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MODERNIZING MINNESOTA'S GRID:

An Economic Analysis of Energy Storage Opportunities

Minnesota Energy Storage
Strategy Workshop Final Report

July 11, 2017

Disclaimer: Views in this report do not necessarily reflect those of all participants.

This report is authored by the University of Minnesota's Energy Transition Lab, Strategen Consulting, and Vibrant Clean Energy. We are grateful to all the workshop participants who shared their insights and expertise, and to those who reviewed the modeling results.

We thank the Energy Foundation, McKnight Foundation, Minneapolis Foundation, Carolyn Foundation, AES Energy Storage, General Electric, Next Era Energy Resources, Great River Energy, and Mortenson Construction for making this work possible.

Contents

1 Executive Summary

1.1 Overview

Stakeholders in Minnesota's power sector convened in two workshops held in September 2016 and January 2017 to discuss a statewide strategy for energy storage deployment. The first workshop helped identify areas for more in-depth analysis. Preliminary results from this analysis and from real-world case studies were presented at the second workshop and used to guide a broader discussion around recommended next steps. The workshops and analysis made the following key findings:

- Under an optimal set of future energy resource investments and operating practices, the least-cost solutions included energy storage.
- Energy storage can be a cost-effective means to help Minnesota meet its state greenhouse gas (GHG) reduction goals.
- The deployment of storage in Minnesota was projected to increase the use of low-cost renewable energy generation dispatched in MISO and to reduce the need for expensive transmission investments.
- Historically, utilities have used gas combustion turbines to meet peak demand. As storage becomes more cost-effective, it will compete with and displace new gas combustion peaking plants (peakers).
- Compared to a simple-cycle gas-fired peaking plant, storage was more cost-effective at meeting Minnesota's capacity needs beyond 2022.
- Solar + storage was found to be more cost-effective than a peaking plant today, primarily because of the federal Investment Tax Credit (ITC) and additional environmental benefits, including reduced greenhouse gas (GHG) emissions.
- At least one distribution cooperative in Minnesota is already pursuing deployment of a solar + storage facility.

Through a series of facilitated discussions, workshop participants generated a set of recommended next steps for immediate action.

- Lead study tours to educate Minnesota stakeholders about existing storage projects.
- Develop a proposal to deploy commercially significant energy storage pilot projects.
- Modify the existing Community Solar Gardens program to facilitate solar + storage projects.

In addition, participants recommended the following steps that are ongoing or longer-term and can be pursued in parallel with the immediate actions.

- Direct energy producers to conduct future capacity additions through all-source procurement processes.

- Update modeling tools used by utilities and regulators for resource planning to better capture the costs and benefits of storage.
- Identify utility cost recovery mechanisms for new energy storage investments.
- Develop MISO rules that appropriately consider energy storage as a capacity and grid resource.
- Conduct an assessment to link storage to Minnesota's system needs.
- Develop innovative retail rate designs that would support a greater deployment of energy storage.
- Educate state policymakers through meetings and briefing materials.
- Identify opportunities for large electric customers to host storage projects.
- Host technical conferences for planners, grid operators, and utilities.

In addition, workshop attendees suggested system analysis to identify high-impact locations for storage system benefits.[1]

1.2 Background

Minnesota is a leading state in clean energy production and grid modernization. Over the last decade, the renewable portion of Minnesota's electricity mix has grown from 7% to over 21%.[2] The state is also a leader in encouraging new energy technologies from a policy perspective, exemplified by its Grid Modernization and Distribution Planning Law (H.F.3, 2015) and related Public Utilities Commission proceedings (Docket #15-556). Despite these efforts to date, Minnesota has deployed relatively little advanced energy storage technology and has not included storage in its integrated resource planning efforts. At the same time, other states are experiencing a variety of storage benefits. In California, for instance, utilities have deployed energy storage to provide necessary generation capacity to critical population areas such as the Los Angeles basin. In the PJM market, storage projects have provided ultra-fast grid balancing services (fast frequency regulation). In Hawaii, storage integrated with solar PV has provided a cheaper alternative to expensive oil-burning power. In light of these success stories and other recent changes in the storage market, a group of Minnesota energy experts participated in a workshop series to explore the future role of energy storage in the state. This report describes the workshop's process and its findings, details the supporting analysis that was presented at the meetings, and presents ideas for appropriate next steps.

1.3 Workshop goals and objectives

In the fall of 2016, the University of Minnesota's Energy Transition Lab (ETL) launched an energy storage planning process with a diverse set of Minnesota energy sector stakeholders, with support from the

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[1] Other suggestions can be found in notes from Workshop 1 and 2, Appendix 19.

[2] Minnesota 2025 Energy Action Plan, https://mn.gov/commerce/policy-data-reports/energy-data-reports/mn-action-plan.jsp

Energy Foundation, the McKnight Foundation, the Minneapolis Foundation, AES Energy Storage, General Electric, Next Era Energy Resources, Mortenson Construction, and Great River Energy. Additionally, the Carolyn Foundation provided support for the preparation and dissemination of this report. The primary objective was to explore whether and how energy storage could be used to help Minnesota achieve its energy policy goals while enabling greater system efficiency, resiliency, and affordability. All workshop participants were encouraged to come to the table with an open mind and no expectation of a particular outcome.

1.4 Approach

The Energy Storage Strategy Workshops included two meetings, the first in September 2016 and the second in January 2017. Between these meetings the project team analyzed possible use cases for energy storage—in Minnesota and in the broader MISO system.

1.4.1 Objectives of Workshop 1

The September 2016 workshop was intended to educate Minnesota's diverse stakeholder group on national trends in energy storage markets and technology. To this end, the project team brought in several out-of-state storage developers and technology companies to present their state-of-the-art case studies. Workshop 1 leveraged the stakeholders' diverse perspectives to formulate hypotheses for how energy storage could potentially be of value to Minnesota's energy system. The stakeholders also outlined potential use cases and identified priority topics that warranted further investigation, including the use of energy storage as an alternative to new gas peaking plants,[3] and the deployment of storage combined with solar at distribution level applications.

1.4.2 Analysis and Modeling

Based on input from Workshop 1, the project team, which included ETL, Strategen Consulting and Vibrant Clean Energy (VCE), analyzed the cost-effectiveness of storage, both for specific use-cases and when applied to the MISO system-level grid. The project team took care to harmonize its modeling assumptions with existing MISO modeling work, building on VCE's 2016 report, "MISO high penetration renewable energy study for 2050,"[4] as well as the 2014 Minnesota Renewable Energy Integration and Transmission Study (MRITS).[5] The project team also used input from vendors and other recent public sources to develop up-to-date energy storage cost estimates.

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[3] This is particularly relevant given the large planned volume of new gas peakers on the planning horizon for MISO. For example, up to 1,800 MW of new peaker capacity additions by 2028 are projected by MISO in the MTEP17 Futures Siting, as reported in the Planning Advisory Committee meeting, 10-19-2016. Similarly. Xcel Energy's 2016-2030 Upper Midwest Resource Plan, (Current Preferred Plan, filed Jan. 29, 2016 in Docket No. E002/RP-15-21) included approximately 1750 MW of new combustion turbine additions by 2028.

[4] Vibrant Clean Energy, January 2016, "MISO high penetration renewable energy study for 2050," https://www.misoenergy.org/_layouts/miso/ecm/redirect.aspx?id=223249

[5] Minnesota Renewable Energy Integration and Transmission Study (MRITS), 2014 https://mn.gov/commerce/industries/energy/distributed-energy/mrits.jsp

1.4.3 Workshop 2

Workshop 2 was used to review findings of the analysis, discuss their implications, and brainstorm and prioritize potential action steps. Additional input was also provided from recent case studies of energy storage deployment in California and anticipated deployment in Minnesota. The mix of participants changed slightly for Workshop 2, to include consumer, large customer, and distribution cooperative perspectives. All of this information and findings are summarized in this report.

1.4.4 Scope of analysis and modeling

Between the two workshop meetings, the project team analyzed the potential costs, benefits, and performance characteristics of grid-connected, stationary energy storage in Minnesota (excluding electric vehicle charging). Participants considered various energy storage configurations and technologies. Due to limited project budget and time, the analysis focused primarily on 4-hour duration Li-ion battery storage technology,[6] which is becoming increasingly inexpensive. Li-ion batteries' recent proliferation has created significant economies of scale, reducing their input costs and giving rise to a large installed base in North America. Forecasts suggest future economies of scale will effect further cost declines.

1.4.4.1 MISO System Modeling

For system modeling, the project team used the VCE WIS:dom optimization model. It is a blended capacity expansion and production cost model that co-optimizes generation, transmission, and storage using high-resolution weather, grid, and demand data (see section 4.2 for a detailed description of the WIS:dom model). A variant of WIS:dom is configured to represent the MISO system with an added emphasis on Minnesota. The model includes hourly, highly granular weather data for variable renewables across MISO territory under both transmission-constrained and transmission-unconstrained scenarios. The present study builds upon the "MISO high penetration renewable energy study for 2050," a report commissioned by MISO and completed by VCE in 2016. MISO also provided input to this round of modeling both through participation in the workshops and through more in depth discussions of key inputs and assumptions and current MISO operations.

1.4.4.2 Energy Storage Use Case Modeling

To evaluate the cost-effectiveness of energy storage at the application, or use-case level, Strategen compared various storage scenarios to new gas peakers. For this analysis, the present value of net benefits and costs of a storage project was compared to the present value of net benefits and avoided costs of a new peaker plant. In calculating the cost-benefit ratio, Strategen's analysis considered quantifiable potential benefit streams, including intra-hourly ancillary services benefits. It also compared GHG emissions associated with the storage project (including charging energy) to those from a new peaker. The analysis did not consider location-specific infrastructure upgrade deferral benefits.

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[6] The project team recommends additional analysis of technologies better suited for long duration energy storage.

1.5 Results and findings of analysis

1.5.1 MISO System Modeling Findings

To measure the effects of adding energy storage in several different future scenarios, the VCE/MISO modeling team created a base case scenario, which did not incorporate energy storage additions or GHG constraints. By comparing cases with storage to the base case, the analysis suggests that storage can be a useful addition to the energy planning toolkit for Minnesota and the broader Midwest region. When compared to the base case, scenarios with storage almost always helped Minnesota to better meet its long-term renewable energy and GHG goals. This was also true when storage was applied to the broader Midwest region. For example, while MISO is capable of reducing GHG emissions by 80% by 2050 without energy storage, scenarios including storage reduced the levelized cost of electricity (LCOE) on average across MISO[7] as well as the amount of fossil fuel generation required, with the balance being made up by low-cost renewable energy additions. These findings complement previous renewable integration studies, such as the MRITS study, which found that Minnesota could technically support significantly higher penetration of variable renewable generation.[8] This new work builds on the previous studies by introducing a cost-optimized approach to better understand which resource investments, including energy storage, can achieve clean energy goals at the lowest total capital and operating cost across MISO. The study also introduces co-optimization of high-resolution variable resources with generation, transmission, and storage. This allows capacity expansion planning to incorporate detailed knowledge of the entire system’s dispatch (including hourly reduced-form power flow across the MISO footprint).

Notably, the WIS:dom optimization model selected energy storage as a significant component of the most cost effective resource portfolio in all scenarios where storage investment was permitted. Where the scenarios constrained GHG emissions, fossil fuel resource additions were capped, and the federal Investment Tax Credit (ITC) applied to storage projects, energy storage became a cost-effective resource by 2030. Even when the federal ITC was not applied, energy storage was still more cost-effective than other resource investments, though in some cases not until a later date, for example, 2045.

Each scenario from the WIS:dom optimization model represents a perfectly economic expansion of the entire MISO system. Additional analysis by the project team indicates discrete storage projects can be cost-competitive sooner than 2030 compared to alternatives. The model showed that like a natural gas peaker, storage is most extensively dispatched during summer peak hours—hours when solar PV is also operating. When used in tandem, solar PV and storage can share the peak load and operate more efficiently than a gas peaker. More solar PV is selected when storage is made available, suggesting that storage also plays a critical role in matching the high variability of solar PV output with local load patterns.

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[7] While LCOE was lower across MISO in the storage scenario, it should be noted that LCOE was also higher within LRZ1, which covers most of Minnesota and where storage was sited within the model. This is due to higher capital expenditures associated with storage investments.

[8] Minnesota Renewable Energy Integration and Transmission Study (MRITS), 2014 https://mn.gov/commerce/industries/energy/distributed-energy/mrits.jsp

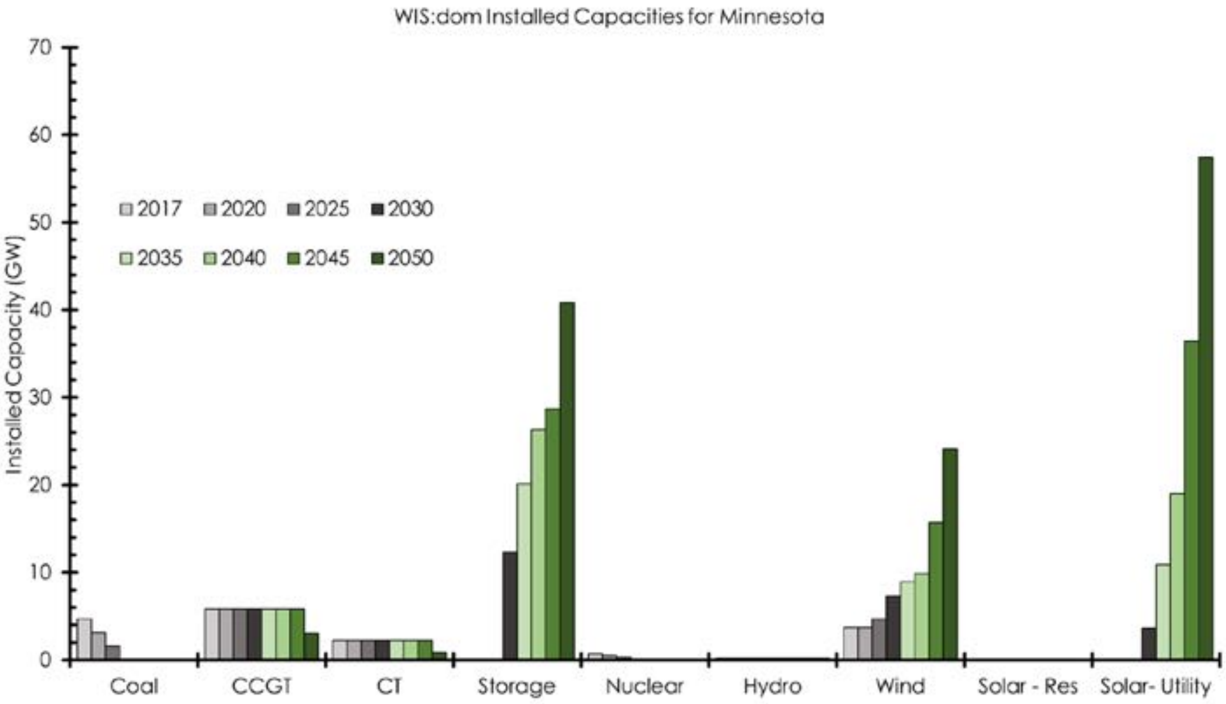

Figure 1. Energy resource installed capacities in Minnesota for Scenario JE6 (storage investment allowed, transmission expansion allowed, ITC applies to storage, GHG constraints applied, and fossil additions capped). Under this scenario, storage is selected by the WIS:dom optimization model as an economic resource in 2030.

