—Incentivize to Operate and to Innovate

The task force believed that mechanisms should be explored to enable more demand resources to support grid reliability than they do today, including giving access to system costs and prices on as granular a basis as possible for the subset of those demand resources that choose to participate, while protecting certain customer classes from financial harm and keeping equity objectives in mind.

Operational Reliability—Incentivize to Operate and to Innovate

Task force participants agreed that continual evaluation is needed of whether new operational reliability products are necessary and whether competitive markets for those products would provide additional benefits that outweigh their costs and administrative burden. Any resource, regardless of its technology, that demonstrates adequate attributes and performance should be qualified to participate in that service.

Operational Reliability—Incentivize to Operate and to Invest

There was a short discussion around whether the opportunity cost design for ancillary service markets is sufficient by itself with extended operating reserve demand curves, and whether forward contracts for grid services may be necessary for certain services.

Resource Adequacy—Incentivize to Invest and to Hedge

The task force largely agreed that energy markets and related market mechanisms by themselves may not accomplish all the functions to ensure investment of an adequate and efficient supply portfolio that meets the clean energy criteria. Interventions may be needed for resource adequacy and for certain reliability attributes as well as for infrastructure. The task force differed on the emphasis and the extent of the intervention, and it considered several different design approaches to this such as existing capacity markets, strong coordinated generation and infrastructure planning, mandatory contracts for hedging, and others.

Transmission and Other Infrastructure—Incentivize to Invest and to Innovate

Most of the task force thought that substantial transmission expansion and other additional infrastructure, currently decided upon largely outside of the wholesale markets, may need further consideration to enable the clean energy transition. Workable policy that could incentivize innovation and efficient investment in infrastructure should be explored further.

Clean Energy Incentives—Incentivize to Invest and to Innovate

Many in the task force believed that clean energy incentives have sound economic principles and designs that focus on reducing emissions. They thought that market designers can play a role to facilitate regional/state policies and accommodate efficient trading of energy with policies built in as constraints in the market design.

Clean Energy Incentives—Incentivize to Operate and to Hedge

A short discussion explored whether loads could or should input their willingness to purchase clean energy within the electricity markets and whether the markets should provide transparency to the premium that may be paid for that clean energy.

As seen in Figure ES-3 (C) (p. xii), in general, price formation and the modifications to design of the energy market were relatively minor as part of this vision and remain on their current trajectory. Larger changes were envisioned by the task force across the categories of demand-side participation and resource adequacy, investment, and hedging. These relate to the expansion of demand-side resources being able to support the grid through more granular pricing or otherwise, and the need for mandatory contracts and/or large-scale coordination to meet the investment needs and resource adequacy of a future 100% clean electricity system. While solutions around infrastructure were not discussed extensively, the task force did discuss the need to expand transmission and other infrastructure such as distribution and fuel delivery infrastructure, which may be done through policy mechanisms. The same discussion occurred regarding clean energy incentives. Substantial changes were not discussed at length regarding operational reliability needs, but the vision notes how new or increased needs for grid services should be continually studied and discusses whether they continue to incentivize operation, investment, hedging, and innovation.

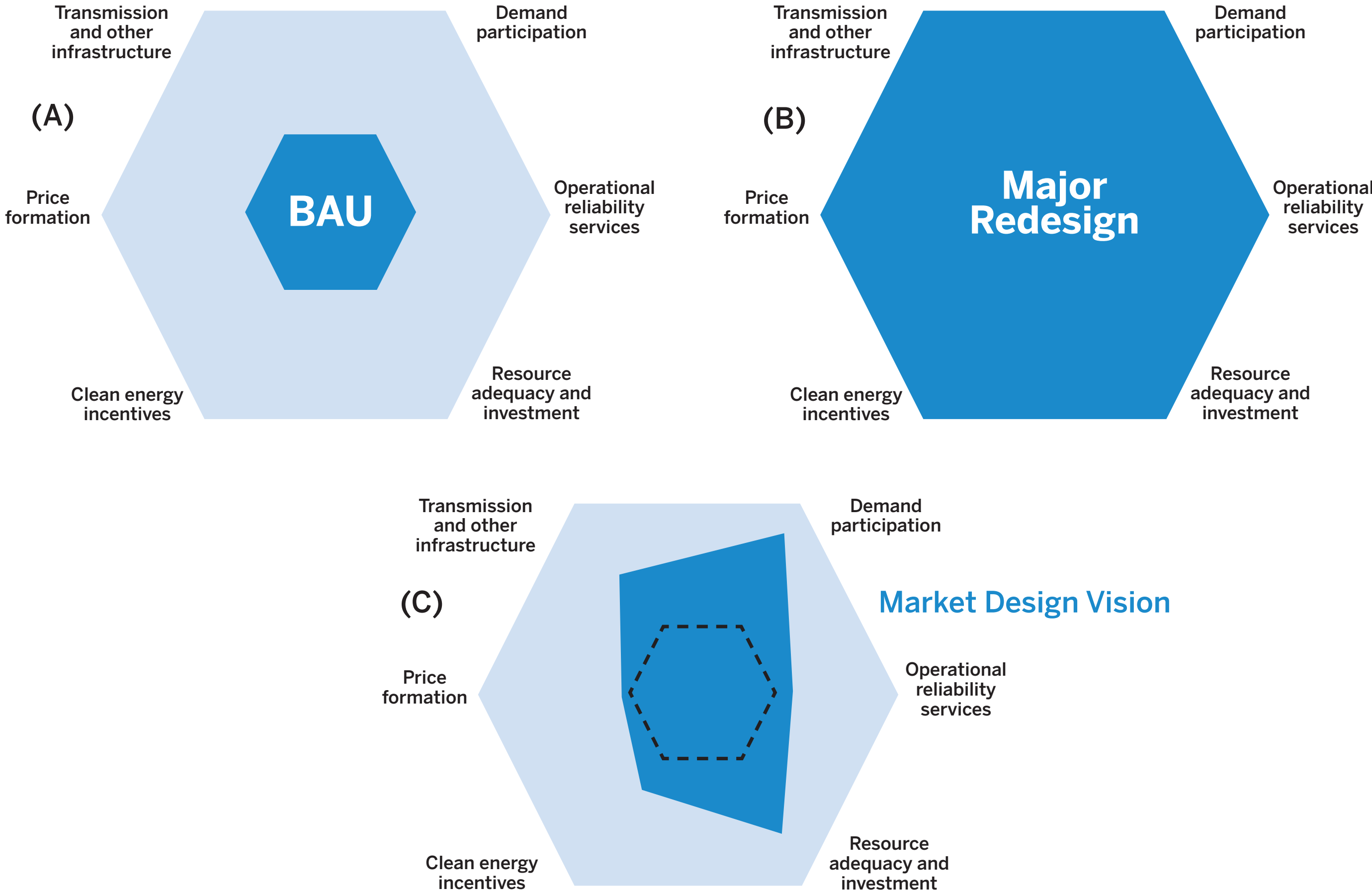
Recommendations

The task force provided a few recommendations. For the parts of the vision where broad agreement was reached, stakeholders can work together to determine whether any additional research or implementation details are needed for further implementation. It also might be worth considering whether policy and rule changes are necessary given the amount of time that some of these may take to move from idea to approval to implementation.

For those parts of the vision where several differing implementations still existed among task force participants, such as how efficient investment and hedging could be attained under the clean supply scenario, further work may be required to evaluate the potential outcomes to see which options may work best in which situations. Metrics are needed that can evaluate market design proposals, and consensus on which metrics to focus on and

FIGURE ES-3

Viewing the Scale of Change of Market Design Futures by Category



The market design vision can be expressed using a rose chart across the six categories shown here. The upper left-hand side (A) illustrates business as usual while the upper right-hand side (B) illustrates what a complete major redesign would look like. The bottom image (C) expresses the market design vision in this paper in these terms.

Source: Energy Systems Integration Group.

Metrics are needed that can evaluate market design proposals, and consensus on which metrics to focus on and how they can be combined is critical.

how they can be combined is critical. In some cases, market design pilots can be introduced to begin gathering information on promising design proposals that are promising but untested. Further, determining whether there may be consensus from technical experts beyond this task force is important. That consensus can be very helpful for decisionmakers and policymakers.

Lastly, the task force recognizes that global collaboration is key. Different regions may see a clean electricity future at different times and thus may introduce market design and policy at different points. Global collaboration will be critical for understanding impacts, including sharing both failures and successes, and exploring future concepts and ideas that can support the evolution toward 100% clean electricity.

Introduction

Electric power systems are undergoing major transformation. The resource mix is changing, both with increased variable renewable energy sources (VRES) and energy-limited resources, including electric storage resources. Climate policies continue to arise in many states within the United States and worldwide. Demand-side resources, including those connecting at distribution systems and those behind the customer meter, are also increasingly responsive, and the load itself is expected to grow, including from data centers, manufacturing, and the electrification of heating and transportation. Clean electricity has also become a priority for individual companies that choose to invest in zero-emitting energy or pay premiums for that clean energy. With these changes, organized electricity markets can likely play a key role in the future in achieving a system that can meet climate goals while still maintaining our overarching goals of affordability and reliability and fostering further innovation.

The Energy Systems Integration Group (ESIG) convened the Electricity Markets Under 100% Clean Electricity Task Force to evaluate the potential design of electricity markets under a system in which all electricity is supplied from clean, zero-emitting supply resources. Task force participants included experts from independent system operators (ISOs) and regional transmission organizations (RTOs), expert practitioners, developers, and other key stakeholder groups. The primary goal of the task force was to determine what kind of changes will be needed to the design of wholesale markets, while also considering future structures, institutions, and processes. It was a collaborative effort to describe a coherent vision of how a future electricity market can provide efficient signals for investment and operational behavior such that meeting all electricity demand with all zero-emitting clean energy resources can lead to a reliable and affordable system that is fair and equitable. Although this report presents a collective vision regarding particular goals and core fundamentals, shared by many though not necessarily all task force participants, it also highlights areas still under active debate within the task force where some participants emphasized certain market design objectives of a fully decarbonized system and

This was a collaborative effort to describe a coherent vision of how a future electricity market can provide efficient signals for investment and operational behavior such that meeting all electricity demand with all zero-emitting clean energy resources can lead to a reliable and affordable system that is fair and equitable.

introduced differing proposals for future market design and structure for such a system. The primary audiences for the report are individuals involved in planning and operating the power system and those who have a basic understanding of electricity market designs in place today.

Electricity Markets Under Deep Decarbonization: Literature Review and Task Force Workshops

There are several different proposals that have discussed potential future market designs under large-scale resource mix changes, such as a 100% clean electricity system or a 100% variable renewable system. ESIG hosted an international workshop in 2019 discussing the key challenges of achieving a 100% renewable electricity system (ESIG, 2019). Several workstreams met in parallel including one on market design challenges and solutions. Around the same time a multi-part paper shared two separate views of future market design by Energy Innovation (Aggarwal et al., 2019). This included a view that focused on the use of existing short-term energy markets with sufficient scarcity pricing and a second view focused on incorporating long-term contracting mechanisms. Several views and empirical evidence of clean energy markets were presented in Ela et al. (2021). The paper shared thoughts on what future market designs aim to do that are similar or different from today's market designs' aims. It also included discussions on the impact that zero-fuel-cost resources can have on wholesale prices, carbon pricing design, and essential reliability services. This paper was part of a multi-part issue that included experiences and future market designs in South America and Europe (Barroso, 2021; Strbac et al., 2021). More recent comprehensive summaries of the proposals that have been shared across the industry can be found in Zhou, Botterud, and Levin (2022), Schoppe (2023), and Lo Prete, Palmer, and Robertson (2024).

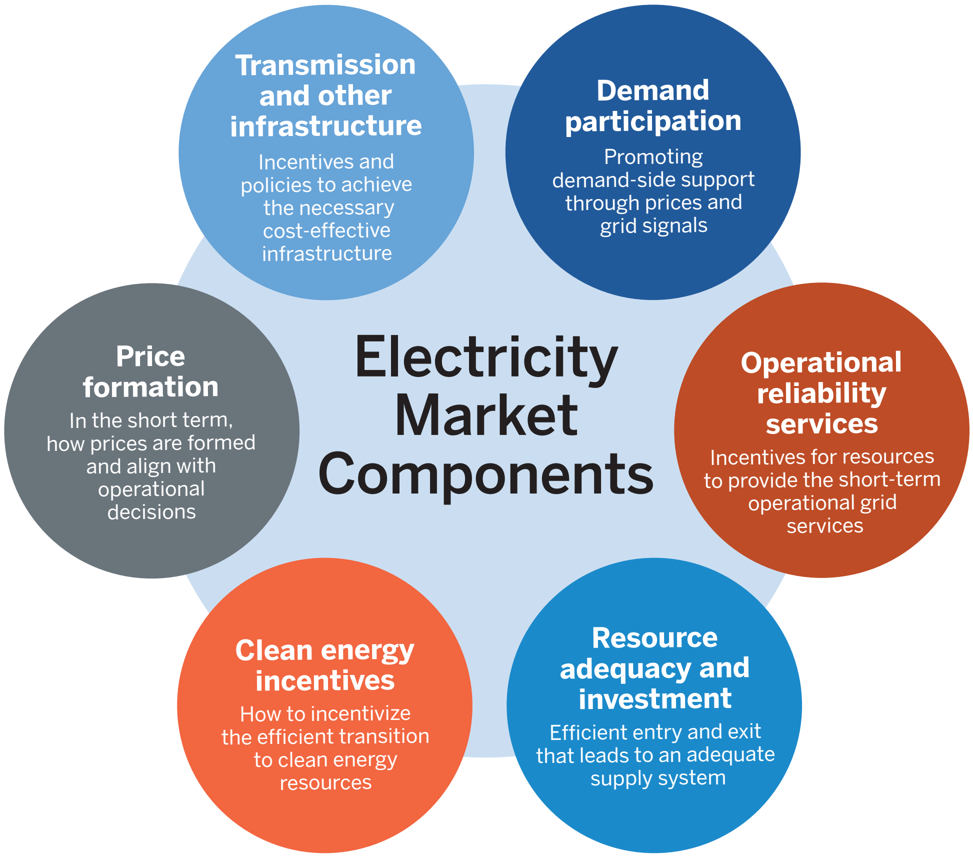
Following the workshop in 2019, ESIG has hosted two subsequent events to discuss future electricity market designs as part of this task force. The first, held in 2023, brought together key stakeholders providing different perspectives that discussed the main challenges with markets that must support reliability and efficiency with a clean electricity supply (ESIG, 2023b). This workshop focused on six key categories that need consideration for future markets as shown in Figure 1 (p. 3), which are themes throughout the remainder of this report. In October 2024, ESIG held a second workshop, titled "Electricity Markets Under Deep Decarbonization," in which participants discussed metrics to evaluate market designs and the visions of the lead authors were shared (ESIG, 2024). The conversations of each of these workshops are captured throughout the report.

Four Key Principles for Electricity Markets' Objectives, Today and in the Future

The electricity market can help achieve many goals, but it cannot do everything. Sometimes the incentives that are built into the market design can be changed by designers or regulators based on what the challenges are and where solutions are needed. The task force focused on four key principles for what a market needs to do today and in the future (Figure 2, p. 4). The first is to enable innovation such that market designs are not fixed to the current technologies or strategies, but rather show the signals to improve upon the existing technology when cost-effective —for example, considering the development of *capabilities* needed for the grid without specifying *how* the capabilities are produced. The second principle is to incentivize investment decisions (entry and exit) when they are needed to meet reliability needs and maximize efficiency. The third is to allow for hedging opportunities when

FIGURE 1

Categories of Change for Future Market Design Vision



Several categories were discussed as part of the workshops and task force discussion that need consideration when sharing the future market design vision. These included price formation, clean energy incentives, resource adequacy and investment, operational reliability services, demand participation, and transmission and other infrastructure.

