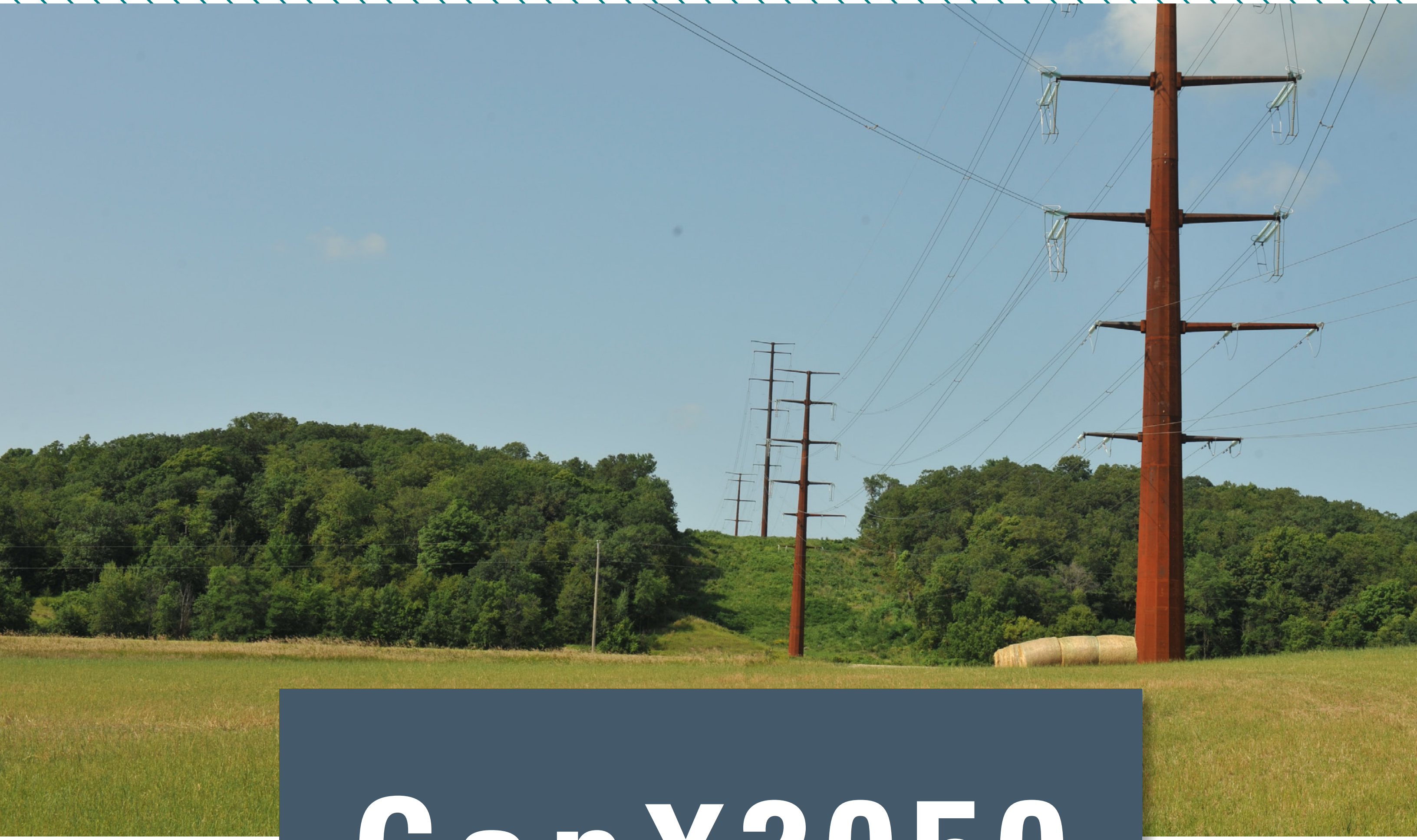


CapX2050

Transmission Vision Report

March 2020

CapX2020

EXECUTIVE SUMMARY

The goal of this CapX2050 Transmission Vision Report is to educate and inform Upper Midwest policymakers and other stakeholders of the implications of a future that is more reliant on non-dispatchable resources. It is not intended to forecast the transmission system in 2050. The challenges identified in this report promote understanding, helping stakeholders identify and implement solutions that enable the generation fleet to transition to a reduced-carbon future. As transmission owners and operators of the transmission system in the Upper Midwest, we are focused on the impacts to transmission system operations and ensuring that grid reliability continues to be met as generation resources transition to non-dispatchable resources. We must also consider the rate and timing of these transitions; particularly the level of non-dispatchable resources in the resource mix. Specifically, the report addresses these top four critical findings that are necessary to continue operating a safe, reliable, and affordable grid:

- Dispatchable resources support the electric grid in ways that non-dispatchable resources presently cannot and therefore, some dispatchable resources will be necessary.
- The ability for system operators to meet real-time operational demands will be more challenging and therefore, we will need to develop new tools and operating procedures to address the challenges.
- More transmission system infrastructure will be needed in the upper Midwest to accommodate the transition of resources.
- Non-dispatchable resources alone will be incapable of meeting all consumer energy requirements at all times and therefore, we will need to understand and promote a future electric grid that can continue to meet consumer energy requirements safely, reliably and affordably.

The CapX2020 utilities are committed and confident in finding viable solutions through future collaboration.

Overview

CapX2020 is a broad mix of 10 investor-owned and not-for-profit cooperative and municipal utilities working together to reliably serve their customers, consumers, members. We all serve load in the Upper Midwest and own and operate transmission infrastructure throughout our respective service territories. We have a unique long-term, collaborative working relationship. We know our system and we know our customers. Read more about **Who We Are**.

Our collaboration allows us to develop needed transmission expansion that benefits our communities and consumers. The CapX2020 collaboration successfully planned and built approximately 800 miles of high voltage transmission lines and 22 substations from 2004 – 2017 to benefit the region. This buildout created a backbone of transmission that improved reliability and enabled more renewable generation to connect into the electric grid (approximately 3,600 megawatts so far).

The CapX2020 utilities are committed to provide continued reliable supply of energy under all conditions to meet customer demand every hour of the year. We are committed to working together with policymakers and other stakeholders to ensure a reliable transmission system that keeps electricity affordable as new, non-dispatchable resources are added and dispatchable resources are retired.

Key Terms

Electric Grid

All components of the overall infrastructure that contribute to powering consumers' lives including the generation, transmission, and distribution systems. A reliable and affordable electric grid is a cornerstone of a strong and healthy economy.

Transmission System

The poles, wires, substations, and associated equipment that provides a reliable connection between generation and distribution. The transmission system should be developed to maintain reliability while supporting different generation resources ('non-denominational'). While the transmission system itself will not affect the change necessary to meet carbon reduction efforts, it is a key enabler of integrating more non-dispatchable energy resources.

Dispatchable Resources

Generation resources that may be called upon with short notice to meet immediate customer needs. Utility operators depend on these resources' ability to ramp up or ramp down their energy output as needed by the system. Dispatchable resources include resources such as coal, natural gas, hydro-electric, and nuclear facilities. Future dispatchable resources may include various new technologies.

Non-dispatchable Resources

Intermittently operating resources whose output cannot generally be controlled when operating. In particular this refers to wind and solar facilities without energy storage. Due to its variability, real-time operators cannot depend on the desired amount of energy at a specific time.

Ancillary Services

For the purposes of this report, grid attributes outside of the production and delivery of real power such as frequency control, inertial energy, voltage regulation, and short circuit current are collectively referred to as 'ancillary services.' They are the collection of attributes that support a reliable grid by helping maintain system strength, stability, and reliability.

Our Approach

CapX2020 announced a plan in August 2019 to study how a concerted effort to reduce carbon emissions from the generation of electricity could affect the transmission system that serves Minnesota, eastern South Dakota and North Dakota, western Wisconsin and the surrounding areas (the "CapX2020 footprint"). The goal of this CapX2050 Transmission Vision Report is to provide stakeholders a basic understanding of the potential operational and planning issues that need to be considered and addressed in order to facilitate the transition from the traditional fleet of dispatchable resources (coal, natural gas, and nuclear) to a more non-dispatchable, weather-dependent resource (wind and solar) fleet. A common understanding as to how the electric grid will operate in the future is important as we undergo this monumental transition.

This report is a critical step toward a common understanding of the issues and the eventual development of a comprehensive transmission plan to ensure the continued reliable performance of the regional transmission system. An emphasis on comprehensive, long-term planning will ensure a successful transition to a reduced-carbon future as the Upper Midwest generation fleet transitions to higher levels of non-dispatchable resources, distributed generation, and new energy storage technologies.

Finding #1

Dispatchable resources support the electric grid in ways that non-dispatchable resources presently cannot. They provide physical attributes that help maintain a stable and reliable grid. As dispatchable resources are retired, it will be essential that new and existing generation and transmission technologies are deployed with the ability to provide grid support in the appropriate locations to ensure reliability is maintained.

- The transmission system was designed in concert with dispatchable resources so that the required ancillary services are available where and when they are needed and are effective in maintaining system stability and reliability. When dispatchable resources are retired, appropriate amounts of grid support (e.g. ancillary services) will need to be provided at specific locations when and where it will be effective. In general, these ancillary services are less effective the farther they are from where they are needed unless sufficient transmission is in place. Read more about the **Fundamentals of Reliability**.

- Without dispatchable resources and the ancillary services they provide, technology advancements will be required to allow non-dispatchable resources to provide an adequate level of ancillary services to maintain a stable and reliable transmission system. Technological advances, in conjunction with new transmission technologies and/or storage resources, will be necessary to provide the required level of ancillary services when and where they are needed. Read more about **Technology Considerations**.
- The results of MISO's Renewable Integration Impact Assessment study (RIIA) are consistent with our findings. Changing the generation fleet from dispatchable resources to non-dispatchable resources will require innovative solutions (existing and new technologies) to maintain system stability and reliability. Read more about the **MISO RIIA Study**.

Finding #2

Reliably meeting real-time operational demands will become more challenging than they have been in the past as dispatchable resources are retired and their corresponding ancillary services are lost.

- Present technologies being used in today's non-dispatchable resources do not support a strong system in the same manner as dispatchable resources, resulting in a weaker transmission system.
- A weaker transmission system is more susceptible to unacceptable voltage fluctuations which can negatively affect consumers. Read more about **System Stability.**
- The power system protection technologies in use today may operate less predictably in a weaker transmission system. Read more about **System Strength**.
- The variability of the output of non-dispatchable resources, even within a single day, could lead to several thousands of MW being transferred across the transmission system, with reversals in direction of flow occurring in an equal, but opposite magnitude during the same day. Operating techniques, transmission infrastructure, and analysis tools will need to become more sophisticated to more accurately identify and adjust in real-time to deal with these changes. Read more about **Interface Flow Patterns**.

Finding #3

To maintain reliability of the system as we integrate more non-dispatchable resources and retire dispatchable resources, more transmission system infrastructure will be needed in the upper Midwest.

- A long-term comprehensive regional transmission plan with appropriate planning and cost allocation policies in place will promote a reliable and affordable electric grid for consumers throughout the region. Read more about **Transmission System Expansion Considerations** and **Energy Market Considerations**.
- Additional transmission infrastructure will:
    - Mitigate some of the negative impacts that retirement of dispatchable resources has on system stability and reliability;
    - Increase the options available for siting dispatchable and non-dispatchable resources in locations that are optimal for energy production;
    - Assure the reliability of the transmission system as distributed generation is added and more local microgrids are established;
    - Provide the necessary amount of capability to move energy between regions and ensure that energy needs are met for all hours of the year;
    - Promote a regional energy market which allows the most economic generation dispatch while maintaining reliability; and
    - Capture weather driven diversity from remotely-sited, non-dispatchable resources.

Finding #4

Non-dispatchable resources alone will be incapable of meeting all consumer energy requirements at all times. Dispatchable resources and/or energy storage with capacity for multi-day support will be needed.

- The increase of non-dispatchable resources combined with the retirement of dispatchable resources will put pressure on maintaining a sufficient supply of energy to match consumer demand at all times.
- Abrupt changes in weather, including prolonged extreme weather conditions, sudden changes in consumer demand, or disturbances on the transmission system (i.e., outages) will increasingly challenge the ability of the electric grid to provide a continuous supply of energy as more non-dispatchable resources are added. Read more about the **Variability of Non-Dispatchable Resources**.

