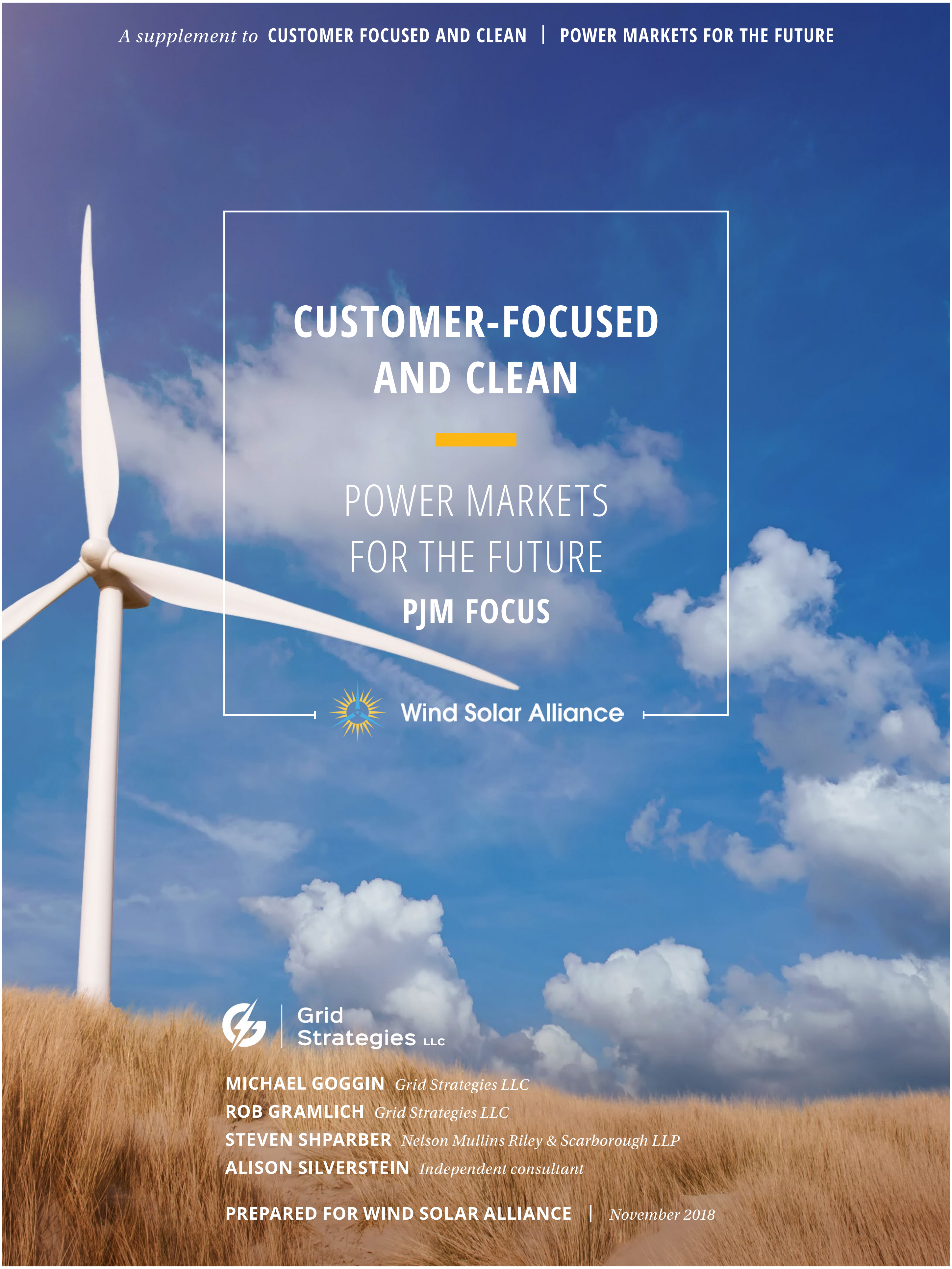

CUSTOMER-FOCUSED AND CLEAN

POWER MARKETS FOR THE FUTURE

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I. INTRODUCTION AND EXECUTIVE SUMMARY

This paper offers recommendations on how to modify wholesale electric market rules in the PJM region to better serve customers' and policy-makers' desire for clean, affordable, and reliable electricity. PJM's core design has historically supported reliability, efficiency, and renewable energy because it generally satisfies the *flexible, fair, far,* and *free* characteristics of market design needed for clean energy portfolios. However, reforms are needed in PJM (as in other regions) to update the design to better account for the new capabilities of wind, solar, storage and demand response that can contribute to regional energy and reliability services needs.

At the same time, attention is needed to address two forces that threaten to steer the market off track: (1) efforts to limit participation of resources subject to state environmental policies; and (2) efforts to insulate certain power plants from market forces by using over-broad conceptions of "resilience" and "fuel security." These actions have the potential to undermine PJM's historic position as the nation's premiere RTO in facilitating innovation and competition in the electricity sector.

The Wind Solar Alliance (WSA, formerly the Wind Energy Foundation) is working in partnership with the American Wind Energy Association and Solar Energy Industries Association on a research and educational campaign called A Renewable America (ARA). As part of this effort, WSA hired a team assembled by Grid Strategies LLC (GS) to research and offer recommendations on how wholesale electric power markets should be designed to foster a reliable, affordable and clean electric system given current trends in energy technologies and economics. WSA also asked the GS team to recommend paths toward that improved market design in the PJM region.

The GS team embarked upon an extensive literature review and expert survey to develop key findings and recommendations about changes needed to ensure a reliable and low-cost power system with much higher levels of wind and solar resources. Experts consulted include wind and solar developers, renewable customers, RTO stakeholders and staff, and other electric sector experts.

Markets that work for renewable resources must foster and facilitate success for all resources that support aspects of system reliability, including conventional and renewable generation, demand-side and storage resources. Transmission infrastructure and interconnection issues also have major impacts on markets, affecting resource participation timing and economics, but those issues are not in the scope of this study.