Source: Energy Systems Integration Group.

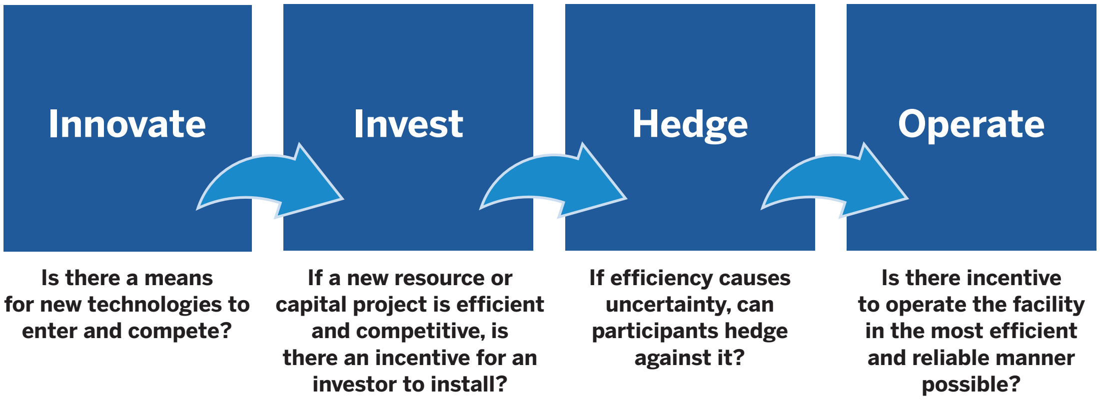
uncertainty or variability can cause greater risk to either suppliers or consumers. And the fourth principle is to provide an incentive for the existing participants in the market to operate in a way that maximizes efficiency and contributes to reliability. Keeping all four principles in mind for any future market design proposal is key and leveraged throughout the later discussion on the market design vision.

A Shared View of a Beneficial Design of Future Electricity Markets

This report shares the details of future electricity markets that were envisioned by participants in the task force. It takes the many proposals and reviews from the literature discussed above and then provides a shared vision of future markets from the task force with a focus on each of the six components shown in Figure 1. The fundamentals described as part of the future market vision in this report generally were agreed on by most task force participants, although there were also alternative paths proposed and supported by task force participants; some design features supported by a subset of the task force are also described here. The task force believes that the market design vision described can provide benefits to society by bringing lower costs and higher reliability under this clean energy scenario, and can be beneficial under other future systems as well. It is important to understand that there may be other designs and structures, including those not yet proposed or imagined, that can potentially achieve similar benefits.

FIGURE 2

Four Key Principles That Markets Aim to Accomplish



Successful markets must incentivize innovation, investment in capital, hedging against risk, and behavior to operate in ways that lead to reliable and economically efficient outcomes.

Source: Energy Systems Integration Group.

We note that the task force is not advocating policy changes to meet this market design vision and that not every task force member, or the lead writers of this report, may agree with every part of the vision. Rather, we share this report to assist industry, regulators, and policymakers and provide clarity on common characteristics of a beneficial market design as well as where debate still exists.

In the future market design vision shared in this report, we assume a 100% clean electricity system, with various characteristics inherent to such a system, and consider how market design may lead to reliable and efficient operation under that scenario. In addition, we explore how the market and accompanying policies can enable a transition of today's power system to invest in a 100% clean, reliable, and efficient system in the future.

In the next section, "Assumptions About and Characteristics of 100% Clean Electricity Systems and Their Implications," we describe several assumptions of the clean electricity system that were made for the purposes of this effort, and how that system can lead to several challenges that may require further attention. These challenges are the motivation to market design solutions articulated in the vision described in the next section, "A Vision for Market Design and Market Structure in Future Systems with 100% Clean Electricity." The market structure—the make-up of the entities and responsibilities within each market—was discussed by the task force but without substantial proposed ideas on any future vision due to the structures being largely policy-driven. Some components of the market design had general agreement across the task force and others had some degree of debate or differing perspectives. The next section is "Possible Next Steps for Realization of the Market Design Vision" and offers further consideration that can help inform decisionmakers of possible next steps. This is followed by a brief summary looking forward.

Assumptions About and Characteristics of 100% Clean Electricity Systems and Their Implications

A decarbonized electricity system can come about in numerous ways. This project did not assume an explicit decarbonization pathway or time frame for our market design vision, but several assumptions had to be made by the task force. These assumptions led to system characteristics that will drive the changes, as well as some challenges whose solutions may necessitate particular features of the future market design. For example, much of the discussion in this section is driven by the characteristics of VRESs that are variable, uncertain, inverter-based, often far from load, and with zero-cost fuel. Here we also discuss other assumptions, along with how they may lead to certain system impacts that may warrant features in the market design discussed later in this report.

The Resource Mix: Pathways to Meet 100% Clean Electricity

The term "clean" can have a range of meanings. In this report, the term is wide ranging and includes any generator or resource that does not actively emit greenhouse gasses or other emissions. This includes VRESs, such as wind (onshore and offshore), solar, and run-of-river hydropower. It may also include other renewable resources such as geothermal and reservoir-based hydropower, and other forms of waterpower, such as tidal and wave. It may include large amounts of energy-limited resources such as short-duration batteries and other storage resources if they charge from the grid when suppliers are also clean, and it may include other long-duration energy

storage technologies. Clean resources can include generators that use hydrogen or other zero-carbon fuels as a primary fuel or that have carbon capture and storage technology. Nuclear energy would also fall into this broad category, as would sustainably harvested biomass. However, we do not wish to be constrained to these existing technologies, as new zero-emitting technologies may become viable. Our scope also includes systems that would be deeply decarbonized even when not 100% supplied from clean sources. However, given that a majority of the existing clean energy technologies—especially wind, solar, and batteries—introduce characteristics such as variability, uncertainty, a displacement of synchronous resources, additional transmission needs, and overall costs that are disproportionately high-fixed-capital with near-zero operating costs, these conditions are present on the future system that is being studied throughout this exercise.

We assume that this future grid will require VRESs that provide large amounts of total energy when the sun is out and/or the wind is blowing. We also assume a substantial number of energy-limited resources and electric storage resources that are fast and flexible for assistance with balancing needs and grid services and shifting energy within the hour and within the day. These resources may or may not co-locate with VRESs. We assume that there is a larger amount of customer demand at residential, commercial, and industrial sites generally, and that demand is more responsive to the market and to grid needs than there has been in the past, but the level of demand response is imprecise, as discussed below. Finally, we assume the presence of resources that provide firm power when VRESs and energy-limited resources lack available energy over long durations, and resources that offer support for grid needs such as voltage control and frequency control. This section explores these technologies and their characteristics in detail.

Figure 3 (p. 7) shows a breakdown of the various supply resource types and technology types within each category. This is not exhaustive, but rather aims to outline the assumptions that can lead to the characteristics discussed in the remainder of this section.

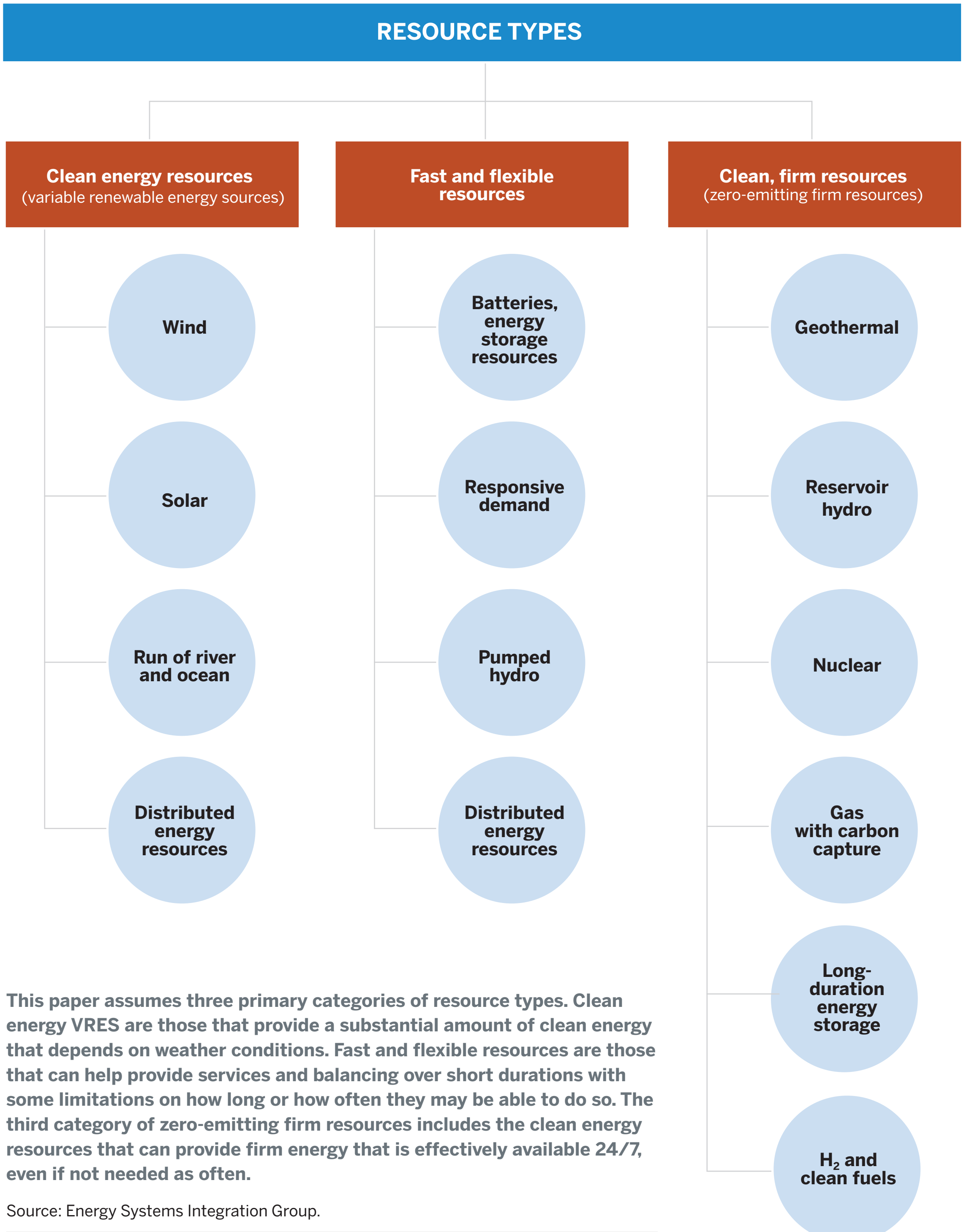
In the future decarbonized grid, we may expect that 70% to 90% of energy may come from VRESs. Short-duration electric storage resources are factored into that amount since they will be shifting the variable renewable energy across time. The remaining 10% to 30% of energy may come from the zero-emitting firm resources, and the amount necessary may depend on how responsive demand is. This resource portfolio projection generally aligns with the assumption of those studied in the literature (Denholm et al., 2022; NYISO, 2022; Jenkins, Luke, and Thernstrom, 2018). The pathway to 100% clean electricity will vary widely by region, and the exact resource mix is not critical to the remainder of the discussion.

Variable Renewable Energy Sources

We assume that substantial amounts of VRES will be part of the future 100% clean electricity system. The maximum available power limit of VRESs varies through time as weather conditions change. In addition, the maximum available power and energy cannot be predicted in advance with perfect accuracy. This variability and uncertainty can cause challenges for the power system and require additional flexibility in order to maintain frequency, minimize area control error, and address other issues. VRESs themselves can provide some additional flexibility, as they are typically able to ramp fast between their level of available energy and zero. It has also been shown that these resources can provide certain grid services, although they often do not provide much of these today (EPRI, 2019). VRESs are inverter-based resources, and

FIGURE 3

Clean Energy Resource Types on a Fully Decarbonized Grid



This paper assumes three primary categories of resource types. Clean energy VRES are those that provide a substantial amount of clean energy that depends on weather conditions. Fast and flexible resources are those that can help provide services and balancing over short durations with some limitations on how long or how often they may be able to do so. The third category of zero-emitting firm resources includes the clean energy resources that can provide firm energy that is effectively available 24/7, even if not needed as often.

Source: Energy Systems Integration Group.

therefore do not inherently provide significant levels of inertia, frequency response, or short-circuit current; however, certain controls and advanced technology additions can allow them to emulate many of the same characteristics of synchronous resources and even provide services in improved ways.[1]

Another characteristic of VRESs is that often, though not always, their greatest resource sites are far from load centers, which can require additional transmission to deliver energy to where it is consumed. Finally, the overall costs of VRESs are predominantly in the fixed capital costs that it takes to build the resource. Once VRESs are built, they have essentially zero operating costs. In many cases, certain production-based incentives can be in place such that VRESs earn outside revenue from governments for every megawatt-hour produced. This can result in these resources submitting a negative cost offer to the wholesale market, and these types of offers can impact energy prices and optimal dispatch.

Fast and Flexible Energy-Limited Resources

We also assume that fast, flexible resources such as short-duration batteries will be necessary to support system balancing on a 100% clean electricity system. These flexible resources smooth out the surpluses and shortages that variable resources cause. Flexible resources can provide flexibility to the grid during periods of high volatility in the VRES or load conditions. Fast, flexible resources are well positioned to take advantage of arbitrage opportunities afforded by the delta between high power prices during times of scarcity and low prices during periods when variable renewable power is abundant. In recent years, prices for lithium-ion batteries have plummeted and the trend is expected to continue (Goldman Sachs, 2024), which should drive ongoing widespread adoption. Fast, flexible resources such as energy-limited resources, including electric storage resources, can typically adjust output faster than traditional generators and move from maximum consumption (charging) to maximum generation (discharging) in a matter of seconds or minutes, thus providing important balancing services.

System operators or owners of fast, flexible resources may require additional algorithms to determine the optimal times for both charging and discharging to avoid energy deficiencies when energy is needed most.

These resources are also typically able to follow control signals with great accuracy such that they can provide a large set of the short-term grid services necessary on the future system. However, because of their energy limits, they can only supply energy in discharge mode in a sustained manner for short durations, typically four hours or less. This means they may run out of energy when the system needs it. It also means that system operators or asset owners may require additional algorithms to determine the optimal times for both charging and discharging to avoid energy deficiencies when energy is needed most. Finally, many, but not all, short-duration electric storage resources are inverter-based resources as well and share that characteristic with VRESs that was described earlier.

Distributed Energy Resources and Aggregations

We assume there will be greater levels of distributed energy resources (DERs) on the future 100% clean electricity system and that most of the DERs will be made up of small-scale aggregations of VRESs and

1 See ESIG's quick reference on grid-forming inverters at https://www.esig.energy/grid-forming-resources/.

electric storage resources. However, we assume that the overall energy contribution will be smaller than that of their large-scale transmission-connected technology counterparts. Small-scale DERs—distributed solar, wind, and batteries—will make up a share of both the VRES and energy-limited resource part of the future portfolio, and this will vary regionally based on policies, local renewable resource energy characteristics, and space and siting constraints. Where DER technologies have large-scale transmission technology counterparts, they share characteristics of the electric storage resources VRESs described above.