Additionally, the analysis appears to demonstrate that the efficacy of transmission investments can be increased through the addition of energy storage, allowing renewable resource output to be utilized more effectively. For instance, in several cases increased transmission expansion led to an increased deployment of energy storage as a least-cost resource.[9]

Meanwhile, for cases where storage was not allowed, there was generally a greater increase in transmission capacity compared to cases that allowed energy storage.[10] This suggests that with the addition of energy storage capacity, less transmission investment may be required over time, particularly under high renewable scenarios, thus contributing to reduced LCOE.

Under the base case scenario (Scenario 9), the least cost portfolio selected by the system optimization resulted in a significant increase in the percentage of energy generated from natural gas (80% of generation by 2050, up from 27% in 2017). This lack of resource diversity could pose additional risks and costs to Minnesota ratepayers, particularly in light of natural gas supply constraints that have afflicted other regions of the country (e.g., the Northeast polar vortex and the gas leak at the Aliso Canyon

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[9] As an example, Scenario 6 (transmission expansion allowed) showed about twice as much economic storage deployed as Scenario 5 (no transmission expansion). Both scenarios are identical apart from transmission expansion.

[10] As an example, transmission capacity expansion is generally greater on most paths in Scenario 12 (no storage) than in Scenario 6 (storage allowed). The only difference between the scenarios is whether storage is allowed.

storage facility in Southern California). The 2014 propane shortage indicates the Midwest may face similar vulnerabilities.[11]

By comparison, the case that includes additional energy storage and transmission investments, along with limits on GHG emissions (Scenario 6) resulted in a MISO portfolio with only 29% natural gas and included a significant increase in wind and solar generation. Thus, energy storage may be an important component of a resource diversification strategy. However, the precise value of storage in achieving diversification was outside the scope of this study.

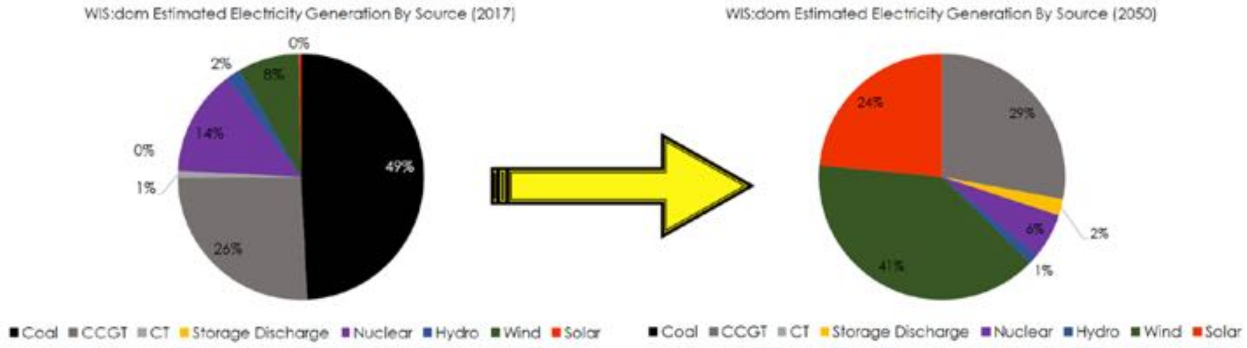

Figure 2. Change in resource mix over time for WIS:dom modeling Scenario 6, which includes energy storage, GHG emissions constraints, and transmission expansion. Storage plays an important role in diversifying the 2050 resource portfolio.

It should be noted that system level modeling focuses on minimizing the production costs for the entire system assuming a perfect forecast for planning and dispatch. As such, the system level modeling is helpful for identifying broad trends, but less useful for evaluating individual resource decisions. Additionally, there are certain potential values that may not be fully captured through the modeling, including intra-hourly ancillary services and location-specific benefits to Minnesota's grid (e.g., distribution system upgrade deferrals).

Conclusions:

- Under a perfectly optimal set of energy resource investments and operating practices energy storage was found to be part of lowest cost solutions.
- Storage was integral to a cost-effective resource mix in 2030 if deployed with the ITC and GHG constraints. Some specific storage solutions may be cost-effective sooner, but were not modeled. These results are based on the assumed cost projections for storage resources within this analysis. An accelerated decline of storage costs over time will lead to different conclusions. This cost decline could occur in the near-term due to synergies with lithium ion batteries and the transportation sector.

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[11] See for example:, https://insideclimatenews.org/news/20140310/us-propane-shortage-provides-lessons-debate-over-oil-and-gas-exports

- The inclusion of storage increased use of low-cost renewable energy generation dispatched in MISO, but without storage, MISO had significant risk of over-reliance on non-diversified fossil fuel sources.
- The inclusion of storage reduced the need for expensive transmission investments.
- While MISO is able to meet an 80% reduction in GHG by 2050, the inclusion of storage enabled MISO to reduce GHG's sooner and at a lower cost.
- As it becomes economic, storage appears to compete with and displace gas combustion turbines used for peak demand.

1.5.2 Use-Case Analysis Findings

Stakeholders in Workshop 1 prioritized several use cases for further analysis. Among the highest priority items was an analysis of whether energy storage could suitably replace gas-fired peaking plants. Strategen performed a use-case cost-effectiveness analysis, comparing the costs and benefits of storage to the costs and benefits of specific alternative resources at the application level. This differs from system-level analysis, which models all resources operating together at the system level. This exercise compared both standalone energy storage and solar + storage as capacity resource alternatives to a new natural gas peaker. This work was based in part on experience in Southern California, where Southern California Edison (SCE) is using energy storage as a Local Capacity Resource (LCR) to address reliability issues related to the 2015 Aliso Canyon gas leak.[12] In Workshop 2 participants heard from national experts with firsthand knowledge of these projects (see Appendix J). Workshop 2 also included a presentation on and discussion of a real-world case study of solar + storage as a means for a Minnesota distribution cooperative to reduce demand charges for its members (see Appendix I).

Strategen's analysis compared the net cost (present value of system cost, net of any benefits) of a new natural gas peaking combustion turbine to the net cost of a new 100 MW 4-hour storage system with a 20-year project life, as well as a 100 MW 3-hour storage + 50MW solar system with a 20-year project life. This comparison considered a suite of costs and benefits, including capacity, energy sales revenue, and sub-hourly ancillary services revenue.[13] The project team took care to ensure that modeled costs and benefits aligned with Minnesota-specific resource planning assumptions and expected market conditions for 2018, with forward looking projections for 2023.

Under this analysis framework, the solar + storage comparison was found to be cost-effective in 2018 (benefit to cost ratio = 1.04). In the analysis, the storage system used with solar PV was downsized from the standalone storage system. Because solar PV generation can coincide with Minnesota's peak demand hours, it can complement stored energy to meet peak demand. As a result, solar + storage projects can provide a capacity resource that meets peak demand using less storage capacity than a

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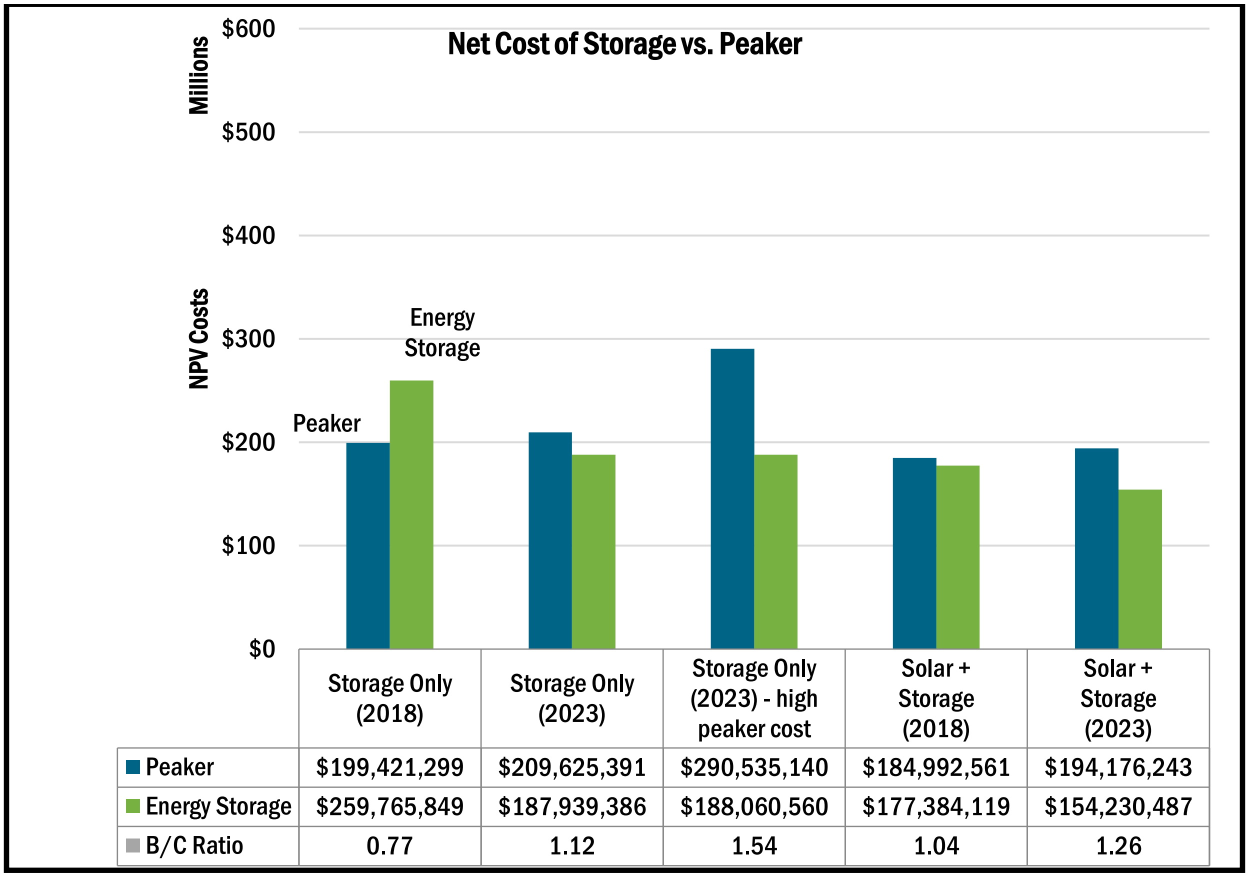
[12] In 2015, a natural gas leak was discovered at the Aliso Canyon underground storage facility in Southern California. Aliso Canyon is the second-largest natural gas storage facility in the U.S. and the leak is the largest in U.S. history. The incident posed major risks to the reliability of California's power system, so the state took emergency steps to mitigate these risks, including accelerating the procurement of energy storage.

[13] Some system-level benefits that storage could provide were not specifically estimated. These included avoided startup costs for thermal units and reduced curtailment.

standalone storage project would require. Storage projects coupled with solar PV are also eligible for the federal Investment Tax Credit, further reducing their cost. These factors coupled with the environmental benefits resulted in a positive benefit to cost ratio.[14] The benefit to cost ratio is comparatively higher in 2023 for the solar + storage case (B/C = 1.26), largely due to anticipated reductions for Li-ion battery costs over the intervening five years.

The storage-only resource was not found to be cost effective in 2018 (B/C = 0.77). However, it was cost effective in 2023 (B/C = 1.12), and even more cost effective in comparison to a higher cost, more flexible peaker (B/C = 1.54). Figure 3 summarizes these findings.



	Storage Only (2018)	Storage Only (2023)	Storage Only (2023) - high peaker cost	Solar + Storage (2018)	Solar + Storage (2023)
🟦 Peaker	$199,421,299	$209,625,391	$290,535,140	$184,992,561	$194,176,243
🟩 Energy Storage	$259,765,849	$187,939,386	$188,060,560	$177,384,119	$154,230,487
⬜ B/C Ratio	0.77	1.12	1.54	1.04	1.26

Figure 3. Summary results for cost comparison of energy storage to natural gas peakers. With the exception of the storage-only project in 2018, all projects including storage are more cost-effective than comparable gas-fired peakers.

These findings are conservative; they do not include any potential systemic benefits, such as reduced startup costs from existing fossil power plants, or locational benefits such as transmission and

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[14] While there is no direct market price for environmental benefits, Minnesota law requires the Public Utilities Commission to account for environmental externality costs in utility resource planning decisions (Minn. Stat. §216B.2422, Subd. 3). For solar in particular, the Minnesota PUC has set a Value of Solar Tariff which incorporates environmental benefit values (see footnote 21).

distribution system upgrade deferrals. These results are based upon storage costs assumed in the study; a steeper decline in costs will allow storage to become more cost-effective more quickly.

From a lifetime CO_2 emissions perspective, the modeling scenario with standalone storage in 2018 resulted in greater CO_2 emissions than its gas peaker counterpart, due to the large amount of high-emitting coal resources on the margin in MISO that are used to charge energy storage, especially in the near term. All other energy storage cases analyzed caused fewer emissions, due to increasing availability of GHG-free renewable generation on the margin. The solar + storage examples delivered significantly less emissions than the comparable gas fired peaker both in the near term and over its lifetime. As GHG-free renewables further penetrate the market, they will often replace coal in charging storage projects.