CONCLUSIONS AND RECOMMENDATIONS

We offer several reform recommendations for PJM markets. To keep the market on track with its technology-neutral tradition, PJM should:

- Study further whether its fuel security scenarios are plausible
- Study further the contributions of all resources to winter peak energy needs
- Ensure that any new or revised product should be based on delivered services needed by the system, not subjectively defined supply side "attributes"
- Ensure that any product should be defined in a technology-neutral, performance-based fashion that allows all resources to compete to provide the service
- Minimize or avoid application of MOPR to competitively procured renewable resources
- Allow MOPR to be avoided through bilateral contracting
- Adopt price formation approaches that better attract flexible resources
  - Bid caps and scarcity pricing that accurately reflect value of energy
  - Use markets to value flexible dispatch
  - Minimize self-scheduling and self-commitment

- Allow full participation of renewables in the capacity market
  - A penalty structure that is more symmetric for over- and under-production
  - Improved aggregation and pairing opportunities
  - A seasonal market
- Allow full participation of renewables in reliability service markets
  - Provide frequency response compensation or create a market for the product
  - Regulation market, with potentially separate reg up/down products

II. PJM'S ENERGY SPOT MARKETS PROVIDE A STRONG PLATFORM FOR A CLEAN ENERGY FUTURE

The PJM market is the largest electricity market in the world and the organization has been rightly recognized as a leader in wholesale power market design internationally. PJM utilitizes a market design based on bid-based security constrained economic dispatch with locational prices, which is the core of a sound market design platform for today's resource mix and the evolving mix driven by technology and economics. The main features of PJM's spot markets — large geographic scope, fast 5 minute dispatch, seamless internal power flow using Locational Marginal Pricing and Financial Transmission Rights, competitive auctions for any services for which competition can work, with options for customers to utilize bilateral contracting — have been generally consistent with the *flexible, fair, far,* and *free* characteristics of a market design that works for high penetration renewable energy.

As described in a companion report, power markets for a clean energy future must be *flexible, fair, far,* and *free*.

- A *flexible* power system should be able to rapidly respond and adapt to changes such as consumption (load), wind speed, solar insolation, other generator output deviations, forced generation outages and transmission disruptions.
- A *fair* market will treat all customers and resources evenly and allow all the opportunity to succeed. Such a market will be designed around service requirements and performance capabilities and be fuel-neutral and technology-agnostic, without implicit or explicit advantages or penalties for customers or resources.
- A *far* market will have a broad geographic span to maximize the efficiency benefits of supply and demand diversity, reducing variability of resources by netting them out against each other.
- A *free* market facilitates customer choice and does not raise barriers to market entry and exit.

With appropriate market rule changes now, PJM has the opportunity to continue offering a flexible, fair, far, and free market system.

III. PJM SHOULD SUPPORT TRUE SYSTEM SECURITY AND RESILIENCE

One fundamental change being considered by PJM and its stakeholders is in the realm of "resilience" and "fuel security." PJM has testified to FERC and the US Congress that action is needed to ensure resilience and fuel security.[1] In April 2018, PJM announced a fuel security process to include analysis of the problem and market design changes.[2] A much

1 Testimony of Andrew L. Ott (2018).
2 PJM (2018c).

anticipated fuel security report was issued on November 1, 2018.[3] Meanwhile the Trump Administration has indicated a desire to provide new compensation to certain power plants based on national security and resilience considerations.[4]

At the time of this writing, no major market failure or design flaw has yet been identified within the current PJM system. The November 2018 Fuel Security study found that "there is NO immediate threat to the reliability of the PJM RTO. PJM is reliable in the announced retirements and escalated retirements cases under all typical winter load scenarios. PJM is reliable in the announced retirements cases under all extreme winter load scenarios."[5] Over the longer term, PJM's stress test found issues only in scenarios with escalated retirements. However the pace of retirement will affect the decisions of remaining generation on the system that could delay their retirement as well as new generation in the interconnection queue which could proceed to construction based on regional need.

PJM SHOULD STUDY FURTHER WHETHER ITS FUEL SECURITY SCENARIOS ARE PLAUSIBLE

As PJM and stakeholders continue to study risk-based scenarios, they should re-consider the plausibility of the assumptions. Specifically it should:

- Re-consider the validity of the escalated retirement scenarios that include no additional entry into the market. The scenarios are supposed to be extreme but plausible; to say there would be no additional entry with 15 gigawatts (GW) of additional retirements is not plausible.
- Consider rising temperatures in assessing the impact of cold snaps on winter loads. As global and regional temperatures rise, heating demands and other factors will change, lessening the impact of Polar Vortices, even if they become more common due to less of a temperature difference between the poles and the rest of the globe.
- Incorporate the impact of Operating Reserves Demand Curve and scarcity pricing, which will attract more resources in the short and long term during peak conditions. PJM providing information to market participants, including through these study scenarios, will assist in this market response.

PJM SHOULD STUDY FURTHER THE CONTRIBUTIONS OF ALL RESOURCES TO WINTER PEAK ENERGY NEEDS

Further study should also consider replacement of retiring units with higher ratios of renewable energy. The November 2018 Fuel Security study replaced retiring units with a fleet made up of 96% gas units. While it is reasonable to consider that scenario to test the vulnerabilities of relying too much on gas, it would be informative to stakeholders and regulators to see the impact of greater reliance on renewable energy. PJM's 2017 resilience study found that many generation portfolios, including many high renewable penetration scenarios, would perform reliably under the scenarios studied, with no violations of reliability criteria.[6]

If further study does identify any need, it is appropriate for PJM to focus on market solutions as it has indicated it would do. In contrast, the Trump administration's potential action to pay for certain units would have a devastating effect on electricity markets. The value of markets is that they incentivize market participants to develop solutions to solve problems. They are very flexible to adapt to changing circumstances and they usually lead to greater innovation because of the rewards that accrue to those who create it.

