Attachment

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Modernizing Electricity Market Design

Efficiently Managing Net Load Variability in High-Renewable Systems: Designing Ramping Products to Attract and Leverage Flexible Resources

Our names are Dr. Kathleen Spees and Dr. Samuel A. Newell. We are employed by The Brattle Group as Principals. On behalf of the New York State Energy Research and Development Authority (NYSERDA), we offer these comments on modernizing electricity market design. Though there are a wide array of reforms and products needed to align current energy and ancillary service markets with rapid decarbonization, we focus our comments on the critical role that a well-designed suite of ramping reserves can play in managing system uncertainties, maintaining reliability, and managing costs.

Our views on the opportunities presented by ramping products derive from our consulting work supporting a wide range of energy and ancillary service market enhancements in jurisdictions across the globe that are at varying stages of clean energy transition.[4] Across many jurisdictions and contexts, we find that the technical challenges and identified design enhancements far exceed the pace at which the solutions can be implemented. In this situation, there is a need for systematic assessments amongst potential reforms so that they can be properly prioritized. We expect that implementing well-designed suite of ramping products (or enhancing existing ramp products, where those already exist) would be likely to rise to the top of such a prioritized list in most regions. In our comments we draw on the insights derived from a number of markets to propose a generalized approach for developing a fit-for-purpose ramping products in regions undergoing rapid decarbonization.

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[4] We derive these views for example from our NYISO Grid in Transition Study that included modeling the New York electricity system throughout clean energy transition to a 100% clean resource mix by 2040; our work for the Australia Energy Market Operator to develop a new vision for the wholesale markets to align with clean energy transition; our work for the Texas market operator and commission to refine their suite of ancillary services and operating reserve demand curve to more cost-effectively manage reliability needs and renewable resources; and our work offering recommendations on SPP's ramping product.

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TABLE OF CONTENTS

Executive Summary

As the grid transforms from dispatchable thermal generation toward variable and uncertain wind and solar power, maintaining an adequate, balanced, secure system will require greater flexibility from resources and consumers. This will require many reforms to planning, operations, and market designs. Chief among the market design aims is to establish reserves for reliability and efficiently meeting net load variability and uncertainty. We refer to such reserves generally as "ramping reserves" without yet presupposing a specific product. The Independent System Operators (ISOs) and Regional Transmission Organizations (RTOs) are at varying stages of needing such a reserve; some have experimented with new ramping products while others have proposed leveraging ancillary services that were designed for other purposes. Our comments discuss how to systematically address this need, particularly as relevant for the future of New York and other regions pursuing deep decarbonization mandates.

Under the Climate Leadership and Community Protection Act (CLCPA), the State must achieve a 70% renewable energy supply mix by 2030; and must achieve a 100% clean electricity supply mix by 2040.[5] The CLCPA also mandates certain amounts of offshore wind, behind-the-meter photovoltaics, and battery storage. In short, the CLCPA will transform the New York resource mix within the decade. The new, clean resource mix will present a completely different set of system challenges, reliability needs, and resource capabilities compared to the historical context in which the energy and ancillary markets were first developed. Through its Grid in Transition analyses and reform efforts, the New York Independent System Operator (NYISO) aims to advance and reform its electricity markets to fulfill its mandate of delivering reliability cost-effectively throughout this transformation.[6]

In New York and other regions in transition, developing a future-ready suite of ancillary services should be founded on analyses of system needs and how they will change over the coming years. Periodic assessments can diagnose emerging reliability challenges and reasons for out-of-market actions; identify future reliability needs that are not yet met via ancillary service products; and review opportunities to unlock the capabilities presented by flexible resources. NYISO has for the last several years been conducting such analyses, some of which has aimed to identify a number of potential reliability gaps that are anticipated to arise absent reform, introduce various metrics for tracking market performance, implement design reforms, and inform the transition work plan.[7] Given that NYISO's work on these issues is ongoing or upcoming, our comments here do not

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5 See NYSERDA, "Climate Leadership and Community Protection Act (Climate Act)".

6 See NYISO, "Update on Grid in Transition Related Work Plan for 2022", December 2, 2021.

7 See, for example, New York ISO, *2021-2030 Comprehensive Reliability Plan*, November 2021; and New York ISO *Reliability and Market Considerations for a Grid in Transition*, December 20, 2019.

presuppose the details of the most relevant products for the New York system, but rather are intended as general comments on ramping challenges that all ISOs may face.

In a broader survey, the Australian market operator recently conducted a meta-analysis of such studies examining emerging system needs in high-renewable systems across the globe, with most systems showing a need for new products to manage system variability (such as ramping), system frequency (such as fast frequency response and inertia), and voltage (provided via non-market means).[8]

Once emerging system needs are identified, they can be translated into fit-for-purpose ancillary service products; subjected to benefit-cost analyses to eliminate or defer less valuable concepts; and prioritized relative to other ongoing reform efforts. In general, the goal is to introduce needed products with a strong value proposition proactively, before an unmet system need materializes into frequent reliability challenges or costly out-of-market actions.