1.5.3 Case Study: Connexus Solar + Storage Procurement

Connexus, Minnesota's largest distribution cooperative, is currently pursuing procurement of a 20 MW, 40 MWh energy storage + solar facility this year to deploy incremental renewable energy for its members, while achieving significant power supply cost savings and without adversely affecting customer rates. After analyzing the potential benefits from the federal ITC capture, energy production from solar PV, and reduced demand charges, Connexus determined that these three benefits alone were sufficient to justify near term procurement of a solar + storage project development on the basis of costs and members' desire for greater renewable energy. As a result, the co-op is actively seeking to procure a battery storage system of a minimum 20 MW, 40 MWh in conjunction with 10 MW of solar PV to be located on impaired land close to the distribution system. Importantly, a key goal of this project is to help Connexus' operating engineers become more familiar with energy storage as a tool in their toolkit. In the future, the co-op may explore additional benefit streams such as distribution deferral or other intra-hourly ancillary services. Connexus presented its plans on this project, including its high-level economic analysis, during Workshop 2 and subsequently released its RFP for this project on March 31, 2017.

1.6 Minnesota Energy Storage Strategy Stakeholder-Recommended Priority Actions

While some states are beginning to deploy grid connected energy storage on a large scale,[15] Minnesota utilities and regulators have been hesitant to deploy energy storage widely because of concerns of cost effectiveness, cost recovery, and lack of operational experience with the asset class in general. Modeling data and peer utilities' experiences can help to identify favorable use cases for Minnesota. However, load-serving entities and regulators eventually need operational experience to link energy storage capabilities to Minnesota's unique grid needs. While the first deployment of any new technology may entail operational and institutional costs—as energy producers, grid operators, and regulatory agencies adapt to the new development—these costs are often one-off and enable future, lower-cost deployment of the technology. In short, there is simply no substitute for 'learning by doing'.

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[15] California, for instance, has procured and deployed hundreds of MWhs of grid storage over the last two years, which is now providing local capacity and other grid benefits.

Generally, most workshop participants agreed that finding opportunities to deploy solar + storage today was a low risk, “least-regrets” strategy in at least two instances: 1 - on the utility side, as an alternative to new gas peaking capacity, which was found capable of delivering net benefits and achieving near-term GHG emissions reductions; and 2 – on the customer side, as a mechanism for Generation & Transmission (G&T) utility customers (e.g. rural cooperatives) to reduce their peak load and avoid demand charges, yielding system cost savings. Because the federal Investment Tax Credit for solar projects is scheduled to phase out over the next four years, a number of stakeholders agreed that solar + storage projects should be identified and deployed in the very near term. A number of stakeholders also expressed that it would be a sensible next step to move forward with a limited, yet commercially significant solar + storage procurement. This would likely yield significant learning benefits for Minnesota’s energy sector and generate lessons for future integrated resource planning efforts. These lessons could outweigh potential near term costs and risks that might arise.

1.6.1 Recommended next steps for immediate action

To help realize these benefits, based on the system level modeling and individual resource cost effectiveness modeling, and in the spirit of ‘learning by doing’, the stakeholder group identified a series of actions that could be undertaken in MN to further advance energy storage as a viable option in MN’s electric power sector planning toolkit. Several of these actions were identified as discrete, near-term steps while others would be longer-term or ongoing, and complementary to the immediate actions.

1. Host a utility-focused **technical conference** (or series of conferences) to advance thinking on energy storage to support planning, grid operations, interconnection, measurement and verification and utility training. This conference could also address at a high level alternative contracting mechanisms, including those for utility-owned, third party-owned and aggregated solutions. Recommended leaders for this effort: ETL/MESA, Minnesota utilities and the PUC
2. Identify and clarify potential utility **cost recovery mechanisms** for prudent energy storage investments. This is critical, as cost recovery risk is a key barrier preventing investor owned utilities from investing in energy storage projects. At the same time, criteria should be established for qualifying pilot projects. Recommended lead: PUC
3. Work with utilities to develop and propose one or more **energy storage pilot projects** to the PUC with broad stakeholder support. A necessary component of this type of proposal would be an agreed-upon mechanism for cost recovery to be approved by the PUC.[16] The steps would include the following:
    a. Identify particular system needs and locations that could be effectively met with energy storage.
    b. Propose a commercial scale Minnesota energy storage procurement process to demonstrate energy storage as a viable alternative to new gas peakers or other

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[16] An example would be the Colorado Public Utilities Commission ICT (Innovative Clean Technology) mechanism, which gives a “presumption of prudence” of the costs in the next rate case. Colorado PUC Decision No. C09-0889, Docket No. 09A-015E (2009).

appropriate use cases. Such a procurement would help discover current price data and help identify best practices for storage project development (e.g. planning, siting, contracting, permitting, interconnection, etc.).

   c. Partner with universities to conduct research and analysis of power control systems, operational integration, economic performance, and other areas of learning, making them explicit goals of these initial pilot projects. This may result in University and other expert partner white papers. These additional research objectives could be optional if they are found to be cost prohibitive.

4. Because of superior cost effectiveness and lower GHG emissions, **solar + storage** should be prioritized near term. For example, the PUC could authorize 20 MW of utility owned and 20MW of third party owned (either centralized or aggregated behind the meter) energy storage and or energy storage + solar procurement pilots, to complement the learning from Connexus' solar + storage procurement underway. Engaging in a commercially significant pilot will shed light on key implementation barriers and issues very efficiently. Recommended lead: PUC, Minnesota utilities

5. Direct future capacity additions to be conducted through technology neutral **all-source procurements.** This would specify the need in terms of its capabilities, rather than its technology or generation type, and allow all resource types (including energy storage and energy storage + solar, as well as other technologies) to participate. The process and methodology for evaluating the all-source procurement should be established well in advance of its implementation. Recommended lead: Utilities; PUC

6. **Update modeling tools** used in integrated resource planning process (i.e. Strategist) to allow for appropriate treatment and evaluation of energy storage as a potential resource. Recommended lead: DOC, PUC, utilities.

7. Craft **MISO rules**, processes and products for energy storage participation. This should encompass not only standalone energy storage, but also behind the meter aggregated energy storage solutions as well as storage coupled with wind and solar. Recommended lead for this effort: MISO Develop innovative rate designs to allow customers to access storage benefits.

8. Conduct an assessment to link storage to Minnesota's **system needs**.

9. Develop **innovative retail rate designs** that would support a greater deployment of energy storage. Recommended lead: utilities, PUC.

10. Lead a **study tour** of MN stakeholders to existing grid connected and customer-sited energy storage installations. Recommended lead: ETL/MESA

11. Conduct outreach and **education for state policymakers**. This could include meetings with both state legislators and regulators. Ideally, it would include development of short briefing materials to summarize use cases, opportunities, and challenges for energy storage in Minnesota. Recommended lead: ETL/MESA

12. Engage large customers to **identify potential project hosting opportunities**. Stakeholders would approach large potential host sites (e.g. large commercial and industrial customers,

distribution centers, etc.) to identify potential value propositions. Recommended leads: MN Sustainable Growth Coalition, ETL/MESA.

13. Refine the existing **Community Solar Gardens program** to include a peak time option for energy storage. This would create a minor modification to existing program structure and methodology to allow for a solar + storage option (credit rate calculation would reflect the additional value of storage). Recommended lead: ETL/MESA, AG's Office.

Other recommendations highly rated by workshop attendees included innovative rate designs to allow customers to access storage benefits and system analysis to identify high-impact locations for storage system benefits.

1.7 Limitations and Opportunities for Further Analysis

The project team's analysis was limited in scope due to budget and time constraints. As with all modeling exercises, the quality and usefulness of the results are a direct function of the underlying assumptions and inputs. The following additional analyses could be undertaken to build on this initial work and further inform the path forward. However, it should be noted that there is still no substitute for 'learning by doing' and these additional modeling suggestions are not intended to be prerequisites for implementing the action recommendations developed by the stakeholders in this process.

1. Additional system optimization scenarios:
    a. Natural gas scarcity and price spike scenarios
    b. Storage with longer than four-hour duration (including flow battery technologies)
    c. Additional years of weather data
    d. More cost trajectories for technology inputs
    e. Future scenarios with more GHG reduction
    f. Future load scenarios including electric vehicle charging and various heating/cooling and thermal storage scenarios
    g. More transmission coordination among MISO, SPP, and PJM
    h. Multiple hub heights for wind generators
2. Individual resource use case cost-effectiveness analysis that could benefit from additional sensitivity analyses:
    a. Locational benefits: identification of specific locations in Minnesota's distribution system that are constrained or experiencing other issues energy storage can address. For example, the integration of energy storage with existing fossil generation could immediately improve local air emissions.[17]

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[17] The PUC docket on Xcel Energy's distribution hosting capacity could accomplish some of this analysis.

b. Installation costs: MISO values used in this study for peaker costs may not be representative of some utilities in the state

c. Frequency regulation: recent experience suggests that frequency regulation values can differ from initial modeling predictions

d. Comparison to or combination with other capacity alternatives such as demand response

e. GHG emissions: additional research into local drivers of marginal generation resources

2 Energy Storage 101

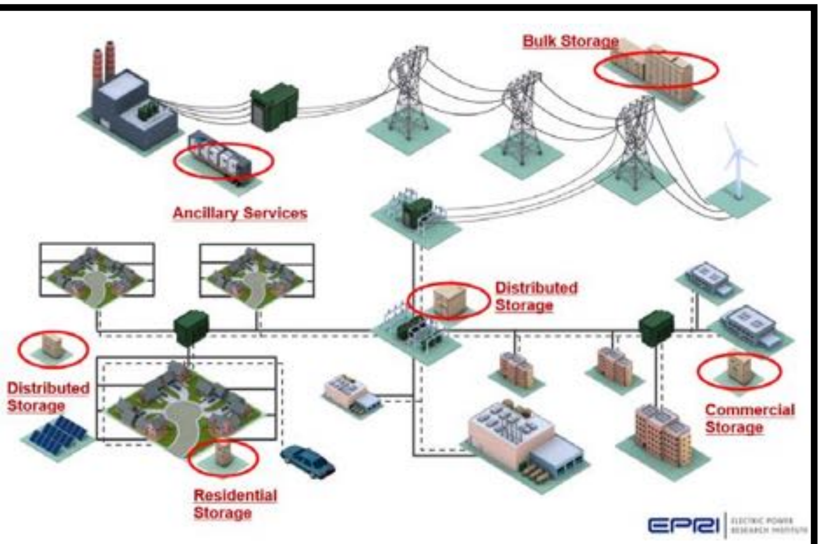

Figure 1. Energy storage has broad power system applicability

Energy storage is a broad class of assets that includes several technology types and potential applications for the power system. Energy storage can be physically deployed in many locations across the power system including generating stations, transmission networks, distribution networks, and at customer premises.

Different storage technologies are better suited for longer or shorter duration energy storage. For example, large-scale pumped hydro or compressed air facilities can store and dispatch many hours of stored energy at a constant power rating. In contrast, flywheels are better suited for output over short durations on the order of seconds to rapidly correct for changes in grid frequency. Meanwhile, batteries have a wide range of performance associated with different types of underlying chemistries (e.g. Li-ion, NaS, etc.). Flow batteries also have potential to provide longer duration storage.

Many types of grid services or "use cases" can be provided by energy storage. Some of the primary use cases are listed in the box to the right. The ability to provide many types of services tends to cut across traditional utility planning areas, such as T&D planning, resource planning, and customer programs. Storage can also cut across different regulatory frameworks, depending on whether it is used at the distribution (state regulated) or wholesale (regional/nationally-regulated) level. The deployment of grid-connected energy storage systems in the U.S. has increased rapidly in recent years, with over 1,400 MW installed over the last decade, compared to less than 100 MW in the prior decade. Bloomberg New Energy Finance predicts that 45,000 MW of new storage could be installed by 2024.[18] Technological improvements in energy storage technologies, particularly batteries, have also occurred, which have significantly reduced installation costs in recent years. Experts expect significant declines in cost over the next five years (e.g. ~40% for Li-ion batteries). [19]

<u>Energy Storage Use Cases:</u>

- Generation capacity (i.e. resource adequacy)
    - Includes local capacity
- Operating Reserves, including:
    - Frequency regulation
    - Load following
    - Spinning reserves
    - Non-spinning reserves
- Energy time shifting (i.e. reducing peak demand and reducing cost by charging off-peak, discharging on-peak, or "arbitrage")
- Peak shaving for deferral of T&D system upgrades
- "Behind the meter" applications for reduced customer bills (e.g. demand charge mitigation)

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[18] Bloomberg New Energy Finance, *Global Energy Storage Forecast, 2016-24*, accessed from: http://energystoragereport.info/tag/bloomberg-new-energy-finance/

[19] Lazard Levelized Cost of Storage Analysis 2.0 (Dec. 2016), Executive summary accessed at https://www.lazard.com/media/438041/lazard-lcos-20-executive-summary.pdf

3 Overview of Workshop Process and Goals

3.1 Objectives

In fall of 2016, the University of Minnesota's Energy Transition Lab, in collaboration with the Minnesota Energy Storage Alliance, the Energy Foundation, the McKnight Foundation, the Minneapolis Foundation, AES Energy Storage, General Electric and Next Era Energy, Mortenson Construction, Great River Energy, launched an energy storage strategy effort with a diverse cross section of Minnesota energy stakeholders.[20] This effort's primary objective was to explore whether and how energy storage could be used to help Minnesota achieve its energy policy objectives while enabling greater system efficiency, resiliency, and affordability.

3.2 Workshop 1

On Friday, September 23, 2016 a group of stakeholders convened to hold the first Minnesota Energy Storage Strategy Workshop. The workshop was hosted by University of Minnesota's Energy Transition Lab, and co-facilitated by Strategen Consulting. The goal of the meeting was to build upon work to date in Minnesota to further explore whether and how energy storage can help Minnesota achieve its energy policy objectives of a clean, affordable, reliable, and resilient energy system.

During the workshop, the Energy Transition Lab, Strategen, and several energy storage project developers gave substantive presentations on the following topics.

