WHOLESALE ELECTRICITY MARKET DESIGN FOR RAPID DECARBONIZATION

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WHOLESALE ELECTRICITY MARKET DESIGN FOR RAPID DECARBONIZATION: **VISIONS FOR THE FUTURE**

BY SONIA AGGARWAL AND ROBBIE ORVIS

Competitive wholesale electricity markets are at a turning point. Current market rules and practices were established to manage a system built around large central plant stations generating electricity to meet inflexible demand. Prices and market revenues are tied to generators' production costs, which have historically been largely dependent on the prices of fuels burned in those plants.

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Today's resource mix is changing. Carbon free resources with near-zero production costs such as wind, solar, and energy storage are replacing fuel-burning power plants due to falling prices and government policy. This trend is certain to continue.

These resources differ in several important ways from the fuel-burning power plants around which wholesale electricity markets were originally designed. First, they have near-zero production costs as they don't require any fuel. Second, these new resources are smaller, and can therefore be deployed more rapidly and in smaller increments. Third, they have very different production characteristics than thermal resources, with output tied to the availability of their energy resource, i.e. wind or sunshine. These differences have significant implications for how markets run and how prices and revenue can support a least-cost electricity mix.

The evolving mix of energy resources on the grid and decarbonization trend leads to the following question: "What wholesale market design would provide the best framework for reliably integrating the new, clean resources needed to decarbonize the power system at least cost?"

Thinking on this subject has generally fallen along two pathways. The "Robust Spot Market" suggests tightening up and extending today's markets for energy and services, eliminating capacity markets, and extending today's practice of voluntary decentralized bilateral contracting.

The "Long-Term Plus Short-Term Markets" pathway envisions complementing those more robust energy and services markets with an advanced, centralized, forward market to support needed resources and services.

This paper, the first in a series of three, outlines underlying questions emerging about wholesale market reform and introduces the two following papers describing alternative pathways for *markets to evolve. Each market concept is discussed more fully in "A Decentralized Markets Approach" and "Long-Term Markets working with Short-Term Energy Markets."*

THE EVOLUTION OF WHOLESALE ELECTRICITY MARKETS

Wholesale electricity markets evolved in the late 20th century in response to changing conditions on the grid. In particular, these markets were formed during a period of rising rates as the costs for new generation grew while demand growth slowed, as a way to incent more efficient investment in and operation of the electricity system.[1] Because existing generation planning practices resulted in high costs for consumers in certain regions, one of the primary goals of wholesale electricity markets was to lower overall system costs for customers by replacing utility-led energy procurement with private investment based on market principles.

Competitive wholesale electricity markets were originally designed to incorporate some demand-side flexibility in addition to their primary function of managing supply-side generation. However, regulatory, economic, and technological barriers largely hamper the ability of demand resources to participate in early wholesale electricity markets. One of the biggest barriers to participation of demand resources arises from the split in decision-making authority between the Federal Energy Regulatory Commission (FERC, which governs wholesale rates) and states (which govern retail rates).

This split authority presents a problem because flexible demand typically needs to arise from the retail level to be incorporated into the wholesale market, but state regulators, keeping the interests of individual consumers top of mind, have typically designed retail rates to be as simple as possible while sharing system costs fairly among users.

Meanwhile, FERC has focused on creating non-discriminatory rates that create an even playing field for sophisticated electricity market participants, no matter how complex and specific those rates get. This disconnect, between simple rates that wash over differences between resources at the retail level, and more complex rates designed to elicit differences between resources at the wholesale level, has made it difficult for wholesale price signals to penetrate the retail system and reach the demand resources that might want to participate in the energy market.

With limited participation from demand resources, the wholesale market has functioned primarily with grid operators dispatching large central station plants to meet unalterable demand. In other words, wholesale electricity market operators have not considered demand a dispatchable resource like supply.

[1] For more information, see: Aggarwal and Orvis (2015), *Distribution System Optimization: Ready for Takeoff* in Public Utilities Fortnightly, available online at: https://www.fortnightly.com/fortnightly/2015/06/distribution-optimization-ready-takeoff

Within this paradigm, production costs[2] (e.g. fuel, and variable operation and maintenance costs) have determined which power plants are dispatched – those with the cheapest production costs are typically dispatched first, with market operators adding power plants with higher and higher production costs until demand is met. The last, most expensive power plant sets the market clearing price at each specific location, so these production costs have also been the principle factor supporting market prices and power plant revenues.

In this model, called "marginal cost dispatch," power plants can be thought of in three categories, based on their ratio of fixed to production costs. Plants with relatively high fixed costs and low production costs have typically been dispatched first, and therefore most often. Plants in a second category with lower fixed costs and higher production costs have been dispatched only when that "unalterable" demand increases enough to justify paying to run them. Finally, plants with comparatively low fixed costs and very high production costs have been used primarily only during a small number of hours each year – the most extreme demand peaks and system emergencies. Of course, not all plants fall neatly into these categories, but this framework is helpful for thinking about how markets operate.

Today's markets are the product of this marginal cost dispatch paradigm. Marginal cost dispatch has been a good way to introduce competition into a growing electricity system composed of a mix of large baseload power plants with high fixed costs and low production costs (e.g., coal and nuclear) and some more flexible power plants with lower fixed costs and higher production costs (e.g., natural gas). The rules, tradeable products, rates, and software used in wholesale electricity markets were designed around these specific resource profiles and the idea of dispatching large central stations to meet variable, unalterable electricity demand.

WHERE WE ARE TODAY

Today's electricity mix is evolving in ways that depart significantly from the past system in which competitive wholesale power markets were born and built. As prices have fallen and policies have pushed wind, solar, and storage onto the grid, their share of the resource mix has grown. These resources differ in several important ways from the fuel-burning electricity resources of the past.

First, these new resources typically have near-zero production costs. Their costs are almost entirely paid up front, and they are very cheap to run once built. Because dispatch and market clearing prices have typically been tied to production costs, this trait is a significant deviation from the fuel-reliant power plants that have made up most of the electric system in the past.

[2] "Production costs" and "marginal costs" are often used interchangeably to describe real-time generator costs. However, in some instances, "marginal costs" can also refer to the cost of the last "marginal" generator that sets the overall wholesale market clearing price. For clarity, we use the term "production costs" here to describe real-time generator costs. In the rest of this series and other literature, however, note that "marginal costs" may also refer to real-time generator costs.

Second, newer resources tend to have smaller minimum unit sizes—on the order of tens of megawatts (MW) rather than hundreds or thousands. As a result, these resources can be deployed more quickly[3] and in smaller unit sizes. Even if each individual wind power plant is less predictable than each traditional dispatchable coal plant, a fleet of wind power plants might actually be more reliable than the single dispatchable coal plant. This is because probabilistically, ten uncorrelated units that are 100 MW in size are more reliable than a single 1,000 MW unit that could trip off all at once.

Third, these resources have different production characteristics than many existing ones and are already changing how grid operators manage the grid. For example, solar output predictably follows the daily cycle of the sun, requiring grid operators to make other resources available in the evening when solar output drops to zero. Planning and running the grid around resource availability is not a new concept for grid operators – they have always had to plan for nuclear refueling outages, for example – but doing so for a large set of resources on a daily basis is pushing operators to consider new rules and tradeable market products.[4] At the same time, newer resources can provide certain services better or more cheaply than the older ones – consider power electronics inside inverters creating (very) fast "frequency response" (an essential grid service), which can offset the need for some "system inertia" (another essential grid service that has historically been provided automatically, as a product of the spinning mass inside thermal power plants).[5]

In addition to new wind, solar, and storage, the technological barriers that limited demand-side flexibility are rapidly disappearing. Smart thermostats, water heaters, and the "Internet of things" can turn electricity demand into a resource for grid and market operators.

Serious technological changes are hitting the electricity grid, but the concomitant changes in market incentives and rules are lagging behind. As it stands today, electricity demand *can* be increasingly flexible, but precious little has been done to access that flexibility. As new technologies come online at an ever-increasing pace, it's worth taking a closer look to see whether existing wholesale market structures are equipped to handle today's technology.

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[3] For example, Tesla installed a 100 MW battery, the world's largest, in under 100 days following blackouts in Australia. See: https://www.greentechmedia.com/articles/read/tesla-fulfills-australia-battery-bet-whats-that-mean-industry#gs.1t4hvf

[4] For more information, see: https://energyinnovation.org/wp-content/uploads/2017/10/A-Roadmap-For-Finding-Flexibility-In-Wholesale-Power-Markets.pdf

[5] If the power system had originally been designed around inverter-based resources with advanced power electronics, the grid might not depend on system inertia at all, as conventional frequency response and system inertia derive from the inherent characteristics of conventional generators with spinning mass inside them. Similarly, the fact that inverter-based resources don't currently automatically provide system inertia does not mean they are incapable of it; their growing presence has exposed the value of system inertia given our current grid design, and technology will respond to the need, provided the right price signals or standards are in place. New resources change the landscape of what grid services are required, and expand possibilities for which resources can provide them.

WHERE WE ARE HEADED

Whether because of dramatically lower prices[6] or government policy[7], the electricity system will continue to decarbonize through the addition of new zero carbon resources.

Many of the constraints on today's system arose from the needs of fuel-burning resources that dominated the system when markets were first created: for example, unit commitment and minimum run rates. But these constraints are increasingly at odds with new resources entering the system. For example, evidence is growing that commitment windows and minimum run rates are routinely overstated by fuel-burning generators, limiting grid flexibility – a service becoming ever more crucial as the electricity mix decarbonizes. In other words, wholesale electricity markets will need to modernize to support decarbonized electricity systems.