PJM has indicated that the fuel security study likely warrants design changes to the capacity or energy market. It is premature to pursue design changes absent a demonstrated market failure or design flaw. PJM's Capacity Performance rules dramatically improved a flaw that had existed prior to the winter 2014 Polar Vortex event where many generators being paid for capacity were not producing. There may be further design flaws that could be corrected. For example, many analysts have observed that correlated plant failures such as multiple gas generators drawing from the same pipeline or compressor station, or coal plant conveyor belts freezing up during extreme cold weather, effectively reduce reliability below projections; assumptions that conventional generator outages are independent, uncorrelated events could be easily corrected with revised capacity values for such units. There are also likely design flaws that could be

3 PJM (2018d).

4 See the Department of Energy's letter to FERC with a Proposed Rule to subsidize coal and nuclear plants based on their "on-site fuel" security attributes at https://www.energy.gov/downloads/notice-proposed-rulemaking-grid-resiliency-pricing-rule, and the leaked DOE memo at https://www.documentcloud.org/documents/4491203-Grid-Memo.html.

5 PJM (2018d), slide 4.

6 See Goggin (2017) for a discussion of the PJM study.

fixed related to gas-electric coordination to increase the flexibility provided from the gas system to the electric system. If there is a restriction against a dual fuel generator reflecting in its energy bids the opportunity cost of saving fuel to burn later in a cold snap period, that could be addressed with more efficient bid limitations.

There is also the potential for market participants to fill the need themselves without regulatory mandates to centrally procure certain resources. Generally in markets it is up to individual market participants to forecast supply and demand and act based on their best information. But if the system operator anticipates particular challenges for energy, capacity, and reliability service acquisition, it can improve system reliability and market pricing through better information provision. As long as spot prices are accurate and reflect true scarcity where and when it occurs, the incentive for market participants is to do their job of procuring sufficient energy at those times and places.

If PJM does pursue market design changes, those changes should reflect the market design best practices outlined below.

A. ANY NEW OR REVISED PRODUCT SHOULD BE BASED ON DELIVERED SERVICES NEEDED BY THE SYSTEM, NOT SUBJECTIVELY DEFINED SUPPLY SIDE "ATTRIBUTES."

All resources have their capabilities and limitations. "Fuel-secure generation" is not a guarantee that the "fuel-secure" plant will perform when needed -- even plants with on-site fuel storage have experienced mechanical failures and other problems that left many such plants unable to produce electricity dependably during severe weather events,[7] and "fuel security" is not in and of itself an electricity market product distinguishable from other kilowatt-hours. Clear definition of the product is important. Products are defined by the value customers receive, not by characteristics of supply sources. Forcing customers to pay for a poorly-defined product with questionable reliability value would lead to unjust and unreasonable rates.

ISO-New England is now focusing on "winter energy security," defined as sufficient megawatt-hours (MWh) of energy during extended extreme cold weather conditions, as opposed to instantaneous availability of megawatts (MW). That is potentially a separable product from most RTOs' existing set of products (energy, capacity, and the set of ancillary or reliability services), though it would be more accurate to focus on winter peak energy.

B. ANY PRODUCT SHOULD BE DEFINED IN A TECHNOLOGY-NEUTRAL, PERFORMANCE-BASED FASHION THAT ALLOWS ALL RESOURCES TO COMPETE TO PROVIDE THE SERVICE.

Both PJM and ISO-New England have performed resilience analyses which revealed that resource scenarios with high levels of renewable resources were among the most reliable of the options tested. These reflect the fact that wind resources tend to deliver above-average output during extreme winter weather events, and solar energy is predictably produced every day. Each of these MWh provide the same contribution as any other MWh during these periods, and should be compensated the same. Defining products in a biased fashion such as fuel availability instead of delivered services could favor resources that do not produce in emergency conditions, while excluding other sources of supply that do contribute when needed to PJM's operational security.

Any new or revised products should provide accurate time- and location-based price signals. There is a choice of whether to rely more on capacity markets or the short-term energy and reliability services markets. The former is a very crude and subjectively defined product that bundles many unrelated values together, while the latter are much more granular and provide more accurate price signals to pay on a technology neutral performance basis. The current capacity market provides zero value for resources that are available during these winter peak conditions, and the same is true for capacity markets as they exist in other regions since they generally focus on summer peak. Energy and reliability spot markets can be much more finely tailored to price the winter peak energy product accurately such that any technology that delivers MWh during those periods receives the same fair compensation.

7 PJM (2018b).

IV. ACCOMMODATING STATE POLICY PREFERENCES

Along with the fuel security and resilience issue, PJM's market faces another fundamental choice in 2018: how to accommodate state policies that benefit some resources more than others. Absent a federal carbon policy, states are acting to internalize environmental externalities and assert state resource preferences.

There are two mutually exclusive visions of how wholesale markets should allow state-supported resources to participate. One view is that state-supported resources (such as renewable projects selling state-created Renewable Energy Certificates (RECs) or nuclear plants earning Zero Emissions Credits) should be able to sell their environmental attributes to entities interested in or required to buy that product while selling their capacity separately to wholesale customers who need that product. In this view of the world, the energy producer is selling two separate products to different customers, just as a coal plant owner may sell coal combustion byproducts to one customer and electricity to other customers. This view is consistent with longstanding FERC and court treatment of environmental attributes, which FERC has maintained are not FERC jurisdictional and not tied to sales of electricity.[8]

An alternative viewpoint is that sales of these environmental attributes constitute distortionary "subsidies" that need to be mitigated in wholesale electricity markets. From this viewpoint, when resources receiving REC payments participate in wholesale markets, Minimum Offer Price Rule (MOPR) requirements (minimum bid levels intended to reflect what the bid would be without the state incentive) are applied to those resource bids. Such minimum offers force those resources' effective bids higher, tend to raise capacity market prices, and potentially lead to those units not clearing the market or selling their capacity.

These views have become more polarized and acute as states act to fill the federal carbon policy vacuum. After FERC rules on rehearing of its major order declaring PJM's capacity market to be unjust and unreasonable, there will surely be a court challenge and an opportunity for the courts to settle this dispute, which affects not only PJM but potentially all other FERC-regulated RTOs.