New and reformed products should also ensure they fully utilize the capabilities of flexible new technologies including batteries, demand response (DR), curtailable renewables, electric vehicles, and other distributed energy resources (DERs). New products should reflect the realities of the future grid they must serve, which in New York and many other places will need to rely primarily on emerging clean technologies to provide system reliability and balancing services. This will require ISOs/RTOs to engage in many more pilot and testing programs to understand new resources' capabilities; advance communication systems; improve visibility and controls; align product definitions to fully enable those resources' contributions; and ensure that the ISO control room has confidence in the ability of new resources to respond to their performance obligations.

We anticipate that for most markets in transition, introducing or refining a tailored suite of ramping reserve products when needed will prove to be among the most beneficial opportunities to manage system variability and uncertainties. As illustrated in Table 1, ramping reserves serve a separate and distinct purpose from other ancillary services in common use such as regulation (balancing intra-interval variability); contingency reserves (responding to unanticipated outages); and frequency response. Even though there could be some similarities in product definitions between ramping products and traditional ancillary services, we do not recommend to simply expand traditional services to meet emerging flexibility needs; ramping reserves should be developed in a targeted fashion to serve their distinct purpose, value proposition, and activation mechanisms. Ramping reserves are a new product that can be defined over 10-minute to 3-hour timeframes that serve the purpose of cost-effectively managing variability and uncertainty in net load. Following current standard practice would manage increasing variability in multi-interval ramping needs

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[8] The systems included in this meta-study included Eastern and Western Australia, Great Britain, Texas, and Ireland. See Australian Energy Market Operator, "Maintaining Power System Security with High Penetrations of Wind and Solar Generation", October 2019, Table 1 (p.15).

through increasing reliance on out-of-market unit commitments, control room actions, unpriced constraints within security-constrained unit commitment (SCUC) software.[9] Ramping products offer a market-based opportunity to cost-effectively pre-position system resources to meet net load variability and adapt to system circumstances, thus maintaining reliability without reaching for costly out-of-market actions.[10]

TABLE 1: THE ROLE OF RAMPING RESERVES COMPARED TO OTHER SYSTEM SERVICES

Product	Needed to:
Regulation *Reg Up & Reg Down*	Manage net load variability within a 5-minute dispatch interval
Contingency Reserves *10-min spin, 10-min non-spin, 30-min*	Respond to generation and transmission outages
Ramping Reserves *Up & Down, 10-min to 3-hours*	Manage increasing ramping and net load variability between dispatch intervals (i.e. capability to meet net load ramps over 10 min, 30 min, or 1+ hours)
Energy	Meet customer demand in each 5 min dispatch interval
Capacity	Ensure sufficient total supply to meet 1-in-10 reliability standard

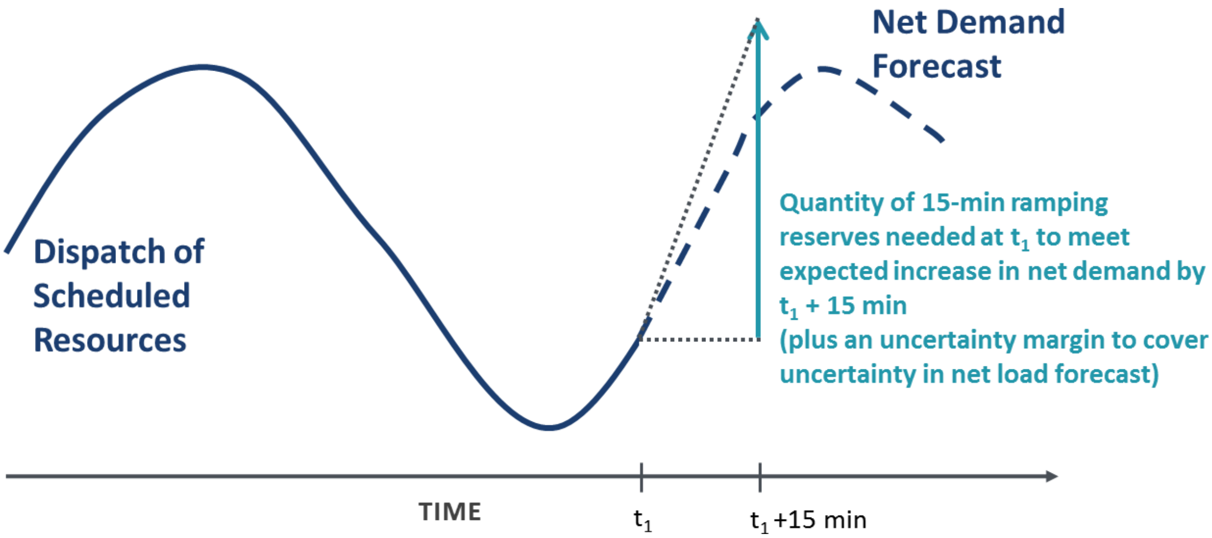
Several markets with high levels of renewables are in the process of designing or have already implemented different variations of a ramping product including in Midcontinent ISO, California, Australia, and Southwest Power Pool. Though the exact approach and parameters differ by jurisdiction, the general concept is illustrated in Figure 1 for a 15-minute ramping product. The ramping product is designed to meet upcoming ramping needs (including the expected ramp plus an uncertainty band around system ramping needs) over future 5-minute dispatch intervals. If net ramping requirements are higher than expected, the available ramp-up resources can be called on to meet the higher net demand. Ramp-up products add value by avoiding short-term reliability shortfalls, managing system uncertainties, improving price formation, reducing out-of-market unit commitments, and reducing out-of-market uplift payments that would otherwise be made (often to

9 An important, but often-missed, nuance in discussing SCUC and security constrained economic dispatch (SCED) software (together, the market management system (MMS)), is that introducing a constraint or parameter into SCUC/SCED is not always equivalent to introducing that parameter into the "market". Both SCED and SCUC often incorporate a number of cost-driving constraints and resource parameters that are not reflected as market-procured products and/or are not reflected in the "pricing run" used to set market energy and ancillary service prices. See Sections A and B.4 below for more discussion of this point.