In addition to the adjustments needed to ensure well-functioning wholesale electricity markets in the context of a changing mix of energy resources, many market observers are asking if more fundamental changes to wholesale market design may be needed.

Before answering the question of whether basic fixes can do the trick or whether more fundamental changes are needed, the first task is to get clear on what we need modern wholesale electricity markets to do.

TEN PRINCIPLES FOR MODERN WHOLESALE ELECTRICITY MARKETS

The ten principles below are intended to ensure technology neutrality and achievement of power system goals at least cost, and are repeated in slightly different form in each of the two following papers in this series. Wholesale electricity markets should:

1) Accommodate rapid decarbonization, including eliminating barriers to participation of zero carbon resources.
2) Support grid reliability, so the incremental costs of reliability do not exceed the amount customers would knowingly be willing to pay for, or do not exceed incremental benefits.
3) Promote short-run efficiency through optimized dispatch of the lowest-cost resource mix, and using existing and emerging technologies to manage reliability and congestion.
4) Facilitate demand-side participation and grid flexibility.
5) Promote long-run efficiency – including efficient, competitive entry to *and* exit from the market – under conditions of significant uncertainty.
6) Minimize the exercise of market power and manipulation.

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[6] In much of the US, renewable energy prices – which are expected to continue dropping – are so low that it is cheaper to build new renewable plants than continue operating existing thermal plants. See; https://www.forbes.com/sites/energyinnovation/2018/12/03/plunging-prices-mean-building-new-renewable-energy-is-cheaper-than-running-existing-coal/#5c78ed1a31f3

[7] For example, California; Hawaii, New Mexico, and Washington, D.C. have all passed legislation mandating a 100% clean electricity mix by 2050 at the latest. Several other states, including Arizona, Minnesota, Illinois, and New York are considering similar standards as well.

7) Minimize the potential for distortions and interventions that would prevent or limit markets' ability to achieve efficient outcomes, consistent with the public interest (including overarching public interest in a sustainable environment and economy).
8) Enable adequate financing of resources needed to deliver cost-effective reliability, based on an efficient allocation of risk (i.e., those that can best mitigate risk should bear it) that prevents customers from bearing the cost of poor investment decisions made by private investors.
9) Be capable of integrating new technology as electricity needs evolve, and adapting as technology changes.
10) Have designs that are readily and realistically implementable.

EMERGING PATHWAYS FOR FUTURE WHOLESALE ELECTRICITY MARKETS

In addition to fulfilling the principles laid out above, future wholesale electricity market solutions must address the following questions, which are central to whether wholesale electricity market solutions can support wide-scale deployment of low cost, low carbon resources:

- Today's market prices are derived from generators' production costs to generate electricity, which for fuel-burning power plants are clearly tied to fuel prices. Renewables and storage typically have no fuel cost. When zero production cost resources form the majority of resources on the system, grid operators will still need to know in real-time which set of resources to dispatch.
    - **How would markets efficiently form real-time prices in a system with large quantities of energy resources with near-zero production cost?**
- A changing set of resources may precipitate changes to the value of products traded in the wholesale markets, altering resources' revenue streams.
    - **How can sufficient investment signals be maintained, and how are new resources efficiently financed as the resource mix evolves?**
- Today's markets are largely oversupplied[8], which mutes grid flexibility price signals. Grid flexibility will become increasingly important as fuel-burning power plants exit the system and are replaced by renewables:
    - **How will markets expose the value of important system characteristics, such as flexibility, through this transition in the energy resource mix?**
- Today's markets struggle to develop and finance transmission, storage, and other resources that support the efficient functioning of the grid.
    - **How are transmission lines; energy storage; and local, non-transmission alternatives efficiently financed and deployed in a future market?**
- Finally, a future market design must be capable of integrating or accommodating policies focused on reducing carbon from the electricity system.

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[8] See also "Power Markets in Transition: Consequences of Oversupply and Options for Market Operators" in *Current Sustainable/Renewable Energy Reports*, April 2019.

- How is carbon policy addressed in a future market?

These are tough but important questions that don't have a single "right" answer. Reasonable people can—and do—arrive at different answers.

The market proposals most commonly discussed in intellectual circles tend to fall along two pathways, each of which seeks to satisfy the principles outlined above and answer the questions posed here. The first pathway emphasizes improving today's markets for energy and services, eschewing capacity markets, and extending today's practice of voluntary de-centralized bilateral contracting – as described in *A Decentralized Markets Approach*. The second pathway envisions complementing those more robust energy and services markets with an advanced, centralized, forward market to procure needed resources and services as described in *Long-Term Markets working with Short-Term Energy Markets*.

Both pathways agree on important features for modern markets:

- Competitive wholesale electricity markets are a good thing: Trading over a diverse portfolio of resources augments reliability and decreases overall costs, and the larger the market, the greater the benefits.
- Wholesale electricity markets need to work with external (state or federal) policies governing the electricity system, not work against (i.e., mitigate) them.
- Shorter dispatch intervals and multi-period optimization can make markets more efficient.
- The capacity markets in use around the U.S. today, which largely trade capacity without much regard to the operational characteristics of the energy resources being traded, should be fundamentally transformed or eliminated.

At the same time, important differences exist between the two pathways, driven in part by the authors' views on the following questions:

- How big of a risk is political interference in markets?
- How much do we expect the "real world" to behave as theory suggests?
- How strong are the counterparties in markets, and how strong do we expect them to be in the future; i.e., can we expect that utilities or other load-serving entities will be able to buy smart energy resource portfolios, flexible and well-hedged, to serve customers over the long-term?
- What extent can factors other than strict production costs set locational marginal prices; i.e., congestion in the transmission system, ancillary service needs, other opportunity costs? If those other factors do play a substantial role setting locational marginal prices, what is the risk that real-world prices (which may be in-part driven by lumpy retirements) are too low to attract needed flexibility resources or too high to expose their value?
- Is keeping voluntary bilateral markets (which already underlie centralized wholesale electricity markets) decentralized the best approach, or would centralizing and organizing those bilateral contracts be more beneficial?

There is no “right” answer to these questions. Wholesale electricity markets will evolve differently in various regions, but the issues raised in this paper series are extremely important for grid managers to study and deliberately consider as the electricity system decarbonizes.

WHOLESALE ELECTRICITY MARKET DESIGN FOR RAPID DECARBONIZATION: **A DECENTRALIZED MARKETS APPROACH**

BY ROB GRAMLICH[9] AND MICHAEL HOGAN[10]

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"What wholesale market design would provide the best framework for integrating reliably and at least cost the new, clean resources that will be needed to de-carbonize the power system?"

This common question includes what model best provides clean sources with fair access, what model best drives timely retirement of the fossil generation these clean resources are meant to replace, and what role the wholesale market should play in enabling new "smart" resources at the distribution/retail level. The question also includes both market structure (which entities perform which functions) and market design (what are the trading, bidding, and price-setting rules).[11] The pace and scale of new investment in clean resources will be determined in part exogenously, by environmental legislation or regulations. Such public policy instruments, including zero-carbon portfolio standards or carbon cap-and-trade, should be designed to address the market externalities of greenhouse gas emissions in a way that complements rather than substitutes for the role of the market in driving investment.

The question above is often motivated by three concerns regarding the standard spot electricity market design that shaped most current organized wholesale energy markets:

1. *Adequate investment (especially in new clean resources) might be compromised by investors being reluctant to rely simply on short-term energy pricing.*
2. *The risks in investing based on short-term energy prices could raise the cost of the transition by raising the cost of capital for new investment.*

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[9] Grid Strategies LLC https://gridstrategiesllc.com/

[10] Regulatory Assistance Project https://www.raponline.org/

[11] The question does not address the substantial transmission infrastructure needs for a de-carbonized grid; this is a more difficult challenge that also must be addressed and involves a significant role for traditional planning.

3. *Current markets rely on production costs to set prices and may not function with a grid dominated by very low or zero marginal production cost resources.*

These concerns are unfounded. A market structure with a central spot market and active de-centralized forward procurement between wholesale buyers and sellers (including exchange-based trading) will lead to sufficient investment to achieve resource adequacy, will facilitate a sufficiently rapid decarbonization, and will do so at the lowest reasonable cost to consumers.

A CENTRALIZED SPOT MARKET WITH DECENTRALIZED FORWARD PROCUREMENT IS THE BEST OPTION FOR DECARBONIZATION AT REASONABLE COSTS

The bedrock of our proposed structure is *bid-based, security-constrained economic dispatch with locational marginal pricing* (explained below) for short-term efficiency. To achieve adequate investment for long-term efficiency, the model relies on electricity buyers procuring power through a range of long-term undertakings that can support financing of new resources. To accelerate new, clean investment beyond what would be adequate to meet demand for reliable electric service, the model relies on complementary, external public policy instruments that internalize to the market the externalities of greenhouse gas emissions rather than replace the role of the market in driving new investment.[12] The central spot market and de-centralized bilateral and traded market are described in more detail below.

THE CENTRALIZED REGIONAL ROBUST SPOT MARKET FOR EFFICIENT DISPATCH AND PRICE FORMATION

Along with an active decentralized voluntary bilateral market, this market model includes a geographically large regional spot market operated by an independent entity, herein referred to as a Regional Transmission Organization ("RTO"). The RTO's market design would feature:

- Economic dispatch based on market bids and reflecting the impact of reliability-driven security constraints on the marginal cost and price of energy, as detailed below;
- Locational marginal prices;
- Tradeable financial transmission rights with trading hubs;
- Scarcity pricing based on the value of reliable service (or Value of Lost Load—VOLL), including co-optimization of energy and reserves and administrative reserve shortage mechanisms;
- Fast dispatch intervals with resource commitments made close to real time;
- Consolidation of real-time balancing authority over the largest practicable footprint and portfolio of system assets;

[12] We note there are some categories of investment, such as cost-effective energy efficiency, that suffer from multiple market failures and should continue to be targeted by complementary out-of-market policy support.