DERs typically have higher levelized costs than their transmission counterparts because of the smaller economies of scale, but they can provide additional benefits such as reduced transmission and distribution losses, more straightforward siting, and lower infrastructure needs and costs. While low levels of DERs can help to reduce or defer transmission and distribution upgrades, there are diminishing marginal returns or even incremental upgrade requirements at higher DER levels in some regions, particularly for DER resources with highly correlated output patterns like solar. Compared to transmission-connected solar, wind, and batteries, DERs may have less control and visibility by transmission system operators, which can lead to additional reliability challenges. Their presence may require complex coordination across multiple organizations to ensure reliability across transmission and distribution systems. While transmission-connected resources are dispatched with an objective of least cost and secure operation of the overall system, DERs may be dispatched to other objectives, such as meeting local distribution needs or reducing customer bills. These more local objectives may conflict with the needs of the overall system. Their much smaller size requires aggregations of multiple DER technology types to participate in wholesale markets. Their smaller size may also make it challenging to meet the same requirements of their transmission counterparts, such as metering and telemetry, and can cause difficulty in market solve times and computation.

Zero-Emitting Firm Resources

We assume the presence of resources that provide firm power when VRESs and energy-limited resources lack available energy over long durations. While lithium-ion batteries and other fast, flexible resources are ideal for filling the short-term gaps during periods of volatile renewable output, other technologies are likely needed during extended periods of high load and/or low renewable output. Zero-emitting firm resources (ZEFRs, also termed dispatchable emission-free resources, or DEFRs) such as geothermal, reservoir hydropower, renewable fuels, natural gas thermal plants with carbon capture and storage, nuclear, and long-duration energy storage can, depending on their specific characteristics, provide clean firm energy and/or support reliability during multi-day weather events that reduce renewable output. These resources can provide flexibility, fast response, and grid services as well, but the key characteristic is being able to supply energy for long periods during which VRES energy is insufficient and energy-limited resources are not able to fill in.

> **Zero-emitting firm resources are able to supply energy for long periods during which VRES energy is insufficient and energy-limited resources are not able to fill in.**

Various companies are bringing clean, firm resources to market, and significant research and development and venture capital is targeted at providing this service. These resources need not operate frequently and they can be ramped up slowly in anticipation of forecasted need. However, they require many of the types of attributes that existing fossil generation may have, primarily the ability to provide energy for long periods of time, while potentially being able to provide many of the necessary grid services on the future system as well. The exact technologies that will make up this set of resources are still unclear; therefore, so are their characteristics, such as operating cost, capital cost, locational siting constraints, infrastructure needs, availability profile, and physical operating parameters.

Responsive Demand Resources

In this project, we do not assume a specific amount of responsive demand in the future system but include it as a factor that may call for further study and as a need to meet the clean electricity goal at lower cost. We do assume that on a system with 100% clean electricity, a

substantial effort will have been made to electrify other sectors. Electrification impacts the overall electricity load as well as its characteristics, including its responsiveness. Responsive demand can include multiple types of demand from large industrial to individual households. Space and water heating and cooling, electric vehicles, and appliances can all play a role. The characteristics of responsive demand today and into the future are complex. It is a type of energy-limited resource: customers may only be willing to be called upon a few times per month or per year before they will not curtail again. It also does not always result in a load reduction; in some cases, a reduction in load in one time period may shift consumption to a different period. And it is unclear how behavior may change in the future with more automation, evolved retail rates, and transmission and distribution coordination programs. The willingness of customers to reduce their power or lose power completely may also change and differ by customer or load type.

Transmission and Other Infrastructure

Looking beyond supply and flexible load resources, the decarbonization of electricity systems in the future will likely require an expansion of infrastructure including ways of transporting energy. This includes high-capacity, long-distance transmission. An analysis by the National Renewable Energy Laboratory indicated a need to double or triple the existing capacity of the transmission system, depending on technology and cost assumptions, and found that the scenario with the largest transmission build-out results in the lowest overall system costs (Denholm et al., 2022). Other studies yielded similar results. For example, a study of the Eastern Interconnection showed that large-scale transmission build-out, even when its expansion costs are considered, can reduce overall costs by $100 billion and decrease the average retail electricity rate by more than one-third (Clack et al., 2020). A study by the Massachusetts Institute of Technology showed that interstate coordination and transmission expansion can reduce the cost of a zero-carbon electricity system by up to 46%, compared to a state-by-state approach (Brown and Botterud, 2021).

Key Functions of Large-Scale Transmission Enabling Decarbonization, and Barriers to Its Deployment

Large-scale long-distance transmission performs a few discrete functions to enable decarbonization. The most obvious is accessing wind and solar resource areas that are remote from load centers—within states, across regions, and across the country. The second function is to improve resource adequacy and operational reliability by connecting geographically disparate renewable resource areas that generate at different times and allowing greater access to flexible and/or firm resources when they are needed. The colloquial phrase "the wind is always blowing somewhere" can be true when geographically-large-enough areas are connected. The third discrete function is to improve system strength; many renewable resource areas are in weaker parts of the grid, where voltage and frequency distortion can occur. Transmission increases grid strength, enabling greater levels of renewable energy integration.

Transmission infrastructure is expensive, but its benefits are valuable and diverse. Transmission capacity expansion is likely necessary for the clean electricity system assumed in the future system, and the total benefits can go beyond decarbonization. Large-scale high-voltage transmission can connect areas with load diversity, reduce grid congestion, and improve system resilience. The New York grid operator has stated that "these interconnections support and bolster reliability and resilience by creating a larger and more diverse resource pool available to meet needs and address unexpected and/or disruptive events throughout an interconnected region."[2]

Barriers exist today that could limit the amount of transmission expansion and upgrades and prevent the construction of the transmission network necessary to enable the transition to the 100% clean electricity system described in this report. The "3 Ps" of transmission infrastructure barriers—planning, permitting, and paying—are gaps that may need further consideration through market rules or policy. Permitting is complex in most jurisdictions. Paying refers to cost allocation, whether and how the costs are allocated to the beneficiaries of the project and whether incentives for building are aligned with the benefits provided to different parties when the transmission is built. Coordinated and robust planning can allow for comprehensive and cost-effective build-outs.

Transmission capacity expansion comes in many forms. "Greenfield" lines—transmission infrastructure on new rights of way—will only be part of the answer, as those lines can take years to build. Grid-enhancing technologies are at the other end of the spectrum. These are added to existing infrastructure to increase transfer capacity, and they are lower cost and quick to deploy (see ESIG's forthcoming report on grid-enhancing technologies (ESIG, forthcoming-b)). These technologies include power-flow control devices, topology optimization software, and dynamic line ratings. Other options are reconductoring with high-performance conductors to increase the capacity of lines using existing structures and rights of way, and rebuilding structures to support higher-capacity wires on existing rights of way. Thus, there is a continuum of expansion options, all of which have an important role in delivering energy going forward.

In most regions of the world, transmission expansion is managed separately from wholesale electricity market design. While markets enable competition to supply power from different locations of the grid, transmission has been assumed a monopoly and the planning and investment of the network performed by the local utility. Decisions are sometimes made through the utility planning function, and some decisions may be part of stakeholder processes. In the clean electricity future envisioned in this project, we assume that transmission expansion will be prevalent, including transmission technologies like grid-enhancing technologies, and we share thoughts on how markets can enable efficient decisionmaking around this infrastructure alongside that of efficient supply investment and operation.

Other Infrastructure

Other infrastructure may also be necessary in the 100% clean electricity future explored in this project that can have an impact on market design. First, there will be distribution infrastructure needs that will depend on the amount of DER participation and consumption patterns across many distribution networks. Second, electric vehicle charging infrastructure will change load patterns but also allow for managed charging to improve system flexibility. Third, while traditional natural gas–fired

2 NYISO Comments to FERC, March 2018, Docket AD18-7.

thermal plants may not be a part of the 100% clean electricity scenario, it is likely that delivery of certain fuels for the firm clean supply technologies will be required, and these may use the existing (or expanded) gas pipeline infrastructure.

While we assume much of this infrastructure may be necessary, it does not, for the most part, directly impact the market design vision presented here, and the level of this infrastructure need is not discussed further.

Configurations Across the Network

The co-location of different supply resource types (such as solar with batteries) may be expected in the future. This co-location of resources, also referred to as hybrid resources, is motivated through cost savings and reducing interconnection time (ESIG, 2022b). This same co-location strategy has begun to take shape with other entities such as large loads that co-locate with generators that can serve almost or completely all of those loads. This may appear to the transmission system and to the market operator as a net injection of 0 MW but will depend on the volatility and sizing of both resources. Co-location of large loads with generation may be taking place for similar reasons as the co-location of generator types, particularly due to the increased interconnection speed that it brings. It also brings up additional questions more related to future market design, such as how these loads may be allocated costs of such items of transmission, independent system operator and regional transmission organization fees, ancillary services, and uplift. While these and potentially other future configurations will be very important for market design decisions on this future system, including aspects of cost allocation, they are out of scope of this work and should be explored further.

Reliability on a System with High Levels of Weather-Dependent, Variable, Uncertain, and Inverter-Based Resources

Resource Adequacy

Achieving resource adequacy will be paramount on the future system given the change in resource mix. Resource adequacy represents the ability of the inherent fleet to meet the needs of the system at a future point in time based on the capabilities of the supply resources on the system and the characteristics of demand. Resource adequacy analysis is performed by running studies under many different scenarios of resource outages and weather conditions and changing the resource side until the system is within the tolerance used for the region. A typical tolerance metric in today's practice is 1-day-in-10-years of involuntary load-shedding. Other metrics that are being considered and used in some systems include the expected unserved energy (EUE), effective load-carrying capability (ELCC) of resource contributions, and additional probabilistic metrics. Each resource is accredited a value reflective of its contribution to resource adequacy, which attempts to make the unit measure equitable across different types, their locations, and individual characteristics.

Resource adequacy is met through various means and market designs. Many regions have capacity markets where resource adequacy is met explicitly with a capacity product that uses the accreditation value and an auction to meet the peak load plus a reserve margin. Prices of that capacity market are paid to all resources that clear the market, and those resources are dedicated to the region for capacity obligations, including offering capacity into the energy markets. Other regions have a resource adequacy compliance requirement that each load-serving entity (LSE) must show that it has met on its own. And there are yet other regions that do not explicitly meet resource adequacy but rely on the energy markets to achieve a reliable system.

The characteristics of a future 100% clean electricity system may prompt changes to resource adequacy approaches and methodologies. It can be more difficult to determine the contribution of VRESs and energy-limited resources toward resource adequacy, with resource accreditation being increasingly sensitive to modeling choices, the characteristics of the assumed portfolio, and data assumptions. Where there are high levels of VRESs dependent on a single resource—solar or wind—the contributions of these resources during periods of grid stress can potentially approach zero, challenging the ability to meet resource adequacy requirements. The time periods with sustained low VRES output (i.e., the dunkel flaute or "dark doldrums") can be difficult to include in resource adequacy modeling, though efforts are underway to develop stress-testing methodologies for use in assessing system resilience (ESIG, forthcoming-a). With more price-responsive demand, the reliability target can also be more complex.

Short-Term Operating Reliability

Short-term operating reliability can also be impacted on the future system that we assume in this project due to the higher levels of weather-dependent inverter-based resources. Reserve requirements for certain ancillary service products have been shown to increase with increasing VRESs to maintain the same level of reliability and balance. Increasing levels of VRESs can lead to changes in operational dispatch procedures and new ancillary service products to provide sufficient ramping capability across different time horizons (e.g., the Southwest Power Pool's uncertainty product and various ramp products (EPRI, 2019)). Without added control capabilities added to VRESs to provide frequency control services, these types of services may require new strategies, grid codes, or even market products to ensure sufficient levels of various frequency control capabilities. Transmission reliability can also be impacted by the variability and uncertainty. This can cause transmission flows to be highly volatile, leading to greater possibility of flows exceeding their limits or leading to instability. However, technology enhancements, such as the use of grid-forming inverters, can provide additional support to system stability if used in sufficient installations of VRES (ESIG, 2023a; ESIG, 2022a).

Wholesale Energy Prices and Price Formation with Zero-Fuel-Cost Resources

The total cost of VRESs is almost entirely made up of the fixed cost to build and finance the resource. Once they are built, they have essentially no operating cost to run. With wholesale energy prices that are set based on the marginal cost to supply energy, these resources would typically offer in with \$0/MWh prices that would generally, all else being equal, lead to lower prices and, when those resources are setting the price, prices set to \$0/MWh. Offers and prices may even be set to negative amounts due to production-based subsidies that are

provided to the resources for supplying energy. Thus, lower prices and prices at $0 or negative could potentially be a result of this clean energy scenario with existing market designs.

At the same time, the uncertainty in available supply at any given moment in time increases, as the high levels of VRESs and potential retirements of firm resources can lead to more periods of tight conditions, which can potentially lead to price spikes and shortage and scarcity pricing. The frequency of very low and very high prices is a function of many conditions that will vary regionally, such as correlation of VRES output with load conditions, operators' risk criteria, payments outside of the market, resource adequacy policies, retirements of reliability resources or transition to reliability contracts, and the responsiveness of demand. Taken together, these can lead to the future average wholesale energy price being either higher or lower than what we see today. That said, most experts agree that regardless of the average, the volatility of wholesale energy prices is likely to increase. This volatility has several consequences for future market design that can impact operational decisions, investment, and hedging.

Price formation is also dependent on the way in which certain technologies offer to the wholesale market. Electric storage resources, for example, have costs that are based on the energy cost that the resource had to pay when charging previously to discharge now, as well as the opportunity cost to discharge now and potentially lose out on the opportunity to discharge later when its compensation would be greater. Understanding the offer strategy as well as market designs, such as how state-of-charge is managed, is complex and not yet well understood for these future scenarios.

Price formation for demand is another complexity. Demand rarely participates actively in wholesale markets, and when it does, it is often as an emergency resource when prices have risen to very high levels at which the load is willing to curtail. With possibly larger levels of responsive demand and more demand types participating in wholesale markets, the way in which those resources will participate in markets and set the price is unclear.

Finally, it is unclear what the operational cost of emerging zero-emitting firm resources might be, as this will depend on the technology, its fuel cost, and other factors. The operating cost of these resources can drive the opportunity costs of electric storage resources and responsive demand and affect how often and for how long scarcity conditions occur. These assumptions are all considered for the market design vision discussed below.

Incorporating Clean Energy Policies as an Externality Within the Wholesale Markets

Policies, consumer choices, utility choices, and economics drive the move toward clean electricity; the wholesale market itself is agnostic to the types of resources on the system. There are many clean energy policy options across U.S. states and other regions, which can lead to inefficiency. In the United States, the 2022 Inflation Reduction Act included various tax incentives for clean energy technologies, including investment tax credits and production tax credits. Individual states have additional policies such as cap-and-trade programs (creating a price on carbon emitted by suppliers), emission limits, renewable portfolio standards, clean energy credits, and various clean energy technology carve-out targets (e.g., offshore wind targets). Policies such as a carbon tax or cap-and-trade programs also exist in other regions such as Europe. This mix of policies across jurisdictions and the lack of comprehensive technology-neutral incentives for emissions reduction can lead to inefficiencies in reaching emissions goals, can create difficulties for markets that span U.S. states with different policies, and create complexity and a lack of transparency for market participants. The market design vision discussed below assumes that this is unlikely to be changed.

In addition to policy options, utilities and customers play a significant role in driving the energy transition. Nearly half of the Fortune Global 500 companies have net-zero greenhouse gas emissions goals by 2050 (CIP, 2024). Twenty-six utilities, half of which are investor-owned utilities, have voluntary targets to reduce emissions by at least 80% by 2030 (Brady, 2023). It is likely for this voluntary corporate trend toward purchasing clean energy to continue and to expand as a mechanism to make the transition to 100% clean electricity.

A Vision for Market Design and Market Structure in Future Systems with 100% Clean Electricity

Having discussed the assumptions on what the future system and resource mix might look like and what implications that mix may have for reliability and affordability of the power grid, we now take a look at how wholesale markets can play a role in supporting reliability and affordability under a 100% clean electricity system. Markets can help provide solutions that may not otherwise have been developed and bring out innovation. They can help achieve many goals, but they cannot do everything. The vision described in this section is an attempt to provide both the characteristics of market design that were generally agreed upon by the task force as well as those design features that are promising but where there was not agreement across all members. We first share the key highlights of the vision and then follow with further detail on each element. We start with market structure, the make-up of the market, and responsibilities of the parties involved, and then move to market design. The vision primarily focuses on the latter.