10 It would also be problematic to introduce a product that is poorly designed, that is not needed for reliability, or that artificially constrains the resources that can provide the product, as this could increase system and customer costs without a commensurate reliability or economic value contribution to the system.

less flexible resources). Ramp-down products add value by cost-effectively managing the level of renewable curtailments imposed during low-demand periods.

FIGURE 1: EXAMPLE OF A 15-MINUTE RAMP-UP PRODUCT THAT CAN ENSURE SUFFICIENT SUPPLY WILL BE AVAILABLE TO MEET UPCOMING RAMPING NEEDS (INCLUDING THE NET LOAD UNCERTAINTY MARGIN)



Source: Adapted from Navid & Rosenwald, *Ramp Capability Product Design for [Midcontinent ISO] Markets*, December 22, 2013.

In systems with low net load variability, ramping reserves may be plentiful at low or zero cost by traditional thermal resources (in which case, ramping products to secure and price the ramping reserves are either not needed or rarely needed). But as net load variability increases, thermal resources will not provide ramping reserves "for free" as a by-product of energy dispatch, meaning that absent ramping products they will need to be dispatched and paid on an out-of-market basis. Ramping products can rationalize the quantity of ramping reserves procured at each timeframe, create a transparent price, and attract lower-cost solutions for managing net load variability. During times when ramping supply as plentiful, ramping reserves would clear at or near a zero price; but if maintaining ramping reserves would impose cycling or opportunity costs on market participants, the price would increase.

Ramping reserves will also prove to be the natural product through which to draw on the capabilities of the next generation of flexible clean energy technologies such as batteries, DR, electric vehicles, and other DERs. Many of these emerging resources can have high responsiveness and minimal cost to stand ready to manage system ramping needs. By incentivizing flexibility through 10-minute to 3-hour ramping reserve products, a much wider array of technologies could be attracted to participate in the wholesale electricity markets. This would enhance the ISOs' visibility and control of DERs, making them an asset in managing system variability (rather than another uncertainty to manage around). Further, DR/DER resources' offers to provide ramping reserves (and energy when called to deliver) would reflect consumers' private willingness to pay for energy; this would greatly enhance energy and ancillary service market price formation by aligning price formation of all products with consumer value, at least if DR/DER resources participate in sufficient volumes.

The component parts of a best-practice suite of ramping products have been proposed or implemented in several jurisdictions, but no market has yet implemented the full package. Drawing on observations from markets that have already implemented these products (and those where the needed ramping products do not yet exist), we suggest that the value of ramping products can be maximized by:

- **Conducting Foundational Analyses to Characterize Unmet System Needs (if Any):** Conducting analysis of historical conditions and simulated future conditions can determine the scale and patterns of net load variability, and which ramping reserve products may prevent reliability shortfalls and out-of-market actions.
- **Defining Fit-for-Purpose Ramping Products:** A ramping reserve is a quantity of supply that is currently not deployed for energy, but that is committed and available to meet higher net demand in future intervals. A market could define one or more ramping products that align with the greatest system needs identified in the foundational analysis, such as one 15-minute product and another 3-hour product. These products could be defined system-wide and on a regional basis if needed. Ramp-up and ramp-down products may also be separately defined (though we anticipate less need for and lower value for ramp-down reserves).
- **Developing Value-Based Demand Curves for Ramping Reserves:** Demand for each product would be based on the need for *expected* ramping needs in the 50/50 net load forecast, plus a an additional uncertainty band to account for *unexpected* ramping needs, representing both the expected short-term increases in net demand and net demand uncertainty.[11] The willingness to pay for each ramping product would be derived from each product's value to the system that each incremental MW of ramping reserves provides. This system value will decline as a function of volume of reserves procured, and should account for: (a) the value of lost load (VOLL) times the probability of lost load (POLL) achieved by the system avoiding ramping-driven load shed; and (b) the avoided costs of out-of-market unit-commitments that may otherwise be needed. This willingness to pay would be translated into an operating reserve demand curve (ORDC) that would set price paid for ramping reserves as a function of quantity procured.
- **Procuring Ramping Reserves Co-Optimized with Energy and Other Ancillary Services:** Ramping reserves would be procured in each 5-minute dispatch interval, even for reserves whose purpose is to meet reserves over longer timeframes. Reserves would be procured (and deployed) in a fully co-optimized fashion alongside energy and other ancillary services. Prices

[11] The need for a ramping product is driven by unexpected ramping needs that the market would otherwise under-provide, yet the product's demand quantity must include the expected ramping quantity. If the demand only covered unexpected needs, resources already providing ramping for expected needs would deploy the reserves as energy sales in the upcoming interval, without expanding the total supply of energy offers available for dispatch.

would be set based on marginal cost and in consideration of opportunity costs of not selling energy and other products in that interval, plus any bid adders submitted by suppliers to reflect other costs of providing the reserve.