PJM and its stakeholders should recognize the power states retain to determine the resource mix. Whether one likes or dislikes certain state policies—and views should certainly be shared with state policy makers as these policies are considered—the reality is that they have the power to implement them. It is also a settled fact that environmental attributes such as RECs are not jurisdictional to FERC and therefore cannot be mitigated or counteracted by RTOs. Raising prices through minimum bid requirements only penalizes customers for something that legislatures did, and generally those customers are also the citizens whose views are being carried out by their elected representatives. At a minimum, renewable energy policies that are competitive such as Renewable Portfolio Standards (RPS) should be spared from mitigation because they were all designed concurrently with restructuring and as such they were designed to allow for robust competition for the sales of RECs, and therefore are compatible with competitive markets.

We offer the following specific recommendations for the PJM market to address the state policy issues being considered in the region.

A. MINIMIZE OR AVOID APPLICATION OF MOPR TO COMPETITIVELY PROCURED RENEWABLE RESOURCES

Applying MOPR to recipients of REC payments results in mitigation of market power and price suppression where none exists. In the case of renewable energy, it is generally not possible for a resource owner to know in advance whether a REC sale is being used for state policy compliance or to voluntarily meet an end-user's own corporate sustainability goals. Voluntary purchases of RECs are not "subsidies" and mitigating them would violate court and FERC precedent on over-mitigation. However, PJM's proposed application of the MOPR will almost certainly subject some voluntary REC purchases to the MOPR.

Another reason to minimize or avoid applying MOPR to REC sales is that RECs are part of an actively traded and

8 The Commission ruled that "an unbundled REC transaction that is independent of a wholesale electric energy transaction does not fall within the Commission's jurisdiction under sections 201, 205 and 206 of the FPA." An "unbundled REC transaction does not affect wholesale electricity rates, and the charge for the unbundled RECs is not a charge in connection with a wholesale sale of electricity." FERC (2012) at P 24.

competitive market in PJM that values the externality benefits of clean energy. No one has alleged there is buyer-side or seller-side market power in these markets, and thus there is no public policy basis for mitigation.

Finally, neither FERC nor PJM have drawn a clear and supportable line between what is to be mitigated and what is not. For example, resources compensated through retail rates in the ratebase of vertically integrated utilities receive state policy support, and there is no sound basis to use MOPR to mitigate sales from third-party generators benefitting from state RPS while not mitigating sales from state-sanctioned utility-owned generation.

B. ALLOW MOPR TO BE AVOIDED THROUGH BILATERAL CONTRACTING

In the June FERC order declaring the PJM capacity market to be unjust and unreasonable, the Commission stated "we do not take this concern—or the states' right to pursue valid policy goals—lightly."[9] To avoid this outcome, FERC opened the door to allowing loads and state-supported resources to contract bilaterally without the MOPR affecting their price. This is called the Resource-Specific Fixed Resource Requirement Alternative. We recommend that load-serving entities (LSEs) and state-supported resources be given maximum flexibility to secure bilateral capacity contracts outside the centralized market, and states be allowed to guide or direct purchases for entities under their jurisdiction. Resources selling capacity in this way would otherwise have the same obligations as any other Capacity Resource, and would participate in energy and ancillary services markets as before.

V. THE PJM MARKET DESIGN SHOULD ADAPT TO TECHNOLOGICAL CHANGE AND CUSTOMER PREFERENCES

Significant shifts are underway across North America's electric industry. Costs have fallen for wind, solar, and battery storage as natural gas fuel and generation costs have also dropped, while technologies and business models for customer demand management have evolved dramatically. Computing power for more sophisticated system operations has grown exponentially and monitoring and control systems have improved, enabling more reliable and efficient power system and market operation.

Customer preferences have changed as well. Large corporate electricity users are transforming energy acquisition by contracting directly to buy low-cost renewable energy, hedging electricity input costs using long-term fixed price power purchase agreements. Since 2013, dozens of U.S. corporations have contracted for 13.5 GW of wind and solar capacity[10] across the nation, supporting renewables fleet expansion.

This shift in the resource mix creates both opportunities and challenges. Wind, solar, and battery resources are inverter-based resources[11] with different operating characteristics from conventional resources. These resources offer new ways to improve system reliability and efficiency, but necessitate different approaches and assumptions about power system design, capability and operation. Market rules, tariff provisions, and NERC and regional reliability standards and guidelines do not yet capitalize on the performance capabilities of wind and solar resources and the inverters that connect them to the grid.

New wind, solar, storage and demand response technologies can only improve grid reliability and efficiency if grid operators and regulators modify reliability and compensation rules to allow these new resources to do so. Table 1 below shows the services that can be provided by these new resources as well as conventional resources. Renewable energy sources perform very well relative to other sources overall in the capability to provide reliability services.

9 FERC (2018b) at Par. 159.

10 RMI Business Renewables Center (2018).

11 Inverter-based resources are connected to the power system by power electronics that convert Direct Current (DC) to the Alternating Current (AC) used on today's grid; conventional resources such as hydro, nuclear and fossil resources all generate AC power and feed it directly into the grid.