- Global Trends in Energy Storage (Strategen)
- Current MN Energy Landscape (UMN-ETL)
- Energy Storage 101 (Strategen)
- Energy Storage Case Studies (AES, GE, NextEra)

Stakeholders then identified several key challenges for the Minnesota energy system. The workshop participants also had the opportunity to vote for which challenges they believed were most important or pressing. They were then asked to identify specific storage applications that could address the challenges. Several high scoring topics were selected for breakout group discussions.

- Resource Planning & Modeling (including peaker replacement)
- Resiliency
- Renewable Energy Integration
- Managing Loads

There was general agreement that now is a good time for Minnesota to consider a broader strategy for and approach to energy storage. Because there is no immediate crisis, the state has time to improve

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[20] Additionally, the Carolyn Foundation provided support for the preparation and dissemination of this report.

market rules and allow storage's full integration into the state's resource mix—all in time to meet future resource needs, including anticipated capacity shortfalls in the mid-2020s.

3.3 Consultation, Analysis and Modeling

Following Workshop 1 and prior to Workshop 2, the project team consulted with several workshop participants to review the first meeting's outcomes and identify several key areas of analysis that could be performed to advance Minnesota's understanding of the role of energy storage. Among these were:

- Use case analysis of energy storage as an alternative to a new natural gas peaker
- A MISO-wide analysis to assess the role of energy storage in optimizing power system capital investments and operations
- An assessment of solar + storage as an strategy to help manage customer loads

The results of these analyses are presented in Section 4.

3.4 Workshop 2

Workshop 2 was used to review the outcomes from Workshop 1 and present the findings of the analysis and modeling conducted in the interim. Guest presentations were also made to share experience from California, both from the utility perspective and a customer participating behind-the-meter. Additionally, a Minnesota distribution cooperative (Connexus) provided an update on its ongoing efforts to procure a solar + storage project. The following provides a list of the presentations given:

- High Levels of Renewable Penetration in MISO (MISO)
- Minnesota Energy Storage: System Level Scenario Analysis (Vibrant Clean Energy)
- MN Energy Storage Use Case Analysis: Peaker Substitution (Strategen)
- Southern California Edison's Local Capacity Requirements RFO (Advanced Microgrid Solutions)
- Energy Storage Implementation (Irvine Ranch Water District)
- Energy Storage Use Case: Distribution Grid Interconnected Solar (Connexus)

Participants then discussed implications of the modeling work and identified potential actions that would strategically advance the deployment of energy storage in Minnesota, based on the information gleaned from the workshops. Participants also voted to prioritize action items. The top action items identified during each day of the workshop are listed below:

Day 1:

- Host a technical conference on energy storage.
- Encourage the PUC to direct an all-source procurement to include energy storage.
- Encourage MISO to develop and finalize rules and market products to accommodate energy storage.

- Encourage the PUC to clarify rules regarding utility cost recovery of energy storage investments.
- Encourage the PUC to direct energy storage pilot deployments to include a range of use cases of sufficient size to allow price discovery.
- Conduct an assessment to link storage to Minnesota’s system needs.
- Develop innovative retail rate designs that would support a greater deployment of energy storage.

Day 2:

- Conduct outreach and educate state policymakers (legislators, regulators, etc.) on energy storage.
- Engage large customers to identify potential project hosting opportunities.
- Host a summit/technical conference on energy storage for utility distribution engineers.
- Develop a joint proposal to file in the PUC’s Grid Mod Docket.
- Refine the existing Community Solar Gardens program to include energy storage to help serve peak demand.

A full list with more detailed descriptions of these action items is provided in the Appendices to this report. It’s important to note that the participants included a broad cross-sector of stakeholders who all weighed in on priorities. However, the process did not seek to reach a consensus position and this report does not specifically represent the views of any individual stakeholder.

4 Analysis of Energy Storage in Minnesota

4.1 Overview

In addition to interactive workshops, the University of Minnesota's Energy Transition Lab(ETL) collaborated with Strategen Consulting and Vibrant Clean Energy (VCE) to conduct specific use-case analyses and system modeling activities to gain a more detailed understanding of the potential role for energy storage in Minnesota, based on priorities set by stakeholders. Long-term system-level optimization modeling was performed by VCE while near-term cost-benefit analysis was performed by Strategen. Both efforts are described in greater detail in Sections 4.2 and 4.3.

4.2 System-Level Scenario Analysis of Energy Storage in Minnesota (VCE)

4.2.1 Study Scope and Background

Previous analyses, such as the 2014 MRITS Study, have demonstrated that integration of 40% renewable energy (and possibly 50% or higher) is technically feasible for Minnesota without the need for energy storage. Vibrant Clean Energy (VCE)'s analysis complements this work by investigating not whether energy storage is required, but rather if storage can help reduce power system costs over the long term as renewable penetration increases and GHG emissions are reduced.

To better understand this issue, VCE conducted an economic analysis of a wide range of future scenarios for the MISO power system, with a specific focus on energy storage in the Minnesota footprint. This study builds upon the "MISO high penetration renewable energy study for 2050," commissioned by MISO and completed by Vibrant Clean Energy, LLC (VCE). In the current project, VCE conducted a more detailed analysis with updated assumptions and an additional variable—storage. MISO also helped to advise this round of modeling.

4.2.2 Methodology and Key Assumptions

The analysis was performed using VCE's WIS:dom optimization model, which is a co-optimized, blended capacity expansion and hourly production cost model (a complete description of WIS:dom is provided in Appendix F). Production costs were modeled in hourly timesteps for each year, and capacity expansion was modeled in five-year increments over the 2017-2050 time horizon. Resource additions (including storage) were selected to minimize costs under various constraints (e.g. CO_2 emissions limits, transmission expansion, etc.).

For the present study, the WIS:dom optimization model was initialized for the MISO footprint, as depicted in Figure 5.

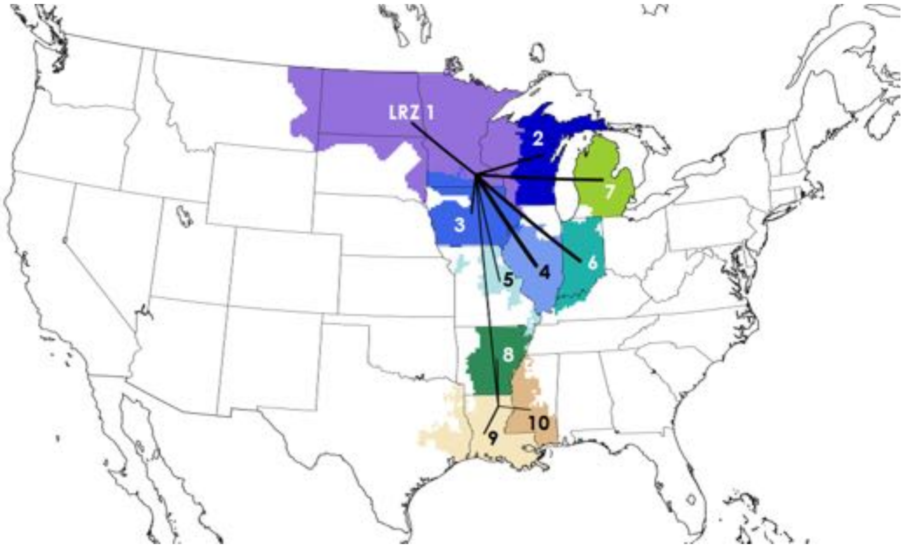


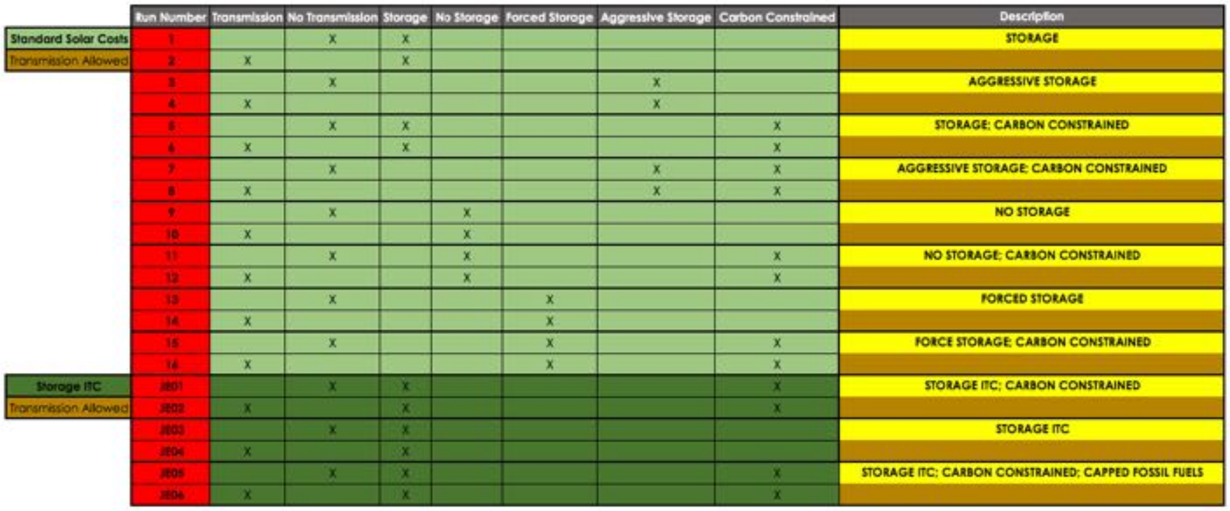
Figure 5. The geographic extent of the MISO footprint. The WIS:dom optimization model for the present study will only process data within the boundaries of LRZs 1-10. The black lines represent the high-voltage transmission links between the LRZs and the hubs.

Figure 5 shows that Minnesota resides mostly within LRZ 1, but its southwest region is within LRZ 3. WIS:dom is initialized with a set of existing generators and those in queue for meeting MISO needs, after which new generators are selected.

The present study considers the following generator technologies: Coal power plants, natural gas combined cycle turbines (NG CCGT), natural gas combustion turbines (NG CT), nuclear power plants, hydroelectric power plants, utility-scale wind turbines (80 m hub height), utility-scale solar photovoltaic (PV) [flat panel, tilted at latitude], solar PV rooftop, concentrated solar power (CSP), geothermal power plants, and utility-scale electric storage. For energy storage, deployment was focused in Minnesota (LRZ 1). Capital and operating cost assumptions for all resources are provided in Appendix F. Because the present study is centered on Minnesota, a more detailed assessment was made of the Minnesota wind and solar PV resource.

For the study, a total of twenty-two (22) sensitivities were performed. Each sensitivity includes eight (8) investment periods; in total, 176 co-optimizations are calculated and analyzed. Each of the 8 investment periods is tied to the previous and next investment period by retirements and additions made in the current investment period.

Key model outputs included the levelized cost of energy (LCOE), MW installed and MWh output of each resource type, and CO_2 emissions. Strategen provided inputs and assumptions for the future capital and operating costs of energy storage.



	Run Number	Transmission	No Transmission	Storage	No Storage	Forced Storage	Aggressive Storage	Carbon Constrained	Description
Standard Solar Costs	1		X	X					STORAGE
Transmission Allowed	2	X		X					
	3		X				X		AGGRESSIVE STORAGE
	4	X					X		
	5		X	X				X	STORAGE; CARBON CONSTRAINED
	6	X		X				X	
	7		X				X	X	AGGRESSIVE STORAGE; CARBON CONSTRAINED
	8	X					X	X	
	9		X		X				NO STORAGE
	10	X			X				
	11		X		X			X	NO STORAGE; CARBON CONSTRAINED
	12	X			X			X	
	13		X			X			FORCED STORAGE
	14	X				X			
	15		X			X		X	FORCE STORAGE; CARBON CONSTRAINED
	16	X				X		X	
Storage ITC	JE01		X	X				X	STORAGE ITC; CARBON CONSTRAINED
Transmission Allowed	JE02	X		X				X	
	JE03		X	X					STORAGE ITC
	JE04	X		X					
	JE05		X	X				X	STORAGE ITC; CARBON CONSTRAINED; CAPPED FOSSIL FUELS
	JE06	X		X				X	

Figure 6. All the completed scenarios for the present study for Minnesota within the MISO footprint.

Figure 6 indicates that half of the scenarios allow transmission while the other half do not. The "transmission allowed" represents scenarios where the transmission capacity between MISO Local Resource Zones (LRZ) can be increased from 2016 levels. Figure 6 identifies each specific scenario, their "run number," and their resource mixes and constraints.

For each of the 22 scenarios, the optimal, least-cost resource mix (including any emissions constrains or other limits) was determined using the WIS:dom model. Detailed results are described in Appendices H & I.

4.2.3 Summary of Key Findings

- Electric energy storage in Minnesota reduces the levelized cost of electricity (LCOE) throughout the MISO footprint and is always selected as an economic resource by 2045 when made available.
- MISO is capable of reducing GHG emissions by 80% by 2050 without storage; however, with storage as an option, LCOE can be reduced and less fossil fuel generation is required;
- Under a carbon-constrained scenario (80% reduction over 2005 levels by 2050), storage is selected as an economic resource sooner and in greater quantities. Under more optimistic assumptions (i.e. ITC for storage, carbon is constrained, fossil additions are capped) storage is selected in the 2030 timeframe.
- Applying the federal ITC to storage projects results in earlier storage adoption and a reduced LCOE.
- In general, more storage is selected in the transmission-expansion scenarios compared to the transmission-constrained scenarios (e.g., 1,800 MW versus 800 MW in 2050 under the base case) suggesting that transmission enables storage resources to be utilized more effectively (and vice versa).
- More solar PV is selected when storage is made available.

- The analysis also examined a carbon-constrained scenario in which a significant amount of storage (24 GW) was "forced" into the model in MISO Zone 1, which overlaps with Minnesota. On a MISO-wide basis the cost impact of this change was found to be small with an overall LCOE increase of less than 1%. However, in Zone 1, the LCOE did increase significantly due to capital costs of storage deployment.
- As it becomes economic, storage appears to compete with and displace gas combustion turbines (CTs). This is especially evident in the "forced" storage scenario.