- Technology-neutral reliability service procurement using market mechanisms where possible;
- A Universal Participation Model[13] where all resources can offer their capabilities (ramp speed, capacity, etc.) and constraints (minimum/maximum output, startup time, etc.);
- Reliability services based strictly on engineering needs, which may evolve over time but will follow NERC's general categories of Essential Reliability Services;
- Optimization and participation of Demand Management and other Distributed Energy Resources directly or through a Transmission-Distribution interface;
- Transparent energy prices with minimal side payments paid by the RTO;
- Multi-settlement between forward and real-time markets to incent accurate forecasting;
- Market power monitoring and mitigation bidding rules, using structural (pivotal supplier) and/or conduct and impact methods;[14] and
- Customers' option to make their own decisions about how much electricity to buy when based on energy prices that reflect the true value.

Prices determined in this centralized short-term market lay the foundation for decentralized long-term contracting of services, which is discussed next.

DECENTRALIZED BILATERAL PROCUREMENT MARKETS TO MANAGE PRICE RISK

New investment will be needed both in variable renewable sources and in short-term and seasonal balancing resources to achieve long-run efficiency. It is possible to finance power plants and demand resources on a pure merchant basis, but the cost of capital can be lowered by access to long-term options to hedge risks. Such risk-hedging options include Power Purchase Agreements (PPAs) and other forms of forward risk management (which are not just possible, but common, in existing wholesale power markets).[15] This model includes active voluntary bilateral energy market trading of PPAs and various other types of hedging arrangements. Wholesale buyers, the counterparties to investors for such arrangements, can include utilities, competitive retail suppliers, or end-users with direct access to the market.

Establishing a well-designed and well-implemented spot market lays the foundation for this activity. Whereas generators are motivated to mitigate the risk of over-supply and sustained low energy prices, wholesale buyers will be motivated to procure their supplies in advance to avoid the risk of very high prices at times when power is scarce. This basic market dynamic—mutually beneficial forward trading to mitigate risk efficiently—is enhanced rather than supplanted by good public policy that internalizes the externality costs of greenhouse gas emissions. This can include establishing a price for carbon emissions, which augments the risks of contracting with

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[13] See Ahlstrom, Mark, https://www.esig.energy/blog-the-universal-market-participation-model/ .

[14] See, e.g., Brattle Group, Review of PJM's Market Power Mitigation Practices in Comparison to Other Organized Electricity Markets.

[15] See Jay Bartlett, Reducing Merchant Risk in Wind and Solar Projects Through Financial Hedges. https://www.rff.org/publications/working-papers/reducing-risk-merchant-wind-and-solar-projects-through-financial-hedges/ .

carbon-intensive resources, or by establishing portfolio purchase standards, which introduce the risk of being able to procure enough of certain types of energy at a reasonable price. Such policies efficiently accelerate the de-centralized procurement of desired resources (and, critically, facilitate the corresponding retirement of existing resources) rather than relying on centralized administrative procurement.

Buyers can be expected to manage these risks in a variety of ways to maximize their competitiveness and sustain their commercial viability, as long as they are in a financial position to do so. One market failure to guard against is when retail competitive suppliers are licensed to operate without sufficient assurance that they have the financial wherewithal to manage the risk of procuring the power needed to serve their contracted load. Failing to mitigate this risk can lead to bankruptcies for retailers when power prices rise. This is a type of "principal-agent" market failure. The result is that generation does not get financed and customers are left unserved.

In the U.S., state regulators are responsible for ensuring that any entity serving retail customers is financially equipped to manage the risks associated with their supply obligations. If state regulators are not willing to let customers go unserved, they should monitor and enforce credit requirements on retail suppliers. Such credit requirements, along with energy prices that reflect true value, will ensure buyers have both the incentive and the ability to appropriately hedge. Fixing this market failure will lead to more credit-worthy buyers signing contracts that help finance new generation.

To maximize competition, all suppliers should have fair access to long-term risk hedging options or handle peak loads with backup generation if they choose to do that rather than always procuring bulk power supply sources. Load-Serving Entities can secure adequate resources under state oversight in states that choose to oversee hedging for some or all customers. States may wish to perform Integrated Resource Planning for the entity that serves the mass retail market, which could include all customers except those more sophisticated and less risk-averse entities willing to take on more responsibility for their own resource portfolio.

As we discuss in the following section, a market structure with a large regional spot market with active decentralized forward procurement between buyers and sellers provides a framework for facilitating a decarbonized electricity supply that is more effective and more efficient than reliance on centrally planned, ratepayer-guaranteed long-term contracting.

EVALUATION CRITERIA

To compare our structure objectively against others, we propose the following set of common public policy criteria, or objectives:

- Facilitate sufficiently rapid decarbonization;
- Promote short-run efficiency, including generation and load dispatch;
- Promote long-run efficiency, including efficient entry and exit by the widest practical range of actors, under conditions of significant uncertainty;

- Provide short-run reliability through power system balancing and congestion management;
- Support the right amount and kind of investment needed to provide consumers with the level of long-term reliability they knowingly would be willing to pay for;
- Minimize the exercise of market power and manipulation;
- Enable efficient financing of investment with equitable and appropriate risk allocation;
- Respect social values;
- Promote innovation;
- Minimize vulnerability to political interference;
- Be readily implementable; and
- Adjust to changing circumstances, technology, politics, and culture.

This is a demanding list. It is very unlikely that any one market construct can claim to satisfy all of these criteria completely. Each market design will be better at meeting some of these challenges than others; it is important to consider alternatives in a consistent manner:

EVALUATION OF PROPOSED MARKET STRUCTURE

Below, the proposed market structure is evaluated against these criteria.

Facilitate rapid decarbonization

This model relies on exogenously set public policy to boost the market's ability to achieve a sufficiently rapid rate of decarbonization of the electricity sources. These policies could be some combination of a carbon price, carbon regulation, or carbon-free energy targets.[16] Maximizing market-driven bilateral contracting for low-carbon resources will reduce the financial and political pressures that inevitably come to weigh on policy-driven investment, making sufficiently rapid decarbonization more likely by optimizing the balance between the role of market participants and the role of public policy.

The proposed model also best facilitates the accelerated retirement of existing fossil generation, which is essential for rapid de-carbonization, in three ways: First, consolidated balancing areas and shortened dispatch intervals reduce the amount of generation needed to meet reliability standards, especially in a system with high shares of renewables and/or nuclear. Second, as policy drives more clean investment and as clean alternatives (including demand response and energy efficiency) become more competitive, a market with free exit, left to its own devices, will inexorably crowd out existing, less competitive sources. Third, by decentralizing the provision of resource adequacy and eliminating centrally administered forward procurement of capacity, the proposed model eliminates a principal source of support for existing generation surplus to what is needed to provide consumers with the level of reliability they want and value. Surplus existing fossil capacity can seem deceptively cheap to keep around despite being outrageously expensive per kilowatt-hour (kWh) of energy, and the temptation for central administrators with the tacit

[16] In the U.S., such policies would be propagated by state and/or federal legislation or environmental regulations.

approval of regulators, to use forward capacity mechanisms to steadily, stealthily over-engineer the system and socialize the cost has in practice proved to be irresistible.

Promote short-run efficiency, including generation and load dispatch

The proposed market design has been demonstrated to dispatch resources and manage congestion efficiently in serving two-thirds of U.S. electric load. This market construct features an independent system operator ("ISO") using security-constrained economic dispatch and locational marginal pricing.

When the pool covers a wide region, it can net the output of resources in different time zones with different wind regimes and cloud cover, reducing overall variability and improving access to reserves. A misconception is that as variable renewables, with their very low or zero short-run production costs, become the dominant resources in the merit order, the marginal cost of energy should be flat at zero or near zero for most hours of the year, eliminating the mechanism used by this market construct to organize economic dispatch.

In fact, dispatch is managed efficiently in many regions today despite having large tranches of the merit order offering little or no differentiation in short-run production costs. Combined demand for energy and ancillary services needed to maintain stability will likely rise at times without plentiful wind and sun, buffering average prices. New and highly flexible demands such as electrified transport and heating can provide sloped demand curves that can be expected to set the price at times of scarce energy or scarce ramping supply, at levels above the short-run operating cost of the marginal generator in the merit order.[17] A surplus of available zero-production-cost energy has implications for grid congestion and the related locational marginal costs of energy.

When these aspects of the proposed model are considered and properly reflected, the combined effect is marginal costs (and prices) dictated less by the short-run production costs of the next resource in the merit order, and more by other cost drivers arising as a consequence. This market model will continue to support efficient economic dispatch, and indeed it will be crucial for efficient dispatch of *both* supply- *and* demand-side resources.[18]

Promote long-run efficiency, including efficient entry and exit

This market structure supports long-run efficiency by promoting the investment needed—and only the investment needed—to meet the level of reliability consumers actually want and are

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[17] Smart demand can mitigate the high-priced end of the price duration curve (driven by demands for more and new types of ancillary services) by shifting to periods of surplus, thus also boosting the low-priced end of the curve.

[18] See, e.g., *The Beginning of the End* (D. Schlissel, Institute for Energy Economics and Financial Analysis, Sept. 2016) at http://ieefa.org/ieefa-texas-beginning-end-coal-fired-electricity-%E2%80%A8/, which shows that the addition of new firm capacity has been sufficient to keep up with increased demand, thus crowding fewer competitive coal-fired plants off the system. Reserve margins have declined since 2016 with unexpected high growth in oil-and-gas industry activity principally in the Permian Basin, but ERCOT's December 2018 Capacity, Demand and Reserves Report identifies planned, permitted capacity additions sufficient to more than make up for that new load growth.

willing to pay for. It supports that investment principally by incentivizing wholesale market actors on both the supply side and the demand side to manage efficiently allocated risks through bilateral contracts, exchange-based trading, and other risk mitigation options.