The Vision

The task force had broad agreement on several key components of the vision. There was also agreement on the need for reform and general approaches, while there were varying ideas around the actual implementations of those reforms. Regarding the four key principles shared in Figure 2 (p. 4)—innovate, invest, hedge, and operate—the task force generally had broad agreement around the approaches for incentivizing **innovation and operation**. Participants also agreed on the need to incentivize efficient **investment** and to provide for **hedging** that also allows for equitable treatment of all consumers, but the approaches and specific implementations of achieving these objectives favored by task force participants were more diverse. **In particular, there was agreement that coordination and some government decisionmaking was necessary to bring about the right set of resources and infrastructure that would be needed on a 100% clean electricity system, but different participants aligned with different parts of the continuum regarding how much coordination and policy were necessary.**

One area in which the task force did not find agreement around any changes was market structure (as distinct from market design), and generally deemed this as out of scope. Some participants recommended substantial coordination between policymakers and grid planners as a way to achieve resource adequacy with a feasible resource mix and infrastructure investments in place. The attributes of current market structures within which the market design vision would unfold are described in the next sub-section.

The specific elements of the market design vision that were deemed as beneficial for a system that has 100% clean electricity were the following.

Price Formation

- A majority of the task force agreed that the existing large regional energy markets with **bid-based economic dispatch and marginal cost pricing** with sufficient locational and temporal granularity should remain largely in place as a way to incentivize operational behavior and provide signals that can support investment decisionmaking.
- Task force participants agreed that **shortage or scarcity pricing** would be used that drive prices high when conditions warrant. Extended reserve demand curves could be used that would allow for less volatile shortage prices before the actual scarcity condition becomes apparent, while providing beneficial operational incentives.
- While most participants believed that **existing energy market design** should largely continue, they also thought that some incremental changes should be explored such as **improved sector coordination**, **regional seams management and efficiency improvements, market power mitigation procedures, and exploration of whether the unit commitment tool for market clearing is still necessary and what might replace it.** Stakeholders and researchers may also explore the feasibility of further granularity of locational pricing, such as distribution network pricing, to determine whether it is practical and whether it provides benefits that outweigh the complexity and administrative costs.
- To incentivize innovation in energy and grid service supply technologies, the task force favored **participation models** that are preemptive and prioritized for reliability but that do not prevent or stall new technologies that are competitive from participating in the electricity market. Participants believed that market design should strive for technology-neutrality but not attribute-neutrality.

Demand Participation

- The task force believed that mechanisms should be explored to **enable more demand resources** to support grid reliability than they do today, including giving access to system costs and prices on as granular a basis as possible for the subset of those demand resources that choose to participate, while protecting certain customer classes from financial harm and keeping equity objectives in mind.

Operational Reliability Services

- Task force participants agreed that continual evaluation is needed of whether new **operational reliability products** are necessary and whether competitive markets for those products would provide additional benefits that outweigh their costs and administrative burden. Any resource, regardless of its technology, that demonstrates adequate attributes and performance should be qualified to participate in a given service.
- There was a short discussion around whether **ancillary service markets** with prices driven primarily by **opportunity cost** are sufficient by themselves to incentivize investment in resources that provide these services, or whether forward contracts for grid services may be necessary for certain services.

Resource Adequacy and Investment

- The task force largely agreed that **energy markets and related short-term market mechanisms by themselves may not accomplish all that is needed** to ensure investment in an adequate and efficient supply portfolio that meets the clean electricity criteria.
- **Interventions** may be needed for resource adequacy and for certain reliability attributes as well as for infrastructure. The task force differed on the emphasis and the extent of the intervention, and considered several different design approaches to this such as existing capacity markets, strong coordinated generation and infrastructure planning, mandatory contracts for hedging, and others.

Transmission and Other Infrastructure

- Most of the task force agreed that substantial **transmission expansion and other additional infrastructure**, currently decided upon largely outside of the wholesale markets, is beneficial and may need further consideration to enable the clean electricity transition. Workable policy that could incentivize innovation and efficient investment in infrastructure should be explored further where applicable.

Clean Energy Incentives

- Many in the task force agreed that clean energy incentives should have **sound economic principles** and designs that focus on reducing emissions. They thought that market designers can play a role to facilitate state and regional policies and accommodate efficient trading of energy with policies built in as constraints in the market design.
- A short discussion explored whether loads could or should **input their willingness to purchase clean energy** within the electricity markets and whether the markets should provide transparency to the premium value paid for that clean energy.

The Continuation of Present Market Structures

Market structure refers to the responsibilities of different entities that are involved in an electricity market region. Market structure is the cornerstone of market design directions for each region that has established a wholesale electricity market or that is proposing reform and enhancements to existing wholesale electricity markets. Market structure is often determined through legislatures and local governments and has less flexibility to be modified by energy regulators, market operators, and their stakeholders. As such, the market design vision discussed here has less focus on market structure and generally assumes the status quo across each region (although task force participants shared some preferences for certain roles of various parties, which are summarized below). We still provide a thorough review here of existing market structure given its complexity and importance to the rest of the market design vision.

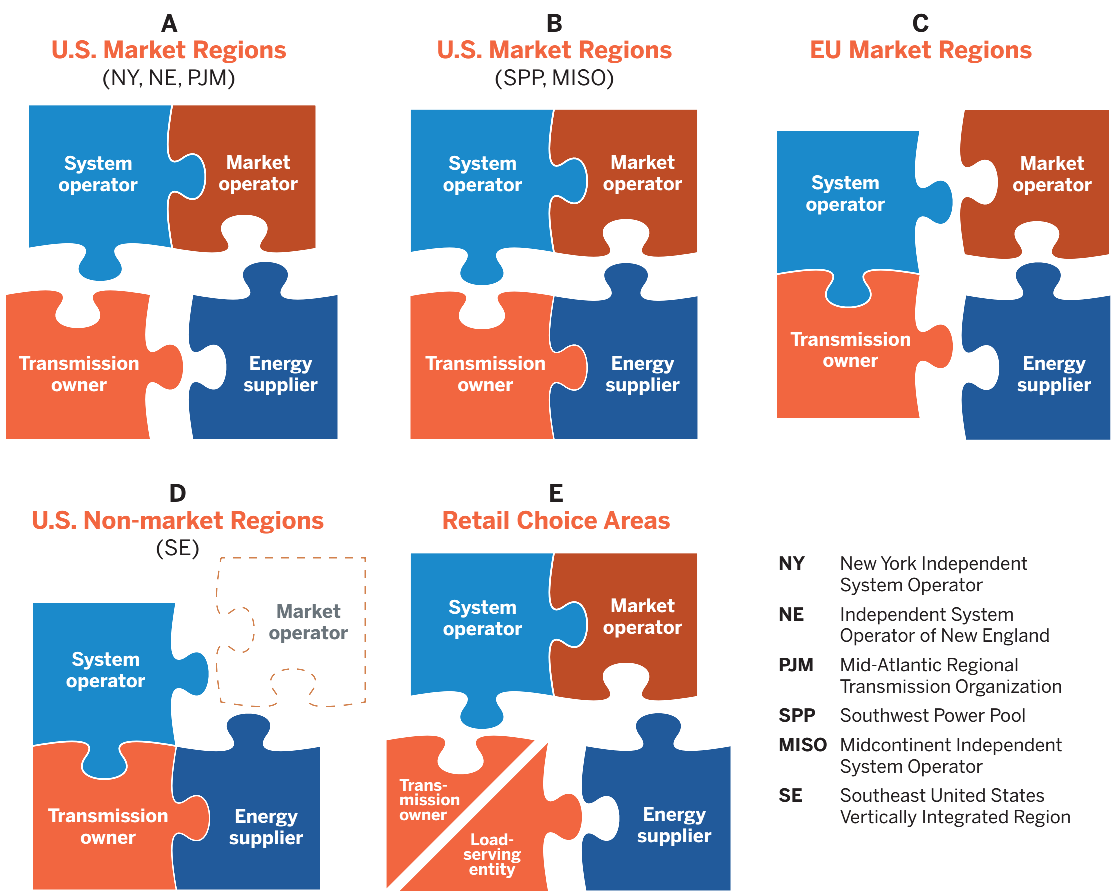
Key participants in electricity markets include the system operator, market operator, transmission owners (usually utilities), energy suppliers (either independent power producers or utilities), and load-serving entities (either

utilities or retailers). Each entity can have different responsibilities with each other as seen in Figure 4. In all ISO/RTO regions of the United States, the market operator is the same entity that acts as the system (and network) operator (Figure 4, A and B). In some market regions (B, in the figure), vertically integrated utilities exist within the region that owns transmission and energy suppliers, while in others (A, in the figure) the transmission owners and energy suppliers are separately owned. While the separation of transmission owner and retail LSE typically occurs alongside the separation of transmission owner and energy supplier in practice, the structure of (A) can be further expanded as shown in (E) in retail choice areas, where transmission owners and retail LSEs are also separate entities. Other structures exist in Europe where the system operator and transmission owner are one entity with a separate market operator (C) or in the southeast United States, where the system operator, transmission owner, and energy supplier are under the vertically integrated utility and a market operator, and a market itself, may not exist (D).

The Role of ISOs/RTOs

ISOs/RTOs are critical institutions in a 100% clean electricity system because they contribute both to physical infrastructure and the integrated wide-area system operation needed to integrate different types of resources. The

FIGURE 4
Differences in the Relationship of Key Entities Involved in Electricity Markets Demonstrating Differences in Electricity Market Structure



Market structure defines the roles and responsibilities of different parties and the eligibility of different company types to hold those responsibilities. A through D show different structures in place in the U.S. and in Europe, and E shows a further structural difference that is in place when retail electricity supply has been deregulated and unbundled.

Source: Energy Systems Integration Group.

role of ISOs/RTOs and market operators in different regions differs significantly today (Figure 5). For the task force's market design vision, the ISOs/RTOs would largely hold the same role as they do today when it comes to transmission planning, bulk power system operations, and administering the energy and ancillary service markets. In the task force vision, ISOs/RTOs would also have a role in resource adequacy and generation planning, but the task force participants differed regarding the extent of that role.

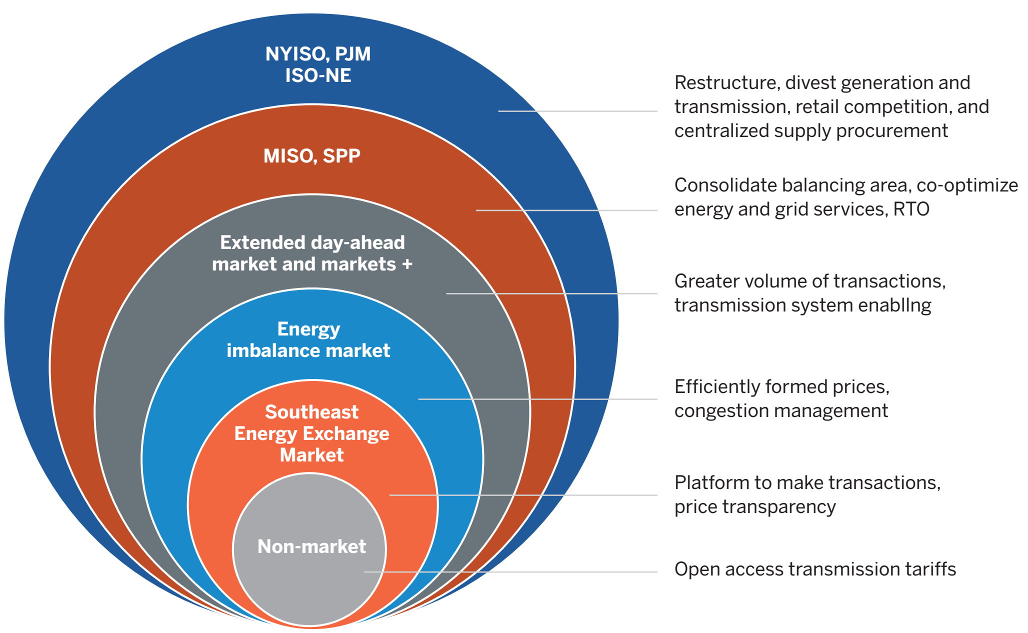
LSEs: Procurement of Power on Behalf of Load

Some entities must be responsible for the procurement of power on behalf of individual customers in the wholesale market. It is realistic for large loads to procure on their own behalf, but that is not the case for the mass commercial or residential market. The choice of entity is up to each state in the U.S. regulatory structure. Texas, for example, has a retail access program in which customers can choose among competitive retail suppliers as LSEs that procure power on a long-term basis for the loads they serve. In other states, regulated utilities are the LSEs that serve load in their footprints. In either case, the LSE needs to have the incentive and ability to procure power and to do it in a way that avoids energy price shocks to its retail customers.

Competitive Markets for Energy Supply

Energy supply can be performed by different entities on today's markets including utilities. Independent power producers are independent of utilities and are for-profit entities that build and operate generation. Using competitive forces for those sectors characterized by competitive structures, including the generation sector, can lead to greater efficiency. As additional technologies become viable on the future system envisioned, it can further depart the sector from the natural monopoly and inherent economy of scale that it had in the early years of the industry.

FIGURE 5
Variations in U.S. Electricity Market Types



Regions around the United States have different features, products, and responsibilities for the market operator. The larger circles have added market features and greater reliance on markets to meet the four principles. Other variations on these types exist around the world.

Source: Energy Systems Integration Group.

Transmission and Distribution Utilities

There is not a good workable alternative to monopoly ownership of most transmission and distribution systems, and the primary owners are utilities. Under a 100% clean electricity system, task force participants agreed that transmission and distribution utility companies and other transmission/distribution owners should look to increase the capacity, efficiency, and reliability of their networks and look for innovations, even if the regulatory structure may not necessarily promote innovation as it does in competitive (i.e., energy) markets. They also agreed that state public utility commissions and the Federal Energy Regulatory Commission (FERC) should make sure that all transmission owners are equipped to perform these key functions and that innovation and cost-reducing solutions are part of decisionmaking.

Coordination Between States and ISOs/RTOs

Some task force participants emphasized the need for a more coordinated approach between states and the ISO/RTO/reliability coordinator in the United States (see Joseph, forthcoming). This kind of coordinated planning can help inform state resource selection and help states think about the energy transition along two timelines: (1) what resources meet system operating reliability needs today, and (2) what resources may be necessary to meet all the needs on a 100% clean electricity system (many of which may be non-commercial technologies). It is possible that this kind of coordination may fill policy gaps that create reliability risk today, but it can also help reduce public and private investment risk in the high-capital but not-yet-commercial technologies (zero-emitting firm resources) and associated infrastructure that are critical to enabling the reliable transition of the electricity sector. This kind of coordination may also highlight and help break down regulatory silos that make it challenging to plan across sectors (such as gas and electricity sectors today).

The Continuation of Short-Term Energy and Grid Services Spot Markets

Large Regional, Bid-Based, Short-Term Energy Markets Function Well Now and Should Continue to in a 100% Clean Electricity Future

Large regional energy spot markets with bid-based economic dispatch algorithms and nodal, sub-hourly marginal cost pricing are a reliable and efficient means of incentivizing operational behavior for all supply resources today as well as on a 100% clean electricity system.