4.3 Use Case Analysis: Storage as an Alternative to a Gas Peaker (Strategen)

4.3.1 Background and Purpose of Analysis

According to some recent projections, Minnesota's utilities have a need for new capacity resource additions to meet peak demand over the next decade. This is especially salient in light of the recently announced retirements of several coal-fired power plants. For example, Xcel Energy's Upper Midwest 2016-2030 Resource Plan (which includes the retirement of Sherco units 1 and 2), shows a capacity deficit beginning in 2024 and increasing to more than 3,000 MW by 2027. To meet this need, Xcel proposed a capacity expansion plan that includes over 1,600 MW of new natural gas combustion turbines (CTs) by 2030, in addition to wind and solar resources.[21] MISO similarly anticipates approximately 1,800 MW of CT additions in Minnesota by 2028 under its MTEP17 Existing Fleet Scenario.[22]

The analysis presented as part of the Minnesota Energy Storage Strategy Workshop examines an alternative set of technologies that could be used to meet Minnesota's peak demand needs in lieu of new natural gas fired CTs. While there are many potential supply-side and demand-side options for meeting capacity needs, this analysis focuses specifically on the potential role of energy storage, for which the total range of costs and benefits is often not fully considered within resource planning contexts.

Our analysis focuses not only on the costs and benefits of storage when compared to a CT, but also on the relative impact of storage on GHG emissions.

4.3.2 Overview of Approach

Generally speaking, this analysis compares the relative cost of building, owning, and operating an energy storage facility with the costs of an equivalent Megawatt capacity Combustion Turbine unit. In addition to standalone storage, a solar + storage facility was also considered as an alternative capacity resource.

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[21] Xcel Energy 2016-2030 Upper Midwest Resource Plan, Docket No. E002/RP-15-21 (Current Preferred Plan, filed Jan. 29, 2016), https://www.xcelenergy.com/staticfiles/xe/PDF/Regulatory/MN-Resource-Plan/MN-Resource-Plan-03-Supplement.pdf

[22] MISO MTEP17 Futures Siting, Planning Advisory Committee Meeting, 10-19-2016

The analysis takes a Societal Cost Test[23] approach to arrive at the total costs and benefits of each investment from a societal perspective for all Minnesotans. Analysis was performed using a custom Storage Resource Cost Calculator tool developed by Strategen, with inputs and assumptions customized for Minnesota and MISO where appropriate. The calculator tool includes a detailed pro forma for calculating the costs of generation and projected market benefits, as well as a dispatch module for estimating energy storage grid charging needs. Using the calculator tool, four preliminary scenarios were examined, plus one sensitivity case:

1. Storage Only – 2018
2. Storage Only – 2023

2a. Storage Only – 2023 (high peaker cost sensitivity)

3. Solar + Storage – 2018
4. Solar + Storage – 2023

In each scenario the storage system was compared to a new CT unit commencing operation in the same year. To capture the effects of rapidly changing storage technology costs, the analysis considered two future commencement dates.

- 2018: representing a near-term installation and reflecting today's technology costs
- 2023: representing a future case in which technology costs decline over the next five years

We compared the net cost of equivalently sized peaking resources, where net cost is equal to the net present value (NPV) of the facility's capital and operating costs, less any benefits derived from the sale of energy or ancillary services in the MISO wholesale market. For solar + storage, additional environmental benefits were also included, consistent with the Societal Cost Test approach. These environmental benefits were based on the environmental attributes estimated as part of Minnesota's Value of Solar tariff methodology. [24]

Cost categories:	Primary Benefit Categories:
• Capital Costs • Tax and Insurance • O&M Costs • Fuel or charging costs (incl. losses)	• Capacity (presumed equivalent for both resource types) • Ancillary services revenue • Energy sales revenue • Avoided environmental costs (solar)

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[23] The Societal Cost Test is one of the five standard cost-effectiveness tests used to evaluate incremental supply-side or demand-side energy resource investments. The test is often used to determine whether or not the state or society as a whole will be better off from the investment. The test generally takes a broad public interest perspective and often incorporates a wider set of benefits than the other cost-effectiveness tests.

[24] Environmental benefits based on Xcel Energy's Value of Solar update from its Sept 30, 2016 compliance filing in Docket No. E002/M-13-867.

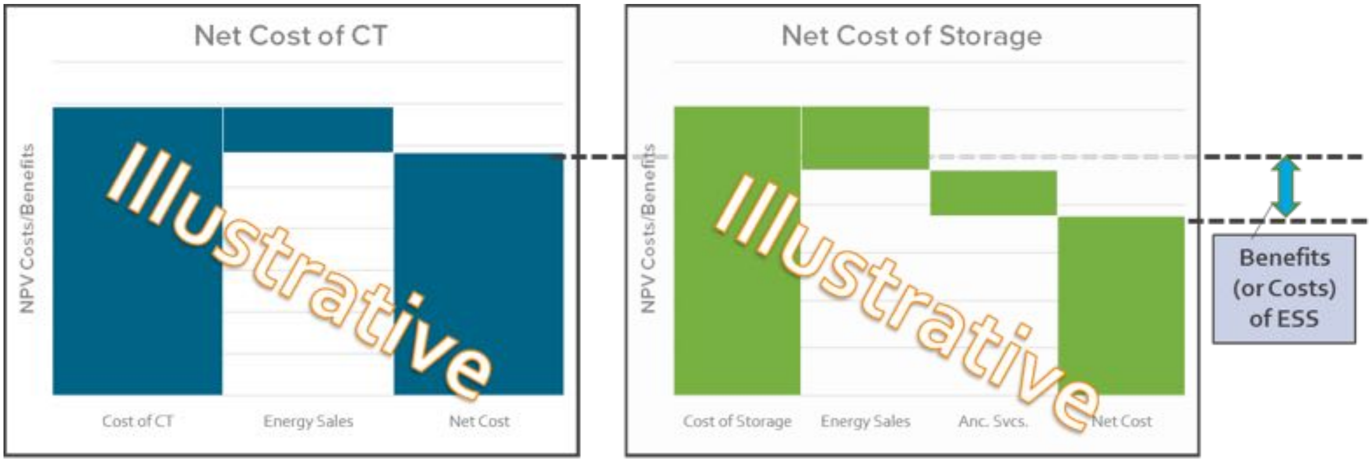

Figure 7. Framework for evaluating costs and benefits of energy storage

It should be noted that storage can provide operational benefits to the grid such as decreasing the number of starts of thermal facilities and reducing the curtailment of wind and solar. Past studies have attempted to quantify these operational benefits that could be derived from deployment of storage.[25] This should be further investigated in future analysis of storage deployment in MISO.

4.3.3 Key Inputs and Assumptions

4.3.3.1 Project Configurations and Lifetime

For comparison, a 100 MW-equivalent capacity of each resource type was considered.

- Combustion Turbine: 100 MW simple cycle advanced frame CT, with a 20-year project life
- Storage Only: 100 MW, 4-hr Li-ion battery energy storage system (BESS), with a 20-year project life
- Solar Plus Storage: 100 MW, 3-hr Li-ion battery energy storage system (BESS) coupled with a 50 MW solar PV system , with a 20-year project life

4.3.3.2 Capacity Value

Energy storage systems with 4-hour duration were assumed to be able to contribute to resource adequacy in MISO as a “Use Limited Resource.” MISO defines a Use Limited Resource as follows:

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[25] For example, see: *Operational Benefits of Meeting California’s Energy Storage Targets*, NREL 2015, http://www.nrel.gov/docs/fy16osti/65061.pdf

> "A Capacity Resource may be defined as a Use Limited Resource if it is capable of providing the energy equivalent of its claimed capacity for a minimum of 4 continuous hours each day across the Transmission Provider's peak."[26]

Thus, ESS resources with 4-hours duration were assumed to provide a capacity contribution comparable to a new natural gas combustion turbine (CT) in terms of serving resource adequacy in MISO. Additionally, we assumed a new storage resource's capacity value in Minnesota is comparable to the capacity value of a new CT built in the same year, rather than using other possible metrics or forecasts.[27]

Because solar PV output partially coincides with MISO peak hours, a smaller battery size was used in solar + storage scenarios (<4 hrs.). We estimate this would yield on-peak output during 90% of the 4-hour peak window. The size and cost of the equivalent CT unit used for comparison was derated accordingly (from 100 MW to 90 MW).

4.3.3.3 BESS Operations

To approximate the Battery Energy Storage System (BESS) operating as a peaking resource, we assumed its full storage capability (i.e. 100 MW) would be discharged during four peak hours, and charged during off-peak hours. Historically in MISO, peak hours have typically corresponded to hours ending (HE) 15 through HE 18 during summer months.[28] All other hours (~16 hours/day) were assumed to be available for the provision of ancillary services. An ancillary service dispatch profile was generated for a 100 MW storage facility in MISO using the Energy Storage Valuation Tool software package.[29] Each resource type is assumed to obtain wholesale market revenue for sales of energy and ancillary services as follows:

- *Energy*: Energy storage facilities are assumed to pay and receive the full locational marginal pricing (LMP) price for all MWh charged and discharged, while CTs receive the full LMP price for all MWhs generated.

- *Operating Reserves (Ancillary Services)*: ESS resources were assumed to receive a market award for one power or energy unit in any given time interval. The highest-value ancillary services product for ESS is Frequency Regulation (FR) and it is most advantageous to bid full battery capacity for FR (versus spin, non-spin, etc.). Dispatch for FR yields some additional cycling. The new CTs were not presumed to be dispatched for ancillary services.

4.3.3.4 BESS+PV Operations

A dispatch module was developed to anticipate how energy would be charged and discharged from the BESS+PV system. This module was used to estimate the portion of the BESS output that is charged using

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[26] MISO Market Training - Resource Adequacy https://www.misoenergy.org/_layouts/MISO/ECM/Redirect.aspx?ID=126470

[27] For example, we did not compare capacity value of new storage resources to recent or projected MISO capacity market prices in LRZ 1, which largely overlaps with Minnesota. Additionally, we did not discount the capacity value of storage resources to account for the fact that CTs built for capacity will not be needed for several years. Finally, we did not compare storage to other potential marginal capacity resources (e.g. demand response).

[28] MISO Historic Peak Load: https://www.misoenergy.org/_layouts/MISO/ECM/Redirect.aspx?ID=229498

[29] Energy Storage Valuation Tool is an energy storage simulation software tool developed by the Electric Power Research Institute (EPRI), https://www.epri.com/#/pages/product/000000003002000312/

energy from the grid. Grid charging helps to maximize output during peak summer hours on days when energy from solar PV may be insufficient. However, the amount of grid charging is limited to a certain amount of energy and during summer hours and the dispatch module takes into account round trip losses. Based on analysis of this dispatch module, the coupled BESS+PV system is sized and operated to ensure the following:

- Maximal output during summer peak hours (hours ending 15 through 18, June through Sept)
- At least 75% of charging energy is derived from coupled solar PV rather than from the grid (this is necessary for federal ITC eligibility)
- Excess energy produced by solar PV (i.e. when storage is fully charged) is exported to the grid

4.3.3.5 ESS Technology Cost Assumptions

Energy storage technology cost assumptions were selected by Strategen based on projected cost information collected from vendors and public information sources.[30] Using this information, Strategen estimated the installed cost for a 4-hour, 100 MW Li-ion battery storage system to be approximately $1600/kW for a 2018 commencement date. This represents the total all-in cost of the storage medium, power conversion system; engineering, procurement, and construction (EPC); replacements; and other ongoing and recurring costs. Table 1 shows that energy storage installed costs are estimated to improve to $1200/kW by 2023. Improvements are also anticipated in the fixed O&M costs and round trip efficiencies over time.

Table 1. Energy storage technology cost assumptions for the four scenarios.

Scenario:	Storage Only (2018)	Storage Only (2023)	Solar + Storage (2018)	Solar + Storage (2023)
Size/Duration	100 MW/ 4 hrs	100 MW/ 4 hrs	100 MW/ 3 hrs	100 MW/ 3hrs
Installed Cost (4-hrs)	$1600/kW	$1200/kW	$1335/kW	$1020/kW
Fixed O&M	$16/kW-yr	$14/kW-yr	$16/kW-yr	$14/kW-yr
Variable O&M	$4/MWh	$4/MWh	$4/MWh	$4/MWh
Round Trip Efficiency (incl. auxiliaries)	85%	90%	85%	90%

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[30] For example, see:
[1] EPRI (November 2016), Energy Storage Cost Summary for Utility Panning: Executive Summary;
[2]: Energy Storage Association (November 2016), Including Advanced Energy Storage in Integrated Resource planning: Cost Inputs and Modeling Approaches.

4.3.3.6 CT Technology Cost Assumptions:

A variety of different capital cost estimates were considered for the natural gas CT. The estimate of $829/kW used in this analysis is based on the MISO MTEP17 Future Summary.[31] This value is appreciably higher than values used in recent Minnesota capacity planning documents.[32, 33] A high peaker cost sensitivity case was also analyzed to examine a scenario in which more expensive aeroderivative CT units served as the marginal capacity resource.[34] This sort of unit appears to be increasingly common in some markets where more flexible capacity is needed (e.g., the western U.S.). However, MISO is at present a relatively flexible system, and there is little evidence to suggest it will require significant new flexible capacity in the near future.

Table 2. Combustion turbine technology cost assumptions for the four scenarios.

Scenario:	Storage Only (2018)	Storage Only (2023)	Solar + Storage (2018)	Solar + Storage (2023)
Installed Cost	$829/kW	Base Case: $829/kW Sensitivity: $1200/kW	$829/kW	$829/kW
Fixed O&M	$8.50/kW-yr	$8.50/kW-yr	$8.50/kW-yr	$8.50/kW-yr
Variable O&M	$2.30/MWh	$2.30/MWh	$2.30/MWh	$2.30/MWh
Capacity Factor	10%	10%	10%	10%
Heat Rate	9,750 BTU/kWh	Base Case: 9,750 BTU/kWh Sensitivity: 9,300 BTU/kWh	9,750 BTU/kWh	9,750 BTU/kWh

4.3.3.7 PV Assumptions

Solar PV cost estimates were derived from the NREL 2016 Annual Technology Baseline (Utility PV – Mid Case).[35] We also assumed the cost of the inverter installation and fixed O&M would be shared between

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[31] MISO Planning Advisory Committee, MTEP17 Futures Summary (October 2016). Note that this value is appreciably higher than values used in Xcel's 2016-2030 Resource p

[32] Xcel reports the cost of a large CT to be $754/kW (inclusive of transmission delivery costs). See Xcel Energy (October 2015), 2016-2030 Upper Midwest Resource Plan, Appendix J – Strategist Modeling and Outputs, Table 13.

