Markets of the Future

A RELIABILITY IMPERATIVE REPORT

Redefining Markets to Meet Changing Needs

NOVEMBER 2021

Highlights

- Drivers of change in the electricity sector require significant and urgent enhancements to MISO's markets to meet new and shifting needs, and to ensure ongoing reliability and value creation for the region

- MISO's Redefining Markets portfolio aims to advance resource adequacy reforms, integrate and optimize new and existing resources, implement new market products, and optimize load

- With a collaborative effort to quickly advance necessary enhancements, the foundational market constructs in place today – resource adequacy, energy, and ancillary reserves markets – will continue to be effective in the future

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A note from Richard Doying, Executive Vice President

Dear friends of MISO,

If you are like me, you have a stack of whitepapers a mile high on your desk or bookmarked on your tablet about the transformational change underway in the energy sector. For a system as complex as our electricity grid and energy markets, so many variables, feedback loops and interdependencies can be dizzying. That said, we cannot let it be paralyzing. Through this period of unprecedented change, it is imperative that we distill the information available to the best of our ability and keep moving forward. We must anticipate the changing needs of the region and accelerate our work to implement on-time solutions to meet the changing needs.

Throughout 2021, a cross-sectional MISO team has worked to gather and synthesize the system analyses, operational experience, and customer conversations over the last many years at MISO to do two things: (1) define and sequence the full landscape of **new and shifting needs** over time, and (2) further shape our Redefining Markets strategy to prioritize the implementation of **market solutions** that anticipate and meet the needs. The aim of this paper is to share key insights gleaned from past and current investigations and provide a conceptual framework for the work ahead – all with the important caveat that adaptability is key, and refinement will be ongoing.

I am proud that the fundamental market structure we have built at MISO over the last 15-plus years has served our customers well. I am energized by the challenging and rewarding work we are doing on **Redefining Markets** to ensure reliability and deliver lasting value for our members and region. The task is not easy, but MISO is committed to building the team and tools to support and enable the transforming energy system. Ongoing stakeholder engagement with this effort is absolutely necessary and I thank you for your partnership.

Sincerely,

Richard

Executive Summary

MISO's market vision is steadfast: to foster wholesale electric markets that deliver reliable and economically efficient outcomes. The objective of this report is to chart a transparent path forward that ensures this market vision is continually achieved amidst the rapidly changing energy landscape. MISO's conclusion is that the foundational market constructs in place today – resource adequacy, energy, and ancillary reserves markets – will continue to be effective in the future, but only with significant market enhancements and optimizations. Those enhancements are the subject of one of the four pillars of MISO's response to the Reliability Imperative, called "Market Redefinition."

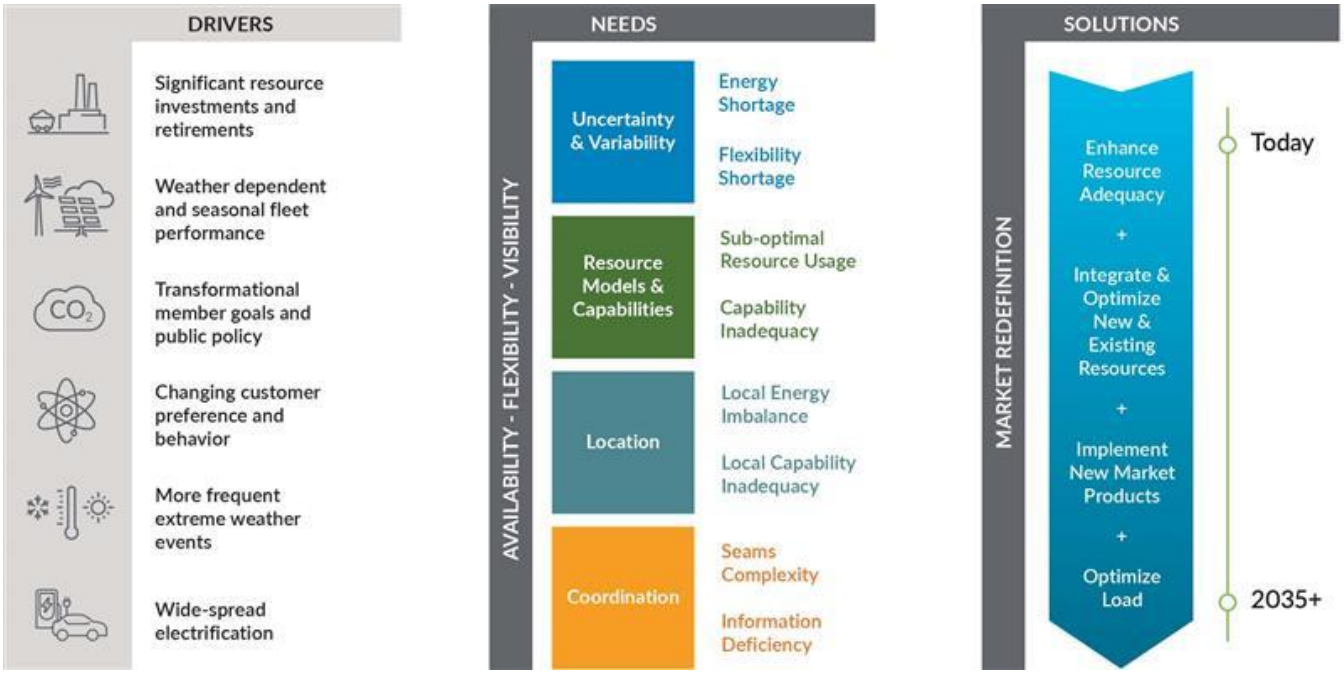

Figure 1: Accelerating drivers are transforming the electricity sector and the needs of the MISO region are changing. Market enhancements and optimization solutions are required to prepare MISO and its members to meet these new and shifting needs.

Significant investment in new renewable electricity generating resources and retirements of existing resources, more frequent extreme weather events, and outlooks for widespread electrification are among the many drivers of change for electricity markets and operators. MISO has conducted major studies and released reports over the last few years including the *MISO Futures Report*, the *Reliability Imperative Report*, the *Renewable Integration Impact Assessment (RIIA)*, *Electrification Insights Report* and the *2021 Arctic Event Report*, which further describe the implications for system performance.

With this report, MISO presents a reliability needs timeline that aims to answer the question, "What will be needed and by when?" The needs are presented in four broad categories: 1) Uncertainty and Variability; 2) Resource Models and Capabilities; 3) Location; and 4) Coordination. Near-term needs include, for example, risks shifting outside of the historic summer season peak and weather-related resource performance. Needs that emerge in later years include grid-stabilizing inertia and frequency response, and load unpredictability. The timeline will serve as a planning guidepost for work across all four pillars of MISO's Reliability Imperative: Market Redefinition; Market System

Enhancement; Long Range Transmission Planning; and Operations of the Future. The goal is to advance a shared understanding of the changing system needs and to demonstrate the urgency of the work ahead.

The paper also puts forward a conceptual framework for market enhancements that anticipate and meet the changing needs, providing a long-range view of the Market Redefinition work that is part of this Reliability Imperative. At a high level, the portfolio targets four primary market outcomes:

Enhance Resource Adequacy: As new resources bring new capabilities and challenges to the resource mix, further enhancements to the Resource Adequacy (RA) construct are needed to ensure long-term resource adequacy and real-time resource availability. This work is underway with the Resource Availability and Need (RAN) program, and includes transitioning to a seasonal Resource Adequacy construct and aligning how resources are accredited with their availability in the highest risk periods to ensure resources are available when needed most. The long planning horizon for members' investment and retirement decisions warrants leaning into this work today. The increase in maximum generation emergency events in recent years provides a reminder of the urgency.

Integrate and optimize new and existing resources: Enhancements to MISO's resource participation models are needed to realize the full advantages of increasingly complex resource capabilities and emerging transmission technologies. The Electric Storage Resource participation model will be available for registration in June 2022. Further enhancements are underway to enable Demand Response Resources to contribute more meaningfully, and to realize the flexibility benefits of combined cycle gas generators. Work to integrate new technologies is advancing through MISO's stakeholder forums. Beginning in 2025, with the Market System Enhancement (MSE) initiative complete, MISO will have the capability needed to more efficiently implement these advancements.

Implement New Market Products: Work to enhance existing products and design new market products will be an ongoing priority. The launch of the Short-Term Reserve product, work to adapt reserves and ramp, and pricing reforms will advance in the near-term to meet the increasing flexibility need. By the late 2020s, MISO anticipates additional ancillary service market products may be needed to address growing variability and stability needs due to retired coal generation resources and potentially significant changes in demand. The analysis, design, and approval process for new market products can take several years. MISO will initiate these efforts well in advance of the implementation need.

Optimize Load: As the load becomes more digitalized, responsive and actively managed, and as the energy production becomes more variable and uncertain, there will be an opportunity and need for "load side" resources to actively participate in the MISO market. Optimizing load participation in the market has the potential to increase visibility, create access to new sources of grid services, reduce energy costs, and increase reliability. Seizing this opportunity will require deliberate collaboration with MISO's members, states, and other stakeholders to foster new ways of thinking about the relationship of supply and demand.

Ongoing assessment and further study will be necessary as technologies advance and drivers of change continue to shape the future. Numerous external factors could impact the timing of new and shifting needs and, therefore, alter the priority and timing of markets solutions. This push-pull is unavoidable. Success is in building a collective understanding of the future needs of the MISO region, enhancing visibility into the plan for change, and engaging with the stakeholder community for continued design and implementation of enhanced market solutions to ensure system reliability and value creation for the region.

The Role of Markets in Addressing the Reliability Imperative

Simply put, electricity markets aim to provide reliable electricity at least cost. MISO's Market Vision[1] identifies five principles that steer MISO's market development toward meeting that objective: 1) Support an economically efficient wholesale market system that minimizes cost to deliver electricity; 2) Facilitate non-discriminatory market participation regardless of resource type, business model, sector or location; 3) Develop transparent market prices reflective of marginal system cost and cost allocation reflective of cost-causation and service beneficiaries; 4) Support market participants in making efficient operational and investment decisions; and 5) Maximize alignment of market requirements with system reliability requirements.

From its inception in 2000, MISO and stakeholders have progressively worked to build, piece by piece, the MISO markets, products and participation models that exist today. Last year's *Redefining Energy and Ancillary Services Markets* report provides a brief history of the four broad MISO markets – the Resource Adequacy Construct, Financial Transmission Rights, and Day-Ahead and Real-Time Energy and Ancillary Services Markets. Within these markets, energy and other market products, such as regulating reserves and contingency reserves, are procured and settled to meet the needs of each operating horizon (*see Appendix Table A.1*). Other key market coordination tools include non-market reliability processes (*see Appendix Table A.2*) and resource participation models.[2] Each market component has been added or enhanced as the needs of the system have changed.

MISO's analyses as part of this report shows that the foundational market constructs in place today will continue to be effective in the future, but only with significant market and operational enhancements and optimizations. And while improving the markets is nothing new, the pace and scale of anticipated change is unprecedented. Meeting the objectives of MISO's Market Vision will require a longer-term strategy, improved transparency, and sustained engagement from the MISO stakeholder community. This urgent work makes up the Market Redefinition pillar, part of MISO's Reliability Imperative.

[1] MISO, "Developing a Market Vision for MISO," January 27, 2014.
[2] MISO, "Business Practice Manual 001, Market Registration, Section 4.2.3.".