- **Enabling Broad Participation:** Ramping reserves should be defined in technology-neutral terms to enable participation of generation, demand response, variable resources, small resources, aggregated resources, and batteries, all types of distributed resources. Distributed resources that are not currently visible and dispatchable by the ISO could need to become dispatchable on the relevant timeframe in order to provide ramping reserves. Qualified quantity could be calculated as ramp rate times ramping window and procured in MW units, but technical characteristics such as resource variability, energy limits, state of charge, and online status would sometimes reduce the qualified capability.

If developed through a process that incorporates broad stakeholder input and builds on a comprehensive foundational analysis, ramping reserves can serve a critical role in helping to manage system variability. Together, the platform of energy and ancillary services (including ramping products) can foster competition, incentivize technology advances, and cost-effectively procure essential reliability services throughout the rapid clean energy transition that we expect in New York and many other regions.

A. Experience to Date with Ramping Reserves and Related Products

The NYISO has been assessing the potential need for ramping reserve products since at least 2018, though at the time certain other reforms were prioritized as more immediate concerns and to allow more time to learn from experience in other jurisdictions.[12] The NYISO is currently proposing to revisit the need for ramping reserve products in its 2022 work plan, but the ISO has not yet proceeded with the detailed system analyses and product definitions that would eventually be needed to introduce such a product(s).[13] Several other markets that already have higher penetration of renewable resources have either already implemented or are in the process of considering ramping reserves and related products, as summarized in Table 2. The reasons for introducing ramping products varies across the regions, but have included to:

- Replace non-priced ramping constraints within multi-interval SCUC and security-constrained economic dispatch (SCED) software with a market product, so that dispatch instructions would better match resources' private economic incentives;
- Replace operations/control room out-of-market activities with a market product (e.g. practice to reserve "headroom" or monitor online responsive capacity and intervene with a reliability

[12] See NYISO, *2018 Master Plan: Wholesale Markets for the Grid of the Future*, June 2018, pp. 17-18.

[13] See NYISO, Update on Grid in Transition Related Work Plan for 2022, December 2, 2021, p. 9.

unit commitment (RUC) whenever some trigger or threshold was met, even if no ancillary service was defined to reflect that trigger);

- Bring more dispatchable supply into online status on a regular basis;
- Bring more DR and DER into the category of "visible and dispatchable" supply;
- Use a market mechanism to better align the volume of renewable curtailments with economic signals; and
- Ensure that day-ahead markets produce enough unit commitments to avoid systematic out-of-market commitments to manage net load uncertainty.

In our experience, these challenges are faced to a greater or lesser extent in most electricity markets, but the exact nature of a ramping product would need to be tailored to the unique circumstances. For example, a ramping product that aims to prevent day-ahead, post-market unit commitments will need to procure the product in the day-ahead market and consider and incorporate the operational and reliability triggers that the ISO has been relying on to proceed with out-of-market commitments. A ramping product aiming to prevent 3-hour-ahead RUC'ing will need to demonstrate that the 3-hour ramping needs are fulfilled with the product. Finally, ISOs likely will need to adjust operating procedures sufficiently to prioritize market-based procurement and build confidence in new technologies as they demonstrate capability to deliver on promised commitments.

TABLE 2: OVERVIEW OF RAMPING RESERVES AND RELATED PRODUCTS IMPLEMENTED OR UNDER CONSIDERATION

Market	Product	Direction?	Ramping Timeframe	Procurement Timeframe	Quantity Procured	Demand Curve	Offer Prices	Location-Based Procurement?
CAISO	**Implemented:** Flexible Ramping Product	Up and Down	5-minute ramping capability	15-min and 5-min markets	Quantity to serve the 97.5th and 2.5th percentile of **unexpected** ramp	Ramp-up capped at $247/MWh Ramp-down capped at $152/MWh	Opportunity cost only (no offer costs allowed)	Not currently, but management has proposed to implement nodal procurement
CAISO	**Proposed:** Imbalance Reserve	Up and Down	15-minute ramping capability	DA	**Unexpected** ramp only	Willing to pay up to constraint relaxation penalty price	Opportunity cost plus offer costs	Nodal procurement
MISO	**Implemented:** Ramp Capability Product	Up and Down	10-minute ramping capability	DA and RT	**Expected and unexpected** ramp (unexpected ramp set at +/- 575 MW)	Ramp-up and Ramp-down both capped at $5/MWh	Opportunity cost only (no offer costs allowed)	No
SPP	**Approved, Pending Implementation:** Ramp Capability-Up and Ramp Capability-Down	Up and Down	10-minute ramping capability	DA and RT	**Expected and unexpected** ramp	Based on cost of committing a fast-start resource to cure deficiency	Opportunity cost only (no offer costs allowed)	No
NYISO	**Preliminary Consideration**: Flexible Ramping Product	Undecided	Undecided	DA and RT	**Unexpected** ramp only	Undecided	Opportunity cost plus offer costs in DA, opportunity cost only in RT	Undecided
Australia	**Preliminary Consideration:** Ramping commitment market	Up and Down	30-minute ramping capability	RT	**Expected and unexpected** ramp	Undecided	Opportunity cost plus offer costs	No