[33] MISO CONE filing reports the CONE for an advanced CT unit to be $728/kW for LRZ 1. See MISO (September 2016), Filing of Midcontinent Independent System Operator, Inc. Regarding LRZ CONE Calculation; FERC Docket No. ER16-2662-000.

[34] Aeroderivative CT capital cost of $1200/kW based upon Energy & Environmental Economics, prepared for WECC (March 2014), Capital Cost Review of Power Generation technologies

[35] NREL (National Renewable Energy Laboratory). 2016. *2016 Annual Technology Baseline*. Golden, CO: National Renewable Energy Laboratory. http://www.nrel.gov/analysis/data_tech_baseline.html.

the PV and storage systems. Solar output was based upon a PV Watts simulation for a single-axis tracking array in St. Cloud, MN that produced a capacity factor of 18.7%.

Table 3. PV technology cost assumptions for the two solar + storage scenarios.

Scenario:	Solar + Storage (2018)	Solar + Storage (2023)
Size	50 MW	50 MW
Installed Cost	$1,608/kW	$1,213/kW
Capacity Factor	18.7%	18.7%

4.3.3.8 Market Price Assumptions

To estimate energy prices for charging storage, discharging storage, and CT output, we examined the MISO Minnesota Hub day-ahead LMP Prices for 2015. These historical hourly prices were applied to the hourly BESS dispatch profile. For year 1, this analysis yielded an average output price of $26.54/MWh and an average charging price of $14.41/MWh, (or about a ~$12/MWh differential). For CT output, we assumed a 10% capacity factor with an average output price based upon the 95th percentile of hourly values (about $39/MWh).

After year 1, we assumed that peak and off-peak prices increasingly diverge as new wind generation serves to continually reduce off-peak price below current levels (-1%/year), while rising natural gas prices increase peak energy prices (1%/year). As a result, we assume that the peak/off-peak price differential increases by 2%/year.

Table 4. Market price assumptions. The 2% annual increase in peak/off-peak energy price difference is a result of an assumed 1% annual decrease in off-peak prices and a 1% annual increase in peak energy prices.

Scenario:	2018 Scenarios	2023 Scenarios
Peak/Off-peak Energy Price Difference	$12/MWh (yr 1); 2% annual increase	$12/MWh (yr 1); 2% annual increase
Regulation Prices	$6/MW-hr (yr 1); 0% annual increase	$5/MW-hr (yr 1); 0% annual increase
Natural Gas Price	$4.11/MMBTU (yr 1) ~2% annual increase	$4.93/MMBTU (yr 1) ~2% annual increase

To estimate ancillary service prices, we examined recent reports of MISO ancillary service markets over the last several years.[36] Prices for regulation over a 13-month period from Sept 2015 through Sept 2016 ranged from $5.20 to $9.63 per MWh. In 2015, the average price was $6.89 per MWh, representing a decline from previous years. We project that this decline could persist as natural gas prices remain low

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[36] MISO September 2016 Monthly Market Assessment Report[37]EIA Annual Energy Outlook 2016, Reference Case (No Clean Power Plan)

and new hydro and storage capacity comes online. Thus, we assume regulation prices for storage of approximately $6/MWh in 2018 and $5/MWh in 2023, with no annual increase. We also note that the total amount of regulation that typically clears in MISO markets is approximately 400 MW. Thus, a hypothetical 100 MW storage project assumed in our analysis would theoretically be supplying 25% of the regulation market for MISO.

Natural gas fuel cost estimates used to determine CT operating costs were derived from the EIA 2016 Annual Energy Outlook reference case.[37]

4.3.3.9 Financing Assumptions

For storage-only resources, we assume investor-owned utility (IOU) ownership. Additionally, we assume that solar + storage is owned by independent power providers (IPP) and financed through a power purchase agreement (PPA). The capital structure that was assumed for the IOU-owned standalone storage is based on values for Xcel Energy and is shown in Table 5.[38]

Table 5. IOU-owned standalone storage financing assumptions. The capital structure is based on values for Xcel Energy.

IOU Capital Structure [1]	
Equity Share	52.6%
Debt Share	47.4%
Debt Cost	5.1%
Equity Return	9.9%

For solar + storage, the assumptions used for IPP financing are shown in Table 6.

Table 6. IPP solar + storage financing assumptions.

IPP Financing	
After-Tax WACC	7.5%
Equity Share	40%
Debt Cost	5.5%
Debt Period	10

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[37] EIA Annual Energy Outlook 2016, Reference Case (No Clean Power Plan)

[38] Based on Xcel Energy, 2016-2030 Upper Midwest Resource Plan, Appendix J – Strategist Modeling and Outputs, Table 13 (October 2015)

Table 7 summarizes other global financing assumptions used. A social discount rate of 3% was used in accordance with values typical for a Societal Cost Test.

Table 7. Other financing assumptions. The 3% social discount rate corresponds to typical values in a Societal Cost Test.

Other Assumptions	
Project Finance Term	20
MACRS Term (CT)	20
MACRS Term (ESS)	7
MACRS Term (ESS+PV)	5
Federal Tax Rate	35%
State Tax Rate (MN)	9.8%
Property Tax	1.5%
Insurance	0.5%
O&M Inflation	2%
Real Discount Rate (social)	3%

The table below indicates the federal investment tax credit (ITC) that was applied based on current law. For solar plus storage, dispatch is optimized to ensure 75% of charging energy comes from eligible renewable resources. The ITC was applied to the portion of the project's storage equipment costs that corresponds to the fraction of output energy that is charged directly from renewable resources (i.e. solar PV). For projects commencing in the 2023 timeframe, the 22% ITC applied assumes projects begin construction prior to December 31, 2021.

Year	Federal ITC [2]
2018	30%
2023	22%

4.3.3.10 CO_2 Emissions Assumptions

To determine the overall impact of an energy storage project on CO_2 emissions, it is necessary to project which energy resources will be on the margin during charging hours and what their emissions factors are. Though this is not possible to predict perfectly, we used recent MISO reports as a starting point for producing a marginal resource forecast. Based on MISO data, the frequency of total instances during off-peak hours (i.e. likely charging hours) when coal is on the margin in MISO's North region has ranged from 40% to 48% in recent years.[39] Meanwhile, wind has ranged from 40% to 43%, and gas has ranged

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[39] In some hours, more than one resource was reported to be on the margin due to transmission constraints. In these cases, each resource was counted as a separate instance.

from 4% to 16%. This means that a new storage project has roughly the same probability of increasing coal-fired generation during charging as it does of increasing wind generation. In addition to the MISO data, the EPA has compiled data on CO_2 emissions factors of fossil units in Minnesota by fuel type. We combined this EPA emissions data with marginal generation data from MISO to determine a weighted average for CO2 emissions factors for energy used to charge storage projects. This information is summarized in Table 8.

Table 8. CO_2 emissions factors for energy storage. The factors are calculated using MISO marginal generation data and EPA CO2 emissions data by fuel type in Minnesota.

Fuel Type	Marginal Resource Frequency (Off-Peak, MISO North) [1]			CO_2 Emissions Factor (lbs./MWh, based on EPA data for MN) [2]
	2014	2015	2016	
Coal	48%	40%	40%	2332
Gas	4%	14%	16%	877
Hydro	5%	3%	0%	0
Other	<1%	< 1%	<1%	1591
Wind	42%	43%	40%	0
2014 Weighted Average				**1159**
2015 Weighted Average	**--**	**--**		**1057**
Peaker (for comparison)	--	--		1141

In developing a forecast, we considered the fact that local transmission constraints are likely to play a key role in determining exactly which type of generation is on the margin and is used to charge energy storage projects. Over time, the frequency of wind generation on the margin may increase as new wind projects come online for which energy output cannot be fully delivered due to transmission constraints. However, the completion of new transmission projects will likely counteract this trend and lead to an increase of fossil generation on the margin (even as overall fossil generation declines). Additionally, the frequency of fossil generation on the margin will likely be affected by specific coal and nuclear unit retirements (e.g. Clay Boswell, Sherco) as well as the expected delivery of additional new hydro resources from Manitoba. To account for these effects, we assumed that the frequency of wind would gradually increase over time, displacing coal. Meanwhile, additional adjustments were made to account for discrete events such as the completion of new transmission projects or generator retirements as discussed above.

On average, we anticipate the average emissions factor for grid charging in Minnesota to begin at ~1,000 lbs./MWh and to decrease by approximately 5%/year over a 10-year period. This could be further impacted by software tools designed to optimize the timing of grid charging for energy storage.[40]

4.3.4 Limitations

While we made the best attempt to present information as accurately as possible, the analysis presented here has its own limitations described below.

- The net cost comparison is highly sensitive to future changes in technology costs and market prices, which are inherently uncertain.
- Lifetime emissions are highly sensitive to the marginal grid resources used for charging, which in turn is affected by future changes to the energy resource mix and transmission network in MISO.
- Certain potential benefit categories were not quantified (e.g. possible reduced unit starts, T&D deferrals, voltage support, etc.) since they are highly location-specific and require additional system modeling that was outside the scope of this analysis.
- In real-world demonstrations of utility-owned storage projects, frequency regulation has provided significantly lower value than modeled estimates.[41] Thus, our predicted value for ancillary services may overstate what can realistically be achieved.
- CT capital cost estimates used in this study are higher than those used by some Minnesota utilities (e.g. Xcel Energy). Utility-specific estimates should be considered in subsequent analyses.
- Environmental benefits included in solar + storage projects are highly contested and may be considered subjective.

In general, the results presented here are for discussion purposes and should be considered subject to further refinement and investigation as Minnesota develops its energy storage strategy.

4.3.5 Summary of Findings

4.3.5.1 Cost Benefit Analysis

The net cost for each scenario is summarized below. These results show that the costs of a new energy storage project exceeded the avoided cost of a new CT unit (i.e. the benefit to cost ratio is less than 1.0) in the Storage Only 2018 scenario. Meanwhile, the avoided costs of a new CT unit exceeded the cost of new storage project (i.e. the B/C ratio is >1.0) in each other scenario. This suggests that standalone energy storage may not be cost effective in the near term (i.e. in the 2018 timeframe), but may become cost effective in the 2023 timeframe as technology costs improve. Additionally, energy storage may

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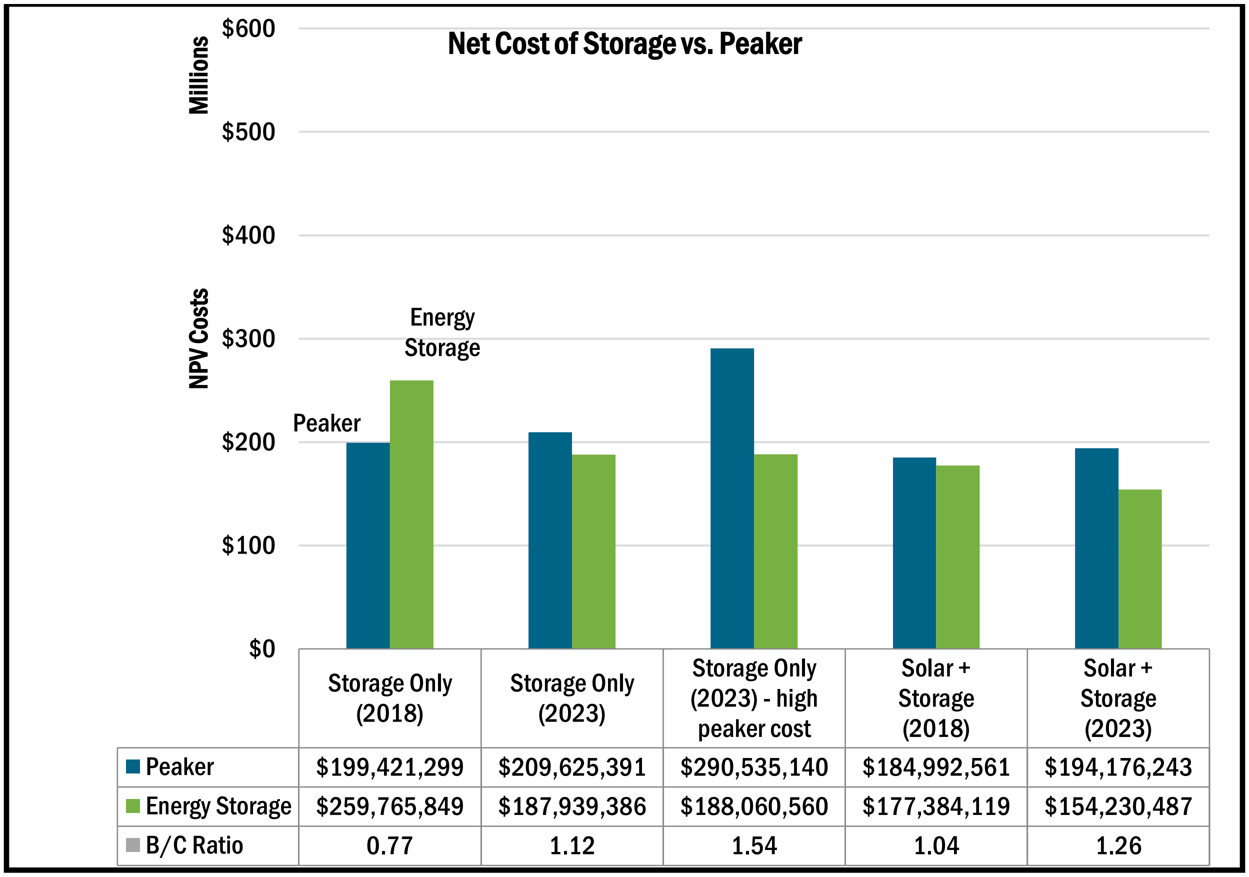
[40] For example, see WattTime http://watttime.org/

[41] See for example: https://www.pge.com/pge_global/common/pdfs/about-pge/environment/what-we-are-doing/electric-program-investment-charge/PGE-EPIC-Project-1.01.pdf

become cost effective sooner if additional benefit streams can be captured (e.g. T&D deferral) or if the cost of peaker units increases substantially.



	Storage Only (2018)	Storage Only (2023)	Storage Only (2023) - high peaker cost	Solar + Storage (2018)	Solar + Storage (2023)
🟦 Peaker	$199,421,299	$209,625,391	$290,535,140	$184,992,561	$194,176,243
🟩 Energy Storage	$259,765,849	$187,939,386	$188,060,560	$177,384,119	$154,230,487
■ B/C Ratio	0.77	1.12	1.54	1.04	1.26

Figure 8. Summary results for cost comparison of energy storage to natural gas peaker. Storage projects are cost-effective in all scenarios with the exception of the 2018 standalone storage scenario.