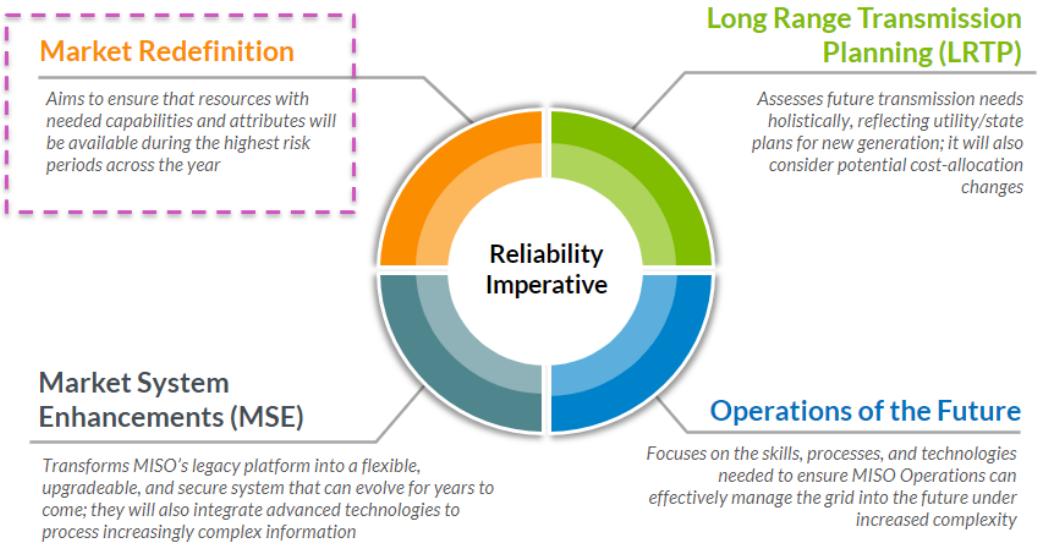

Figure 2: The four pillars of the MISO Region's Reliability Imperative, including Market Redefinition which is the focus of this report.

Success in **Market Redefinition** depends on simultaneous progress across each of the other Reliability Imperative efforts. These key interdependencies are important to understand as MISO and stakeholders chart a path forward:

Market System Enhancement (MSE): As a crucial technology enabler, this strategic priority updates MISO's market platform technology and drives elements of the sequencing and timing of the Market Redefinition workstream, particularly in the near-term years of transition from the old to new market systems. Once in place (targeting 2024), MSE will enable MISO to meet new technology demands, improve computational performance, and reduce the complexity of implementing market enhancements in the future.

Long Range Transmission Planning (LRTP): Transmission is vital to moving electricity from where it is generated to where it is needed. Locational needs and deliverability are where markets and transmission planning intersect. In a scenario constrained by transmission, there is risk that areas with inadequate transmission (load pockets) must rely on local generation to maintain system reliability. This reliance on local generation is dependent on market mechanisms like locational reserve margins and scarcity pricing. In a scenario with more transmission and wider deliverability, energy and ancillary services can be shared more broadly, reducing the risk of overbuilding generation and lowering the system's reliance on complex market mechanisms. Striking the right balance is key.

Operations of the Future: Operations and markets are two sides of the same coin, functioning in tandem to achieve efficient reliability. Markets enable efficient day-ahead and real-time operations, signaling the value of generation and load to the system through price variation. In both normal operations and emergencies, a well-designed market provides operators with effective tools to incent behaviors that swiftly normalize system conditions.

The Reliability Imperative report and accompanying MISO Roadmap (to be published early 2022) provide an organization-wide view of MISO's many interconnected efforts to meet the changing needs of the region.

Building upon MISO Insights and Analyses

Many researchers, policy makers, and markets experts are focused on the complex transformational change ahead for the power sector. MISO's staff, members and other stakeholders are among those experts – working together to forecast and prepare.

Drivers of change: The first *MISO Forward* publication highlighted three global trends poised to transform the electric power industry: De-marginalization, Decentralization and Digitalization. The follow-on MISO Forward reports drilled down on the nonuniform drivers and diversity across the MISO membership and extended to drivers of adjacent sectors. These trends are materializing in members' resources plans and are increasingly being codified in decarbonization goals. Customer preferences and behavior are driving technology development and changing load shapes. More frequent extreme weather events have exacerbated weather-dependent and seasonal fleet performance, threatening grid reliability. Research and strategy teams, both internal and external to MISO, work to understand these trends and prepare for the potential impact to the MISO region and system.

Futures Scenarios: MISO uses a set of future scenarios to plan for changes across Planning, Operations and Markets. Through collaborative stakeholder engagement, the MISO Futures[3] were created to bookend a range of possible future resource outlooks. This set of scenarios provide reference points for the timing of needs and solutions outlined in this report.

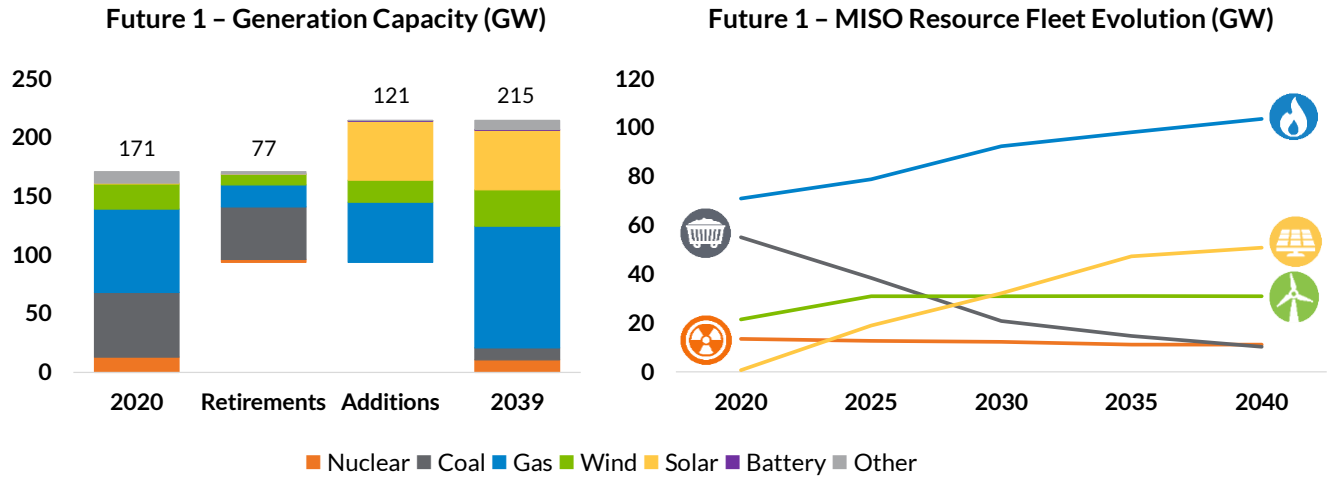

Figure 3: On the left, the generation capacity and fuel mix of the Future 1 scenario of the MISO Futures. On the right, the pace of Future 1 fleet change over time. Future 1 is the lower planning bookend; slowest pace and least load growth.

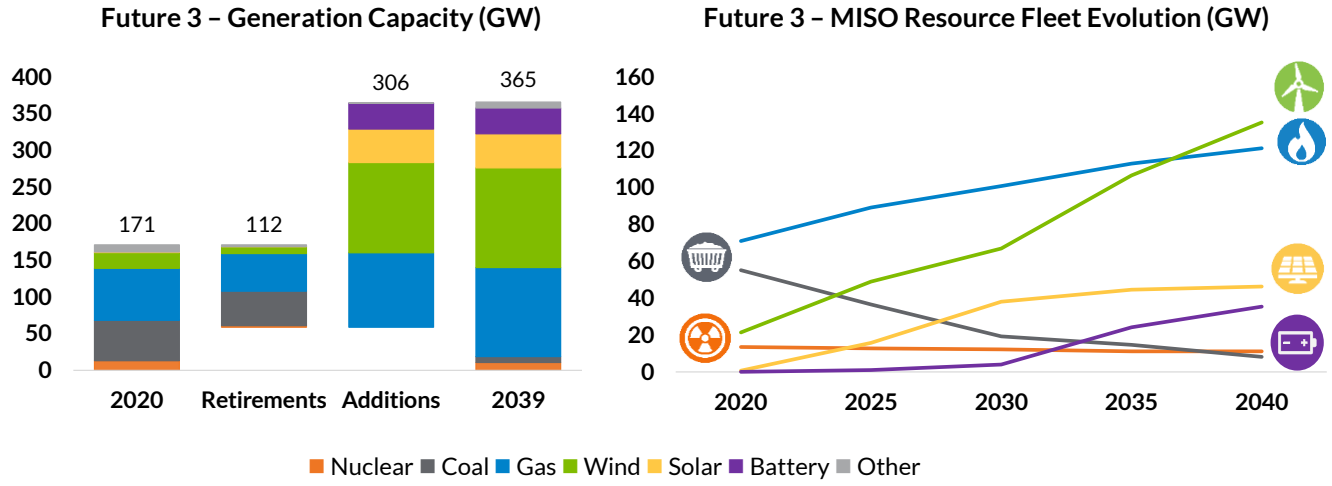

Figure 4: On the left, the generation capacity and fuel mix of the Future 3 scenario of the MISO Futures[3]. On the right, the pace of Future 3 fleet change over time. Future 3 is the higher planning bookend; fastest pace and most significant load growth. The Future 2 scenario (not pictured) is in the middle.

The MISO Futures share a few common themes; significant retirement of the aging coal fleet across the region, steady growth of wind and solar resources, and needed availability and flexibility (provided in the models by natural gas capacity). Where the Futures most differ is the pace of fleet change and load growth. Future 3 models significant electrification and has much higher capacity values (GW) than Future 1 as shown in Figures 4 and 3 respectively. The mix of wind and solar is highly dependent on economic assumptions and the growth of new technologies, such as battery storage, is uncertain.

System Needs Analyses: MISO has performed in-depth analyses on fleet change and system performance over the last few years, including the *Renewable Integration Impact Assessment (RIIA)*, modeling efforts through the many phases of the *Resource Availability and Need (RAN)* effort, and this year's first Regional Resource Assessment (to be published later this year), which looks at resource adequacy and flexibility considerations. MISO's post-event analyses following extreme weather events (e.g., Hurricane Laura and the 2021 Arctic Event[4,5] and the increasingly frequent occurrences of resource shortages during typical conditions, give recent historical context. All these collectively inform this report's framing and priority.

Customer Insights: The paper also benefits from stakeholder engagement and discussions, including targeted outreach conducted as part of this effort to capture insights and timeline considerations from the customer perspective. Consistent themes include the need for more granular time and location data visibility, future system needs and gaps, improved forecasts, more support in resource planning, engagement across the seams, and adaptable market products and pricing signals to optimize investment in new technologies.

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[3] Expansion results reflect MISO, "Correction to MISO F2/F3 EGEAS Resource Expansion," October 13, 2021.
[4] MISO, "The February Arctic Event, February 14-18, 2021, Event Details, Lessons Learned, and Implications for MISO's Reliability Imperative," September 15, 2021.
[5] FERC and NERC and Regional Entity Joint Staff, "February 2021 Cold Weather Grid Operations: Preliminary Findings and Recommendations; FERC, NERC and Regional Entity Joint Staff Inquiry," September 23, 2021.

Categories of Needs

The *Redefining Energy and Ancillary Services Markets* paper introduced four categories of need which bridge to this report: **Uncertainty and Variability** considers new and growing risks, spotlighting energy and flexibility shortages; **Resource Models and Capabilities** considers the optimal use of resources and their inherent capabilities; **Location** examines regional differences and transmission limitations; and **Coordination** explores complexity along the seams (bulk power system *and* transmission-distribution) and information needs to enhance collaboration and visibility.

Figure 5: Broad to narrowing categories of system and customer needs (left two columns) alongside high-level descriptions of related opportunities and risks (right two columns).

Reliability Needs Timeline

Having gathered insights from MISO's modeling, Futures analyses, operational experience and customer conversations, the objective of this report is to create a holistic view of emerging and shifting needs and approximate the time remaining to advance solutions. The reliability needs timeline, shown in Figure 6, displays each of the identified future needs by category; the placement (left side of the word) on the timeline illustrates the estimated timing of emergence or significant shift.

