www.energyinnovation.org
98 Battery Street, Suite 202
San Francisco, CA 94111
power@energyinnovation.org

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

BY STEVEN CORNELI, ERIC GIMON, AND BRENDAN PIERPONT ● JUNE 2019

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.

TABLE OF CONTENTS

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](#).[1]

WHY LONG-TERM MARKETS?

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 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

[1] 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*.

and other clean energy resources needed to reliably create and operate a decarbonized grid.[2] 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 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

[2] 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.

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.[3]

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.[4] 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-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

---

[3] 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.

[4] 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.

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.[5]

[5] 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

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.[6] 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 policies to guard against any lower-cost, high emitting technologies dominating them and preventing adequate rates of decarbonization.[7]

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

---

and voluntarily exit the market. Proposals with contract terms incenting efficient operation also address principle 3 (short-run efficiency).

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

[7] 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).

each market round contracts of a long enough term to support low-cost financing.[8] 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.[9]

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 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

---

[8] 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.

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

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.[10] 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.[11]

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 energy policies for an era when clean energy resources are cost-competitive but face new system integration, operation, and optimization challenges.[12]

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

---

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

[11] 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.

[12] 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).

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.[13] 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.[14] 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.[15] 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.[16]

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 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

[13] 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 .

[14] 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 .

[15] 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 .

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

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 agreements17 from resources that have been selected to work well together to balance supply and demand reliably 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

[17] 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.

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.[18]

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 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

---

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

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.