A breakdown of costs and benefits is provided for each scenario in Table 9.

Table 9. Breakdown of costs and benefits of each use case scenario that was analyzed. Storage projects are cost-effective in all scenarios with the exception of the 2018 standalone storage scenario. Costs of individual storage projects are compared to costs of comparable gas-fired peakers.

Scenario: ($ millions)	Storage Only (2018)	Storage Only (2023)	Storage Only (2023) - high peaker cost	Solar + Storage (2018)	Solar + Storage (2023)
Cost of Storage	$ 385	$ 304	$ 304	$ 310	$ 280
Energy Sales	$ (67)	$ (67)	$ (67)	$ (45)	$ (47)
Anc. Svcs.	$ (59)	$ (49)	$ (49)	$ (59)	$ (49)
Env. Benefit	$ -	$ -	$ -	$ (29)	$ (31)
Net Cost, Storage	**$ 260**	**$ 188**	**$ 188**	**$ 177**	**$ 154**
Cost of CT	$ 253	$ 266	$ 347	$ 233	$ 245
Energy Sales	$ (53)	$ (56)	$ (56)	$ (48)	$ (50)
Net Cost, CT	**$ 199**	**$ 210**	**$ 291**	**$ 185**	**$ 194**
Net Benefits **(Net Cost of CT avoided less Net Cost of Storage)**	**$ (60)**	**$ 22**	**$ 102**	**$ 8**	**$ 40**
B/C Ratio	**0.77**	**1.12**	**1.54**	**1.04**	**1.26**

4.3.5.2 CO$_2$ Emissions Analysis

The chart below summarizes the findings for the lifetime impact a storage project would have on CO$_2$ emissions under each scenario. [42] The results suggest that a standalone storage unit built in the near term may lead to an overall increased lifetime CO$_2$ emissions relative to a new CT. This is due to the significant amount of energy that is likely to be charged from coal-fired generation in the near term.

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[42] We define lifetime emissions as the total CO2 emissions generated over the full 20-year lifetime of the project under our assumed operating conditions and accounting for the marginal resource forecast described herein. [43] For example, by 2028 up to 1,800 MW of new peaker capacity additions in Minnesota are projected by MISO in the MTEP17 Futures Siting, as reported in the Planning Advisory Committee meeting, 10-19-2016.

However, over time as wind penetration increases, new storage projects may eventually be in a position to decrease lifetime CO_2 emissions. We note that these impacts may differ if storage projects are built in locations where wind generation is transmission constrained. Meanwhile, solar plus storage projects have a significant advantage in terms of lifetime CO_2 emissions compared to a peaker both in the near term and in the short term. This is because the solar component of the project produces energy that is likely to displace fossil emissions during some hours.

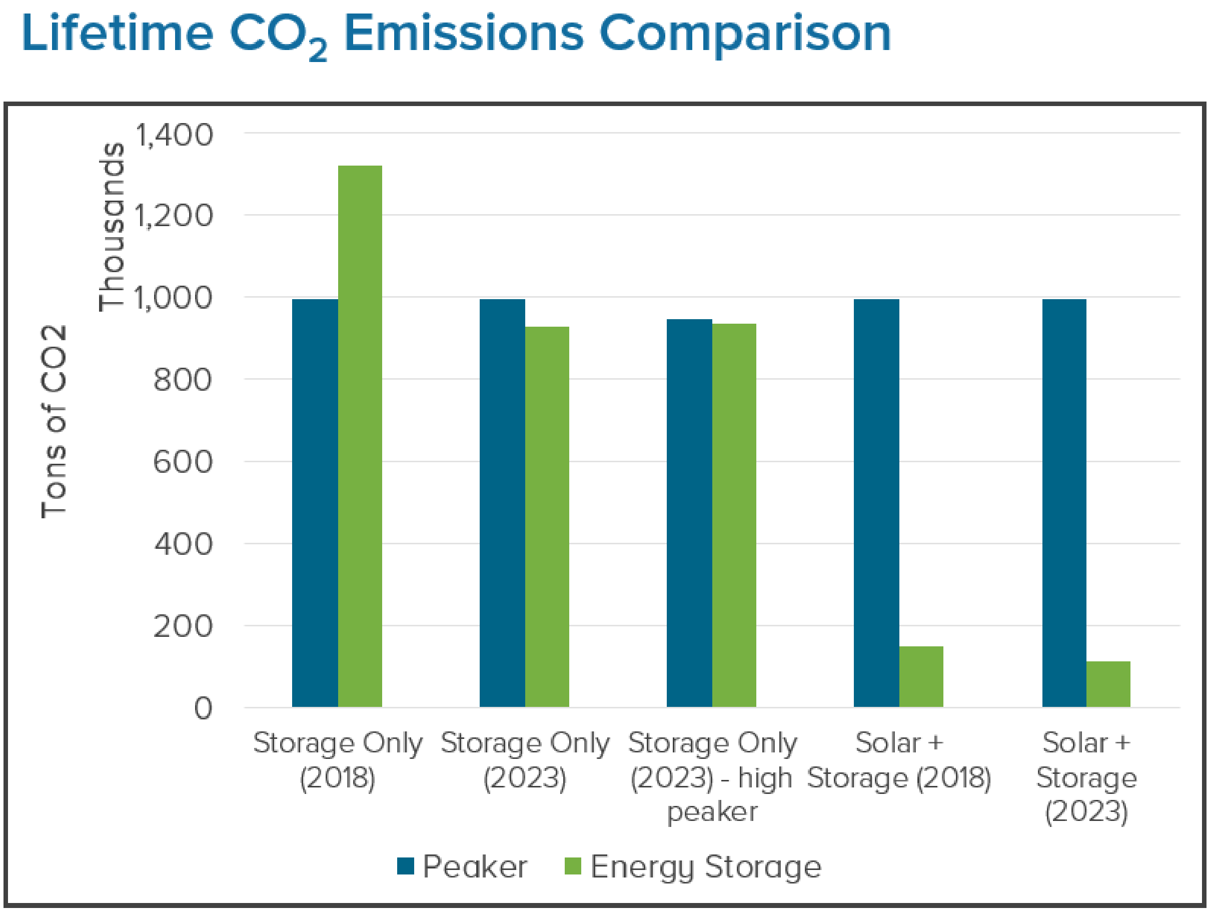

Figure 9. Summary results of lifetime CO_2 emissions for use case scenarios analyzed. Storage projects produce less lifetime CO_2 emissions in all scenarios with the exception of the storage-only project in 2018.

4.3.5.3 Overview of Findings

The following summarizes our findings from the peaker versus storage analysis.

- Standalone energy storage may not be cost competitive versus a new CT in the near term (2018) for MN.
- Standalone energy storage may become cost competitive within the next 5 years provided that storage technology costs decline as anticipated. This could occur sooner if:

  - Additional locational benefits (e.g. T&D deferral, etc.) can be captured
  - CT costs increase due to a need for more flexible unit types
- A coupled energy storage + solar resource may be cost-effective both in the near term (2018) and long-term (2023) provided that:
  - The federal investment tax credit (ITC) is fully leveraged
  - Environmental benefits are considered
- Both standalone storage and solar + storage have the potential to reduce emissions relative to a CT:
  - Solar + storage is significantly more effective at reducing emissions
  - The relative emissions impact of standalone storage can improve over time if the frequency of wind “on the margin” increases

5 Case Study: Solar + Storage for Minnesota's Electric Coops (Connexus)

Minnesota has forty-four (44) electric distribution cooperatives, of which the largest is Connexus. For twenty-eight (28) of these coops, including Connexus, generation and transmission service is provided by Great River Energy (GRE) through power purchase contracts. While specific details of these contracts are confidential, monthly rates are based on two key components: 1) coincident demand charges for capacity and transmission and 2) energy charges for on-peak and off-peak consumption. Thus, there is a strong incentive for individual coops to encourage their members to reduce both coincident demand and on-peak energy consumption.

Most of GRE's energy is supplied from coal-fired power plants, however GRE does offer its member coops a 5% renewable energy option, allowing it to build or purchase renewable energy interconnected to the coop's distribution system. In 2016, Connexus conducted a survey of its members and found that a majority were willing to pay up to 5% more for efforts to reduce greenhouse gas emissions and increase renewable energy.

Key Project Details (as currently anticipated)

- 10 MW solar PV ($11-13M)
- 20 MW, 2 hr Li-ion battery ($40-44M)
- 50-60 acres of land ($4-6M, plus contingency)
- ~$60 M total project cost
- $4-6 M annual power supply savings:
    - $3-4.5M storage
    - $1M solar
    - $100K energy arbitrage

The combination of these two drivers – the desire to increase renewable energy and the desire to reduce peak demand charges -- led Connexus to explore the procurement of a solar plus storage facility that could accomplish both goals.

While solar provides clean energy that partly coincides with the Connexus' peak demand, it is not a perfect match. Thus, the inclusion of storage helps to carry energy output through the early evening hours to maximize reductions in peak demand. This in turn maximizes the savings that Connexus can achieve for its members. Additionally, it was determined that a centrally owned facility would help take advantage of certain economies of scale that might not be available for facilities located at a customer's premises. This includes the substantial benefits available through the Federal Investment Tax Credit, which can apply to a storage facility that is co-located with and charged by solar PV.

Finally, it was recognized that the value of the storage facility could evolve over time as the needs on Connexus' system change. Eventually the storage's dispatch may change to include other possible benefits such as distribution upgrade deferral.

Currently Connexus is in the process of issuing a Request for Proposals for developers to develop a project. However, the current expectation is that a 10 MW solar PV with 40 MWh of energy storage could accomplish its goals and could be built for approximately $60 million. Connexus anticipates that a project of this size would be able to achieve power supply savings of $4-6 million annually. This is primarily the result of reduced demand from the solar and storage facilities. However, it also includes a small amount of energy arbitrage (~$100,000).

One key challenge is identifying a suitable location to site the project. A key criterion was the need to supply power only to Connexus’ distribution system and not export to the MISO transmission system. Thus, the project had to be sited in an area with sufficient load to accommodate its output. This could be a challenge for some co-ops in more sparsely populated areas.

6 Discussion and Conclusions

6.1 Long-term Implications

The system analysis performed suggests that storage can be a useful addition to Minnesota's energy planning toolkit to help it achieve its long-term renewable energy and GHG goals. For example, although MISO is capable of reducing GHG emissions 80% by 2050 without energy storage, it was found that including storage could reduce both the levelized cost of electricity (LCOE) in MISO and the amount of fossil fuel generation required, with the balance being made up by low-cost renewable energy additions. By 2045, and possibly sooner, energy storage is very likely to be a cost-effective addition to MISO's energy mix.

In general, several headwinds stand in the way of greater economic deployment of energy storage in Minnesota. These include:

- Relatively low differential between on-peak and off-peak wholesale energy prices in Minnesota
- Low wholesale capacity prices in Minnesota's Load Resource Zones and uncertainty regarding ability for Minnesota utilities to claim MISO capacity credit for storage resources
- Relatively low prices and small market size for ancillary services in MISO
- Very inexpensive capital costs for traditional capacity resources such as natural gas peakers (e.g. advanced frame combustion turbines)
- High degree of existing flexibility within MISO and surrounding control areas, enabling substantial integration of new renewable resources
- Lack of retail rate options that support customer-sided deployment of energy storage technologies
- High frequency of fossil generation on the margin, thereby diminishing the environmental benefits of grid-charged storage.
- Lack of stronger policies to alleviate GHG emissions (e.g. emissions reduction requirements)

6.2 Near Term Opportunities

Despite these factors, a detailed use-case analysis reveals that utility-scale energy storage is an increasingly cost-competitive alternative to traditional capacity resources such as natural gas peakers. While standalone storage may not be cost effective compared to a new peaker today, technology costs are changing rapidly and could lead standalone storage projects to be cost-effective within a 5-year timeframe. This timeframe appears to nearly match Minnesota's anticipated needs for new capacity resources as forecasted by some utilities. Additionally, if environmental benefits are considered, and the federal ITC is applied, then solar plus storage facilities could even be a cost-effective option today. The current viability of solar plus storage in Minnesota is readily apparent by Connexus' ongoing efforts to procure such a facility for the benefit of its cooperative members.

Given the timing of resource needs[43] and growing competitiveness of storage, we believe that it's appropriate for Minnesota utilities and regulators to immediately begin incorporating energy storage technologies into the tools and models (e.g. Strategist) used to assess resource planning decisions. If these tools and models cannot adequately incorporate storage today, then alternatives or workarounds should be developed quickly.

Finally, even if certain applications of energy storage are found not to be strictly cost-effective under current assumptions, workshop participants believe there is significant value gained from direct experience with storage deployment and operation. Such experience or "learning by doing" can have the effect of lowering soft-costs and will ultimately drive towards greater cost effectiveness and aid market transformation for storage technologies. Additionally, experience will better prepare market participants for a possible near-term future in which storage deployment is a more widespread and cost-effective option compared to traditional alternatives. Minnesota's experience with renewable energy reflects this pattern well. When Minnesota began incenting and requiring initial amounts of wind energy production, it was still considered higher cost than fossil resources. That long-term vision and investment proved beneficial, as Minnesota became a market leader in renewable energy, enjoying significant cost reductions and carbon reductions for Minnesota residents.

Adequate experience is most likely accomplished through medium scale pilot projects using competitive solicitations (i.e. larger than a typical pilot, perhaps in the 20-50 MW range). This would be of sufficient size to attract industry attention, contribute to robust price discovery, and provide meaningful operational experience. An immediate focus on solar + storage facilities is warranted given the significant benefit and time-limited availability of the federal investment tax credit.

There are several existing venues at the PUC to consider such a procurement: the grid modernization proceeding, integrated resource planning process, and the community solar garden program (i.e. through a solar + storage deployment). Workshop participants are aware of the potential risks and concerns of directing ratepayer funds towards a project of this scale. However, due to the substantial learnings that would come from such a project, it may well be a worthwhile investment in order to better position Minnesota for achieving lower energy costs from energy storage in the future, and maintaining the state's leadership in the clean energy economy.