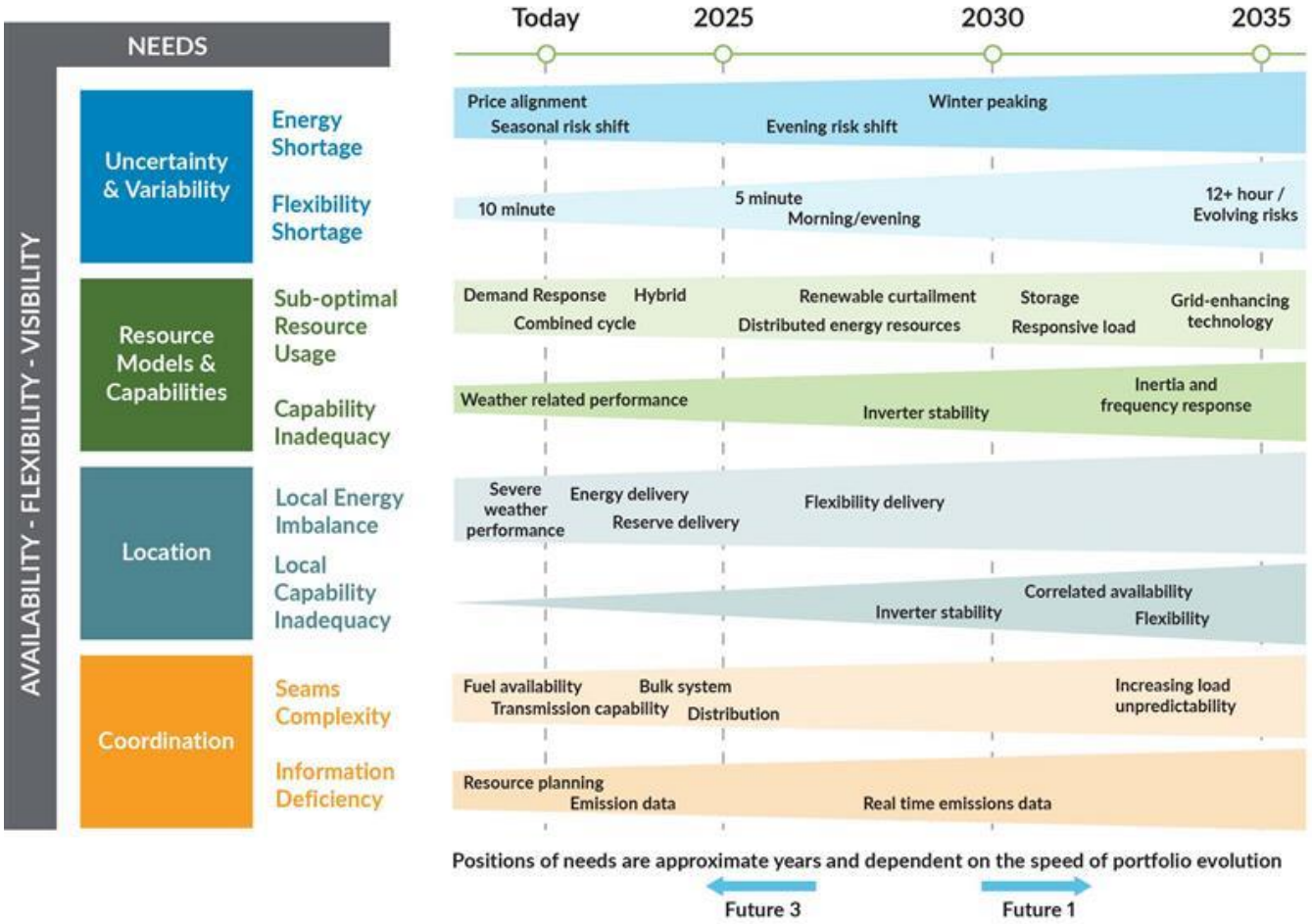

Figure 6: Future needs by category and estimated timing of emergence or significant shift in need for the region. Expanding colors are illustrative of relative size of aggregated category risk over time. Future arrows indicate potential shift in timing depending on the pace of change.

The pace of portfolio change will impact the timing – faster fleet change or adoption of new technologies will pull the needs into earlier years; a slower pace will push them further into the future. Each need presented on the timeline is explained in detail in the subsections that follow.

Needs: Uncertainty and Variability

The Uncertainty and Variability category considers extreme weather events, increasing short-term uncertainty, seasonal and diurnal patterns of renewables, load characteristic changes due to electrification, and digitalization. Tight margin periods will become more difficult to predict and manage, and then shift to new seasons and new times of day. Generation performance will be increasingly correlated with load, weather and other generators (e.g., the setting sun impacts the entire solar fleet). Absent enhancements to existing capabilities, ramping shortages will become routine, and intense. Resource Adequacy processes may not fully recognize the varying capability of resources throughout the day and year. Day-ahead processes may not fully predict the inter-hour variability. Operational complexity will grow in both day-ahead and real-time, requiring expanded visibility to manage the grid successfully.

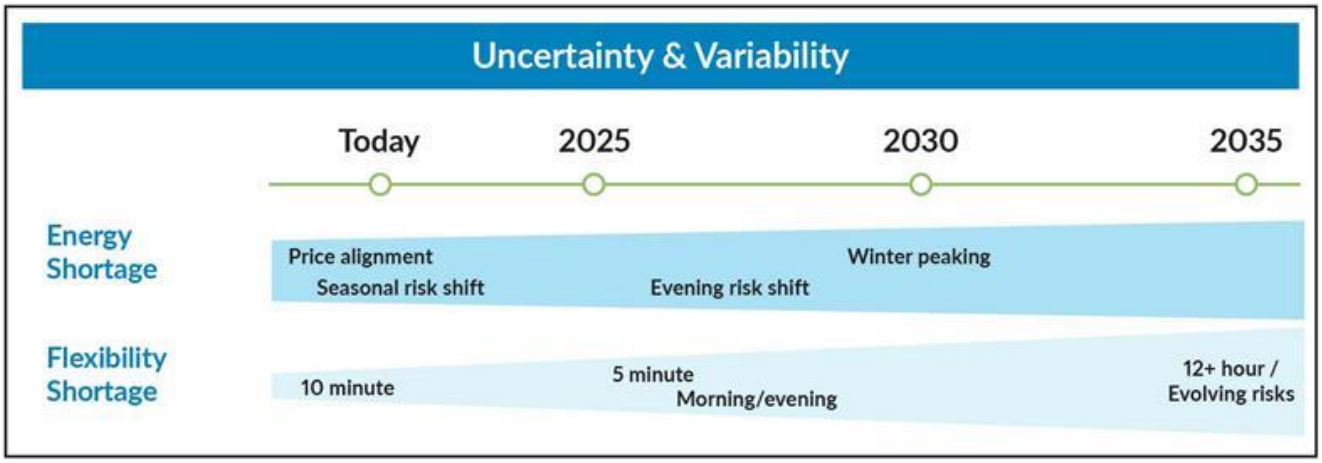

Figure 7: Reliability needs related to uncertainty and variability as they emerge or significantly shift over time. Each need is described in the paragraphs that follow.

ENERGY SHORTAGE

Price alignment: Accurate and timely price signals reflecting underlying conditions are needed to efficiently signal and garner responses to shortages. Effective pricing of scarcity and shortage conditions can be complicated by uncertainty in forecasted conditions, the onset of emergency rules, curtailing load, deploying emergency resources, and out-of-market actions to ensure reliability. These complexities can inadvertently lead to lower or oscillating prices during scarcity conditions.[6,7] For example, curtailing load to

"Always start with shortage pricing. The issue always boils down to delivering energy reliably. Shortage pricing is a fundamental price signal: it is based on the expectation that energy might not be provided when and where it's needed under current conditions. It is key because the frequency and causes of shortage conditions is likely to change as the system evolves over the next decade."

Dr. David Patton
President, Potomac Economics
MISO's Independent Market Monitor

[6] MISO, "Scarcity Pricing Evaluation," May 2021.
[7] MISO, "Emergency Pricing Evaluation," September 2020.

maintain system balance and restore reserves will lower system demand, suppressing prices associated with demand curves and the highest resource offers.

Seasonal risk shift: Risk is shifting from the summer months to spring, fall, and winter. This shift is driven by outage scheduling practices and will be accelerated by the growth of solar generation and expected electrification trends in the coming years.[8, 9] Studies show that some new periods of risk will emerge in winter.[9] Effective outage coordination and levels of capacity surplus also have an impact on risk patterns. Since 2016, MISO has declared significant numbers of grid emergencies in all four seasons, with a majority occurring outside of summer.[8]

"Ramping capabilities will be crucial to flexibility due to the substantial amount of renewable generation coming on."

Nick Detmer,
Director of Market Operations & Analytics,
Xcel Energy

Evening risk shift: Availability and flexibility needs will increase in the evening hours. As the proportion of solar generation increases, MISO's period of highest loss-of-load risk may shift from afternoons to evenings (especially during summer will concentrate the risks in a shorter and the net-load peak will move to later in the day.[10] Additionally, electric vehicle charging could broaden the summer evening hours with highest risk.[8]

Winter peaking Risk of loss-of-load events in the winter will increase due to a confluence of factors. FERC and NERC report that four cold weather events have jeopardized reliability in the past ten years.[11] The risk is increasing for loss-of-load events in winter, caused by heating loads competing with gas generation, coupled with low seasonal solar generation and low wind generation on calm, cold days.[9] Electrification of heating creates a new winter peak load that drives an even larger loss-of-load risk on winter mornings.[8]

FLEXIBILITY SHORTAGE

10-minute: More resources that can ramp-up quickly enough to deliver power within 10 minutes are needed. MISO is already experiencing occasional shortages of ancillary services that are caused by a lack of flexible resources. rather than transmission outages. Existing market products are being adjusted to address the current shortages, and more changes may be necessary as the magnitude or frequency of shortages grows with renewable penetration. Extreme 15-minute net-load ramps caused by generation variability will increase in the future.[7] MISO's RIIA Summary report shows the number of generators dispatched to their ramp-rate limits will increase significantly at sunset and variability and uncertainty could cause real-time capacity or reserve scarcity.[9]

[8] MISO, "Aligning Resource Availability and Need," December 2019.
[9] MISO, "MISO Electrification Insights," April 2021.
[10] MISO, "Renewable Integration Impact Assessment (RIIA) Summary Report," February 2021.
[11] FERC and NERC and Regional Entity Joint Staff, "February 2021 Cold Weather Grid Operations: Preliminary Findings and Recommendations; FERC, NERC and Regional Entity Joint Staff Inquiry," September 23, 2021.

5-minute: Fast ramping resources that can ramp quickly enough to deliver power within 5 minutes also will be needed. With more solar generation, energy variations on the grid on days with scattered cloud cover will increase inside of the five-minute interval of dispatch solutions.

Morning/evening: Increased morning and evening ramp capabilities will be needed to effectively manage changes in net load during the morning and evening hours. These larger daily swings in net load will be driven by both solar generation and electrification. High penetrations of solar generation increase need for other resources to quickly ramp down in the morning as the sun rises (providing more energy to meet the increasing. load need). In both morning and evening, non-solar resources will need to adjust quickly to maintain balance, may start and stop more often and may receive more commitments by operators ahead of ramps. As an example, the California Independent System Operator (CAISO), which has significant solar penetration, has sufficient ramping capability to meet its evening ramp but is sometimes constrained by minimum downtimes and startup times.[12] To respect these physical parameters, some generators may be kept online during the day, leading to negative wholesale prices in the mid-day and the potential for out-of-market make whole payments.