- Adding more non-dispatchable resources alone will not mitigate insufficient energy supply. For example, under certain extreme weather conditions non-dispatchable resources would produce little additional energy when needed. At other times, these non-dispatchable resources would provide more energy than required to meet consumer needs and must be curtailed or exported.
- As non-dispatchable resources are added, sufficient dispatchable resources, which may include significant amounts of energy storage will be needed to maintain a reliable transmission system.
- Dispatchable resources and/or storage will be needed for periods when non-dispatchable resources are not sufficient to meet consumer demand. To be an effective dispatchable resource, storage would need enough capacity to provide energy for multiple consecutive days and/or during unusual weather conditions when there is not enough excess energy from non-dispatchable resources to re-charge the storage devices during that period. Read more about **Storage**.
- To complement the dispatchable and non-dispatchable resources, increased transmission system capacity will be needed to bring additional energy in and move surplus energy out of this region at different times of the year. When used to increase transfer capability, transmission expansion has been shown to be cost-effective when considered as part of a larger market. This is because it can act as a form of dispatchable resource to meet demand when local non-dispatchable resources are unavailable or producing in excess of local demand. Read more about **Transmission System Expansion Considerations**.

Looking Ahead

Understanding the critical issues outlined in this report will lay a foundation for more extensive studies in the future. We want to build on our history of listening and welcome the opportunity to provide information to policymakers and stakeholders as we plan the transmission system to support future objectives while addressing reliability concerns. We will use the feedback we receive to inform the technical issues that need to be addressed in one or more subsequent phases of this CapX2050 effort, and how to best integrate our efforts with those of MISO and others.

We don’t have all the answers today but we will work on comprehensively studying a long-term transmission vision that will facilitate a greater reliance on non-dispatchable resources while ensuring reliable, safe, and affordable energy is provided to the consumers we serve. This remains a unified objective of the CapX2020 members. We will need to partner with our consumers, communities and stakeholders to embrace the changes of the future and address the challenges ahead of us, encourage innovation, and forge a path in the evolving energy future.

INTRODUCTION

Who We Are

CapX2020 is one of the largest transmission-development initiatives in the nation. Our duty is to reliably and affordably serve consumer's current and future power supply needs and growth. Our goal is to enable regional energy policies and provide safe, reliable, and affordable energy in the evolving electric industry.

The ten CapX2020 utilities include cooperatives, municipals, and investor-owned utilities providing reliable transmission service to nearly 5.5 million electric customers, consumers, and members ("consumers") for decades. Collectively, we operate over 42,000 miles of transmission lines in our combined service territories and are national leaders in planning, building, and maintaining a reliable transmission system capable of using the most cost-effective resources available. The CapX2020 utilities include:

- Central Municipal Power Agency/Services
- Dairyland Power Cooperative
- Great River Energy
- Minnesota Power
- Missouri River Energy Services
- Otter Tail Power Company
- Rochester Public Utilities
- Southern Minnesota Municipal Power Agency
- WPPI Energy
- Xcel Energy

Our ability, experience, and dedication to providing consumers with safe, reliable, and affordable energy allows us to plan and implement a future grid that can be flexible. It is our duty, as owners and operators of the transmission system, to enable consumers - and all users of our regional transmission grid – to achieve the energy choices they desire in the future.

The CapX2020 initiative began in 2004 with the intention of planning and constructing the transmission facilities necessary to maintain electric reliability and supply additional capacity for load growth while also providing transmission capacity for the development of non-dispatchable resources within the operating areas of the CapX2020 utilities. The initiative included the successful development of five major high voltage transmission projects: Big Stone South (SD) to Brookings County (SD); Brookings County (SD) to Hampton (MN); Fargo (ND) to St. Cloud (MN) to Monticello (MN); Bemidji (MN) to Grand Rapids (MN); and Hampton (MN) to Rochester (MN) to La Crosse (WI). This $2 billion expansion, consisting of approximately 800 miles of new 161kV, 230kV and 345kV transmission lines and 22 substations created a high-voltage transmission backbone necessary for a robust grid in the Upper Midwest. In total, the transmission lines enabled the interconnection of approximately 3,600 megawatts (MW) of wind generation which powers over 1.5 million homes and avoids 6.3 million tons of carbon dioxide (CO_2) per year. At present, approximately 50 new generation projects have requested to interconnect to these new transmission facilities. The CapX2020 projects are the largest development of new transmission in the area in over 40 years and have changed the energy landscape of the region.

Obligation to Serve

As transmission owners and operators, we are obligated to operate and maintain a safe, affordable, and reliable system within our bounds. In fact, our duty to serve is provided for in Minnesota Statute 216B.04 which states: "Every public utility shall furnish safe, adequate, efficient, and reasonable service…" Additionally, Statute 216B.029 states that "The commission and each cooperative electric association and municipal utility shall adopt standards for safety, reliability, and service quality for distribution utilities. Standards for cooperative electric associations and municipal utilities should be as consistent as possible with the commission standards."

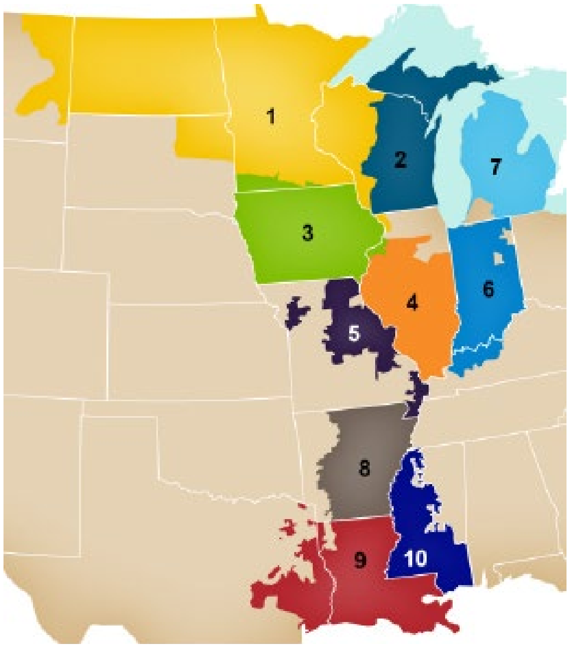
NERC, formed in 1968, is a non-profit entity that oversees six Regional Entities. NERC's primary responsibility is to develop power system standards, monitor and enforce those standards, and ensure power system operators are qualified through training. The CapX2020 utilities are a part of the Midwest Reliability Organization (MRO), one of the six Regional Entities overseen by NERC. The MRO provides "clarity on industry expectations and regulatory requirements; assurance of reliable operations across the connected power grid; and results that improve the reliability of the bulk power system".

Additionally, the CapX2020 utilities are transmission-owning members of the Midcontinent Independent System Operator (MISO). MISO is an independent, non-profit Regional Transmission Organization that delivers safe, cost-effective electric power across 15 U.S. states and the Canadian province of Manitoba. MISO provides non-discriminatory access to the transmission network under the guidance of FERC regulations, manages the movement of power across the grid through a wholesale energy market and performs regional transmission planning with stakeholders.

In addition to state regulations, utilities are also governed by federal entities such as the Federal Energy Regulatory Commission (FERC) and non-governmental organizations (NGOs) delegated by FERC such as the Midcontinent Independent System Operator (MISO), the North American Electric Reliability Corporation (NERC) and its regional delegate the Midwest Reliability Organization (MRO). The Institute of Electrical and Electronics Engineers (IEEE) is a leading NGO that encourages advancements of standards relating to new technology, providing guidance when it comes to reliably serving our consumers.

This report includes a discussion on some of the current regulations and guidelines including how they may need to adapt integrate more non-dispatchable resources. For the purposes of this report, we generally discuss grid operation including generation and transmission, consumer demand (load), and import/export relationships in the MISO Local Resource Zone 1 (LRZ 1). Figure 1 depicts LRZ 1 in yellow.

Figure 1. Local Resource Zones (LRZ)



Purpose of this Report

The goal of this CapX2050 Transmission Vision Report is to educate and inform Upper Midwest policymakers and other stakeholders of the implications of a future that is more reliant on non-dispatchable resources; it is not intended to forecast the future of the upper Midwest transmission system in 2050. The challenges identified in this report are intended to help stakeholders and policy makers better understand the impacts of the generation transition occurring. As owners and operators of the transmission system, we believe that it is important to understand these challenges. Specifically, the report addresses the critical elements that are necessary to continue operating a safe and reliable grid; describe how weather has, and will continue to influence how we plan and operate the transmission grid that includes more non-dispatchable resources; and identify what policies and procedures may need to change to successfully transition to a reduced-carbon future. It will provide foundational information upon which to identify transmission solutions and potential technology opportunities to integrate more non-dispatchable resources in the future.

This report does not provide definitive solutions to the issues that are expected to arise as the dispatchable resource fleet transitions to a non-dispatchable resource portfolio, nor does this report predict where modifications or additions to the transmission system should occur. Collectively, the CapX2020 utilities have the experts and industry experience and we envision this report to be the start of further study phases that will account for a future which is more reliant on non-dispatchable resources with the objective of maintaining a transmission system which offers reliability, safety and affordability.

Dispatchable Resources: Generation resources that may be called upon with short notice to meet immediate customer needs. Utility operators depend on these resources’ ability to ramp up or ramp down their energy output as needed by the system. Dispatchable resources include resources such as coal, natural gas, hydro-electric, and nuclear facilities. Future dispatchable resources may include various new technologies.

Non-dispatchable Resources: Intermittently operating resources whose output cannot generally be controlled when operating. In particular this refers to wind and solar facilities without energy storage. Due to its variability, real-time operators cannot depend on the desired amount of energy at a specific time.

TRENDING: A REDUCED-CARBON FUTURE

The transition to a reduced-carbon future has woven its way into all aspects of our economy. In this section we discuss the state energy goals in the Upper Midwest and a few carbon-reduction goals of the companies who operate within our collective service territories. As transmission owners and operators, we are committed to providing a transmission system that supports different generation scenarios and ensures reliability.

In 2007, Minnesota Governor Tim Pawlenty signed the Next Generation Energy Act which requires the state to reduce its greenhouse gas emissions (GHG) by 80% between 2005 and 2050. The Act also supports clean energy, energy efficiency, and supplementing other renewable energy standards in Minnesota. Interim goals included a 15% reduction in GHG by 2015 and 30% reduction by 2025. According to the Minnesota Pollution Control Agency's (MPCA) January 2019 Greenhouse gas emissions in Minnesota: 1996-2016 biennial report, GHG emissions declined by 12% relative to 2005 levels, missing the 15% reduction by 2015 goal. It is important to note that emissions from electricity usage have been reduced by about 29% since 2005. The electricity generating sector has almost reached the 2025 emissions reduction goal. The MPCA report projects that as large, dispatchable resources are retired, electricity-based emissions will continue to decline.

In 2016, Minnesota advanced the 2025 Energy Action Plan, laying out a path forward for Minnesota to move toward a clean, reliable, resilient, and affordable energy system. The Energy Action Plan identifies strategies to capture opportunities that can strengthen Minnesota's clean energy leadership and help to meet the goals established by the Next Generation Energy Act.

Additionally, Minnesota Governor Tim Walz has stated that he will push for legislation and issued an executive order that would lead to 100% carbon free electricity by 2050, stating he wants utilities to be able to determine how and at what pace they achieve the goal.

In fall 2019, Wisconsin Governor Tony Evers issued Executive Order #38 that directs the new Office of Sustainability and Clean Energy to "achieve a goal of ensuring all electricity consumed within the State of Wisconsin is 100% carbon-free by 2050."

While North Dakota has not recently announced any additional goals around renewables, in 2007, North Dakota established a "Renewable and Recycled Energy Objective". That objective set a goal of 10% of all electricity sold at retail within the state by 2015 be obtained from renewable energy and recycled energy sources.

Similarly, while South Dakota has not recently announced any additional goals around renewables, in 2008 South Dakota established a "Renewable, Recycled and Conserved Energy Objective". That objective sets a goal of 10% of all electricity sold at retail within the state by 2015 be obtained from renewable energy and recycled energy sources.

Despite having less aggressive carbon reduction goals than Minnesota or Wisconsin, the impacts of the trend toward carbon-reduction in other Upper Midwest states may impact North and South Dakota. Both states have good resource availability for non-dispatchable resources, including wind and solar, while the interconnected nature of the transmission system means they, along with other states, will likely be impacted as the generation fleet transitions.

In addition to the Upper Midwest states advancing toward reduced-carbon generation resources, so have many Midwest companies. Companies within our service territories committed to a reduced-carbon future will rely on our reliable transmission system to achieve their goals. Here are just a few energy goals from companies in our region.

3M: Committed to reducing their GHG emissions by at least 50% below their 2002 baseline and increasing total renewable energy use to 25% percent by 2025. As of 2018, they've met or exceeded both goals. 3M's entire 409-acre headquarters is now powered 100% by renewable energy.

Ancillary Services:
For the purposes of this report, grid attributes outside of the production and delivery of real power such as frequency control, inertial energy, voltage regulation, and short circuit current are collectively referred to as 'ancillary services.' They are the collection of attributes that support a reliable grid by helping maintain system strength, stability, and reliability.