Acronyms: DA= Day-Ahead. RT = Real-Time

Sources: CAISO, "Flexible Ramping Product Uncertainty Calculation and Implementation Issues," April 18, 2018, pp. 4-5; 43. CAISO, "Decision on flexible ramping product refinements proposal," Memorandum, September 23, 2020. CAISO, "Day-Ahead Market Enhancements, Second Revised Straw Proposal," July 21, 2021. MISO, "Ramp Capability Modeling in MISO Dispatch and Pricing," FERC Technical Conference on Increasing Real-Time and Day-Ahead Market Efficiency through Improved Software, June 27-29, 2016. *Southwest Power Pool, Inc.,* 172 FERC ¶ 61,027 (2020). NYISO, "Market Design Concepts to Prepare for Significant Renewable Generation," Market Issues Working Group, April 26, 2018. AEMC, "Reserve Services in the National Electricity Market," Directions Paper, January 5, 2021.

B. Maximizing the Value of Ramping Products

We offer here a generalized framework for developing a suite of ramping products that would be tailored to the needs and value proposition in a particular market, accounting for the region's unique system flexibility needs, resource mix, system value, and market design. The general purpose of a ramping reserves product is to ensure that sufficient supply (or responsive demand) is pre-positioned to meet net demand variability in future dispatch intervals. As a general matter, we recommend that the need for ramping products across intervals ranging from 10-minutes to 3-hours should be evaluated; that particular focus should be placed on opportunities to integrate flexible new technologies; and that ramping products should be procured in a co-optimized fashion alongside energy and other ancillary services using a value-based demand curve.

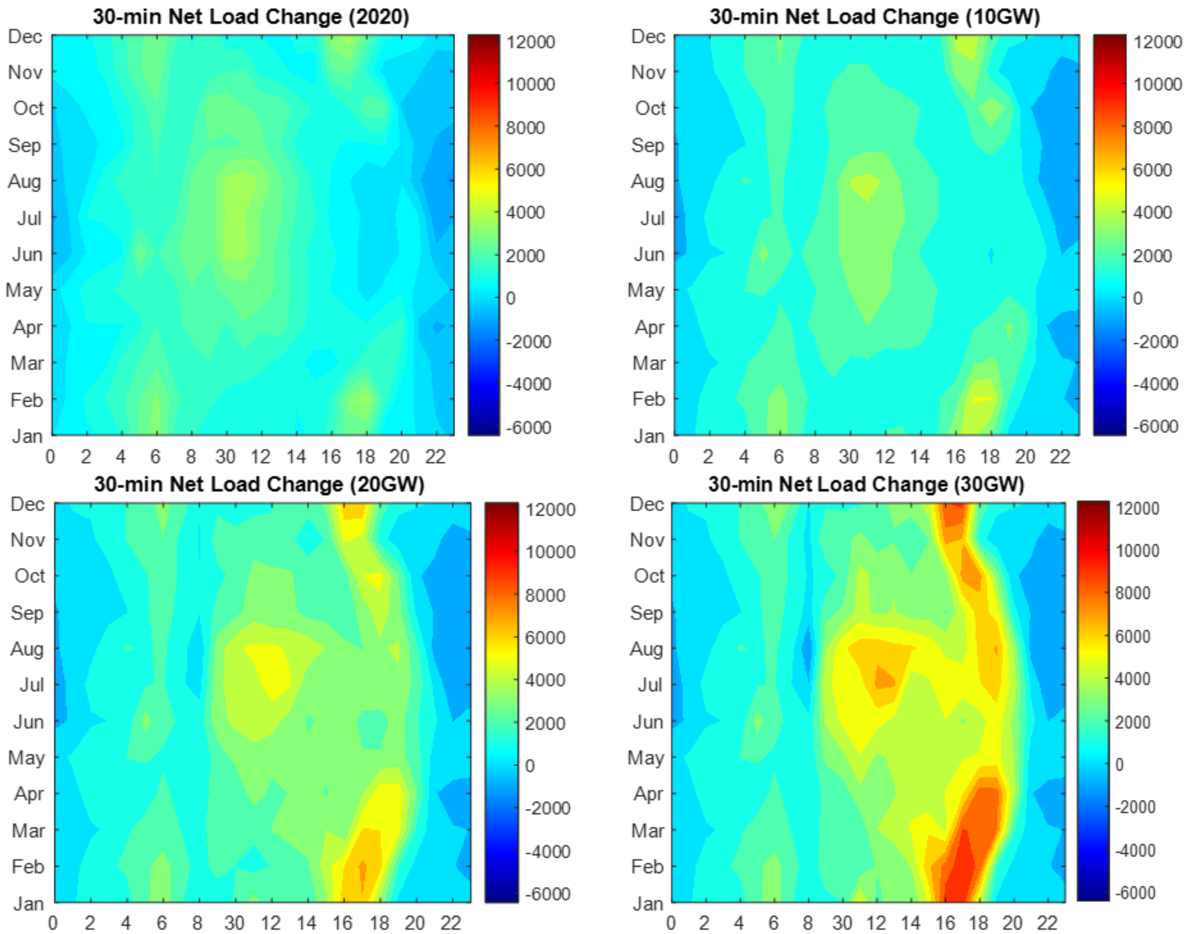
The component pieces of this recommended approach have all been implemented in some fashion, but nowhere have all of these best practices been implemented in their entirety.