12+ hour / Evolving risks: Net load ramps across 15-minutes to 8-hours caused by variability of renewable generation will be significantly larger in the future.[13] The largest ramping needs in the future could be 40 to 150% larger than today, partly driven by electrification of heating and transportation.[14] Weather-dependent resources will create large multi-day power swings under certain weather patterns. This effect increases as wind and solar account for higher portions of the energy mix. In RIIA's predictive models, the largest continuous ramping period shifted from 12 hours to 16 hours under the 40% renewable scenario.[15] More study is needed to determine: (1) how generation forecast uncertainty affects ramping needs; and (2) what mix of future resources will have sufficient ramping capability to meet those needs.

Needs: Resource Models and Capabilities

The Resource Models and Capabilities needs are driven by increasing weather dependence of the resource fleet, emerging resource technologies with new operational characteristics (e.g., storage and distributed energy resources), electrification, and evolving transmission technologies. Resource capabilities, such as dynamic voltage support, frequency response, and ramp, become scarce as thermal generators retire. Adapting the resource models to reflect resource capabilities, costs and constraints will increase optimal resource usage in day-ahead and real-time. Supporting processes like load forecasting, outage coordination and fuel supply management will need to adapt as new technologies and capabilities are incorporated into MISO's markets.

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[12] CAISO, "2020 Annual Report on Market Issues & Performance," August 2021.
[13] MISO, "Aligning Resource Availability and Need," December 2019.
[14] MISO, "MISO Electrification Insights," April 2021.
[15] MISO, "Renewable Integration Impact Assessment Finding integration inflection points of increasing renewable energy," November 28, 2018.

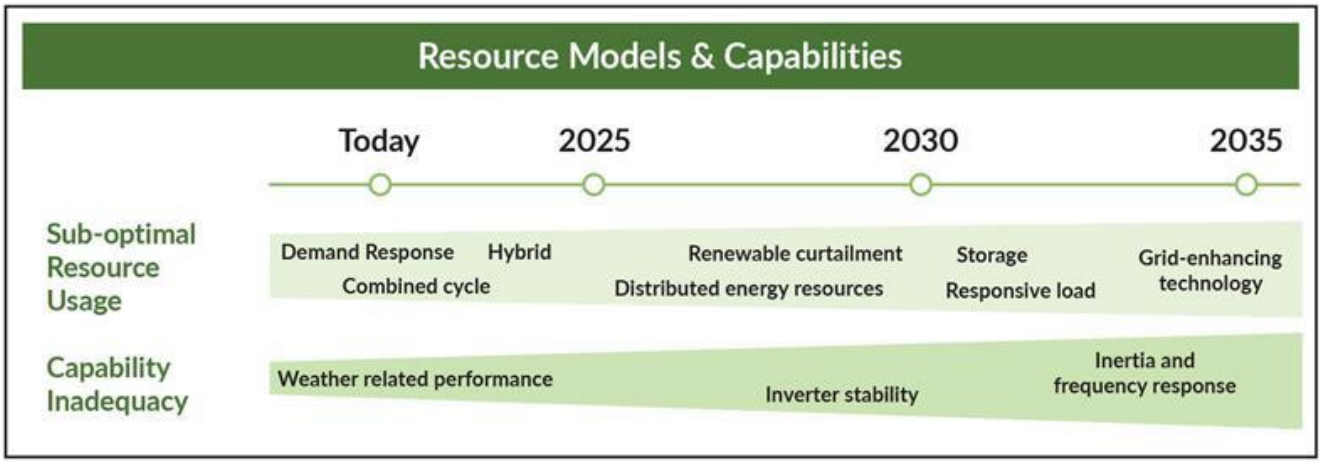

Figure 8: Reliability needs related to resource models and capabilities as they emerge or significantly shift over time.

SUB-OPTIMAL RESOURCE USAGE

Demand Response (DR): Load Modifying Resources (LMRs) have grown in share of total planning resource capacity, but the majority of DR today provides emergency-only services. Updates to LMR accreditations based on notification times and call limits are in progress.[16] Further transparency regarding both DR and LMR locations and outages is needed for reliability, to increase their potential value, and to remove barriers for market participation.

Combined Cycle: MISO Futures indicate continued growth of gas combined cycle resources. Better representing transitions between combined cycle operating configurations in MISO's commitment and dispatch could reduce annual production costs by $14 to 34 million[17] Emerging multi-configuration technologies (e.g., hybrids or aggregated distributed resources) could also potentially be used more efficiently with optimized configurations.

Hybrid / Distributed Energy Resources (DER) / Storage: Interest in MISO's generator interconnection queue indicates that the installed capacity of storage and hybrid (primarily solar and battery) resource will rapidly increase to several gigawatts (GW) in the next five years. Further, DER installed capacity has been rising steadily. As penetration of these technologies grow, forecasting processes may need to anticipate charging/discharging drivers for market participants with storage or hybrid assets. MISO is also exploring market participation options for storage developed as a transmission-only asset when it is not needed for system reliability. Ultimately, MISO markets must adapt to fully reflect the capabilities, costs and limitations of newer resources.

Responsive load: The falling cost of communication and control technologies is leading to digital controls being installed on customer load which could enable many loads to be dispatched to provide grid services. Dispatchable loads can shave (reduce demand), shift (move demand to lower cost hours) or shimmy (controllable loads that can instantaneously adjust to help meet the power balance). Responsive loads could potentially bid significant amounts of dispatchable grid services into the market but may have forecasting and state-of-charge challenges. If responsive

[16] MISO, "2021-22 Seasonal Readiness Presentation," October 26, 2021
[17] MISO, "MISO Enhanced Combined Cycle White Paper I Research and Development Report," January 31, 2018.

loads respond to price but do not participate in the wholesale market directly, this limited visibility may require MISO to infer their changing sensitivity to price in order to maintain power balance.

Renewable curtailment: High levels of curtailment, due to system constraints and oversupply, create an optimization need. In June 2021, an average of 2,361 MW of MISO wind resources were curtailed during the off-peak hours.[18] When renewables penetration reaches 30%, large amounts of renewable generation are anticipated to be curtailed to keep needed resources providing necessary ancillary services online and manage congestion on the transmission system.[19] With increasing investment in renewable resources, curtailment becomes a risk to market efficiency.

Grid-enhancing technology: Improved visibility and control of the transmission system through grid-enhancing technologies and optimization will be needed. As an example, opening or closing transmission lines can moderate power flow capability. Power flow control devices have a similar effect by limiting flow through individual lines. While there are important near-term use cases for these technologies advancing today, broad application and automation will add complexity to market optimization and require significantly more computing power to solve quickly enough for daily operations. As the magnitude, distance and variability of power transfers grows, so will the need to utilize this type of emerging technology.

CAPABILITY INADEQUACY

Weather-related performance: Resources may lack the ability to perform as needed in extreme weather conditions, in some cases due to lack of winterization investment (e.g., freezing equipment/fuel, overheating). In February 2021, extreme cold demonstrated that some generators are not sufficiently "winterized" to operate at very low temperatures.[20] Thermal generators, wind turbines, and transmission lines were affected by ice accumulation and low temperatures limits. FERC, NERC, and regional staff performed an investigation finding that freezing issues and fuel supply were the main causes of generation outages and derates with natural gas contributing to 87% of fuel supply issues.[21] Extreme cold in 2019 caused approximately 10 GW of generator forced outages—mostly wind and gas.[22]

Inverter stability: Current inverter technology lacks the ability to maintain grid stability at high penetrations and grid-following inverters can cause stability challenges in weak grid areas with 30% renewable penetration.[23] The typical grid-following inverters may disconnect from the grid or operate unreliably after faults. Inverters can also cause low-frequency undamped oscillations of real or reactive power. Tuning the inverter control parameters can

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[18] MISO, "Informational Forum (IF) - July 20, 2021," July 20, 2021.
[19] MISO, "Renewable Integration Impact Assessment (RIIA) Summary Report," February 2021.
[20] MISO, "The February Arctic Event, February 14-18, 2021, Event Details, Lessons Learned, and Implications for MISO's Reliability Imperative," September 15, 2021.
[21] FERC and NERC and Regional Entity Joint Staff, "February 2021 Cold Weather Grid Operations: Preliminary Findings and Recommendations; FERC, NERC and Regional Entity Joint Staff Inquiry," September 23, 2021.
[22] MISO, "MISO January 17-18 Maximum Generation Event Overview," February 8, 2018.
[23] MISO, "Renewable Integration Impact Assessment (RIIA) Summary Report," February 2021.

mitigate some challenges, but control parameters may need to be re-tuned as conditions change. While inverter technology is advancing quickly, additional transmission, more online headroom and grid stabilizers (e.g., synchronous condensers) will be needed to mitigate inverter stability.

Inertia and frequency response: As inverter-based generators displace thermal generators, MISO may face challenges with inertia and primary frequency response.[22] Frequency response in MISO may not be stable above approximately 40% interconnection-wide renewables penetration.[22] More online headroom or a fast frequency response product may be required to maintain primary frequency response, especially when few conventional generators are online. Inverter-based resources can provide fast frequency response but cannot sustain it without a reserve of power. Note: the need for inertia and frequency response depends on the entire Eastern Interconnect resource mix because the frequency is the same throughout. The timing of this need will depend on portfolio changes throughout the Eastern Interconnect.

Needs: Location

The Location category of needs is driven by regional portfolio changes and the associated increasing interdependence among resources and changing transmission usage. Depending on location, congestion may increase and become more variable and less predictable. Over time, local ancillary service shortages are expected to increase in size and frequency and resource evolution may not provide capabilities where needed. Furthermore, locational needs will span both transmission and distribution. With DER participation in the market, delivery dependence on the distribution grid will increase. Improved visibility and simulation capability will be needed to manage local delivery risk. Coordination with electric distribution companies will be needed, consistent with MISO's role as FERC defined under Order 2222.

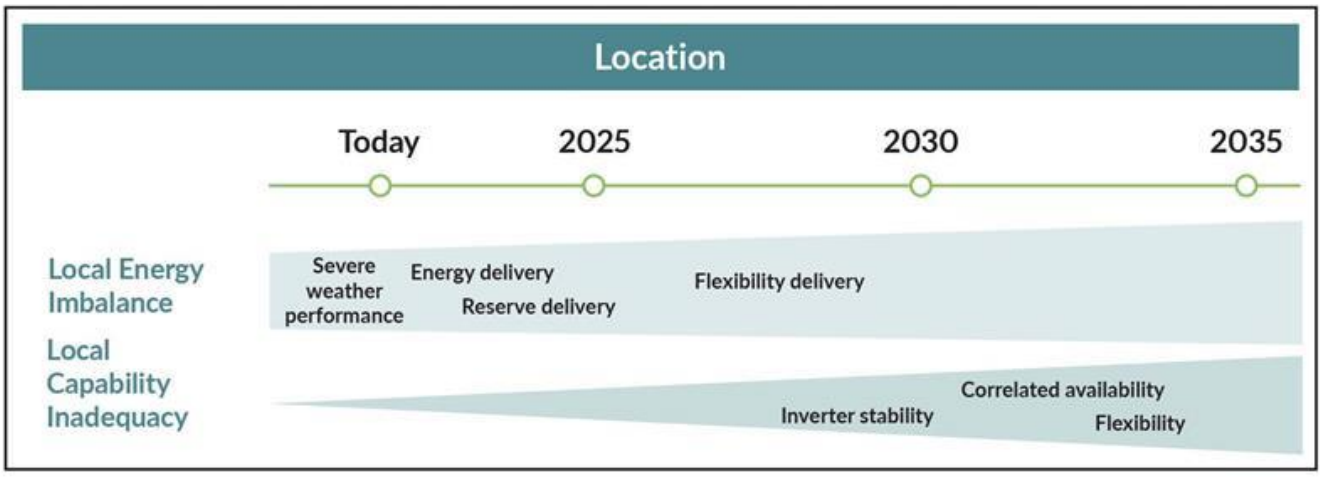

Figure 9: Reliability needs related to location as they emerge or significantly shift over time.