This has been the consensus means of efficient reliable balancing and facilitating competitive electricity markets for many years and can likely be the case in future years under a clean electricity system (Schweppe et al., 1988). Most U.S. ISOs/RTOs have settled on a relatively standard approach of bid-based security-constrained economic dispatch with locational marginal prices (LMPs) (Hogan, 2008). The following features are included in these energy markets, and the task force largely agreed that these mechanisms will play an important role in future energy markets:

- Flow-based congestion management with no physical capacity reservations
- Real-time spot markets to support real-time balancing and reliable and economic scheduling, with the ability to support bilateral contracts outside of that market
- Bid-based security-constrained economic dispatch with a reasonable representation of the transmission network

- Locational marginal pricing for every time and location as granular in space and time as is practical[3]
- Scarcity pricing design that allows prices to rise above the marginal cost of the most expensive resources when the system has or is approaching insufficient resources
- Transparent market power mitigation procedures that prevent market power from influencing pricing while also allowing for complex offer strategies

This market design is particularly valuable when integrating VRESs, because the variable supply of any resource can be pooled with all the other supply and demand resources on the system to achieve system balance and efficiently manage transmission congestion. Conducting these markets at granular time intervals can also incentivize flexibility and incentivize energy to be supplied and load consumption reduced when and where it is needed.

It is important to note that the use of LMPs does not in theory or practice replace the need for planned transmission or other infrastructure. While LMPs can show the value of economic transmission build, empirically they have not been found to directly incentivize that expansion through financial transmission rights or other means. Separate expansion planning practices will still be necessary in the future as they are today.

The task force believes that prices should be able to rise so they reflect scarcity and are set more by the demand than the supply in those instances of scarcity. Some task force participants recommended the use of "full strength" spot market prices. "Full strength" refers to prices where the market can reasonably be expected, in the long run, to result in revenues high enough to support the efficient investment in a mix of generation, storage, and demand-side resources expected to meet the resource adequacy targets set for the system. The task force recognizes that policymakers and regulators may have legal obligations to limit price risk for consumers. This obligation can highlight the importance of pairing the use of full-strength energy prices with appropriate hedging practices to manage risk.

The use of efficient pricing to incentivize flexibility is also important to consider given the challenges associated with supply variability across time. With the potential for increased volatility in the operational needs and corresponding spot prices due to the variability of VRESs, it will be important for these markets to incentivize operational behavior to accommodate that volatility. When there are incentives for increasing supply in an interval when it is needed that work alongside incentives for increasing demand (or storage charging) in other intervals, this can result in an efficient and flexible combination of supply/demand resources needed in a high-renewable system.

Continued Incremental Enhancements to the Energy Markets

Continued incremental changes to the energy markets should be considered as gaps are discovered and priorities allow.

While the previous sub-section focused on the benefits of the existing energy markets, there will continue to be incremental improvements to these designs to accommodate the different challenges posed by the 100% clean electricity system. Market operators and researchers are working on several ideas that may not have been prioritized or implemented by most regions yet but are understood as beneficial to many. These include the following:

- **Improved multi-sector alignment such as with other fuels markets.** While traditional gas-fired generation may not be part of the 100% clean electricity system, other fuels and gas-fired plants with carbon capture may continue to use this system. Thus, the existing gas/electricity coordination challenges today may still be present in the future system, and improvements to align these sectors should be explored.
- **Improved seams management across ISOs and RTOs.** We assume that there will be as many market operators in this future system as there are today, and getting prices to lead to efficient flow of energy across the seams of multiple markets will be even more critical in the future given increased volatility.

3 While financial transmission rights are typically a complementary function of these markets, the task force did not discuss at length the benefits of this mechanism on a future 100% clean electricity system.

- **Getting scarcity pricing right.** While the task force generally agreed that scarcity pricing is critical, it can be challenging to get that value right without a demand-side sharing what these resources' proxy value of reliable power is. Industry should strive to get real scarcity prices from those affected instead of proxy values wherever possible.
- **Determining market power and market power mitigation rules for resources that do not have fuel cost, while avoiding automatic mitigation that prevents offers from reflecting truly high opportunity costs.** Market operators are just now learning about the ways in which electric storage resources are offering in costs to the markets, and these offers are more complex given that there are not standard fuel costs or heat rates to determine these storage resources' true costs.
- **Determining whether unit commitment on a future system is still necessary.** The thermal resources that require day-ahead start-up notification may no longer be part of a 100% clean electricity system, and therefore the algorithms that focused on getting these resources online may no longer be useful. The task force discussed the change from a security-constrained unit commitment model that is the engine of the day-ahead market to a security-constrained storage optimization model instead given the changes in the resource mix. This change should be explored further to understand its merits and implementation.
- **Determining whether additional granularity of the network representation within the market clearing is feasible**, including some form of locational pricing that incentivizes operational behavior on the distribution network, particularly if large levels of DERs can support energy needs and reliability.

Enabling Demand Participation

Ways need to be found for demand-side resources to participate in supporting the grid and flexibility needs more so than they do today. This may include exposing some demand to system costs on a more granular basis for the subset of those demand resources that choose to participate, while protecting from financial harm those customer classes that are unable or challenged to respond.

Demand-side flexibility can act as a key lever in managing grid stress, high spot prices, and reliability events, and will be increasingly important as VRES levels continue to rise. Customers can provide grid services through demand response and DER aggregation programs including those that pass wholesale prices on to customers. For example, demand response programs or critical peak pricing can be used to reduce capacity needs or reduce an LSE's exposure to high spot prices (Schittekatte et al., 2022).

Demand is often treated as inelastic and as must-take in the wholesale markets; however, many reasons for why this was historically the case may no longer hold.

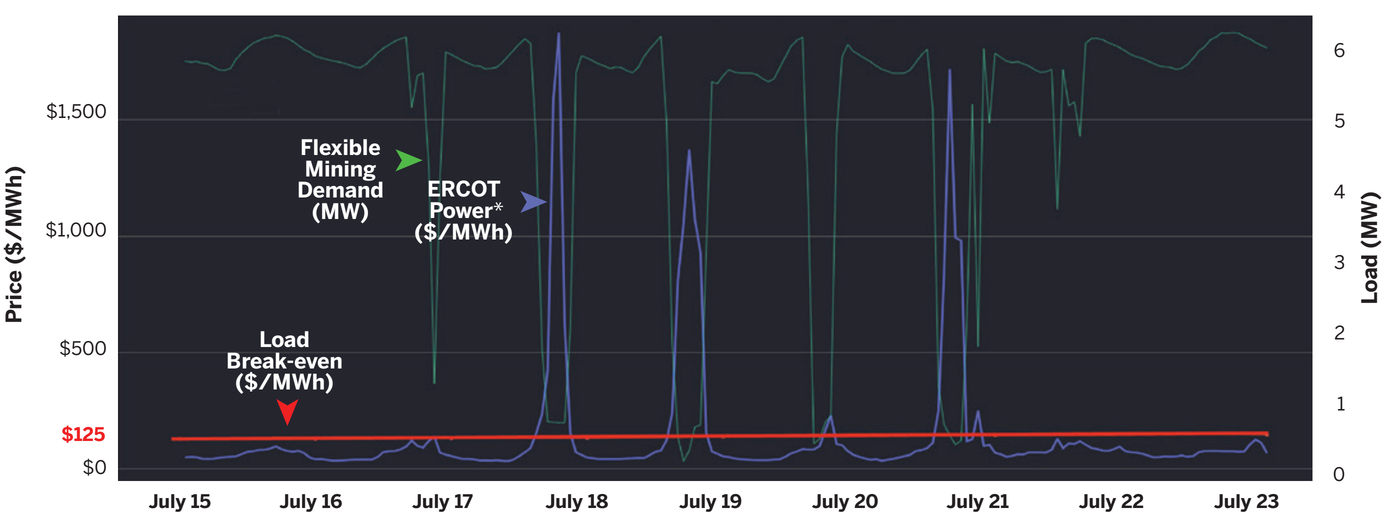
Demand-side participation in wholesale markets was assumed when these markets were first designed (Schweppe et al., 1980). This flexibility in the load is an important source of fast system balancing services. It provides economic efficiency (especially when available as a regular part of day-to-day market operations (Alstone et al., 2017; Hale, Stoll, and Mai, 2016; Hurley, Peterson, and Whited, 2013)); it can reduce the potential need to overbuild generation, transmission, and distribution infrastructure; and it can enhance operational reliability by giving the operator control over both sides of the supply/demand balance (O'Neill, Lew, and Ela, 2023; Hogan, 2023; Kavulla, 2023). However, demand-side participation has not been well integrated in practice. Demand is often treated as inelastic and as must-take in the wholesale markets, with only small amounts of responsive demand reacting to prices or providing grid services. However, many reasons for why this was historically the case may no longer hold.

In the past, demand was much more inelastic because: there was a lack of affordable communication and control technologies that could enable automated participation; decisionmakers did not want to expose customers to the volatility of prices or to complex rate structures; many customer loads did not have inherent flexibility; customers did not have advanced metering infrastructure; baselining, monitoring, and verification of demand response was challenging; traditional utility incentives were based on capital expenditures rather than operational programs that incentivized demand flexibility; and system operators did not know to what degree they could depend on demand flexibility for reliability. Today, much of this has changed. In the United States 72% of electricity meters (119 million) were smart meters as of 2022 (U.S. EIA, 2023). Controllable thermostats and electric vehicle charging applications are being rapidly deployed, which can extract flexibility from these loads. Wholesale market participation models and retail tariffs allow for customers to be exposed to wholesale market prices in a way that incentivizes flexibility without the need for baselining, monitoring, and verification (see ESIG's report *Gaps, Barriers, and Solutions to Demand Response Participation in Wholesale Markets* (ESIG, 2025)).

The Electric Reliability Council of Texas's (ERCOT's) Controllable Load Resource model enables loads to be treated like a generator.[4] These loads can participate in the day-ahead and real-time markets and receive security-constrained economic dispatch setpoints at 5-minute intervals. Figure 6 shows an example of a crypto mining data center being dispatched to real-time prices. While, today, loads are settled at zonal prices and generators at nodal prices, in the future it may be useful to settle certain load resources at nodal prices to avoid potential conflicts in pricing and to fully utilize load resources to relieve congestion (Lew et al., 2024).

A core element of this market design vision is to further extract the flexibility inherent in demand, and to fully realize a two-sided market in which there is a deep stack on both the demand and supply sides and in which both dynamically adjust to maintain balance and grid reliability. The task force realizes the benefits of implementing dynamic prices on retail rates and of wholesale market participation for providing incentives to support the grid, while also protecting consumers and resulting in an equitable outcome for all customer types. This does not mean that all demand becomes flexible, just as not all generation is flexible. But it does mean far more elasticity in demand than exists today.

FIGURE 6
Real-Time Economic Dispatch of a Flexible Load Resource



* ERCOT Load Zone West Real Time Settlement Point Price

This illustrates the accurate response of a flexible demand resource and its ability to adjust its consumption behavior to energy prices. A bitcoin mining datacenter in the ERCOT territory follows the ERCOT base points and reduces its demand when real-time prices are high, providing additional flexibility to the grid.

Source: Lancium.

4 https://www.ercot.com/services/programs/load/laar/index.html

The first key to unlocking demand flexibility is exposure to prices. As an ESIG white paper explained, "Someone, somewhere must face the clear price incentive to actively manage demand in order for it to happen" (Kavulla, 2023). A customer on a flat rate or a customer with a weak price signal—such as a low peak-to-off-peak ratio in a time-of-use rate—may lack a clear price incentive. Demand flexibility driven by exposure to prices goes hand in hand with full-strength spot prices, which give a clear signal to a customer or an LSE, making responsiveness worthwhile. Strong price signals can make enabling technology cost-effective (such as communications and control technologies for automation) (ESIG, 2025) or can incentivize the behavioral change needed by the customer. Importantly, we note that this does not mean that all residential customers should be exposed to extreme scarcity prices; there are many residential tariff options that can provide better price signals than flat, volumetric rates. For example, an analysis of a combination of time-of-use rates and critical peak pricing in the California Independent System Operator (CAISO), ERCOT, and Independent System Operator of New England (ISO-NE) markets found that these simpler and less volatile tariff options can provide up to 60% to 70% of the potential of real-time prices (Schittekatte et al., 2022).

Another key to demand flexibility is exposure to as many components of system costs as possible. Energy prices are important, especially because flexible demand can reduce generation capacity needs. However, transmission demand charges—which are used to recover transmission investment costs—provide a strong price signal in some regions, and managing load in response to transmission demand charges can provide larger savings to a customer than managing load in response to energy prices. These larger savings from opportunities to reduce transmission demand charges can combine with strong energy price signals to make enabling technology cost-effective or incentivize behavioral changes. A 100% clean electricity future is expected to have significant growth of transmission and distribution infrastructure, and these higher grid costs will present the customer with a stronger price signal to try to manage their demand, too.

Dispatchable loads will be available on a variety of time scales and may be designed to include increases in consumption and bi-directional products, in addition to traditional demand reduction (CPUC WGLS, 2019).

The need for, and potential benefits of, load flexibility will increase as transportation and other sectors of the economy electrify and new large loads come online. To the extent that these new loads can be shifted temporally, they will be able to work in concert with the clean supply-side resources. Price responsiveness will provide significant value to the power system by reducing peak demand and shifting consumption to periods with lower energy cost. As a result, demand will better align with VRES production, since real-time energy costs are lowest when zero-marginal-cost wind and solar resources are abundant (Mills and Wiser, 2014).

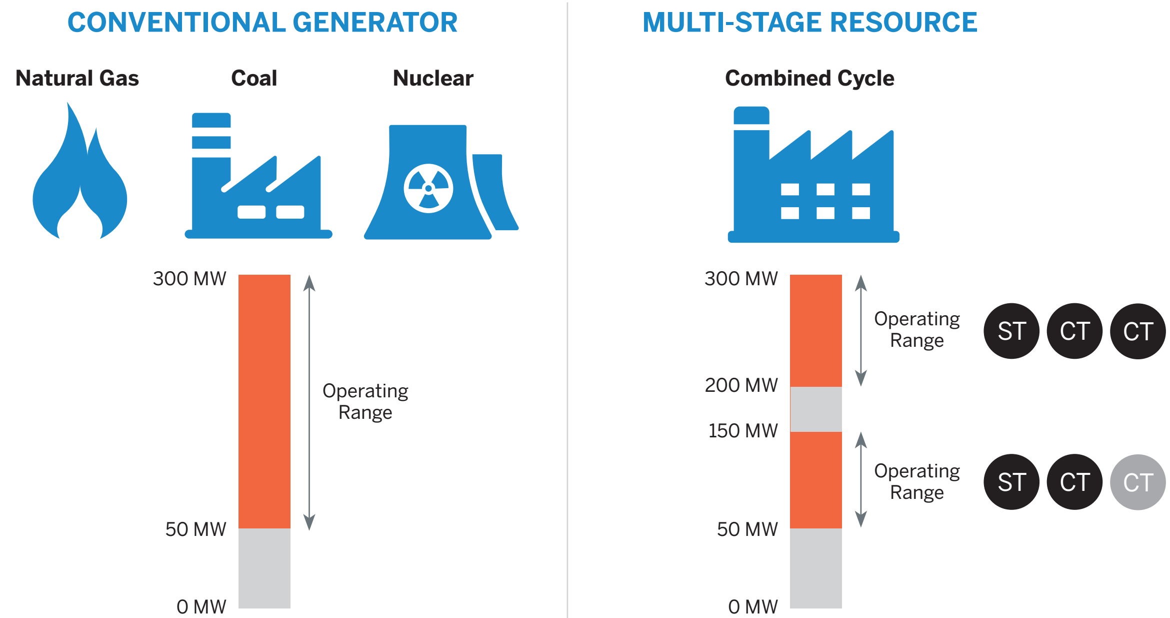
Participation Options for Emerging Technologies

Participation models are favored that are preemptive, with features that are prioritized for reliability reasons, but that also do not prevent or stall innovation in technologies that are competitive from participating in the electricity market. Market design should strive for technology-neutrality but not attribute-neutrality.