B.1. Conduct Foundational Analyses to Characterize Unmet System Needs (if Any)

Determining whether ramping products are needed should be grounded in analyses of wind/solar/load variability, forecast errors, and how the existing energy market (and operator actions) can maintain supply-demand balance. The starting point is historical analysis, supplemented by simulated operations with future increases in renewable penetration, perhaps with and a broader distribution of weather patterns. Indicators of need for ramping products would be ramp-limited loss of load, meeting load but only through out-of-market operator actions, or increases in uplift payments to compensate for cycling or maintaining headroom. Characterization of the need would examine the frequency and depth of shortages and the limiting factors, such as 15-minute fast ramping and/or 3-hour sustained ramping, for example.

A recent analysis conducted by the Electric Reliability Council of Texas (ERCOT) offers an excellent example of a net load analysis that informs the scale and patterns of system ramping needs that the market will face in coming years. ERCOT staff examined the distribution of net load ramping that would be needed to avoid both curtailments and load shedding, utilizing historical load and renewable patterns, after increasing the level of renewable resources on the system. The size of net load ramps was characterized at the 10-minute, 15-minute, 30-minute, 1-hour, and 3-hour timescales, with the results of the 30-minute analysis illustrated in Figure 2 below. If the system reaches 30,000 MW of renewables, ERCOT expects that the largest 30-minute ramp over any given year would approximately double from 6,000 MW to 12,000 MW. The most significant 30-minute ramping would be observed in evenings over the winter months. ERCOT identified a different pattern of net load ramping needs across other timescales. Such analyses are the first step toward determining whether the current market design is already adequate to meet ramping needs without frequent interventions, or whether and how a new product(s) should be developed to meet those needs in the context of the energy and other ancillary services markets.

FIGURE 2: ERCOT ANALYSIS OF 95TH PERCENTILE NET LOAD INCREASES OVER 30 MINUTES AT VARYING RENEWABLE PENETRATION LEVELS (HISTORICAL, 10 GW, 20 GW, AND 30 GW)



Source: Electric Reliability Council of Texas (ERCOT), "Impact of Growth in Wind and Solar on Net Load" October 2021, p. 20.

B.2. Define Fit-for-Purpose Ramping Products

If and once unmet system needs are identified, they can be translated into a one or more ramping products. A "ramping reserve" is the quantity of scheduled supply that is currently not deployed for energy, but is available to meet increases in net demand in future intervals. Defining this need as a product requires specifying the direction, timeframe, locational specificity, duration requirements, and perhaps other characteristics.

To ensure the products are fit-for-purpose to address system needs, consider:

- **Direction:** *Ramp-up* products would be needed if the system experiences or expects to experience substantial out-of-market actions, uplift payments, and shortage events associated with steep, sustained and/or uncertain increases in net load. Multiple ramp-up products may be needed at many timeframes ranging from 10-minute to 3-hours so as to align with the timeframes needed to manage forecast errors and prevent out-of-market unit commitments (both fast-start and longer-start). Ramp-up products can help to economically pre-position the fleet to balance the cost of holding ramping reserves against the system benefit of holding those reserves; this product is likely to attract resources such as dispatchable thermal, DR, and batteries to maintain the proper volume of at-ready supply. *Ramp-down* products may be needed if a system is facing uneconomically high renewable curtailments, such as curtailments occurring at the same time that thermal generation is online and operating at minimum generation levels. A properly-defined ramp-down product will never clear at high prices (never higher than the expected value of renewable curtailments avoided), but may still provide incremental incentives for thermal resources to reduce their minimum generation levels and encourage batteries to optimize their charging profiles.

- **Timeframes:** The most beneficial product depends on a view of both system needs and fleet capabilities. Short-term ramping needs (e.g. 10-minute) are relatively modest since net load can move only so far in a short time, but they must be met by fast-ramping resources. Longer-forward timeframes (e.g. 3-hour) need more ramping reserves but can be met by less flexible resources. The longest timeframes beyond when plentiful offline resources could be activated are the easiest to serve. No reserve product is needed for longest-forward timeframes since there is ample reserve for "free," and it can be activated at later times without any action needed to reserve it at present. The system needs examined in the foundational analysis therefore should be compared to the capabilities and economics of the anticipated fleet, in consideration of the extent to which the ramping needs will be served without intervention. A combination of analysis of historical system conditions and simulations of the future system can be used to characterize the circumstances leading to shortage events, out-of-market actions/payments, and excess curtailments. Additional simulations of how the market would operate with ramping products of different timeframes can be utilized to demonstrate which products address the identified problems most cost-effectively.
- **Locational Needs:** Many markets will have certain subregions that will face greater net load variability and associated challenges than in the broader system. In these markets, the ramping reserve products can be defined on a locational basis.
- **Duration Requirements:** In some cases, particularly for longer-timeframe ramping products, the product definition will likely need to incorporate an element of resource duration. For example, a 3-hour ramping product that is needed to manage a system "duck curve" may need to include a 1-3 hour sustained output capability as part of the requirement to ensure the pre-positioned resources are capable of performing throughout the net peak load period. However, a 10-minute ramping reserve product may require only a 10-minute sustained output capability, given the rolling effect of subsequently-committed resources across intervals. The nuances of interaction between each dispatch interval and amongst products will need to be considered when establishing any such duration requirements to ensure that: (a) system ramping needs are met and can be fulfilled by the committed resources; while also (b) avoiding the imposition of excess duration requirements that would impose costs and prevent some resources from participating. Once duration requirements are established, battery resources would need to be

tracked relative to their current state of charge in order to determine their eligible capability at any moment.