In the first instance, energy prices fully reflecting demand for energy and reliability give rise to risks on the supply side of surpluses and low prices during periods of over-investment, and on the demand side of shortages and high prices during periods of resource scarcity. In addition, in a market complemented by appropriate public policy instruments the risks faced by market actors can include those arising from such instruments. As in any healthy commodity market, buyers and sellers exposed to such risks seek to manage them efficiently through various types of bilateral or exchange-based trading. This decentralized support for needed capital investment creates investor-imposed discipline on generation investment decisions and mitigates the opportunities for central administrators to force consumers to pay for unneeded new investment. Minimizing centralized decisions over how much and what kind of resources consumers must pay to retain promotes free exit of older, uncompetitive generation, especially as appropriate public policy supports the entry of new resources, an essential condition for rapid decarbonization. Free entry is promoted by ensuring the price signal available to the widest possible set of stakeholders—the energy price—fully reflects the true marginal cost of energy, including demand for both energy and reliability services, eliminating the price suppression effect that in practice follows over-reliance on centralized forward capacity procurement mechanisms. It also promotes free entry by mitigating the in-built design and institutional bias in such mechanisms toward conventional supply-side resources.

Forward bilateral contracting and trading would efficiently and equitably provide investors with the revenue stability they seek compared to reliance simply on the short-term spot energy market. This includes investors in clean energy resources, which may be at even less risk than conventional resources since they bear no fuel price risk and earn infra-marginal rent at virtually any market price. As the market design pays for energy and services well defined by universal engineering principles, the rules would be more stable over time. In contrast, central procurement involving subjective factors would be vulnerable to continuous meddling.

Some observers point to limited liquidity in long-term bilateral and exchange-based trades in many organized market regions as evidence that this cannot be relied upon for needed new investment. In reality it is evidence of something much more straightforward: the regions in question have excess capacity, leaving buyers with little price or volume risk to manage and therefore with little need to engage in new long-term contracts. In the few regions where supply is better matched to demand (e.g., ERCOT) and/or where the all-in cost of new clean investment is below the cost to retain existing generation, new entry supported by bilateral and exchange-based traded contracting has been quite healthy.

A limited set of creditworthy counterparties is sometimes cited as another limitation on this construct, but this is a structural industry issue that to the extent it exists, can be corrected as described above, through state oversight of the creditworthiness of retail suppliers.

Finally, regarding cost of capital and cost of the transition, in contrast to centralized procurement, this structure does not transfer and socialize investment costs and risks to consumers and/or taxpayers who have far less understanding of, or ability to manage, the risks of long-term investment choices. Furthermore, as already noted, centralized procurement generally leads to over-procurement. As a result, the societal cost can far exceed any savings resulting from lower cost of capital for investors, even assuming the benefits of such lower costs are passed on to consumers.

Provide short-run reliability through power system balancing and congestion management

This market construct features an ISO using security-constrained economic dispatch and locational marginal pricing. This construct has ensured generation and load are efficiently in balance at all times at all nodes on the system while respecting transmission constraints. It has now been employed by each of the seven U.S. ISOs/RTOs successfully for many years, the most recent adoption being the ERCOT market in December 2010. Based on that sustained record of success, the multi-settlement, nodal market structure is being adopted by the Independent Electricity System Operator in Ontario to address longstanding challenges Ontario's market has faced.

Provide long-run reliable service at the level customers want and are willing to pay for

The role of decentralized provision of resource adequacy has already been described. The market must deliver reliability for the benefit of consumers, not for the benefit of investors, system administrators, regulators, or elected officials. What constitutes "long-run reliable service" must be grounded in that principle. What consumers want is energy, not "capacity," and system operators ensure consumers can rely upon supply *to an agreed-upon standard* every hour of every day by positioning the reserves and other services in real time needed to comply with that standard.

This market model ensures the price of energy reflects the true resulting marginal cost of energy, every hour of every day. This creates the right level of incentives (i) for market players to support new investment when new investment is needed, (ii) to support investment in the kinds of resources operationally best suited to the needs of the system, and (iii) for market players to shed surplus, uncompetitive resources. Voluntary, pre-arranged load shedding would still be an important tool to keep generation and load in balance, as it has been for decades, but a decarbonized power system will place great value in a more dynamic response to uncontrollable changes in primary energy supply from one dispatch interval to the next. This market structure, combined with new technology and services becoming widely available, will make it increasingly possible for consumers to play a role by making their own choices about an increasing range of electricity-based energy services and long-term lock-in of poor investment choices. As a result, the societal cost can far exceed any savings resulting from lower cost of capital for investors, even assuming the benefits of such lower costs are passed on to consumers.

Minimize the exercise of market power and manipulation

In real life, even an optimized power grid will experience congestion from time to time, since some solutions to congestion will cost more than the congestion itself. When markets narrow geographically, market power tends to increase. Thus, the risk of market power exercise exists with all energy market models, and no approach to preventing such behavior will be 100 percent effective. RTOs and their market monitors and regulators, operating in markets employing versions of the proposed market construct, have developed a set of techniques to prevent economic withholding by pivotal suppliers and other forms of market power and market manipulation.

Our survey of annual independent market monitor reports suggests that for the most part these mechanisms have been successful in keeping the exercise of market power to a very low level. In fact, in most cases concerns about market power are far greater in the centralized procurement mechanisms than they are in the energy markets. The potential for greater penetration of demand management will become an increasingly important means for the market itself to prevent market power from being exercised. This proposed market structure, where the value of responsive distributed energy resources is fully visible through energy prices, offers the most reliable means of ensuring that the technology and services needed to facilitate efficient response are developed and deployed. Demand response is the most potent antidote to seller market power.

Enable affordable financing of needed resources with appropriate allocation of risk

By encouraging long-term contracting by electricity buyers, the proposed market construct reduces the financing cost of new resources. Where the market indicates a need for investment, this model incentivizes wholesale buyers and sellers to allocate investment risks efficiently to those best able to assess and manage those risks. Given the rate of investment needed in new clean resources compared to the rate of load growth and natural retirements, public policy instruments will be needed to create high levels of demand for such new investment. Appropriately structured, such instruments will enhance rather than circumvent decentralized procurement by giving rise to new volume and price risks that market buyers and sellers will want to manage. This model offers the best chance that the financing of new resources will allocate those risks efficiently and at a reasonable cost to consumers. Participation of financial participants can increase liquidity, but regulators would have a critical role in monitoring financial participants for excessive risk taking and retail providers for adequate credit to serve their contractual obligations.

Respect social values

As differentiated reliability opportunities spread, some basic levels of electricity service should be ensured. For example, the social value of access to adequate heating and cooling should be respected. At the same time, consumers should not be forced to pay for the illusion of zero-risk of supply interruption due to generation supply shortages when they regularly experience supply interruptions from distribution system and other causes. The standard for firm load interruptions should be high, and it should be uniform regardless of the root cause. Ideally regulators would ensure that each dollar spent on consumers' behalf results in comparable and cost-effective improvements in reliability. Costs can be exorbitant to meet unjustifiable reserve margin targets for "adequacy" in a decarbonized power system. "Never" is neither an affordable nor an achievable standard when it comes to selective firm load-shedding. Selective firm load-shedding due to a shortage of available generation within the limits implied by prevailing standards is neither immoral nor unacceptable. It is not a failure of a reliable power system; it is a *feature* of a reliable power system—a perfectly legitimate tool long employed by prudent system operators as a last-resort measure to keep the system running.

In reality, consumers have long been accustomed to *uncontrolled* firm load-shedding due to incidents on the transmission and distribution system at rates many times more frequent than what is implied by the current standard for generation adequacy. From a consumer's perspective one loss of load looks like any other, regardless of its cause. It is far more equitable and economic to give those consumers willing and able to shift some loads the opportunity to do so than it is to charge all consumers the cost of adding or retaining more costly generation. The proposed market construct sets the foundation for this more equitable and economic approach. States should engage in public conversations about expectations and trade-offs between "reliability at all costs" and this alternative approach to protecting critical and vulnerable loads.

Promote innovation

In this market-based system, privileged positions granted by centralized forward procurement mechanisms are kept to a practical minimum. All market participants must compete to provide what consumers want—energy at the lowest reasonable cost and to a desired standard of reliability. Free entry provides innovative companies and technologies a fair shot at out-competing established players and resources and access to energy pricing that can reward them commensurate with the value they're providing.

Minimize risk of political intervention

Political intervention in an industry as central to modern life as electricity is an ever-present threat. Some RTO stakeholders have advocated recently for higher compensation for "baseload" or "fuel secure" resources. Even the U.S. Secretary of Energy has asserted the need to change market rules[19] to do so. These efforts usually target centralized capacity markets. The RTOs that operate centralized capacity markets are also intervening to mitigate state clean energy policies. The mechanism is in the centralized capacity markets, using a Minimum Offer Price Rule.

As these examples illustrate, the more centralized and complex market constructs become, the more opportunities arise for politically convenient intervention or capricious withdrawal of political support. The market model proposed here allows most decisions to be made on a decentralized basis by informed wholesale market participants. Wholesale buyers and sellers

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[19] https://www.energy.gov/sites/prod/files/2017/09/f37/Notice%20of%20Proposed%20Rulemaking%20.pdf

choose their willingness to buy or sell. Retail energy providers stand between retail consumers and the wholesale market. They can be relied upon or required to provide consumers with a sufficiently diverse range of service choices representing, among other things, a range of risk and reward opportunities. This system does not rely on a central bureaucracy to make resource choices that can be captured by incumbent or political interests.