Several technologies have begun to participate in the electricity market that were nascent when the market was initially designed. In addition to most VRESs and electric storage resources, we have seen co-located resources and aggregations of DERs. When each of these technology types started interconnecting and participating in the market, it was discovered that, due to their unique characteristics, there typically had to be changes to the market design to allow for new participation models that would reliably and efficiently enable the technologies to offer in and supply energy and grid services. These participation models were designed to incorporate the unique characteristics of the technology that may either be necessary for the grid operator to maintain reliability or that allowed more accurate and efficient scheduling of energy or ancillary services for the resource. This could include the bidding parameters for the resource, whether and when it is eligible to provide certain services, how it is modeled within the market clearing software, and other rules and features that may be part of the market services tariff. For example, the participation model for conventional generators allows for start-up costs, no-load costs, minimum capacity limits, and unit commitment parameters (e.g., minimum run time) to account for the unique

FIGURE 7

Participation Models for Thermal Generation



- Minimum and maximum operating range
- Ramp rates
- Start-up time, start-up cost, minimum up time, minimum down time
- Need commitment variables
- Fuel-based operation
- Generally eligible to participate in all ISO services

- In addition to bidding parameters of a conventional generator, it may need transition costs, transition times, operating parameters in different configurations, etc.

Participation models began with conventional thermal resources (left) that had their own unique characteristics that the model reflected to reliably and accurately schedule the resources of that technology for energy and ancillary services. This includes parameters such as no-load and start-up costs and unit commitment parameters. Combined-cycle resources (right) may have additional features in a participation model given that there are ways in which those technologies could be more accurately scheduled when different configurations are provided (e.g., 1 steam turbine, 2 combustion turbines; or 1 steam turbine and 1 combustion turbine).

Source: Energy Systems Integration Group; adapted from EPRI.

characteristics of those resources (Figure 7). Alternatively, some U.S. market operators have distinct participation models for multi-stage resources such as combined-cycle generation. In these participation models, the resource can improve the accuracy and efficiency of its schedule by providing the configuration-based parameters of operation, such that the market can clear not only the schedule and unit commitment but the configuration as well.

Participation Models for Electric Storage Resources, DER Aggregations, and Hybrid and Co-located Resources

One of the most well-known emerging participation models is for electric storage resources. In 2018 FERC issued Order 841 which directed market operators to develop participation models that included certain parameters reflecting the characteristics of electric storage resources (FERC, 2018). In particular, the models consider these resources' state of charge and related parameters and allow them to participate in any product or service that they are technically capable of providing. Rules around participation models for DER aggregations followed with FERC Order 2222 (FERC, 2020), and models for hybrid and co-located resources were designed and implemented by individual market operators where it was prioritized (CAISO, 2020).

These models take several years from design to implementation, involving stakeholder consensus, regulatory approval, and software design and testing. If there are not existing participation models available for emerging technologies to use prior to the new implementations, it can limit their ability to participate and expand market share when they may otherwise be competitive with existing technologies.

The goal of markets to be fair and technology-neutral, without providing advantages or disadvantages to any one technology, can sometimes be challenged by the mere presence of technology participation models, given their tailoring to specific technologies. In addition, incorporating certain participation models in market clearing models can sometimes lead to other challenges, such as difficulty solving the market clearing software within reasonable time frames, market power, data, or reliability concerns (ESIG, 2022b). While technology-neutrality is a sound objective of these markets, they should not be attribute-neutral—attributes important to the power system should be valued higher with the resources that can provide greater levels.

Participation Models Still Needed for Zero-Emitting Firm Resources, Some Grid-Enhancing Technologies, and Long-Duration Storage

While the participation models for electric storage resources and DER aggregations are still evolving and may have several iterations to come, many of the technologies that may be part of the 100% clean electricity system do not yet have participation models specifically developed for (or applicable to) them. This is particularly true for zero-emitting firm resources and some grid-enhancing technologies (e.g., in one region, a participation model was developed for high-voltage DC controllable lines as an internal controllable line was in development (Yuan et al., 2023)). Long-duration storage may also have unique characteristics compared to limited-duration electric storage resources and require new participation models, such as the ability to store energy beyond the typical 24-hour market period.

Possibility of a Universal Participation Model

There may be other technologies not yet known that can help meet clean energy targets, and a new participation model is not necessarily needed for each possible technology in advance—especially when they share characteristics with existing technologies. A "universal participation model" has been discussed, starting with the most general and idealized case and allowing certain features to be ignored when not needed for a given technology (Ahlstrom, 2018). The challenge may be in thinking of all the types of features that may be necessary for a future technology and finding the time to create such a universal model, when so many other priorities are already taking the time and money of the market operators and stakeholders. Features that are overly complex for designing the universal participation model for all possible situations may be expensive to develop and potentially not used in the future, as is the case with some participation models developed to date. This may limit the practical application of a universal, "one-size-fits-all" participation model.

The task force recognizes the trade-off of ensuring the efficient integration of competitive emerging technologies and bringing innovation to energy and grid service suppliers. It is inefficient to wait for new participation models to be developed when the technologies are ready to go to market, yet it may be overly expensive or complex to develop a conceptualized model for all future technologies in advance. **The task force recommends further analysis of a universal participation model and its practical implementation. It also recommends prioritizing participating models that are necessary for maintaining grid reliability over those focused on improving the efficiency of the resource, as the latter may be easier for the assets to internalize and incorporate into their offer strategy. Eligibility for different products and services should not necessarily be tied to technology participation models, but rather to individual market participant proof-of-performance requirements. Also**

recommended is an exploration of ways to streamline the new participation model development process.

Incentivizing a Set of Reliability Services from All Capable Service Providers

Industry stakeholders need to (1) explore whether the reasons why competitive market products did not exist in the past for certain grid reliability services are still valid going forward, especially for systems with a 100% clean electricity resource mix, and (2) could introduce those products that have value and outweigh the costs and complexities of implementation using performance as eligibility assessment and technology-neutrality (but not attribute-neutrality) objectives.

As discussed in the section "Assumptions About and Characteristics of 100% Clean Electricity Systems and Their Implications," there is a valid assumption that operational reliability needs will change under a future resource mix that is of a 100% clean electricity supply. With the potential for increasing demands for active power ancillary services and the potential need for other grid services that were inherently provided with the resource mix of the past, there may be value in introducing additional competitive mechanisms for new products in the future. While the need for a service itself is usually not new, there are reasons why explicit products or competitive auctions have not been tied to the service thus far. As systems evolve, new products sometimes need to be created and defined by the changing physical system needs.

Table 1 provides a few examples of why markets may not exist for certain services with today's resource mix in mind. (While the examples are illustrative, there are cases around the world where each of those reasons has existed for different grid services at different times.) **The task force recommends that industry stakeholders explore whether the reasons why competitive market products did not exist in the past for certain services are still valid going forward, especially for 100% clean electricity resource mix systems.**

The task force also recommends that any new market products be as specifically defined as possible to ensure that the necessary service is provided, but not be overly specific in a way that would limit eligible resources and reduce competition or innovation. All demand- and supply-side resources should be eligible to provide all products when they have demonstrated their capability to do so, although their physical characteristics may limit them from being selected for some services or the quantity of the service. Good market design will co-optimize the various services such that each supply- and demand-side resource will be selected to provide the service it is best suited to provide, and this will lead to higher efficiency

TABLE 1

Reasons Why a Market Product May Not Be Implemented

Reason	Example
Product may be too complex to design (e.g., software complexity).	Volt/VAR support
Product may be too specific to certain local areas (little to no competition).	Volt/VAR support
The system inherently has more than sufficient amounts of the service.	Synchronous inertia
Costs for the service may be small, so the cost of administering market product may outweigh benefits.	Black start (restoration) service
A specific resource requirement may be necessary.	Low-voltage ride through

There are many reasons that certain grid services do not have explicit market products or competitive auctions associated with them. The examples shown are just illustrative and may not be true today in all cases. These reasons may not necessarily remain on a system with 100% clean electricity. The task force recommends continuing to examine the services to understand where changes may benefit reliability or economic efficiency.

Source: Energy Systems Integration Group; adapted from EPRI.

Any new market products should be as specifically defined as possible to ensure that the necessary service is provided, but not be overly specific in a way that would limit eligible resources and reduce competition or innovation.

and reliability. **The qualification process to demonstrate adequate performance must also allow new technology innovation to show performance in ways that may not look quite the same as how an existing technology provides the service, so long as it still meets the goals of the service and the goals of system reliability.**

With the increasing demand for certain ancillary service products due to the increased level of variability on the system, such as various reserve and ramp products, it will be important to provide incentives for resources to provide those services. With increasing demand for some reserve products, one might expect the prices of those reserve products to rise and provide greater incentives for resources within the future fleet to provide those services. However, ancillary service pricing is nuanced. Some markets do not allow for non-zero offers in certain reserve products. Designs currently differ across market regions in terms of shortage pricing curves, cascading price hierarchies, how co-optimization is performed, and whether the ancillary services are procured in day-ahead markets, real-time markets, or both. Most of the impacted ancillary services use marginal-cost pricing like energy markets. However, with limited clarity on the cost to provide reserve, and in some cases prevention of providing non-zero offers, the prices of these services are set primarily based on the lost opportunity cost from selling in the energy markets. When wholesale energy prices are more often set at zero, due to VRESs setting those prices during many intervals, the opportunity cost to provide an ancillary service for any resource is also likely to be zero. Where the demand for some ancillary services will increase on a 100% clean electricity system, counter-intuitively, this opportunity cost–driven pricing could drive their prices to be lower, even zero, thus limiting the incentives to provide the service.

This result is not necessarily a problem, as it follows economic principles. However, resources might incur costs from providing these services that they are not able to recoup within the price formation logic. For example, the start-up and no-load costs of potential zero-emitting firm resources could be non-negligible but ignored in pricing. While opportunity costs between reserve and energy are typically included in reserve prices, the opportunity costs across products and across time that are incurred by storage resources may not be captured explicitly. Neither may resource degradation costs or demand-side costs. **The task force recommends that these costs either be reflected directly in market clearing and price formation or be allowed for the assets to include in their offers in an accurate way. If it is truly found that the operational costs of ancillary services are still low even with increased reserve demand but that the types of resources that can provide those services have less incentive to invest, then other designs may also be useful to explore.** This might include forward contracting for the ancillary services when the existing ancillary service market designs, priced on opportunity costs, may not otherwise lead to the appropriate investments in resource characteristics to provide the service. Some task force participants emphasized that operating reliability was a key reason for a more coordinated planning approach so that the

specific types of resources were chosen competitively in a long-term procurement mechanism and sufficient levels of the operational reliability characteristics would be present on a future system.

Finally, the task force sees promise in extended operating reserve demand curves. The curves provide a value to reserve beyond the minimum requirement and allow for prices of the service to rise while the risk is increasing but before the system is truly in scarcity. This can have a similar effect to existing scarcity pricing but with less customer risk or political blowback from the extreme pricing that might be applied while customers are losing power or being told to conserve. This type of sloped demand curve has already received much buy-in from the market design community with its application in capacity markets, and the design for operating reserve works in mostly the same way.

> Extended operating reserve demand curves allow for prices of a service to rise while the risk is increasing but before the system is truly in scarcity, having a similar effect as existing scarcity pricing but with less customer risk.

Hybrid Market Approaches to Ensuring Resource Adequacy, Risk Mitigation, and Investment Certainty

Energy markets and related market mechanisms by themselves may not accomplish all of the functions to ensure investment of an adequate and efficient supply portfolio that meets the clean energy criteria. Hybrid approaches that supplement the energy markets with additional coordination and forward mechanisms may be needed for resource adequacy, certain reliability attributes, clean energy resource development, and for infrastructure needs.

The task force was generally in alignment that while energy and ancillary service markets are beneficial for operational behavior and supporting investment decisions via market signals, on their own they would be challenged to lead to efficient and necessary investments for supply and infrastructure while meeting resource adequacy and clean energy objectives. Additional mechanisms are likely required to achieve long-run equilibrium, resource adequacy, price certainty and risk mitigation, and investment incentives. While all participants agreed that there may be a need for policy choices, additional market products and/or long-term contracting mechanisms, and coordinated decisionmaking, the lead writers differed in their proposed solutions, including how much coordination is necessary and how much decision-making outside of market signals would be required. **Thus, the recommendation for the market design vision is that additional design features may be necessary to achieve the objectives of resource adequacy, risk mitigation, investment incentives, and long-run equilibrium, and it is suggested that industry stakeholders explore options, including those discussed here, that might work well for them given their market structure and stakeholder perspectives.**

Resource adequacy mechanisms in place today in regions across North America vary from capacity auctions, to integrated resource plans, to relying purely on energy markets. The first two, and many other proposed options, may be considered under the so-called hybrid approach. The hybrid market paradigm was described by Roques and Finon (2017) and further developed by Joskow (2022) as an approach that combines planning and long-term arrangements established with public or regulated entities on one side and short-term organized markets on the other. This has also been further explained as competition *in* the market (centralized energy markets) combined with competition *for* the market (various long-term procurement mechanisms that support investment). Forms of this hybrid approach include the use of capacity market auctions, LSE capacity "showings," and government requirements for power purchase agreements for certain technologies alongside competitive energy markets. These have varying degrees of government coordination, competitiveness, and forward horizon, which are noted by different task force members in their specific proposals (see papers by Gramlich and Goggin (forthcoming), Joseph (forthcoming), and Mays (forthcoming)).

Some reasons for this approach are as follows:

- A lack of emission pricing, uncertainty of the end result of emission pricing, or preference and comfort

- with other policy approaches such as tax credits and renewable energy credits
- Uncertainty over energy prices that result on a future 100% clean electricity system, and whether it would drive toward the attributes needed on the system
- Complexity in the attributes necessary to meet resource adequacy; having capacity and meeting peak demand will no longer guarantee resource adequacy, and energy delivery across all hours, transmission delivery, and flexibility attributes all may come into play

Proposals from the task force included additional mechanisms that vary in their implementation details and how far they depart from the status quo of either capacity markets or ISO/RTO resource adequacy targets with utility integrated resource plans accepted by regulators. A comprehensive review of proposals by other researchers to meet the objectives of efficient and reliable clean energy investments can be found in Lo Prete, Palmer, and Robertson (2024). Readers are also encouraged to review the white papers by individuals that were produced as part of this task force (Gramlich and Goggin, forthcoming; Joseph, forthcoming; and Mays, forthcoming).

Long-Term LSE Hedging Mechanism

One option described in Mays (forthcoming) is for a resource adequacy mechanism based on the idea that sound risk management practice would dictate that LSEs sign long-term contracts for much of the energy needed, to reduce risk both for consumers and for generators. Policymakers such as economic regulators usually have legal obligations to limit price risk for consumers, so long-term hedging is usually included to manage risk since spot prices are allowed to be as dynamic as needed to reflect energy value at all times and places. Lower financing costs can be secured for generators using long-term contracts, and those savings can be passed on to consumers. LSEs, under state oversight, could procure generation through competitive solicitations in order to achieve the best prices for consumers from the set of suppliers that bid for these contracts. If most consumers are well hedged through long-term contracts, there may be less political blowback from occasional high scarcity-driven prices. Part of the design is to ensure that LSEs are sufficiently creditworthy to have the incentive and ability to procure power on a long-term basis. Much of the challenge comes from the illiquidity in the forward markets, which has been observed in other work such as Wolak (2021) and Cramton et al. (2024).

This procurement could be made mandatory by regulators. The primary motivation for mandatory contracting to date has been the lack of full-strength spot pricing. Without sufficient revenues coming from energy and ancillary service products, additional payments must be made to guarantee resource adequacy. Since the artificial products created for this purpose are not that clear, contracts must be made mandatory to ensure that buyers of electricity will agree to them. With high enough prices, as in an energy-only design, it can be questioned whether contracts need to be mandatory at all; however, even with full-strength prices guaranteed, three additional points in favor of mandatory contracting warrant discussion.