These product definitions may also need an element of flexibility, particularly in regions experiencing rapid fleet transition. We anticipate that many regions will need to updated their ramping products or introduce new ones as system and locational needs evolve.

B.3. Develop Value-Based Demand Curves for Ramping Reserves

The quantity of ramping reserves needed should change every interval as a function of the current net load forecast, so that the reserves are actively supporting system needs at all timeframes and conditions. The quantity of ramping reserves needed is in two components; the sum of expected and unexpected ramping reserves would determine the volume procured at each timeframe:

- **Expected Ramping Needs to Meet 50/50 Net Load Forecast:** This portion of the ramping reserves are needed simply to ensure that the system can meet the net load forecast. This portion of ramping reserves should be set based on the current net load forecast at any given time, with the required volume being large immediately prior to a daily net load ramp and zero when system demand is declining;[14] *plus*
- **Unexpected Ramping Needs:** This portion of the ramping reserves accounts for the uncertainty band around the net load forecast according to a probability distribution in net load (load minus wind minus solar) in the relevant timeframe. The parameters of this uncertainty distribution around net load variability would likely be developed in advance in a systematic analysis of net load uncertainty, and how that uncertainty changes across times of day and seasons.

Even more so than most other ancillary services, ramping reserves should not be procured in a fixed volume regardless of price. Contingency reserves should be maintained under nearly all circumstances to ensure that the system can react to instantaneous, unpredictable outage events; in contrast, ramping shortages emerge over several intervals and can be managed with various actions including curtailments, unit commitments, and load shedding if necessary. The possibility of and value of such measures can be expressed economically, to be traded off against the costs of avoiding them, through the market. As long as the value-based ORDC is developed accurately, the procurement of ramping reserves will always enhance value to the system and ultimately to consumers. The market will optimally make that trade-off if the demand for ramping reserves reflects the willingness to pay or the marginal value of reserves. As in the demand curves for other goods, the value should be highest for small amounts of reserves, then diminishing at higher quantities.

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[14] More precisely, this portion would be negative in a period of net load decline. If the sum of the expected and unexpected net ramping needs is negative, the procured quantity would be zero.

An ORDC for ramping reserves can be developed to reflect the economic value at stake in any given market, and would account for the declining probability of lost load due to lack of ramping at each level of reserve, times the value of lost load (VOLL). This is not to suggest that prices would often or even ever clear near VOLL, as long as sufficient ramping supply is available from flexible resources, committing additional resources, and/or curtailing variable resources (as discussed under “Participation” below). The specifics of how to design the ORDC will need to be tailored to the realities of each market and defined product, but should aim to reflect the but-for cost of other out-of-market actions and out-of-market uplift payments that would be pursued in the absence of in-market ramping reserves. Though ORDCs developed to date have only considered the costs of involuntary load shedding when calculating ORDCs, it will be increasingly important to incorporate other costs such combined-cycle and fast-start resource unit commitment costs; uplift payments awarded to less flexible resources (whether dispatched by SCUC/SCED or the control room operator); non-SCED-integrated DR/DER dispatch costs; and emergency imports that may be called upon. Once these common non-market intervention costs are accounted for in the development of the most accurate ORDC for ramping reserves for a given system, we anticipate that the resulting ORDC would be relatively wide (i.e. showing positive economic value even at relatively large volumes), but with low or zero prices most of the time.

The estimated ORDC values would be developed in advance, likely using the same analysis and parameters used to characterize net load uncertainty across different seasons and times of day. The analysis would be updated annually or on some other periodic basis. The result of this analysis would be a price for ramping reserves as a smooth downward-sloping function of quantity, which could be translated to a series of penalty factors to be utilized in energy and ancillary market clearing.

The primary purpose for developing and implementing the ORDC is to reflect an in-market value-based means of paying for ramping reserves that are needed for system security so as to avoid out-of-market actions that would otherwise be taken to maintain. However, the ORDC will contribute other benefits to the system as well including to support efficient scarcity pricing that aligns with system needs, incrementally contribute to investment signals for reliability, and incentivizing emerging resources to become more dispatchable.