Cargill: Committed to reduce absolute GHG emissions in their operations by a minimum of 10% by 2025, against a 2017 baseline.

Ecolab: Goal to reduce GHG emissions by 50% by 2030 and to net-zero by 2050.

Organic Valley: Announced in August, 2019, that construction of three community solar projects totaling approximately 12 MW is complete, making the cooperative 100% powered by renewable resources.

The Minnesota Sustainable Growth Coalition: A business leadership group of nearly 30 organizations committed to sustainability, and recognizing that together they can have a larger, societal-level systemic impact on their operations, industries, environment, and community. Their collective vision is to surpass the State of Minnesota's current economy-wide GHG targets of 30% reduction by 2025 and 80% reduction by 2050.

GRID OPERATIONS

As previously stated, the operation of a safe and reliable transmission system is regulated by government agencies and non-governmental organizations. This report focuses on the transmission system because as transmission operators, planners, and owners we all have a responsibility to remain compliant with various standards enforced by the entities that regulate us.

In this section, we discuss the technical fundamentals that all transmission owners and operators must maintain to assure the reliable transmission of energy to consumers: system stability and system strength. Grid operations in a future more reliant on non-dispatchable resources will require more situational awareness and the ability to accurately identify and respond to disturbances.

Fundamentals of Reliability

The transmission grid was generally developed to move power from large, dispatchable resources (coal, nuclear, natural gas, and hydro-electric plants) to consumer demand areas, sometimes close in proximity, but oftentimes located far from the high-demand load centers they served. This configuration has operated successfully for decades by enabling reliable and affordable service to consumers. As increasing amounts of non-dispatchable resources have been added, changes have been made to transmission infrastructure and operations; however, many dispatchable resources are still operating and providing the necessary ancillary services, along with energy, to the grid.

When considering large-scale changes to generation resources (additions and retirements), we must do more than just replace the energy these resources provide but also determine how to provide the ancillary services that are essential to maintaining grid reliability and energy supply to consumers. Operating the grid is extremely complex and requires the management of numerous critical factors within defined limits, including but not limited to facility loadings, thermal and voltage ratings, voltage stability, frequency, and inertia, etc. For discussion purposes, we've focused our attention in this section on just a few critical components of reliability.

System Stability

In order to reliably serve consumers, it's critical that power system operators maintain system stability. In other words, it is our responsibility to ensure that our system responds predictably to disturbances on the system to minimize prolonged outages. A stable system operates normally under all reasonably expected conditions and is able to quickly return to a normal state if there is a disturbance to the system. Disturbances may include a transmission line or generator tripping off-line in response to a problem. First, we'll provide information on the key ancillary services attributed to system stability: frequency and inertia. Then we'll discuss disturbances on the grid and how responses to those disturbances are managed.

Frequency

In a stable U.S. power system, energy on the grid is constantly flowing at a rate of about 60 Hz (a frequency of 60 voltage cycle changes every second). This frequency is maintained by balancing how much energy is loaded onto the system and how much is used by consumers. If energy generation and consumer demand are generally equal, the frequency of the system remains stable at 60 Hz. If energy generation exceeds consumer demand, the frequency rises above 60 Hz. Conversely, if consumer demand exceeds generation, the frequency falls below 60 Hz. Consumer demand must equal energy production at all times to keep the system balanced. Without a balanced system, some end-use consumer equipment does not operate as intended when it is exposed to large frequency deviations from 60 Hz. Figure 2 depicts the relationship of energy supply and demand with system frequency.

Figure 2. Maintaining Frequency: Energy Supply and Demand

Inertia

Inertial energy helps maintain system stability. Dispatchable resources create energy by spinning massive rotating turbines and generators. When combined, the entire system's spinning turbines and generators provide inertia on the system which slow the effects of disturbances on the grid caused by outages to transmission lines or generators. If a disturbance were to occur, the system would initially respond to falling frequency by taking inertial energy from the remaining spinning turbines online. Then generators would respond to any sustained fluctuations by changing the amount of fuel delivered to the turbine, to increase or decrease the generator power production. Without sufficient inertia, this ramping action may be unable to return the system to a stable state (60 Hz).

Disturbance Event Response

NERC reliability documentation characterizes system stability as three distinct concepts: Pre-disturbance Equilibrium (how the system is currently balanced and operating), Disturbance Event (how disturbances, large or small, affect that balance), and Post-disturbance Equilibrium (how well the system regains balance after a disturbance). In the event of a disturbance to the system, there are several key variables that are monitored to ensure a reliable and predictable response occurs.

Rate of Change of Frequency

The Rate of Change of Frequency (RoCoF) is the rate at which the system is impacted by an event. It measures how fast the frequency decreases from 60 Hz.

Frequency Nadir

The nadir is the greatest point of system frequency departure from 60Hz. It is the point at which controls, including the generators, stop the drop in frequency, and after which the system starts to recover. In other words, the peak level of disturbance of an event.

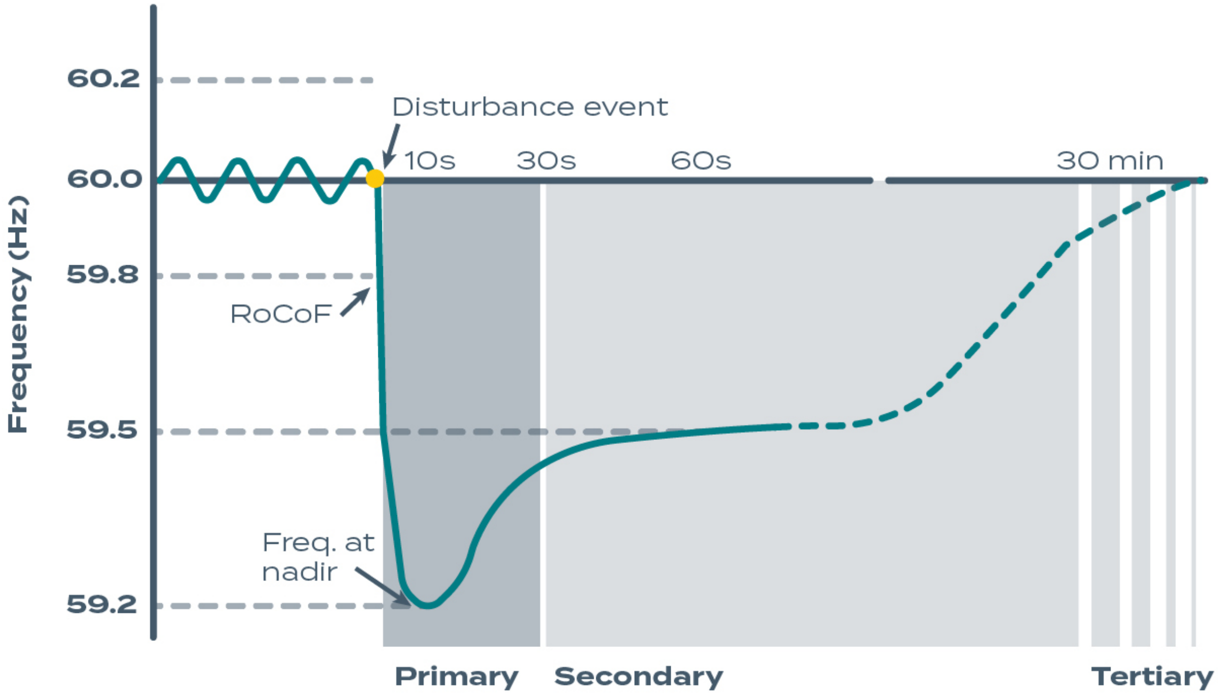
If the RoCoF is too steep, or the frequency nadir is outside the acceptable range for a given area, the system could involuntarily disconnect consumers or even suffer a catastrophic collapse and could result in that area becoming disconnected (islanded) from the rest of the electric grid.

Phases of Response

When a disturbance occurs, there are three phases of system response. The Primary response is generally a mechanical or electrical response that occurs very quickly – fractions of a second to a few seconds. Secondary response continues to restore system frequency to stable operating levels on a slightly longer time scale – seconds to minutes. Finally, Tertiary response (also known as reserve response) is intended to take the system back to normal operating conditions by economically rebalancing generation and demand.

Figure 3 depicts the RoCoF and frequency nadirs in a disturbance event and the subsequent phases of response thereafter.

Figure 3. Disturbance Response



This figure shows the grid operating at 60 Hz until an incident (yellow dot) creates a disturbance. In this example, the RoCoF is how quickly the frequency dropped and the nadir is the greatest drop in frequency experienced before the primary response mechanisms were able to stop the frequency drop.

Non-dispatchable resources, as presently operated, generally do not provide the same amount of inertia as dispatchable resources. Non-dispatchable resources are unable to maintain frequency by tapping the momentum stored in their turbines, nor can they adjust their fuel consumption (change wind speed or solar irradiance) in response to a system disturbance or changing load levels. Non-dispatchable resources may be able to provide stability support when operating if they contain advanced inverter technology.

KEY TAKEAWAYS ABOUT SYSTEM STABILITY

It’s imperative that we maintain grid stability by balancing energy production and consumer demand. The current mechanism to best maintain stability is the amount of inertial energy and response capabilities of the system.

As dispatchable resources are replaced with more non-dispatchable resources, it will be important to replace them with resources that can provide the same attributes and ancillary services that maintain system stability.

Non-dispatchable resources, while they have some attributes to help maintain system stability, do not have all of the necessary attributes to maintain system reliability. In addition, unlike most dispatchable resources, non-dispatchable resources are not available at all hours of every day. The current fleet of non-dispatchable resources provide ancillary services in different ways with different characteristics when they are operational, which may not always meet the system needs.

As we increase our reliance on non-dispatchable resources, we need to ensure that we have the right mix of ancillary services available at the right times and in the right locations to ensure that grid operations remain stable and to facilitate a real-time response in the event of a disturbance. These sources of ancillary services in the future may be provided by a combination of non-dispatchable resources, dispatchable resources (storage, synchronous condensers, natural gas, hydro-electric, load control, etc.), additional transmission system equipment such as static synchronous compensators (STATCOM), and technology not yet realized today. Future system strength and stability issues along with these potential mitigation alternatives will need to be explored and analyzed to identify the most effective method for maintaining a reliable grid.

System Strength

System strength is typically measured by the available fault current or by the Short Circuit Ratio (SCR). Available fault current refers to the amount of current flowing from generators to a short circuit on the transmission system. Automatic protection schemes and control systems need a certain minimum amount of current flow to reliably operate. The stronger a system is, the more quickly and reliably it can respond - and mitigate - disturbances. In weak systems, maintaining operational control and reliability in response to disturbances can become increasingly complex.

Fault Current

There are a number of different types of faults, but for this discussion, a fault or fault current is an abnormal electric current on the system due to a disturbance event.

Short Circuit Ratio

A short circuit is the resulting impact of a fault that results in the electrical current on the system exceeding the normal load. In protection and control systems, the difference between normal system condition and abnormal conditions is measured and used as a reference point to adequately protect the grid. The difference between normal and abnormal conditions is referred to as the SCR.

In today's system, areas with low SCR make it difficult for protection and control systems to differentiate between normal and abnormal conditions caused by a disturbance. Because of this, an abnormal condition may be allowed to propagate further than desired due to misidentification of a condition by the protection system. The reverse may also occur where protection and control systems may take action to mitigate a perceived abnormal condition when in reality the system was operating under a normal condition.

Today, most wind and solar facilities use inverters that are "grid-following" meaning they rely on a strong reference signal from the electric grid to operate in a reliable manner. Without a strong system providing a strong reference signal at the point of interconnection, the operation of these inverter-based generation resources may become less predictable, or in extreme cases, they may become inoperable all together. Alternatively, grid-forming inverters are an emerging technology that may operate without a strong reference signal and provide some of the ancillary services that existing dispatchable, non-inverter-based resources provide. The differences in grid-following and grid-forming inverters contribute to the reason why SCR as a measure of system strength isn't universally accepted.

Voltage Regulation

Voltage is the force that makes electricity move through the grid. Large changes to voltage levels can cause system instability and damage to electrical components, and even cause outages. A strong system can be measured by its ability to maintain voltage control in response to disturbances. Devices such as voltage regulators and capacitor banks are used to help maintain acceptable voltages on the transmission and distribution system within reasonable operating conditions.

Dispatchable resources add to system strength by acting as strong voltage sources ("reference signal") and are typically able to provide over 6 times their normal energy output during abnormal conditions. Their generator turbines spin at regulated or controlled speed so adjustments to the output voltage can be accomplished very quickly by changing the input voltage.

Non-dispatchable resources are largely inverter-based power sources that act as a constant voltage source and are typically only able to provide up to 1.5 times their normal load output in abnormal conditions.