Potentially the most important of these is consumer protection and political economy. Consider the example in which prices can go as high as $10,000/MWh. Whether enforced formally through anti-gouging laws or informally through public opinion, charging extreme prices to retail customers is in general not acceptable. Even in the case of Texas during Winter Storm Uri in 2021—where retailers and not the end-use customers themselves bore the brunt of high prices—the extreme prices provoked a severe response and eventually led to a reduction in the market cap. By comparison, in PJM the large non-performance penalties initially levied on suppliers that failed to deliver on capacity obligations during Winter Storm Elliott in 2022 caused some controversy within the industry but did not animate the public or political leaders. By shifting exposure to high prices away from buyers to sellers, mandatory contracts can significantly change the public perception of price spikes, enabling more efficient price signals and a more durable market design.

The second point in favor of mandatory contracting is market power mitigation. Market power gives suppliers the ability to raise prices above the efficient price. While an uncontracted generator clearly has the incentive to raise prices, the incentive disappears with a contract. By itself, contracting does not fully resolve issues with market power, given the potential for it to be expressed in the forward rather than the spot market. Nevertheless, greater forward trading is often considered to be associated with reduced potential for exercise of market power. Accordingly, efforts to promote or mandate contracting can be considered as part of an overall market power mitigation strategy.

The third point in favor of mandatory contracting is that it addresses the problem of "missing markets" for risk management in liberalized electricity markets. To secure financing, investors in power projects use various strategies to de-risk cash flows in the face of volatile spot prices. It is generally felt that barriers to contracting prevent fully efficient risk-sharing, motivating many proposals to facilitate smoother contracting and hedging (Wolak, 2021; Cramton et al., 2024; Pierpont, 2020; Lo Prete, Palmer, and Robertson, 2024). The risk implications of different contract forms for different technologies can vary significantly. For example, the simple base load swap could reduce risk for a nuclear unit substantially by allowing it to lock in a price for its power over the duration of the contract. For variable producers like wind and solar, however, the implications are not so clear: by selling forward a fixed volume in each hour, they would expose themselves to price spikes in hours when their production was below the contracted volume. Accordingly, variable producers attempt to sell contracts that are closer to a shape they can physically deliver. It is important that the contract design does not lead to inefficient operational decisions, such as what has been found in the past with traditional contract for differences designs (Newberry, 2020).

Planning Coordination Under a Hybrid Approach

A second option described in Joseph (forthcoming) includes greater coordination across ISOs/RTOs and governments for specific investment decisions that meet the needs of resource adequacy and reliability. Reliability throughout the energy transition depends on a specific mix of resources that meet both policy targets and provide specific reliability attributes. This does not mean that we cannot rely on competition, or even on organized wholesale power markets. Competitive solicitations for specific resource types, alongside short-term spot markets, can help.

As the resource mix changes, and as generation output becomes more variable and seasonally dependent, it is not the case that all resources meet the requirements for providing critical ancillary services, like balancing energy and operating reserves, at all times in real-time power system operations. This makes it hard to rely on prices alone to coordinate investment decisions. Coordination may be valuable in the following areas.

Accounting for the Interdependence of Critical Infrastructure

Policy that does not account for the interdependence of critical infrastructure, like gas and electricity, creates reliability risks (NERC, 2023; 2024) and makes it hard to focus public and private investment on the kinds of technology and associated infrastructure needed to transition the sector (Joseph, 2024). This makes it hard to rely on prices alone to coordinate investment decisions, and state-level policy, informed by reliability-coordinator studies, may be needed. This kind of policy and planning coordination can connect entities that are responsible for grid reliability with entities that set electricity policy.

Reducing Public and Private Investment in High-Capital Emerging Technologies

Coordinated planning can also provide a mechanism to reduce the amount of public and private investment needed in the high-capital but not-yet-commercial technologies and associated infrastructure needed to transition the sector to 100% clean electricity. Competitive solicitations for specific resource types, alongside short-term spot markets, emphasize the need for market designs that center regional system planning and the need for public investment in critical infrastructure.

The challenge with existing market approaches is that they may not recognize the need to incentivize or procure specific types of resources and attributes. Further, existing designs may not fully recognize the role of policy in coordinating public investment. The planning coordination process proposed is an example of a planning framework that could enable the integration of state policy and reliability planning on the regional bulk electricity system despite differing state decarbonization policy targets.

The Use of Strategic Reserve Capacity

Another option that requires coordination is the use of strategic reserve capacity. Changing reliability standards highlight the need for resources that can produce energy during all hours, not just peak hours, especially during extreme weather events. Given the policy coordination needed, and the challenges with aligning the regulatory, planning, and operations across critical infrastructure

sectors, strategic reserves could be an alternative to explicitly secure the resources needed by the system for reliability.

Strategic reserves are assets that do not necessarily participate in the short-term market and are only intended to be operated during times of critical need. In strategic reserve programs, a specific entity is designated to procure needed assets on behalf of all end-use consumers, and all consumers pay the full costs for these assets. These assets could be procured through a competitive solicitation.

The Formulation of Regional Integrated Resource Plans

A regional integrated resource plan or a coordinated regional procurement mechanism for the resources needed could also be considered. A coordinated, regional integrated resource plan that relies on competitive solicitations for specific attributes could help enable the benefits envisioned by regional integration. In the long term, the kind of coordinated regional planning that considers state policies alongside grid reliability needs may enable coordinated procurement for the kinds of resources that can replace existing fossil resources.

Capacity Accreditation Concepts

Currently, the standard approach for converting a resource's nameplate capacity to the metric that is used within capacity auctions, through resource adequacy showings, and in integrated resource plans is to use effective load-carrying capability (ELCC) or other marginal reliability contributions. The method and metric have gone through significant evolution over the last several years and may need further evolution in the future given the portfolio effects, modeling needs, and data used. The task force did not discuss recommendations in detail here, as it has been covered at length in other ESIG task forces and elsewhere (see ESIG (2023c)).

The values under these accreditation methods are complex, requiring advanced modeling and substantial amounts of data and assumptions. They can be critical, though, as a significant portion of a resource's potential revenue and incentives for investment and retirement under these hybrid approaches that may use them. The challenge with accreditation values is the difficulty in validating the quantities determined through modeling or historical data. The values are probabilistic and may be demonstrating the contribution of a resource to reliability over hundreds of years of possibilities, making it challenging to validate after a single year where it could have under- or over-performed. **The main task force recommendation is that, if needed and used for resource adequacy mechanisms under any of the proposed market designs, that revenues be tied to performance as best they can in a technology-neutral manner.**

Markets Should Not Subsidize Clean Electricity Resources but Can Facilitate Outside Policy Instruments That Provide Incentives and Subsidies to Clean Electricity Resources

It is encouraged that clean energy incentives have sound economic principles and designs and that the market design can facilitate these clean energy policies.

There was agreement among task force participants that ISO/RTO markets can facilitate a transition toward clean energy that is decided and funded by governments or private industry, but markets should not subsidize such a transition themselves. In the context of this market design vision, three points warrant mention.

First, policy instruments, whether in the form of subsidies or contracts, should preserve incentives for efficient operation and price formation on the margin. Second, contracts with generators backed by state or federal governments are in general compatible with most of the long-term contracting elements of the market design vision, especially if they preserve incentives on the margin. And third, given the lack of clear "market-like" solutions for transmission cost recovery, subsidies for transmission may be beneficial. In any case, workable policy that could incentivize innovation and efficient investment in the transmission sector (and potentially other infrastructure) should be explored further.

Relative to regulated or publicly owned utilities, participants in ISO/RTO markets have much greater exposure to policy risk that cannot be hedged. To the extent that the business case for certain technologies relies on decarbonization policies, investment in them will depend on market participants having confidence in the stability of those policies. By the same token, to the extent that fossil-based resources rely on weaker climate policies, capital expenditures in support of their continued operation will depend on some degree of confidence that market participants will be made whole if stronger policies are introduced. Because of this, uncertainty about future climate policy could pose an even bigger challenge to the viability of competitive markets than climate policies themselves, with investors less willing to commit capital to either traditional resources or their clean replacements.

A move away from competitive markets may not resolve issues that stem from an inconsistent and uncertain policy environment. Instead, perhaps the most likely effect would be to weaken regional coordination, with negative consequences for cost, reliability, and emissions. **Given these considerations, the recommended approach is for the markets to facilitate clean energy policies without causing undue harm to competitive forces.** The clearest way to enact this approach is through sound market design.

While a universal carbon price set at the social cost of carbon has been discussed as an ideal solution that can be integrated into the existing wholesale markets and efficiently set prices that can lead to an efficient set of lower-emitting resources, the task force largely understood the political difficulties of this implementation across the United States. A carbon price may need to be adjusted throughout the transition to achieve the 100% clean electricity system. Tax credits and resource targets are more commonly used policy incentives (and typically preferred by policymakers), as the industry knows how to factor these into its investment modeling. But there could be more decentralized ways of putting a price on carbon. **Another recommendation is to consider ways that loads (including utilities or corporations with clean energy goals and GHG Scope 2 reporting)[5] can input their willingness to pay a premium for getting their consumption served by clean energy.** For example, this could include ways that existing 24/7 carbon-free energy contracts, which are largely bilateral and outside of organized markets, can be transformed with greater transparency in mind so that (1) more loads can participate by finding more clean energy matches, and (2) more clean energy resources can see where, when, and by how much clean energy is more desirable compared to energy from emitting resources. This can be similar to a carbon price but introduced in a decentralized manner by loads with clean energy goals rather than by governments.

Summary of Possible Future Market Designs Including Alternative Proposals

Table 2 shows different designs that have been proposed for future wholesale markets, including some not discussed in detail in this report. Many of the proposals fall into the category of "hybrid markets," discussed above in this report's market design vision. Although there are outliers, the wider industry is converging on a hybrid approach combining some form of coordinated and centralized planning with efficient energy markets, where the main debate revolves around the lower-level details of how the investment side can best be implemented.

In addition to the market designs shared throughout the vision laid out in this report, there are others not discussed. Some authors/analysts have proposed price adders to energy markets to accommodate the components that are missing in the energy markets including long-run marginal costs (see, for example, Tooth (2014)). An integrated clean capacity market was proposed for ISO-NE stakeholders as an alternative to capacity markets where clean energy goals would be part of the forward capacity market (Spees et al., 2019). A configuration market was proposed that represented a forward market that procures clean energy resources and those that can meet the reliability needs of the system every few years (Corneli, 2020). Swing contracts have been introduced where each swing contract consists of an offer price representing the avoidable fixed costs and a performance cost that is analogous to the variable costs (Tesfatsion, 2021). Finally, a capacity-only auction has been introduced where, following competitive procurement of the resource, the resource is then optimized by costs but there is not a further revenue stream (i.e., there is no energy market).

The wider industry is converging on a hybrid approach combining some form of coordinated and centralized planning with efficient energy markets, where the main debate revolves around the lower-level details of how the investment side can best be implemented.

TABLE 2

Future Market Design Proposals

Potential Ways of Categorizing Future Market Design Proposals	
Energy Only Markets	• Long-term marginal cost • Price adders • Energy with operating reserve demand curve (ORDC)
Hybrid Markets	• Capacity markets • Mandatory bilateral capacity transactions • Strategic reserves • Coordinated planning • Integrated clean capacity market • Configuration market
Complete Redesign	• Cost-of-service regulation • Swing contracts • Capacity only auction

There are many ways to categorize the ideas and proposals that are being discussed across the industry and research community. In particular, we see these separated into those that focus primarily on competitive energy spot markets as the prime piece, those that include the hybrid design which combines efficient energy markets with some intervention to support investment, and those that are larger redesigns that may veer off from the primary design components of existing electricity markets.

Source: Energy Systems Integration Group.

5 Scope 2 emissions are indirect greenhouse gas emissions associated with the purchase of electricity, steam, heat, or cooling. See https://ghgprotocol.org/.

Possible Next Steps for Realization of the Market Design Vision

Certain aspects of the market design discussed here are part of the status quo or are incremental design changes that may happen naturally as part of each region's stakeholder process and the natural needs that come up through regulatory processes. Others may require additional action. Even the aspects that are closely aligned with the status quo may require some actions from industry to keep the alignment from straying to other, less desirable outcomes.

Some of the actions discussed in task force meetings as well as the two task force workshops held as part of this project are listed below.

Potential Actions

Piloting New Market Design Ideas

It may sound odd given the scale and impact, but piloting new market design in ways that have lower impacts if undesirable outcomes result can help in testing for their future use. This could take place as implementation at either a smaller geographical scale or a smaller participation scale. For example, Korea has gone through a market reform process in which it initiated new market designs on the small Jeju Island before implementing designs across the country in order to learn about any complications.[6] ERCOT has implemented pilots for new participation options (such as its aggregated DER pilot and fast regulation pilot) with limited participation before it scales up. It is not yet clear which of the parts of the market design vision a pilot program may fit, but exploration is encouraged into whether these would be practical when changes are being proposed that could be disruptive or when unclear outcomes are present.

Finding Alignment from Technical Experts and Providing Further Education

The more alignment from technical experts on paths forward, the easier it may be to enable policymakers to agree upon those paths and move forward with them. Policymakers rely on experts including the comments of key stakeholders in rulemakings in their decision-making. If these experts are not aligned, it can be challenging to determine actions. Alignment could occur through collaboration reports similar to this one and encouraging experts to share their input on any proposed rulemakings. Further education is also recommended that can bring new policymakers and decisionmakers up to speed on existing and proposed market designs.

6 https://www.shinkim.com/eng/media/newsletter/2215

Deciding upon Metrics

To assess the efficiency of a market design, some form of baselining is first needed as well as some concept of ideal efficiency across all objectives (recognizing that there is still subjectivity in the definition of optimal or ideal). Metrics should be based on these objectives and prioritized. Traditionally, reliability has been the priority metric, with cost as secondary in some sense—for example, when there is a reliability event, cost becomes secondary. Other key metrics include sustainability, equity/fairness, and market stability. The task force had a large discussion on metrics during the second workshop, which we expand on next.

Identifying Metrics to Evaluate Future Market Designs

While there are some items on which the task force had broad agreement, participants also favored many differing design ideas. And beyond the task force, proposals by industry and thought leaders around the world differ far more. The challenge is how to evaluate a market design proposal or a change to the existing market design to allow for entities to get on board with the proposal. A comprehensive assessment and comparison of these proposals requires agreed-upon metrics that can allow for fair comparisons to the status quo and against different designs. The participants in the ESIG task force and workshops talked at length about metrics and how they can be used.

