COMMERCE DEPARTMENT

March 1, 2024

Senator Nick Frentz, Chair
Energy, Utilities, Environment and Climate Committee
95 University Avenue W. Minnesota Senate Bldg., Room 3109
St. Paul, MN 55155

Senator Andrew Mathews,
Ranking Minority Member
Energy, Utilities, Environment and Climate Committee
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St. Paul, MN 55155

Representative Patty Acomb, Chair
Climate and Energy Finance and Policy Committee
593 State Office Building
100 Rev. Dr. Martin Luther King Jr. Blvd.
St. Paul, MN 55155

Representative Chris Swedzinski,
Ranking Minority Member
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245 State Office Building
100 Rev. Dr. Martin Luther King Jr. Blvd.
St. Paul, MN 55155

**RE: Energy Storage Capacity Study – Minnesota Session Laws 2023, Chapter 60 (HF2310), Article 12, Sec. 74**

Dear Chair Frentz, Chair Acomb, Ranking Member Mathews, and Ranking Member Swedzinski:

Attached is the *Energy Storage System Capacity Study Report* from Siemens PTI, submitted on February 28, 2024, by:

Chelsea LaRicci Cupit
Project Manager
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Houston, TX 77064

The applicable legislation; study methodology, assumptions, and results; stakeholder meeting feedback; and recommendations for future policy efforts are discussed in the attached document.

**This study is an important first step and points to the need for further evaluation of storage and energy technologies as well as market environments**. Due to the study's complexity and the short timeline, **the modeled scenarios are limited to current market environments and technologies**. For example, the model primarily selected 4-hr lithium-ion battery storage based on the model constraints, though numerous storage technologies are under development.

The model results are based on an assumption that the electric system gravitates towards a least cost energy outcome by utilizing economic energy dispatch backed up by sufficient dispatchable resources to ensure resilience and reliability. These study results demonstrate the potential outcomes for this type of approach. However, this is not how the Midcontinent Independent System Operator (MISO) actually dispatches resources; instead, over half of MISO's generation capacity is self-committed as 'must run,' which means the units run even if they are uneconomic. Accordingly, **real-world emissions reductions, particularly in the early years of the model, will not likely be as substantial as implied in this report.**

The Department would like to highlight the following key points:

- While Minnesota's utilities indicate they are prepared to meet the carbon free by 2040 requirement, **opportunities exist to make this transition cheaper and more reliable**. Energy storage can play an important role, allowing the integration of large amounts of renewable resources, while simultaneously meeting reliability requirements.
- **Storage can lead to lower cost for ratepayers**, as scenarios with more storage may require fewer Renewable Energy Credit purchases and minimize transmission upgrades, which will limit uncertainty and decrease cost.
- **Storage technologies are actively being developed** through research into longer-duration batteries (such as the iron air batteries scheduled for installation by Great River Energy and Xcel), as well as hydrogen, ammonia, and other potential storage technologies.
- The report focuses on short term battery storage, renewable energy technologies, and current market rules. As the timeline of the model approaches 2040, the price structure and assumptions about storage duration, renewable technologies, and market rules become more uncertain. Accordingly, this model is meant to provide decision makers insights based on what is currently known, while acknowledging that **significant uncertainties remain about Minnesota's energy markets 15 years from now.**
- As technologies evolve, policy-makers and markets will need to **adapt to enable efficient deployment of various energy storage technologies**. This will require a variety of initiatives, such as effective battery operating controls, incentives, and targets; engaging with MISO to ensure storage technologies can effectively participate in markets and monetize their value; and lessening or removing barriers to storage deployment.
- Areas of further investigation include different storage technologies and longer duration storage with fast ramping and grid stabilization capabilities.

The study indicates that **the ideal path to achieve 100% clean electricity by 2040 would include substantial build-out of "clean dispatchable" electricity sources** that can be used to balance out clean energy sources that are intermittent. Clean dispatchable resources could include short and long duration energy storage or other emerging technologies such as next generation nuclear power, gas turbines run with clean fuels, fossil fuel gas turbines with carbon capture and storage, among others. The Department, however, notes that **a limitation of the report is that it doesn't provide guidance about recommended amounts and types of storage that will be needed beyond 4-hr lithium-ion batteries**. This is understandable, as current energy system capacity expansion models—including the one used here—are not well positioned to answer that question.[1]

As required by Minnesota Statutes § 3.197: This report cost approximately $250,000 to prepare, including staff time.

If you have questions or concerns regarding this report, please contact Assistant Commissioner of Energy Resources Pete Wyckoff at (651) 319-3555.

Sincerely,

Grace Arnold
Commissioner

[1] Levin, T., Bistline, J., Sioshansi, R. *et al.* Energy storage solutions to decarbonize electricity through enhanced capacity expansion modelling. *Nat Energy* 8, 1199–1208 (2023). https://doi.org/10.1038/s41560-023-01340-6

# Energy Storage System Capacity Study Report

Prepared for the State of Minnesota

February 28, 2024

Siemens PTI

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Further, certain statements, findings and conclusions in this Report are based on Energy Business Advisory's interpretations of various contracts. Interpretations of these contracts by legal counsel or a jurisdictional body could differ.

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# 1. Glossary

| | |
|---|---|
| AACE | American Association of Cost Engineers |
| CAES | Compressed Air Energy Storage |
| CAISO | California Independent System Operator |
| CAGR | Compound Annual Growth Rate |
| CCGT | Combined Cycle Gas Turbine |
| CGM | Current Generation Mix |
| Co-op | Cooperative Utility |
| Co-ops | Cooperative utilities |
| CT | Combustion Turbine is a peaking generation technology |
| Clean Base | Combined Cycle burning clean fuels (non-emission producing) |
| Clean Peaking | Combustion Turbine burning clean fuel (non-emission producing) |
| EIA AEO | Energy Information Administration's Annual Energy Outlook |
| ELCC | Effective Load Carrying Capability |
| ESR | Electricity Storage Resources |
| ESS Study | Energy Storage System Capacity Study |
| FERC | Federal Energy Regulatory Commission |
| H2 | Green hydrogen fuel |
| HH | Henry Hub |
| IOU | Investor-Owned Utility |
| IRA | Inflation Reduction Act |
| IRP | Integrated Resource Plan |
| ITC | Investment Tax Credit |
| kW | Kilowatt |
| LBAs | Load balancing authorities |
| LNG | Liquified Natural Gas |
| LOLE | Loss of Load Expectation |
| LTCE | Long-Term Capacity Expansion |
| LRZ | Local Resource Zone |
| MISO | Midcontinent Independent System Operator |

| | |
|---|---|
| MTEP | MISO Transmission Expansion Plan |
| MW | Megawatt |
| NERC | North American Electric Reliability Corporation |
| NPV-RR | Net Present Value of Revenue Requirements |
| NYMEX | The New York Mercantile Exchange |
| PHES | Pumped Hydro Energy Storage |
| PTC | Production Tax Credit |
| PUC | Public Utilities Commission |
| REC | Renewable Energy Credit |
| Siemens PTI | Siemens Power Technologies International |
| SATA | Storage as a Transmission Asset |
| SATOA | Storage as a Transmission-Only Asset |
| The Department | The State of Minnesota Department of Commerce |
| The State | The State of Minnesota |
| UCAP | Unforced Capacity |
| WACC | Weighted Average Cost of Capital |

# 2. Executive Summary

Siemens Industry Inc. (Siemens), for its Power Technologies International (Siemens PTI) Business Unit, was engaged to assist The State of Minnesota Department of Commerce (The Department) in its efforts to develop an Energy Storage System Capacity Study (ESS Study).

The ESS Study has two primary objectives: first, define the optimal energy storage system capacity required to achieve the state's renewable energy standard and carbon-free goals, and second, obtain recommendations from stakeholders and the public on policies and programs to accelerate energy storage system deployment to achieve the storage capacity required.

The purpose of this report is to provide a comprehensive understanding of the Energy Storage System Capacity Study. It will outline the process employed, key assumptions, findings, and interpretation of results. Siemens PTI will demonstrate the structured approach to designing the ESS Study and provide rationale for the recommended storage capacity.

### Key Findings and Implications:

1. Utilities in Minnesota must procure a significant amount of renewable capacity to meet the 2040 carbon-free electricity standard, estimated to require approximately 8 GW of wind and 7.6 GW of solar additions by 2040.
2. Energy storage resources are essential for Minnesota's transition to carbon-free electricity to avoid excessive renewable capacity additions and unnecessary costs to consumers. The capacity, duration, and type of storage deployed will depend on the development of various emerging technologies in this field and their cost effectiveness. The range of necessary storage capacity for the various portfolios in the analysis is between 1,350 MW and 2,800 MW by 2040 based on the resource plan outlined in the report. Refer to Section 8 of this report for key findings and results from the study.
3. The analysis indicates that the expected Energy Market revenues (energy arbitrage) and Capacity Market revenues appear to be insufficient to incentivize storage adoption and additional sources of revenue are likely to be required. Although not analyzed within the study, ancillary services markets at MISO are going through multiple reforms including the introduction of new products and improvements in price determination that can improve revenue streams for storage.

### Key Recommended Actions:

1. Implement state-level policies, targets, and programs for electric utilities to promote the adoption of energy storage technologies that the state needs to transition to a decarbonized power sector. As implemented in other states, Minnesota should enable storage technologies to be procured by the utilities, provide complementary funding mechanisms where necessary, and establish policies that reduce barriers and promote energy storage adoption.
2. The Utilities in Minnesota should each conduct a detailed energy storage capacity study as part of their individual integrated resource plans in order to create a holistic strategy to meet the 2040 carbon free target. Such a study should : a) comment on the optimal location for storage resources based on their ability to mitigate transmission constraints and improve the overall efficiency of the grid, b) assess the challenges associated with integrating large amounts of renewable generation on reliability, ramping requirements, and resource adequacy, c) assess the challenges to meeting their system peak during periods when

renewable energy is scarce and d) produce a storage action plan that the state can refer to with a road map and key milestones for the deployment of the required storage.

3. Advocate for the reform of ancillary services markets within MISO that are currently underway to enable and fairly compensate generators for the services they provide in a power system that is experiencing a rapidly changing resource mix, with increased uncertainty and locational constraints. Energy storage technologies have the potential to provide a variety of services (including, but not limited to, frequency regulation, fast reserves, voltage stabilization and blackstart capabilities) that will be crucial to operating a flexible grid. Such revenue streams will be an important part of making storage technologies more economic in the coming years as the penetration of renewable generation increases in our grid.
4. Promote market structures to enable time based environmental attribute certificates to facilitate the development of 24/7 hourly matching of electricity[1], according to which the energy consumed is paired with the sources that produce it. This type of information and related policy is necessary to help achieve total decarbonization of the energy system by providing a signal that helps value clean peaking (i.e., carbon free firm dispatchable) resources. While there has been increasing interest in this area from multiple organizations, the regulatory environment can operationalize this idea through the development of effective guidelines. Energy storage will be a key part of such a strategy and has the potential to enable customers to meet their own sustainability targets.
5. Collaboration between Minnesota and MISO is required to address the limitations of storage as a transmission asset. Specifically, policies should be implemented that address the inability of storage to participate in the Market and the limitation that only allows storage to be considered a transmission asset in the absence of market (e.g., redispatch/ curtailment) solutions.

While Minnesota's utilities are prepared to meet the 'Carbon Free by 2040's targets, there exist opportunities to make this transition cheaper and more reliable. Energy storage can hold the key to helping integrate large amounts of renewable resources while simultaneously meeting reliability requirements through fast ramping capabilities. Storage technologies are actively being developed through research into long-duration batteries, as well as hydrogen and other potential storage technologies. As technologies evolve, there will be an increasing role for policymakers to help create an enabling environment that can ensure efficient deployment of various energy storage technologies. The study highlights these opportunities and lays the foundation for additional work to create a strategy to cost effectively plan for a clean energy transition. For the remainder of this report, the use of the term "storage" refers to battery storage technologies, unless specified otherwise.

[1] The matching of electricity generation and consumption on a 24/7 basis seeks to put in place the necessary market infrastructure and practice to significantly reduce power sector emissions and provide electricity from zero emitting resources 24 hours a day, 365 days a year.

# 3. Background

## 3.1. MN Department of Commerce

Legislation passed in 2023 (refer to Minnesota Sessions Laws 2023, Chapter 60 (HF2310), Article 12, Sec. 74) mandates the Department to conduct a study of the energy storage system capacity required to achieve the state's renewable energy standard and carbon-free goals, as outlined in Minnesota Statutes, section 216B.1691. Further, the legislation stipulates that the Department must host a meeting to gather input from stakeholders and the public regarding policies and programs aimed at accelerating the deployment of energy storage to achieve the determined storage capacity requirements.

## 3.2. Statutes

On February 7, 2023, legislation instituting a carbon-free electricity standard for Minnesota was enacted through Senate File 4. The bill delineates the following provisions:

**Figure 3-1: Summary of Minnesota Statutes**

| Standard | Statute | Summary of Statue |
|---|---|---|
| Carbon-free Standard | Section 216B.1691, subdivision 2g | Each utility is required to ensure that the following proportion of total retail electric sales to their Minnesota customers is generated from carbon-free resources[2]:<br>• 2030 – 80% for public utilities; 60% for other electric utilities<br>• 2035 – 90% for all electric utilities<br>• 2040 – 100% for all electric utilities |
| Clean Energy Standard | Section 216B.1691, subdivision 2a | Each utility is required to ensure that the following proportion of total retail electric sales is generated by eligible clean energy technologies[3]:<br>• 2012: 12%<br>• 2016: 17%<br>• 2020: 20%<br>• 2025: 25%<br>• 2035: 55% |

## 3.3. Utilities in Minnesota

The State of Minnesota comprises of 175 electric utilities, with 3 utilities accounting for approximately 60% of the state's 2022 electric sales. The top 10 utilities collectively served 77% of Minnesota's retail electric sales in 2022. Among the 175 utilities within the state,

[2] Carbon-free resource means a technology that generates electricity without emitting carbon dioxide, and includes solar, wind, hydroelectricity (<100-MW or >100-MW in operation as of Feb 2023), green hydrogen, or biomass. As defined in Minnesota Session Laws 2023, Chapter 7 (HF7), Section 10.

[3] Solar Thermal Electric, Solar Photovoltaics, Wind (All), Biomass, Hydroelectric, Hydrogen, Municipal Solid Waste, Landfill Gas, Wind (Small), Anaerobic Digestion Landfill Gas, Co-Firing, Anaerobic Digestion.

there is a mix of Investor-owned utilities (IOUs), Municipal utilities and Cooperative utilities (Co-ops). These three types of utilities are further detailed in the Table 3-1 below:

**Table 3-1: Minnesota Utility Types**

| Type | Description |
|---|---|
| IOUs | Corporations with shareholders who receive a regulated return on their investments in the company. The rates IOUs can charge are regulated and approved by the state's Public Utilities Commission (PUC). |
| Municipal Utilities | Nonprofit public entities. Muni rates are regulated by city councils or locally appointed utility commissions. Rochester is the state's largest municipal utility, but municipals mainly serve smaller communities throughout Minnesota. |
| Co-ops | Member-owned nonprofit organizations. A Co-op's rates are governed by a board of directors elected by its members. While co-ops can opt to have the PUC regulate their rates, only one–Dakota Electric Association, south-east of the Twin Cities–has chosen that option. Co-op service territories cover 85% of Minnesota, but account for only 32% of 2022 retail electric sales. |

Comprising only three utilities, IOUs accounted for 52% of Minnesota's 2022 retail electric sales, followed by Co-ops providing 32%, and Municipal utilities contributing the remaining 16%.

A full list of utilities in Minnesota can be found in Appendix E of this report.

## 3.4. Energy Storage System Inventory

As of December 2023, as reported in the EIA 860 Generator report[4], there is currently 82 MW of utility scale storage operating in MISO, of which 16 MW resides in Minnesota.

Table 3-2 shows the current energy storage resources in Minnesota and in MISO, including its owner, location, size, type, and duration of energy storage resource.

There is currently 1,935 MW of energy storage capacity in the MISO queue (complete or active request status and have successfully passed phase 1 of the study phase). A list of these resources can be found in Appendix B of this report with their corresponding owners, location, capacity, and applicable in-service date.

[4] Form EIA-860 detailed data with previous form data (EIA-860A/860B)

**Table 3-2: MISO Storage Resources in Operation (located in Minnesota shaded)[5]**

| Plant Name | Owner | County | Plant State | Nameplate Capacity (MW) | Type | Nameplate Energy Capacity (MWh) | Date in Operation |
|---|---|---|---|---|---|---|---|
| Harding Street | Indianapolis Power & Light Co | Marion | IN | 20.0 | Lithium-Ion | 20.0 | 6/1/2016 |
| ENO Paterson Solar | Entergy New Orleans, LLC | Orleans | LA | 0.5 | Lithium-Ion | 0.5 | 6/1/2016 |
| TAC-Distributed Energy Resource Hybrid | Ameren Illinois | Champaign | IL | 0.3 | Lithium-Ion | 0.5 | 5/1/2017 |
| Parkview Battery | Consumers Energy Co | Kalamazoo | MI | 1.1 | Lithium-Ion | 1.0 | 9/1/2018 |
| Knoxville Battery Energy Storage | MidAmerican Energy Co | Marion | IA | 1.1 | Other Lithium-Based | 4.0 | 12/1/2018 |
| Anoka BESS | Gopher Energy Storage, LLC | Anoka | MN | 6.0 | Lithium-Ion | 12.0 | 12/1/2018 |
| Athens BESS | Gopher Energy Storage, LLC | Isanti | MN | 6.0 | Lithium-Ion | 12.0 | 12/1/2018 |
| Athens - Coopers Corner BESS | Gopher Energy Storage, LLC | Isanti | MN | 3.0 | Lithium-Ion | 6.0 | 12/1/2018 |
| Volkman Road Solar Array Hybrid | Southern Indiana Gas & Elec Co | Vanderburgh | IN | 1.0 | Lithium-Ion | 4.6 | 1/1/2019 |
| Camp Atterbury Microgrid Hybrid | Duke Energy Indiana, LLC | Johnson | IN | 5.0 | Flow | 5.0 | 11/1/2019 |
| Marshalltown Generating Station | Interstate Power and Light Co | Marshall | IA | 0.3 | Lithium-Ion | 0.6 | 10/1/2020 |
| Nabb Battery Energy Storage System | Duke Energy Indiana, LLC | Clark | IN | 5.0 | Lithium-Ion | 5.0 | 12/1/2020 |
| Crane Battery Energy Storage System | Duke Energy Indiana, LLC | Martin | IN | 5.0 | Lithium-Ion | 5.0 | 12/1/2020 |
| Decorah Battery | Interstate Power and Light Co | Winneshiek | IA | 2.5 | Lithium-Ion | 2.9 | 6/1/2021 |
| Bissell Solar and Battery Generator | Consumers Energy Co | Kent | MI | 0.3 | Lithium-Ion | 0.5 | 10/1/2021 |
| Searcy Solar Hybrid | Searcy Solar, LLC | White | AR | 10.0 | Lithium-Ion | 30.0 | 1/1/2022 |
| USS Itasca Clean Energy Solar LLC | United States Solar Corporation | Itasca | MN | 1.0 | Lithium-Ion | 3.0 | 8/1/2022 |
| Portage Industrial Battery | Wisconsin Power & Light Co | Columbia | WI | 5.0 | Other Lithium-Based | 10.0 | 8/1/2022 |
| Deer Run Battery | Interstate Power and Light Co | Linn | IA | 5.0 | Lithium-Ion | 5.0 | 1/1/2023 |
| Boaz Microgrid Battery | Wisconsin Power & Light Co | Richland | WI | 3.6 | Lithium-Ion | 4.0 | 8/1/2023 |

## 3.5. Storage as a Transmission-Only Asset

MISO rules allow for energy storage technologies to be used as energy assets in the MISO as either market resources or transmission assets, if identified as a viable solution to a transmission problem.

[5] Form EIA-860M, S&P, and Siemens.

MISO's Business Planning Manual 20 (BPM-20) Transmission Planning, defines Storage as a Transmission Only Asset (SATOA) and "An electric storage facility that is connected or proposed to be connected to the Transmission System through inclusion in Appendix A of the MTEP [MISO Transmission Expansion Plan], as a transmission facility that is part of the Transmission System, that is capable of receiving energy from the Transmission System and storing energy for injection to the Transmission System, and is operated only to support the Transmission System[6]".

There are specific requirements of a storage to be designated a "SATOA," for example if a market solution (e.g., generation redispatch and curtailment) would address a transmission issue, then a SATOA would not be considered. This puts a SATOA in disadvantage with respect of other transmission solutions that could be considered to address market inefficiencies (i.e., congestion).

Another limitation SATOA's effectiveness it that the storage is to be operated only to support the transmission system and must be under the functional control of MISO. This implies that the storage must actively participate in the Market (day ahead, real time, ancillary and capacity) and any profits made from the purchasing and selling of energy under the transmission function, is to be credited through the transmission rates. Thus, its entire revenue requirement needs to be recovered under MISO's tariff.

There are ongoing discussions in the industry to allow a SATOA to transition to a SATA (Storage as a Transmission Asset) allowing for its market participation when this would not compromise its role as a transmission reliability asset. CAISO has made progress in this context to develop a revenue model that ensures cost recovery and avoids double recovery or cost shifting, between the market and the transmission function. This will require establishing contractual arrangements between CAISO and SATA owners that define the rights and obligations of each party and designing market participation and bidding rules that enable SATA to provide market services without compromising transmission reliability.

We understand that the CAISO plans to continue the stakeholder engagement process and submit a tariff amendment to FERC by the end of 2024. CAISO also intends to coordinate with other regional transmission organizations and independent system operators to share best practices and harmonize SATA policies across regions.

It is recommended that Minnesota participates in discussions and collaborate with MISO to address the limitations of storage as a transmission asset highlighted above, leading to the implementation of the SATA option in Minnesota.

## 3.6. Market Participation-Electricity Storage Resources

As resources in the MISO energy market, energy storage assets are registered as Electricity Storage Resources (ESRs) which are treated as and modeled similar to generators. ESRs may participate in all MISO products they are capable of offering and are eligible to meet capacity/resource adequacy requirements. ESRs are treated much the same as generation

[6] Transmission Planning Business Practices Manual BPM-020-r30 Effective Date: DEC 01-2023, page 183

assets from a market participation and modeling perspective. A market participant or owner will submit the technical parameters of the ESR with interconnection and submit bids in accordance with operations. ESRs may be submitted in three modes reflective of a storage assets interoperability: Charging, Discharging, and Continuous where continuous allows the market to flexibly deploy the ESRs storage as needed. There is no tariff limitation on the ancillary services a generating asset may participate in, rather they are eligible to participate in all ancillary services they are tested as capable of providing.

### Planning and Resource Adequacy

MISO treats ESRs the same as generating resources for planning and resource adequacy purposes. Load balancing authorities (LBAs) are required to remove ESR generation from the Residual Load calculation to reflect total load prior to the ESR's generation contribution.

### Physical and Financial Hedging

ESRs are treated similarly to generators meaning they may be used as physical asset to meet ancillary service, energy, and resource adequacy obligations. Entities may also use ESRs as a physical hedge during price spikes to offset the cost of serving load.

In concept, batteries should be able to make revenues off energy arbitrage by shifting low-cost generation into high price hours. However, batteries have not been viable on arbitrage alone. Rather, batteries have made and are expected to make most of their revenues from the Capacity Market and may receive some added revenue from in the Ancillary Service (largely spinning reserves, fast reserves and regulation), which renewables cannot economically meet. However, these ancillary service revenues have been a historically shallow market and revenues were not included in this assessment.

Minnesota should advocate for the reform of ancillary services market within MISO that are currently underway to enable the grid and fairly compensate generators for the services they provide.

## 3.7. Current Status

MISO has made progress in developing market rules that integrate energy storage into the market and long-term resource and transmission planning. However, it is unclear if these rules and regulations correctly identify storage's role in the MISO system. This is because there has not been enough storage integrated into MISO to understand battery operation options and potential. MISO's current position for storage is to receive transmission tariff revenues only if identified to be the preferred solution to a transmission issue and become a transmission only asset, not being able to participate in the market and any profits made by the purchasing and selling of energy. This limits the participation of storage as a dual benefit asset (market and transmission), and this is being actively addressed by other markets as is the case of CAISO.

Minnesota should participate in the required reforms as mentioned earlier in this report (ancillary services and storage as a transmission asset).

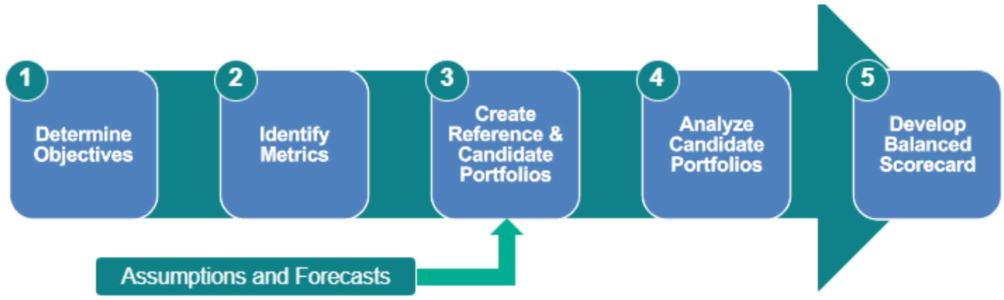
# 4. Siemens PTI Resource Plan Five-Step Process

The Department engaged Siemens PTI to create candidate portfolios for the State of Minnesota to identify the optimal amount of energy storage system capacity required to be installed by electric utilities located in Minnesota to achieve the state targets established under the regulations described in Section 3.2.

The process, detailed below, provides a holistic approach to identifying the optimal amount of storage required to achieve Minnesota's objectives. Siemens PTI's scope of work is based on a highly vetted and rigorous approach that is customized to answer motivating questions to identify the State's optimal storage capacity.

A Five-Step analysis process was applied to the State of Minnesota. This process, diagrammed in Figure 4-1, provides a holistic approach to identifying the portfolios that best meets The Department's defined objectives and metrics over a wide range of potential future conditions.

**Figure 4-1: Siemens PTI Five-Step Process for Resource Planning**




## 4.1. Step 1: Determine Objectives

The purpose of the ESS Study is to evaluate the State of Minnesota's current energy resource portfolio and a range of alternative future portfolios to meet recent legislation's carbon reduction goals. The process evaluates Candidate Portfolios in terms of environmental stewardship, market and price risk, reliability, and resource diversity.

This initial step in the process is conducted as a collaborative effort, where Siemens PTI and The Department worked together to clearly define Minnesota's resource planning objectives (Objectives). These objectives are conveyed in Table 4-1 below.

**Table 4-1: Minnesota's Objectives**

| Objective | Definition |
|---|---|
| Affordability | An electric system's ability to produce and deliver energy at an affordable cost with minimal price fluctuations |
| Sustainability | An electric system's ability to produce energy in a way that proactively reduces carbon emission and impacts on the surrounding ecosystem |
| Reliability and Risk[7] | An electric system's ability to effectively produce and deliver the energy required by customers with minimal interruptions and consistent quality while maintaining compliance |

## 4.2. Step 2: Assign Metrics

Metrics were developed early in the study for each objective to evaluate Portfolio performance across a wide range of possible future market conditions. Table 4-2 shows The Department's objectives and metrics. All measures of Portfolio performance are based on the results of Step 4, an analysis of the cost and performance characteristics of Candidate Portfolios across a broad range of market conditions.

Once Siemens PTI and the Department finalized the objectives, Siemens PTI worked with the Department to identify metrics (Metrics) for the analysis that were used to identify Minnesota's optimal portfolio strategy. Metrics are tied to each of the identified Objectives. For each Candidate Portfolio, the Objectives are tracked and measured through Metrics which evaluate portfolio performance across a wide range of possible future market conditions.

**Table 4-2: Minnesota's Objectives and Metrics**

| Category | Objective | Metric |
|---|---|---|
| Affordability | Cost | 2023-2040 NPV-RR |
| Sustainability | Carbon Free Generation | % of Total Generation in 2040 |
| | Eligible Resources | Clean Energy 2035 |
| Reliability and Risk[7] | Resource Flexibility | Fast Ramping Capacity |
| | Resource Adequacy | Reserve Requirement[8] |
| | Market Exposure | Energy Balance[9] |

[7] Reliability in power systems include both the reliability of supply and the reliability of delivery of the power to the loads. In this assessment we are considering the reliability aspects of the supply and not those associated with transmission (NERC-TPL 001-5) that ensures that the system can sustain a set of contingencies without interruptions to the load.

[8] NERC standard BAL-502-RFC-02 requires resource adequacy requirements that the loss of load expectations (LOLE) is less than once every 10 years. Based on this MISO establishes annual minimum reserve requirements for the system and each Local Resource Zone (LRZ) to achieve this metric (MISO Planning Year 2023-2024 Loss of Load Expectation Study Report).

[9] Energy Balance is reflective of Minnesota's generation/demand, represented as a percentage. This metric is utilized to define whether Minnesota is a net importer or net exporter of energy.

## 4.3. Step 3: Create Reference and Candidate Portfolios

The purpose of Step 3 is to create candidate generation portfolios based on State objectives, strategic alternatives, scenarios, and sensitivities. Siemens PTI developed a Reference Portfolio based on the current resource plan outlooks as provided by various utilities in the state of Minnesota. In addition to Reference Portfolio, 2 other candidate portfolios were created. These portfolios will be described in detail later in the report.