KEY TAKEAWAYS ABOUT SYSTEM STRENGTH

As non-dispatchable resources replace dispatchable resources the overall system SCR (i.e. the difference between normal and abnormal conditions) is reduced, making it harder for transmission protection systems to determine the difference between normal and abnormal conditions. The reduction in the SCR must be replaced or new methods for system protection must be developed.

Protection systems using today's technologies can also become less predictable or more erroneous due to their reliance on a strong system signal. In a future that is more reliant on inverter-based, non-dispatchable resources that have little to no short circuit contribution, new technologies may be required to reliably respond and isolate abnormal conditions on the transmission system.

As more non-dispatchable resources are added to the electric grid and dispatchable resources are retired, system disturbances may become more severe if other suitable system enhancements or resources are not implemented. Presently, dispatchable resources help maintain system stability by being strong voltage sources; however, the ancillary services market may need to provide more incentive for non-dispatchable resource owners to choose equipment with grid-forming capability over less complex grid-following equipment.

CHALLENGES OF A CHANGING FLEET

As we transition away from a relatively small number of traditional dispatchable resources in our region and toward a large number of dispersed and relatively small, non-dispatchable resources in different locations across the Upper Midwest, we are challenged by the difference in ancillary services each type of generation provides. But we are also challenged by the way in which predictable and non-predictable weather events affect the energy output of non-dispatchable resources. To illustrate, this section provides several analyses of the ability for non-dispatchable resources to meet consumer demand during peak demand or extreme weather events. Following that, we provide an 8,760 hour-by-hour analysis of energy surplus and deficit, and lastly, an analysis on dispatchable resource needs in a zero-carbon future.

Variability of Non-Dispatchable Resources

Delivering energy becomes complicated by the fact that non-dispatchable resource output is heavily impacted by daily weather patterns and fronts as well as the daily and seasonal sun and cloud patterns. The variability of their energy output, in conjunction with consumer demand patterns, can result in periods of excess energy output while at other times providing insufficient energy output. Three distinct historical weather-related energy generation/consumption mismatch events, described below, illustrate the impacts that weather variability has on meeting consumer demand.

Historical Energy Production/Consumer Demand Mismatch Days

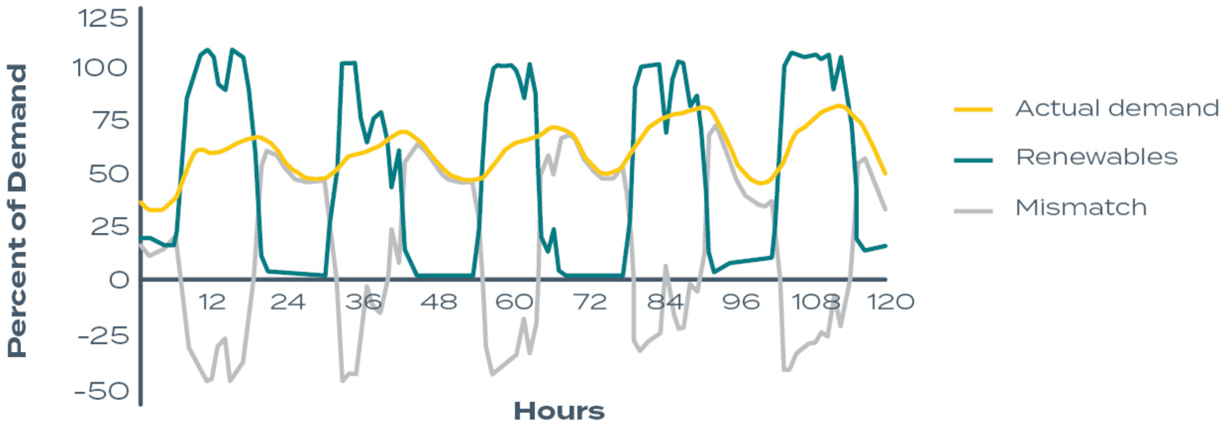
The review of historical market data illustrates the complexity of a sole reliance on non-dispatchable resources to deliver reliable energy that meets consumer demand in all hours of the year. Three historical events are recreated below in which it is assumed that there are no dispatchable resources to complement non-dispatchable resources. For each event non-dispatchable resource output and consumer demand are normalized, allowing the analysis of equal levels of nameplate wind, solar capacity and customer demand (i.e. for every 1 MW of peak demand there is 1 MW each of nameplate solar and nameplate wind). Actual consumer demand and renewable output values were then netted against each other to show the mismatch, or net demand in those hours. In each case, negative values for the mismatch (net demand) data indicates potential energy export to other areas outside of MISO LRZ 1 (refer to Figure 1) or generation curtailment scenarios. Curtailment is the reduction of non-dispatchable resource output below what it could have otherwise produced. Conversely, positive values for the mismatch data indicates the potential need for energy import from other areas outside of LRZ 1 or increased reliance on dispatchable resources.

July 28-31, 2018: System Peak with Negligible Wind Contribution

Wind and solar energy output can be predicted for typical weather patterns and is generally granted a level of accredited (expected) capacity based on its expected level of energy output during peak consumer demand periods. However, given the variability of non-dispatchable resources, it cannot be guaranteed that the expected amount of energy will be available to serve consumer demand during peak consumer demand periods. An example of this scenario occurred over a four-day period during July 28-31, 2018 over a wide area within the MISO footprint. During these potential peak demand days of summer, wind produced well below its expected levels for over 100 consecutive hours while high output from solar resource was ineffectual due to low penetration levels.

Normalized data is shown to better depict the mismatch in renewable output versus demand. In Figure 4, there are distinct hours where renewable output exceeded consumer demand (teal line exceeds yellow line) and areas where renewable output was significantly less than consumer demand (yellow line exceeds teal line). The mismatch that occurred when renewable output did not match or meet consumer demand is shown as the positive values of the gray line. Conversely, the mismatch that occurred when renewable output would have exceeded consumer demand is shown in the negative values of the gray line.

Figure 4. July 28-31, 2018 Normalized Market Data



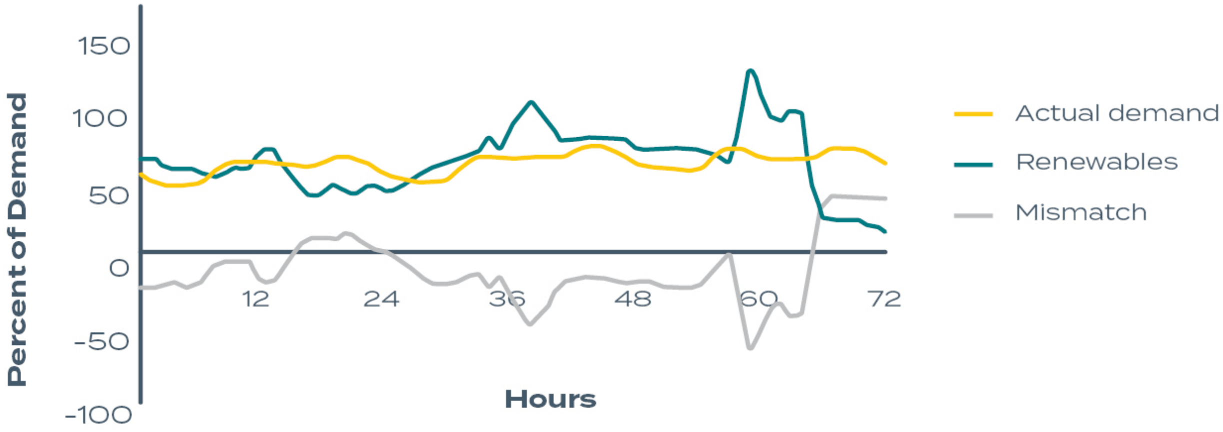
During the hours that wind was production was negligible, solar output reached nearly 100%. When solar output exceeded consumer demand, energy export and/or generation curtailment would have likely occurred.

During the periods where solar output did not meet consumer demand (i.e. at night), mitigation measures such as ramping up of dispatchable resources and/or importing energy to 'fill the gaps' to meet consumer demand would likely have been employed.

January 8, 2019: Historic Wind Peak

There are times in which non-dispatchable resources produce energy at levels significantly higher than their accredited level. On January 8, 2019, MISO recorded a historical peak of wind energy being produced on the system. Normalized data is shown in Figure 5.

Figure 5. January 8, 2019 Normalized Data

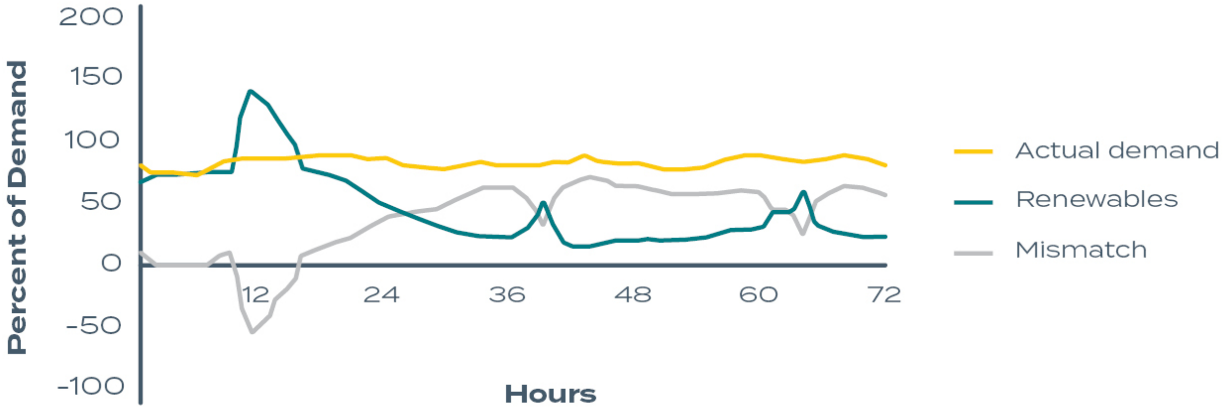


As shown in the figure above, there would have been more renewable energy being produced than the total consumer demand (teal line exceeds the yellow line). In this event, the mismatch shows swings in energy imports (positive values of the gray line) and energy exports (negative values of the gray line), nearly exceeding 50% of consumer demand. Simulations show that the present import/export capabilities of the transmission system in this region are less than 40% of the peak consumer demand in this region and would have been exceeded during this event.

January 29-31, 2019: Polar Vortex

Non-dispatchable resources are significantly impacted by the environment in which they are operating. This extends to when those renewable resources are exposed to conditions outside of their designed operating limits. As shown in the data from the 2019 Polar Vortex, despite having relatively high wind speeds for much of the time depicted, the output from wind resources was significantly lower than expected due to the ambient temperature dropping below the minimum operating temperature of the wind turbine equipment. This also occurred at a time in which solar resources were unavailable (i.e. due to snow cover on many of the solar panels in this region and during nighttime hours). Normalized data is shown in Figure 6.

Figure 6. January 29-31, 2019 Normalized Data



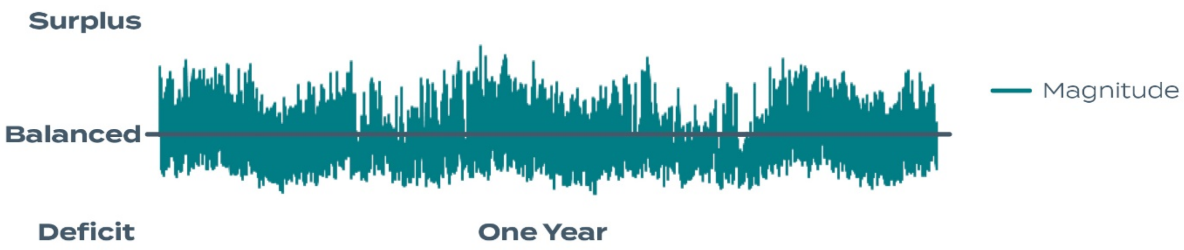
This graph shows an extended period during which renewable output would not have met actual consumer demand (positive values of the gray line) without contribution from dispatchable resources.

The conclusions we can draw from these three mismatch examples is that non-dispatchable energy output does not always match up with consumer demand. As dispatchable resources are replaced by non-dispatchable resources, it will be important to find alternative resources than can be dispatchable and provide ancillary services and energy when and where it’s needed.

Meeting Hourly Consumer Demand

Beyond the isolated examples of extreme specific, short-duration events detailed above, we performed an analysis to illustrate the extent that non-dispatchable resources could serve consumer demand in all hours of the year. We compared non-dispatchable resource production (based on MISO wind output and available hourly solar output) to hourly consumer demand data for a typical year. Figure 7 displays the energy surplus and deficit over the course of that year.