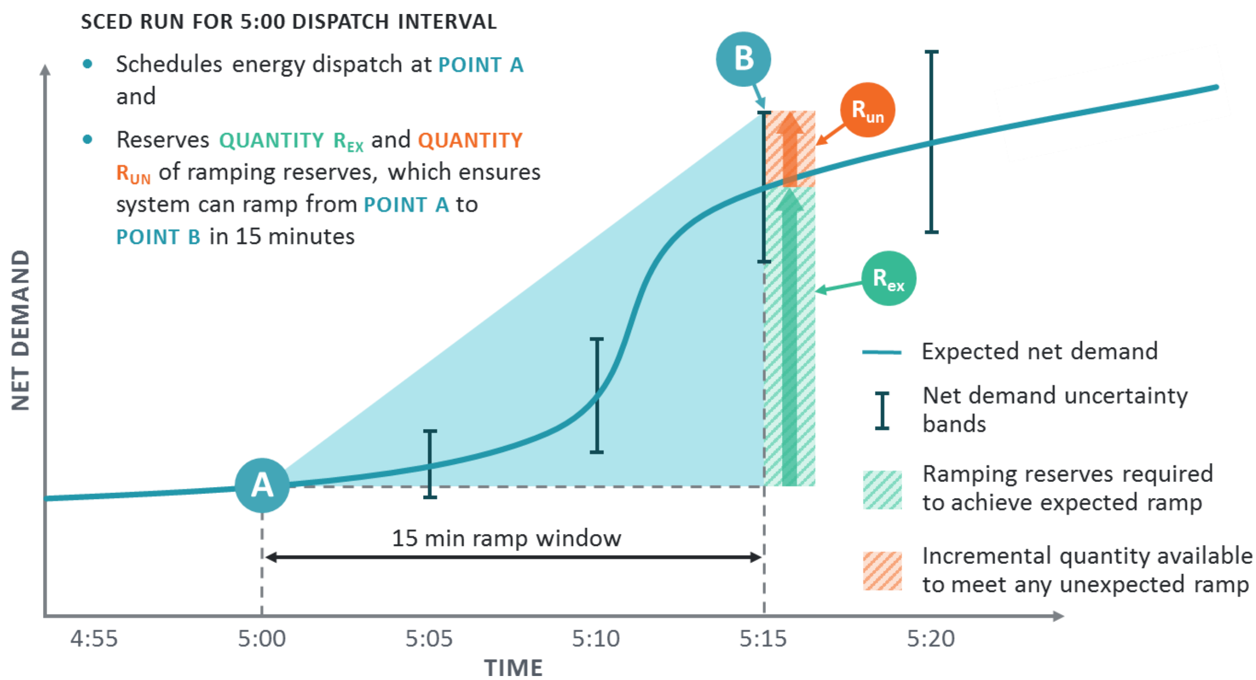
B.4. Procuring Ramping Reserves Co-Optimized with Energy and Other Ancillary Services

Ramping reserves would be procured in each hourly day-ahead dispatch interval and real-time 5-minute dispatch interval in a fully co-optimized fashion alongside energy and other ancillary services. Like other ancillary services, prices would be set based on marginal cost and in consideration of the opportunity costs of not selling energy and other products.

In the example illustrated in Figure 3, the SCED run for the 5:00 dispatch interval would schedule the energy needed to meet demand at 5:00 as well as the ramping capability that must be held in reserve at 5:00 in order to meet the energy needs 15 minutes later at 5:15. The required quantity of ramping reserves is equal to the expected demand plus an uncertainty margin at 5:15 (illustrated as point "B") minus the expected demand at 5:00 (illustrated as point "A"). Resources clearing as ramping reserves at 5:00 would take on the obligation to offer their cleared capacity into the energy market by 5:15 (but would not be obligated to necessarily clear in the energy market).

In the next dispatch interval (at 5:05), the market would again procure sufficient quantities of energy for the current interval and enough ramping reserves to meet the ramping needs at 5:20. Thus, the quantity of ramping reserves would be updated every five minutes and would always maintain a rolling window that ensures the ability to meet upcoming system needs over the coming 15 minutes.

FIGURE 3: EXAMPLE OF 15-MINUTE RAMPING PRODUCT PROCUREMENT



B.5. Enable Broad Participation

Ramping reserves should be defined in a technology-neutral fashion that enables participation of generation, demand response, variable resources, small resources, aggregated resources, electric vehicles, storage, and other DERs. In order to maximize the value of the ramping product in supporting cost-effective, reliable system transition, we recommend placing a new emphasis on ensuring that emerging resources are enabled to participate. This would include a program of pilot testing and iterative refinements to operational procedures, market rules, and controls/information systems to ensure that a wide array of emerging resources are enabled to offer their full capabilities to the system, and that the system operator can be confident in the promised supply. New ramping products will create an opportunity for more fully integrating these resources into the wholesale market and appropriately remunerating resources for that participation. Aggregated, distributed, or small resources that are currently not visible or controllable by the ISO, may become visible and controllable in order to qualify to provide these services.

The qualified quantity to sell each product will be calculated as the resource ramp rate times the ramping window and procured in MW units. Offline generation resources would only be eligible to sell ramping reserves if they are able to offer and dispatch for energy in the upcoming energy intervals. Storage resources would be eligible to participate, but only if the resource state of charge indicates the resource can fulfill the obligations to offer the required quantity of energy in future intervals (and deliver that quantity if dispatched). Demand response and DERs would be enabled to participate directly or through aggregators, but would need to meet telemetry and dispatchability requirements commensurate with the necessity of supporting system reliability at each timeframe.

Variable energy resources could qualify to sell ramp-up supply by voluntarily curtailing energy. Curtailment helps in two complementary ways: most obviously, by creating headroom to be able to quickly uncurtail and increase energy output to the extent the wind or sun might allow in subsequent intervals. And to the extent the wind or sun might decrease, the resources may provide less ramp-up supply, but their advance curtailment will have limited the loss of generation as wind/sun weaken, and thereby reduce the need for ramp-up. Thus, if the demand for ramp-up is defined based on forecast net load ramps plus a distribution of forecast errors *assuming variable resources will not be curtailed* (except to the extent caused by transmission constraints), then any curtailment they do provide could qualify as ramp-up "supply."