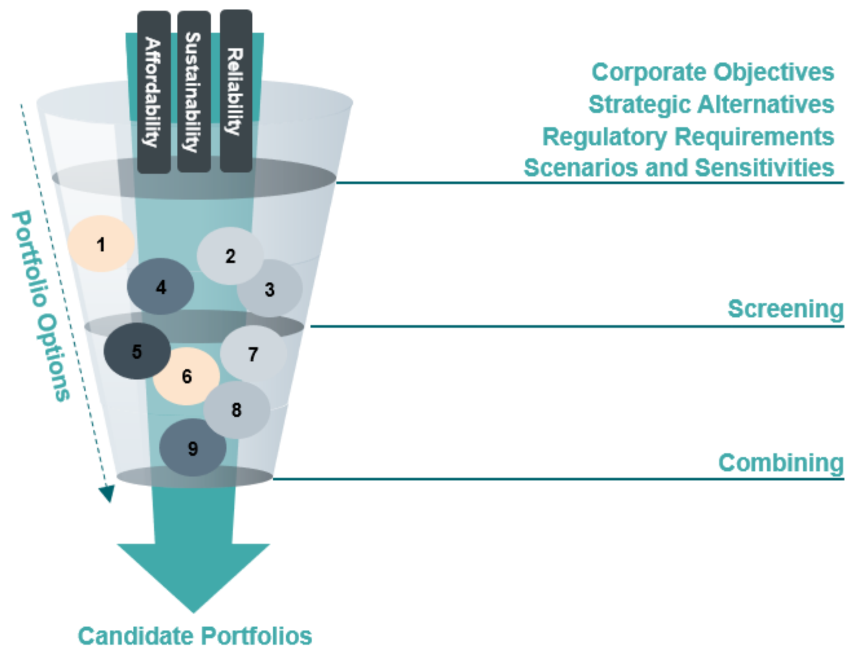
In this step, Siemens PTI determined three (3) distinct optimized supply portfolios for achieving the state's targets from 2023 to 2040 (Candidate Portfolios). These portfolios were developed based on a series of inputs that were informed by:

- State objectives
- Stakeholder requirements
- Strategic alternatives
- Development opportunities

For each Candidate Portfolio, Siemens PTI determined the scale, technology, and timing for the solution path (additional resources entering service). Siemens PTI made it a priority to make sure the Candidate Portfolios are optimized between renewables and storage to maintain reliable supply.

Siemens PTI considered technological advances in energy storage technology that are likely to be made by 2040, and their impact on the cost-effectiveness of deploying energy storage systems.

**Figure 4-2: Approach for the Development of Candidate Portfolios**




## 4.4. Step 4: Analyze Candidate Portfolios

In Step 4, the Candidate Portfolios developed in Step 3 were tested, analyzed, and evaluated by Siemens PTI and the Department to identify the optimal portfolio.

Both in the short term and in the long term, Siemens PTI recognizes that uncertainty is a fundamental characteristic of markets. The quantification of that uncertainty is key to improving the quality of decisions regarding resource planning. Siemens PTI performed a sub-hourly flex capacity requirement analysis to confirm that the Candidate Portfolios comply with the required fast ramping resources to ensure energy sufficiency and reliability down to the sub-hourly level of granularity.

## Module A. Flex Capacity Requirements

Siemens PTI understands the Department's concern that the increasing levels of renewables in their portfolio to meet carbon reduction goals could raise resource flexibility concerns; particularly for their fast ramping or "flex" capacity needs. It is important that the State knows when its existing and planned fast-ramping resources will not be adequate to meet its resource flexibility requirements, even at sub-hourly time periods.

Due to the nature of the uncertainties underlying intermittent renewable resource (i.e., solar, wind) generation and load variability, there is a critical need to evaluate the flexibility requirements. Siemens PTI utilized a stochastic-based approach to simulate the full range of potential conditions of load and renewable generation and examine the flex capacity needs on the 10-min sub-hourly level.

Siemens PTI has developed and vetted through client engagements an analytical approach to determine Minnesota's unique system requirements to ensure energy sufficiency including resource adequacy[10] and fast ramping capability to ensure energy and capacity requirements 24/7, 365 days a year under the uncertainty of future conditions. This is vital to manage the integration of increased amounts of green resources, including the fast-ramping resources needed to backfill intermittent technologies.

Siemens PTI structures the reliability problem and analysis by defining reliability along two sets of conditions:

- Expected Conditions: Includes seasonal changes, driven by variations and volatility in load and intermittent resources that vary by time of year.
- Exceptional Conditions: Includes event driven conditions, including out of the ordinary potential circumstances such as storms, pipeline disruptions, fires, etc.

Siemens PTI provides solutions to the reliability problem in terms of the technologies or commercial products that are required:

- Very Fast Ramping Resources (supply or demand side) can change output in the very short-term (10-minute ramping).
- Fast Ramping Resources (supply or demand side) can change output over a longer period (3-hour ramping).
- Total capacity, commercial products, or demand-side options.

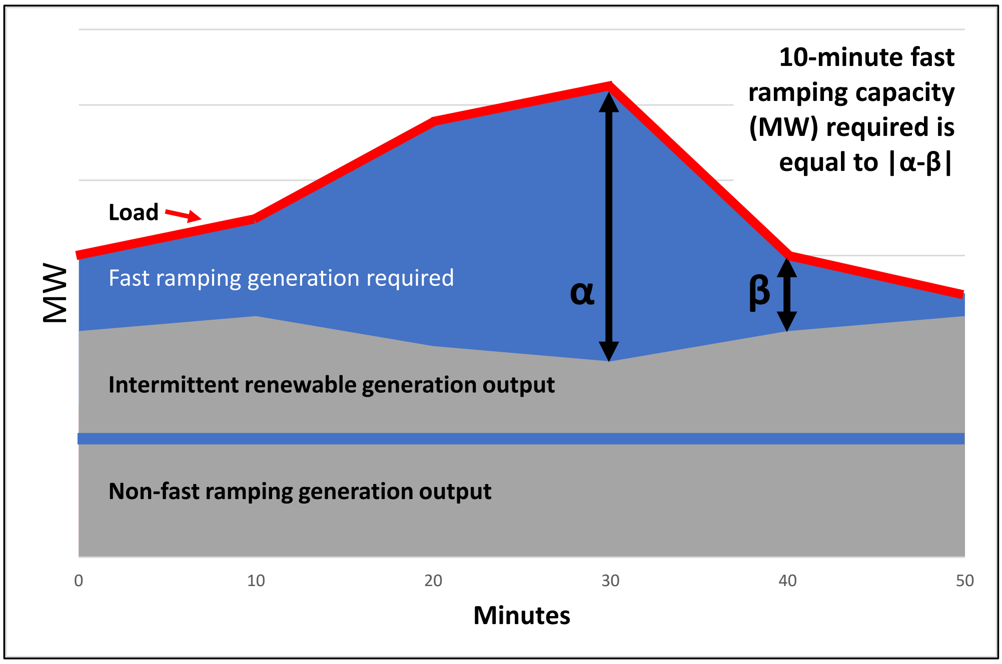
[10] Resource adequacy is assessed by tracking the yearly reserves afforded by the plans and compared with MISO requirements. This is addressed by the reserve required and covered later in this report (section 8.3)

The analytical approach used for Minnesota was the "very fast ramping" on both a 10-minute and 5-minute interval.

Figure 4-3 below is an illustration of the flexible capacity shortfall when there is a change in Load minus generation from one period (α) to the next (β).

**Figure 4-3: Siemens PTI Flexible/Fast Ramping Capacity Methodology**




As shown in Figure 4-3, for any period, the amount of fast ramping capacity needed is equal to the absolute value of α-β, or the change in:

- α: the difference between load and renewable generation in the first period.
- β: the difference between load and renewable generation in the second period.

Using historical volatility for load and renewable output, Siemens PTI utilized Monte Carlo analysis to simulate load and renewable generation thousands of times to find the maximum amount of fast ramping resources needed for Minnesota's mix of generating technologies. This approach allows for the development of confidence bands for the desired balance of costs vs. benefits for fast ramping resources. Available resource ramping capacity is equal to the sum of all generating resources net of expected forced outage, planned maintenance outages, effective load carrying capability (ELCC), and economic unit dispatch.

The flex capacity requirement determined in this analysis will be used to ensure sufficient flex resources in Minnesota's supply stack, to ensure that the variability introduced by intermittent resources and load volatility are covered reliably.

## 4.5. Step 5: Select Top Portfolios Using a Balanced Scorecard

The final step of the process involves developing a scorecard (Balanced Scorecard) which will compare the performance of each Candidate Portfolio against the Objectives and Metrics defined in the initial steps of the planning process. The Balanced Scorecard allows for assessing the tradeoffs between the Candidate Portfolios and enables the team to determine the best performing portfolio or the optimal portfolio.

# 5. Forecast and Assumptions

Siemens PTI developed several forecasts around key performance indicators that were used to help develop candidate portfolios. Consistent modeling assumptions and the Department's practical considerations were used as inputs or constraints across all the candidate portfolios.

## 5.1. Load Forecast

Siemens PTI performed a long-term load forecast for resource planning studies. The long-term load forecast was developed based on Purdue University's Energy and Peak Demand Forecast prepared for MISO in November 2022, forecasted monthly. This consists of a multi-step approach, where first, econometric models were used for each state to forecast retail sales for the period of 2023 to 2040. Then these statewide forecasts were used to construct annual energy forecasts at the LRZ level based on allocation factors. Afterwards, said new forecasts were used to develop monthly non-coincident peak demand projections by LRZ. Finally, LRZ monthly peak projections were obtained from their non-coincident peak counterpart by applying the zonal monthly coincidence factors. This lets MISO aggregate a system-wide energy and peak forecast from the LRZ energy and coincident peak forecasts, respectively.

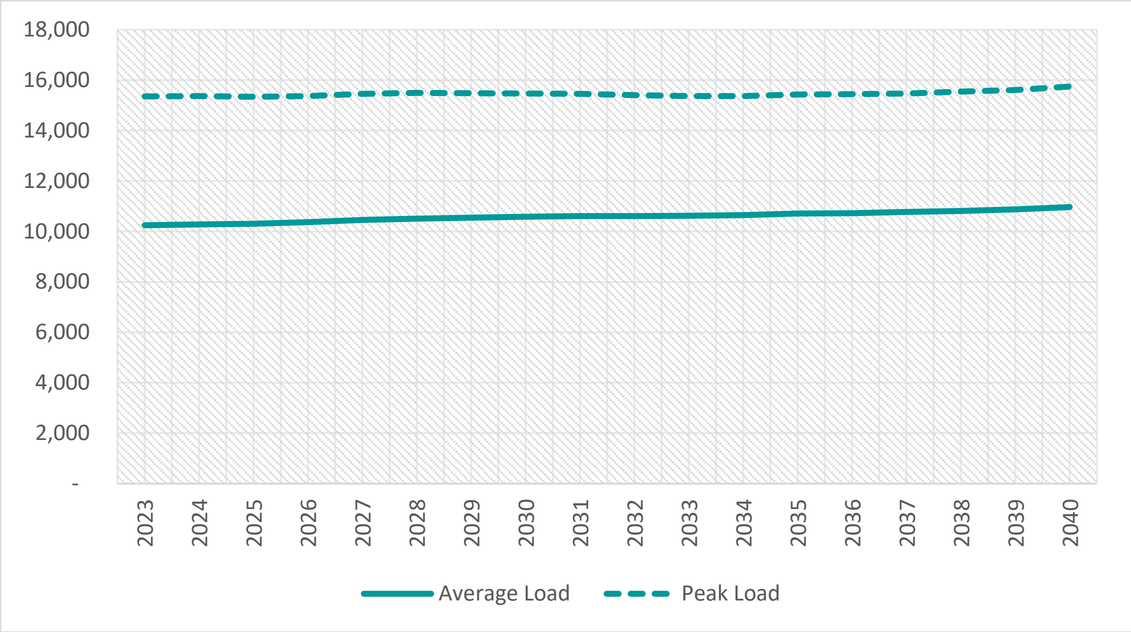
MISO LRZ 1 consists of the state of Minnesota, parts of Montana, North Dakota, South Dakota, and Wisconsin, and small portions of Iowa, Illinois, and Michigan. MISO LRZ 1's average load is assumed to grow at a compounded annual growth rate ("CAGR") of 0.4 percent and the peak load at 0.1 percent between 2023 and 2040[11].

As with every forecast, there is a large range of uncertainty within the forecast. This is based on the current outlook reported by Purdue University and there is potential for increased building electrification, or large new electricity demanding industries like AI, cryptocurrency, data centers, or green hydrogen as a few examples. The load forecast is representative of gross load and does not incorporate behind the meter adjustments.

[11] LRZ load outlooks are based off Purdue University's November 2022 MISO Energy and Peak Demand Forecasting for System Plannings Report. Energy Efficiency adjustments were performed by Siemens PTI based on MISO's EGEAS model from 2020 as no updated forecast has been released to Purdue.

**Figure 5-1: MISO LRZ 1 Forecasted Average and Peak Load (MW)**




Expected growth in behind the meter distributed generation and electric vehicle additions are accounted outside of the described load forecast.

## 5.2. Commodity Prices

### Natural Gas

Natural gas price projections were developed for Henry Hub according to primary supply and demand drivers that influence domestic production costs as well as international market dynamics. On the short-term (2024-2026) we predict that Henry Hub (HH) prices, in real 2021 dollars, will remain below $3/MMBtu on average in 2023, with an anticipated increase to approximately $3.90/MMBtu by 2026. The reference case prices are based on NYMEX forwards, averaged across trade dates on September 18, September 25, and October 2, 2023, covering the initial 18 months of the forecast period. Beyond this, market forwards inform projections up to March 2025, followed by a blend of various data types through August 2026, when our fundamental forecast commences. The cooler-than-normal summer weather across much of the US resulted in underground storage levels being 6% above the five-year average. With the expected warmer winter conditions due to a strong El Niño weather pattern, a decrease in space heating demand in residential and commercial sectors is anticipated. This could lead to storage levels in March 2024 being approximately 20% higher than the five-year average.

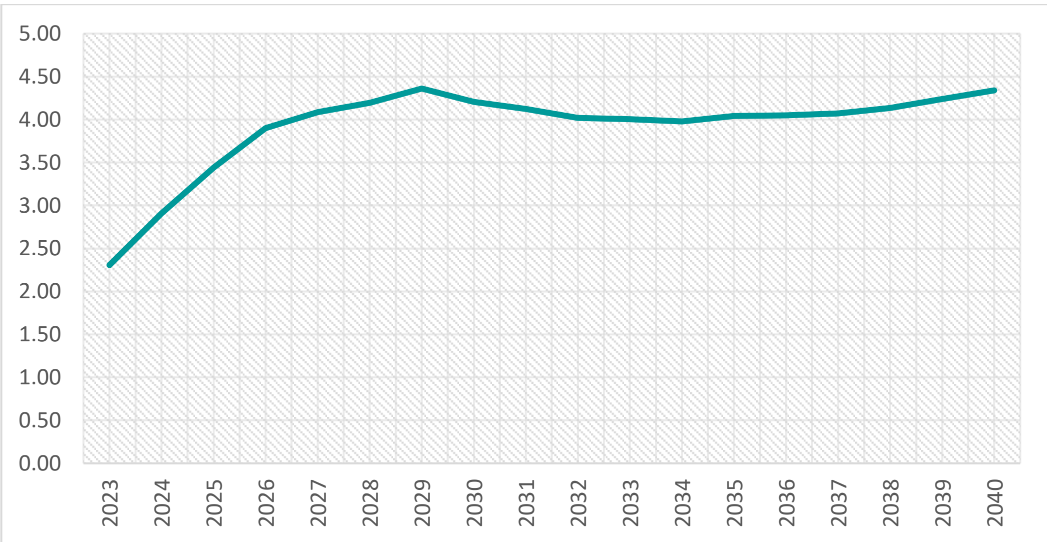
In Europe, the demand for LNG exports is likely to decline due to energy conservation efforts and near-full storage capacities. Meanwhile, in the U.S., we expect to continue as a flexible supplier in the global spot LNG market. Domestically, supply dynamics are projected to align with our previous forecasts. However, an increase in production in the Permian and Haynesville regions is anticipated, driven by lower supply costs and sufficient pipeline capacity. This is expected to support both industrial demand and LNG export capabilities, especially in the Gulf Coast region.

On the mid-term (2027-2035) we anticipate a modest increase in average gas prices due to augmented exports to Mexico and an uptick in natural gas consumption in the power sector. We anticipate HH prices to average around $4.11/MMBtu. The increase in gas usage in the power sector can be linked to substantial backlogs of renewable energy projects currently in interconnection queues. These delays in transmission assessments are likely to slow the introduction of new capacity, resulting in heightened reliance on natural gas for power generation.

Overall, the demand for natural gas in the U.S. is expected to remain relatively stable throughout the mid-term period. Pipeline exports to Mexico are also anticipated to grow modestly in response to increased power demands and expanding LNG export capacities.

For the long-term (2035-2050) outlook, we foresee a gradual increase in HH prices, from $4.05/MMBtu in 2036 to $6.07/MMBtu by 2050. Our projections indicate a steady increase in natural gas prices. This trend is largely due to the higher production and transportation costs associated with new, non-associated supply sources. Because of the growing trend towards electrification, we anticipate declining natural gas demand in the residential sector, with relatively flat demand growth in the commercial and industrial sectors. In the power generation sector, the role of natural gas-fired power is projected to remain pivotal, primarily serving as a source of peaking power in the wake of expanding renewable generation capacity.

**Figure 5-2: Henry Hub Reference Outlook (2021$/MMBTU)**



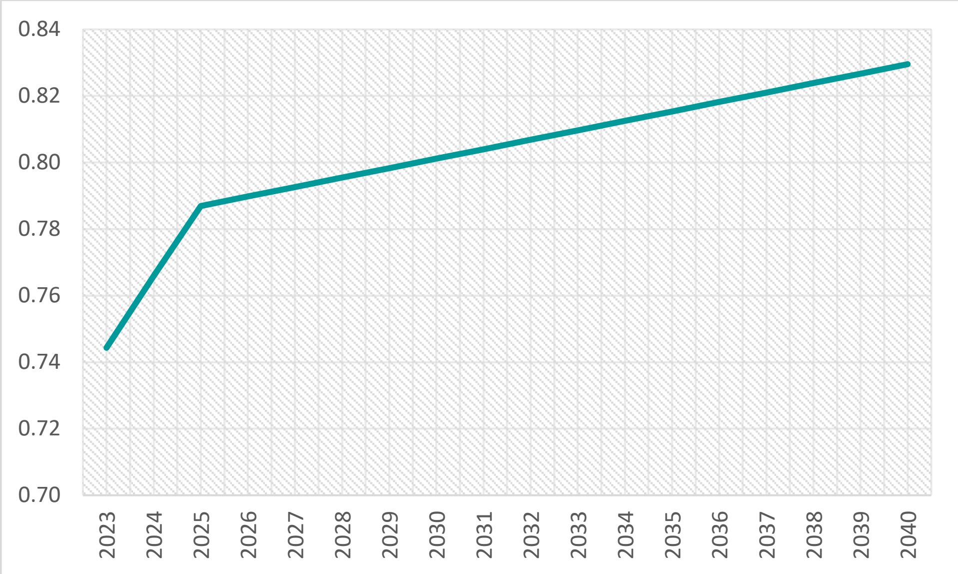

## Coal

Coal price projections were developed according to primary supply and demand drivers that influence production costs. Wyoming and Montana supply the coal Minnesota consumes, sourced from the Powder River Basin.

For the short-term (2023-2024) the 2023 prices shown reflect the CoalDesk, LLC forward price curve as of 4/21/2023. The 2024 prices are interpolated between the forward prices for 2023 delivery of each coal type, and the fundamental forecast starting 2025. As of late April 2023, spot prices for most of the major types of steam coal produced in the United States have declined significantly from the high points reached in September 2022.

As for the long-term (2025-2050) the coal price forecasts for each coal type reflect the balance between coal demand trends, expected coal production costs, reserve depletion effects, and declining coal demand that are expected to play out over time.

**Figure 5-3: Coal Price Outlook – Powder River Basin (2021$/MMBTU)[12]**



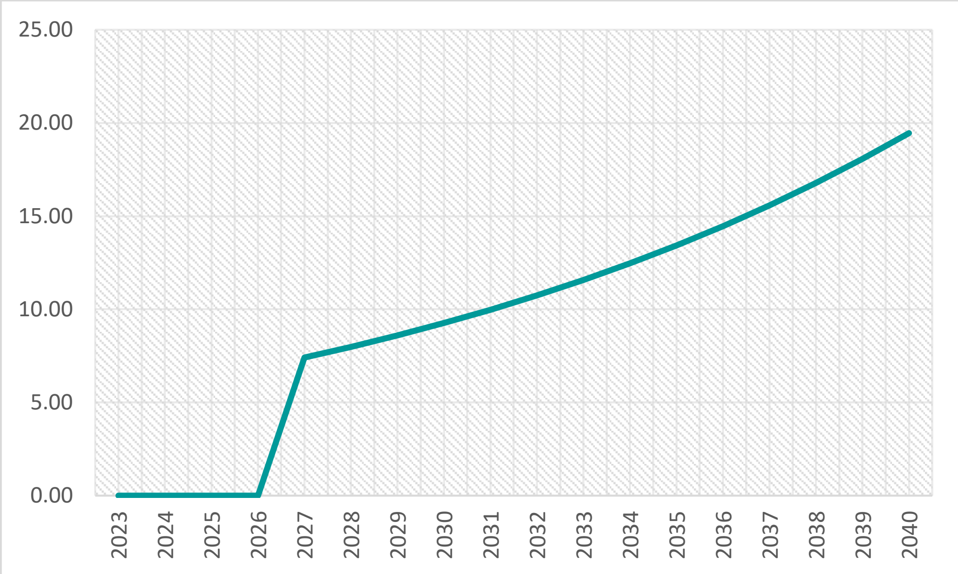

## Carbon Dioxide Costs

Despite uncertainty over a future national price on carbon, carbon dioxide ($CO_2$) price projections were developed based on the National $CO_2$ forecast provided by Siemens PTI. In April 2021, President Biden announced the United States is formally committing to cutting economy-wide greenhouse gas (GHG) emissions between 50 and 52% from 2005 levels by 2030 and reaching net zero emission by 2050. As part of the new US Nationally Determined Contribution, the administration also set a goal to reach 100% carbon pollution-free electricity by 2035. Several analyses have found that to reach the overall target, power sector emissions need to achieve around 80% reduction from 2005 levels by 2030[13]. Power companies (Xcel Energy, AEP, etc.) and states (Oregon, Colorado, California, etc.) across the country have already made specific commitments to achieve significant reduction in carbon emissions from their operations or power sector. Siemens PTI performed the $CO_2$ pricing analysis in Aurora in our National Forecast Model for the power sector. Aurora performs iterations of $CO_2$ price search and iterations in the long-term capacity expansion (LTCE) per $CO_2$ price search until the $CO_2$ reduction target is reached. The price search function uses a bisection method to find a price path (Hotelling price path) that meets a $CO_2$ reduction target. Figure 5-4 reflects expected future national policy, which will require reducing $CO_2$ emission from the power sector. See Figure 5-4 for assumed $CO_2$ tax projected by year.

[12] Coal price forecast and coal delivered prices are provided by an external consultant, Hawk Consulting, to Siemens PTI. Coal forecast is consistent with Siemens PTI's coal demand outlook and natural gas forecast.

[13] Environmental Defense Fund. https://www.edf.org/sites/default/files/documents/Recapturing%20U.S.%20Leadership%20on%20Climate.pdf

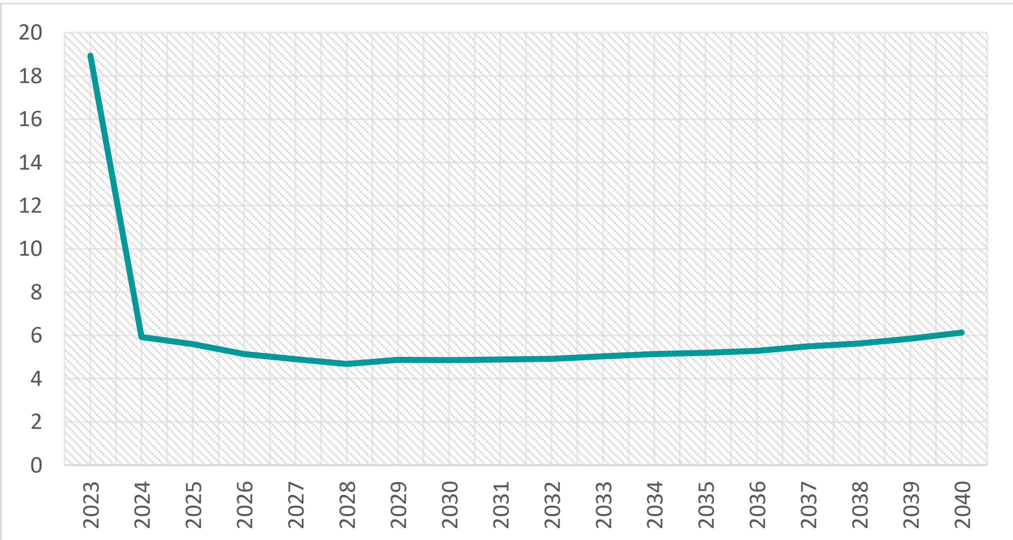
**Figure 5-4: National $CO_2$ Price Forecast (2021$/Ton)**




### H2 Costs

Siemens PTI developed an average hydrogen price forecast for the US market, reflecting the actual cost of producing green hydrogen while factoring in post-IRA tax benefits. Additionally, Siemens US acknowledges the opportunity cost, which represents the cost of producing clean fuel (natural gas + National CO2 price). The final hydrogen price forecast has been determined by selecting the maximum value from both curves (green hydrogen or clean fuel).

**Figure 5-5: H2 PRICE FORECAST – AVERAGE CLEAN FUEL US (2021$/MMBTU)**



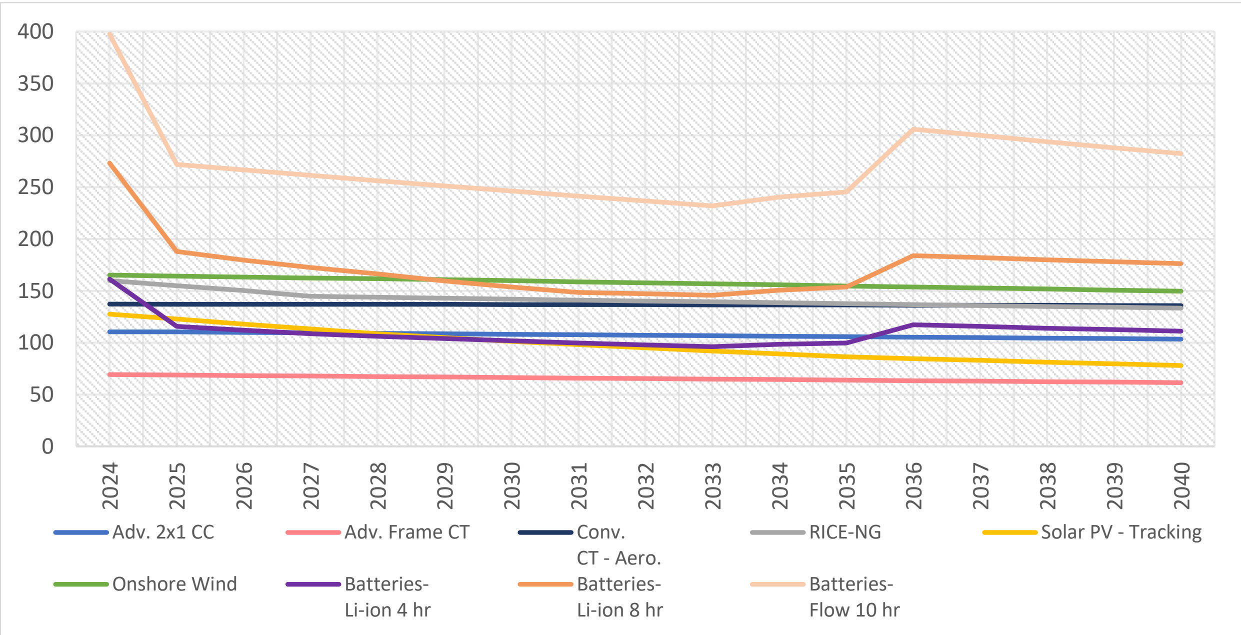

## 5.3. Capital Cost of New Generating Assets

Siemens PTI created the long-range forecasts for key power generation technologies in October of 2023. The capital cost forecast uses a combination of both public and private sources to best estimate the costs of new proven technologies to ensure reliable and predictable outcome. The sources for capital costs development originate from IRPs, IRP related studies, Thermoflow software, and client confidential project information. The capital cost assumptions reflect regional multiplier based on Energy Information Agency (EIA) data to account for local labor and economic factors. This update accounts for several new sources including the most recent update of the Energy Information Administration's (EIA) Annual Energy Outlook (AEO).

Using a blend of several sources provides multiple benefits. First, no single source is definitive or will represent any undefined project. According to the American Association of Cost Engineers (AACE) cost classification system, budgetary estimates are Class 4 estimates. Class 4 is defined as an estimate on a project that is 1% to 15% completed, where the low side of the estimate can vary 15-30% below the 80% confidence interval and 20-50% above the 80% confidence interval. However, given the modular nature of most generation technologies, Siemens PTI considers our estimates to be between Class 3 and Class 4, with an estimated accuracy of -19% to +27.5% in general.

Significant capital cost increases are expected in the near- and long-term for most power generation technologies. These increases are driven in part by higher interest rates which impact construction financing, as well as lingering global supply chain constraints limiting the production and transportation of key components and equipment. Stricter Made in America requirements are also driving price increases which reflect higher costs of local materials and labor compared to prior years. Figure 5-6 shows the levelized cost of various resources. Renewable resources such as solar and wind are the cheapest.

**Figure 5-6: Levelized Cost of New Resources (2021$/KW-YR)**




With the passage of the 2022 Inflation Reduction Act, there are substantial savings associated with technologies that reduce carbon emissions. However, most of the savings are in the form of investment or production tax credits from the U.S. Government.

## Emerging Storage Technologies

There are numerous short and long duration technologies in various stages of commercialization available to support bulk power needs. Storage technologies such as pumped hydro energy storage (PHES) and compressed air energy storage (CAES) have been in use for decades but are only applicable where local topology or geology is appropriate. Since these generally require high elevation or underground caverns, they are likely not applicable in Minnesota.