Figure 7. Forecasted Energy Surplus and Deficit



This exercise demonstrates that attempting to meet peak consumer demand of 20,000 MW with 40,000 MW of non-dispatchable resource capacity (i.e. for every 1 MW of peak demand there is 1 MW each of nameplate solar and nameplate wind) - and assuming perfect delivery of energy from renewable resource location to demand center - results in numerous instances throughout the year when consumer demand would not be met without some source of dispatchable resource (See several hours that have a deficiency). Through this evaluation, it was determined that there could be periods in which 85% of consumer demand would need to be met by a combination of actions or conditions, such as dispatchable energy resources, demand response and/or imports from other regions.

2050 Zero-Carbon Analysis

In addition to the historical analyses provided above, an analysis was conducted with production cost modeling software to determine whether there could be insufficient energy generation to meet consumer demand in 2050. Three scenarios were reviewed, each consisting of the lowest wind four-day period in the summer and winter, for a total of eight days per scenario. Similar to the historical analyses described above, this analysis highlights the challenge of meeting hourly consumer energy requirements with non-dispatchable resources exclusively, or near exclusively, when experiencing not-uncommon extreme weather events. Sensitivities that varied the assumptions for nuclear generation status and/or renewable resource type mix were not included in this analysis.

All scenarios were conducted for a hypothetical 2050 and assumed that all coal generation within the MISO LRZ1 footprint and neighboring local resource zones (LRZ 2 & 3) had been retired and replaced with non-dispatchable resources (wind and solar). The characteristics of the scenarios are described below:

Scenario 1 - Baseline: Baseline consumer demand and non-dispatchable output

Assumptions:

- Dispatchable natural gas simple- and combined-cycle resources are available
- 23.8 GW of wind and 15.8 GW of solar
- 90% of annual energy requirements are met with non-carbon emitting resources

Scenario 2 – Extreme Weather Event & Natural Gas Retired: Increased consumer demand by 15% above winter and summer peak

Assumptions:

- Natural gas retired
- 23.8 GW of wind and 15.8 GW of solar
- 100% carbon-free

Scenario 3 – More Non-Dispatchable Resources: Baseline consumer demand; non-dispatchable resources increase 10 GW (wind) and 10 GW (solar) above Scenarios 1 and 2

Assumptions:

- Natural gas retired
- 33.8 GW of wind and 25.8 GW of solar
- 100% carbon-free

Results

Simulation 1 results showed a heavy reliance on natural gas generation during both the four-day summer and four-day winter periods to meet consumer demand during low wind periods. In the extreme summer and winter weather events simulated in Scenario 2, all consumer demand could not be met in all hours of both four-day periods analyzed, demonstrating that replacing natural gas generation with large additions of non-dispatchable resources alone is not a viable solution to achieve energy balance in the most severe hours of the year. In Scenario 3, the addition of non-dispatchable resources beyond what was modeled in Scenario 2 failed to satisfy the consumer demand that was unable to be met in both four-day periods analyzed in Scenario 2.

The results showed there are many extended periods of time where the CapX2020 footprint is generation-deficient in a 100% carbon-free future. Adding more non-dispatchable resources in this area would not mitigate deficient energy periods because under these weather conditions, non-dispatchable resources would produce little additional energy. During generation-deficient time periods, there would be a need for dispatchable resources to generate for several days, meaning that using only short-term or daily cycling energy storage is not a viable solution. Storage would need to have high capacity and be available for multi-day durations.

KEY TAKEAWAYS OF THE VARIABILITY OF NON-DISPATCHABLE RESOURCES

The variable nature of non-dispatchable resources causes periods of time of insufficient energy output and times with excess energy output in relation to consumer demand. As dispatchable resources are replaced by non-dispatchable resources, it will be important to find alternative resources or technology enhancements that can be dispatchable and provide ancillary services and energy when and where it's needed. It may also require transmission expansion to facilitate the import/export capabilities of the region to address mismatched conditions.

The yearly study further demonstrates the effect of non-dispatchable resources on the grid by concluding that, when 40,000 MW of non-dispatchable resources is used to meet 20,000 MW of consumer demand, there will still be times in which 85% of consumer demand will need to be met by a dispatchable energy resource.

Lastly, the 2050 study, concluded that a reduced-carbon future needs dispatchable resources capable of generating for several days consecutively. This generation can come from existing technology, new technology advancements that enable long-term energy storage capability, neighboring areas via increased inter-area transmission capacity, or technology not yet realized today.

Heavy reliance on non-dispatchable resources to achieve a reduced-carbon future may result in the need for transmission expansion in combination with other grid solutions to allow energy to be imported and surplus energy to be exported during different times of the year. This expansion may be beyond the capacity of the existing transmission system necessary to get the non-dispatchable resources' energy to areas of consumer demand. However, the existence of increased interregional transmission capacity does not guarantee neighboring areas have energy available to export.

Increasing Non-Dispatchable Resources

MISO RIIA Study

Beginning in 2017, MISO embarked on a Renewable Integration Impact Assessment (RIIA) to analyze the regional impacts of increasing non-dispatchable resource penetrations across its footprint that extends beyond the CapX2020 utilities' combined footprint. The purpose of their study was to:

- Provide technically rigorous, concrete examples of integration issues related to non-dispatchable resources and examine potential solutions to mitigate them;
- Inform areas of focus and the sequencing of actions required as the addition of non-dispatchable resources increase; and
- Facilitate a broader conversation about non-dispatchable energy-driven impacts of fleet change on the reliability of the electric system.

This analysis was broken into several phases and is still currently underway. For the purposes of this report, we focus on the conclusions the MISO RIIA study made on the impacts of increased non-dispatchable resources on system strength and system stability.

System Stability Study

The MISO RIIA analysis also reviewed the impacts of non-dispatchable resources on system stability in the form of frequency response. Through this analysis, MISO found that retaining a stable and reliable system becomes more complex as the level of non-dispatchable resources increase. (Read more about **System Stability**).

In addition, MISO identified a more granular issue that shows the role today's dispatchable resources play in system stability. In this finding, MISO notes that with the reduction of large dispatchable resources (equipped with power system stabilizing equipment), small signal stability deteriorates on the region-wide system. Small signal stability is a core component of overall system stability and must be maintained to ensure a stable and reliable power system.

System Strength Study

As part of the MISO RIIA efforts, an analysis was performed to review system strength as non-dispatchable resource additions increased using the technologies of today. As shown below, when non-dispatchable resources are increased, the strength of the system deteriorates. (Read more about **Short Circuit Ratio** and **System Strength**).

Figure 8. Non-dispatchable Resource Additions and their Effects on System Strength

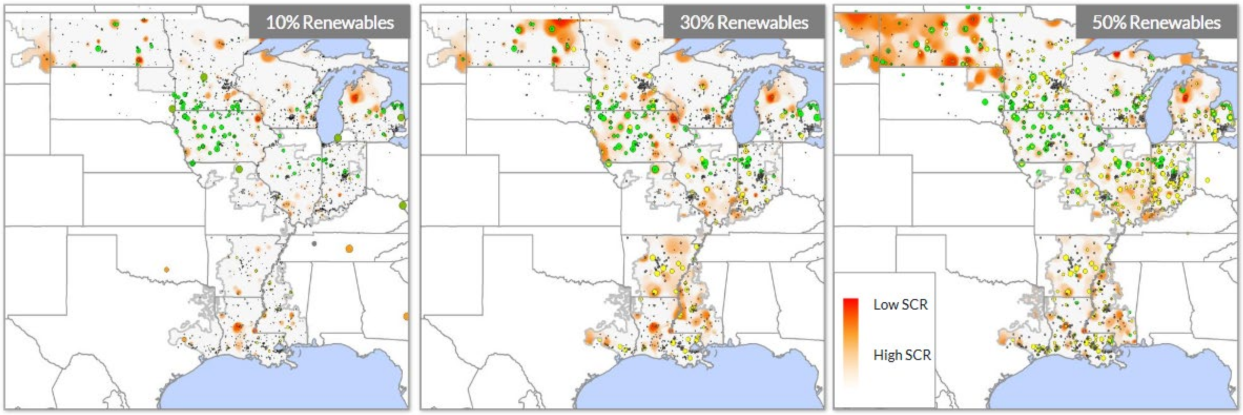


Figure 8 shows the progression of system strength deterioration (dark orange areas) as increasingly more non-dispatchable resources are added to the grid. Non-dispatchable resources provide little to no short circuit contribution, which is a functional measure of system strength. As discussed previously, this phenomenon increases the complexity of operating the system to reliably deliver energy to meet consumer demand.

KEY TAKEAWAYS FROM INCREASING NON-DISPATCHABLE RESOURCES

The MISO RIIA study indicates that several types of stability problems could occur when non-dispatchable resources comprise between 20% and 60% of all resources across the MISO footprint. The CapX2020 utilities operate in an area with the best wind resources relative to the rest of the MISO footprint. We expect our region to exceed the footprint-wide penetration level, meaning the CapX2020 utilities will be on the leading edge of finding and implementing solutions for expected stability challenges.

The results of the MISO RIIA study are also consistent with the CapX2020 utilities' findings that the transition from dispatchable resources to non-dispatchable resources will necessitate new and innovative solutions to maintain system stability and reliability.

Retiring Dispatchable Resources

Today's transmission system has evolved based on the understanding that large, dispatchable resources were available to respond to and mitigate the effect of (dampen) disturbances in the system. The existing dispatchable resources provide the necessary ancillary services to maintain system strength and provide immediate (i.e. less than 5 seconds) response during disturbances. Disturbances may include a transmission line or generator going off-line in response to a problem or undesirable fluctuations in voltage or frequency (read more about **Disturbance Event Response**).

The transmission system within this region has been developed over several decades with the objective of using the coal fleet to serve large consumer demand centers. Because of this historic coupling between generation and demand, ancillary services offered by the coal fleet were able to provide system stability. When these plants retire and are replaced with generation in different locations, the demand center may be served by generation resources located farther away. As both the geographic and electrical distance between generation resources and demand increases, the complexity of operating increases and the benefits of ancillary services provided by those resources is decreased. The resulting change has a negative impact to system stability that must be managed.

Before an owner is allowed to retire existing generation, MISO conducts an analysis of the retirement impact to the transmission system. If the analysis determines that the retirement of generation causes adverse reliability impacts, the generator owner will be required to keep the generator in-service until transmission projects or other solutions are placed into service to mitigate the impacts.

We discuss the implications of retiring dispatchable resources through the results of a large consumer demand center stability study and through a recent real-life example in northeastern Minnesota.

Large Consumer Demand Center Stability Study

A study was performed as part of a metro-focused study in conjunction with this report to determine the minimum amount of ancillary services required to maintain reliable service to a targeted large consumer demand center with major changes to the surrounding system.

Assumptions and Methodology

The analysis was performed using the 2018 MTEP dynamic model which represents light consumer demand and 90% wind output conditions in the year 2023. No load growth was assumed between 2023 and 2030 to limit the number of variables potentially affecting the results. Consistent with the industry trends, substantial additions of non-dispatchable resources were assumed to be added to the system. An addition of 5,800 MW of non-dispatchable resources dispatched at 4,440 MW was assumed to depict a higher reliance on non-dispatchable resources to replace the existing dispatchable resources. This study did not consider maintenance, forced outages, or economic factors into the ability of those services to be provided in all hours.

In order to determine system stability in this modeled environment, faults (i.e. disturbances) were simulated on the system to assess the ability of the grid to recover and return to a reliable state. (Read more about faults in **Disturbance Event Response**). This study was performed by 'turning off' dispatchable resources in a large metro area until stability issues were identified. To determine the level of stability services needed to maintain a stable system during severe conditions, previously retired dispatchable resources were 'turned back on' until the system was stable again.

Results and Conclusions

The results indicate that the system, as modeled today, cannot maintain stability without the assistance of a sufficient level of support that was, for this analysis, provided by dispatchable resources.

Furthermore, this stability study demonstrated that the system would remain stable when a fault occurs on a part of the transmission system where sufficient ancillary services are available from nearby dispatchable resource facilities. Whereas, a fault at a location farther from generation greatly increases the risk of system instability.

Finally, in these scenarios studied, an equivalent level of ancillary services as provided by the three natural gas generation facilities were all required to be operating at all times for the system to remain stable and sufficiently recover from disturbance events. This demonstrates the important role these services play in serving consumers with reliable electric service.