TABLE 1. *Essential Reliability Services Provided by Different Generation Technologies*

RELIABILITY SERVICE	WIND	SOLAR PV	DEMAND RESPONSE	BATTERY STORAGE	GAS	COAL	NUCLEAR
Voltage support: Reactive power and voltage control	Provides, and can provide while not generating by using power electronics.	Provides, and can provide while not generating by using power electronics.	Could provide, though this would require detailed knowledge of distribution system state and dispatch.	Power electronics provide fast and accurate response.	Must be generating to provide.	Must be generating to provide.	Must be generating to provide.
Voltage support: Voltage and frequency disturbance ride-through (also important for frequency support)	Voltage and frequency ride-through capabilities due to power electronics isolating generator from grid disturbances. Wind meets more rigorous ride-through requirement (FERC Order 661A) than other generators.	Can thanks to power electronics, but standards have prevented use of capability.	NA	Power electronics isolate battery from grid disturbances.	Generators often taken offline by grid disturbances.	Generators and essential plant equipment, like pumps and conveyor belts, often taken offline by grid disturbances.	Generators and essential plant equipment, like pumps, often taken offline by grid disturbances.
Frequency support: Frequency stabilization following a disturbance (through primary frequency response and inertial response to disturbances)	Wind regularly provides fast and accurate PFR in ERCOT today. Can be economic to provide upward response if curtailed. Can provide fast power injection (synthetic inertia) if economic to do so.	Can provide downward frequency response today, can provide upward frequency response and fast power injection if curtailed.	Load resources currently provide this in ERCOT through autonomous controls when frequency drops below a certain point.	Power electronics provide very fast and accurate power injection following a disturbance.	Only 10% of conventional generators provide sustained primary frequency response.	Only 10% of conventional generators provide sustained primary frequency response.	Nuclear plants are exempted from providing frequency response, but they do provide inertia.
Ramping and balancing: Frequency regulation	Fast and accurate response. Can provide but often costly, particularly for upward response. Provides on Xcel's system.	Fast and accurate response. Can provide but often costly, particularly for upward response.	Autonomous loads like water heaters can provide, though the cost of disruption may be too great for other DR.	Very fast and accurate response.	Must be generating to provide.	MISO data show a large share of coal plants provide inaccurate regulation response.	Does not provide.
Ramping and balancing: Dispatchability / Flexibility / Ramping	Fast and accurate response. Can but often costly, particularly for upward response. Provides on Xcel's system.	Fast and accurate response. Can provide but often costly, particularly for upward response.	Many forms of DR are likely to be energy limited or too expensive for longer duration deployment.	Many types of batteries will be energy limited for longer-duration events, particularly if state of charge is not optimal going into event.	Most gas generators are operated flexibly.	Many coal plants have limited flexibility, with slow ramp rates, high minimum generation levels, and lengthy start-up and shut down periods.	Almost never provides.
Ramping and balancing: Peak energy, winter (color reflects risk of common mode unavailability reducing fleetwide output below accredited capacity value)	Wind plants typically have high output during periods of extreme cold, as seen in ERCOT in 2011 and much of the country in 2014.	Solar plants have lower output during the winter.	Many DR programs are not currently designed for winter peak demand reduction.	Good, though will be energy limited for longer-duration events.	High gas demand can cause low gas system pressure, fuel shortages. Can be mitigated with dual fuel capability or firm pipeline contracts.	Many coal plants failed due to cold in ERCOT in February 2011, polar vortex event in 2014, and other events.	Some failures due to extreme cold.
Ramping and balancing: Peak energy, summer (color reflects risk of common mode unavailability reducing fleetwide output below accredited capacity value)	In many regions wind output is lower during hot summer days, though that is accounted for when calculating wind's capacity value. In some regions, like coastal areas or mountain passes, wind output is higher on hot summer days.	Solar plants typically have high output on hot summer days, though solar output has typically declined by the early evening peak demand period.	Many forms of DR are used for summer peak load reduction today, including air conditioning curtailment.	Good, though will be energy limited for longer-duration events.	Gas generators experience large output de-rates when air temperatures are high.	Coal plants experience de-rates when cooling water temperatures are high.	Nuclear plants experience de-rates when cooling water temperatures are high.

HIGH CAPABILITY TO PROVIDE SERVICES | SOME CAPABILITY TO PROVIDE SERVICES | LITTLE TO NO CAPABILITY TO PROVIDE SERVICES

Current market design and grid operations protocols were written without any of the changes above in mind or any recognition of the capabilities of these new technologies. Most of the power system planning, operations and market methods now in use were developed around the operational capabilities of large, utility-owned fossil, nuclear and hydro power plants.

With rapid changes in PJM's resource mix and operational needs, it is time to modify PJM's rules and procedures to address and anticipate current and future renewable penetration levels. The reform proposals below are intended to improve the effectiveness of PJM's market and operations at serving all customers and resources under a range of future resource mixes, technology paths, and societal and customer preferences. They are consistent with the principles discussed in Section 1, that wholesale electric markets and systems should be flexible, fair, far, and free.

A. ADOPT PRICE FORMATION APPROACHES THAT BETTER ATTRACT FLEXIBLE RESOURCES

"Price formation" refers to the protocols and constraints involved in establishing energy and reliability services prices. While typically in electricity markets the price is set by the marginal production cost of the last unit dispatched, that is not always the efficient price nor the price that attracts the efficient amount of flexibility. The efficient market-clearing price could be higher at times of scarcity to reflect the value of the energy to consumers.

BID CAPS AND SCARCITY PRICING THAT ACCURATELY REFLECT VALUE OF ENERGY

Any energy market offer caps should reflect the full value of providing reliable electric service during times that generation is scarce.[12] An Operating Reserve Demand Curve adder to the energy market price can be used to reflect the value of scarce operating reserves during shortage events.[13] PJM caps energy market prices at levels well below the $9,000/MWh cap used in ERCOT.

Scarcity pricing helps incentivize needed flexibility. Allowing prices to swing high or low during periods in which flexibility is needed incentivizes resources to become more flexible. In an effective power market, most customers do not actually pay the scarcity-based price, as they have been shielded by advance forward contracting for energy at reasonable costs; only customers that did not plan for their needs pay during the scarcity event. Scarcity pricing serves as a penalty or a speeding ticket to dissuade inefficient behavior (in this case, leaning on the system or free riding through insufficient long-term contracting), but should rarely have to be paid.

USE MARKETS TO VALUE FLEXIBLE DISPATCH

Market operators have tried several different approaches to procuring additional flexibility. One approach is simply to use the hourly markets with sufficient scarcity pricing to signal to resources that they should ramp up or down. That may be sufficient to attract flexibility. However different resource configurations and load characteristics may require different speeds and durations of ramping, necessitating the opportunity and need for different types of flexibility products. New flexibility products allow fast-acting but duration-limited resources, like renewable resources and some storage resources, to provide the services they can contribute.