However, some newer maturing technologies such as lithium-ion batteries are not limited by topology or geology. Lithium-ion batteries are well understood and increasingly common in both vehicle and land-based applications, which combined offer substantial market size supporting continuous research and cost improvements since they share production facilities. By power system standards, lithium-ion batteries are relatively small in both capacity and duration. So while they typically serve smaller capacity needs for a few to several hours, they may not be appropriate for many bulk energy storage with high capacities and multi-day or more storage requirements. Further, the capacity of lithium-ion batteries declines materially over time based on use cycles, and the useful life is generally considered to be ten years, both of which hamper their economics.

To meet this need, other storage technologies like flow, iron-air, gravity, zinc-based, and liquified-air energy storage technologies were developed and are in the pilot phase with a few installations of each gathering data and operational experience.

Hydrogen and its derivative products can also serve this bulk power need, and by using electrolyzer and renewable power, the resulting hydrogen is a zero-carbon product. Hydrogen can be combusted in conventional technologies like combined cycle generators, combustion turbine generators, boilers, and reciprocating engines for bulk power purposes or used as a fuel in fuel cell in smaller applications. In either case, hydrogen can be stored in bulk for long duration needs providing another alternative energy storage option. Green hydrogen projects are under development all over the world, and in the US the federal government is supporting hydrogen development with billions of investment dollars though several programs.

## 5.4. Minnesota Generating Assets

Siemens PTI utilized Energy Exemplars database to represent the existing generation resources within the state of Minnesota. Energy Exemplar uses several sources to update and enhance the Aurora EIC Zonal dataset which include the EIA 860, 923, 930, AEO, STEO, among others. Also included in the base dataset is new additions as reported in the May 2023 EIA 860 Generator report that have begun construction.

Based on feedback from the State and utility outlooks, current nuclear units within Minnesota are assumed to remain online through 2040 within this analysis.

## 5.5. Environmental Consideration

All portfolios were created with the main objective of meeting Minnesota´s electricity load with zero carbon emissions by 2040. This target was more restrictive than the Minnesota clean energy 2040 standard (100% carbon free generation or procurement by 2040 for electric retail sales in Minnesota), since the entire MISO region couldn’t be modeled in the timeframe available, and Minnesota inherently utilizes energy generation from neighboring regions to satisfy its load. Based on feedback during the December 22nd stakeholder engagement, the use of REC purchases is expected to offset any emergency thermal generation as needed for reliability.

The objective for Minnesota, as represented in the analysis, was to produce an equivalent amount of carbon free generation as their retail sales. Any excess generation above this threshold that may have stemmed from thermal generation does not count against Minnesota's ability to meet this requirement.

While Siemen's PTI does not believe that relying on any potential RECs market is suitable for planning purposes, there are instances within the candidate portfolio that this does occur. Siemens PTI does not have any official REC purchase outlook and has assumed a relatively low amount of $1.75/MWh (Real 2021$) based on current MISO REC markets.

As the REC purchases are a small amount of overall portfolio cost and do not change the respective order of least to most expensive portfolio, it is worth noting that these REC purchases could be unnecessary in all scenarios as various utilities within Minnesota own clean energy resources located outside of Minnesota. This clean energy can be imported directly into Minnesota to count towards the utilities overall carbon free goals and reduce the need for REC purchases. A test LTCE sensitivity was performed under this 10% clean energy import assumption, which did not materially impact the buildout decisions.

### $CO_2$ Footprint

An increasing concern regarding global climate change has put specific emphasis on the carbon footprint associated with different power generating resource options. Although coal-fired generation remains one of the low-cost resources, its environmental impacts pose a growing concern to the public and utility planners. Moreover, the potential for significant costs associated with $CO_2$ emissions constitutes a major risk for coal plant owners. Furthermore, the legislation establishing a Minnesota carbon-free electricity standard signed into law under Senate File 4, pushes this objective as a non-negotiable since all utilities must reach 100% of their retail sales to Minnesota customers through carbon free generation by 2040.

### Renewable Generation

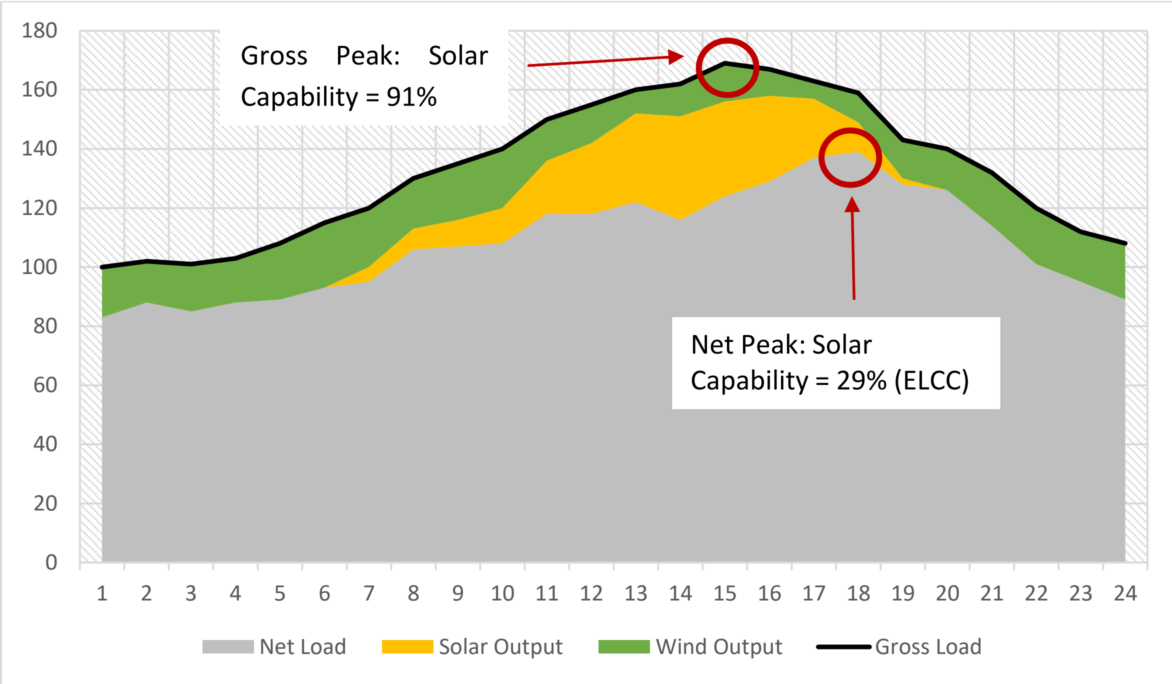
Minnesota's environmental goals require the addition of renewable resources to the supply mix, especially in the long term. Renewable generation, particularly solar and wind with PTC benefits after the passage of the IRA in August 2022, are one of the cheapest resources under most conditions, which helped Minnesota with its Affordability objectives. Analysis showed that increasing generation from renewable resources will also directly result in reduced CO2 emissions for the portfolio. As stated in Statute Section 216B.1691, subdivision 2a, 55% of utility retail sales must come from eligible resources, as described in Section 3.2 of this report.

### Reliability and ELCC

As Minnesota experiences increased renewable penetration, the Effective Load Carrying Capacity (ELCC) of this type of generation can drastically decrease. The renewable resources' ELCC as calculated within AURORA is the equivalent to the capability of the resource at Minnesota's peak *net demand*. The net demand is defined as the gross load minus renewable output. See figure below for an illustrative example of this process for a solar unit, although the process is the same for wind and storage.

**Figure 5-7: ELCC Calculation Process**[14]




[14] *"Net Load" is equivalent to gross load minus solar and wind production. "Net Peak" is peak amount of net load.*

# 6. Candidate Portfolio Development (Step 3)

The objective of this ESS Study is to identify a portfolio of generation resources that best aligns across all The Department's objectives around Affordability, Risk, Environment and Operability.

The construction of Reference and Candidate Portfolios is aimed at satisfying the State's energy demand by 2040 under expected conditions. The resource planning process is designed to adapt with the analysis incorporating updated market information, operational considerations, and logistic limits as available.

Siemens PTI defined the development of a Reference Portfolio, which serves as a business-as-usual outlook of expected market conditions and expected load. The Reference Portfolio is based on Siemens´ view of base market conditions around commodity prices, thus serving as a benchmark to measure the performance of other portfolios that are optimized to meet potential policy and regulation goals, as well as potential future market conditions (high or low commodity prices). The Reference Portfolio short term expected additions and retirements provided by various utilities in Minnesota, including Xcel Energy, Southern Minnesota Municipal Power Agency (SMMPA), Great River Energy (GRE), Ottertail, and Minnesota Power. These additions were locked into the expected portfolio with no additional economic selections through 2032.

To establish the appropriate Candidate Portfolios, Siemens PTI developed multiple scenarios to observe different methods to meet these objectives. Developing scenarios provided guidelines for the design of the Candidate Portfolios.

## Candidate Portfolios

The three Candidate Portfolios were:

1. **Reference Case** based on status quo regulations, and utility expected future resource plans (provided).
2. **Siemens PTI's Market Outlook** based on its National Forecast Model, excluding current utility resource plans.
3. **High Renewable Penetration** based on aggressive renewables targets for all MISO Long Range Transmission planning (LRTP) – Future 2A.

All portfolio results shown below reflect dispatch results in which Minnesota can interact with the greater MISO market. However, an objective while *creating* the portfolios was that Minnesota would not *rely* on the surrounding MISO regions to achieve its clean energy goals[15]. As shown in the results below, Minnesota has the capability to provide the necessary energy and capacity to meet the state's demand but interacts with MISO to dispatch in the most economical way.

An additional sensitivity was conducted in which the generation in Minnesota is unchanged through 2040 to analyze the cost of making no progress towards clean energy goals on a

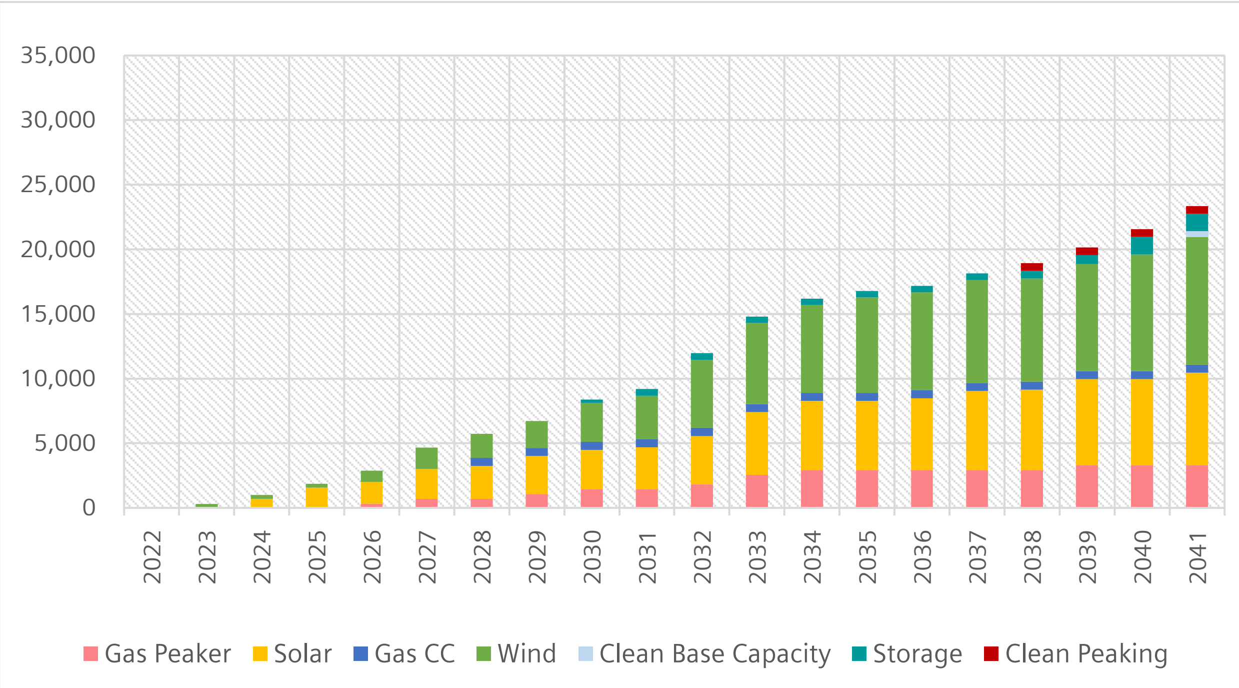
[15] A sensitivity was made where 10% of the energy imported into the state was from clean resources. This was not enough to materially modify the expansion plan, but if this was achieved then the need for RECs would be reduced or eliminated completely.

current generation mix model (CGM). This was evaluated with the inclusion of regulation on cost on carbon and without. A key finding in these results was that these alternatives are not cheaper that the cleaner options, but rather more expensive across most of the evaluated years, and that the increase in market purchases, as surrounding regions transition to cleaner and more efficient generation, puts Minnesota at risk of losing their energy independence. These sensitivities will be referenced further in the following section, specifically as a comparison to their overall portfolio cost.

## 6.1. Candidate Portfolio #1: Reference Case

The Reference Portfolio is the current outlook based on status quo regulations and expected market conditions. As stated in the summary above, Siemens PTI released a data request to various utilities in Minnesota to receive their expected resource plans. Utilizing these resource plans to integrate into the Reference Case buildout assumptions, the new addition selections through a capacity expansion optimization were available to be added beginning in 2032.

**Figure 6-1: Reference Portfolio Cumulative Capacity Build (MW)**




Within the Reference Portfolio, expected utility buildouts consist of 5,150 MW Solar, 625 MW Gas CC, 3,311 MW Gas Peaker, 4,700 MW Wind, and 1,350 MW Storage by 2040.

Beginning in 2032, economic additions beyond utilities plans were allowed. These additions consisted of 1,500 MW Solar, 4,300 MW Wind, 595 MW of clean peaking, and no additional storage between 2032-2040. Despite the opportunity to select 8-hour lithium ion or 10-hour flow batteries, the higher capital investment compared to the 4-hour lithium-ion battery units made it uneconomic to select these longer duration units. See figure below for total portfolio capacity mix for 2024 and 2040. In this report, clean (both base and peaking) capacity refers to thermal generation (combined cycles or combustion turbines respectively) burning clean fuels (no CO2 producing). This is not to be confused with renewable + storage that are sometimes called dispatchable. Within the figures below, gas CC and gas CT are combined into 1 "Gas" classification for simplification purposes.

**Figure 6-2: Reference Portfolio Nameplate Capacity Mix (MW) 2024**

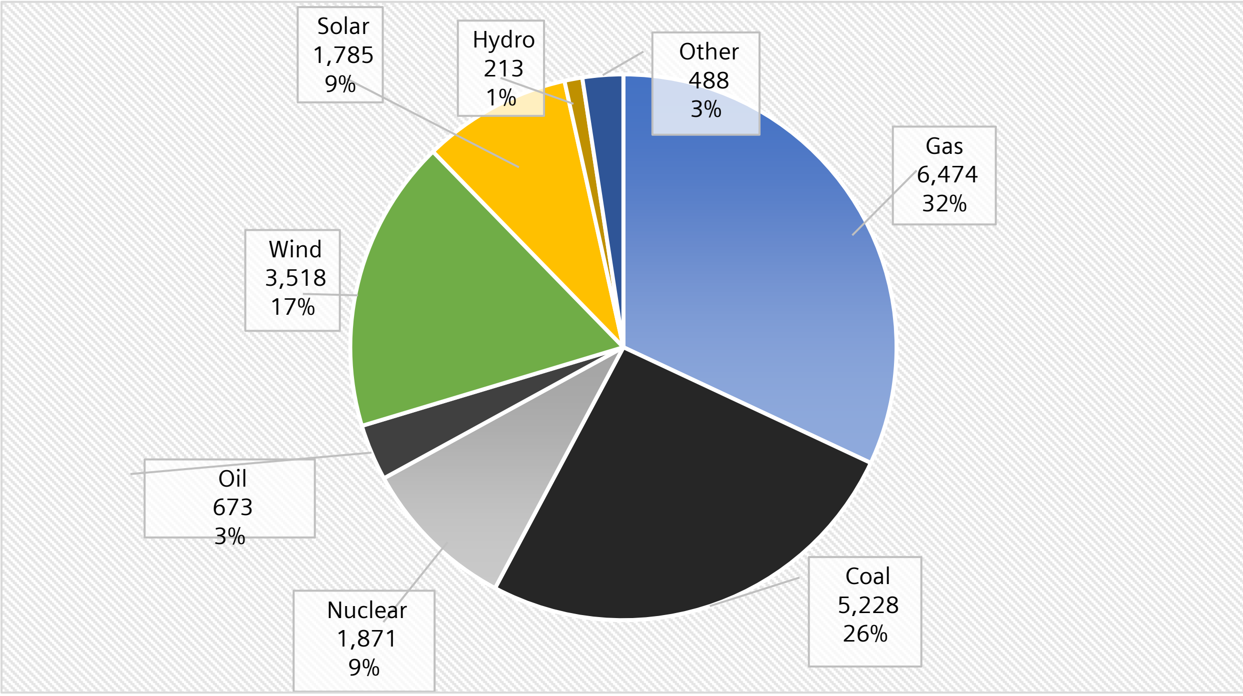



**Figure 6-3: Reference Portfolio Nameplate Capacity Mix (MW) 2040**

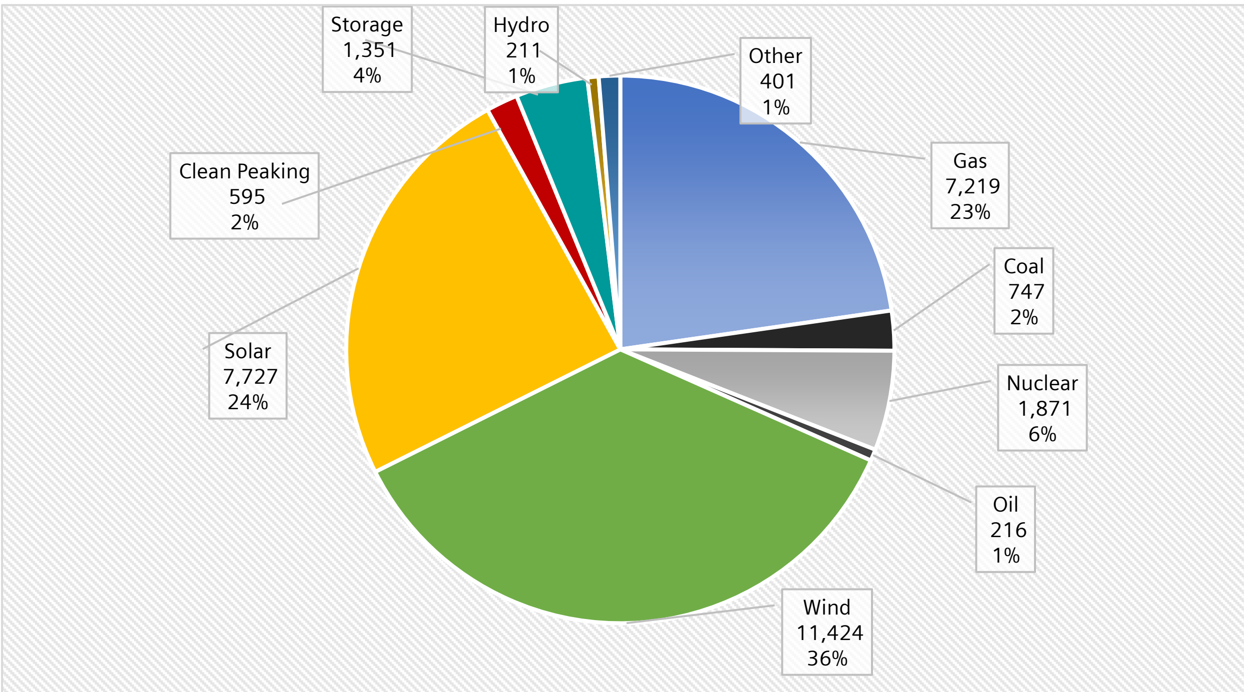
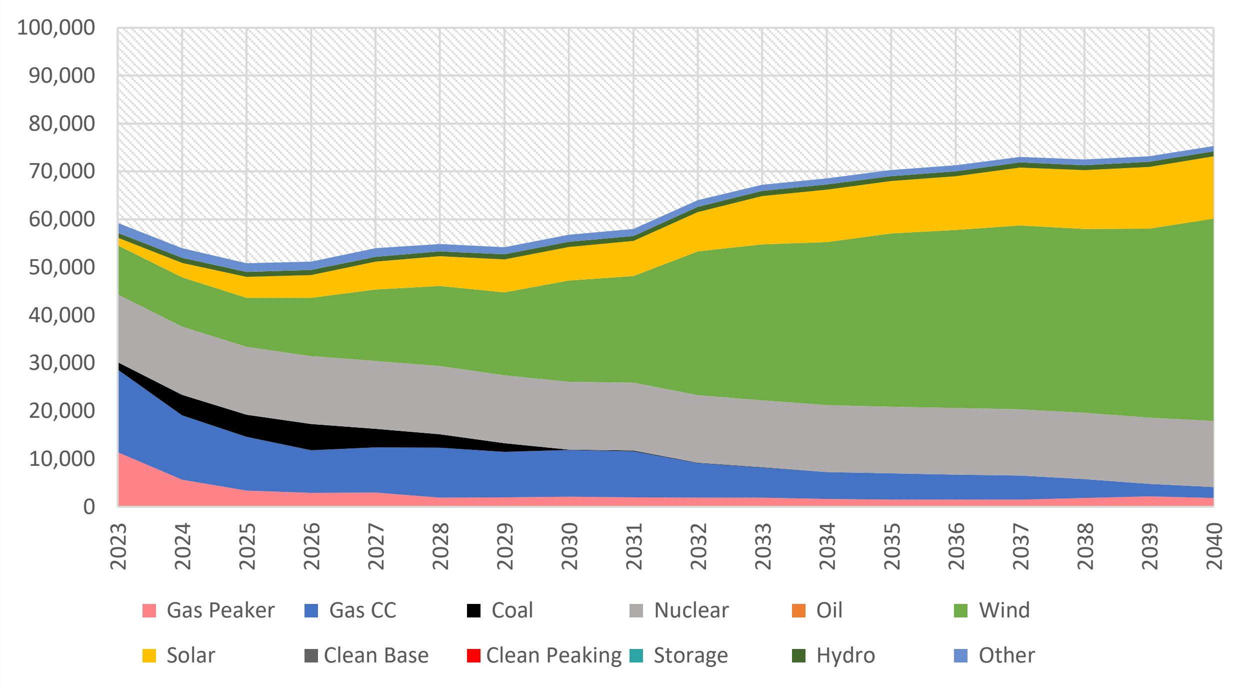


**Figure 6-4: Reference Portfolio Generation Mix (GWh) (Based on economic dispatch)[16]**

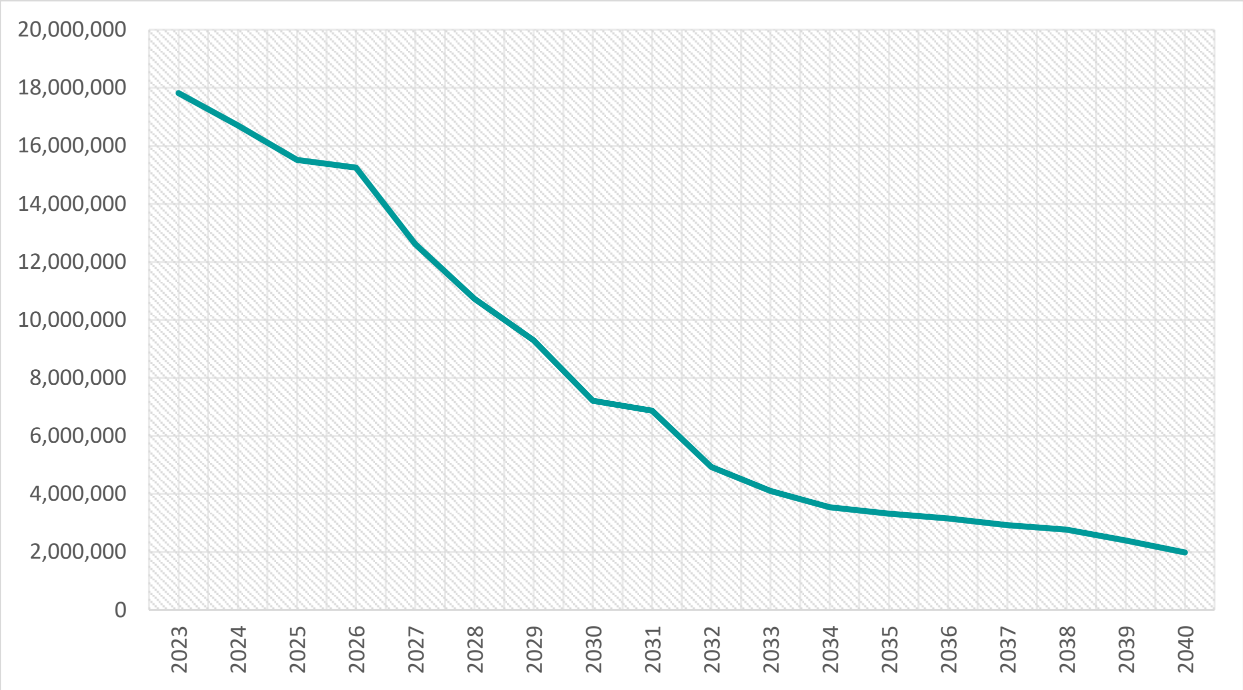



As shown in Figure 6-5, the Reference Portfolio results in significant carbon reduction from Minnesota's generating units. Significant reductions begin immediately as new renewable resources are added in 2023. The combination of thermal retirements with renewable adoption results in an 88% reduction in carbon emissions from 2023-2040.

[16] Generation shown in the figure is representative of a projected economic dispatch simulation, which may not capture current bidding strategies and fuel delivery contractual limitations (take-or-pay) that may result in a deviation on MISO's Day-Ahead and Real-Time markets.

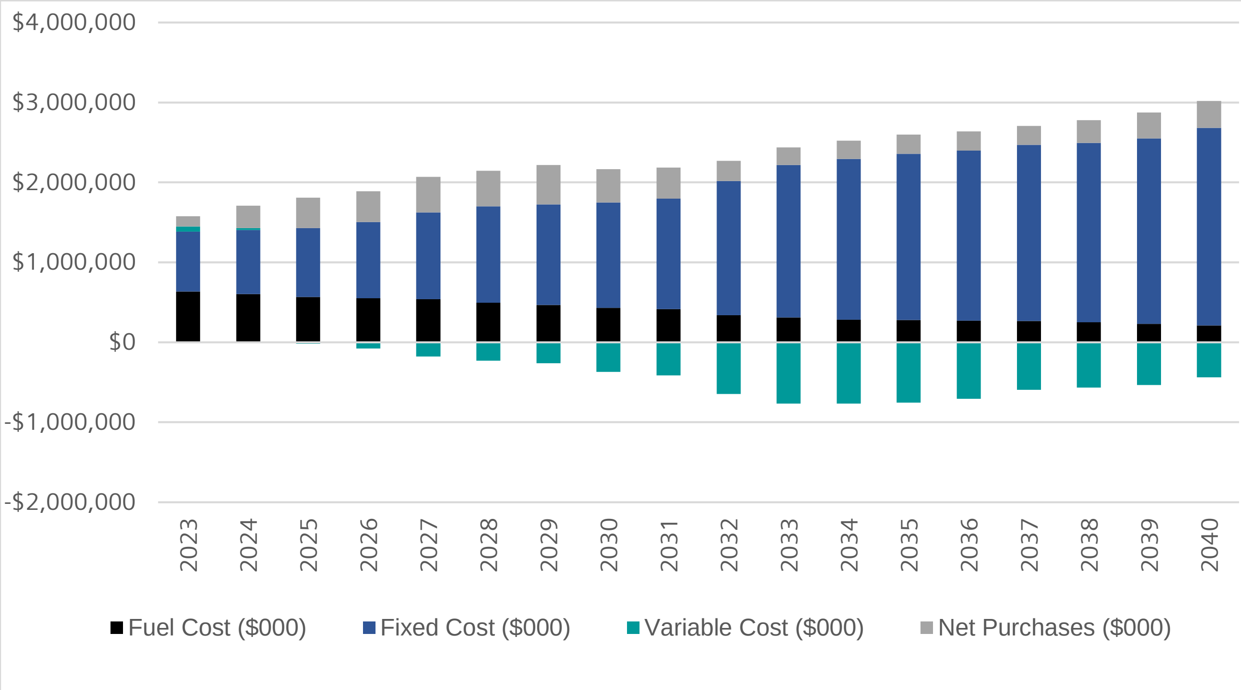
**Figure 6-5: Reference Portfolio Carbon Emissions (Tons)**




Despite significant reductions in carbon emissions, the Reference Portfolio does not meet the carbon reduction requirements without a contribution from REC purchases. Although the current outlook is a low cost of $1.75/MWh, this puts the Reference Portfolio at risk of a competitive RECs market and the 2040 emission reduction target in jeopardy.

Figure 6-6 shows the cost components of the portfolio. We note in this figure that there is a reduction on the costs beginning in 2029, as the additions of renewable resources early on, result in an effective negative variable cost advantage due to the PTC benefits of wind and solar resources, reducing the total portfolio cost along with the reduction of fuel costs. As the PTC benefits begin to wear off and market purchases increases, the Reference Portfolio costs increase alongside. This portfolio has the highest net market purchases of all 3 Candidate Portfolios.

**Figure 6-6: Reference Portfolio Cost Components (2021 $000)**




As shown in Figure 6-7, the orange dashed line is the total cost of the CGM portfolio (no new renewable additions) and no GHG costs and the red dashed line is the CGM including these regulatory GHG costs. We note that in both CGM cases the costs are above the costs of the Reference Portfolio for all years if GHG costs are considered and until 2037 if not. This demonstrates that the clean energy policies not only make societal sense but also economic sense.