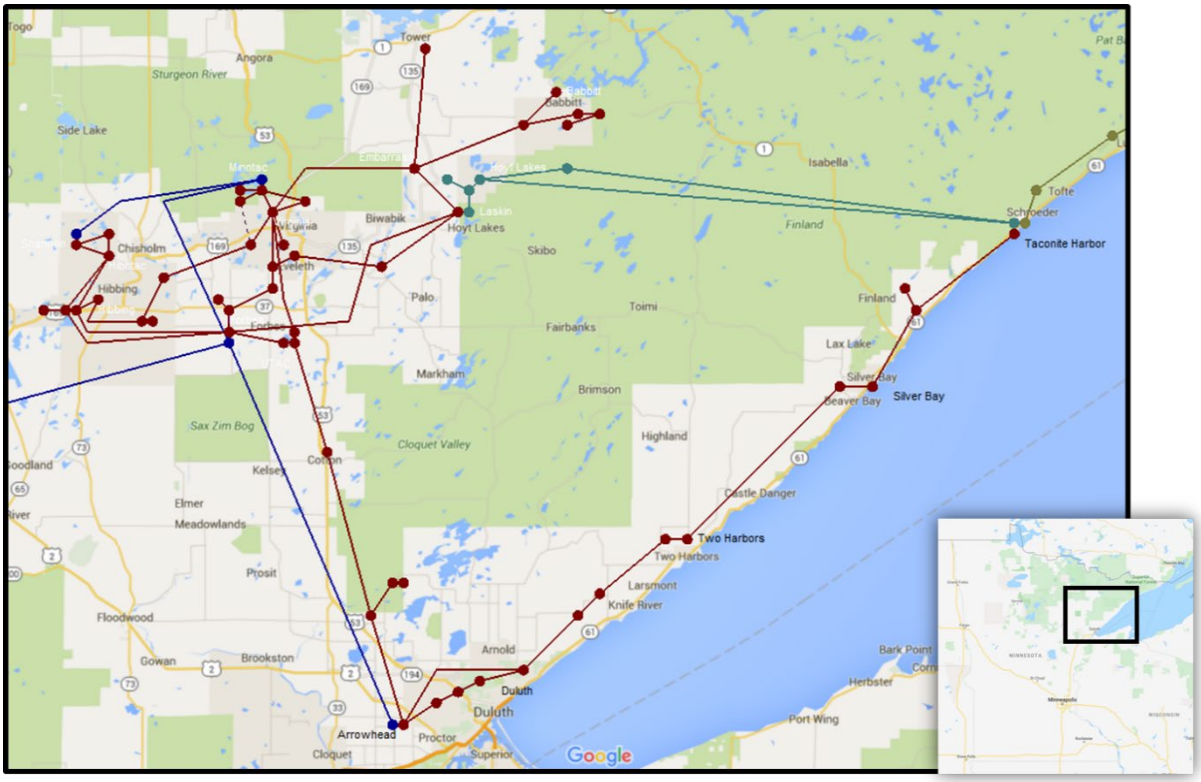
Minnesota Dispatchable Resource Retirement Example

The previous section details the expected system impacts resulting from retirement of dispatchable generating units in a large consumer demand center. Experience in our region has shown that even small-scale, dispatchable resource retirements cause transmission system impacts that must be mitigated and illustrates that transmission enhancements and/or expansion may be required in the future as dispatchable resources retire.

North Shore

The North Shore Loop (Figure 9) in northeastern Minnesota is a 140-mile system of 115kV (red lines), 138kV (green lines), and 230kV (blue lines) transmission lines and substations (dots) that are used by Minnesota Power and Great River Energy to serve consumers in a large area of northeastern Minnesota.

Figure 9. North Shore Loop Transmission System



Historically, the North Shore loop contained an abundance of dispatchable resources. Over a span of approximately five years beginning in 2015, all seven of the coal-fired generating units located at three sites have been idled, retired, or converted to limited dispatchable operation, operating only at times of peak consumer demand. The cumulative impact of these operational changes has effectively decarbonized the North Shore Loop, but leaves no dispatchable generators normally online to support the local grid.

Local dispatchable resources have contributed to the reliability of the North Shore Loop transmission system for decades by providing voltage support, power delivery capability, and redundancy, among other ancillary services. As a result of the rapid decarbonization of the North Shore Loop, several transmission projects throughout and adjacent to the North Shore Loop have been implemented since 2016 to maintain reliability. The most significant and complex of these transmission projects included a FACTS device (see **FACTS Devices**), specifically a static synchronous compensator (STATCOM) system in the Silver Bay area to support local voltage stability. Planning for this transition began in 2012 and project implementation is expected to continue through 2025 to fully address the reliability impacts of a fleet transition in the North Shore Loop.

KEY TAKEAWAYS FROM RETIRING DISPATCHABLE RESOURCES

The metro-focused stability study demonstrates that it is vital to perform a stability analysis and resolve any issues for each potential facility retirement so the analysis mirrors expected actual conditions at the time of retirement as closely as possible. The results of the stability study show that the technologies on the grid today cannot maintain system stability in a zero-carbon future without the assistance of a sufficient level of dispatchable resources or replacement of the ancillary services those resources provide. In the future, technology advances will be required so that non-dispatchable resources can provide the necessary capabilities when they are producing energy or, as an alternative, new technologies will need to provide the required ancillary services.

Additionally, the North Shore retirement example demonstrates that the replacement of dispatchable resources at their current locations and/or substantial transmission system development will be fundamentally essential to the reliable delivery of energy to serve consumer demand.

The results of the stability study for the large consumer demand center and experience within the North Shore Loop with small-scale dispatchable resource retirements support the ideas in this report; it is extremely important to consider the timing and location of dispatchable resource retirements, in addition to the type, timing, and location of incorporating new technologies into the electric grid. A discussion of new technologies begins in the next section.

STRATEGIES FOR CHANGE

The cost of non-dispatchable resources is decreasing; state and local jurisdictions have and continue to set decarbonization goals; and technological breakthroughs in energy technology and efficiency are on-going. The transition to a reduced-carbon future has woven its way into all aspects of our economy. While we can’t predict what breakthroughs may occur as non-dispatchable resources increasingly replace dispatchable resources, we will consider operational strategies based on what we know today and projections made by key technology experts in the industry. We have a history of planning, developing, and delivering transmission solutions to address system challenges and intend to remain industry leaders in the future.

To recap, here are the major drivers of change that we’ve discussed in this report:

- States, utilities, and individual corporations are setting goals for a reduced- or zero-carbon future. As owners and operators of the transmission system, the CapX2020 utilities – in conjunction with the federal agencies and non-governmental organizations that govern and inform us – we will be key players in achieving the goals of our stakeholders;
- When studied, the results of a reduced- or zero-carbon future indicate that some amount of system stability (frequency and inertia) and system strength (SRC and voltage control) is required; however, the technologies on the grid today cannot maintain reliable system stability without the assistance of a sufficient level of dispatchable resources or replacement of the ancillary services those resources provide. Furthermore, the MISO RIIA study concluded that the addition of more non-dispatchable resources and the reduction of large dispatchable resources will result in the deterioration of system strength and system stability;
- Wind and solar energy output can generally be predicted during typical weather patterns. However, given the variability of weather and un-predictable extreme weather events, we cannot always guarantee the availability of that energy to serve consumer demand at all times. The 2050 zero-carbon study concluded that in modeled simulations, there is still a need to rely on dispatchable resources during minimal wind periods and adding more non-dispatchable resources alone is not a viable solution to achieve energy balance in the most severe hours of the year.

The strategies outlined in this section begin to address the issues listed above and provide additional cause-and-effect discussions on the predicted challenges of transitioning to a future more reliant on non-dispatchable resources.

Technology Considerations

Topics discussed in this section are a summary of a few technologies that may be employed to accommodate the predicted challenges associated with transitioning the grid to a future more reliant on non-dispatchable resources. Ongoing research and development, and subsequent commercialization in these and other technologies, may support breakthroughs that make new and different types of solutions viable.

Additionally, it will be the responsibility of transmission owners and operators, federal regulatory bodies (FERC), and non-governmental organizations (NERC, MRO, MISO, and IEEE) to work together to develop standards, guidelines, policies, and training to accommodate these developing technologies and alternatives.

FACTS Devices

Flexible Alternating Current Transmission Systems (FACTS) is a collection of power electronics-based devices used to adjust the power transfer capabilities of the system and/or improve stability or controllability of the system, particularly at critical conditions. Essentially, FACTS devices help make the most of existing resources' distributing power, reducing transmission system losses and improving the efficiency of the transmission system.

As we transition to a future more reliant on non-dispatchable resources, it will be important to closely follow FACTS developments. Their intended purpose of increasing the utilization of the existing transmission system by increasing capacity, make them attractive devices for maximizing transmission capacity for both present and future generation portfolios.

Advanced Inverter Technologies

Inverters convert wind and solar energy from Direct Current (DC) to Alternating Current (AC) power so that it can be fed into the transmission system. Advancements in inverter technologies have expanded upon the basic conversion function to provide additional benefits that include:

- Ability to control the amount of energy fed into or removed from the transmission system to maintain system stability by providing frequency and voltage regulation, and
- Communication with distributed generators (see **Distributed Energy Resources**) to provide backup during minor disturbance events.

Non-dispatchable resources in use today generally utilize inverters that most often require an external power supply in order to operate. They rely heavily on having a strong, consistent AC signal from the surrounding system to operate effectively. Most renewable generators today are referred to as ‘grid-following’. If the external voltage is decreased as a result of a disturbance, the inverters turn off until a consistent AC signal is restored and thus the wind and solar resources they are connected to stop injecting energy into the transmission system. When this occurs, the load must be immediately served by another means (for example, dispatchable resources or imports from other areas).

A new technology to address this current-day issue is ‘grid-forming’ inverters. Unlike grid-following inverters, grid-forming inverters replicate the operations of dispatchable resources in helping to shape the AC signal of the system around them without reliance on a voltage established by an external source in the surrounding system. As inverter technologies become more heavily used, new breakthroughs of advanced inverters and dispatchable resources, and other transmission technologies will need to be developed to ensure a stable system with adequate system strength.

Distributed Energy Resources

Distributed Energy Resources (DER) are resources connected to the distribution system close to the consumer demand centers they’re intended to support. DER can include wind, solar, micro-grids and energy storage (see next section).

DER is primarily a local energy resource with little to no visibility or control by the transmission system operator. DER often has capabilities for demand response or ancillary services for the transmission grid that go unutilized (or even work against system needs) because it is impractical for each individual DER to be a market participant. In the future, it is feasible to consider that entities, such as utilities, may act as an aggregator for DER in a local area and participate in the energy and ancillary services markets or a regional transmission organization, like MISO, as a virtual power plant.

In a growing DER landscape, the transmission system wouldn’t be delivering energy from large, centralized generators all of the time, but may act as a network through which local areas could sell aggregated, excess energy produced via their DER systems. In essence, the role of the transmission system as being the connection point between sources of energy and concentrated areas of demand may remain largely the same, the difference being where and when those resources are producing and the areas and directions the power is transferred to meet consumer demand.

It should be noted that the increased use of DER challenges the current capabilities of the grid and challenges the existing operating paradigm. If the amount of DER surpasses the amount of local consumer demand at the same substation, power will flow onto the transmission system, resulting in present operational mechanisms and protections no longer operating safely and reliably.

As the use of the DER technologies grows, the wholesale energy market and operational paradigms will need to be redeveloped to accommodate these resources. The CapX2020 utilities will continue to research system protection systems and operational mechanisms that can adequately address an increase in DER.

Storage

As described in the **Historical Energy Production/Consumer Demand Mismatch Days** discussion, non-dispatchable resources will sometimes produce excess energy. This energy will need to be stored for later use, curtailed, and/or exported to other areas. In times of insufficient energy production, consumer demand will need to be served via dispatchable resources, or from stored energy, energy imported from other areas, and/or consumer demand will need to be reduced.

Storage devices include a broad range of different technologies such as batteries, flywheels, pumped hydro, power electronics (high-voltage, high-power, high-frequency materials), control systems (magnetics, capacitors), and software tools. Storage can be used to provide real-time energy to maintain a stable grid by releasing stored energy when non-dispatchable resources are insufficient and by storing energy during times of excess energy production from non-dispatchable resources. Storage can also provide some ancillary service contributions to the grid.

When there is sufficient capability on the transmission system to deliver energy from non-dispatchable resources to a storage device, it becomes a valuable energy resource to assist during periods of insufficient energy. It’s important to adequately size a storage device so it delivers the quantity of energy for the length of time necessary to accommodate the short-term and long-term needs of the transmission system. However, the value of storage to the transmission system is limited if there is inadequate energy to recharge the devices.

OVERVIEW OF TECHNOLOGY CONSIDERATIONS

Technologies, like FACTS devices, advanced inverters, DER, and storage may all be viable solutions in maintaining system strength, stability, and energy sufficiency with the increased use of non-dispatchable resources. Improvements in today’s technology, as well as new technologies that we can’t even name today, are expected over the next several decades that will assist in the development of the future electric grid.