MISO has reported success from its implementation of a 10-minute ahead Ramp Capability Product.[14] MISO assesses likely variability and uncertainty over the next 10 minutes and then procures enough flexibility to meet that need. MISO allows renewables and other resources but not storage to provide the service and has seen 95-97% of eligible resources participating. Pricing is based on a resource's opportunity cost, a ramp capability demand curve, and incentives for performance in following dispatch.

CAISO has tried a different approach to procuring capacity with its flexible resource adequacy criteria and must offer obligations (FRACMOO) program.[15] Under FRACMOO, utilities are required to demonstrate on an annual basis that they have enough flexible capacity to meet their contribution to the CAISO system's ramping needs, and the resources they

12 FERC acted in Order No. 831 to ensure offer caps reflect the value of reliable electricity, although that order limits offers to $2,000/MWh. See FERC (2016b).

13 ERCOT has set an energy market price cap and an ORDC that reflects a Value of Lost Load of $9,000/MWh. *See* ERCOT (undated).

14 MISO Market Subcommittee (2016).

15 CAISO (2014).

use for compliance are required to then offer into the energy market. This is an addendum to the resource adequacy requirements that are imposed on the utilities, so it functions more like a capacity market product than a flexibility service product in that it is a forward procurement of a capability, not actual performance in providing a service. As a result, it has failed to efficiently incentivize the actual provision of flexibility, and CAISO is working on alternative approaches.[16]

MINIMIZE SELF-SCHEDULING AND SELF-COMMITMENT

Many conventional generators in PJM are self-committed or self-scheduled by their owners rather than dispatched by the RTO through the centralized unit commitment and scheduling process.[17] Many of these generators are owned by regulated utilities that are under the jurisdiction of state regulators, which in some cases can create a perverse incentive for self-commitment and self-scheduling. Regulated generators pass through operating costs to utility customers, and the utility has an incentive to operate the plant to demonstrate its continued usefulness so that it can justify to regulators that the plant should remain in the utility's ratebase, where it earns a rate of return for the utility. Analysts have identified regulated coal plants that incur an average of about $230 million in operating losses annually in PJM.[18]

Both self-commitment and self-scheduling tend to increase overall system costs because the self-scheduled unit is not necessarily the least-cost unit and it may force more economic plants to cycle or curtail output. A plant that is self-committed and self-scheduled typically produces more energy in more hours than that plant would produce if it were to compete with other resources in the RTO's security-constrained unit commitment and dispatch process. For that reason, plants that self-commit effectively reduce the level of load to be served through the RTO's competitive market process, and thus the amount of energy that is priced at the lowest competitive level through the RTO's centralized market competition. This suppresses the energy market prices paid to all of the resources serving loads through the centralized RTO market.

There is a jurisdictional barrier to RTO and FERC remedies to the self-scheduling problem, because most self-scheduling resources are owned by utilities that are providing bundled retail service under state jurisdiction. At the same time, however, this raises a potential discrimination problem under the Federal Power Act because newer renewable and natural gas resources are generally required to be dispatchable. If FERC chose to address this fairness problem, a consistently applied rule could affect self-scheduled and self-committed resources within RTOs.

Another potential concern is that RTO operators often act conservatively to protect grid security. They tend to commit more conventional units within the operating day than official schedules say are needed to ensure that sufficient resources will be available to meet later contingencies.[19] This excess supply decreases market-clearing prices — which underpays all power producers — and keeps more inefficient, inflexible units on-line. While it is understandable that operators may act conservatively, probabilistic tools and market-based solutions should allow more optimal decision-making about how to mitigate risk.

B. ALLOW FULL PARTICIPATION OF RENEWABLES IN THE CAPACITY MARKET

"Capacity" is defined as a separate product in each US RTO/ISO region (except ERCOT). When a generator or demand resource sells capacity, it is generally committing to bid in the spot market at all times including at annual peak load, and to pay a penalty for non-performance. It can be viewed as a call option on a resource purchased by the grid operator on behalf of all load. In these markets, each LSE is required to procure capacity based on their own contribution to peak load (the exact allocation is up to states and can vary) and thus pays a share of the system capacity requirement.

Capacity market design has been problematic for renewable resources. In recent years PJM has imposed penalties for non-performance that exceed the benefit of selling the capacity, as well as requirements that resources be available year-round.[20] "Capacity" has never been a well-defined or quantified term, which makes it subject to stakeholder

16 CAISO (2018).

17 Unit commitment is the process that selects, a day in advance, which generators (and other resources) will operate the next day; scheduling and dispatch refer to hourly output levels and instructions for each resource.

18 Daniel (2018).

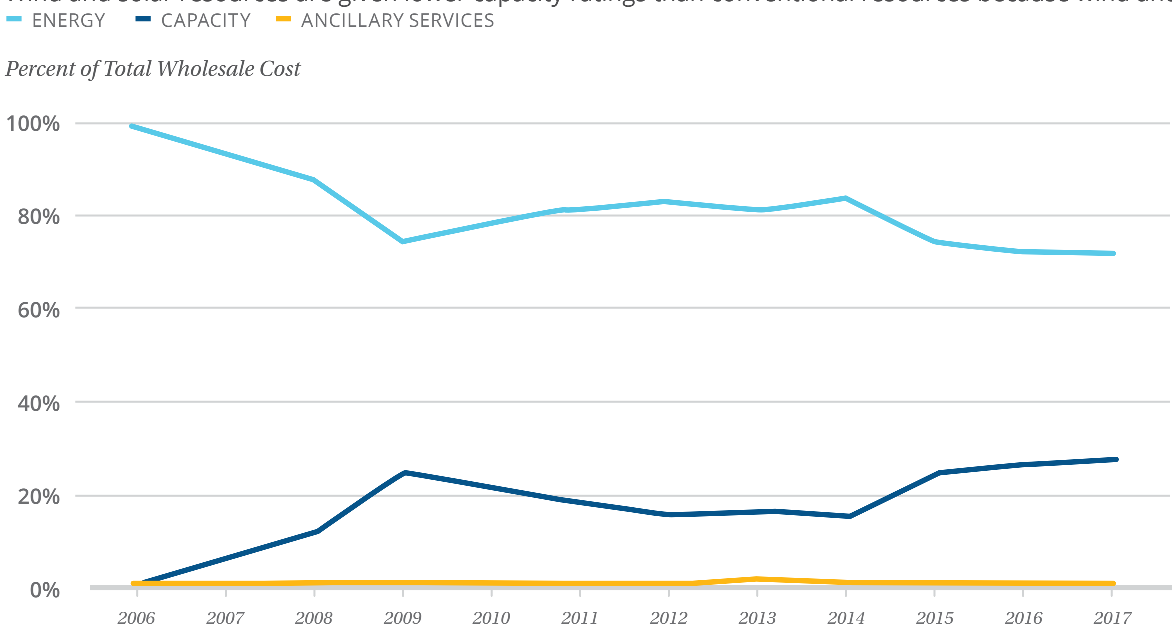
19 This dispatch of excess units occurs even though the extra units called up are not required under the official dispatch plan for the day or hour.