**Figure 6-7: Reference Portfolio Total Cost vs CGM Portfolio Cost (2021 $000)**

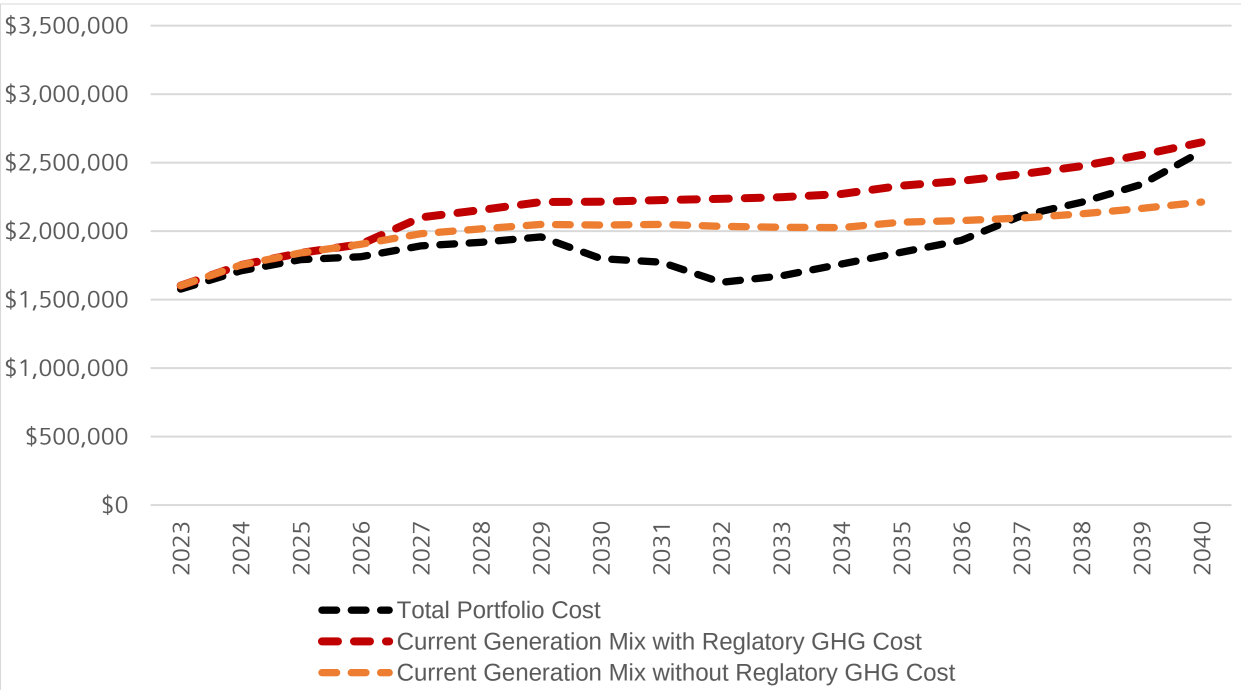


Table 6-1: Reference Portfolio Costs

| Year | Fixed and Variable Cost[17] | Net Purchases | REC Purchases | Total Costs |
|---|---|---|---|---|
| 2023 | $1,448,576 | $128,100 | $0 | $1,576,676 |
| 2024 | $1,428,430 | $281,297 | $0 | $1,709,727 |
| 2025 | $1,410,209 | $380,439 | $0 | $1,790,648 |
| 2026 | $1,426,041 | $386,428 | $0 | $1,812,469 |
| 2027 | $1,449,558 | $443,003 | $0 | $1,892,561 |
| 2028 | $1,471,953 | $445,041 | $0 | $1,916,994 |
| 2029 | $1,465,872 | $492,750 | $0 | $1,958,621 |
| 2030 | $1,381,051 | $417,908 | $0 | $1,798,959 |
| 2031 | $1,382,420 | $391,571 | $0 | $1,773,991 |
| 2032 | $1,374,538 | $251,615 | $0 | $1,626,153 |
| 2033 | $1,454,293 | $217,812 | $0 | $1,672,105 |
| 2034 | $1,530,205 | $229,224 | $0 | $1,759,429 |
| 2035 | $1,606,477 | $239,878 | $12 | $1,846,367 |
| 2036 | $1,690,345 | $241,636 | $12 | $1,931,993 |
| 2037 | $1,875,986 | $236,919 | $11 | $2,112,916 |
| 2038 | $1,928,018 | $282,535 | $10 | $2,210,562 |
| 2039 | $2,018,323 | $322,089 | $8 | $2,340,420 |
| 2040 | $2,245,907 | $335,165 | $7 | $2,581,079 |
| **NPV (2021 $)** | **$21,056,584** | **$4,343,438** | **$55** | **$25,400,077** |

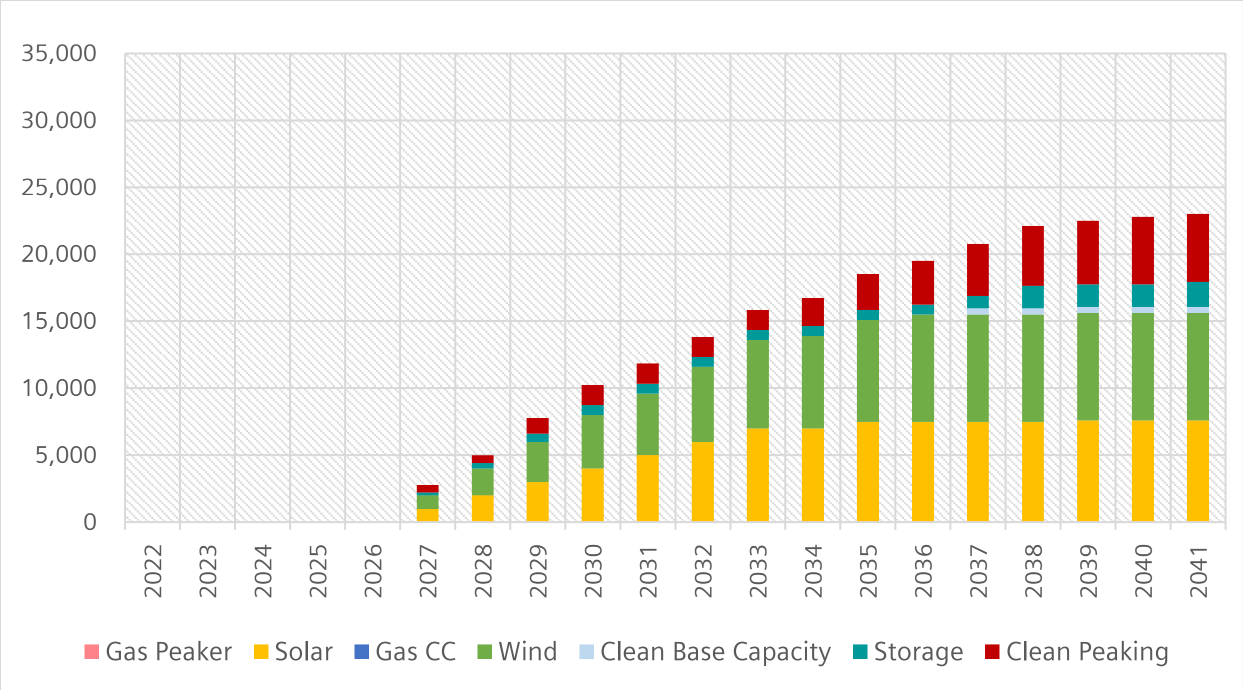
## 6.2. Candidate Portfolio #2: Siemens PTI Market Outlook

This second option is based on current National Forecast Model produced by Siemens PTI, in which no utility outlooks were incorporated.

Under current assumptions, all new builds that have begun construction according to the latest EIA 860 form are included in the generation assets for Minnesota. On top of this, no other new builds are included before 2027 with the assumption that current supply chain issues and regulatory processes would not allow these to be built prior to that date.

[17] Incorporates capital expenditure, fuel costs, fixed and variable O&M

**Figure 6-8 Siemens PTI Market Outlook Cumulative Capacity Build (MW)**




.

Within the Siemens PTI Market Outlook Portfolio, the expected capacity buildouts consist of 7,600 MW Solar, 450 MW Clean base, 5,058 MW Clean peaking, 8,000 MW Wind, and 1,700 MW Storage by 2040.

We assessed 8-hour lithium-ion and 10-hour flow battery options but they were not selected over the 4-hour lithium-ion options, which provided adequate levels of reserve and energy arbitrage.

This portfolio contains much more clean peaking and clean base capacity compared to the Reference Portfolio. This is driven by the utility resource plans which are inclusive of gas peaking and gas CC capacity, making the additional clean base and clean peaking capacity unnecessary in the Reference Portfolio.

**Figure 6-9 Siemens PTI Market Outlook Portfolio Nameplate Capacity Mix (MW) 2024**

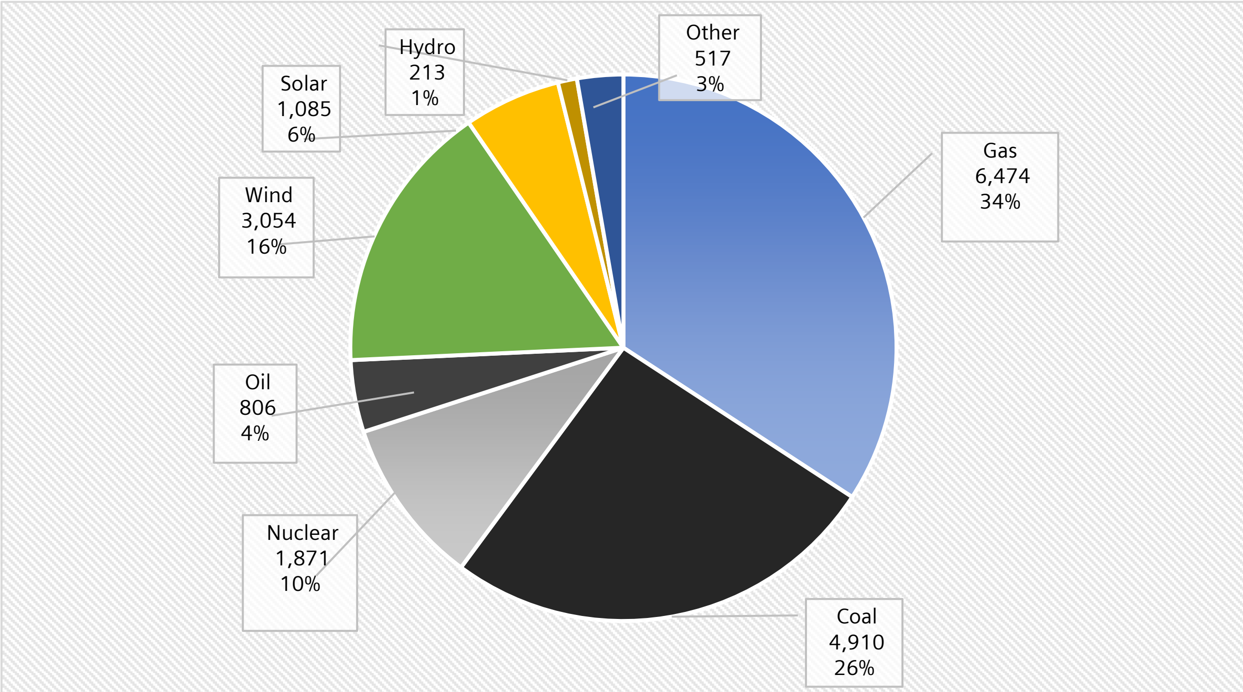



**Figure 6-10 Siemens PTI Market Outlook Portfolio Nameplate Capacity Mix (MW) 2040**

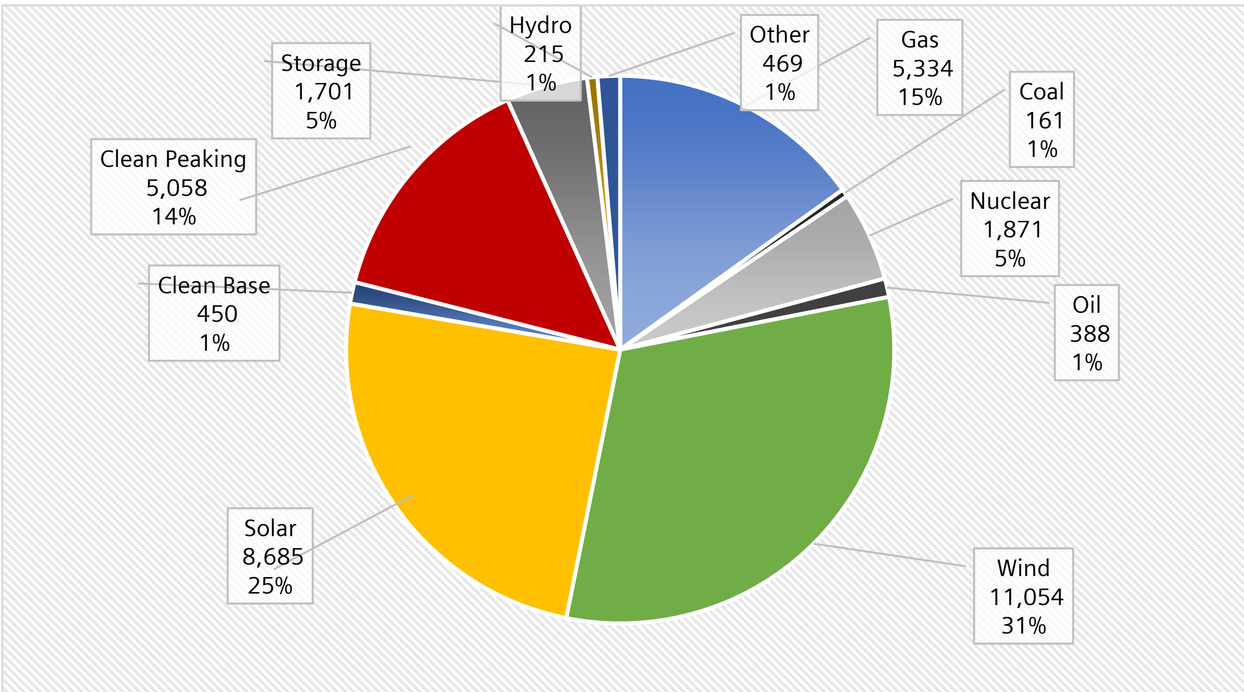
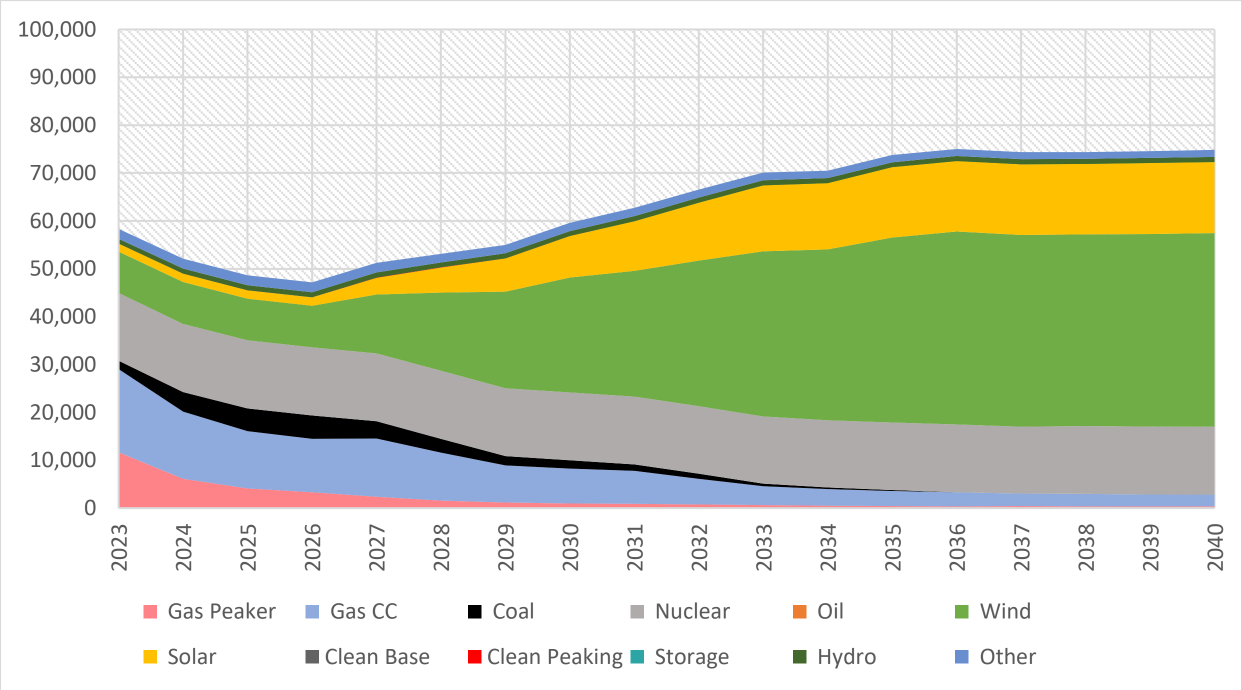


**Figure 6-11: Siemens PTI Market Outlook Portfolio Generation Mix (GWh) (Based on economic dispatch)**




Clean dispatchable capacity makes up roughly 15% of the installed capacity in 2040, as shown in Figure 6-10, but these units seldom run and have an average capacity factor for the peaking units of less than 1% and for clean base of about 4% throughout the forecast period. For this reason, their energy production cannot be appreciated in Figure 6-11.

Like the Reference Portfolio, the Siemens PTI Market Outlook Portfolio resulted in large reductions in CO2 emissions. Major reductions in this portfolio do not begin until the 2027 timeframe due to the lack of additions prior to 2027. With less thermal additions and higher renewable additions as compared to the Reference Portfolio, the Siemens PTI Market Outlook Portfolio resulted in higher reductions by the end of the study period, with a 92% carbon reduction projection between 2023-2040. With this increased reduction of carbon emissions, the Siemens PTI Market Outlook Portfolio is at less risk on RECs reliance than the prior portfolio.

**Figure 6-12: Siemens PTI Market Outlook Portfolio Carbon Emissions (Tons)**

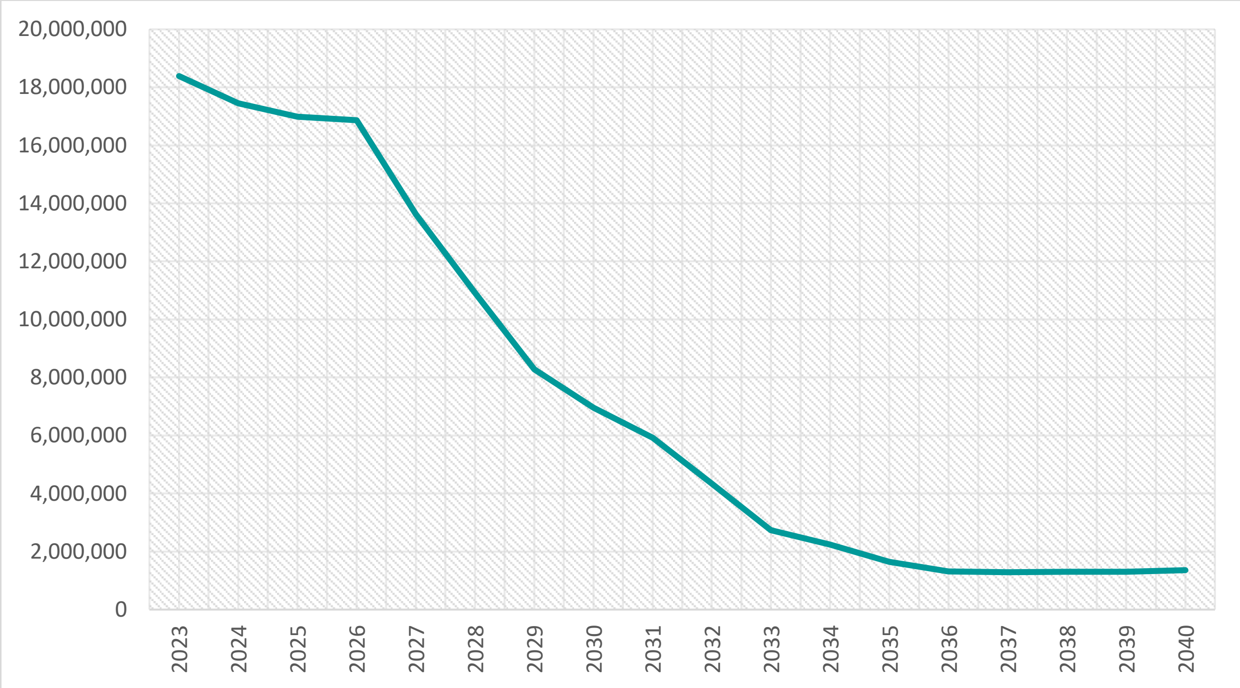
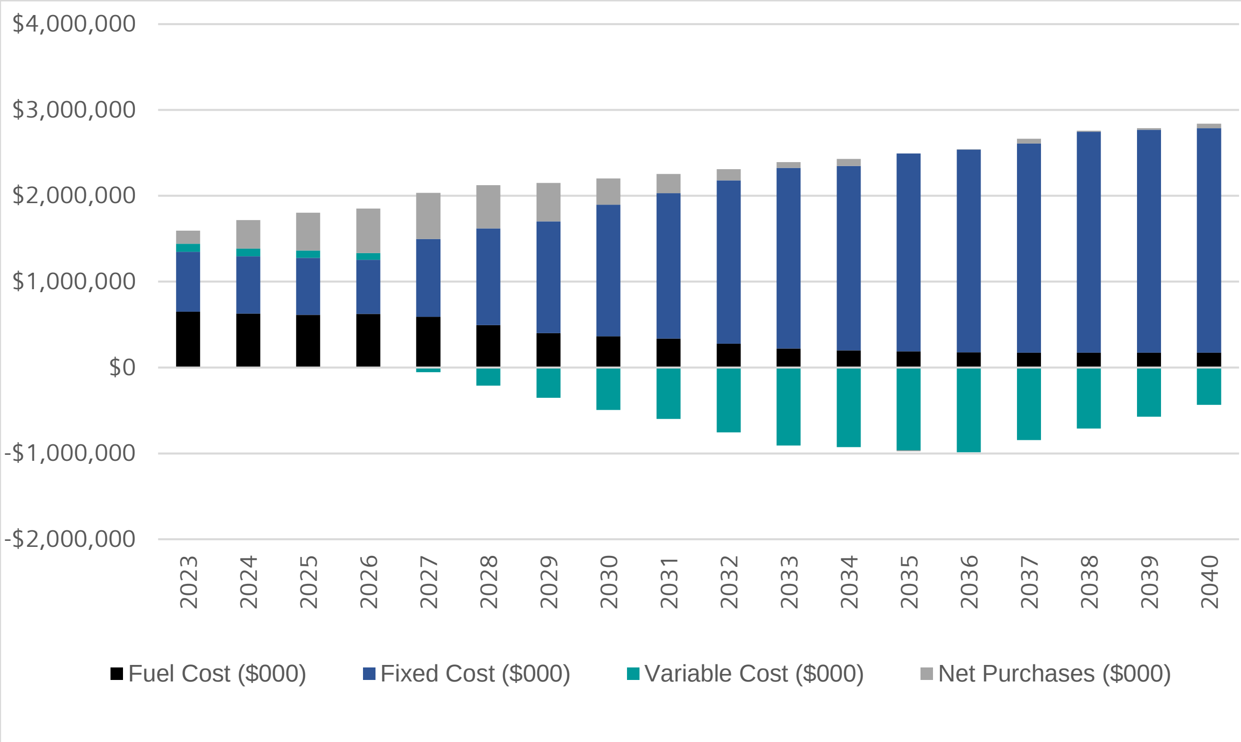



Figure 6-13 shows the cost components of the portfolio. In this case the reduction of the costs beginnings in 2027 again helped by the negative variable costs (due to PTC) and the reduction in fuel costs. The PTC benefits begin later in the Siemens PTI Market Portfolio as compared to the Reference Portfolio, due to the later additions assumed. However, an overall increase in wind and solar adoption, along with resource timing, results in lower variable costs and much lower fuel costs in the later years of the study horizon and a very small amount of net purchases.

**Figure 6-13: Siemens PTI Market Outlook Portfolio Cost Components (2021 $000)**




In Figure 6-14, as before, the orange dashed line is the total cost of the CGM portfolio (no new renewable additions) and no GHG costs and the red dashed line is the CGM including these regulatory GHG costs. We note that in both cases the CGM costs are above the costs of the Siemens PTI Market Portfolio for all years if GHG costs are considered and until 2039 if not. This again demonstrates that the clean energy policies make societal and economic sense.

**Figure 6-14: Siemens PTI Market Outlook Total Cost vs CGM Portfolio Cost (2021 $000)**

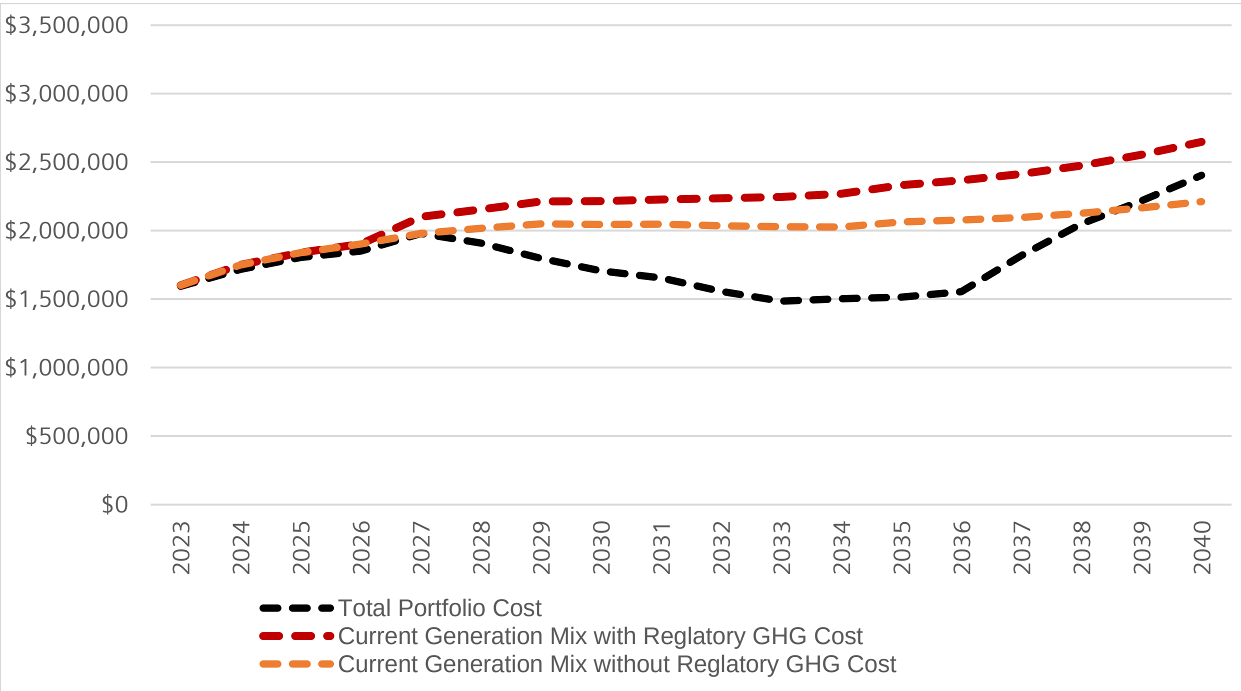


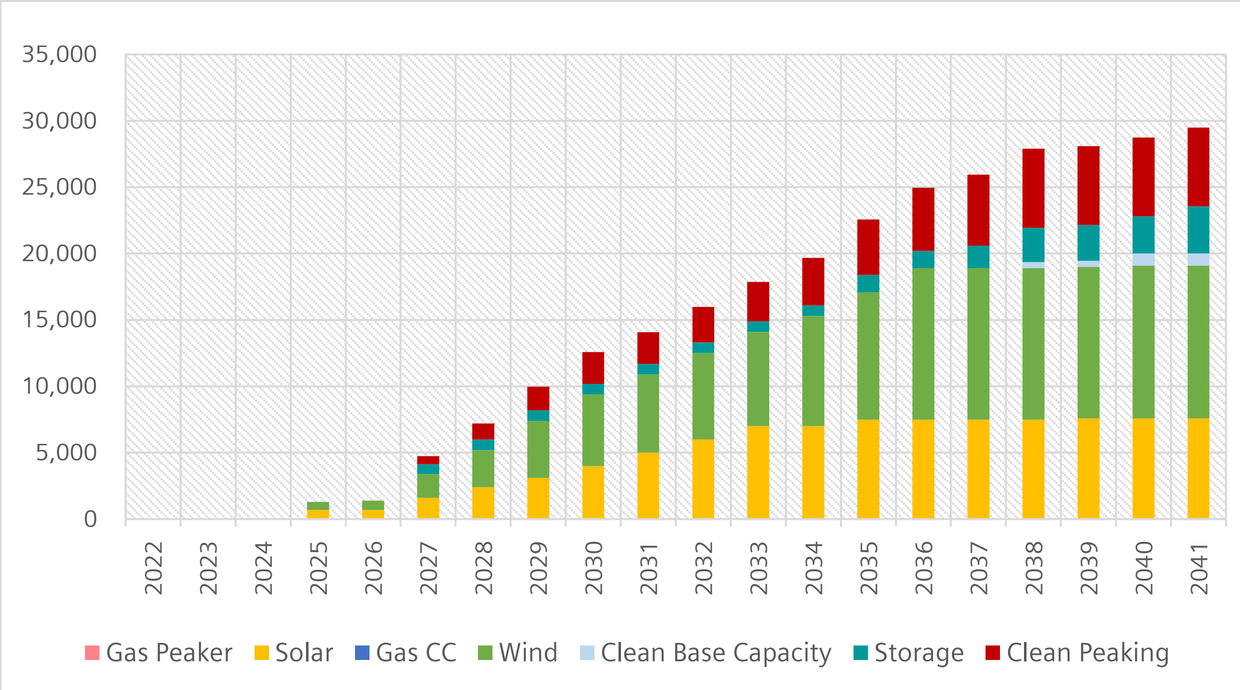
**Table 6-2: Siemens PTI Market Outlook Portfolio Cost**

| Year | Fixed and Variable Cost | Net Purchases | REC Purchases | Total Costs |
|---|---|---|---|---|
| 2023 | $1,442,709 | $150,852 | $0 | $1,593,561 |
| 2024 | $1,384,134 | $333,754 | $0 | $1,717,888 |
| 2025 | $1,362,368 | $441,643 | $0 | $1,804,011 |
| 2026 | $1,334,664 | $515,746 | $0 | $1,850,410 |
| 2027 | $1,445,420 | $535,561 | $0 | $1,980,982 |
| 2028 | $1,408,886 | $501,471 | $0 | $1,910,357 |
| 2029 | $1,350,599 | $447,233 | $0 | $1,797,832 |
| 2030 | $1,402,320 | $304,138 | $0 | $1,706,458 |
| 2031 | $1,431,894 | $223,149 | $0 | $1,655,042 |
| 2032 | $1,426,130 | $131,155 | $0 | $1,557,284 |
| 2033 | $1,417,562 | $68,115 | $0 | $1,485,677 |
| 2034 | $1,423,801 | $78,733 | $0 | $1,502,534 |
| 2035 | $1,526,180 | -$10,596 | $4 | $1,515,588 |
| 2036 | $1,554,365 | $576 | $3 | $1,554,944 |
| 2037 | $1,763,802 | $54,441 | $4 | $1,818,248 |
| 2038 | $2,038,899 | $12,186 | $5 | $2,051,090 |
| 2039 | $2,197,033 | $20,755 | $5 | $2,217,793 |
| 2040 | $2,355,211 | $49,294 | $5 | $2,404,510 |
| **NPV (2021 $000)** | **$20,752,426** | **$3,224,478** | **$23** | **$23,976,928** |

## 6.3. Candidate Portfolio #3: High Renewable Penetration

Siemens PTI utilized MISO's long range transmission planning, Future 2A, based on aggressive renewable targets to analyze a third candidate portfolio. Within MISO's future, high renewable penetration inside Minnesota will take place. Similar levels of wind and solar adoption were reflected in the 3rd candidate portfolio consisting of 11,500 MW new wind capacity and 7,600 MW of new solar capacity by 2040.