The National Renewable Energy Laboratory (NREL), a highly-regarded energy research-based organization provided considerations for policymakers as they consider a reduced-carbon future; some of them are summarized below:

- Should non-dispatchable resources be required to contribute to grid-stabilizing ancillary services (frequency and voltage regulation) - and how long/often should they provide these services and should they be compensated for such services?

- Consider updating policies and rules that allow for more flexibility in the existing reliability criteria.

To enable the use of these technologies, the CapX2020 utilities will continue to work with policymakers and stakeholders to ensure that the transmission system continues to be safe, reliable, and affordable. A key foundational concept for utilities, regulators and other policy-makers in subsequent planning phases of this CapX2050 effort is to consider the degree to which the **Local Resource Zones (LRZ)** area should or must be self-sufficient in energy supply in a reduced-carbon future, including under extreme weather conditions. This concept has implications for the amount and type of dispatchable and non-dispatchable resources that will be needed and the transmission capacity within the area and to external regions to allow for the import/export of energy during different times of the year.

Transmission System Expansion Considerations

The transmission considerations discussed in this section provide a brief description of present operating circumstances and outlines the changes needed to accommodate a transitioning generation resource fleet.

In this section we discuss: high voltage direct current transmissions alternatives; transmission expansion related to the transition of dispatchable resources to non-dispatchable resources, load growth and predicting consumer demand, how power flows through the grid within and between regions, transmission planning, predicting customer demand, and maintenance.

High Voltage Direct Current (HVDC) Transmission

The transmission system of today was built to provide access to the most economic resources available. While the type, size, and location of those resources may change over time, the role of the transmission system to allow access to the most economic resources remains the same.

In comparison to today’s grid which primarily uses AC technology, HVDC transmission is appropriate for moving large amount of power long distances and other case-specific needs. With lower losses and greater power transfer capability compared to AC for the same corridor size HVDC transmission could be an appropriate mechanism for certain future generation development scenarios. Also, because HVDC lines connect to the existing transmission grid through the inverter technology, they have the ability to replicate certain ancillary services provided by localized generation. HVDC transmission technology has been used in LRZ 1 since the 1970’s, but technology has and continues to advance, providing more capability and flexibility than in the past.

Retiring Dispatchable Resources

The retirement of dispatchable resources has resulted in transmission system investments to assist in replacing the energy and ancillary services they once provided. Historically, dispatchable resources were typically located near consumer demand areas or had strong transmission interconnections to them; however, without these dispatchable resources, those consumer demand areas could become deficient in being able to provide the required amount of energy or ancillary services to meet consumer demand and may require new transmission facilities to import energy or provide the necessary amount of ancillary services.

Load Growth and Predicting Consumer Demand

The need to build new transmission was historically driven by peak demand growth. Peak consumer demand growth over the last decade has been minimal due to a combination of utilities' energy efficiency programs and economic slowdown. Growth began to increase as the economy improved, but as utilities continue to encourage efficient energy use by their consumers, growth remains low. Electrification, including transportation and other industries could change that. Today, however, most transmission system expansion is being driven by the need to integrate and deliver increasing amounts of non-dispatchable resources and the retirement of dispatchable resources.

Non-dispatchable resources and consumer demand - which are uncorrelated and often mismatched - are often summed together and called 'Net Load'. The Net Load changes on a continual basis which has caused transmission system planners to examine each of the 8760 hours in a year, not just the traditional seasonal peak and off-peak periods.

Historically, the profile of consumer demand generally followed the daily activities of an area. In a highly residential area, there will typically be a rise in demand in the morning hours as people start their day followed by a small reduction in demand while those people head off to work. Once the typical workday is over, the system would see the highest demand of the day as people return home and start evening activities such as preparing a meal and cooling or heating their homes. As people end their day, the demand drops to the lowest levels overnight until the next morning starts the cycle over again. In comparison, an industrial area will likely have a much flatter demand curve, only increasing or decreasing as their processes ramp up and down. A commercial area may have a load profile that looks nearly opposite of residential demand with the highest demand levels occurring during normal working hours.

There are two major consumer-side incentives that can help stabilize consumer demand: time-of-use rates and demand management. Time-of-use rates are variations in energy costs to consumers depending on the cost to supply the energy and sometimes the impact to the transmission and/or distribution systems. Demand management modifies energy consumption at the consumer's location that would naturally occur and includes a wide variety of programs and types of implementation, including direct control of consumer loads by a utility.

In a future that successfully implements incentives that modify consumers' consumption behavior, the varying demand profiles of today could become significantly less variable and much flatter. A near constant level of consumer demand would require a unique approach to operational planning. For example, consumer demand and energy supply would need to be simultaneously balanced to ensure demand is being served while other services, such as energy storage, are being replenished for use at another time.

Forecasting future consumer demand growth becomes more challenging as consumers contemplate DER and micro-grids, in addition to continuous energy efficiency improvements occurring in appliances and building design. When consumers are using energy provided by DER and micro-grids, they're less reliant on the energy the transmission system provides at those times, making it appear that consumer demand is lower than its maximum demand. At other times DER might impose its full output on the transmission system or conversely inject energy into it, bringing new challenges for ensuring a robust and reliable electric grid.

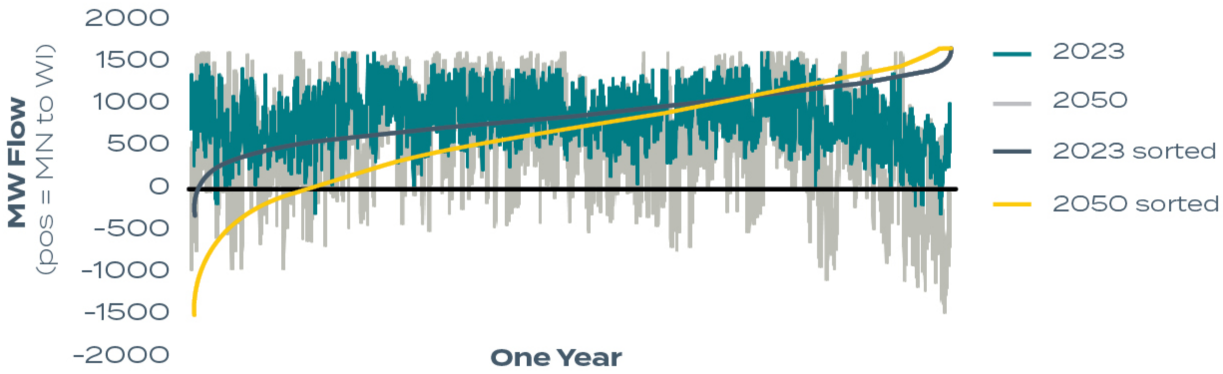
Interface Flow Patterns

Historically, energy between different regions of the transmission system, typically referred to as interfaces, flowed in one direction with minimal fluctuations. Three major interfaces exist within our region: North Dakota Export (NDEX), Manitoba Hydro Export (MHEX), and Minnesota-Wisconsin Export (MWEX). For the purposes of this report, we discuss one example, MWEX, to illustrate the challenges associated with energy flow between our region and neighboring regions – and how important it will be to accommodate changes in power flow in our operation of the future transmission system.

Example of Regional Interface Interactions

An analysis examining the annual power flows on the Minnesota-Wisconsin Export (MWEX) interface was performed to gain insight into operational differences between near-term conditions and a future with much more non-dispatchable resources. Figure 10 shows significant near-term, hour-by-hour variation between -500 MW to +1500 MW (green lines) in a near-term 2023 simulation. The 2050 simulation representing an even further fleet transition to include more non-dispatchable resources shows greater variability, widening to -1500 MW to +1600 MW (grey lines).

Figure 10. MWEX Interface Flow



In the 2050 scenario, electricity flows from Minnesota to Wisconsin during most of the year, but for 17% of the year the flow is in the opposite direction, from Wisconsin to Minnesota. This is unlike the near-term 2023 simulations where flow is from Minnesota to Wisconsin nearly 99.9% of the time.

As a result, it is expected that oscillating flow patterns, such as those across the MWEX interface, will occur more frequently and have higher magnitudes due to daily solar cycles, weather fronts, and increased geographic diversity of the non-dispatchable resources in the region. These changes could necessitate transmission system modifications to provide more capacity through certain interfaces and will certainly require more sophisticated operating techniques to deal with rapidly changing flow patterns.

Transmission Planning

Historically, transmission planning focused on several key distinct moments in the future; seasonal peak and off-peak periods and low consumer demand conditions. Each of these periods had well-defined base assumptions; the generation dispatch geography was well understood; consumer demand was based on projections developed from historical growth models; and power transfers were modeled based on transactions between entities. The idea was that if the system was deemed reliable during these key time periods then the system could be operated reliably during the rest of the hours of the year.

These historical assumptions were challenged as non-dispatchable resources were integrated into the transmission planning process. Early non-dispatchable resources had limited impact to transmission system planning due to their minimal size and share of the overall generation fleet. Due to the limited consumer demand growth, there were sufficient dispatchable resources available in the event that non-dispatchable resources did not generate. Additionally, because dispatchable resources typically have adequate fuel at all times, new non-dispatchable resources could be modeled based on their typical power output.

Increased reliance on non-dispatchable resources requires a more robust application of comprehensive, long-term planning processes that assure the transmission system is able to deliver adequate ancillary services to maintain system reliability at or above what is present today. The development of new transmission infrastructure is complex and can take seven to ten years to develop a single large-scale project. This development timeline could make it challenging to build the right projects within acceptable timelines. It is our obligation to provide a reliable transmission system so that a reliable supply of energy can be delivered to consumers during all hours of the year. Likewise, we must also develop the necessary transmission projects at the appropriate scale to avoid overbuilding, to retain flexibility to respond to unforeseen changes to the grid, and ensure affordability is balanced with reliability.

The existing rules and mechanisms that currently provide the robust, reliable, and cost-effective delivery of electric energy may need to be modified to better reflect the operational realities of increased non-dispatchable resources. Traditional transmission planning practices need to evolve in the future to encompass more operational scenarios that will become more challenging and more common with higher penetrations of non-dispatchable resources that are weather dependent. Likewise, separate study processes that exist today for interconnection planning, economic planning, operational planning and annual reliability assessments may need to be combined into a more comprehensive study to increase certainty that future transmission plans are able to provide multiple benefits. These changes to the traditional study processes will need to be implemented through necessary policy changes and must proceed expeditiously.

Future planning efforts will need to be integrated across generation, transmission, and distribution and will need to consider a combined approach that considers all three aspects of the electric grid through a single planning study. The CapX2020 utilities will continue to plan, coordinate, and collaborate with MISO and policymakers to ensure an appropriate and timely expansion of the transmission system in our region.

Maintenance

There has already been a major shift in the way transmission system facilities are de-energized for upgrades or maintenance. Historically, this work was completed during times of the year that were considered off-peak when the transmission system was not near its maximum capacity. Across the MISO footprint, this typically lends itself to a few months during the spring and fall.

As non-dispatchable resources increase, these typical maintenance or outage times are becoming less viable. High levels of energy transfers are now occurring during off-peak periods when consumer demand is lower and non-dispatchable resource output is high. Because of the decreased window of time to perform upgrades and maintenance, this necessary work either gets delayed, or performed on energized facilities which not only increases costs but greatly increases risk of injury or unexpected system events. In more localized areas, maintenance work could occur in the hottest summer months or the coldest winter months depending on the location.

In a future that is increasingly reliant on non-dispatchable resources, additional considerations of planned outages must occur to allow for the reliable and cost-effective delivery of energy.

KEY TAKEWAYS OF TRANSMISSION CONSIDERATIONS

Transmission considerations are pivotal as we transition to a future more reliant on non-dispatchable resources for electricity supply. Properly expanding grid infrastructure will:

- Mitigate some of the negative impacts that dispatchable resource retirements have on system stability and reliability;
- Increase the options available for siting dispatchable and non-dispatchable resources in locations that are optimal for energy production;
- Assure the reliability of the transmission system as distributed generation is added and more local microgrids are established;
- Provide the desired amount of capability to move energy between regions and ensure that energy needs are met for all hours of the year;
- Promote a regional energy market which allows the most economic generation dispatch while maintaining reliability; and
- Capture weather driven diversity from remotely-sited, non-dispatchable resources.

We must encourage policy changes to enhance existing planning processes to become more comprehensive to increase certainty that new transmission projects are offering multiple benefits.

In addition, we must consider the implications of consumer demand modeling and planned maintenance and outages as generation resources change and new technologies are incorporated into the transmission system.

Energy Market Considerations

The concepts discussed in this section describe current industry practices and standards related to resource adequacy and wholesale energy market interactions.