20 See PJM Tariff, Attachment DD.

influence, and the balance of stakeholder interests supports conventional resources rather than new technologies. Storage resources have been excluded from capacity markets due to unnecessary performance duration requirements. All such exclusions or limitations on participation have the effect of decreasing supply and raising costs for customers.

With decreasing wholesale market energy prices, capacity market revenues in PJM are making up an increasingly large percentage of total market revenues, as shown in Figure 1,[21] even though PJM has experienced a significant capacity surplus over the past decade. This revenue shift reflects the fact that capacity prices have stayed relatively flat while energy prices have fallen due to declining natural gas prices and increasing low-cost renewables, as well as flattening demand and reduced scarcity in the PJM market.

FIGURE 1. *Energy, capacity, and reliability services as shares of total PJM market revenues*
(Source: PJM (2017), p.7)



Wind and solar resources are given lower capacity ratings than conventional resources because wind and solar resources have variable generation patterns and wind rarely produces at full capacity levels during hot summer afternoons when annual peak loads tend to occur. But capacity ratings methods (including linking capacity to peak load expectations and relying on historic performance averages for technologies experiencing rapid performance improvements) and capacity pricing terms have to date been structured in ways that disfavor renewable resources. In recent years, many notable scarcity events involving significant generation shortages relative to load (such as the 2014 Polar Vortex and 2018 Bomb Cyclone winter events) have occurred at times other than summer peak demand, and wind has performed well during those events.

Another concern is that capacity markets delay the retirement (market exit) of uneconomic conventional generation. This is partially because capacity market auctions reward promises of availability at peak load periods, and procure capacity three years in advance. In recent years demand growth has fallen short of projections (meaning that capacity needs were over-stated relative to actual loads) and actual economic conditions (such as natural gas prices and wind generation costs) changed markedly between the capacity auction and the date of use. Thus, PJM has been making high capacity payments to capacity that was not needed and was not always operating during true system emergencies, keeping uneconomic capacity online. In contrast, a large amount of coal capacity has recently retired in ERCOT's energy-only market because it did not have the economic support of capacity market payments and could not compete against lower-priced natural gas-fired and renewable generation.

We recommend several capacity market reforms below to improve reliability and efficiency in a high renewable energy

21 PJM (2017).

future.

A PENALTY STRUCTURE THAT IS MORE SYMMETRIC FOR OVER- AND UNDER-PRODUCTION

PJM rules and penalty structure place more of a downside to under-performing than an upside (from the capacity payment plus energy scarcity pricing) to over-performing. For variable resources, this structure needs to be more symmetric for resources to be willing to participate and for their full contribution to be counted in the market. Otherwise the risk would exceed the reward.

IMPROVED AGGREGATION AND PAIRING OPPORTUNITIES

While the benefits of pairing specific storage and renewable plants usually result from design flaws that could be fixed, if RTOs fail to fix those flaws, it is important that market participants have the opportunity for resource aggregation and pairing. Ideally the bulk power system will inherently aggregate all resources and achieve a higher capacity value and less variability than the sum of its parts because output deviations among generators are not perfectly correlated, such that formal resource pairing is not needed. But under current market rules the synergistic capabilities offered from pairing can create more revenue for both resources than operation alone. Pairing makes sense if resources are being denied credit for their actual contributions to system capacity needs, as due to the lack of seasonal markets and the asymmetric penalty structure in PJM, if they are overly penalized for their operational deviations, or if the two resources can achieve interconnection at a lower total cost than interconnecting separately. While the best solution is fixing market design flaws, if that is not feasible then formal resource pairing can add value to the system.

A SEASONAL MARKET

Current PJM rules require resources to perform year-round to earn the capacity payment, yet wind, solar and residential demand response have season-specific performance. A more efficient market would establish separate summer and winter capacity products with separate capacity value calculations and performance requirements. The MISO Independent Market Monitor has recommended this change for the MISO market with reasoning that applies equally well to PJM:

- The revenues would be better aligned with the value of the capacity;
- Relatively high-cost resources would have an opportunity to achieve savings by taking seasonal outages during shoulder seasons;
- Resources retiring in mid-year would have more flexibility to retire then without
- having to procure significant replacement capacity to satisfy post-retirement capacity obligations in the remainder of the year;
- The qualification of resources with extended outages can better match their availability; and
- The duration of [System Support Resource] contracts can be matched with planning seasons, which removes a barrier for SSR Units to serve as Planning Resources.[22]

C. ALLOW FULL PARTICIPATION OF RENEWABLES IN RELIABILITY SERVICE MARKETS

Reliability services, also known as ancillary services, cover a range of services beyond energy and capacity that are necessary for the reliable operation of the power system. In RTOs, separate markets are used to procure many of these services, though some services cannot be efficiently obtained through markets so standards or cost-based rates are used instead. Renewable resources should be allowed to offer any and all services they can provide, and receive the market-based compensation as other resources do.