**Figure 6-15: High Renewable Penetration Cumulative Capacity Build (MW)**




With no other solar and wind units economically selected, the remaining additions consisted of 5,950 MW Clean peaking, 900 MW Clean base, and 2,800 MW storage. All storage additions represent 4-hour lithium-ion selections, like the two prior portfolios.

**Figure 6-16: High Renewable Penetration Portfolio Nameplate Capacity Mix (MW) 2024**

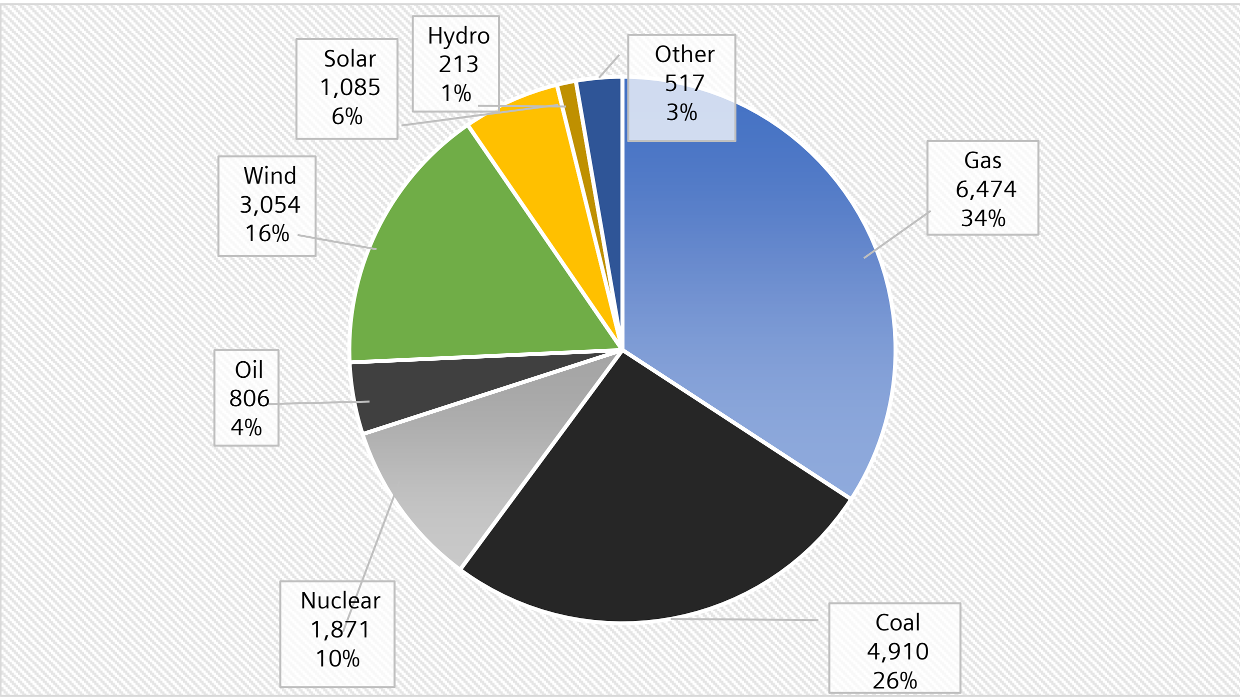


**Figure 6-17: High Renewable Penetration Portfolio Nameplate Capacity Mix (MW) 2040**

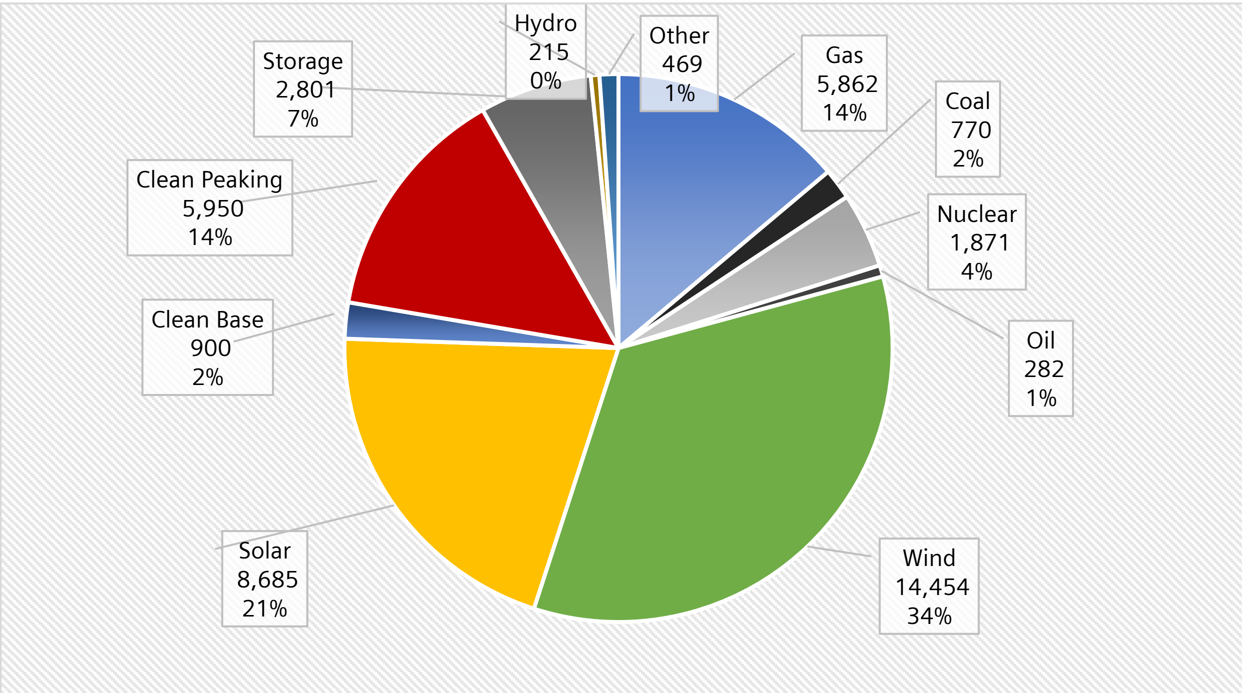
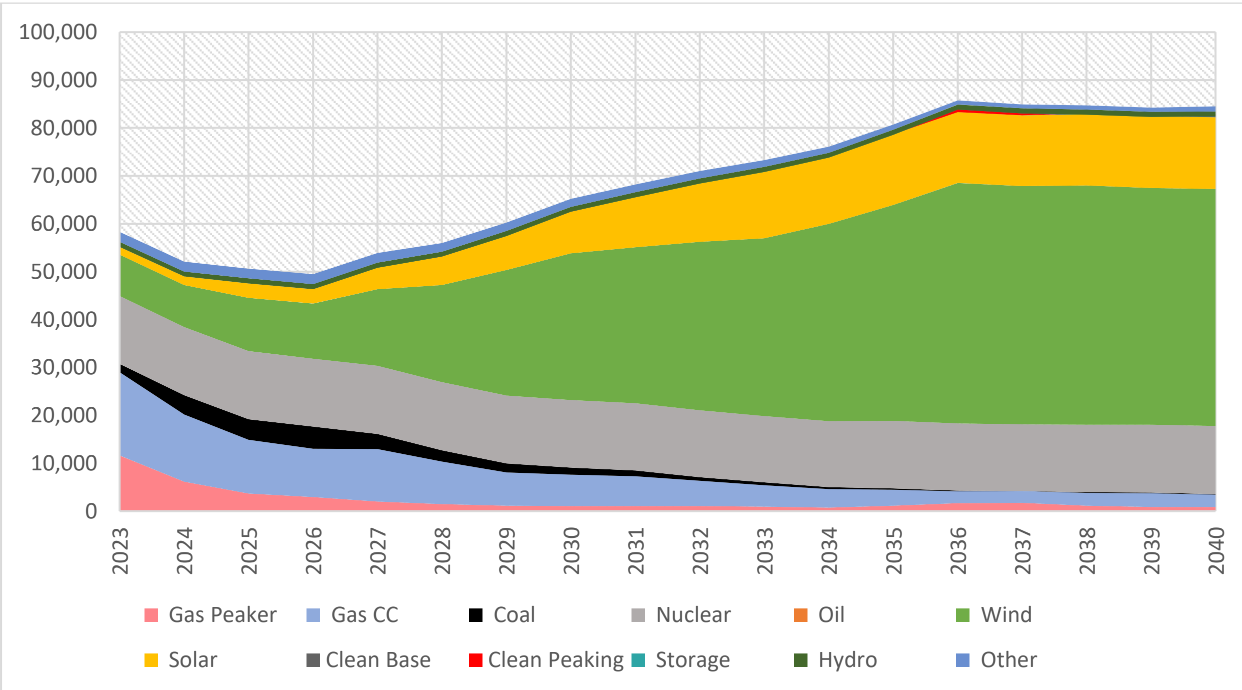



**Figure 6-18: High Renewable Penetration Portfolio Generation Mix (GWh) (Based on economic dispatch)**




Similar to the Siemens PTI Market Outlook Portfolio, clean dispatchable capacity makes up roughly 16% of the installed capacity in 2040, as shown in **Figure 6-17**, but these units seldom run and have an average capacity factor for the peaking units of less than 1% and for clean base of about 6% throughout the forecast period. For this reason, their energy production cannot be appreciated in **Figure 6-18**.

The High Renewable Penetration Portfolio has the largest carbon reduction of all portfolios with a 94% reduction from 2023-2040. However, in this portfolio the overall energy balance is greater than 100% of Minnesota's load, meaning that Minnesota is a net exporter of energy and the amount of carbon-free generation within the portfolio is enough to serve Minnesota's load. Since Minnesota can produce enough carbon free energy to meet their load, the High Renewable Penetration Portfolio does not have any reliance on RECs purchases to meet the legislation's carbon reduction goals. Large reductions in emissions begin sooner than the Siemens PTI Market Outlook Portfolio as renewable resources are added to the portfolio beginning in 2025, per MISO's Long-Range Transmission Outlook renewable addition timing.

**Figure 6-19: High Renewable Penetration Carbon Emissions (Tons)**

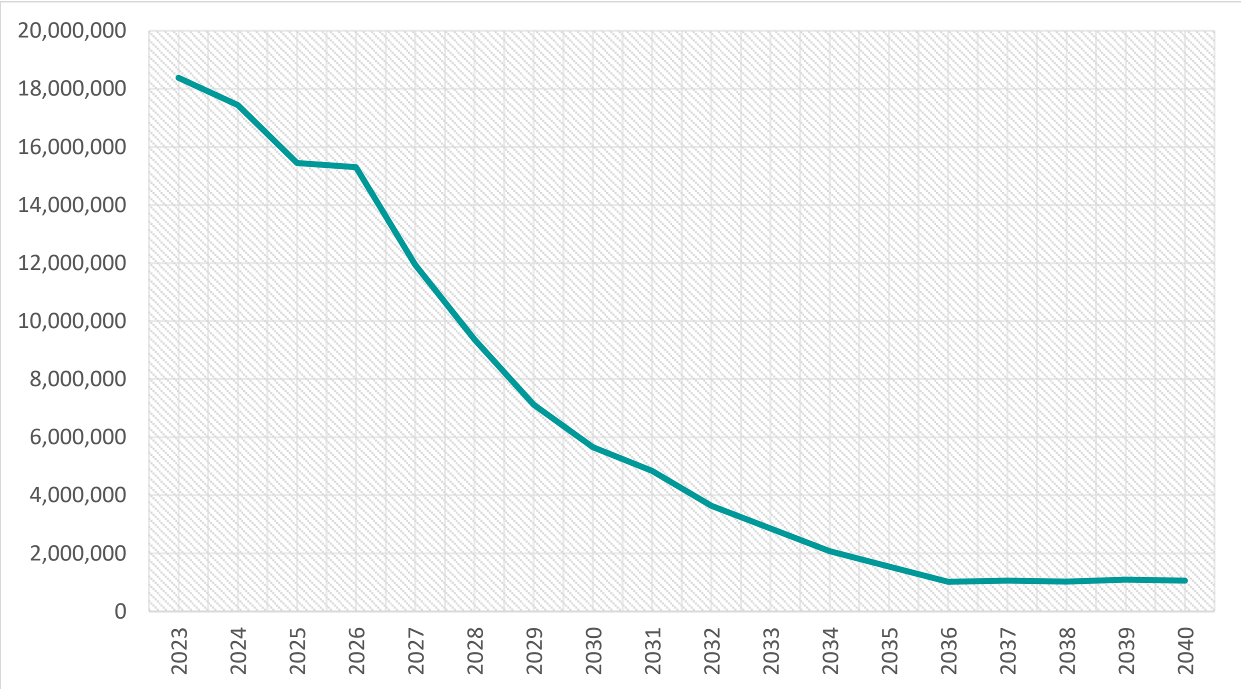
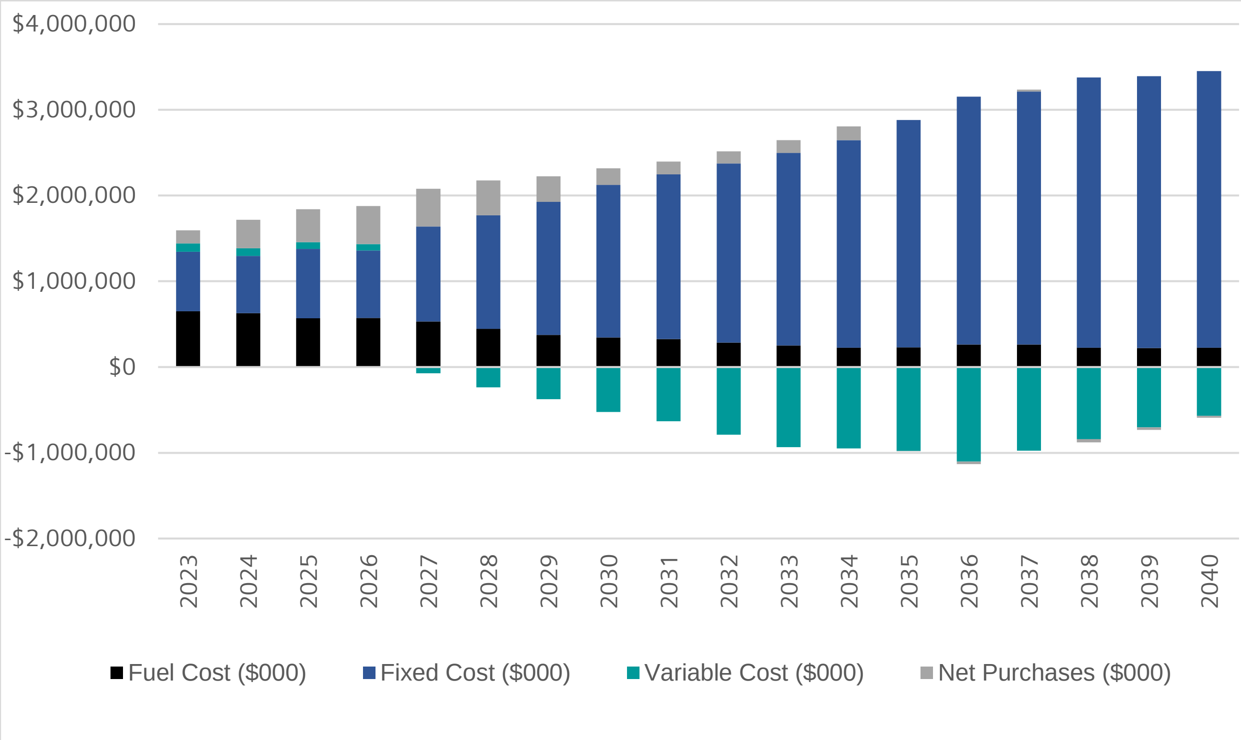



Figure 6-20 shows the cost components of the portfolio for High Renewable Penetration Portfolio. In this case the PTC advantages quickly result in overall negative variable costs (PTC more than covering other variable costs), beginning to offset the high capital expenditure and completely compensating the cost associated with fuel and net purchases.

**Figure 6-20: High Renewable Portfolio Cost Components (2021 $000)**




In the figure below, as before, the orange dashed line is the total cost of the CGM portfolio and no GHG costs, and the red dashed line is the CGM portfolio including these regulatory GHG costs. We note that in both CGM cases the costs are above the costs of the High Renewable Portfolio until 2038 if GHG costs are considered and until 2036 if not.

**Figure 6-21: High Renewable Penetration Total Cost vs CGM Portfolio Cost (2021 $000)**

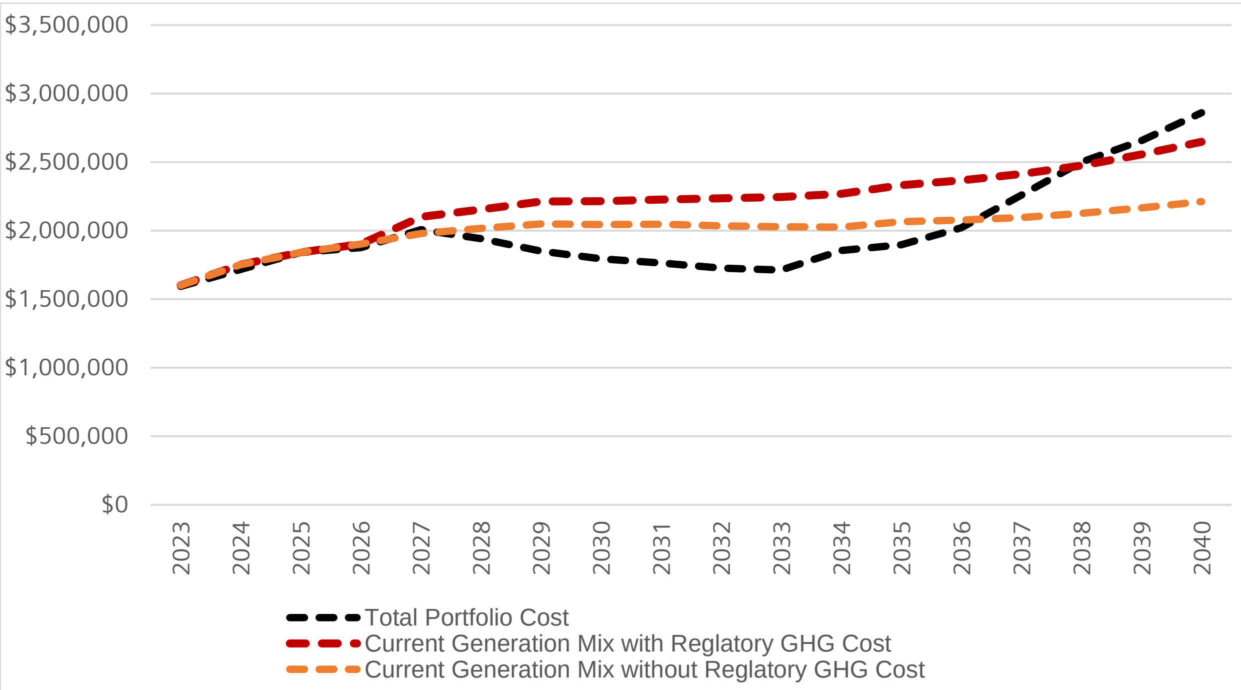


**Table 6-3: High Renewable Penetration Portfolio Costs**

| Year | Fixed and Variable Cost | Net Purchases | REC Purchases | Total Costs |
|---|---|---|---|---|
| 2023 | $1,441,877 | $151,949 | $0 | $1,593,827 |
| 2024 | $1,384,010 | $333,300 | $0 | $1,717,311 |
| 2025 | $1,457,524 | $383,002 | $0 | $1,840,526 |
| 2026 | $1,435,130 | $441,446 | $0 | $1,876,576 |
| 2027 | $1,568,261 | $439,871 | $0 | $2,008,132 |
| 2028 | $1,534,785 | $406,186 | $0 | $1,940,971 |
| 2029 | $1,550,418 | $300,965 | $0 | $1,851,383 |
| 2030 | $1,600,111 | $193,941 | $0 | $1,794,052 |
| 2031 | $1,615,210 | $148,566 | $0 | $1,763,775 |
| 2032 | $1,584,607 | $143,079 | $0 | $1,727,686 |
| 2033 | $1,563,977 | $148,853 | $0 | $1,712,830 |
| 2034 | $1,694,174 | $162,225 | $0 | $1,856,398 |
| 2035 | $1,900,696 | -$2,995 | -$6 | $1,897,695 |
| 2036 | $2,051,394 | -$29,412 | -$14 | $2,021,968 |
| 2037 | $2,236,329 | $23,918 | -$12 | $2,260,235 |
| 2038 | $2,537,031 | -$37,154 | -$11 | $2,499,866 |
| 2039 | $2,688,490 | -$31,475 | -$9 | $2,657,006 |
| 2040 | $2,885,700 | -$25,299 | -$8 | $2,860,392 |
| **NPV (2021 $000)** | **$23,744,965** | **$2,673,525** | **-$56** | **$26,418,434** |

# 7. Candidate Portfolio Analysis (Step 4)

## 7.1. Storage Economics

Siemens PTI conducted its economic analysis of the energy storage resources selected using technology and financial assumptions based on Li-Ion 4-hour duration battery storage. Technology and financial assumptions are reflected in Table 7-1 and Table 7-2 below.

**Table 7-1: Storage Technology Assumptions**

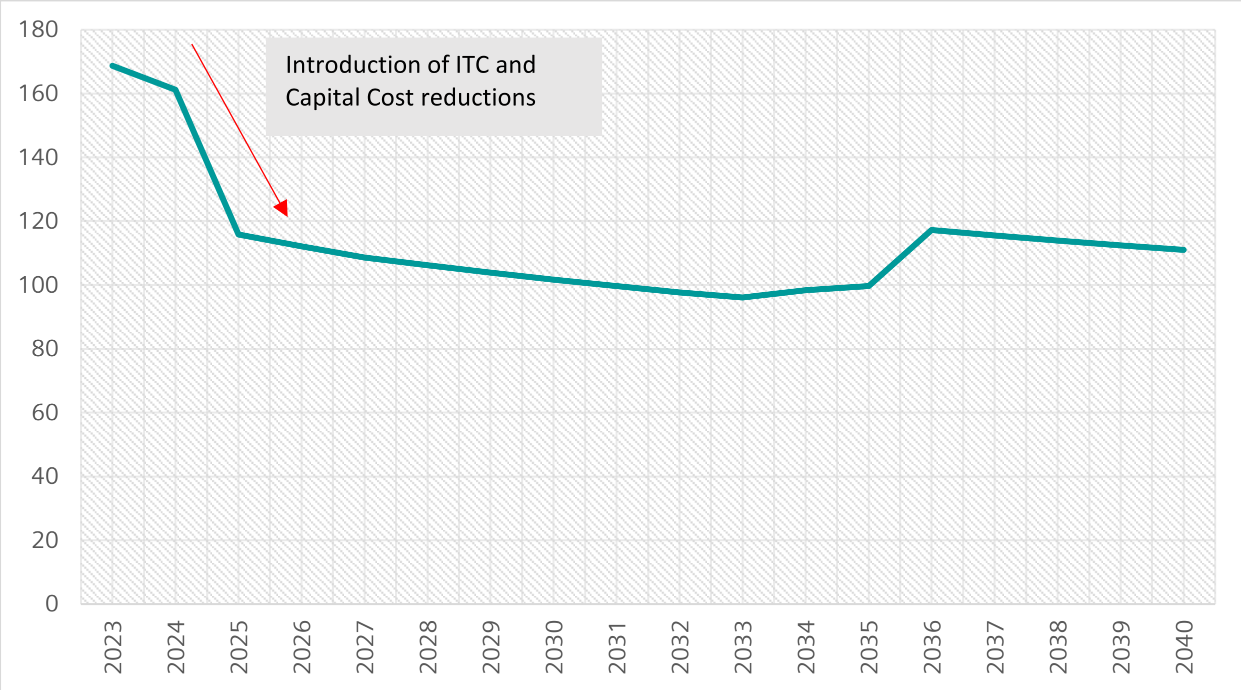
| Assumption | Value |
|---|---|
| Battery Capacity per Addition | 50 MW |
| Maximum Storage Capability (4 hr.) | 200 MWh |
| Start Year | 2027 |
| Battery Capital Cost | $1,180 (2021$/kW) |
| Interconnection Costs/ Network Upgrades | $2.5 MM USD |
| Battery Variable O&M | $0.0 (2021$/MWh) |
| Battery Fixed O&M (Includes Augmentation) | $31.5 (2021$/kW-yr.) |
| Effective Load Carrying Capability (ELCC) | 90% |

**Table 7-2: Storage Technology Financial Assumptions**

| Financial Assumption | Unit |
|---|---|
| Debt | 60% |
| Equity | 40% |
| Cost of Debt | 7.2% |
| Cost of Equity | 12.2% |
| Tax Rate (Federal + State) | 26% |
| Property Tax Rate (% of Capex) | 0.80% |
| Nominal After Tax WACC | 8.11% |
| BESS Book Depreciation | 15 Years |
| BESS ITC Credit | 30% |
| Debt Amortization | 10 Years |
| Tax Depreciation | 7-yr MACRS Schedule |

Recent market developments including the introduction of the federal ITC in addition to overall capital cost reductions have improved economics significantly. As reflected in the levelized costs (see Figure 7-1), storage economics are forecasted to continue to improve as further capital cost reductions are realized.

**Figure 7-1: Li-Ion Storage Levelized Cost (2021$/kW-yr.)**




Under the market assumptions of Portfolio #2: Siemens PTI Market Outlook, a cumulative capacity total of 1,700 MW of additional battery storage was selected for inclusion in Minnesota's portfolio by 2040. Based on future conditions of the system this level of storage was determined to be adequate in meeting the various policy targets of the portfolio while maintaining system reliability.

Sources of revenue for battery storage include MISO capacity payments as well as energy arbitrage[18]. In general, arbitrage revenue is projected to increase as more renewable generation is added to the system and is the leading source of revenue by 2036. However, results continue to indicate that projected capacity and energy revenues[19] alone will not be sufficient in meeting revenue requirements of battery storage deployment at an assumed WACC of 8.1%., reflecting the current time value of money. Even with consideration of the federal ITC and projected cost reduction within the study period, external support is required for feasibility of battery storage deployment at a large scale.

Figure 7-2 shows the 2030 present value of the costs (capital and O&M) for 50 MW of 4 hours lithium-ion storage installed in 2030 and compares with the present value of the revenues (Capacity and Arbitrage). In this figure we observe that there is an expected shortfall of $21 million or 28% of the costs.

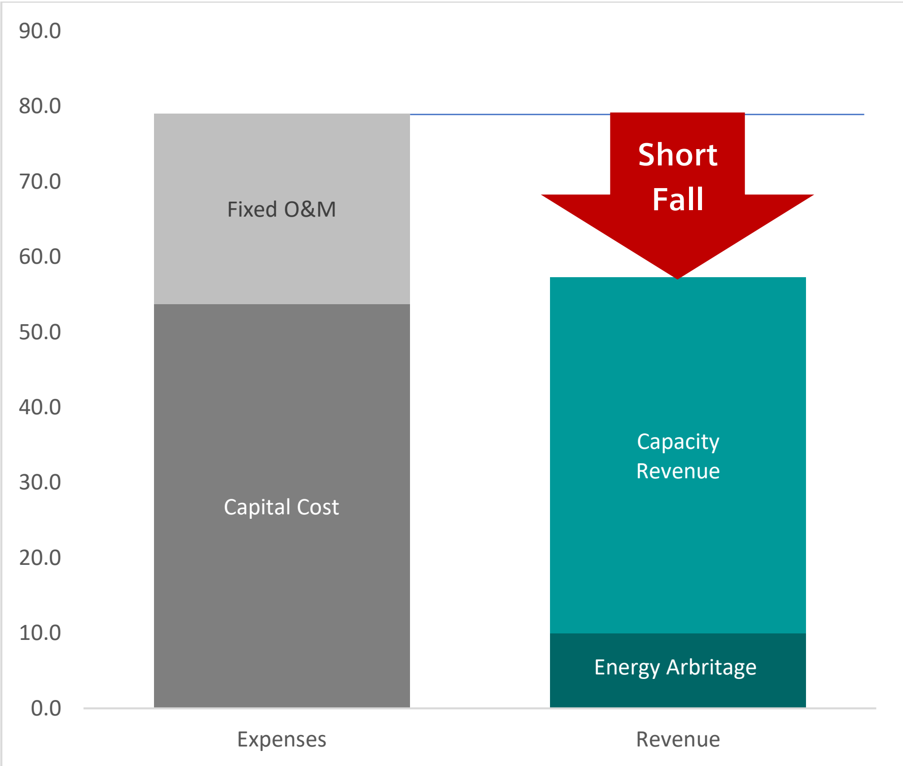
[18] Revenue from ancillary markets is considered small compared with capacity and energy arbitrage.