Resource Capacity Accreditation and Resource Adequacy

Resource capacity accreditation is the amount of power (MW) a specific generating resource is expected to contribute during the time period of the likely peak demand for electricity. The current process for determining a resource’s capacity accreditation considers the historical performance of the resource over a three-month summer operation period which then determines the accreditation level for an entire operational year. To date, this has provided a high level of reliability by ensuring there will be enough generation capacity with sufficient actual energy output from the generation fleet to meet the highest demand period of the year.

The premise of the current resource adequacy process is assuring that load-serving entities have the necessary level of dispatchable resources to meet their resource adequacy requirement. Requirements are determined by regional analyses and in a few cases by local regulation. Requirements are usually based on assuring a 'less than one day in ten years' loss of load expectation or better.

The existing processes have proven to be successful as large dispatchable resources consistently produce energy output close to their accredited values whenever desired, but that framework may need to change going forward. The output of non-dispatchable resources vary greatly. As a result, accredited capacity based on probabilistic analysis of history will have little correlation to the actual amount of energy a resource will produce in a given hour. Additionally, reliability concerns have historically been based on seasonal peaks in summer and winter. As our studies have found, the increasing amounts of non-dispatchable resources, and the ability of those resources to serve consumer demand make it increasingly probable that reliability in the future will be a consideration for all hours of the year, not just critical peak or off-peak hours.

Physics dictate that energy consumption and supply be balanced every moment for the transmission system to operate at its desired frequency. The connection between energy balance and the resource adequacy requirement to transmission system planning and operation is that it is the responsibility of the grid operators, transmission-operating utilities, and MISO to assure the balance between supply and demand. The existing resource adequacy requirement that uses accredited capacity based on a probabilistic assessment of historical conditions and output levels will not provide reasonable assurance that there will be adequate energy to serve all load for each hour. In a future with considerable non-dispatchable resources, new rules and policies for resource adequacy and accreditation, if that concept continues to exist, will to need to change to assure that transmission operating utilities and MISO have enough energy during all times to maintain this critical balance.

Cost-Effective, Grid Congestion Mitigation

Today's wholesale energy markets are an intricate balance between system reliability and delivery of the lowest-cost energy available at any given time. With that balance comes the reality of transmission system limitations, which present themselves as congestion in market operations. Because a system with zero congestion (e.g. a copper sheet) would not be a cost-effective solution, the type, magnitude, and location of congestion becomes a vital consideration in accommodating a reduced-carbon future.

The transmission system of today has evolved around the availability of dispatchable resources and was designed to maximize the efficient and reliable use of those resources. This evolution has led to mostly consistent patterns in how electricity flows on the transmission system with historical areas of system congestion that are widely understood in their local and regional long-term planning processes. The facilities causing congestion change as upgrades are made to relieve congestion, but the flow patterns generally remain consistent and the next limiting facility is often predictable for system planners. In the MISO transmission planning process focused on identifying projects that lower the cost of delivered energy, one of the major considerations of a project's viability is whether the congestion that the project is mitigating has been shown to be present in real-time market operations. If the congestion has only been identified through modeling, but has not occurred in real-time operations, the congestion might be considered hypothetical and the project may not be approved due to its uncertainty of providing market benefits.

As we transition to a future more reliant on non-dispatchable resources, there will be a wider variety of flow patterns, depending on where it is windy or sunny and/or where the load is higher or lower. These flow patterns will be less predictable and less controllable, leading to more uncertainty in predicting where and how often congestion will occur. Historical congestion will not always represent the highest potential for cost-effective mitigations. Reliance on historic information of congestion patterns may actually hinder the development of mitigation that would enable the delivery of non-dispatchable resources in the most cost-effective way possible. Therefore, the processes currently used to identify and mitigate transmission congestion will need to evolve to better predict future congestion under a wider range of operating conditions.

Non-Dispatchable Resources Price Impact

In the existing wholesale energy market, the price that most non-dispatchable resources are offered into the market reflects a zero fuel cost. As more non-dispatchable resources are added to the system, there will be greater effects on the amount and output levels of dispatchable resources that are brought online. The energy market will need to accommodate this by providing appropriate price signals to all resources in the market to ensure sufficient levels of ancillary services are available at all times, as well as the desired amount of energy production.

Generation Costs

One of the major factors that led to the development of the current bulk power system in the U.S. was the realization of the benefits associated with economies of scale. The principle where cost savings are realized proportionally with increased levels of production led to large, centralized generation resources designed to serve large amounts of consumer demand. In today's industry, though somewhat skewed by variations in costs between large scale (or utility scale) and behind-the-meter consumer scale resources, that principle of realized savings through increased production still holds true. Lazard, an independent financial analysis firm, developed Levelized Cost of Energy charts (Figure 11 and Figure 12) for generation and storage technologies. These charts show, among other things, that the larger the scale of the individual facility, the lower the levelized cost. For example, a combined-cycle natural gas plant produces energy at $41-$74 per megawatt hour (MWh) vs. a residential rooftop solar panel array which produced $160-$367 per MWh.

Figure 11. Levelized Cost of Generation

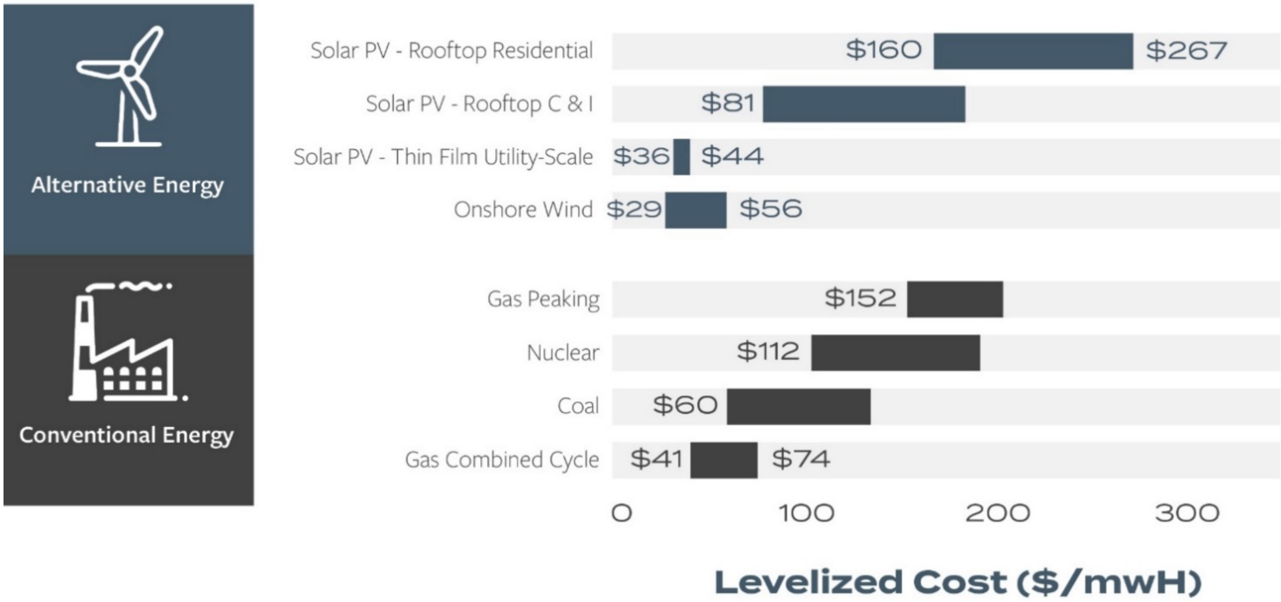
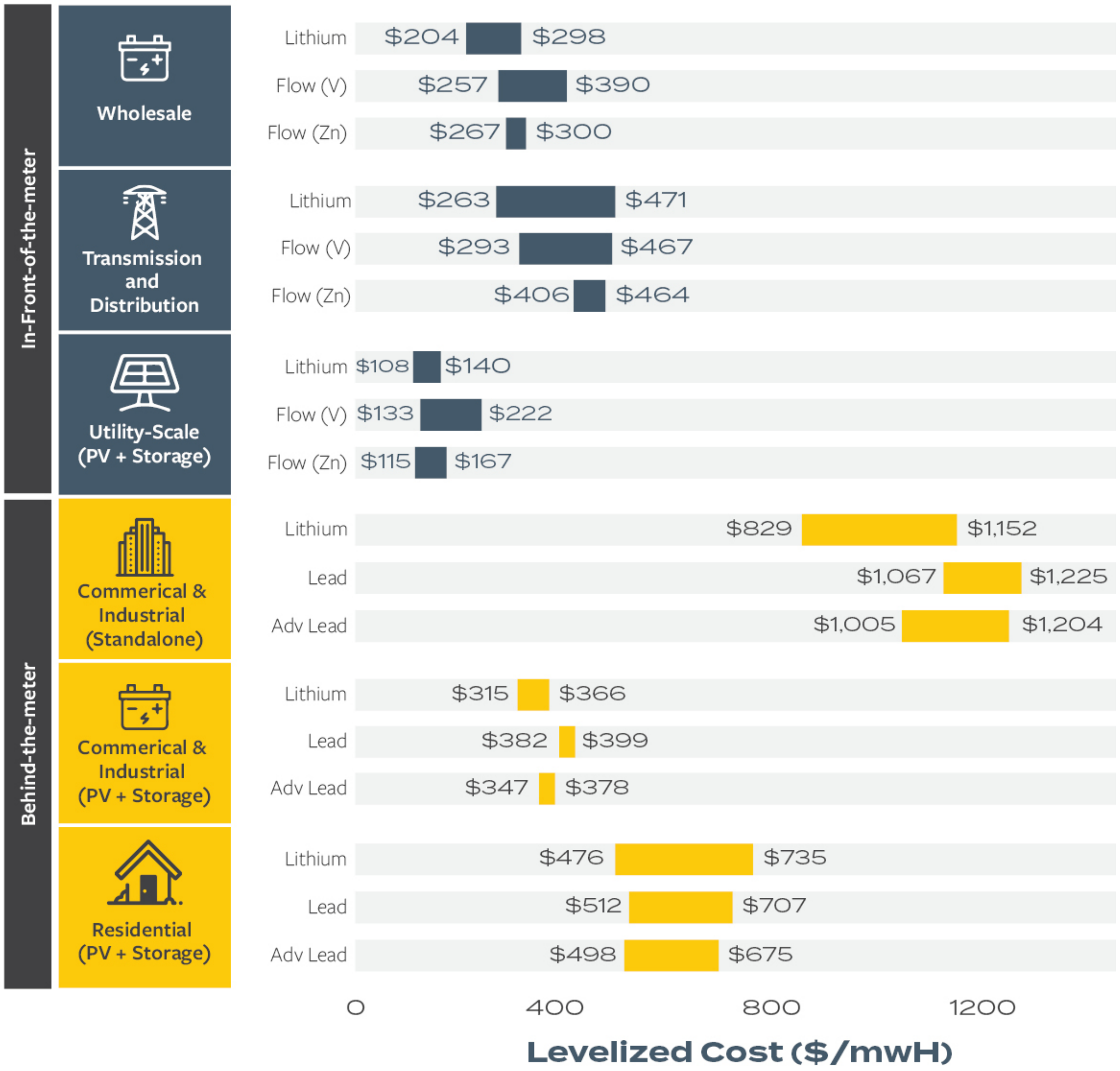


Figure 12. Levelized Cost of Storage



In a future more reliant on non-dispatchable resources, a more detailed examination of total "all in" costs - costs for modifications to the transmission and distribution systems, and costs to provide necessary ancillary services - will be required. These considerations will ensure the decisions about future resources represent the most cost-effective approach to achieving reduced-carbon future.

Distributed Generation Costs

A future more reliant on non-dispatchable resources is likely to include a heavier penetration of distributed generation. The existing mechanisms for assigning cost responsibility to distributed generation and compensating generators for benefits provided will need to be enhanced to provide appropriate incentives for how these units contribute to energy adequacy and grid reliability.

Transmission Cost Allocation and Recovery

New transmission projects (e.g., generation interconnection or reliability projects) are analyzed through separate planning processes based on the need for the project. Cost-allocation and cost-recovery is also based on this same planning process. If this current practice continues, it could result in too few or sub-optimal project proposals being approved. Transmission planning and cost allocation/cost-recovery need to be better aligned with each other to ensure that the right projects are being built at the right time, and paid for by the right beneficiaries.

LOOKING AHEAD

Understanding the critical issues outlined in this report will lay a foundation for more extensive studies in the future. We want to build on our history of listening and welcome the opportunity to provide information to policymakers and stakeholders as we plan the future grid to support future objectives while addressing reliability concerns. We will use the feedback we receive to identify the technical issues that need to be addressed in one or more subsequent phases of this CapX2050 effort, and how to best integrate our efforts with those of MISO and others. We will continue to comprehensively study a long-term transmission vision that will facilitate a reduced-carbon future while ensuring reliable, safe, and affordable energy is provided to the consumers we serve.