LOCAL ENERGY IMBALANCE

Local severe weather performance: Resources experiencing severe weather conditions may perform below their full capacity during times of high demand. Hot and cold weather conditions can cause mechanical failures or de-

rating of generators, including inverter-based resources.[24] For example, during the 2021 February Arctic Event, MISO had approximately 21 GW of gas-fired generation capacity unavailable for dispatch due to weather-related gas restrictions.[25] MISO's analysis[26] and an analysis in an academic study of PJM data[23] show that the correlations between generator forced outages are significantly higher in extreme hot and cold weather than in typical weather could put stress on sub-portions of the MISO footprint. As part of ongoing RAN Resource Adequacy reforms, MISO is enhancing sub-annual Resource Adequacy modeling for outages to better reflect seasonality of outages and correlation with extreme temperatures. Additional work will be needed to enable a more accurate representation of reliability risks throughout the year.

Local energy delivery: Available transfer capacity is needed to serve local load when local resources are unavailable. MISO's *2021 February Arctic Event* report describes the impact of losing transmission lines that serve an import-constrained local area. Local generation losses can lead to the potential overload of the remaining lines, depressed voltage due to overloads and instability in the load pocket. If energy cannot be delivered, load in the area must be curtailed or will depend on price responsiveness to maintain stability. Furthermore, increased variability and uncertainty from the new resource portfolio could increase the difficulty of predicting and managing congestion patterns.

Local reserve delivery: Available transmission is needed to deliver reserves to meet local needs. Delivery of 30-minute headroom and reserves will be challenged by 40% renewables penetration.[27] At smaller penetration levels diversity between wind and solar helps mitigate issues, once 40% renewable penetration is reached additional delivery challenges were revealed. MISO's current process incorporates zonal reserve deliverability in the energy and reserve co-optimization. Similarly to local energy delivery, extreme conditions can impede the delivery of reserves. The local transmission system will need to have enough capacity to deliver reserves to the local area. Market formulations that account for locational constraints will be needed to efficiently deliver reserves to where needed, even if grid topology changes.

Local flexibility delivery: The RIIA Summary report shows that if no new transmission is built, some needed 10-minute ramp capability product may have "delivery challenges" at 40% renewable penetration (half of it solar).[27] The transmission system was not designed to enable regional balancing and is limited in its ability to support these very high penetrations.[27] Local generation flexibility needs will greatly increase, relying on market formulations that account for deliverability constraints and the high voltage transmission system to enable regional transfer and balancing.

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[24] S. Murphy, F. Sowell and J. Apt, "A time-dependent model of generator failures and recoveries captures correlated events and quantifies temperature dependence," 2019.
[25] MISO, "The February Arctic Event, February 14-18, 2021, Event Details, Lessons Learned, and Implications for MISO's Reliability Imperative," September 15, 2021.
[26] MISO, "Resource Availability and Need (RAN) Workshop: MISO Technical Paper Conditional Forced Outage," June 30, 2020.
[27] MISO, "Renewable Integration Impact Assessment (RIIA) Summary Report," February 2021.

LOCAL CAPABILITY INADEQUACY

Local inverter stability: Local stability risks emerge due to high volume of inverter-based resources sited in the same local areas. As inverter-based renewable generators replace thermal generators, MISO will face voltage-stability challenges, especially in weak-grid areas.[27] At 30% renewables penetration, post-contingency low voltage (static stability) and transient voltage stability (dynamic stability) challenges emerge at the local area.

Local correlated availability: The lack of local resource availability due to correlated risks grows as the resource fleet becomes more weather dependent. Wind and solar resources exhibit the same generation patterns in local areas leading to correlated times of high and low resource availability. In cold weather conditions, natural gas fuel supply for heating customers has priority over gas-fired electricity generation. For example, during the 2021 February Arctic Event, MISO had nearly 21 GW of gas-fired generation capacity unavailable for dispatch due to weather-related gas restrictions.[28] This reliability consideration will become more important as coal-fired generation retires and gas makes up a increasing proportion of dispatchable generation capacity in a local area. Additionally, extreme hot weather conditions can result in higher-than-normal capacity derates due to air or cooling water temperatures. Climate change has already increased the frequency of peak and near-peak temperatures relative to historical weather.[29]

Local flexibility: Adequate generation may not be available to follow demand in import constrained areas. Particularly in local areas of high renewable generation without storage, resources may be challenged to meet local demand on cold, dark mornings or hot, still nights. In the 2021 Annual Reliability Technical Conference, NERC filed a statement for the record in Docket No. AD21-11-00 recommending that system planners should study flexibility need in the system and larger load pockets as the portfolio evolves.[30]

Needs: Coordination

Coordination needs are driven by the growing complexity of distribution grid sited resources, fuel supply concerns, dependence on neighboring Regional Transmission Organizations (RTOs) and Independent System Operators (ISOs), and regional dispatch transfers. In an increasingly complex and interdependent energy future, robust coordination is needed for improved decision making, goal tracking, and proactive risk mitigation. Emerging technologies make data more accessible than ever before, increasing the potential for sharing and coordination amongst MISO and stakeholders.

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[28] MISO, "The February Arctic Event, February 14-18, 2021, Event Details, Lessons Learned, and Implications for MISO's Reliability Imperative," September 15, 2021.

[29] Electric Power Research Institute, "Exploring the Impacts of Extreme Events, Natural Gas Fuel and Other Contingencies on Resource Adequacy," January 28, 2021.

[30] NERC "Statement of the North American Electric Reliability Corporation," September 30, 2021

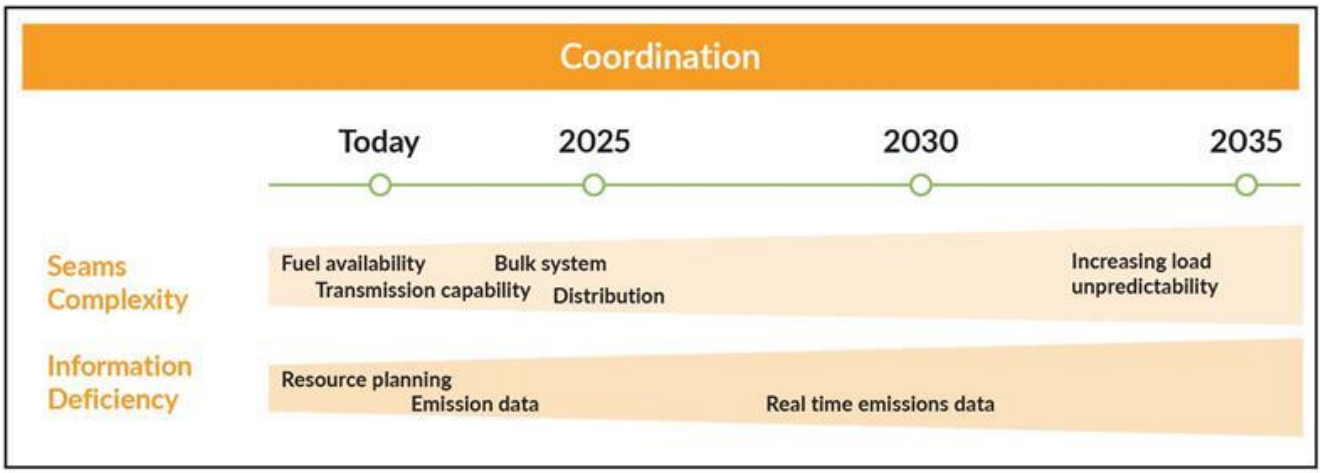

Figure 10: Reliability needs related to coordination as they emerge or significantly shift over time.

SEAMS COMPLEXITY

Fuel availability: Coordination around the availability and delivery of fuel is increasingly needed to reliably serve electric load. MISO has the benefit of a large geographic area served by many fuel delivery systems such as pipelines, barges and railways. That said, increasing reliance on natural gas-fueled generators, decreasing coal supplies and recent cold weather events have highlighted the need to strategically coordinate across sectors to simultaneously meet heating, industrial processes and electricity needs.[31] The lack of a centralized secondary market for gas customers to trade firm supplies hinders generators in unexpected congested areas from buying gas from uncongested areas. NERC included a Natural Gas-Electric Reliability Forum as a key preliminary recommendation in February 2021.[32] Further disruptions to the coal supply chain could also impact generator availability.[33]

Transmission capability: The capabilities of individual transmission assets are designed and measured by Transmission Owners, and most transmission capabilities are modeled conservatively based on the assumed worst case system conditions. As variability and uncertainty of the system increases, consideration of real-time conditions will be needed to achieve reliable and efficient outcomes. Ongoing coordination between MISO and stakeholders on how to effectively represent and utilize these emerging technologies in planning and operational timeframes is needed in order to chart an efficient path forward.

Bulk system: Improved coordination across the entire Eastern Interconnection will be needed as resource portfolios evolve, particularly between MISO and our neighboring balancing authorities. A recent FERC Staff report states that Variable Energy Resources (wind and solar) account for approximately 90% of generation seeking interconnection

[31] MISO, "The February Arctic Event, February 14-18, 2021, Event Details, Lessons Learned, and Implications for MISO's Reliability Imperative," September 15, 2021.
[32] FERC and NERC and Regional Entity Joint Staff, "February 2021 Cold Weather Grid Operations: Preliminary Findings and Recommendations; FERC, NERC and Regional Entity Joint Staff Inquiry," September 23, 2021.
[33] MISO, "Winter Readiness Workshop," October 26, 2021.

to the United States transmission system based on nameplate MW.[34] Balancing increasing amounts of variable resources and load will require a coordinated, interconnected transmission grid and evolving market products. Existing market-to-market approaches between MISO, PJM, and SPP facilitate coordination. However, further work is needed to ensure that these approaches are robust under growing uncertainty and variability. In addition, work is needed to ensure reliability and efficiency on non-market seams.

Distribution: The deployment of more distributed generation and storage on the distribution system prompts the need for increased visibility across the transmission and distribution seams, and coordination between wholesale and retail entities to ensure reliability. Further work to coordinate market participation is also needed to enable efficient and reliable use and avoid, for example, inadvertent power and price oscillation or transmission or distribution violations.[35] Per FERC Order 2222, ISO/RTOs will be enabling DERs to participate in the wholesale markets. Initial discussions on coordination approaches are underway among distribution companies, regulators, transmission owners, DER aggregators and DER asset owners. Non-market-participating DERs are also expected to grow substantially prompting increased need for visibility of location, capacity, and fuel type to assess load predictably and understanding of equipment settings to prepare for grid events.

Increasing load unpredictability: Sensitivity to price signals and real-time load shifting is expected to increase significantly by 2040, driven by demand programs such as time-of-use retail rates, electrification, DER generation and storage. MISO expects load forecast uncertainty to increase as emerging technologies (e.g. charging stations, thermostats) enable end-users to respond to real-time market characteristics (e.g. price, emissions) without participating in the market. MISO's *Electrification Insights* study suggests by the 2030-2035 timeframe the "load itself is more variable."[36] MISO's analyses suggests that the market will be challenged once 5–7% of load moves to real-time pricing. Increasing load unpredictability is anticipated in day-ahead as well as real-time timeframes.