[19] The capacity price forecast is a function of the reserve margin requirements, the available capacity to meet it and the Cost of New Entry (CONE) that sets a theoretical maximum. Capacity market prices reflects reasonable returns for producers, while meeting system reliability targets. Siemens PTI's capacity price reflects the Net CONE of an advanced simple cycle frame CT, which is the least-cost new entrant needed to maintain reliability, less the expected revenues that the CT would have in the energy market. The CONE is expected to decrease slightly as the capital cost for a gas CT decreases through time and in the long-term, the CONE is expected to be given by battery energy storage unit.

State-level incentives and other policy measures will continue to serve as important tools to accelerate the energy storage market by serving as a supplementary source of funding until storage becomes cost-competitive.

Based on the above findings, a central recommendation of this study is for Minnesota to consider implementing state-level policies, targets, and programs for electric utilities to promote the adoption of energy storage technologies that the state needs to transition to a decarbonized power sector. As implemented in other states, Minnesota should enable storage technologies to be procured by the utilities, provide complementary funding mechanisms where necessary, and establish policies that reduce barriers and promote energy storage adoption.

**Figure 7-2: 2030 Storage Addition Cost and Revenues (2024$/kw-yr.)**




This detailed cost analysis was not conducted on the 8-hour or 10-hour flow battery options as these resources were not selected in any portfolio (due to cost assumptions within the model).

## 7.2. Resource Flexibility / Fast Ramping Analysis

Combining the system load and renewable variable energy generation Siemens PTI utilized a bounded moving sampling method to flush out the intra-hour profiles for load and renewables. Siemens PTI then processed the intra-hourly profiles to determine Minnesota's need to adapt to sudden changes in load and generation in both the 5-minute and 10-minute intervals.

Analysis of the 5-minute resource flexibility requirement identified a maximum requirement increase proportional to the increase in load and renewable energy. Computing the maximum value with a 95% confidence the system flexibility requirement increases from historically peak of 1,415MW in June of 2023 to a forecasted peak of 6,351MW in November of 2040. Table 7-3 represents the fast-ramping capacity needed within Minnesota to ensure at a 95% confidence level that Minnesota has adequate coverage for the potential sub-hourly changes in load and/or renewable generation.

**Table 7-3: 5-Minute Fast Ramping Requirement (MW), 95th Percentile Confidence**

| Month | 2026 | 2027 | 2028 | 2029 | 2030 | 2031 | 2032 | 2033 | 2034 | 2035 | 2036 | 2037 | 2038 | 2039 | 2040 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1,615 | 1,972 | 2,239 | 2,785 | 3,168 | 3,345 | 3,526 | 3,754 | 4,167 | 4,638 | 5,314 | 5,348 | 5,490 | 5,542 | 5,658 |
| 2 | 1,498 | 1,817 | 2,191 | 2,733 | 3,058 | 3,238 | 3,478 | 3,627 | 4,036 | 4,602 | 5,163 | 5,232 | 5,370 | 5,500 | 5,565 |
| 3 | 1,502 | 1,839 | 2,178 | 2,642 | 3,040 | 3,179 | 3,437 | 3,614 | 3,992 | 4,424 | 5,056 | 5,239 | 5,323 | 5,456 | 5,359 |
| 4 | 1,322 | 1,688 | 1,953 | 2,414 | 2,766 | 2,834 | 3,112 | 3,274 | 3,715 | 4,078 | 4,565 | 4,686 | 4,919 | 4,982 | 4,848 |
| 5 | 1,259 | 1,553 | 1,868 | 2,232 | 2,610 | 2,809 | 3,011 | 3,174 | 3,515 | 3,894 | 4,532 | 4,631 | 4,801 | 4,743 | 4,742 |
| 6 | 1,651 | 1,971 | 2,257 | 2,813 | 3,189 | 3,376 | 3,637 | 3,791 | 4,144 | 4,641 | 5,315 | 5,348 | 5,586 | 5,614 | 5,711 |
| 7 | 1,405 | 1,639 | 1,981 | 2,434 | 2,803 | 2,841 | 2,984 | 3,188 | 3,580 | 4,038 | 4,638 | 4,602 | 4,597 | 4,765 | 4,941 |
| 8 | 1,171 | 1,399 | 1,654 | 1,995 | 2,322 | 2,421 | 2,589 | 2,663 | 3,037 | 3,288 | 3,850 | 3,951 | 4,051 | 3,976 | 4,127 |
| 9 | 1,532 | 1,871 | 2,254 | 2,694 | 3,049 | 3,378 | 3,708 | 4,048 | 4,277 | 4,684 | 4,967 | 5,202 | 5,170 | 5,316 | 5,324 |
| 10 | 1,523 | 1,973 | 2,431 | 2,934 | 3,401 | 3,610 | 3,959 | 4,261 | 4,715 | 5,242 | 5,770 | 5,719 | 5,931 | 5,960 | 6,086 |
| 11 | 1,663 | 2,127 | 2,454 | 3,048 | 3,524 | 3,865 | 4,147 | 4,502 | 4,882 | 5,408 | 6,200 | 6,197 | 6,438 | 6,304 | 6,351 |
| 12 | 1,402 | 1,695 | 1,966 | 2,352 | 2,643 | 2,820 | 3,038 | 3,265 | 3,587 | 3,952 | 4,261 | 4,311 | 4,485 | 4,562 | 4,595 |
| **Annual Max** | **1,663** | **2,127** | **2,454** | **3,048** | **3,524** | **3,865** | **4,147** | **4,502** | **4,882** | **5,408** | **6,200** | **6,197** | **6,438** | **6,304** | **6,351** |

Like the 5-minute resource adequacy requirement, the 10-minute flexibility requirement identified a maximum requirement increase proportional to the increase in load and renewable energy. Computing the maximum value with a 95% confidence the system flexibility requirement increases from historically peak of 1,410 MW in January of 2023 to a forecasted peak of 6,443 MW in November of 2040.

**Table 7-4: 10-Minute Fast Ramping Requirement (MW), 95th Percentile Confidence**

| Month | 2026 | 2027 | 2028 | 2029 | 2030 | 2031 | 2032 | 2033 | 2034 | 2035 | 2036 | 2037 | 2038 | 2039 | 2040 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1,605 | 1,928 | 2,234 | 2,763 | 3,189 | 3,281 | 3,451 | 3,787 | 4,178 | 4,576 | 5,328 | 5,390 | 5,458 | 5,516 | 5,839 |
| 2 | 1,514 | 1,873 | 2,210 | 2,714 | 3,106 | 3,209 | 3,453 | 3,608 | 4,157 | 4,627 | 5,163 | 5,292 | 5,401 | 5,418 | 5,681 |
| 3 | 1,501 | 1,870 | 2,146 | 2,618 | 3,044 | 3,175 | 3,459 | 3,558 | 3,961 | 4,491 | 5,094 | 5,247 | 5,387 | 5,404 | 5,381 |
| 4 | 1,328 | 1,664 | 1,979 | 2,429 | 2,728 | 2,845 | 3,166 | 3,336 | 3,691 | 4,116 | 4,533 | 4,754 | 5,035 | 4,927 | 4,853 |
| 5 | 1,271 | 1,577 | 1,867 | 2,248 | 2,566 | 2,789 | 3,059 | 3,191 | 3,469 | 3,860 | 4,483 | 4,629 | 4,731 | 4,804 | 4,784 |
| 6 | 1,654 | 1,960 | 2,268 | 2,891 | 3,176 | 3,421 | 3,591 | 3,764 | 4,212 | 4,647 | 5,202 | 5,373 | 5,629 | 5,564 | 5,676 |
| 7 | 1,416 | 1,689 | 2,000 | 2,463 | 2,758 | 2,867 | 2,999 | 3,166 | 3,562 | 4,060 | 4,521 | 4,619 | 4,679 | 4,793 | 5,031 |
| 8 | 1,197 | 1,433 | 1,691 | 2,016 | 2,352 | 2,438 | 2,601 | 2,705 | 3,070 | 3,359 | 3,862 | 3,952 | 4,012 | 3,965 | 4,069 |
| 9 | 1,566 | 1,904 | 2,219 | 2,682 | 3,079 | 3,369 | 3,646 | 4,170 | 4,222 | 4,726 | 5,013 | 5,091 | 5,205 | 5,281 | 5,263 |
| 10 | 1,556 | 1,965 | 2,404 | 3,015 | 3,385 | 3,622 | 3,951 | 4,279 | 4,762 | 5,296 | 5,738 | 5,872 | 5,852 | 6,064 | 6,057 |
| 11 | 1,666 | 2,099 | 2,476 | 3,098 | 3,516 | 3,868 | 4,098 | 4,549 | 4,791 | 5,394 | 6,213 | 6,246 | 6,487 | 6,368 | 6,443 |
| 12 | 1,432 | 1,725 | 1,954 | 2,343 | 2,598 | 2,810 | 3,022 | 3,252 | 3,687 | 3,918 | 4,208 | 4,312 | 4,515 | 4,631 | 4,692 |
| Annual Max | **1,666** | **2,099** | **2,476** | **3,098** | **3,516** | **3,868** | **4,098** | **4,549** | **4,791** | **5,394** | **6,213** | **6,246** | **6,487** | **6,368** | **6,443** |

Upon analyzing the flexible peaking capacity within all 3 Candidate Portfolios as compared to the potential sub-hourly need on a 5 and 10-minute interval level laid out in the tables above, all portfolios exceeded the flex requirements to ensure a reliability for all years, shown in the following section in Table 8-3.

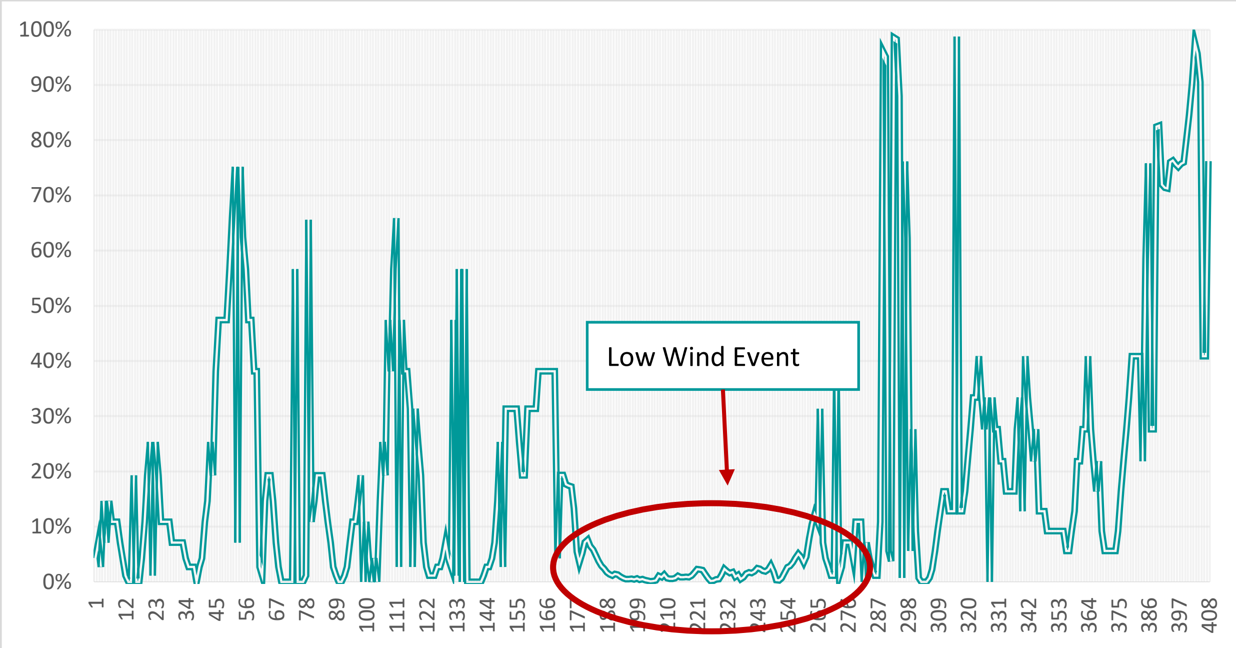
## 7.3. MISO Low Wind Sensitivity Analysis

Based on feedback received following the initial (December 22nd) stakeholder engagement, Siemens PTI has included an additional reliability analysis regarding a low wind event sensitivity. This analysis was conducted upon the portfolio which contains the highest wind capacity (Candidate portfolio #3).

Using the low wind event seen in 2018, Candidate Portfolio #3 was run on an hourly basis with a similar 4-day low wind event in 2035 to analyze the overarching affects throughout MISO.

See Figure 7-3 for a closer look at how this expected event is incorporated into the wind capability for these days. Selected for a peak month (July), the figure is an hourly representation of 7/20/2035 – 8/5/2035.

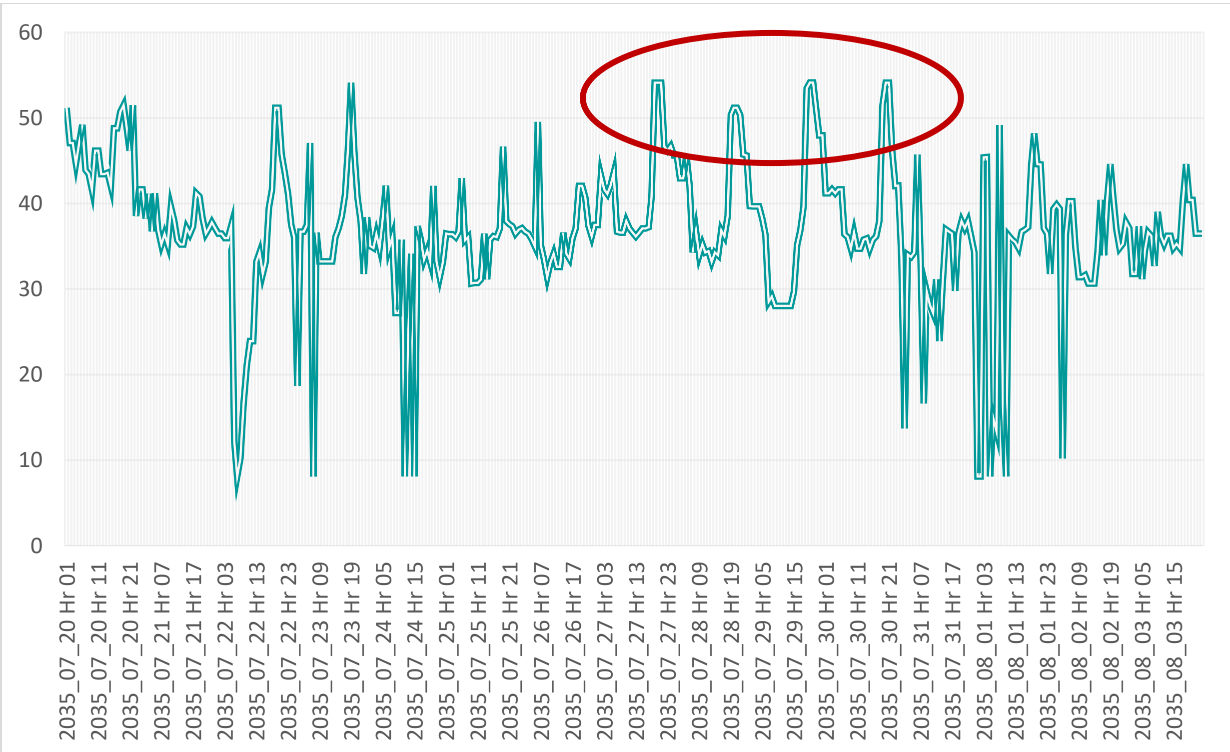
**Figure 7-3: Minnesota Wind Capability**




This same wind event was applied to the rest of the MISO wind units as well for the same time frame, assuming there would be a lack of wind throughout to analyze the repercussions of such an event.

While this does result in price spikes, specifically in hours 19-22, for the days involved in the low wind event, no large scarcity or unserved energy is observed.

**Figure 7-4: Hourly Minnesota Power Prices (2021$/MWh)**



As the states surrounding Minnesota do not have strict carbon reduction targets, a slight ramp in coal generation is seen in the surrounding regions to help serve some non-Minnesota base load energy throughout the event, despite the assumed additional carbon tax in this timeframe. Gas peaking units also picked up, both inside and outside Minnesota. While more expensive than typical baseload and renewable units, these peaking units do not have an astronomical dispatch cost, setting the marginal cost in the low solar hours to roughly $55/MWh (2021$). Since this event is assumed to occur in the summer, where solar production is at its peak, specifically in the high load hours, solar generation can keep daytime prices reasonably low.

Overall, the mix of renewable technologies and peaking capacity associated with the High Renewable Penetration Portfolio is adequate to stabilize prices and reliability throughout such an event.

# 8. Analysis Results and Comparison (Step 5)

## 8.1. Energy Storage Capacity Study Findings

This ESS Study report is designed to provide Minnesota with optimal amount of storage capacity needed within the state of Minnesota associated with the different Candidate Portfolios. By comparing all Candidate Portfolios, this study was able to establish some key findings.

**Table 8-1: Balanced Scorecard**

| Category | Objective | Metric | Reference Case | Siemens PTI Market Outlook | High Renewable Penetration | Current Mix with Regulatory Cost | Current Mix without Regulatory Cost |
|---|---|---|---|---|---|---|---|
| Affordability | Cost | 2023-2040 NPV-RR (2021 $000) | $25,400,077 | $23,976,928 | $26,418,434 | $29,149,481 | $26,816,360 |
| Sustainability | Carbon Free Generation | % of Total Generation in 2040 | 92% | 93% | 105% | 34% | 34% |
| | Eligible Resources | 55% Clean Energy 2035 | 67% | 75% | 84% | 15% | 15% |
| Reliability and Risk[7] | Resource Flexibility | Fast Ramping Capacity | Exceeds | Exceeds | Exceeds | Study Not Conducted | Study Not Conducted |
| | Resource Adequacy | Reserve Requirement | Exceeds | Exceeds | Exceeds | Exceeds | Exceeds |
| | Market Exposure | Energy Balance (2040) | 99% | 98% | 111% | 55% | 56% |

- All portfolios meet the required legislature of carbon free electricity by 2040.
  - Some portfolios relied more heavily on REC purchases, with the Reference Portfolio relying on the heaviest as only 92% of Minnesota demand was met by carbon free energy, with the Siemens Market Outlook portfolio not far behind at 93%. Although the Siemens PTI Market Outlook Portfolio does not differ much from REC purchases than the Reference Portfolio, it does have the clean base capacity to utilize more if REC prices begin to show volatility.
  - An assumed 10% clean energy imported from owned generation assets located outside of Minnesota put all portfolios above the carbon free generation requirements without the need for REC purchases.

- The lowest cost portfolio came out to be the Siemens PTI Market Outlook Portfolio. While by 2040, the Reference Portfolio is similar in terms of renewable capacity, the upfront additions at slightly higher capital costs in the Reference Portfolio as well as overall timing of renewable additions in the Siemens PTI Market Outlook portfolio ultimately resulted in lower fixed and variable costs in the Siemens Outlook Portfolio.

- The portfolio with the lowest market exposure was the High Renewable Penetration Portfolio while the highest market exposure portfolio was the Reference Portfolio, as late additions made it prone to market purchases up until 2040.

- The largest storage capacity needed is roughly 2,800 MW to support the renewable additions assumed in the High Renewable Portfolio.

- The minimal storage capacity needed in Minnesota by 2040 is 1,350 MW consistent with the Reference Portfolio.
- Keeping the current portfolio in Minnesota as it is today results in overall higher costs due to reliance on fuel prices and increases in market purchases.

Based off the balanced scorecard, the Siemens PTI Market Outlook portfolio meets the reliability and sustainability objectives of the model while minimizing cost, proving to be the optimal portfolio for Minnesota. Therefore, the optimal amount of energy storage capacity that allows Minnesota to reach their 2040 carbon reduction goals while minimizing cost and maximizing reliability is 1,700 MW, with 850 MW being installed prior to 2030.

The overall analysis considers a multitude of metrics across the 3 categories described in Table 4-2. Each category, objective and associated metrics are explained in more detail in the next section.

## 8.2. Affordability

The Affordability of the portfolios is important because it ultimately determines the costs for Minnesota to serve all load. There are many cost components that feed into the NPV-RR, including fuel costs, fixed operating and maintenance costs, variable operating and maintenance costs, emission costs, capital costs and spot market sales and purchases.

**Table 8-2: Affordability Metrics and Results**

| Category | Objective | Metric | Reference Case | Siemens PTI Market Outlook | High Renewable Penetration |
|---|---|---|---|---|---|
| Affordability | Cost | 2023-2040 NPV-RR (2021 $000) | $25,400,077 | $23,976,928 | $26,418,434 |

Ultimately, the Siemens PTI Market Outlook Portfolio came out as the least cost portfolio, beating the Reference Portfolio by roughly $1.5 Billion. With similar levels of renewable resources, the overall timing of resources gave this portfolio a cost advantage over the Reference Portfolio, as the Reference Portfolio has more upfront capital investments that heavily affect the NPV. Another factor is the timing of late addition renewable resources. In the Reference Portfolio, these additions occurred after PTC benefits expired, whereas the Siemens PTI Market Outlook Portfolio had these additions come online in time to still receive PTC credits.

The High Renewable Penetration Portfolio resulted in the highest cost due to its heavy capital investments that ultimately did not result in enough additional savings or revenue to recover.

## 8.3. Risk

The Risk of the Candidate Portfolios is important because these metrics measure the potential volatility in cost to Minnesota based on uncertainty in market conditions. Additionally, the Risk category identifies the amount of generation capacity located in Minnesota and amount of Spot Market purchases that may be required to meet load. There are 3 different metrics utilized in this analysis to measure risk to ensure Minnesota complies with Reliability expectations.

### Resource Flexibility

This metric calculates the ability of Minnesota's portfolio to adapt to the intermittent sub-hourly changes in load and renewable generation. The ability to adapt to these sudden changes in available generation and load largely depend on the amount of fast-ramping capability within Minnesota's portfolios. Fast-ramping capacity is defined by a unit's ability to ramp up from a cold start within seconds to minutes. These units are largely based off peaking unit types which include various combustion turbines or storage resources. Based off the fast-ramping analysis conducted for Minnesota, the minimum fast-ramping capacity requirements by year are shown in the table below. The Resource Flexibility metric is based off whether the portfolio meets this value every year.

**Table 8-3: Annual Fast-Ramping Capacity Requirements (MW)**

| | Requirement | Reference | Siemens Outlook | High Renewable |
|---|---|---|---|---|
| 2023 | 1,415 | 3,508 | 3,508 | 3,508 |
| 2024 | 1,434 | 3,493 | 3,493 | 3,493 |
| 2025 | 1,637 | 3,320 | 3,493 | 3,493 |
| 2026 | 1,666 | 3,465 | 3,470 | 3,470 |
| 2027 | 2,127 | 3,675 | 4,007 | 4,557 |
| 2028 | 2,476 | 3,559 | 4,201 | 5,202 |
| 2029 | 3,098 | 3,933 | 4,996 | 5,797 |
| 2030 | 3,524 | 4,557 | 5,444 | 6,392 |
| 2031 | 3,868 | 4,807 | 5,444 | 6,392 |
| 2032 | 4,147 | 5,181 | 5,444 | 6,690 |
| 2033 | 4,549 | 5,929 | 5,444 | 6,987 |
| 2034 | 4,882 | 6,303 | 6,039 | 7,582 |
| 2035 | 5,408 | 6,303 | 6,634 | 8,677 |
| 2036 | 6,213 | 6,303 | 7,229 | 9,272 |
| 2037 | 6,246 | 6,303 | 8,024 | 10,267 |
| 2038 | 6,487 | 6,998 | 9,369 | 11,762 |
| 2039 | 6,368 | 7,472 | 9,666 | 11,862 |
| 2040 | 6,443 | 8,116 | 9,964 | 11,956 |

### Resource Adequacy

This metric follows the requirements set by NERC that systems must have a loss of load expectation (LOLE) of a maximum of once every 10 years. MISO annually defines the minimum reserve requirements at the system level and the Local Resource Zone (LRZ) to achieve this goal.

### Market Risk Minimization

This metric indicates the amount of spot market purchases that are required over the Planning Horizon. The metric is shown as an energy balance as seen in 2040, which is depicted as the portfolio generation relative to Minnesota's total annual demand. A value of less than 100% implies that Minnesota is a net importer of energy from the MISO market, while greater than 100% implies that Minnesota is a net exporter to the MISO market. Higher cost indicates greater level of spot market purchases and is viewed unfavorably relative to portfolios that require fewer purchases.

**Table 8-4: Reliability Metrics and Results**

| Category | Objective | Metric | Reference Case | Siemens PTI Market Outlook | High Renewable Penetration |
|---|---|---|---|---|---|
| Reliability and Risk[7] | Resource Flexibility | Fast Ramping Capacity | Exceeds | Exceeds | Exceeds |
| | Resource Adequacy | Reserve Requirement | Exceeds | Exceeds | Exceeds |
| | Market Exposure | Energy Balance (2040) | 99% | 98% | 111% |

As shown in Table 8-4, all portfolios meet the minimum requirements for the fast-ramping capacity analysis, with the High Renewable Penetration Portfolio containing the largest amount of fast-ramping capacity. All portfolios have limited market exposure, with the lowest energy balance of 98%, meaning that within this portfolio, Minnesota is a net importer of roughly 2% of their demand. However, this portfolio does have the clean capacity to utilize more (both base and peaking) if necessary, making the reliance of market prices as a small concern in all portfolios.

All portfolios reserve requirement was met on an annual basis utilizing Minnesota's projected generation UCAP and the LRZ1 import limit of 5,300 MW.

Ultimately, all portfolios are proven have minimal risk and surpass the modeled reliability metrics.

## 8.4. Sustainability

With a strict carbon-free target according to Minnesota legislation, all portfolios were required to meet the same sustainability goal. This goal was met in various ways, however. For example, the Reference Portfolio fell slightly short of 100% carbon free and had to meet this goal through the purchase of RECs to offset the associated carbon emissions. These REC purchases are accounted for within the "Affordability" metric, as they are a cost component considered in the NPV.

While REC purchases are one way of helping alleviate the strict carbon free target, Siemens PTI acknowledges that the RECs market is 2040 is unknown and reliance on REC purchases puts this portfolio at risk of not meeting the 2040 carbon free target or potentially exposing Minnesota to high REC prices in the future.

However, under the assumption that roughly 10% of Minnesota's generation may be clean energy located outside of Minnesota, all portfolios would comply with the carbon emission goals without the need for REC purchases. This assumption is not currently incorporated into the total portfolio cost but is worth noting. The incorporation of this assumption does not change the respective order of the portfolios' affordability metric.

## $CO_2$ Footprint

An increasing concern regarding global climate change has put specific emphasis on the carbon footprint associated with different power generating resource options. Although coal-fired generation remains one of the low-cost resources, its environmental impacts pose a growing concern to the public and utility planners. Moreover, the potential for significant costs associated with $CO_2$ emissions constitutes a major risk for coal plant owners. Furthermore, the legislation establishing a Minnesota carbon-free electricity standard signed into law under Senate File 4, pushes this objective as a non-negotiable since all utilities must reach 100% of their retail sales to Minnesota customers through carbon free generation by 2040.

## Renewable Generation

Minnesota's environmental goals require the addition of renewable resources to the supply mix, especially in the long term. Renewable generation, particularly solar and wind with PTC benefits after the passage of the IRA in August 2022, are one of the cheapest resources under most conditions, which helped Minnesota with its Affordability objectives. Analysis showed that increasing generation from renewable resources will also directly result in reduced CO2 emissions for the portfolio. As stated in Statute Section 216B.1691, subdivision 2a, 55% of utility retail sales must come from eligible resources, as described in Section 3.2 of this report.

**Table 8-5: Sustainability Metrics and Results**

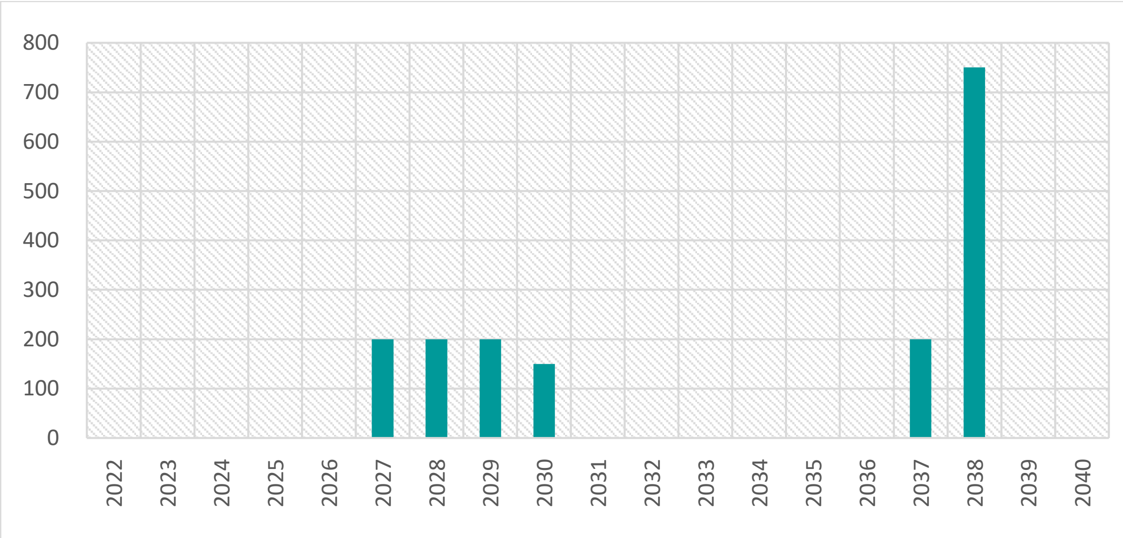
| Category | Objective | Metric | Reference Case | Siemens PTI Market Outlook | High Renewable Penetration |
|---|---|---|---|---|---|
| Sustainability | Carbon Free Generation | % of Total Generation in 2040 | 92% | 93% | 105% |
| | Eligible Resources | 55% Clean Energy 2035 | 67% | 75% | 84% |

# 9. Energy Storage System Deployment

Upon finding the optimal energy storage capacity to achieve the state renewable energy standard and carbon-free goals under Minnesota Statutes, Siemens PTI was requested to define the corresponding amount of capacity required on a utility-by-utility basis.