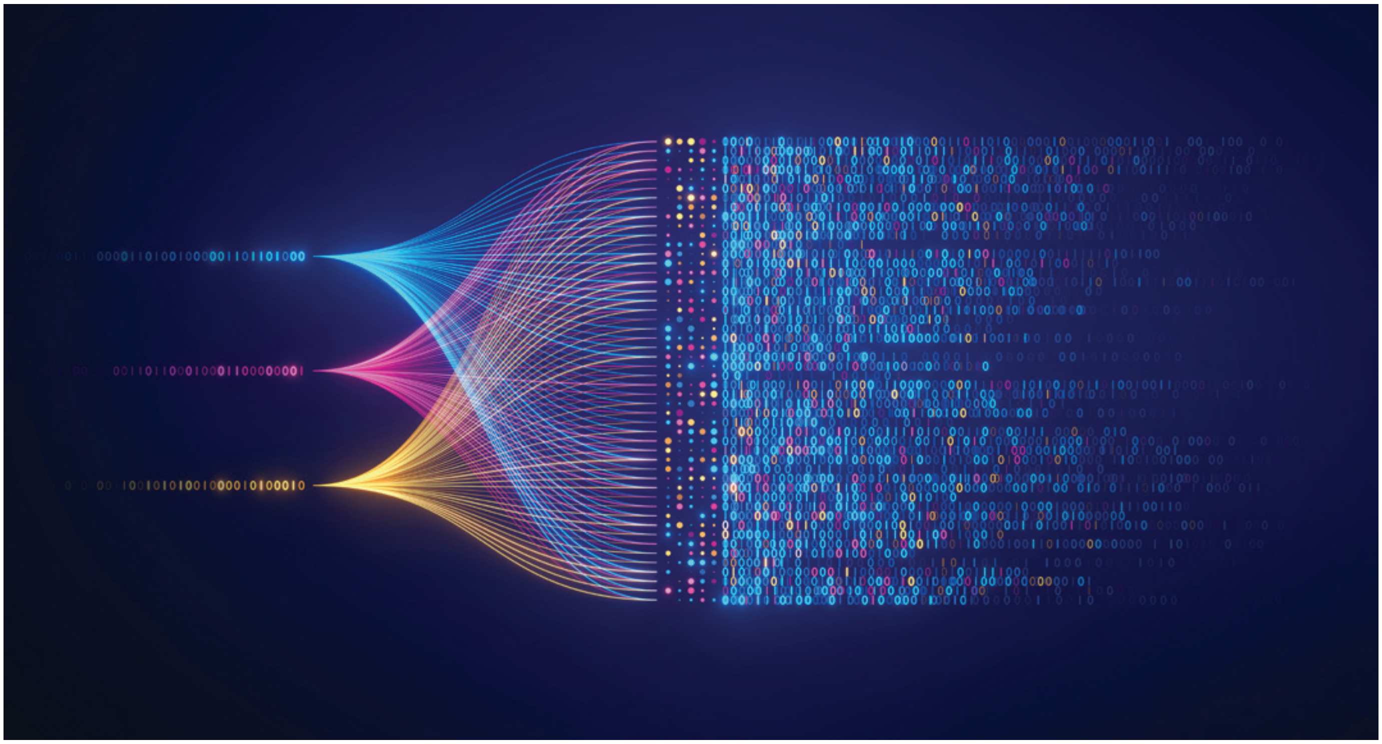
The metrics below were discussed as part of the task force discussions and include both quantitative and qualitative metrics.

- Economic efficiency, social welfare, and costs
- Reliability metrics that show how well the market leads to a reliable system
- Transparency, including the amount of settlements that are provided through side payments not observed by other parties or new entrants
- Liquidity in the market
- The extent to which market power can be present
- Adaptability to change and flexibility
- Market stability, where participants have a reasonable expectation of outcomes
- Simplicity and ease of understanding of the design
- Practicality
- Political or social acceptance
- Implementation timeline

Using Economic Efficiency Metrics Already Commonly Used and Adding Reliability Metrics

The group noted that many of the quantifiable metrics—including many of the metrics above that refer to economic efficiency, performance, and liquidity—are already well defined through existing practices such as those shared by market monitoring units for their annual state of the market reports or through other means. However, these metrics usually evaluate existing markets, sometimes compared to past years or to other markets and regions. It is more challenging to apply these to market proposals, especially those that are for systems and resource mixes not yet realized. Sometimes simulations of the market design proposals can be used along with the metrics. Experimental economics may be suitable for some but can be challenging with the complexity involved. They can be linked to pilot programs to determine whether the pilot was successful and whether it should be expanded. In sum, applying metrics used to evaluate existing and past systems to tomorrow's systems was a key issue that needed further thought.

The task force recommends using important economic efficiency metrics that are already commonly used by market monitoring units in their state of the market reports, and adding reliability metrics to the set of quantifiable metrics. Market designs that have hidden flaws may lead to reliability degradation, and some proposals can potentially lead to higher costs but a more reliable system. Combining economic efficiency and reliability metrics together can avoid this and prioritize both objectives. As much as possible, the group recommends some general test beds to evaluate proposals consistently but understands that this is not easy. Lastly, the group wishes to emphasize the importance of the qualitative metrics in discussions of new market design proposals.



Using Qualitative Metrics to Aid in Market Design Evaluation

It is important to include the qualitative metrics discussed above in market design assessments. Some market designs may be theoretically favorable to the status quo for a 100% clean electricity system and in a study with perfect behavior can lead to the optimal set of efficiency and/or reliability metrics; however, if a new market design requires substantial time and costly changes, is overly complex, or is not politically or socially acceptable, then it may not be feasible. Market design changes take time, sometimes nearly 10 years for what seem like simple changes given the stakeholder debate, design, testing, and regulatory approval. Large-scale changes that completely shift the market to a different design may not be acceptable if market changes cannot keep up with the resource mix transition assumed in this effort. These large-scale changes can also be very expensive even when they look cost-effective, given the time spent of all involved. Aspects that need to be included in the assessment include simplicity and transparency, implementation time, social and political acceptance, market stability and avoiding too much disruption, and general practicality. Such metrics should be considered just as important as those that are quantifiable. These could be assessed using a scale (e.g., 1 through 5) by third-party assessors when considering future market design concepts.

The task force generally agreed that, since complexity in electricity markets is inherent and unavoidable and the physics of the electricity grid is complex, over-simplifying the market representing the grid can cause unintended consequences. For example, simplifying parts of the market can allow for some that understand the physics to take advantage, as was part of the challenge during the California electricity crisis in 2000–2001.[7] Generally, the task force agreed that complexity is natural for electricity markets, but that simple solutions that do not violate the physical system can be desirable when they put all participants on a level playing field. There needs to be recognition that markets are complex. They are complex for a reason. It is important to find ways to simplify but not if it leads to severe inefficiencies. The quote often attributed to Albert Einstein rings true here, of keeping things "as simple as possible, but not simpler."

7 "Testimony of S. David Freeman," May 15, 2002, archived from the original on March 1, 2006. https://web.archive.org/web/20060301072016/http:/commerce.senate.gov/hearings/051502freeman.pdf.

Looking Forward

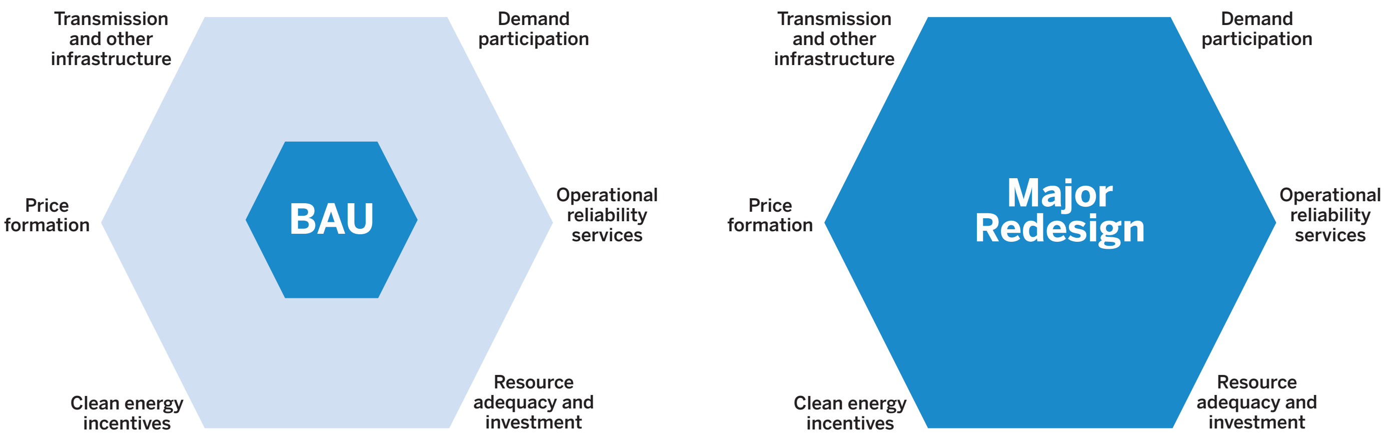
Summary of the Market Design Vision

The market design vision presented in this paper can be examined by the extent of changes from the status quo. The task force explored this using a rose chart with the six categories discussed in the introduction and in Figure 1 (p. 3). Figure 8A shows two bookends using this scale. The left side illustrates maintaining business as usual, while the right side illustrates what a major redesign would look like if a massive modification to the market design were made in every category. Figure 8B (p. 39) shows the actual extent of the changes proposed by the vision described in this paper.

Although the scale is subjective and the status quo is different in markets across the world, below we use it to evaluate the market design vision discussed throughout the paper. This can be observed with Figure 8B. In the market design vision, price formation and the modifications to design of the energy market were relatively unchanged and remain on their current trajectory. Larger changes, but not necessarily major redesigns, are described in the categories of demand-side participation and resource adequacy, investment, and hedging. This includes the expansion of demand-side resources being able to support the grid through more granular pricing or otherwise, and the need for mandatory contracts

FIGURE 8A

Viewing the Scale of Change of Market Design Futures by Category

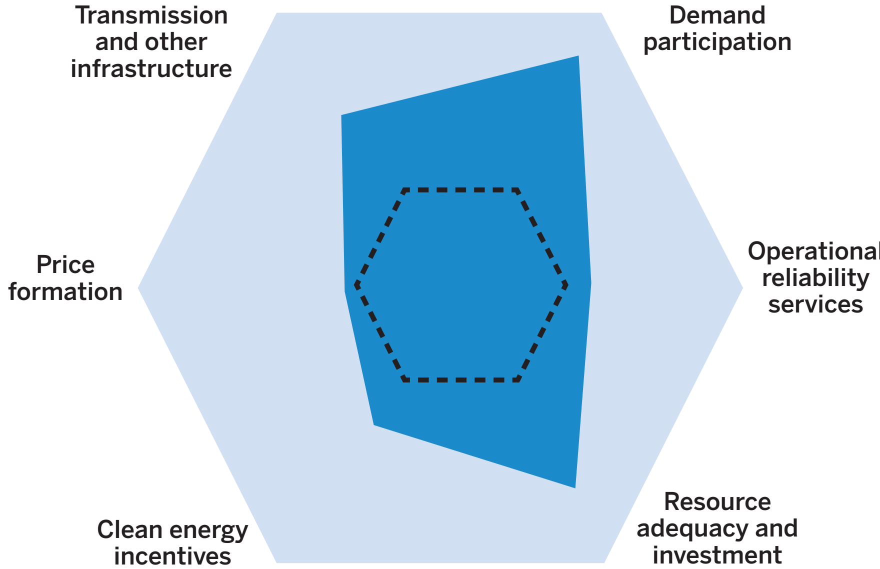


The market design vision can be expressed using a rose chart across the six categories shown here. The left-hand side illustrates business as usual while the right-hand side illustrates what a complete major redesign would look like. Figure 8B expresses the market design vision in this paper in these terms.

Source: Energy Systems Integration Group.

FIGURE 8B

Viewing the Scale of Change of the Market Design Vision Shared by This Task Force



This graphic conceptually shows the degree of change relative to business as usual for each of the categories in the market design vision discussed in this report.

Source: Energy Systems Integration Group.

and/or large-scale coordination to meet the investment needs and resource adequacy of the future 100% clean electricity system. While solutions were not discussed extensively by the task force, this report does note the need to expand on transmission and other infrastructure to enable the high levels of renewables and deliver its energy to load, which may be done through policy mechanisms. Changes to clean energy incentives are also typically outside the market design, but large-scale changes may be necessary to achieve a 100% clean electricity system. Substantial changes were not discussed at length regarding operational reliability needs, but the vision notes how new or increased needs for services should be continually studied and that those changes could come in the form of market design changes. While there may be some components of the vision that are particularly useful under a 100% clean electricity system (e.g., new operational reliability service products), much of what this vision presents can provide value to economic efficiency, certainty, and reliability to other futures or if implemented on today's power system.

While some components of the vision are particularly useful under a 100% clean electricity future, much of what this vision presents can provide value to economic efficiency, certainty, and reliability to other futures or if implemented on today's power system.

This vision's embrace of existing spot markets with marginal cost pricing and scarcity pricing along with separate coordinated planning for investment may not satisfy those who argue for more fundamental changes to the electricity system. Nor is it likely to satisfy those who envision a "pure" market with less intervention from policymakers. A key question in this regard is whether such a market can expect operators of independent, non-subsidized plants to continue operating (and performing well) in the face of diminishing market share and growing regulatory uncertainty (Grubert and Hastings-Simon, 2022). In an effort to restore some measure of regulatory certainty, some have sought to return generation assets to the regulated asset base, while others have sought to "overrule" state policies (e.g., by excluding subsidized resources from the market). Instead, this report presents several key recommendations to keep under consideration through the normal market design evolution process. With the lengthy timeline associated with these changes that can take 10 years or more, some entities—whether market operators, regulators, or researchers who can impact decisionmakers—need to be looking further into the future under clean energy scenarios, testing for any market flaws where solutions can be built into the evolution pipeline sooner than later. It will be essential to ensure that market designs continue to meet the principles that incentivize innovation in technology, efficient investment (entry and exit), hedging, and equity, and reliable short-term behavior.

Many regions have significant experience with zero-operating-cost resources and can provide information and insights for other parts of the world.

Evolution, Not Revolution

A key insight from this task force is how the vision of future wholesale market design is one of evolution rather than revolution. The wholesale markets will largely continue in their present forms, but incremental changes will develop with regard to supply- and demand-side technologies and their mechanisms for interfacing with the market, mechanisms to assist with investment, and potentially even with how the various institutions interact (i.e., coordination between state regulators and ISOs/RTOs in order to ensure reliability). A major catalyst for the energy transition will be the build-out of transmission and potentially other needed infrastructure, which can allow for significant cost savings. One area of ongoing debate involves the level of interaction between federal and state-level policymakers (and those policymakers in other jurisdictions around the world) and wholesale market operators and stakeholders. One approach may rely more on market design changes and requirements to drive change, while another involves a tight feedback loop among the various institutions (e.g., state regulators, ISOs/RTOs, utilities, and policymakers) and the markets themselves where they work together to ensure a reliable energy transition.

A Need for Global Collaboration

The future holds many unknowns. It is unclear what policies will be enacted at federal and state levels and across the world. It is always possible that particular events, such as large-scale outages or others (geopolitical conditions, pandemics) can shift the focus and priorities of electricity markets. It is hard to estimate what the impact of artificial intelligence and electrification may have on electricity consumption and how that can challenge decarbonization. It is also unclear what technology might have a breakthrough in the next decade. Predicting the potential outcomes of electricity markets is difficult even for the next day, let alone a decade or more in the future. Much of the discussion of price formation assumes certain outcomes of the wholesale energy prices such as prevalence of prices of zero and high volatility. But those outcomes can change with minor shifts, and the industry should be prepared for many outcomes in its design decisionmaking.

Different parts of the world can provide lessons to decisionmakers evaluating new paths. Many regions, including Latin America, have had significant experience with zero-operating-cost resources (i.e., hydro) and can provide information and insights for other parts of the world (Barroso et al., 2021). Even within the United States, market operators have had experience with VRES integration and solutions that each has discovered, which can be shared with other market operators and stakeholders. Global collaboration will be critical for understanding impacts, including sharing both failures and successes, and collaborating on future concepts and ideas that can allow the evolution toward 100% clean electricity.

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A Report by the Energy Systems Integration Group's Electricity Markets Under 100% Clean Electricity Task Force

This report is available at https://www.esig.energy/market-evolution-report/.

To learn more about our work in this area, please send an email to info@esig.energy.

The Energy Systems Integration Group is a nonprofit organization that marshals the expertise of the electricity industry's technical community to support grid transformation and energy systems integration and operation. More information is available at https://www.esig.energy.

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