Readily implementable approach

This approach involves an improvement on the existing market structure in most market regions. In the case of U.S. market regions, the required improvements are largely incremental though not insignificant. From an implementation perspective this represents a far less daunting challenge than throwing out the existing market construct altogether and starting over. It also benefits from the facts that the implementation challenges are largely known as a result of decades of experience in different regions, and that good examples exist of what improved implementation might look like (most notably, in the ERCOT market region). It requires no change in federal law and little change in federal regulations.

Where no independent system operation has been established, utilities would need to be encouraged to join ISOs/RTOs, and there is value in encouraging those organizations to encompass the largest practicable regions. However, where no ISO/RTO is in place today, any alternative market construct would require that states agree to submit system operation and resource decisions to newly created market institutions. States would need to significantly improve their retail regulation to ensure there are credit-worthy buyers who know it is their job to secure long-term sources of energy, and to activate demand side resources. These are significant challenges today in many market regions, but in the time frame of this scenario they are very manageable.

Adjust to changing circumstances, technology, politics, and culture

The model is flexible and allows changing circumstances to be quickly and transparently communicated through wholesale prices and appropriate retail tariffs to participants who are willing and able to adjust their behavior in response. It has minimal reliance on bureaucratic rules and political compromises, including the all-important question of what existing generation to retain versus what to retire. It achieves a practical balance between the role of public policy and the role of a competitive wholesale market in facilitating a sufficiently rapid decarbonization of the power system. Uncertainty has always been a challenge in the electricity industry, but uncertainty may now be at an all-time high on both sides of the supply-demand divide. This makes over-reliance on centralized procurement needlessly rigid, it makes the risk of long-term lock-in to the costs and operational consequences of poor decisions especially acute, and it dramatically increases the importance of giving consumers access to transparent real-time information about the value of distributed energy resources. It will be critical for the market model to be flexible and to evolve as technology and energy services undergo rapid transformations. No market structure does everything well, but flexibility and ready adaptability is a particular strength of the proposed market structure.

CONCLUSION

A robust central spot with decentralized contracts model supports decarbonization, short- and long-run efficiency, and reliability. It puts grid operators in the role they should be in—reliably and efficiently operating the grid. It puts load-serving entities in the role they should be in—determining and implementing their resource and risk management objectives. It avoids the political wrangling of the centralized model and the over-capacity and stranded costs to which that model often leads. It maximizes competition, innovation, and flexibility, especially in the critical sectors of responsive demand and distributed resources, which will tend to bring costs down over the long term. The principal challenge is building up sufficient credit-worthy buyers. We suggest a strategy to solve that challenge involving state regulatory oversight.

WHOLESALE ELECTRICITY MARKET DESIGN FOR RAPID DECARBONIZATION: **LONG-TERM MARKETS, WORKING WITH SHORT-TERM ENERGY MARKETS**

BY STEVEN CORNELI, ERIC GIMON, AND BRENDAN PIERPONT

Competitive electricity markets will play an important role in rapid decarbonization of the power sector. Competitive markets can drive the efficient development, financing, and operation of an evolving, innovative, and low-cost mix of resources that can also ensure reliability and safety. These abilities may well be critical to the successful transformation of the electric sector to a zero-carbon platform for an entirely clean energy sector.

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Efficient prices are essential features of competitive markets. They underlie markets' ability to attract investment, ensure a least-cost resource mix capable of meeting consumer needs, and allocate risks to those best able to manage them. Yet today's clean energy technologies have characteristics that raise concerns about whether current wholesale electricity market designs will support price levels sufficient to sustain – directly or indirectly – investment in the types and mix of resources needed to achieve deep decarbonization. In our view, current market designs, combined with high levels of variable renewable energy (VRE) resources with negligible short-run marginal costs, face a serious risk of failing to produce market price signals sufficient to sustain the investment needed for successful decarbonization. This is a particular concern since VRE appears certain to play a large and critical role in the rapid decarbonization of the power sector, due to the low and falling costs of wind and solar power in many regions and their ability to be deployed quickly.

Accordingly, we see a growing need for adding some kind of long-term market to today's short-term spot markets to support investment in the types and quantities of these promising technologies needed, along with critically important complementary *clean energy technologies, to decarbonize the power system quickly while meeting the other core principles outlined in the introductory paper to this series.*[20]

WHY LONG-TERM MARKETS?

In electric utility financial transitions from fossil fuels to clean power, fossil plants that retire early leave utilities with unrecovered investment balances on their books that must be addressed. While early fossil plant retirements can produce consumer savings by avoiding fuel purchases and reducing other operating costs, paying down the remaining value of investments tends to increase consumer rates. In particular, accelerated depreciation schedules,[21] which move investment collection up in time to match recovery to earlier retirement dates, tend to offset near-term savings related to early retirement by raising consumer rates.

Two characteristics of VREs raise widespread concerns for current wholesale market designs. The first is their minimal, often zero, short-run marginal costs, combined with their substantial up-front costs. Current U.S. spot markets usually base their locational marginal prices (LMPs) on the short-run marginal cost of the "marginal resource"—whichever resource is needed to meet demand while maintaining the system within its various reliability constraints. This price-formation process suggests, quite strongly, that high levels of VRE will result in very low prices in short-term markets at times when the available supply of VRE exceeds total demand, including energy bought to put in storage and use by shifting load. This means VRE resources will primarily need to recover their costs from prices set at times when there is not enough VRE production to meet all demand.

In today's short-term markets, some fixed cost recovery for resources with relatively low marginal costs, including VRE resources, is achieved through the prices set by the relatively high marginal cost of fossil fueled flexible resources needed at times of high or varying demand. The rest of the fixed costs can only be recovered during periods of scarcity—that is, occasional periods when the very highest levels of energy demand exceed the total amount of all resources available to provide that energy. At such times, scarcity and the cost of rationing consumption can set the market's energy prices well above the marginal cost of the highest-cost available resources. As power systems decarbonize, flexibility will increasingly need to be provided by non-emitting resources, such as storage and flexible load. As a result, there likely will be fewer hours with prices set by relatively high-cost fossil fuels. This suggests that, in short-term markets

[20] We summarize these principles as follows: *Market design should support 1) rapid decarbonization; 2) efficient levels of grid reliability; 3) short-run operating efficiencies; 4) demand side participation; 5) long-run efficiency including ready market entry and exit; 6) effective competition and mitigation of market power; 7) efficiently sustainable institutions; 8) adequate financing of needed resources; 9) integration of new technology; and 10) ready and realistic implementation*.

[21] See: "Depreciation and Early Plant Retirements" Issue Brief posted at: https://energyinnovation.org/wp-content/uploads/2018/11/Depreciation-and-Early-Plant-Retirements-Brief_December-2018.pdf

with high levels of VREs, fixed cost recovery will rely increasingly on both the frequency of and the prices during scarcity events.

A key question then, is whether current spot market designs will create prices when VREs are not the marginal price setting units, and especially during periods of scarcity, that are high enough and frequent enough to incent efficient investment in and maintenance of all the VREs and other clean energy resources needed to reliably create and operate a decarbonized grid.[22] If not, some market modifications will be needed to do so. We think that properly designed long-term markets, operating in concert with short-term spot markets, can fill this need, to the degree it arises.

The other feature that may prove challenging for current spot market designs is the well-known dependence of VRE on the availability of underlying intermittent wind or sunshine for producing energy. Both experience and increasingly sophisticated studies suggest that the resulting variability in VRE production profiles is not itself an insurmountable challenge for operating power systems with high shares of VRE, e.g., up to perhaps 80 percent of all energy. For example, operating variability can be reduced by selecting an optimal portfolio of different types of VRE across broad regions with different wind and sunshine patterns. Complementary technologies such as dispatchable clean energy resources, energy storage, and flexible load, can be operated to reshape the remaining variability on both the supply side and the demand side, to ensure the constant balancing of energy production and consumption needed for a reliable electric system.

Translating this operational set of resources into effective short-term market prices, however, could be difficult in a system with high levels of VRE production. In such a system, many of the periods with the potential for scarcity prices will occur because of significant lulls in wind and sunshine, when many VRE resources are unavailable. With no energy to sell, those VRE resources would be unable to capture those scarcity prices directly.

We certainly can imagine an appropriate suite of complementary technologies with the right amount of storage and load shifting capabilities solving this problem in a short-term market. The complementary technologies would purchase extra power during periods of ample VRE output, when prices would otherwise be near zero, and sell it during lull-induced scarcity periods when prices would otherwise be very high. This would bid up the otherwise very low energy prices during periods when VRE output alone is sufficient to meet demand, and put downward pressure on otherwise very high scarcity prices. The net effect would be to transfer some of the

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[22] We use the term "efficient" in the sense of both productive efficiency (using the mix of technologies and inputs that produces a given amount of product at the least cost) and allocative efficiency (producing the quantity and mix of characteristics that create the maximum benefits for consumers). Prices in such a system need to be sufficient to support investment in the right mix of technologies, as well as to support appropriate consumption choices by consumers. Efficiency also implies market and price features that minimize the cost of managing risk.

scarcity prices to the VRE resources, while at the same time capturing enough of the scarcity prices to pay for the complementary technologies themselves.

For the resulting prices to actually support investment in VREs and the complementary resources, the suite of complementary resources would need to have some additional characteristics. First, the suite would have to be large enough to be able to buy the quantity of energy needed during periods of very low prices to drive those prices up to levels that support VRE investment. But at the same time, it would have to be small enough to not consistently exceed energy needs during scarcity periods, which would simply eliminate the scarcity prices rather than transferring some of them to the VRE resources and the complementary resources.