The figure below reflects the optimal incremental storage capacity to be added to Minnesota's system through 2040 to achieve the state renewable energy standard and carbon free goals under Minnesota Statutes. Beginning in 2027, 200 MW of storage capacity is projected to be needed, continuously adding through 2030 to reach 600 MW before 1/1/2030. An additional 150 MW storage is necessary through 2035, with another additional 950 MW necessary prior to 2040.

**Figure 9-1: Minnesota Incremental Storage Additions (MW)**




Utilizing 2022 retail sales, Siemens PTI has allocated the energy storage capacity required by the various utilities by 2030, 2035, and 2040. As Minnesota is composed of over 100 electric utilities, the top 12 utilities which comprise of 80% of the state's electric retail sales have been allocated a specific capacity, while the remaining utilities are totaled together for reporting purposes.

The allocated capacity listed in the various years represents the capacity needed before the year's start. For example, the capacity reported in 2030 represents capacity necessary on or before 12/31/2029.

**Table 9-1: Minnesota Utility Energy Storage Capacity Allocation (MW)**

| Utility | 2030 | 2035 | 2040 |
|---|---|---|---|
| Xcel Energy | 235 | 294 | 664 |
| Minnesota Power Co | 68 | 85 | 192 |
| Great River Energy | 66 | 82 | 186 |
| Southern MN Municipal Power Agency[20] | 16 | 19 | 43 |
| Otter Tail Power Company | 23 | 28 | 63 |
| Connexus Energy | 17 | 21 | 48 |
| Dakota Electric Association | 15 | 18 | 43 |
| Minnkota Power Cooperative, Inc. | 12 | 15 | 35 |
| Rochester Public Utilities | 9 | 11 | 27 |
| Wright-Hennepin Coop Electric Assn | 8 | 9 | 22 |
| East Central Energy | 8 | 9 | 21 |
| Minnesota Valley Electric Cooperative | 7 | 9 | 20 |
| All Others (163 Utilities) | 119 | 149 | 336 |
| **Total** | **600** | **750** | **1,700** |

With this allocation split, most of the storage capacity will be added by IOUs, followed by Cooperatives and then Municipals. An allocation by utility type is shown in Table 9-2.

**Table 9-2: Minnesota Energy Storage Capacity by Utility Type (MW)**

| Utility Type | 2030 | 2035 | 2040 |
|---|---|---|---|
| Investor-Owned (3) | 317 | 397 | 898 |
| Cooperative (48) | 188 | 234 | 533 |
| Municipal (124) | 95 | 118 | 269 |
| **Total (175)** | **600** | **750** | **1700** |

Although a smaller amount than IOUs, co-ops and municipal utilities are responsible for over 800 MW of energy storage by 2040, highlighting the need to implement policies and programs that not only benefit IOUs, but also smaller co-ops and municipals.

[20] SMMPA is expected to reduce load by roughly 50% due to a power contract expiration in 2030. This reduction was accounted for in the allocation process utilizing their post-expiration forecasted load as reported in their latest IRP. This should be monitored and adjusted accordingly if the contract is extended in the future.

# 10. Recommended integration to IRPs

There are risks and factors that require further study and that should be addressed by the utilities on a detailed energy storage capacity study as part of their individual integrated resource plans. These risks and factors are discussed below .

## 10.1. Define the storage location on the utilities transmission system.

This study identified the amounts of storage that are likely to be required on preferred portfolio to achieve the state clean energy goals but not its location in the network. The utilities are to conduct a study to identify the optimal location of the storage on the transmission system to allows minimizing the impact of congestion and maximizing the deliverability of the renewable generation to the load on one hand while adding resiliency on the other.

This objective is achieved by co-optimizing the transmission and capacity expansion plan, where the actual size and location of the energy resources in general and the storage in particular is selected to minimize the capital and operating cost while ensuring that the system is secure and resilient.

There are procedures for this co-optimization including procedures developed by Siemens in our Integrated System Planning.

One challenge to this optimization is current treatment of storage as a transmission asset in MISO that does not allows for it to receive payments under the transmission tariff if there are market solutions to the transmission issue. Market solutions to transmission issues result in generation redispatch, including curtailment and congestion, and if storage is installed to address and eliminating it, the remaining market revenues may not compensate the storage costs. This is different to classical transmission solutions that have a guaranteed revenue under the tariff independent of the remaining congestion and prices in the market.

## 10.2. Impact of weather patterns uncertainty.

Although some assessments were done on wind reduction, a more comprehensive study assessing the combined impact of weather pattern on solar, wind generation and the load may uncover risks on the resource adequacy and the security of supply, that is the risk that there will not be enough generation available to supply the load at any moment in the future (e.g., a loss of load expectation (LOLE) greater that once every ten years.

With an aggressive emission reduction goal such as Minnesota's, a large adoption of renewable resources is inevitable, as it is one of the most cost effective and environmentally friendly ways to drastically reduce carbon emissions. The intermittent nature of renewable resources poses a major threat to reliability within Minnesota. Although currently surrounded by various states with not-so-aggressive carbon reduction goals, it is easy to rely on various MISO market participants to pick up the slack in hours that renewable energy is unavailable. This poses a major reliance risk as surrounding regions that may not be conducting resource plans to support Minnesota's load. This also poses an environmental risk of increasing carbon emissions outside Minnesota. With this, it is strongly recommended that each utility conducts a study to confirm that they can support their own load demands if needed, during events resulting in renewable energy being scarce and factor this assessment in the final future resource plans within an IRP.

The study should consider the stochastic nature of the weather and its impacts on the renewable generation and the load as well as the maintenance and forced availability of the generating resources and confirm the ability of the system to meet selected metrics as for example the LOLE on once every ten years maximum, maximum energy not served or maximum loss of load hours.

The study will identify the reliance of neighboring utilities and the capability of the transmission system to deliver this power and may result in modifications on the duration of the in-state storage selected adding longer duration storage, even in the tens to hundreds of hours range.

This detailed study will provide further confirmation on the adequacy of the fast-ramping generation available in the plant (Fast Ramping Analysis) as well as the location and amounts of generation providing ancillary services (spinning and fast reserves).

## 10.3. Storage Action Plan.

Once the final size and location of the storage resources are identified, an action plan needs to be developed. This action plan must include for each location milestones and dates for items including: a) final site selection, b) environmental impact studies, c) community engagement, d) regulatory approvals (if required) and permitting, e) interconnection studies, basic and detailed engineering, f) EPC contractor or developer selection and g) commissioning.

This Action Plan will provide Minnesota with a road map and key milestones for the deployment of the required storage for the state.

# 11. Policies and Programs Recommendations

## 11.1. Stakeholder Engagement

Legislation passed in 2023 required the Department to host a meeting to obtain recommendations from stakeholders and the public on policies and programs to accelerate energy storage system deployment to achieve the storage capacity the study determines to be required.

An initial stakeholder engagement meeting was held on December 22, 2023, in which the goals of the study as well as preliminary results for 1 candidate portfolio were presented. Meeting minutes for this engagement can be found in Appendix C. As seen in Appendix C, stakeholder feedback consisted largely of modeling assumptions and portfolio feedback. While insightful and Siemens agreed with these comments, no recommendations regarding policies and programs to accelerate energy storage systems were obtained.

A second stakeholder engagement meeting was held on January 31, 2024, to obtain feedback specific to policy and programs to incentivize storage resources. Stakeholders were presented with various storage policy and incentive strategies used in various jurisdictions across the United States. The meeting minutes which contain all comments and feedback for both stakeholder meetings can be found in Appendix C and D of this report.

Siemens and the Department accepted written comments after the January 31st meeting through February 5th. The following summarizes the comments received.

### Recommended Policies and Programs

Table 11-1 shows a summary of the policies, procedures and programs recommended by the Stakeholders. This specifically identifies the feedback received regarding policy and program recommendations. A multitude of topics were discussed throughout both stakeholder meetings which is captured within the meeting minutes found in Appendix C & D.

**Table 11-1: Stakeholder Feedback Regarding Recommended Policies, Procedures, and Programs**

| Stakeholder | Policies, Procedures, and Program Recommendations |
|---|---|
| Clean Energy Economy MN (CEEM) | CEEM recommended the use of holistic approaches to MISO and the State of Minnesota policies can coincide. CEEM recommended reviewing policies within the frame of Minnesota's regulatory environment. CEEM recommended the analysis of markets where energy storage is rapidly growing though did not identify preferred incentives.<br><br>*(Written)* |
| Malta Inc. | Technology commercialization grant funding for non-lithium mid and long duration energy storage (MLDES) technologies more than $100 million to buydown capital costs of those technologies<br><br>*(Written)* |
| Malta Inc. | MLDES procurement targets and supporting inclusion of MLDES in future planning studies without attaching those targets to renewable co-location requirements.<br><br>*(Written)* |
| Malta Inc. | Utility-scale storage capacity incentive program to encourage the development of MLDES resource now. The program should give greater incentives for longer duration resources, resiliency benefits, electrification, and grid stability.<br><br>*(Written)* |
| Missouri River Energy Services (MRES) | MRES comments that many traditional tax-based incentives are not applicable to municipalities due to their tax-exempt status. Any incentives implemented should be financial and not a mandate.<br><br>*(Written)* |
| Solar United Neighbors | Xcel Energy could revise their current solar+storage interconnection policy to reflect that a solar array and storage system do not discharge to the grid at once, as currently modeled. Revising this policy would lessen congestion issues for solar+storage installations. |
| Southern Minnesota Municipal Power Agency (SMMPA) | SMMPA stated their concern using present sales to determine shares of future energy goals due to the expiration of contracts it services. SMMPA suggested the allocation of future goals be reflective of actual energy contracts and demand.<br><br>*(Written)* |
| TruNorth Solar | Target residential storage incentives in areas that specifically need it most.<br>For low-income policies or programs, make eligibility as clear, understandable, and easy to communicate as possible.<br>Find or create opportunities to pair storage with heat pumps or other thermal benefits.<br><br>*(Verbal comment, summarized)* |

One major storage barrier expressed by multiple stakeholders at the January 31st meeting was the modeling of energy storage resources within MISO's planning practices. MISO's current planning process disadvantages storage resources as a transmission asset, not allowing its consideration for return under the Tariff if market solutions (i.e., redispatch, curtailment and congestion) address the issue. This is not the case of classical solutions that can be considered for market efficiency and selected if the benefit to cost ratio (the ratio of benefits in reduction of adjusted production cost to capital and operating cost) is high enough.

Siemens PTI recommends that Minnesota will need to work with MISO to relieve some of these concerns and shed light on the potential benefits of siting storage resources in high congestion areas.

# 12. Appendix A. Modeling Software

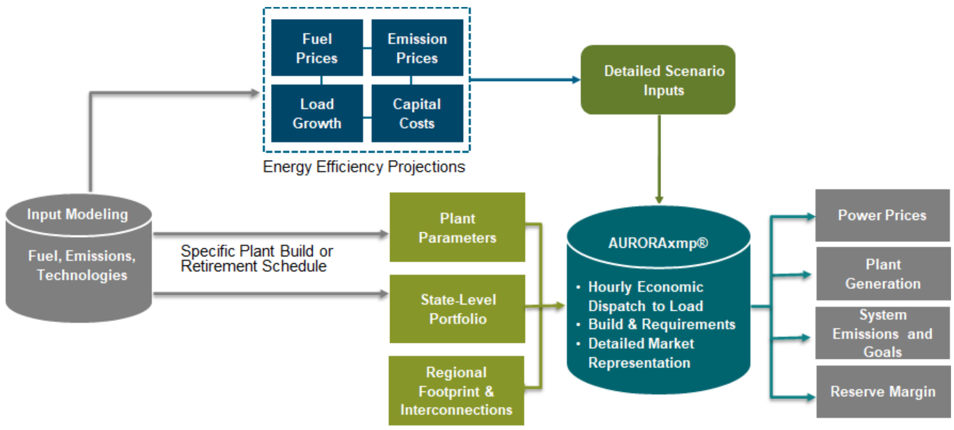
## AURORA (For Long-Term Capacity Expansion and Zonal Analysis)

For modeling work outside Excel based models, Siemens PTI used AURORA as our primary optimization tool for the 20-year study period from 2023 through 2040, to develop the Candidate Portfolios.

AURORA is an industry standard chronological unit commitment and dispatch model with extensive presence throughout the electric power industry. The model uses a state of the art, mixed integer linear programing approach to capture details of power plant and transmission network operations while observing real world constraints, such as emission reduction targets, transmission and plant operational limitations, renewable energy availability and the mandatory RPS targets.

It is widely used by electric utilities, consulting agencies, and other Stakeholders to forecast generator performance and economics, develop IRPs, forecast power market prices, and assess detailed impact of regulations and market changes affecting the electric power industry. Siemens PTI has used AURORA for over 17-years and is one of its most sophisticated users.

**Figure 12-1: AURORA Dispatch Model Framework**




AURORA's long term capacity expansion (LTCE) capabilities forecast changes in the generation infrastructure, including economic additions and retirements given candidate resources and the corresponding technical and financial assumptions and market constraints including: 1) reserve margins, 2) fuel price forecast, 3) emission costs, 4) load growth and modifiers (Energy Efficiency and Demand Response), 5) Distributed Energy Resources (behind the meter DG and Storage), 6) RPS and GHG targets/limits and 7) transmission limitations between zones.

The LTCE makes use of an iterative logic to develop a regional capacity expansion plan to minimize systems given resource options and constraints delineated above. The full set of standard operational and cost parameters for new and existing resources are considered in the LTCE, providing a robust framework from which to evaluate different technologies with different operational (intermittent vs. baseload) cost and incentive profiles. At the end of any given iteration, it has the information it needs to take retirement actions on existing uneconomic resources and to select economically viable new resource options. Convergence criteria reduce the total number of resource alternatives which are considered by the LTCE through the iterations, with a converged solution being defined as one in which system prices remain stable even with change in resource alternatives. In other words, the solution reflects an expansion plan that is at once both economically rational and stable.

The results of the LTCE include hourly generation by resource, fixed and variable costs, emissions and emission costs, resource value, energy revenue and capacity revenue, marginal costs and shadow prices by constraint, reserve margins, energy not served if any, among others.

To analyze the Candidate Portfolios, Siemens PTI ran the analysis hourly (8760 hours a year) from 2023 to 2040.

### PYTHON (For Fast Ramping Requirement Analysis)

Siemens PTI intends to use Python for the analysis of fast ramping generation. Python is a computer programming language often used to automate tasks and conduct data analysis. Python is a general-purpose language, meaning it can be used to create a variety of different programs and is not specialized for any specific problems.

# 13. Appendix B – MISO Queue Storage Inventory

| Transmission Owner | County | State | Study Phase | Capacity | Post GIA Status | Appl In Service Date |
|---|---|---|---|---|---|---|
| NORTHERN STATES POWER COMPANY | Murray County | MN | Phase 3 | 20 | Under Construction | 2021-10-31 |
| MIDAMERICAN ENERGY COMPANY | Muscatine County | IA | Phase 3 | 50 | Not Started | 2023-10-30 |
| ENTERGY LOUISIANA, LLC | Tangipahoa Parish | LA | Phase 3 | 20 | Under Construction | 2022-10-30 |
| Southern Indiana Gas & Electric Company d/b/a Vectren Energy Delivery of Indiana, Inc. | Vanderburgh County | IN | | 50 | Under Construction | 2022-07-01 |
| American Transmission Co. LLC | Kenosha County | WI | Phase 3 | 50 | Not Started | 2022-10-30 |
| NORTHERN INDIANA PUBLIC SERVICE COMPANY LLC | LaGrange County | IN | | 25 | Not Started | 2023-10-30 |
| American Transmission Co. LLC | Dane County | WI | Phase 3 | 75 | Not Started | 2022-10-30 |
| ITC MIDWEST | Washtenaw County | MI | Phase 3 | 20 | Under Construction | 2022-10-30 |
| HOOSIER ENERGY | Decatur County | IN | | 146 | Not Started | 2023-05-30 |
| NORTHERN INDIANA PUBLIC SERVICE COMPANY LLC | LaPorte County | IN | | 160 | Not Started | 2023-05-30 |
| DUKE ENERGY INDIANA, LLC | Madison County | IN | | 150 | Not Started | 2023-05-30 |
| NORTHERN INDIANA PUBLIC SERVICE COMPANY LLC | LaPorte County | IN | | 125 | Not Started | 2023-05-30 |
| ENTERGY ARKANSAS, LLC | Jackson County | AR | Phase 3 | 0 | Not Started | 2021-08-01 |
| American Transmission Co. LLC | Dane County | WI | Phase 3 | 75 | Not Started | 2022-10-30 |
| MIDAMERICAN ENERGY COMPANY | Scott County | IA | Phase 3 | 50 | Not Started | 2021-10-01 |
| INDIANAPOLIS POWER & LIGHT COMPANY | Marion | IN | Phase 2 | 200 | Not Started | 2022-12-15 |
| Northern States Power (Xcel Energy) | Dunn | WI | Phase 3 | 0 | Not Started | 2024-06-06 |
| | Ouachita | LA | Phase 3 | 25 | Not Started | 2023-04-01 |
| ENTERGY ARKANSAS, LLC | Grant | AR | Phase 3 | 0 | Not Started | 2024-01-15 |
| Michigan Electric Transmission Company LLC | Branch | MI | Phase 2 | 100 | Not Started | 2022-02-01 |
| AMEREN ILLINOIS | Jefferson | IL | Phase 2 | 50 | Not Started | 2022-09-15 |
| ITC Transmission | Washtenaw | MI | Phase 2 | 100 | Under Construction | 2022-02-01 |
| DUKE ENERGY INDIANA, LLC | Miami | IN | Phase 2 | 74.7 | Not Started | 2023-08-01 |
| | Perry | IL | Phase 2 | 50 | Not Started | 2023-09-01 |
| ENTERGY TEXAS, INC. | Grimes | TX | Phase 3 | 100 | Not Started | 2022-02-01 |
| CLECO Corporation | Sabine | LA | Phase 3 | 0 | Not Started | 2024-01-15 |
| NORTHERN INDIANA PUBLIC SERVICE COMPANY LLC | LaPorte | IN | Phase 2 | 0 | Not Started | 2024-04-12 |
| ENTERGY ARKANSAS, LLC | Lee | AR | Phase 3 | 0 | Not Started | 2023-09-13 |
| ENTERGY ARKANSAS, LLC | Lee | AR | Phase 3 | 0 | Not Started | 2023-09-13 |
| DUKE ENERGY INDIANA, LLC | Clark | IN | | 100 | Not Started | 2026-09-30 |
| MICHIGAN PUBLIC POWER AGENCY | Saginaw | MI | | 120 | Not Started | 2026-08-31 |

# 14. Appendix C – Stakeholder Engagement #1 Meeting Minutes

# Memorandum

**Date:** 1/5/2024

**To:** Minnesota Department of Commerce

**CC:** Associated Stakeholders

**From:** Siemens PTI

**RE:** **Dec 22, 2023 Stakeholder Engagement Meeting Minutes**

## 14.1. Objective of the Meeting

*Siemens PTI was tasked with gathering* ***stakeholder input and recommendations on policies and programs*** to accelerate energy storage system deployment in Minnesota, as mandated by Minnesota Sessions Laws 2023, Chapter 60 (HF2310), Article 12, Sec. 74, to achieve the state's renewable energy standard and carbon-free goals.

## 14.2. Agenda of the Meeting

The agenda of the meeting is outlined as follows:

1. Introduction and objectives - presented by Nelson Bacalao (Siemens PTI)
2. Technical methodology - presented by Angelina Martinez (Siemens PTI)
3. Initial results of the study - presented by Chelsea Cupit (Siemens PTI)
4. Storage economics - presented by Nelson Bacalao (Siemens PTI)
5. Policies and programs - presented by Chris Matos (Siemens PTI)
6. Next steps - presented by Nelson Bacalao (Siemens PTI)

## 14.3. Technical Methodology – Angelina Martinez (Slides 5-12)

Angelina began by emphasizing how a proper understanding Siemens PTI's methodologies is important in finalizing the scope of work for this project.

Angelina explained that this Siemens PTI process has been utilized for 10 years for integrated resource and system planning and is now being applied to identify the optimal amount of storage required for Minnesota. The overall process consists of 5 steps:

1. Determining the objectives of the study.
2. Identifying metrics to assess portfolios.
3. Identifying a reference portfolio and two candidate portfolios.
4. Analyzing the portfolios through risk and Montecarlo analysis.
5. Developing a balanced scorecard to measure and compare portfolios.

**Table 14-1: Verbal Questions Captured During the Technical Methodology Section**

| Questions | Response |
|---|---|
| Are you going to be allowing the deployment of new thermal resources like combustion turbines or simple cycle resources to meet reliability needs? (Zachary Ruzycki, GRE) | Hydrogen resources which assume a blend of hydrogen and natural gas (until 2035) are allowed. It's assumed that there will be new combustion cycles and combustion turbine builds which utilize hydrogen fuel throughout the study. |
| The legislation is clear that thermal resources can continue to operate in dispatch if those emissions are offset by REC retirements. Are you completely disallowing the use of thermal resources throughout the study period? (Zachary Ruzycki, GRE) | We are assuming that new carbon emitting thermal resources will not be deployed after 2040. There will be some additions of CTs and combined cycle turbines in the study, but there will be a complete transition to hydrogen by 2040. Some gas CTs remain online but we cannot rely on the availability of RECs while creating the portfolios. |
| Will there be non-normal weather modeling or application of non-normal or stochastic weather-based modeling in some portion of the process? (Zachary Ruzycki, GRE) | In steps 3 and 4, we ensure portfolios comply with fast-ramping capability and variability of wind & solar output. We use Monte Carlo simulation to address the variability. |
| Regarding the 2040 carbon free standard, it's mentioned that 100% of sales from utilities to Minnesota must be carbon-free. Many utilities have territories which extend outside of Minnesota, so there may be circumstances where an entire utility's portfolio doesn't need to be carbon-free but only the portion that will serve Minnesota. Does your modeling capture those impacts? (Adway De, Dept. of Commerce) | The model doesn't look on a utility-utility basis. Generating assets located outside of Minnesota are not complying with this mandate, so the model is treating Minnesota as a single large utility. |
| What type of storage are you modeling (Kyle Leier, GRE) | 4-hour lithium-ion storage is starting 2027 and 8 and 10-hour storage resources are an option beginning in 2028 and 2035, respectively, however they were not selected. |
| For the information not included in the initial data request such as heat rates, ramp rates, and dispatch, where is that information coming from? Will it be made available? (Kyle Leier, GRE) | That's from Energy Exemplar's database which is sources from publicly available data. Yes, it will be made available. |
| Will the cost assumptions for new resources also be shared and where are they sourced from? (Zachary Ruzycki, GRE) | They are developed by Siemens internally and will be made available. |
| What new Tech is being considered and are you analyzing cycle times and new tech coming online? Are you looking at data around the world as far as cycle times for batteries that are going to be coming online in the future and say 5 to 10 years? (Adam Illif, Vessyll) | We do have an internal technical expert that forecast the improvement of storage technologies through time. We can share our technical assessment and you can provide any comments you may have. |

## 14.4. Initial Study Results – Chelsea Cupit (Slides 13-17)

Chelsea walked through the initial round of results which are based on the second portfolio mentioned, Siemens PTI's Market Outlook. She prefaced the discussion by mentioning that Minnesota has an aggressive mandate, but neighboring states do not.

Chelsea began summarizing the new additions and retirements present in the study. She then outlined the expected increases in renewables which culminate in an expected total of that aligns with MISO's updated Future 2 ("2A").

Chelsea highlighted that hydrogen capacity and generation trends across the study, which are positively correlated with the timeline of the mandate.

Understanding the necessity that Minnesota can meet its load with carbon-free energy, Chelsea identified that the state would require some natural gas units if needed. However, acknowledging that this methodology may change as RECs are made available in the future, provisions were made to ensure that load will be covered solely with hydrogen if needed.

Chelsea then summarized the capacity mix produced from the results. She highlighted that an additional 1.7 GW of storage is needed to meet the 2040 mandate.

Chelsea also compared how the Siemens PTI market outlook compares with current IRPs and MISO's 2A future. The identified IRPs illustrate much less renewable energy in comparison because many were published prior to Minnesota's new legislation.

**Table 14-2: Verbal Questions Captured During the Initial Study Results Section**

| Question | Response |
|---|---|
| Will you be separating capacity out into nameplate capacity and effective capacity in the study? (Zachary Ruzycki, GRE) | Yes, it will be broken out both ways. |
| Are you using MISO's ELCC calculation? (Zachary Ruzycki, GRE) | As a part of this study, while creating the portfolios, we use AURORAs internal dynamic peak credit calculations. |
| One thing I have noticed is that for our sample hours we typically choose every 2nd hour, 2 days a month and figure out an expansion plan then do the dispatch modelling. With respect to storage, the model tends to favor storage during the capacity expansion portion and selects a decent amount during the LTCE but does not utilize the storage much during the dispatch run. Is this something you see in your models? (Adway De, Dept. of Commerce) | We see the opposite most of the time. However, we utilize different sampling hours and tend to use every hour, 4 days a week, and 2 weeks a month. We usually see it struggle to select large amounts of storage, but it dispatches them pretty well or over utilizes so it may be a difference cause by sampling. |
| Regarding the adoption of EV and at home electric devices, are these impacts being addressed at all in the model? (Adam Illif, Vessyll) | Yes. We don't have any significantly aggressive electric vehicle or behind the meter solar forecast for Minnesota currently, but it's factored into the total load, and you do see a little bit of offsetting if we looked at it on an hourly basis. |

## 14.5. Storage Economics – Nelson Bacalao (Slides 18-24)

Nelson began by discussing the technological and financial assumptions that were used. He then outlined trends regarding the levelized cost of 4-hr Li-ion batteries, highlighting that levelized costs vary with time, the addition of investment tax credits and the associated capital cost reductions.

Based on the initial results, a deployment of BESS in 2027 and 2030 would not be able to cover an associated WACC and external support will be required to ensure economic feasibility. Nelson then outlined the necessary revenue required to cover the associated WACC.

**Table 14-3: Verbal Questions Captured During the Storage Economics Section**

| Question | Response |
|---|---|
| I can foresee situations where the lifetime of batteries is lower than the assumption. (Adam Illif, Vessyll) | It shouldn't impact the financials too much, but we will consult with our storage expert. |
| Is the graph for levelized cost of storage a Siemens projection? (Zachary Ruzycki, GRE) | Yes, it is internal to Siemens, but it's built using a combination of public and internal calculations. |
| What are you assuming for your ITC? (Zachary Ruzycki, GRE) | We're assuming a 30% ITC. |

## 14.6. Programs and Polices – Chris Matos (Slides 25-29)

Chris highlighted the importance of state incentives as well as the key aspects of different incentives and polices. He then did an overview of some incentive programs from other states that may be applicable.

Chris emphasized that if any additional incentives weren't mentioned to please reach out.

**Table 14-4: Verbal Questions Captured During the Programs and Policies Section**

| Question | Response |
|---|---|
| Minnesota has several pilot programs that are being tested within the state with batteries of longer duration. How may this impact the results? (Adway De, Dept. of Commerce) | We do offer longer duration of storage for the capacity expansion plan, but it's not being picked up in this initial because of the associated cost. |

## 14.7. Next Steps – Nelson Bacalao (Slides 30-32)

Nelson emphasized the need for adjustments to model based on the discussions had during the meeting. Written recommendations are expected to be provided along with meeting notes on January 5th.