INFORMATION DEFICIENCY

Resource planning: A systemwide and zonal view is needed for reliable resource planning. MISO's 2021 *RIIA*, *Electrification Insights*, and *February Arctic Event* reports demonstrate that renewables, newly electrified load and severe weather generator performance, respectively, produce resource deficiencies that cannot fully be seen by a local only view. These challenges present a need for regional resource planning visibility and coordination.[37,38,39]

Emissions data / Real-time emissions data: With increasingly more prevalent decarbonization goals and targets, improved transparency and specificity of emissions data is needed. MISO's Market Vision guiding principles[40]

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[34] Federal Energy Regulatory Commission (FERC) Staff Paper, "Energy and Ancillary Services Market Reforms to Address Changing System Needs," September 2021.
[35] MISO, "MISO and DER Ensuring Grid Reliability Through Visibility and Communication," 2021.
[36] MISO, "MISO Electrification Insights," April 2021.
[37] MISO, "Renewable Integration Impact Assessment (RIIA) Summary Report," February 2021.
[38] MISO, "MISO Electrification Insights," April 2021.
[39] MISO, "The February Arctic Event, February 14-18, 2021, Event Details, Lessons Learned, and Implications for MISO's Reliability Imperative," September 15, 2021.
[40] MISO, "Market Vision Guiding Principles."

include support market participants in making efficient operational investment decisions. A MISO survey of electricity end users and utilities, described in the 2021 *MISO Forward* report, finds that more spatially and temporally granular estimates of carbon and other emissions is desired.[41] Access to this data would allow some users to adjust their energy use or purchases in response to emissions targets. For example, data centers may shift processing to times and locations with lower emissions. ISO New England is exploring this type of coordination, including incentives and carbon pricing.[42] Increasingly, third-parties are providing emissions approximations. End-users are seeking a trusted source.

Having defined and sequenced the needs related to **Uncertainty and Variability**, **Resource Models and Capabilities, Location**, and **Coordination** – the balance of the report focuses on the proposed Market Redefinition portfolio of solutions.

Market Solutions Timeline

Market Redefinition means re-thinking the methods by which reliability risk is assessed in the planning and operating horizons and evolving markets to incent and enable availability, flexibility and visibility. Adapting markets to meet the needs of the future will require step-by-step design enhancements informed by stakeholders and with approval from FERC, and ensuring reasonable runway for implementation. This work takes time and resources and the scope of work is significant. Ongoing strategic decisions will be required for resource allocation, project prioritization and stakeholder committee timelines. As market adaptations are realized, operational enhancements and actions, including the potential increase in out-of-market actions, will be used to bridge to a full transition.

Based on the needs outlined above, and their expected timing, MISO is putting forward a conceptual framework for market solutions and a long-range view of the Market Redefinition portfolio of work. The timeline below (Figure 11) presents a high-level description and time-bound parameters for each solution. Many solutions in the near years are defined and underway. Solutions in the longer-term are much more conceptual. The left end of each box indicates that MISO intends to begin or is continuing the work - the right end of the box is the estimated implementation timeframe or start of a phased implementation transition.

[41] MISO, MISO Forward – Energy Ecosystems: The Changing Nature of Demand," April 2021.
[42] ISO New England, "The Power of Change NOW 2021 Regional Outlook," 2021.

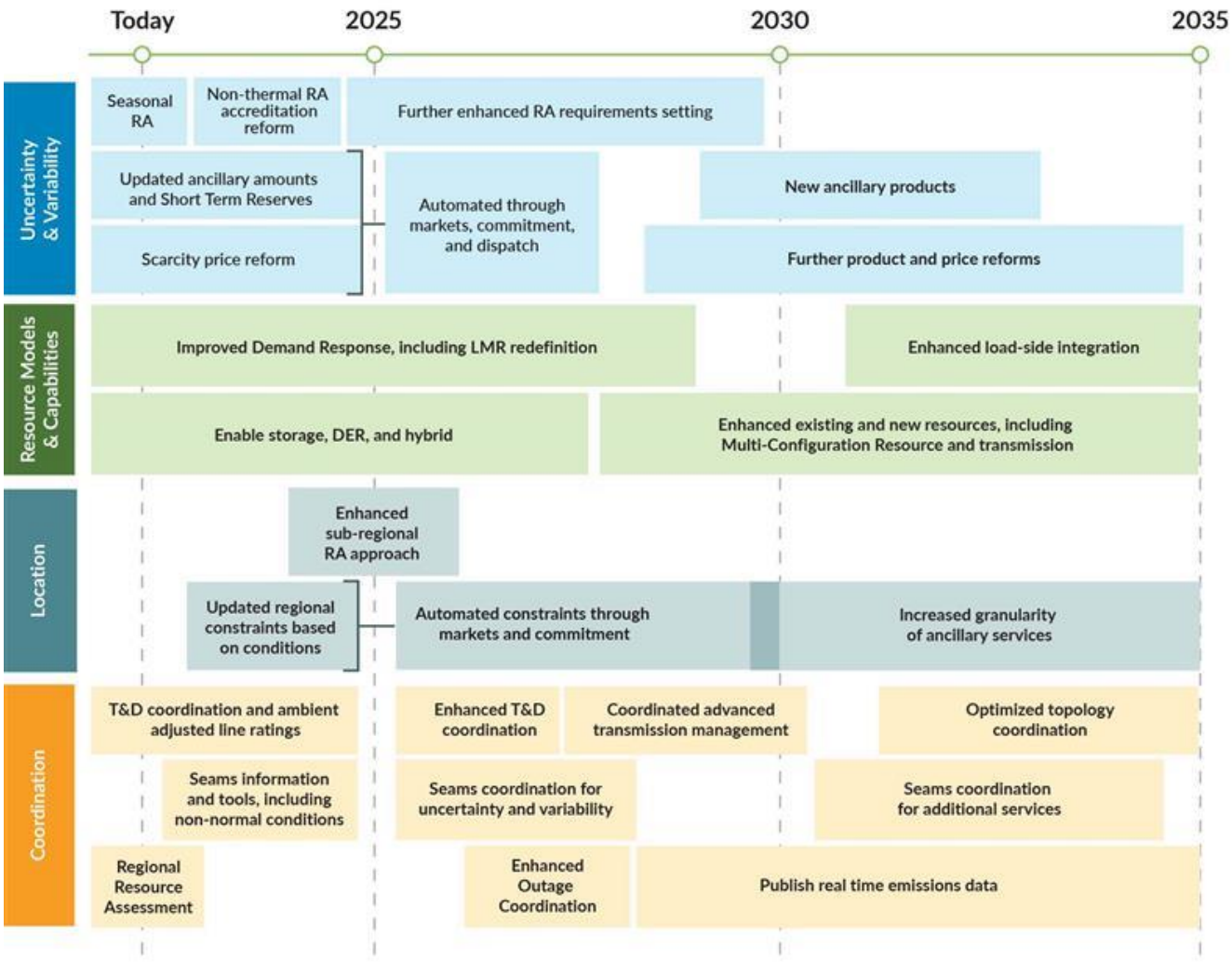

Figure 11: Planned market enhancement work aimed at addressing new and shifting system and customer needs. Solutions are grouped by need category and sequenced over a 15-year planning horizon. Each row is a "swim lane" indicating phases of related work.

The subsections that follow provide additional detail on the list of projects or potential projects summed up by each enhancement in Figure 11. The association of the solution with the corresponding need is outlined and gaps are acknowledged. Reference numbers for MISO's Issue Tracking tool are provided, were applicable, as a resource for additional project-level detail.

Market Solutions: Uncertainty and Variability

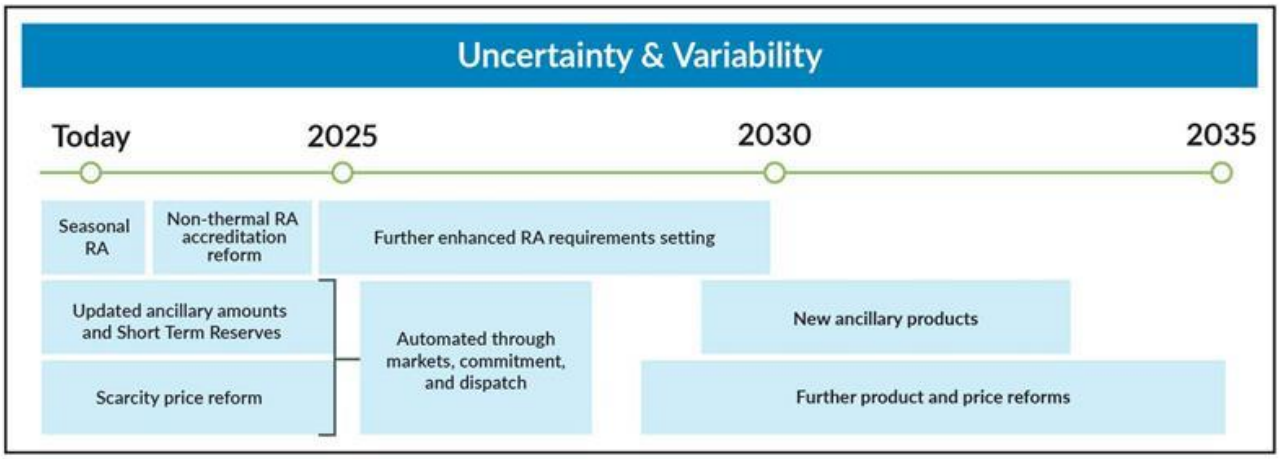

Figure 12: MISO's solutions to address needs leading to uncertainty and variability on the bulk electric system. Project-level detail for each box is provided in Table 1.

The proposed Resource Adequacy reforms being filed on or before December 1, 2021 will transition from an annual to a seasonal construct to identify and mitigate shifting reliability risks as demonstrated by the increasingly frequent operational challenges today, and the heightened **seasonal risk shift**[43] and **winter peaking** needs of the future. Coupled with the seasonal transition is an enhanced thermal accreditation approach that accounts for availability during the hours of highest system need and prepares MISO for the expectation that the riskiest hours will shift over time toward **evening hours** in the near-term and eventually to **12+ hour** and increasingly unpredictable **evolving risks**. Further enhancements on accreditation methodologies for non-thermal resources (e.g., solar, Load Modifying Resources) will begin in 2022.

Enhancements to MISO's emergency and scarcity pricing mechanisms are underway and will continue in the coming years to address the **price alignment** need. Additional solutions to address flexibility shortage risk will advance in parallel. MISO's STR product will launch in December 2021. Work is underway to identify **10-to-30-minute** reserve needs and adapt the reserve and ramp product suite to prepare for higher levels of uncertainty. Additional work be needed to evaluate approaches to address **5-minute** needs as a growing amount of solar come online. This work will leverage existing products and in some cases be implemented as manual adjustments through improved tools and processes in the near-term. Manual solutions will be necessary to bridge to automation and full implementation of market solutions.

Once MSE is complete (expected 2024), work will begin to automate tools through markets, commitment and dispatch systems. Previous manual adjustments will be assessed for incorporation into the new market system based on ongoing need analyses and prioritization at that time.

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[43] *Note to reader: New or shifting needs described in the earlier section of this report appear as bolded text in the solutions sections that follow. The objective is to help bridge related needs and solutions.*

As MISO's in-service solar fleet grows to an impactful size, market solutions such as increased ramp capability will be assessed and implemented to manage quick solar changes more efficiently and address emerging **morning and evening** risk. In parallel, MISO will explore the potential addition of new market products to address heightened uncertainty and variability challenges, including a potential uncertainty product.

The table below lists ongoing and planned market enhancement projects aimed at addressing **energy shortage** and **flexibility shortage** needs. Each heading in Table 1 corresponds to a box in Figure 12.