Meeting both these conditions could be challenging. For example, with large enough amounts of VRE, meeting the first condition (being big enough to absorb all excess VRE) would violate the second condition (not having so much energy to sell that scarcity is persistently eliminated). For scarcity to provide effective cost recovery for VRE and complementary resources, such a market would have to avoid significantly excessive levels of investment in both VRE and complementary resources. This is especially important since significant overbuilds in either are likely to last a long time due to the very low marginal costs and significant fully sunk fixed costs of both VREs and many complementary technologies. Avoiding such overbuilds may be particularly challenging during the decarbonization process, when more deployment of both VRE and of complementary resources is likely to be generally desirable, regardless of the impact on scarcity prices.

The challenge goes beyond simply getting the quantities of VREs and complementary resources in the right balance. In a high-VRE electric system, the amount of scarcity likely also will be a function of how well the VRE's aggregate production profile, including any significant lulls in underlying sunshine and wind, fits with the profile of aggregate load on the system. These factors are determined largely by the type and location of the VRE resources, rather than by their total annual energy production. VRE portfolios that are more diverse in both type and location have smoother production profiles that better match load profiles, with fewer lulls, and thus produce less scarcity. This suggests that a short-term market with the right amount of complementary resources to help support local VREs of one type (e.g., wind) during initial stages of decarbonization may suddenly have too many complementary resources, with prices that are too low for both its local VREs and those complementary resources, if the next stage of decarbonization requires replacing a local fossil plant with a transmission line to a portfolio primarily made up of solar resources in a different region.

These kinds of complex and dynamic sensitivities to resource quantities, types, locations, and mixes suggest that it may be particularly challenging for a short-term market's prices alone to put together and support an efficient clean energy portfolio with high levels of VRE and the key complementary technologies. While a short-term market could perhaps get the solution right, the risks of getting it wrong, together with the potential consequences of lengthy periods with prices below levels needed to provide a return on clean energy investment, could be daunting to clean energy investors and developers alike. Indeed, a primary reason we propose long-term markets, running alongside short-term markets, is to better solve the problems of identifying and developing these complex portfolios over time. In particular, we think the addition of organized long-term markets will do a better job than short-term spot markets alone at identifying and incentivizing these complex portfolios, while preserving the benefits of competition in terms of innovation and cost reductions, risk management, cost and price discovery, and system operation.[23]

This view is bolstered by emerging computerized mathematical tools that can simulate electric system operation and cost with growing levels of VRE and complementary resources over time.[24] Such tools are rapidly making it easier to identify efficient and low-cost incremental pathways of technology deployment, and to incrementally update such pathways as technologies and electricity needs evolve over time. In addition, these tools can be used either as part of the market itself or in an earlier planning process to identify the types, locations, and amounts of new resources—such as new VRE portfolios, needed transmission expansion, the right amount and type of complementary technologies, and the systematic phase-out of existing fossil resources—needed to gradually build effective and efficient portfolios of clean energy technologies. By avoiding incompatible and imbalanced mixes of clean energy technologies, such long-term markets can reduce the risk of serious spot market malfunctions, while enhancing their effectiveness in sending good price signals to resources—particularly flexibility resources—that help manage short-term variability in supply and demand. And, at the same time, such long-

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[23] The question of whether a fully decentralized, price-driven short-term market can give rise to an efficient set of clean energy resources with high levels of VRE may be related to whether the underlying technologies comprise what economic theory characterizes as a "convex production set." See Koopman's *Three essays on the state of economic science*, Chapter 1, New York, 1957; and Baumol and Oates' *The theory of environmental policy,* Cambridge, 1988, Chapter 8. Convexity is required for an efficient decentralized market, but is prevented by significant increasing returns to scale, or if the output of a firm using one technology directly alters the output of another firm using a different technology, e.g., in the case of externalities in production. Baumol and Oates offer an example where technologies' locations cause such negative interactions, with an illustration of how identifying appropriate locations for the firms, outside of the price system, can avoid these inefficiencies. Excessive curtailment and other equilibrium problems in a high-VRE power system similarly could be due to the difficulty of avoiding non-convexities in the production set. The system simulation tools used in Gimon's and Corneli's long-term market proposals, like Baumol and Oates' location planning, could help avoid these problems by selecting a more complementary mix of types, locations, and quantities of VRE and key complementary resources.

[24] Examples of such tools are Energy and Environmental Economics, Inc.'s (E3) RESOLVE and PATHWAYS models, Vibrant Clean Energy, LLC's (VCE) WIS:dom model, and Bloomberg New Energy Finance's (BNEF) New Energy Outlook modeling tools. For descriptions and examples of their uses, see E3, *Pacific Northwest Pathways to 2050,* November 2018, available at:

https://www.ethree.com/wp-content/uploads/2018/11/E3_Pacific_Northwest_Pathways_to_2050.pdf ;

VCE, *Minnesota's Smarter Grid,* July 31, 1918, available at https://www.mcknight.org/wp-content/uploads/MNSmarterGrid-VCE-FinalVersion-LR-1.pdf ; and

BNEF, Statkraft and Eaton's *Flexibility Solutions for High-Renewable Energy Systems, United Kingdom,* November 2018, available at: https://data.bloomberglp.com/professional/sites/24/2018/11/UK-Flexibility-Solutions-for-High-Renewable-Energy-Systems-2018-BNEF-Eaton-Statkraft.pdf term markets would support large-scale investment in the more capital-intensive resources that find short-term market prices excessively uncertain and risky, particularly in a high VRE system.

This last benefit is perhaps the most important benefit we anticipate from adding long-term markets alongside short-term markets. Long-term markets, such as those we propose, will replace the uncertainty and volatility facing clean energy investors in a short-term market alone, with the broadly available contractual certainty needed for low-cost debt and equity on the massive scale needed for several decades of continuous decarbonization.

This scale benefit will be critical in our view, even with well-functioning short-term markets, due to the volume of clean energy investment needed in the next two decades and the limited current availability of creditworthy counterparties to enter into voluntary contracts with them. And the contractual certainty will be even more important if short-term markets prove unable to consistently meet the challenges we have outlined here.

Finally, a long-term market is preferable to a return to regulation in our view, since the amount of capital that must be deployed to achieve the goal of rapid decarbonization is so large that it is crucial to support it through structures that minimize the uncertainty of capital recovery, while allocating the various other risks, such as execution, cost, completion, and performance risks, to those best able to mitigate and manage them.

HOW OUR LONG-TERM MARKET PROPOSALS ADDRESS THESE KEY CONCERNS

A mix of the above reasons led each of the three authors of this paper to develop our own long-term market proposals. Though we developed these proposals independently and they have significant differences (see Appendix), reviewing them together shows that they share six core elements. This emergent deep structure in our proposals may be as important as their differences in terms of stimulating and refining the development of long-term market designs. The six core commonalities in our long-term market solutions are:

LONG-TERM CONTRACTS, POWER PURCHASE AGREEMENT, OR OFFTAKE AGREEMENTS FOR ALL PROJECTS FOR WHICH PRICE RISK OTHERWISE INHIBITS OR LIMITS LOW-COST FINANCING

In each proposal, the long-term market offers long-term PPAs or similar contractual cost recovery assurances to competitively bid and selected projects, assuming the projects meet specified performance requirements. Each proposal's market allocates the cost of these contracts to load. This supports the creditworthiness of the contracts, due to the assurance of cost recovery from final customers, while also pooling the risk of the projects at the market level, further enhancing contract creditworthiness. These features are designed to ensure cost-recovery by efficient projects, even if high levels of resources with minimal marginal costs prevent adequate spot market prices. Further, by minimizing price risk and ensuring creditworthy PPA counterparties, they are designed to assure low-cost financing for the large volumes of clean energy resources needed to decarbonize the power system.[25]

VOLUNTARY PARTICIPATION, BY RESOURCES SEEKING MITIGATION OF PRICE RISK, IN COMPETITION TO MEET THE MARKET'S DESIGN OBJECTIVES

In each proposal, the long-term market seeks voluntary bids from projects that meet, or could potentially meet, market objectives established by policymakers. The market evaluates these bids competitively and selects the least-cost mix capable of meeting those objectives. These features, combined with PPAs that condition cost recovery on meeting suitable levels of performance, preserve the key benefits of robust competition by allocating the risk of cost over-runs and project failure to the developer rather than customers. Participation on the part of projects is voluntary however, since any projects or technology types that wish to rely fully on the short-term market or on private, bilateral contracts are free to participate in only the short-term market.[26] This ability to opt into the market with the greatest benefits is central to long-term and short-term markets working well together.

COORDINATION AND CO-EVOLUTION WITH THE SHORT-TERM MARKET

While the long-term market's PPAs and competitive procurement are intended to ensure revenue sufficiency and ready financing for resources in a high-VRE environment, they are also designed to do so only to the extent the short-term market fails to. In each proposal, the short-term market still dispatches and creates dispatch-based prices for resources capable of helping balance the system in real time by producing, shifting the time of use of, or absorbing and discharging electricity. It may well be that the volatility and levels of prices in the short-term markets offer greater returns to some resources (e.g., complementary resources with low capital costs and a high degree of flexibility) than the long-term market does. The proposals all anticipate such resources will migrate to, or remain in, the short-term market rather than participate in the long-term market. Further, each proposal contemplates a variety of feedback loops from the short-term market that would guide the amount and type of resources solicited through the long-term market. The short-term market could even displace the long-term market, incrementally or fully, if the technologies that participate in the short-term market have operating and cost characteristics that support high enough price and revenue levels over time. Both short-term and long-term markets, however, probably will need additional state or federal

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[25] These design elements support principles 1 (rapid decarbonization), 5 (long-run efficiency), and 8 (sufficient and efficient financing for needed investments). They also address principle 7 (efficiently sustainable) by not leaving critical resources underfunded or under-deployed and by encouraging inefficient or outdated resources to orderly and voluntarily exit the market. Proposals with contract terms incenting efficient operation also address principle 3 (short-run efficiency).