**Table 14-5: Verbal Questions Captured During the Next Steps Section**

| Question | Response |
|---|---|
| Can we get more clarification on how the model will consider utilities with territories that expand beyond Minnesota? (Adway De, Dept. of Commerce) | In Aurora, MN is modeled as a single zone with links to outside markets. This means that utilities whose territories expand beyond Minnesota, we will solely focus on the Minnesota portion of. |

## 14.8. List of Attendees

**Table 14-6: List of Attendees**

| First | Last | Affiliation | Contact Email |
|---|---|---|---|
| Sarah | Whebbe | All Energy Solar | sarah.whebbe@allenergysolar.com |
| Jay | Anderson | CMPAS | jaya@cmpas.org |
| Andy | Ristau | CMPAS | andyr@cmpas.org |
| Heidi | Martinson | CMPAS | heidim@cmpas.org |
| Chad | Hanson | CMPAS | chadh@cmpas.org |
| Jason | Houck | Form Energy | jhouck@formenergy.com |
| Ward | Einess | Form Energy | wardeiness@icloud.com |
| David | Meyer | Glencoe Light and Power | dave@glencoelightandpower.com |
| John | Williams | GRE | jwilliams@grenergy.com |
| Kyle | Leier | GRE | kleier@grenergy.com |
| Zachary | Ruzycki | GRE | zruzycki@grenergy.com |
| Zachary | Ruzycki | GRE | zruzycki@grenergy.com |
| Laura | Lyons | MN Dept. COMM | laura.lyons@state.mn.us |
| Jack | Kluempke | MN Dept. COMM | Jack.Kluempke@state.mn.us |
| Chris | Watkins | MN Dept. COMM | christopher.watkins@state.mn.us |
| John | Wachtler | MN Dept. COMM | john.wachtler@state.mn.us |
| Dennis | Duffy | MN Dept. COMM | |
| Adway | De | MN Dept. COMM | adway.de@state.mn.us |
| Emily | Nguyen | MN Dept. COMM | emily.nguyen@state.mn.us |
| Reece | Chambers | MR Energy | reece.chambers@mrenergy.com |
| Derek | Bertsch | MR Energy | derek.bertsch@mrenergy.com |
| Tim | Beddow | OTPCO | tbeddow@otpco.com |
| Dean | Lee | OTPCO | dlee@otpco.com |
| Joe | Hoppe | OTPCO | jhoppe@otpco.com |
| Lucas | Spaeth | Red River Valley | utilities@rrv.net |
| Ryan | Rooney | Runestone Electrice | ryan.rooney@runestoneelectric.com |
| Chelsea | Cupit | Siemens PTI | chelsea.laricci@siemens.com |

| | | | |
|---|---|---|---|
| Angelina | Martinez | Siemens PTI | angelina.martinez@siemens.com |
| Nelson | Bacalao | Siemens PTI | nelson.bacalao@siemens.com |
| Michael | Licata | Siemens PTI | michael.licata@siemens.com |
| Brandon | Scott | Siemens PTI | brandon.scott@siemens.com |
| Carlos | Gomez | Siemens PTI | carlos.gomez-acosta@siemens.com |
| Christopher | Matos | Siemens PTI | chris.matos@siemens.com |
| Joe | Hoffman | SMMPA | ja.hoffman@smmpa.org |
| Adam | Iliff | Vessyll | zahra@vessyll.com |
| Jim | Pearson | Xcel Energy | james.g.pearson@xcelenergy.com |

## 14.9. Completed List of Questions/Comments

**Table 14-7: Complete List of Questions Answered on Call**

| Question Asked | Response |
|---|---|
| Are you going to be allowing the deployment of new thermal resources like combustion turbines or simple cycle resources to meet reliability needs? (Zachary Ruzycki, GRE) | Hydrogen resources which assume a blend of hydrogen and natural gas (until 2035) are allowed. It's assumed that there will be new combustion cycles and combustion turbine builds which utilize hydrogen fuel throughout the study. |
| The legislation is clear that thermal resources can continue to operate in dispatch if those emissions are offset by REC retirements. Are you completely disallowing the use of thermal resources throughout the study period? (Zachary Ruzycki, GRE) | We are assuming that new carbon emitting thermal resources will not be deployed after 2040. There will be some additions of CTs and combined cycle turbines in the study, but there will be a complete transition to hydrogen by 2040. Some gas CTs remain online but we cannot rely on the availability of RECs while creating the portfolios. |
| Will there be non-normal weather modeling or application of non-normal or stochastic weather-based modeling in some portion of the process? (Zachary Ruzycki, GRE) | In steps 3 and 4, we ensure portfolios comply with fast-ramping capability and variability of wind & solar output. We use Monte Carlo simulation to address the variability. |
| Regarding the 2040 carbon free standard, it's mentioned that 100% of sales from utilities to Minnesota must be carbon-free. Many utilities have territories which extend outside of Minnesota, so there may be circumstances where an entire utility's portfolio doesn't need to be carbon-free but only the portion that will serve Minnesota. Does your modeling capture those impacts? (Adway De, Dept. of Commerce) | The model doesn't look on a utility-utility basis. Generating assets located outside of Minnesota are not complying with this mandate, so the model is treating Minnesota as a single large utility. |
| What type of storage are you modeling (Kyle Leier, GRE) | 4-hour lithium-ion storage is starting 2027 and 8 and 10-hour storage resources are an option |

| Question Asked | Response |
|---|---|
| | beginning in 2028 and 2035, respectively, however they were not selected. |
| For the information not included in the initial data request such as heat rates, ramp rates, and dispatch, where is that information coming from? Will it be made available? (Kyle Leier, GRE) | That's from Energy Exemplar's database which is sources from publicly available data. Yes, it will be made available. |
| Will the cost assumptions for new resources also be shared and where are they sourced from? (Zachary Ruzycki, GRE) | They are developed by Siemens internally and will be made available. |
| What new Tech is being considered and are you analyzing cycle times and new tech coming online? Are you looking at data around the world as far as cycle times for batteries that are going to be coming online in the future and say 5 to 10 years? (Adam Illif, Vessyll) | We do have an internal technical expert that forecast the improvement of storage technologies through time. We can share our technical assessment and you can provide any comments you may have. |
| Will you be separating capacity out into nameplate capacity and effective capacity in the study? (Zachary Ruzycki, GRE) | Yes, it will be broken out both ways. |
| Are you using MISO's ELCC calculation? (Zachary Ruzycki, GRE) | As a part of this study, while creating the portfolios, we use auroras internal dynamic peak credit calculations. |
| One thing I have noticed is that for our sample hours we typically choose every 2nd hour, 2 days a month and figure out an expansion plan then do the dispatch modelling. With respect to storage, the model tends to favor storage during the capacity expansion portion and selects a decent amount during the LTCE but does not utilize the storage much during the dispatch run. Is this something you see in your models? (Adway De, Dept. of Commerce) | We see the opposite most of the time. However, we utilize different sampling hours and tend to use every hour, 4 days a week, and 2 weeks a month. We usually see it struggle to select large amounts of storage, but it dispatches them pretty well or over utilizes so it may be a difference cause by sampling. |
| Regarding the adoption of EV and at home electric devices, are these impacts being addressed at all in the model? (Adam Illif, Vessyll) | Yes. We don't have any significantly aggressive electric vehicle or behind the meter solar forecast for Minnesota currently, but it's factored into the total load, and you do see a little bit of offsetting if we looked at it on an hourly basis. |
| I can foresee situations where the lifetime of batteries is lower than the assumption. (Adam Illif, Vessyll) | It shouldn't impact the financials too much, but we will consult with our storage expert. |
| Is the graph for levelized cost of storage a Siemens projection? (Zachary Ruzycki, GRE) | Yes, it is internal to Siemens, but it's built using a combination of public and internal calculations. |
| What are you assuming for your ITC? (Zachary Ruzycki, GRE) | We're assuming a 30% ITC. |
| Minnesota has several pilot programs that are being tested within the state with batteries of longer duration. How may this impact the results? (Adway De, Dept. of Commerce) | We do offer longer duration of storage for the capacity expansion plan, but it's not being picked up in this initial study because of the associated cost. |

| Question Asked | Response |
|---|---|
| Can we get more clarification on how the model will consider utilities with territories that expand beyond Minnesota? (Adway De, Dept. of Commerce) | In Aurora, MN is modeled as a single zone with links to outside markets. This means that utilities whose territories expand beyond Minnesota, we will solely focus on the Minnesota portion of. |

**Table 14-8: Comments Received via Email upon Completion (through 1/5/2024)**

| Comment/Question | Response |
|---|---|
| We discussed a few potential energy-storage scenarios on our recent call. I wanted to offer a potential scenario based on a low-wind event in MISO in 2018 (attached.)<br><br>I'm not certain if your Monty Carlo simulation would represent this scenario as it is a significant outlier, however there may be some value in determining how much storage would be needed if/when we see another such event as MISO's wind footprint continues to grow.<br><br>(Kyle Leier GRE) | While it would not be reasonable to create a portfolio based around this low wind scenario, we will plan to run a sensitivity utilizing the portfolio consisting of the highest amount of wind to analyze the consequences of this type of event occurring throughout MISO. |
| The 6.5 GW of long-term hydrogen resource needs identified should be interpreted to<br><br>represent needs for multi-day energy storage and other firm zero carbon resources in general. It is recommended that future studies should more fully investigate the inclusion of multi-day energy storage resources. (Form Energy) | Siemens PTI agrees that it is reasonable to interpret the 6.8 GW of hydrogen as a need for 7 GW of "dispatchable clean energy". With the current technology outlook, hydrogen combustion turbines are the most economic option to meet Minnesota's current goals, and this can easily change as other technologies advance in the future. Siemens PTI will be meeting with Form Energy to learn more about their 100-hour duration storage technology to possibly incorporate into future studies as a multi-day storage alternative. |
| Include scenarios that capture periods of real grid stress, such as multi-day lulls in renewable energy generation or periods of high commodity prices. (Form Energy) | Siemens PTI agrees to conduct a sensitivity analysis on low wind production based on the extreme weather event as seen in 2018 for MISO. |
| Storage build and dispatch should be modeled over multiple weather years, and should capture periods of grid stress caused by extreme weather events (Form Energy) | Siemens PTI agrees that utility-specific resource plans should consider weather variability and the potential for extreme weather events. Typically, Siemens PTI conducts this kind of utility-specific analysis with utility-defined energy import (spot market purchases) limitations and utility-defined resiliency metrics. These resiliency metrics are produced using separate resiliency scenarios. |

| | |
|---|---|
| Weather-correlated load profiles and renewable generation profiles should be used as input assumptions to capacity optimization modeling (Form Energy) | Siemens PTI agrees that weather, load, and renewable output uncertainty should be explicitly incorporated into resource planning modeling and analysis. However, Siemens PTI has concerns about using the historical correlation between weather, load, and renewable generation in long-term resource planning analysis. As technology and consumer behaviors change over the long-term, these correlations can change. Siemens PTI prefers to treat energy demand and renewable generation uncertainty as independent over long-term modeling horizons using stochastic simulations. Siemens PTI uses short- and mid-term deterministic scenarios that more closely correlate these inputs in resource planning analysis. |

# 15. Appendix D –Stakeholder Engagement #2 Meeting Minutes

# Memorandum

**Date:** 2/5/2024

**To:** Minnesota Department of Commerce

**CC:** Associated Stakeholders

**From:** Siemens PTI

**RE:** **Jan 31, 2024 Stakeholder Engagement Meeting Minutes**

## 15.1. Objective of the Meeting

*Siemens PTI was tasked with gathering* ***stakeholder input and recommendations on policies and programs*** to accelerate energy storage system deployment in Minnesota, as mandated by Minnesota Sessions Laws 2023, Chapter 60 (HF2310), Article 12, Sec. 74, to achieve the state's renewable energy standard and carbon-free goals.

## 15.2. Agenda of the Meeting

The agenda of the meeting is outlined as follows:

1. Introduction and objectives - presented by Nelson Bacalao (Siemens PTI)
2. Policies and programs - presented by Chris Matos (Siemens PTI)
3. Next steps - presented by Nelson Bacalao (Siemens PTI)

## 15.3. Storage Economics – Nelson Bacalao (Slides 2-5)

Based on the initial results, a deployment of BESS in 2027 and 2030 would not be able to cover an associated WACC and external support will be required to ensure economic feasibility. Nelson then outlined the necessary revenue required to cover the associated WACC.

## 15.4. Programs and Policies – Chris Matos (Slides 6-14)

Chris highlighted the importance of state incentives as well as the key aspects of different incentives and polices. He then did an overview of some incentive programs from other states that may be applicable, such as grants and rebates. He then proceeded to let stakeholders start questioning and doing relevant comments.

**Table 15-1: Verbal Questions Captured During the Programs and Policies Section**

| Comments/Question | Response |
|---|---|
| Does the study address barriers/opportunities at the RTO level as well as state level? Does Minnesota have the potential to ride the | The results shown are both high-end and low-end scenarios, but we do have a couple of scenarios |

| Comments/Question | Response |
|---|---|
| wave of energy storage development that is happening around the country? – Brent Bergland | with even higher storage scenarios, towards the 750MW region. -Chelsea Cupit |
| We already have to do energy storage assessments with various costs, technologies, etc. to see how they fit with our resource plans moving forward. However, this study was supposed to look into if we need anything more than what our studies already tell us?<br><br>- Mike Bull | We provide the context for the amount of storage needed, but the way you can implement that is subject to a lot of options, and the purpose of this study is looking at those options that you might consider integrating, as a part of a broader plan of resiliency or equity.<br><br>-Chris Matos<br><br>The objective of this study will provide state outlook as to how much storage will be recommended and break it down to a utility-by-utility basis, which is still to be finished. We also want some feedback to accelerate storage adoption to reach those levels needed.<br><br>-Chelsea Cupit. |
| I second a little of Mikes concern but understand what you are trying to do here. To what end are we enabling by providing rate payer or general fund money? And what do we need? Helpful to get some suggestions to jump start this. Say what's the right start and mix for Minnesota. Do they want to fill something to fill the gap? Why do we need storage and what role is it filling?<br><br>- Beth Soholt | This is why grants might be a good option since the technology that is available to Minnesota makes it that ratepayers may not need some of the solutions storage provides.<br><br>-Chris Matos |
| How are we going to allocate storage requirement utility by utility? What is the granularity? – Eric Palmer | We don't have the exact answer for that right now, we are still going over how granular it will be. We will try our best to make it as realistic as possible.<br><br>-Chelsea Cupit |
| Define what barrier exists for storage technologies? Top **barriers**: Permitting, interconnection, and RTO tariff. - Brent Bergland | RTO tariff is the hardest to deal with, given state rules and how they affect the applications.<br><br>-Chris Matos |
| It could go either way, by state decisions for certain reasons, or because MISO is looking at the challenges of 2028 out. State is in | n/a |

| Comments/Question | Response |
|---|---|
| best position to say they need it because of a certain reason, but there are barriers on both sides.<br><br>-Beth Soholt | |
| Talking about residential storage, this will not incentivize solar since you will end up giving less to the grid, since less input is needed. So, there should be a policy fix to incentivize residential storage as a way to deal with congested areas.<br><br>- Bobby King | Just to clarify you speak about the use of storage as a way to mitigate the need for expansion, which has been considered as an option as well.<br><br>-Nelson Bacalao |
| RTO tariff isn't that a revenue shortfall. Can we control other aspects around it?– Nelson Bacalao | I think there will be an element of the utilities having uptake agreements, to figure out how to earn additional revenue, for the services that the storage assets provide. Figure out if there is a dual-purpose revenue stream. We have to dig into other projects going around the country to figure out how they are implementing this.<br><br>-Brent Bergland<br><br>We have to figure out how we can implement those strategies available in other states, in order to reduce friction and incentivize storage development.<br><br>-Chris Matos |
| I don't see a real reason to incentivize storage unless there is a specific goal in mind. In CAL there are income legibility requirements, and the hardest part is just understanding if a person is legible or not. Needs to be easy to do this and given our climate we need to pair storage with heat pumps or seasonal storage or some thermal benefit.<br><br>-Marty | That makes a lot of sense and really appreciate the idea of electrification in the winter, and we could probably consider some of that as well.<br><br>-Chris Matos. |
| On the MISO, situation, there's approx. 35-40 GW of storage in the queue so there's a lot of incentive there and the barriers are more on the line of interconnection. Is there a similar effort at state level to attend the interconnection issues? Theres a lot of information gaps and the development community is concerned, because solar and storage are undervalued together.<br><br>- Rhonda Peters | This was incredibly helpful and definitely will take it into consideration.<br><br>-Chris Matos. |

**Table 15-2: Written Questions Captured During the Programs and Policies Section**

| Comments/Question | Response |
| --- | --- |
| I'm confused. When we worked on this study legislation last session, the plan was that we'd hear the results of the study before asking stakeholders to comment on whether additional energy policies were needed and what those policies might be. Are we going to hear any results from the study today?<br><br>Mike Bull | Today is to gather input on policies and incentives, which we need before the study is completed. The results so far confirmed this need. |
| Does the study address barriers/opportunities at the RTO level as well as state level? | No |
| Is there any reason thermal energy storage would be treated/incentivized differently than chemical/electrical storage for incentivizing building owners (I work primarily with C&I customers)? – Mike Filler | n/a |
| Have Siemens considered the Index Storage Credit mechanism for bulk storage developed by NYSERDA as part of their Energy Storage Roadmap? https://www.renewableenergyworld.com/storage/new-yorks-energy-storage-incentives-are-changing-heres-what-you-need-to-know/#gref – Roy Sashwat | It is on the longer list just didn't make it to the slides |
| Is there a reason that MinnPACE qualifying equipment does not specifically call out energy storage as included? https://minnpace.com/commercial-property-owners/ - Mike Filler | n/a |

## 15.5. Next Steps – Laura Lyons (Slides 15-17)

Laura explains Siemens main task and the final report due date of February 15th. But explains the department is aware of how many questions have risen and that there is plenty more studies to be done. Thanks everyone and concludes the call.

## 15.6. List of Attendees

**Table 15-3: List of Attendees**

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**Table 15-4: Comments Received via Email Upon Completion (through2/5/2024)**

| Comments/Feedback |
|---|
| SMMPA is uniquely concerned about the use of present-day energy sales to determine its share of any future state-wide energy storage goal. As illustrated in SMMPA's current IRP, SMMPA anticipates that in 2030 its annual energy sales will decrease more than 50% due to the expiration of power sales contracts with two members. Using present-day energy sales (e.g., 2023) to determine SMMPA's share of a state-wide goal in the years beyond 2030 may require SMMPA to deploy energy storage at a rate more than double that of other utilities in Minnesota. To address SMMPA's unique position, and to ensure fairness for the SMMPA member communities, we strongly suggest that any allocation of a future state-wide goal be based on the actual present-day energy sales of SMMPA to those members SMMPA will be serving when a storage goal goes into effect.<br><br>***SMMPA*** |
| Senator Ann Rest has included in her omnibus tax policy package a limited tax exemption for distribution-scale BESS. The policy was supported by a bipartisan group of legislators and clean energy and rural development organizations, including Connexus Energy, Fresh Energy, Vote Solar, CURE, and others.<br><br>Distribution sited-BESS projects often have more challenging economics. Distribution-sited BESS create local value to resiliency and are worth consideration distinct from transmission-connected BESS.<br><br>***Connexus Energy*** |
| The list of potential incentives was aimed at for-profit, investor-owned utilities (IOUs) and did not take into account the municipal utility model.<br><br>Some of the incentives mentioned are based on taxes and tax credits. Such incentives do not work for municipal electric utilities, which are largely exempt from state and federal taxation. Therefore, any state tax credits would have to be designed to place the not-for-profit customer owned municipal utilities on the same economic footing as for-profit utilities.<br><br>Any direct grants funded by the state should be set aside for the municipal utilities in an amount comparable to for-profit utilities.<br><br>***MRES*** |

| |
|---|
| We encourage and recommend a more holistic view referencing and intersecting where and how the Midcontinent Independent System Operator (MISO) energy storage work plan efforts coincide with the State of Minnesota. Similarly, we suggest that references to the intersection with Minnesota's regulated utilities' energy storage efforts be considered.<br><br>***CEEM*** |
| Malta strongly encourages the Department to consider and adopt LDES-specific considerations in any recommendations for policies and programs.<br><br>*Technology commercialization grant funding:* Malta recommends that the state support a grant program dedicated to supporting the commercialization of non-lithium MDES/LDES storage technologies, with a meaningful amount of available funding (e.g., $100 million).<br><br>*MDES/LDES procurement targets:* Using the forthcoming study as a potential starting point, Malta recommends that scenario targets be established as firm energy storage procurement targets, with some portion of this overall amount being allocated to MDES/LDES resources.<br><br>*Utility-scale storage capacity incentive program:* Consistent with our comments above on taking actions now to support some no-regrets MDES/LDES procurement rather than waiting until a future time, Malta recommends that a potential capacity incentive program incorporate elements that will enable the participation of MDES/LDES resources.<br><br>***MALTA*** |

# 16. Appendix E: List of Minnesota Utilities

**Table 16-1: List of Minnesota Electric Utilities**

| Utility Name | |
|---|---|
| Adrian Public Utilities | Iowa Lakes Electric Coop |
| Agralite Cooperative | Itasca-Mantrap Coop Electric Assn |
| Aitkin Public Utilities | Janesville Municipal Utility |
| Alexandria Light & Power | Kandiyohi Power Coop |
| Arrowhead Electric Coop, Inc | Keewatin Public Utilities |
| Austin Utilities | Kenyon Municipal Utilities |
| BENCO (Blue Earth Nicollet Faribault Coop) | Lake City Utility Board |
| Bagley Public Utilities Commission | Lake Country Power |
| Barnesville Municipal Power | Lake Crystal Municipal Utilities |
| Beltrami Electric Coop, Inc. | Lake Park Public Utilities |
| Benson Municipal Utilities | Lake Region Electric Coop |
| Biwabik Public Utilities | Lakefield Municipal Utilities |
| Blooming Prairie Public Utilities | Lanesboro Public Utility |
| Blue Earth Light & Water Dept | Le Sueur Municipal Utilities |
| Brainerd Public Utilities | Litchfield Public Utilities |
| Breckenridge Public Utilities | Lyon-Lincoln Electric Coop, Inc. |
| Brown Co Rural Electrical Assn | Madelia Municipal Light & Power |
| Brownton Municipal Light & Power | Madison Municipal Utilities |
| Buhl Public Utilities | Marshall Municipal Utilities |
| Ceylon Public Utilities | McLeod Coop Power Assn |
| City of Ada | Meeker Coop Light & Power Assn |
| City of Alpha | Melrose Public Utilities |
| City of Alvarado | MiEnergy Coop. |
| City of Anoka | Mille Lacs Electric Coop |
| City of Arlington | Minnesota Power Co |
| City of Baudette | Minnesota Valley Coop Light & Power Assoc |
| City of Bigelow | Minnesota Valley Electric Coop |
| City of Brewster Light & Power | Moorhead Public Service |
| City of Buffalo | Moose Lake Water & Light Commission |
| City of Caledonia Electric Dept. | Mora Municipal Utilities |
| City of Chaska | Mountain Iron Water & Light Dept |
| City of Dundee | Mountain Lake Municipal Utilities |
| City of Dunnell | Nashwauk Public Utilities |
| City of Ely - Ely Utilities Commission | New Prague Utilities Commission |
| City of Granite Falls | New Ulm Public Utilities |
| City of Harmony | Nobles Cooperative Electric |
| City of Henning Electric Dept | North Branch Municipal Water & Light |
| City of Jackson | North Itasca Electric Coop |
| City of Kandiyohi | North Star Electric Coop |
| City of Kasota | Northwestern Wisconsin Electric Co |

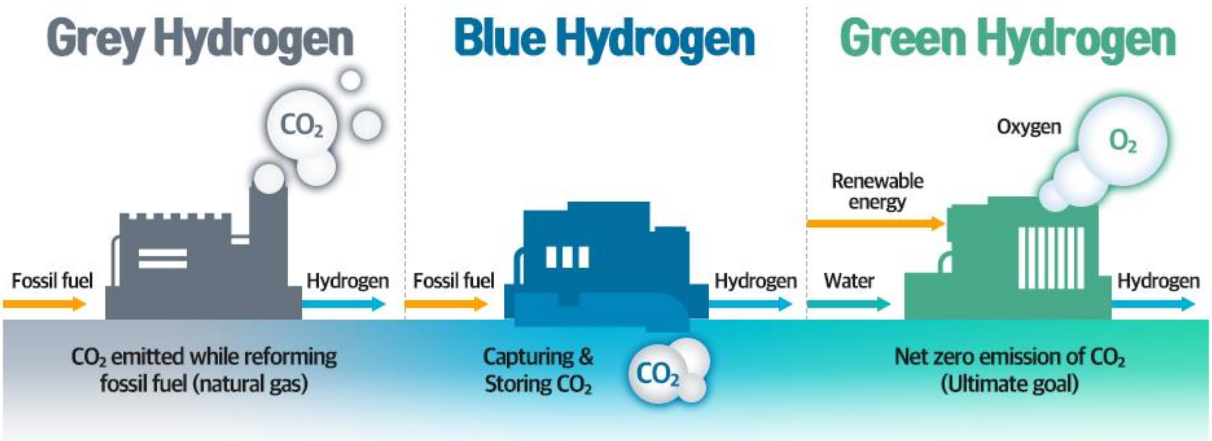
| | |
|---|---|
| City of Kasson | Ortonville Light Department |
| City of Luverne | Otter Tail Power Co |
| City of Mabel | Owatonna Public Utilities |
| City of NewFolden | PKM Electric Coop, Inc |
| City of Nielsville | Peoples Cooperative Service |
| City of North St Paul | Pierz Utilities |
| City of Olivia | Preston Public Utilities |
| City of Peterson Electric System | Princeton Public Utilities |
| City of Randall Electric | Proctor Public Utilities |
| City of Round Lake | Red Lake Electric Coop |
| City of Rushford | Red River Valley Coop Power Assn |
| City of Rushmore | Redwood Electric Coop |
| City of Spring Grove | Redwood Falls Public Utilities |
| City of Staples | Renville-Sibley Coop Power Assn |
| City of Two Harbors | Rochester Public Utilities |
| City of Tyler | Roseau Electric Coop |
| City of Warren | Roseau Municipal Water & Light |
| City of Whalan | Runestone Electric Assn |
| City of Winthrop | Sauk Centre Public Utilities |
| Clearwater Polk Electric Coop | Shakopee Public Utilities |
| Connexus Energy | Shelly Municipal Light Dept |
| Cooperative Light & Power | Sioux Valley Energy |
| Crow Wing Coop Power & Light, Inc. | Sleepy Eye Public Utility |
| Dakota Electric Assn | South Central Electric Assn |
| Delano Municipal Utilities | Spring Valley Public Utilities Comm |
| Detroit Lakes Public Utility | Springfield Public Utilities Comm |
| East Central Energy | St. Charles Light & Water |
| East Grand Forks Water & Light Dept. | St. James Municipal Light & Power |
| Eitzen Light and Power | St. Peter Municipal Utilities |
| Elbow Lake Municipal Power | Stearns Coop Electric Assn |
| Elk River Municipal Utilities | Steele-Waseca Coop Electric |
| Fairfax Municipal | Stephen Electric Dept |
| Fairmont Public Utilities | Thief River Falls Municipal Utility |
| Federated Rural Electric Assn | Todd Wadena Electric Coop |
| Fosston Municipal Utilities | Traverse Electric Coop, Inc |
| Freeborn-Mower Coop Svcs | Truman Public Utilities |
| Gilbert Water & Light | Virginia Dept. of Public Utilities |
| Glencoe Light & Power Commission | Wadena Light & Water |
| Goodhue County Coop Electric Assn | Warroad Municipal Light & Power |
| Grand Marais Public Utilities | Waseca Utility |
| Grand Rapids Public Utilities Commission | Wells Public Utilities |
| Grove City Electric Dept | Wild Rice Electric Coop |
| H-D Electric Coop, Inc | Willmar Municipal Utilities |
| Halstad Municipal Utilities | Windom Municipal Utilities |
| Hawley Public Utilities | Worthington Public Utilities |

| | |
|---|---|
| Heartland Power Coop | Wright-Hennepin Coop Electric Assn |
| Hibbing Public Utilities Commission | Xcel Energy |
| Hutchinson Utilities Commission | |

# 17. Appendix F: Siemens PTI Clean Fuel Alternative Outlook

Desire to reduce carbon emissions across the economy coupled with extensive government support, and improving technology performance and cost is spurring interest in green hydrogen as a green fuel alternative and storage of energy. While hydrogen can be used as both a fuel and foundational element of various chemical feedstocks, green hydrogen can also be converted to green forms of common fuels and products such as methanol, ammonia, and several distillates (diesel, kerosene jet fuel, etc.). Thus, hydrogen or its derivative products can be used in power generation, transportation, industrial energy, and building heat and power applications as well as chemical feedstocks.

Hydrogen is currently used primarily as a chemical feedstock or in refining or metals manufacturing and is produced via steam methane reforming of natural gas. Since this process releases CO2, it is not green, so alternative production means were developed to lower the CO2 content from production. These include auto thermal reforming or gasification of either coal or biomass – either process including post processing carbon capture and sequestration. While not 100% green, these processes can reduce CO2 emissions by 95%. For 100% green hydrogen, electrolyzers are employed which apply renewable power and split water molecules into hydrogen and oxygen. Alkaline electrolyzers have been in use for decades, and more recently polymer electrolyte membrane and solid oxide technologies have been introduced. Further, high temperature electrolyzers, which are more efficiency, use both heat and electricity to split water. In the US, excess heat from nuclear power plants is used in this process.




*Source: PSCO*

Depending on how hydrogen is produced, it can be 100% sustainable, stored in bulk. It is technically well understood, versatile, and heavily supported through federal policy. These advantages are generally considered to offset the relatively high cost and low efficiency of production. To support hydrogen development, the US DOE set a goal of reducing the cost of hydrogen produced with zero or near-zero carbon emissions to $1/kg by 2031. Further, the bipartisan infrastructure law of 2021 authorized the DOE to spend $8 billion on the development of regional hydrogen hubs, or networks of producers and off takers. The agency set aside $1 billion of that funding for a separate program to spur hydrogen technology.

Seven hubs across the country were selected each using different production technologies and focused on different end customer types.

Despite a flurry of excitement and funding, the question remains: when will green hydrogen be reliably available in the necessary quantities at attractive prices, and how will that market develop? To answer that question, Siemens PTI developed two hydrogen price forecasts. The first is based on the expectation that the market will initially develop from individual projects with dedicated off takers where pricing is based on production economics, and indeed several projects are currently under development applying this commercial approach. In this case, our forecast is based on a proprietary bottom-up production cost forecasting model which includes all equipment and costs required to produce the capacity needed for a 1x1 combined cycle power plant. The model adjusts costs, especially renewable power supply costs, for different regions and includes the impact of federal subsidies. To that cost is added a supplier margin consistent with other alternative fuel projects, which is added to fixed costs elements and passed through variable costs to arrive at a contract price. The second forecast assumes a more developed and liquid market in which green hydrogen is primarily delivered via pipelines and must compete with the combined cost of natural gas and CO2.

For power generation purposes, hydrogen and natural gas can be blended and combusted up to the limits of the combustion turbine model. Some smaller models, most common in industrial applications, can combust 100% hydrogen. However, larger turbines commonly employed for power generation must currently combust a blend of hydrogen and natural gas with most equipment capable of about 30% hydrogen mixes. For this reason, Siemens PTI blends our hydrogen and natural gas price forecasts in the proportions in which we expect large scale combustion turbine technology to be capable of combusting hydrogen for use in dispatch economic analysis.