Uncertainty & Variability Projects
Seasonal Resource Adequacy (RA) (Today-2022): - File with FERC for a seasonal construct, enhanced availability-based thermal resource accreditation and improved outage coordination - [IR094], [RASC010] - File a Minimum Capacity Obligation to incentivize long-term resource planning - [IR025] - Prepare systems to enable sub-annual construct, including risk assessment - Improved forecasting tools for RA Non-thermal Resource Adequacy accreditation reform (2022-2024): - Assess existing Effective Load Carrying Capability (ELCC) methodology for wind - [RASC009] - Consider applicability of ELCC for other resource types, including energy-limited resources (e.g., solar, storage) - [RASC009] - Adapt accreditation for Demand Response resource types to match contribution (additional DR/LMR market integration steps described in Table 2) - [RASC009] Further enhanced RA requirements setting (2022-2030): - Enhance modeling of inputs and correlations of inputs - Improve reporting of unserved energy - Improved tools for both RA and Operations for extreme weather risk assessment
Updated ancillary amounts and Short Term Reserves (Today-2025): - Increase Ramp Capability Product amounts - Launch Short-Term Reserves product - [IRO10] - Enable condition-based ancillary requirements - Adapt reserves and ramp to include uncertainty events (amount and pricing) - Improved forecasting tools for Operations Scarcity price reform (Today-2025): - Re-evaluate price caps and Value of Lost Load (VOLL) - [MSC-2021-3] Automated through markets, commitment, and dispatch (2025-2028): - Predict generator on/off ramp (Unit Dispatch System) - Pursue automated ancillary service amounts for grid conditions - some or all projects, priority TBD: ▪ Improve forecasting and scenario generation tools to enable uncertainty management with headroom in market commitment tools (Day-Ahead, Forward Reliability Assessment and Commitment (FRAC), Look Ahead Commitment (LAC)) ▪ Extended intraday commitment timeframe (LAC) ▪ Extended look ahead-timeline and continuously improve headroom management ▪ Dynamically adjust reserve amounts based on conditions, building on the short-term reserve product
New ancillary products (2028-2033): - Implement uncertainty product upon analysis of prior enhancement outcomes [MSC-2021-9] - Implement additional ancillary service reserves as needed, potentially including fast frequency response, inertia and voltage control - Pursue further services to be provided by inverter-based resources Further product and price reforms (2028-2035) - TBD

Table 1: Ongoing and planned MISO projects contributing to solutions addressing Uncertainty and Variability needs. Headings and timeframes correspond to Figure 12.

Market Solutions: Resource Models and Capabilities

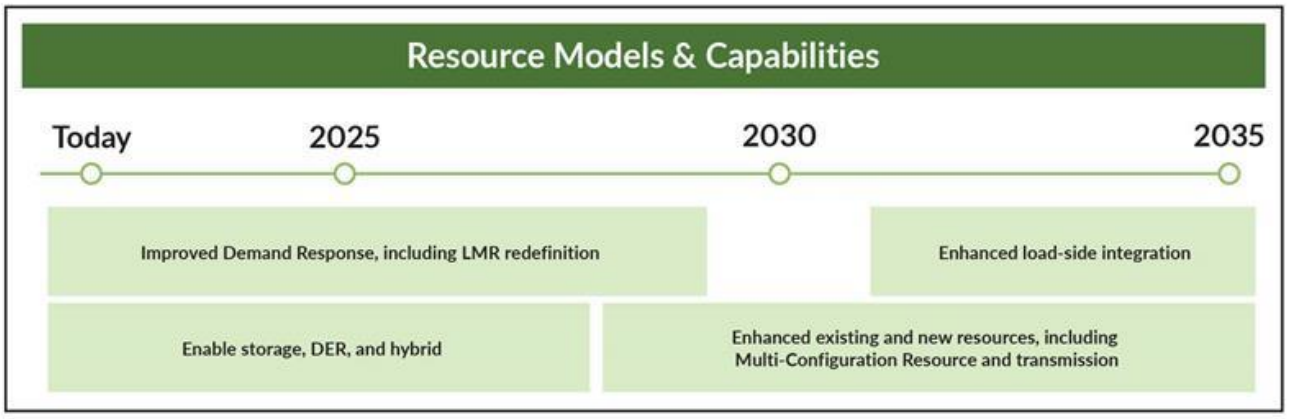

Figure 13: MISO's solutions to address needs resource models and capabilities on the bulk electric system. Project-level detail for each box is provided in Table 2.

Work is underway with the DER program to reevaluate the role that **Demand Response** plays in the MISO markets, including reconsidering emergency resource call rules, resigning and simplifying DR resource types, and removing market participation barriers. Incremental progress will be required to leverage increasingly digitalized demand at scale by 2035. By this time, **renewable curtailment** or "dumped energy" presents a market inefficiency that has the potential to be mitigated, in part, by increasingly **responsive load**. Many questions remain on what this new framework will include and how it will evolve, but MISO has heard clearly from its members and the industry that load participation in the markets needs to be a central part of the energy transition.

Explore, frame and design work to integrate and enable **storage, DER** and **hybrid** resources is also ongoing with guidance from the stakeholder community and FERC. MISO anticipates significant growth in these resources in the coming years and expects to gain valuable operational experience and insights as they deploy. With the MSE initiative completing in 2024, MISO will have the capability needed to efficiently prioritize, sequence and implement these advancements in the years that follow.

By the 2030 timeframe, resource usage and capability inadequacy needs emerge for inverter-based resources and transmission. Research and development is needed to enable ancillary services from inverter-based resources by this time to address **inverter stability** and **inertia and frequency response** needs. Additionally, while MISO has the capability to support ambient adjusted ratings in real-time, longer-term enhancements will be needed to further integrate these and other **grid-enhancing technologies** into markets and transmission rights processes.

MISO has developed improvements for combined cycle models to address the **combined cycle** need. These improvements are awaiting enhancements to MISO's market system for implementation. MISO acknowledges the gap between timing of the need and sequencing of the solution that has arisen due to the emergence of new needs.

Additionally, the generating fleet's **weather related performance** is a known risk without a direct mitigation solution. Through winterization and fuel surveys, MISO has improved visibility of the functional and operational

ability of generators to perform as dispatched during extreme weather events. Actions to weatherize are the responsibility of generator owners subject to regulatory oversight. In September 2021, FERC proposed changes to several NERC reliability standards that will require generators to undertake improvements for winterization and to increase training for operators to prepare for extreme weather events. This is an important resiliency step in preparation for the impacts of a changing climate.

The table below lists ongoing and planned market enhancement projects aimed at addressing **sub-optimal resource usage** and **capability inadequacy** needs. Each heading in Table 2 corresponds to box in Figure 13.

Resource Models & Capabilities Projects
Improved Demand Response, including LMR redefinition (Today-2028): - Consider emergency resource call rules and enhance visibility into resource availability - Enhance transparency regarding LMR locations and outages - Redesign and simplify DR resource types, remove barriers from market participation, and migrate resources to the market Enhanced load-side integration (2032-2035+): - Pursue additional demand response reforms as needed to adapt to changing resource capability - Expand load participation in markets
Enable storage, DER, and hybrid (Today-2027): - Electric Storage Resource tariff effective June 2022 for September 2022 participation in MISO's energy and capacity markets - Enable Hybrid Resource participation under existing resource types - [IR087] Enhanced existing and new resources, including Multi-Configuration Resource and transmission (2027-2035+): - FERC Order 2222 compliance and implementation[44], enabling Distributed Energy Resources participation, pursue DER communication and forecasting methods - [IRO70] - Implement Multi-Configuration Resource enhancements - Further optimize and leverage flexibility of hybrids and storage (including long-duration storage) - Enable ancillary services from inverter-based resources - Take steps to enhance coordination for Grid Enhancing Technologies (GET) to facilitate efficient integration of widespread novel transmission resources

Table 2: Ongoing and planned MISO projects contributing to solutions addressing Resource Model and Capabilities needs. Headings and timeframes correspond to Figure 13.

[44] *The timing associated with implementation of DER compliance with FERC Order 2222 is subject to sequencing relative to other initiatives, review with stakeholders, and FERC filing, review and acceptance.*

Market Solutions: Location

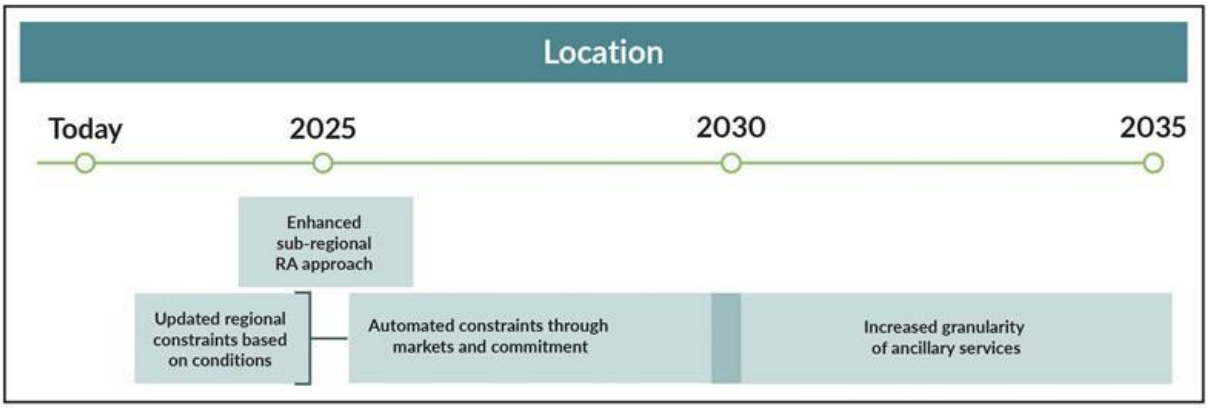

Figure 14: MISO's solutions to address locational needs on the bulk electric system. Project-level detail for each box is provided in Table 3.

With the pace of fleet change and electrification poised to outpace transmission development timelines, an enhanced sub-regional RA approach will be evaluated to meet the most immediate needs of **local energy delivery** and **reserve delivery**, and the longer term need of **local flexibility delivery**. Investment in improved situational awareness of constraints and steps toward inverter-based resources optimization will be needed to address **local inverter stability** and **flexibility** risk.

Severe weather performance limitations of generators already pose an energy shortage risk, as previously discussed. Pockets of load shed during the 2021 Arctic weather event illustrate the local energy shortage risk that exists today. Additionally, in the realm of climate change resilience, **correlated availability** in seasons outside of winter is a growing need within the timeframe of this report, especially at the local level. Generators are much less efficient and in some cases unable to operate under extreme heat conditions. Again, this risk is challenging for MISO to mitigate directly given limited jurisdiction over weatherization planning and investment.

The table below lists ongoing and planned market enhancement projects aimed at addressing **local energy imbalance** and **capability inadequacy** needs. Each heading in Table 3 corresponds to box in Figure 14.

Location Projects
Enhanced sub-regional Resource Adequacy approach (2024-2026): - Enhance Resource Adequacy sub-regional assessments and requirements
Updated regional constraints based on conditions (2022-2025): - Enable reserve zone adjustments based on grid conditions Automated constraints through markets and commitment (2025-2030): - Consider ways to enforce locational ramp needs and implement - Enable condition-based penalties/demand curve for the Reserve Procurement Enhancement - Enable more granular and automated reserve zones adjustments for when system conditions change Increased granularity of ancillary services (2029-2035+) TBD

Table 3: Ongoing and planned MISO projects contributing to solutions addressing Location needs. Headings and timeframes correspond to Figure 14.