[26] These elements support principles 5 (long-run efficiency), 6 (effective competition), and 9 (integration of new technologies).

policies to guard against any lower-cost, high emitting technologies dominating them and preventing adequate rates of decarbonization.[27]

INCREMENTAL AND INNOVATION-SUPPORTING IMPLEMENTATION

A long-term market would operate regularly, e.g. on a three-year forward basis, and each such market round would procure only a fraction of the total system's resources, granting projects in each market round contracts of a long enough term to support low-cost financing.[28] These tranches would procure only the resources needed to replace uneconomic or otherwise unsustainable resources and to meet growing needs for electricity. But the markets would also include smaller "incubation" tranches to stimulate continued innovation, cost-reductions, and accelerated commercialization of new technologies with the potential to enhance, accelerate, and reduce the cost of decarbonizing the energy sector. Procuring only a portion of market needs in each round helps avoid premature lock-in of evolving technologies, and preserves additional procurement for future periods with more effective technologies and lower costs. This step-wise procurement approach also supports the effective phase-in of long-term market structures alongside current short-term energy markets.

This process is intended to support continuous deployment of the clean energy technologies that are commercially viable at the time of each market round. This allows continuous improvement of technologies and the power system, while limiting cost and technology risks as well as the path dependency that can arise from making planning assumptions before technologies are fully commercialized. Including "incubation" tranches helps new technologies bridge the gap between venture funding and full commercialization, while reinforcing those that are most able to bid and perform successfully in the competitive incubation process.[29]

GREATER COOPERATION WITH AN OPTIMIZATION OF POLICY GUIDANCE

A fundamental problem with today's long-term and short-term markets is conflict between market processes, which require free entry and exit to achieve efficient and reliable technology mixes, and clean energy policies, which are typically based today on mandates and various incentives for specific resource types and quantities. This creates a potential policy conflict: Without such out-of-market incentives, today's markets might perform according to their original design, but fail to attract and deploy the mix of clean energy technologies needed to maintain power system performance while effectively addressing the growing climate crisis. Yet simply continuing today's out-of-market incentives for legislatively favored resources could

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[27] These elements support principles 3 (short-run efficiency), 4 (demand side participation and flexibility), 6 (effective competition), 7 (efficiently sustainable), and 9 (integration of new technologies).

[28] To be clear, each market round would procure additional tranches of new clean energy projects. We anticipate the contracts for projects in each tranche could be for substantially longer than the interval between market rounds. For example, projects with 15-year contracts could be procured in every market round, with three years between market rounds.

[29] These elements support principles 9 (integration of new technologies), 7 (efficiently sustainable), 5 (long-run efficiency), and 1 (rapid decarbonization).

impair current market design's ability to function efficiently, while also leading to a severely sub-optimal mix of the resources needed for efficient, reliable, and rapid decarbonization.

Such sub-optimal mixes could result for example, in excessive and costly levels of curtailment of clean energy production due to too much of a particular VRE (e.g., local solar or wind) in the supply mix, relative to cheaper and more balanced clean energy supply portfolios. This is especially likely because of the complex interdependencies between VRE types, quantities, locations, and enabling transmission, as well as with flexible load, storage, and other existing and emerging complementary technologies. Many of these critical system elements are excluded from today's wholesale markets. Further, many of these elements may only be available regionally, and thus will be difficult to optimize through traditional intra-state legislative and regulatory approaches to incenting more clean energy development.

All of the long-term market proposals discussed here would reduce this conflict between market objectives and clean energy and climate change policy objectives. Pierpont's long-term market's procurement objectives could be determined by independent resource planning processes that both reflect and inform policy-maker preferences. Corneli's and Gimon's long-term market alternatives rely on an emerging set of dynamic system design and planning tools to transparently generate an optimized regional electric resource portfolio capable of meeting policy-makers' energy system objectives, including reliability, universal service, and decarbonization goals, with a least-cost, best-fit set of competitively procured resources of all types, across broad geographies. These seemingly different approaches could converge into a very similar process if the policymakers who determine Pierpont's procurement objectives were informed by the same type of dynamic portfolio optimization tools that form the basis for the Corneli and Gimon proposals.[30] With a resource planning process based on such tools, and especially one that uses competitive bids as an input to the planning process, Pierpont's long-term market probably would look and perform very much like the other two in central ways.[31]

Importantly, all three proposals would provide critical, objective market- and system-based insights to policymakers on how best to achieve their various goals, with the potential to dramatically increase the pace and cost-effectiveness of clean energy deployment and the continuous reduction of GHG emissions. This same transparency and objective feedback process would help policymakers identify and implement the most cost-effective carbon and clean

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[30] See, e.g., the resources cited in footnote 4 above.

[31] Such system optimization tools, working either as a market platform or as a planning tool using market-based inputs, would support a critically important aspect of principle 5 (long-run efficiency) that may be difficult or impossible to achieve with the "invisible hand" of LMP markets alone, or with the geographically limited reach of state planners and regulators. Neither of these existing approaches is well-suited to achieving the efficient configuration of an overall multi-region supply portfolio consisting of co-optimized regional VRE resources, transmission, and predominantly local, flexible load and storage.

energy policies for an era when clean energy resources are cost-competitive but face new system integration, operation, and optimization challenges.[32]

INCREMENTAL DEVELOPMENT AND IMPLEMENTATION PATHWAYS

The final key element of all three proposals is their ability to be implemented incrementally and organically without rewriting all the software, rules, and laws that govern current market designs. Pierpont's proposal, for example, builds on RPS and other clean energy procurement practices for capital-intensive, low-marginal-cost resources and leaves today's LMP-based short-term markets to evolve to attract and support the less-capital-intensive and often more distributed flexible resources needed in a high-VRE system.[33] Gimon envisions that his long-term firm market could potentially evolve out of an energy-only spot market's need for liquid secondary markets, or even out of the forward capacity markets associated with some of today's wholesale energy markets.[34] Corneli proposes that the system optimization software that clears the bids in his long-term configuration market could evolve through its early use in transmission expansion planning by regional RTOs.[35] This pathway would bring together regional planning with state regulators, in one of the few instances of state and federal regulatory coordination envisioned in the Federal Power Act and actually taking place today.[36]

CRITICAL DIFFERENCES IN THE THREE PROPOSALS

Despite their common core elements, there are important differences among the three proposals, which illustrate the complexity of issues and the range of choices that long-term market designs must consider. Four key differences, in particular, stand out.

ENDOGENOUS OR EXOGENOUS PORTFOLIO SELECTION?

As mentioned above, both the Corneli and Gimon proposals call for explicit portfolio optimization across a large regional scope, through the market process itself. This new kind of market process would combine competitive bidding from existing and proposed new resources

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[32] This feedback loop from market performance to climate and energy policymakers could also dramatically improve long-run economic efficiency (principle 5), rapid decarbonization (principle 1), and efficient sustainability of markets and institutions (principle 7).

[33] Brendan Pierpont and David Nelson, *Markets for low carbon, low cost electricity systems.* September 2017. Climate Policy Initiative Working Paper. Available at https://climatepolicyinitiative.org/wp-content/uploads/2017/10/CPI-Markets-for-low-carbon-low-cost-electricity-systems-October-2017.pdf .

[34] Eric Gimon, *On Market Designs for a Future with a High Penetration of Variable Renewable Generation (working draft).* September 2017. America's Power Plan. Available at https://americaspowerplan.com/wp-content/uploads/2017/10/On-Market-Designs-for-a-Future-with-a-High-Penetration-of-Renew.pdf .

[35] Steven Corneli, *Efficient markets for high levels of renewable energy.* Oxford Energy Forum 114, June 2018, 15-19. Available at https://www.oxfordenergy.org/wpcms/wp-content/uploads/2018/06/OEF-114.pdf . See also Steven Corneli, *Efficient Markets for 21st Century Electricity.* Unpublished white-paper, December 2017. Available at https://www.slideshare.net/slideshow/embed_code/key/qC6nanVAcr10WJ .

[36] These diverse features designed for incremental implementation present relatively detailed pathways and strategies for meeting principle 10 (ready and realistic implementation).

with sophisticated system expansion models that incorporate load profiles and granular weather and renewable energy potential profiles. By including actual developer costs and performance specs for renewable energy and various complementary resources, such as flexible load, storage, and existing or new dispatchable generation, these markets would endogenously identify or "clear" combinations of practicable new and existing projects that would minimize the total cost, including both transmission and the cost of balancing the system, under a wide variety of likely future weather, load, and fuel cost scenarios. These cleared resources would be eligible for long-term PPAs or related cost recovery mechanisms. Either lower total costs for clean energy portfolios or appropriate state and federal policies would drive the results toward rapid, efficient, and low-cost decarbonization.

This innovation is intended to address not only revenue sufficiency challenges, discussed above, but also the much deeper problem of discovering and realizing the optimal configuration of high-VRE electricity systems. This would be achieved by designing the market's objective function to include the bid-based cost and performance characteristics of locations, quantities, and mixes of VREs, along with those of any needed transmission and complementary technologies such as storage and flexible load. Optimization tools capable of addressing such a diverse objective function are proliferating, and some are already being used for policy analysis and system planning purposes. Corneli and Gimon, in essence, propose using market-based bids as inputs into these tools, and treating the optimized portfolios they produce as the projects cleared or selected by the long-term market. Further, both see periodic runs of such a market over time serving to create dynamically efficient markets, capable of avoiding costly path dependency while supporting and incorporating continued technological change.