PROVIDE FREQUENCY RESPONSE COMPENSATION OR CREATE A MARKET FOR THE PRODUCT

In Order 842 earlier this year, FERC declined to address compensation for providing primary frequency service,[23]

22 Potomac Economics (2018), pp. 101-102.
23 FERC (2018a).

leaving it up to RTOs to create markets or compensation mechanisms for the service.[24] Markets for primary frequency response should yield more economic operation of the power system because the cost of providing the service varies considerably across different resources and over time. The lack of compensation for primary frequency response is a primary reason why provision of the service has lagged, with NERC finding in 2012 that only 10% of conventional generators were providing sustained primary frequency response.[25]

PJM and other RTOs should also explore creating separate markets for fast frequency response, which offers higher value to the power system and inverter-based resources can provide. This would be modeled on the fast frequency response service FERC created in Order No. 755.

RTOs should not require renewable resources to curtail production to reserve headroom to provide upward primary frequency response, as has been discussed in some PJM stakeholder meetings. FERC was clear in Order No. 842 that it was not imposing a headroom requirement, although that does not prevent an ISO from attempting to do so. Such a requirement would keep low-marginal cost resources like wind and solar from earning revenues on their full operational output and would likely be viewed by FERC as not just and reasonable and unduly discriminatory.

During a frequency disturbance requiring upward primary frequency response, resources should be allowed to increase their output above interconnection limits or dispatch limits imposed by thermal constraints on the transmission system. This allows resources that are curtailed due to transmission thermal limits to offer valuable upward primary frequency response at essentially zero opportunity cost, and there is no significant harm to the transmission system from exceeding thermal limits over the seconds-to-minutes timeframe for which primary frequency response is deployed.

REGULATION MARKET, WITH POTENTIALLY SEPARATE REG UP/DOWN PRODUCTS

PJM market rules effectively prevent renewable resources and other advanced technologies from providing operating reserves including frequency regulation service. While some ISOs directly exclude renewable generators from providing operating reserves, in others the barrier is a requirement that a resource be able to provide sustained regulation response over an extended period of time. That is not typically feasible for wind and solar generators, but if the service interval were shortened they could commit to providing the service with high confidence.

Beyond letting renewables provide frequency regulation services, there is potential value in establishing separate markets for up- and down-frequency regulation, because wind and solar typically face a greater opportunity cost for providing up-regulation than down-regulation.[26] Providing up-regulation ("reg-up") requires holding a plant below its maximum output at all times while it is offering the service so that it can increase output when needed to provide the reg-up service. In contrast, reducing the output of a plant to provide frequency down-regulation ("reg-down") only requires withholding the amount of output that is necessary to bring the system back into balance. Separate reg-up and reg-down markets could also enable greater regulation provision by storage resources, which at high or low levels of charge may be able to provide one service but not the other, and demand response resources (which typically provide only reg-up service by cutting load).

Wind and solar plant use inverters to provide regulation services with greater speed and accuracy than conventional power plants. CAISO has found that frequency regulation from solar PV is around 90% accurate at meeting specific regulation demands quickly, which is almost twice as accurate as conventional generators and some energy storage technologies.[27] Even though wind and solar resources typically face higher opportunity costs than other resources for providing frequency regulation, their fast and precise response constitutes a premium product under the terms of FERC Order No. 755.[28] This product and compensation change could significantly improve grid operational reliability.

24 There is currently no market and no compensation for the provision of primary frequency response, which results in many generators failing to provide sustained primary frequency response. See, e.g., NERC (2012) pp. 32-33.

25 NERC (2012) p. 95.

26 Up-regulation ("reg-up") entails quickly increasing generation to restore frequency to safe operating levels when load on the grid exceeds available generation (as when a large generator fails or transmission drops, cutting delivery from one or more power plants). Down-regulation ("reg-down") involves a fast drop in generation to restore frequency to safe operating levels when generation on the grid exceeds load (as when an extensive transmission or distribution event drops a large amount of load).

27 Loutan & Gevorghian, p. 30.

28 FERC (2011).

V. CONCLUSION

The PJM market has been a model for grid operators around the world, leading the way in bid-based security constrained economic dispatch with locational prices and financial transmission rights. That design is the core platform that best enables competition, reliability, efficiency, and supports a transition to a cleaner generation fleet. All markets, PJM included, need to continue an evolutionary process to better attract and retain flexible resources in order to maintain reliability in a faster moving system with more variable resources on the system. All markets, PJM included, also need to continue reviewing the market and operating protocols that were designed with conventional resources in mind, in order to make them truly technology neutral. Grid operators also need to find ways to utilize the new capabilities provided by new technologies including modern wind and solar plants, which are in many ways superior to conventional sources at providing some reliability services. Finally, PJM must manage some specific issues related to interaction with state policy and fuel security, which threaten to take the RTO off the track of technology neutral and efficient markets. PJM, its stakeholders, and state regulators in the region should evaluate these aspects of the long term direction of these markets in order to remain a leading RTO that benefits customers in the region.

Specifically we recommend that PJM:

- Study further whether its fuel security scenarios are plausible
- Study further the contributions of all resources to winter peak energy needs
- Ensure that any new or revised product should be based on delivered services needed by the system, not subjectively defined supply side “attributes”
- Ensure that any product should be defined in a technology-neutral, performance-based fashion that allows all resources to compete to provide the service
- Minimize or avoid application of MOPR to competitively procured renewable resources
- Allow MOPR to be avoided through bilateral contracting
- Adopt price formation approaches that better attract flexible resources
  - Bid caps and scarcity pricing that accurately reflect value of energy
  - Use markets to value flexible dispatch
  - Minimize self-scheduling and self-commitment
- Allow full participation of renewables in the capacity market
  - A penalty structure that is more symmetric for over- and under-production
  - Improved aggregation and pairing opportunities
  - A seasonal market
- Allow full participation of renewables in reliability service markets
  - Provide frequency response compensation or create a market for the product
  - Regulation market, with potentially separate reg up/down products

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