Market Solutions: Coordination

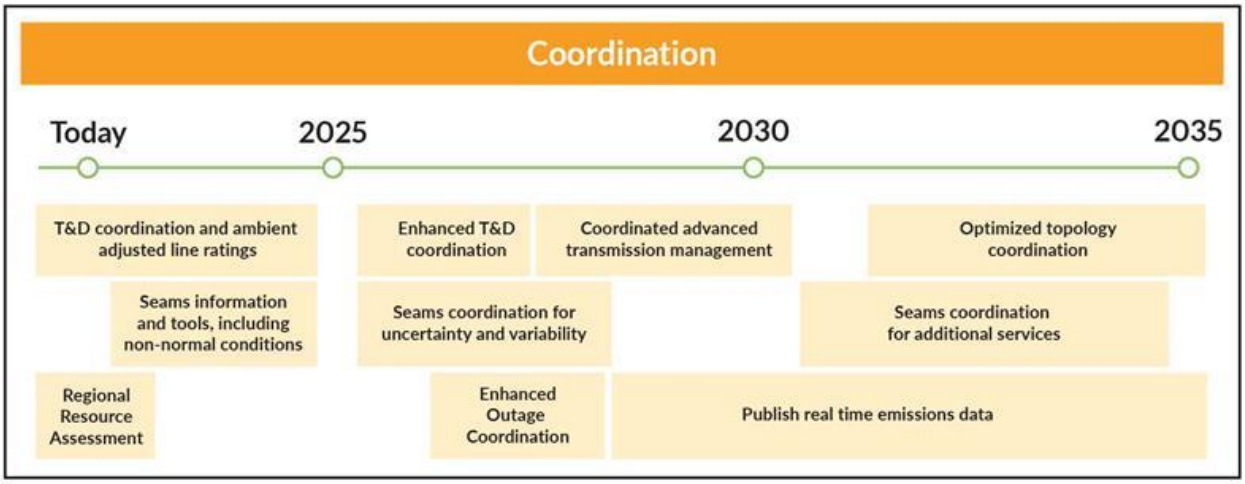

Figure 15: MISO's solutions to address needs regarding coordination on the bulk electric system. Project-level detail for each box is provided in Table 4.

MISO and the Transmission Owners are currently working to expand the use of ambient adjusted line ratings to meet near-term **transmission capability** needs, with significant work ahead to realize the potential of topology optimization in the markets. Similarly, while Order 2222 is the current task at hand, more coordination will be needed between MISO and distribution operators to meet **distribution** visibility needs and prepare for **increasing load unpredictability**.

The expectations of the transmission system and markets are growing, and members are requesting MISO's input on system and locational needs as a consideration in planning decisions. The Regional Resource Assessment (RRA) is being developed and will improve over time with input from stakeholders, but the ultimate objective is to provide an input to meet an emerging **resource planning** need across states and mitigate **bulk system** planning risks as accelerating decarbonization goals require fast action and assurance that reliability is not being compromised.

> *"We have to continue to work together on this. A unified effort between the MISO, member utilities, and all industry partners is essential."*
>
> Mark C. Birk
> Senior Vice President
> Customer and Power Operations
> Ameren Missouri

Resource coordination enhancements must also address outage coordination as thermal generators age and retire. The next step to improve outage coordination, to be filed with the 2021 RAN package, proposes modifications to planned outage exemptions. Exploration of economic outage planning will follow.

As decarbonization goals are accelerated and customer engagement with their energy usage increases, MISO will explore and advance solutions to meet **emissions data** and **real-time emissions data** needs.

Fuel availability is another documented need without a directly correlated solution. MISO is participating in the NERC Electric-Gas Working Group and the Eastern Interconnection Planning Collaborative (EIPC) Electric-Gas Task

Force to explore ways to improve fuel availability for gas-fired generation. Renewed efforts are also underway to identify critical gas facilities (e.g., compressor stations) that are dependent on electricity to operate so that they can be added to the roster of facilities that will be exempted in the event of load shedding. The risk of supply chain strain or collapse for gas and coal generators prior to having in-service capacity of replacement resources is a known risk that cannot be fully mitigated with MISO's levers.

MISO is continuously working with its seams neighbors to improve efficiency and reliability. Additional work will help to assess what needs might emerge as market rules change across ISO/RTOs, uncertainty and variability grow across multiple footprints and efforts to bolster preparedness for extreme weather events are advanced.

The table below lists ongoing and planned market enhancement projects aimed at addressing **seams complexity** and **information deficiency** needs. Each heading in Table 4 corresponds to a box in Figure 15.

Coordination Projects
T&D coordination and ambient adjusted line ratings (Today-2025): - Expand use of ambient adjusted ratings [RSC-2018-54A] - Improve Organization of MISO States (OMS)/MISO survey Enhanced T&D coordination (2025-2027): - Forecast DER impact on transmission flow Coordinated advanced transmission management (2027-2031): - Pursue incorporation and optimization of flow control devices - Utilize grid topology optimization in limited cases - Incorporate the ability to dispatch High Voltage Direct Current (HVDC) transmission Optimized topology coordination (2032-2037) - Improve system reconfiguration capability to relieve congestion
Seams information and tools, including non-normal conditions (2022-2025): - Net Scheduled Interchange (NSI) analysis - Reexamine firm flow entitlements Seams coordination for uncertainty and variability (2025-2028): - Enhanced market-to-market rules, including with new market entities [MSC-20212-2] Seams coordination for additional services (2031-2035+): - Advanced congestion management
Regional Resource Assessment (Today-2022): - Enhanced annual Regional Resource Assessment, ongoing publication beyond 2022 Enhanced Outage Coordination (2026-2027): Implement, pending exploration, economic outage planning Publish real time emission data (2028-2035): - Provide emissions data transparency in the aggregate - Implement real-time emissions data, pending exploration of ability to provide - Pursue other emissions enhancements, depending on policy and member preferences

Table 4: Ongoing and planned projects contributing to solutions addressing Coordination needs. Headings and timeframes correspond to Figure 15..

Ongoing Assessment and Further Study

As technologies advance and drivers of change continue to shape the future, ongoing assessment and further study will be necessary. The following moving pieces are poised to have the potential to significantly disrupt the Market Redefinition framework described in this report:

The pace of transmission development - The ability to build reasonable transmission to accommodate new needs is assumed in the Market Redefinition portfolio. MISO does not expect the current Long-Range Transmission Planning (LRTP) effort will remove all locational risks, but it does assume major locational needs will be met by improved transmission interconnectivity across the region.

Resource technology enhancements – Fundamentally, nascent technologies are difficult to forecast and account for in future planning. This report utilizes the MISO Futures to assess a reasonable range of future resource scenarios, but new disruptive technology can change that view. For instance, if technology such as flexible small modular nuclear reactors, long-duration storage, or hydrogen fueled resources become widely deployed, those technologies could play a larger mitigation role than anticipated in this report. The pace of new technology adoption within the MISO footprint could also impact prioritization and sequencing.

Technology systems – MISO's Market System Enhancement (MSE) is currently building the platform in which most of the new market changes will be constructed and aims to reduce the deployment time of market changes. Additional large system changes will be needed in communication, data storage, backend systems, optimization techniques, and other areas to realize the market changes described in the paper. Changes to vendor-dependent projects could affect the timeline for implementation of market changes.

The pace and scale of electrification – Electrification and the widescale digitalization of electric demand presents opportunities and challenges for the region depending on the pace and scope of the change. The *2021 MISO Electrification Insights* report detailed many of the changes MISO anticipates, but additional insight is needed to fully understand how this accelerating trend will impact the markets.

Decarbonization beyond 80% emissions reductions – Current *MISO Futures* and analyses do not capture 80%, 100%, or net-zero region-wide scenarios. MISO and other industry experts are contemplating whether this level of change would require a fundamental reexamination of markets. The needs and solutions required to meet that magnitude of decarbonization are outside of the scope of this report.

As MISO and stakeholders advance this work together, the Redefining Markets strategy will be continuously presented as a pillar of the Reliability Imperative and progress will be tracked through the MISO Roadmap (to be published early 2022). The effort to explore, design, and implement this portfolio of work is substantial and will be ongoing. The analyses, operational experiences, and stakeholder dialogue that informed this report will continue.

APPENDIX:

Appendix Table A.1: MISO's Markets, as of November, 2021

Market	Market Product	Geographic Granularity	Requirement	Offer Cap	Max. Scarcity Price	Why does this market exist? What is the business case?
Resource Adequacy	**Capacity Planning Resource Auction**	Local Resource Zone (LRZ)	MISO calculated LRZ needs and import/ export limits	Cost of New Entry (CONE)	Cost of New Entry (CONE)	Address Resource Adequacy Needs in MISO's footprint
FTR	**Financial Transmission Rights**	Point-to-Point	n/a			FTRs are financial instruments used to hedge the risk of congestion cost in the Day-ahead Market.
	Auction Revenue Rights (ARRs)	Point-to-Point	Allocated based on firm historical usage	Allocation process; no market offer	n/a	ARRs are entitlements to a share of the revenues generated in the annual FTR Auction to address transmission investments.
Day-Ahead Energy and Operating Reserves Market	**Energy**	Nodal	Demand Bids	$1,000 (soft cap), $2,000 (hard cap)	Value of Lost Load (VOLL) ($3,500)	The Energy market uses transmission and generation assets more efficiently and reduces the need of additional assets.
	Regulating Reserve	System-wide	300-500MW, depending on hour of day	$500	Regulation Demand Curve, up to VOLL	Address small deviations in frequency and tie-line flows, meeting NERC standards.
	Spinning Contingency Reserve	Reserve Zone with RPE	901 - 1201 MW, depending on hour of day	$100	ORDC* plus Spin Demand Curve, up to VOLL	Address larger deviations resulting from system contingencies, meeting NERC standards.
	Supplemental Contingency Reserve	Reserve Zone with RPE	1,109 MW	$100	ORDC, up to VOLL	Address larger deviations resulting from system contingencies, meeting NERC standards.
	Ramp Capability Product (Up & Down)	System-wide	Based on estimated real-time needs	No offer	$5	Manage resource flexibility to address forecast uncertainties.
	Short Term Reserves	System-wide, Sub-Regional, Local	~3,600 MW (System-wide)	None for on-line; $100 for off-line	$100-200	Efficiently ensure capacity to manage imbalance and reserve replacement

Real-Time Energy and Operating Reserves Market	**Energy**	Nodal	Short Term Load Forecast	$1,000 (soft cap), $2,000 (hard cap)	Value of Lost Load ($3,500)	The Energy market uses transmission and generation assets more efficiently and reduces the need of additional assets.
	Regulating Reserve	System-wide	300-500MW, depending on hour of day	$500	Regulation Demand Curve, up to VOLL	Address small deviations in frequency and tie-line flows, meeting NERC standards.
	Spinning Contingency Reserve	Reserve Zone with RPE	901 - 1201 MW, depending on hour of day	$100	ORDC plus Spin Demand Curve, up to VOLL	Address larger deviations resulting from system contingencies, meeting NERC standards.
	Supplemental Contingency Reserve	Reserve Zone with RPE	1,109 MW	$100	ORDC, up to VOLL	Address larger deviations resulting from system contingencies, meeting NERC standards.
	Ramp Capability Product (Up & Down)	System-wide	Based on short-term load forecast & uncertainty	No offer	$5	Manage resource flexibility to address forecast uncertainties.
	Short Term Reserves	System-wide, Sub-Regional, Local	~3,600 MW (System-wide)	None for on-line; $100 for off-line	$100-200	Efficiently ensure capacity to manage imbalance and reserve replacement

** ORDC: Operating Reserve Demand Curve*

Appendix Table A.2: MISO's Non-Market Reliability Processes, as of November 2021

Reliability Process	Period of Focus	Interval	Objective	Settled
Multi-day FRAC	Tomorrow and the following 5 days	Hourly	Commitment cost	Day-Ahead and Real-Time Market
Next-day FRAC	Tomorrow	Hourly	Commitment cost	Real-Time Market
IRAC	Remainder of Current Day	Hourly	Commitment cost	Real-Time Market
LAC	Next 3 hours (default), but can run longer cases	15-min & 30-min (hourly if study >3 hr)	Production cost	Real-Time Market

Appendix B: Other MISO papers and reports

- MISO Forward – De-marginalization, Decentralization, and Digitalization: Delivering Reliability and Value in a 3D Future, 2019
- A Configuration Based Pumped Storage Hydro Model in the MISO Day-Ahead Market, 2020
- MISO Forward – Utilities of the Future: What Do They Need from a Grid Operator?, 2020
- MISO Futures Report, 2021
- MISO Transmission Expansion Plan (MTEP), 2021
- Redefining Energy and Ancillary Services Markets, 2020
- Reliability Imperative Report, 2021