Pierpont by contrast, relies more on policymakers and planners to specify the content of the long-term energy supply portfolio, and the market to simply procure the specified portfolio at least cost through competitive bidding. His proposal, nonetheless, incorporates feedback loops from the short-term market to the long-term market regarding the value of different production profiles and location of the long-term market's portfolio. It also recognizes the need for more sophisticated policy guidance in specifying the portfolio over time. As discussed above, the use of the same system design tools and a bid-based process for this purpose that Gimon and Corneli rely on could lead to significant convergence between the three proposals.

SCOPE

Both Corneli and Gimon recognize that substantial cost savings are available from optimizing the mix of VREs of different types, across broad regional geographies, to produce an aggregate production profile over time that best fits the profile of load. This would minimize the amount of VRE overproduction and underproduction relative to demand, and thus could dramatically reduce curtailment and balancing costs, creating savings greater than the cost of any additional transmission needed to integrate the more optimal VRE portfolio. Local flexible load and storage offer additional beneficial trade-offs that could further reduce the costs of transmission, VREs, and balancing costs.

Accordingly, Corneli's and Gimon's long-term market proposals are for large, regional markets that incorporate transmission, along with flexible load and storage, and both new VREs and existing supply resources. Pierpont's long-term market, at least initially, focuses primarily on capital-intensive, low-marginal cost resources that may have difficulties securing financing in short-term markets, leaving resources that are not capital intensive and more flexible to recover costs through the short-term markets. The geographical scope is unspecified, but could include current state-level scopes as well as broader regional efforts, assuming policy making institutions with such a scope. Transmission cost recovery is outside of Pierpont's long-term market, though it could be addressed through a combination of long-term financial transmission rights and regulated transmission cost recovery, guided by policymakers and planners.

PRODUCTS AND PRICING

Gimon's and Pierpont's long-term markets both create an energy-based product, denominated in megawatt hours (MWh) of energy production. Gimon's market would establish a default or base hourly energy production schedule for every resource, and its PPAs would pay for this default amount of energy production, potentially as modified through weather, fuel, and other indexes. Payments would be made to each project on an as-bid basis, rather than through a single market clearing price for each time period in the schedule. Deviations of actual energy consumption and production from the default energy schedules would be provided by the short-term market, which would pay resources to run less or more than their default schedules, while charging them for failure to meet the schedules.

Pierpont's long-term market would elicit and purchase contracts for specified annual MWh production. Most of each contract's volume would be sold as take-or-pay so that bidders would not have to factor in the risk of curtailment, consistent with this proposal's reliance on policymakers and the short-term market to do a good job in selecting and incenting an efficient overall portfolio that avoids excessive levels of curtailment. Bidders would be free to choose how much of their expected output to lock into long-term contracts, allowing some control over how much weather risk they are exposed to. The weighted average price across all contracted energy for a given year would be established as the long-term market's benchmark energy price, which the short-term market could add to or subtract from, isolating the value of flexibility from that of energy.

Corneli's proposed long-term market, by contrast, does not buy or sell energy or create future or even current dispatch schedules. It is more like a market for tolling agreements37 from resources that have been selected to work well together to balance supply and demand reliably

[37] Conceptually, a tolling agreement is where an entity that needs the output of a power plant or similar resource pays its owners a series of regular payments in return for the ability to call on the resource according to agreed terms. Typically, the buyer of a tolling agreement gets the power at the plant's busbar and pays for the fuel and other variable costs of producing the power, while the seller of the tolling agreement gets payments high enough to cover the seller's fixed and non-variable operating costs.

and economically during a wide variety of weather, cost, and demand conditions. These cleared resources would be eligible for a variety of cost-recovery mechanisms under federal and participating state regulatory authority, provided they meet specified performance requirements. For example, regulated transmission would recover costs through federal or state tariffs. Competitive resources would recover costs, above and beyond those recovered in the short-term market, through tolling agreements, PPAs, or related means.

All operating resources that clear in Corneli's long-term market would be required to participate in the short-term market, which, as in all proposals, is an evolving version of today's LMP markets. The short-term market would commit and dispatch all resources, and provide only energy or ancillary service payments received by the resources cleared in the long-term market. Contract-for-difference or related terms in the long-term market's fixed cost recovery agreements would keep total compensation in balance, with high short-term prices resulting in lower long-term payments and vice-versa.

SUMMARY

Each of the three long-term market proposals compared here was developed with the goal of stimulating discussion and debate about the best approach to adjusting or reforming wholesale electricity markets so they can support rapid decarbonization of the power sector, under the increasingly compelling assumption that such decarbonization will include high levels of VRE resources. This overview suggests two primary areas for discussion, debate, and further work:

First, the concerns and critiques of energy-only markets articulated above, while made in good faith and on the basis of a collectively large amount of experience and thought, are relatively discursive and intuitive. Similarly, much of the support for energy-only markets for decarbonization is based on arguments by analogy to LMP theory for fully dispatchable resources with ample fuel supplies. Supply portfolios of historical dispatchable resources appear to readily meet the basic assumptions required by economic theory for decentralized markets to achieve efficient outcomes. Supply portfolios with high levels of VRE, however, may fail to meet these same requirements.[38]

A better understanding, based on much more detailed analysis of the impacts of high levels of VREs on both price and revenue effects, would be extremely helpful in informing all discussions of market reform and design. In particular, detailed analysis of energy price levels and volatility, along with related equilibrium conditions (including type, location, and amount of VRE and complementary resources) that give rise to high prices, including scarcity prices, would shed light on the likelihood of price sufficiency in a high-VRE-energy-only market. Similarly, more simulation-based research into the incidence of any scarcity revenues across resource types due to correlation of scarcity with the unavailability of VRE, inframarginal rents captured by VREs

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[38] See references and discussion in footnote 3 above.

during such scarcity, and the impacts of varying amounts of storage and flexible load would help us understand the question of revenue sufficiency in such markets. These insights should help market design discussions move from the realm of relatively subjective belief, intuition, and preferences to the realm of more objective, verifiable, and actionable insights.

The second line of work is even more pragmatic. If all the analysis above supports the proposition that long-term markets are needed alongside short-term markets, we need to quickly determine which features among these three proposals, and what features missing from them, are needed to implement long-term markets quickly and in a way that will truly work to support continued safe, reliable, and affordable—but increasingly clean—electricity to 21st century economies.

APPENDIX – KEY DIFFERENCES IN THE THREE LONG-TERM MARKET PROPOSALS

Key features	*Configuration Market (Corneli)*	*Long-term Energy Market (Pierpont)*	*Firm Market (Gimon)*
1. How is LTM portfolio selected?	Bid-based, region-wide system co-optimization model for all resources.	Through exogenous guidance from policy makers and system planners.	Bid-based, region-wide system co-optimization model for all resources.
2. What is the objective function of the LTM?	To minimize the expected cost of meeting reliability (security and adequacy) requirements across a wide variety of possible weather, load and resource availability scenarios	To minimize the cost of meeting a share of total load, specified by policy makers, from eligible resources that choose to bid in the LTM.	To minimize the cost of producing a significant share of total energy through a "default dispatch" that short term markets take as a baseline for real-time balancing and operation.
3. What products are bought in LTM market?	Capabilities to perform as needed to meet objective function.	Annual energy output, subject to shape, location, resource type guidance from policy makers.	Long term energy schedules.
4. How is fixed cost recovery carried out for selected resources?	Resources selected in CM are eligible for fixed cost recovery through a variety of means: PPAs, CfDs, tolls, regulated tariffs, single market clearing prices, as worked out through additional design work. Contract duration to be established in light of item 9 below.	Long-term PPAs for energy, which may be either pay-as-bid or single market clearing price.	Pay-as-bid long term PPAs.
5. Is participation in the LTM mandatory?	No. Resource owners that can recover fixed costs in the operating market alone can skip the CM; states participate purely voluntarily.	No. Resource owners can choose to bid in either the LTM or the parallel short term delivery market.	Participation is presumed, but not required.
6. Which regulatory authorities oversee it, under what standards?	The CM is FERC-jurisdictional, but contemplates federal – state coordination, building on the approach in regional transmission planning, and potentially using regional or joint boards as provided for in the FPA.	Not specified, but appears to anticipate state policy mandates.	Not specified.
7. How often is the LTM conducted, and how much does it purchase?	Periodically, e.g., once every 3 – 5 years, to purchase incremental needs to optimize the system. In practice, a relatively small share of total resources is likely to consist of new resources in each market round.	Annually, for an incremental share needed to meet load and retirement needs, plus any additional mandates required by policy makers.	Periodically, to cover incremental amounts of resources needed to optimize the system.
8. How does the LTM nurture innovation and new technology?	Each market round would set aside a tranche to be filled by competitive new or emerging technologies.	See item 7.	Not specified.
9. How does the LTM address the risk of technology becoming (or being) obsolete or inefficient within its ex-ante economic life?	The tenor of PPAs, CfDs, etc. would be set at a duration that balances the benefits of low-cost financing with those of efficient technology risk allocation to developers. The market could also pay an exit premium to existing resources that are in the way of cleaner, more efficient resource deployment.	Not specified.	Not specified.
10. Does the LTM drive rapid decarbonization, and how?	Where co-optimized clean energy resources are cheapest, the CM will naturally select decarbonizing choices. Otherwise, the CM will best reflect carbon prices and other relatively efficient state and federal policies to select decarbonizing resources.	Presumably through both clean energy resources becoming increasingly competitive with fossil, and through state and policy mandates and policies.	Similar to Configuration Market.