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[43] For example, by 2028 up to 1,800 MW of new peaker capacity additions in Minnesota are projected by MISO in the MTEP17 Futures Siting, as reported in the Planning Advisory Committee meeting, 10-19-2016.

7 Next Steps and Recommendations

Based on the system level modeling and individual resource cost effectiveness modeling, and in the spirit of 'learning by doing', the stakeholder group identified a series of actions that could be undertaken in MN to further advance energy storage as a viable option in MN's electric power sector planning toolkit.

1. Host a utility-focused **technical conference** (or series of conferences) to advance thinking on energy storage to support planning, grid operations, interconnection, measurement and verification and utility training. This conference could also address at a high level alternative contracting mechanisms, including those for utility-owned, third party-owned and aggregated solutions. Recommended leaders for this effort include MESA, Minnesota utilities and the PUC.
2. Identify and clarify potential utility **cost recovery mechanisms** for energy storage investments. This is critical, as cost recovery risk is a key barrier preventing investor owned utilities from investing in energy storage projects. At the same time, criteria should be established for qualifying pilot projects. Recommended lead for this effort: PUC
3. Work with utilities to develop and propose an **energy storage pilot project** to the PUC with broad stakeholder support. A necessary component of this type of proposal would be an agreed-upon mechanism for cost recovery to be approved by the PUC.[44] The steps would include the following:
    a. Identify particular system needs and locations that could be effectively met with energy storage.
    b. Propose a commercial scale Minnesota energy storage procurement to achieve progress on demonstrating energy storage as a viable alternative to new gas peakers or other appropriate use cases. Such a procurement would help achieve current price-discovery and help identify best practices for storage project development (e.g. planning, siting, contracting, interconnection, permitting, etc.).
    c. Conduct research and analysis of power control systems, operational integration, economic performance, and other areas of learning, making them explicit goals of these initial pilot projects, with an outcome of University and other expert partner white papers. These additional research objectives could be optional if they are found to be cost prohibitive.
4. Because of the superior cost effectiveness and lower GHG emissions, solar + storage should be prioritized near term. For example, the PUC could authorize 20 MW of utility owned and 20MW

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[44] An example would be the Colorado Public Utilities Commission ICT (Innovative Clean Technology) mechanism, which gives a "presumption of prudence" of the costs in the next rate case. Colorado PUC Decision No. C09-0889, Docket No. 09A-015E (2009).

of third party owned (either centralized or aggregated behind the meter) energy storage and or energy storage + solar procurement pilots, to complement learning from impending Connexus' solar + storage procurement underway. Engaging in a commercially significant pilot will shed light on key implementation barriers and issues very efficiently. Recommended lead for this effort: PUC and MN utilities

5. Direct future capacity additions to be conducted through technology neutral **all-source procurements.** This would specify the need in terms of its capabilities, rather than its technology or generation type, and allow all resource types (including energy storage and energy storage + solar, as well as other technologies) to participate. The process and methodology for evaluating the all-source procurement should be established well in advance of its implementation. Recommended lead: Utilities; PUC
6. **Update modeling tools** used in integrated resource planning process (i.e. Strategist) to allow for appropriate treatment and evaluation of energy storage as a potential resource.
7. Craft **MISO rules**, processes and products for energy storage participation. This should encompass not only standalone energy storage, but also behind the meter aggregated energy storage solutions as well storage coupled with wind and solar. Recommended lead for this effort: MISO
8. Develop innovative retail rate designs that would support a greater deployment of energy storage. Recommended lead: utilities; PUC.
9. Conduct an assessment to link storage to Minnesota's **system needs**.
10. Lead a **study tour** of Minnesota stakeholders to existing grid connected and customer-sited energy storage installations. Recommended lead: UMN Energy Transition Lab and MESA
11. Conduct outreach and **education for state policymakers**. This could include meetings with both state legislators and regulators. Ideally would include development of a short handout to summarize use cases and benefits of storage for MN. Recommended lead: MESA
12. Engage large customers to **identify potential project hosting opportunities**. Stakeholders would approach large potential host sites (e.g. large commercial and industrial customers, distribution centers, etc.) to identify value proposition. Recommended leads: MESA; MN Sustainable Growth Coalition.
13. Refine the existing **Community Solar Gardens program** to include a peak time option for energy storage. This would create a minor modification to existing program structure and methodology to allow for a solar plus storage option (credit rate calculation would simply reflect additional value of storage). Recommended lead: MESA, AG's Office.

Other recommendations highly rated by workshop attendees included innovative rate designs to allow customers to access storage benefits; system analysis to identify high-impact locations for storage system benefits; and develop utility cost recovery models to enable prudent storage investment.

8 Appendices

Appendix A – Workshop Attendees

Appendix B – Meeting Agendas

Appendix C – Minnesota Energy Landscape (UMN Energy Transition Lab)

Appendix D – Global Trends in Energy Storage (Strategen Consulting)

Appendix E – Energy Storage 101 (Strategen Consulting)

Appendix F – WIS:dom Model Description and Input Assumptions (Vibrant Clean Energy)

Appendix G – Use Case Analysis of Storage as a Peaker Alternative in Minnesota (Strategen Consulting)

Appendix H - System Level Scenario Analysis of Minnesota Energy Storage: Interim Results (Vibrant Clean Energy)

Appendix I - System Level Scenario Analysis of Minnesota Energy Storage: Final Results (Vibrant Clean Energy)

Appendix J – Energy Storage Use Case: Distribution Grid Interconnected Solar (Connexus)

Appendix K – Additional Workshop Presentations

Appendix L – Workshop Action Items

9 Appendix A – Workshop Attendees

Workshop 1

Name	Title	Organization
Mark Ahlstrom	Vice President, Renewable Energy Policy	NextEra Energy Resources, WindLogics
Ellen Anderson	Executive Director	Energy Transition Lab
Christine Andrews	Energy Storage Project Manager	Energy Transition Lab
Brent Bergland	General Manager	Mortenson Construction
Matthew Blackler	Co-founder/CEO	Power Over Time/ZEF Energy
David Boyd	VP of Government & Regulatory Affairs	MISO
Mike Bull	Director of Policy and Communications	Center for Energy and Environment
Edward Burgess	Manager	Strategen
Megan Butler	Graduate Research Assistant	Energy Transition Lab
Aakash Chandarana	Regional Vice President, Rates and Regulatory Affairs	Xcel Energy
Cedric Christensen	Director	Strategen
Brian Draxten	Manager, Resource Planning	Otter Tail Power
John Frederick	Consultant, and former CEO	Silent Power
Allen Gleckner	Director, Energy Markets	Fresh Energy
Bill Grant	Deputy Commissioner of Energy and Telecommunications	Minnesota Department of Commerce
Lon Huber	Director	Strategen
Barb Jacobs	Committee Administrator	Senate Environment and Energy Committee
Ralph Jacobson	CEO	IPS Solar
Robert Jagusch	Director of Engineering and Policy Analysis	Minnesota Municipal Utilities Assoc.
Praveen Kathpal	Vice President	AES Energy Storage
Rao Konidena	Principal Advisor, Policy Studies	MISO
Kiran Kumaraswamy	Director, Market Development	AES Energy Storage
Janice Lin	Co-Founder and Managing Partner	Strategen

Dan Lipschultz	Commissioner	Minnesota Public Utilities Commission
Graham Morin	Energy Storage Account Management	GE
Minh Nguyen	Business Development Manager	Enel Green Power North America
Rolf Nordstrom	CEO	Great Plains Institute
Hari Osofsky	Law Professor and Faculty Director	Energy Transition Lab
Julie Pierce	Manager, Resource Planning	Minnesota Power
Jeffrey Plew	Project Director-Energy Storage Development	NextEra Energy Resources
Randall Porter	Vice President, Transmission	Geronimo Energy
Matt Prorok	Policy Associate	Great Plains Institute
Phyllis Reha	Consultant	PAR Energy Solutions
Greg Ridderbusch	CEO	Connexus Energy
Ryan Rogers	Strategy & Business Development Manager, Renewable Energy Division	3M
Laureen Ross McCalib	Manger of Resource Planning and Regulatory Affairs	Great River Energy
Matt Schuerger	Commissioner	Minnesota Public Utilities Commission
Bria Shea	Regulatory Manager	Xcel Energy
Ken Smith	CEO	Evergreen Energy/St. Paul District Energy
Beth Soholt	Executive Director	Wind on the Wires
Sean Stalpes	Economic Analyst	Minnesota Public Utilities Commission
Lise Trudeau	Engineer, Renewable Energy and Advanced Technologies	Minnesota Department of Commerce
Chris Villarreal	Policy Director	Minnesota Public Utilities Commission
Julie Voeck	Director, Legislative and Regulatory Affairs	NextEra Energy Resources

Workshop 2

Name	Title	Organization
Ellen Anderson	Executive Director	Energy Transition Lab
Christine Andrews	Energy Storage Project Manager	UMN Energy Transition Lab
Jordan Bakke	Policy Studies Lead	MISO
Brent Bergland	General Manager	Mortenson Construction
Jesse Bryson	Vice President, Global Market Development	Advanced Microgrid Systems
Brian Burandt	Vice President, Power Supply	Connexus Energy
Ed Burgess	Senior Manager	Strategen Consulting

Carmen Carruthers	Outreach Director	Citizens Utility Board Minnesota
Chris Clack (via phone)	Founder	Vibrant Clean Energy
Amanda Clementson	Lead Program Manager, Energy and Sustainability	Target
Sarah Cron	Marketing Manager	Co-op Light & Power
Leigh Currie	Energy Program Director	Minnesota Center for Environmental Advocacy
Allen Gleckner	Director, Energy Markets	Fresh Energy
Bill Grant	Deputy Commissioner, Energy & Telecommunications	Minnesota Dept. of Commerce
Lon Huber	Director	Strategen Consulting
Barb Jacobs		
Ralph Jacobson	Senior Manager	Innovative Power Systems, Inc.
Rao Konidena	Principal Advisor, Policy Studies	MISO
Kiran Kumaraswamy	Director, Market Development	AES Energy Storage
Janice Lin	Co-Founder and Managing Partner	Strategen Consulting
Graham Morin	Energy Storage Account Management	General Electric
Seth Mullendore	Project Director	Clean Energy Group
Ron Nelson	Economist	MN Dept. of the Attorney General
Rolf Nordstrom	President & CEO	Great Plains Institute
Hari Osofsky	Robins Kaplan Prof, and Faculty Director Energy Transition Lab	University of Minnesota Law School
Rhonda Peters	Principal, InterTran Energy Consulting	Technical Consultant, Wind on the Wires
Jeffrey Plew	Project Director, Energy Storage Development	NextEra
Bob Sandberg	VP of Power Supply and Business Development	Wright Hennepin Electric
Matt Schuerger	Commissioner	MN Public Utilities Commission
Curtis Seymour	Program Director, Power	Energy Foundation
Chris Shaw	Principal Rate Analyst	Xcel Energy
Patrick Sheilds	Executive Director, Operations	Irvine Ranch Water District
Lise Trudeau	Engineer, Renewable Energy and Advanced Technologies	MN Dept. of Commerce
John Tuma	Commissioner	MN Public Utilities Commission
Dinner Speakers: ● Sen. David Senjem ● Rep. Melissa Hortman		

10 Appendix B – Meeting Agendas

Minnesota Energy Storage Strategy Workshop (1st Meeting, Friday, September 23rd, 2016) – Agenda

Start	*Stop*	*Agenda Item*	*Led By*
9:00 am	9:15 am	Breakfast Available	--
9:15 am	10:10 am	Welcome and Introductions	Ellen Anderson (University of Minnesota)
10:10 am	10:25 am	Group Discussion: Workshop Objectives, Context, and Ground Rules	Janice Lin (Strategen Consulting)
10:25 am	10:45 am	Presentation: Global Trends in Energy Storage	Lon Huber (Strategen Consulting) Ed Burgess (Strategen Consulting)
10:45 am	11:00 am	Break	--
11:00 am	11:30 pm	Presentation: Current MN Energy Landscape	Christine Andrews (UMn Energy Transition Lab)
11:30 pm	12:00 pm	Group Discussion: MN Challenges and Issues	Janice Lin (Strategen Consulting)
12:00 pm	1:00 pm	Lunch	--
1:00 am	1:30 pm	Presentation: Energy Storage 101	Lon Huber (Strategen Consulting) Ed Burgess (Strategen Consulting)
1:30 pm	2:30 pm	Presentations: Energy Storage Case Studies	Kiran Kumaraswamy (AES) Graham Morin (GE) Jeffrey Plew (NextEra)
2:30 pm	3:00 pm	Group Discussion: Brainstorm applications of storage to address MN challenges	Janice Lin (Strategen Consulting)
3:00 pm	3:15 pm	Break	--
3:15 pm	4:00 pm	Break-out Discussions: Brainstorm future storage scenarios for MN	Janice Lin (Strategen Consulting)
4:00 pm	4:30 pm	Next Steps & Preparation for Future Meetings	Janice Lin (Strategen) Ellen Anderson (UMn)
4:30 pm	5:30 pm	Reception	--

Minnesota Energy Storage Strategy Workshop (2nd Meeting) - Agenda

Day 1: January 10th 2017			
Start	***Stop***	***Agenda Item***	***Led By***
8:00 am	9:00 am	Breakfast Available	--
9:00 am	9:50 am	Welcome and Introductions; Workshop Objectives	Ellen Anderson (University of Minnesota) Curtis Seymour (Energy Foundation)
9:50 am	10:00 am	Workshop Ground Rules	Janice Lin (Strategen Consulting)
10:00 am	10:30 am	Recap of Meeting #1 and work conducted since	Ellen Anderson
10:30 am	10:45 am	Break	--
10:45 am	11:45 am	System Benefits Analysis Results and Discussion	Jordan Bakke (MISO) and Chris Clack (Vibrant Clean Energy)
11:45 am	1:00 pm	Lunch	--
1:00 pm	2:00 pm	Peaker Substitution Implementation Guest Speaker	Jesse Bryson (AMS, formerly Southern California Edison) and Patrick Shields (Irvine Ranch Water District)
2:00 pm	3:00 pm	Application 1: Peaker Substitution Cost Effectiveness Analysis for MN	Ed Burgess (Strategen Consulting) and Janice Lin
3:00 pm	3:15pm	Break	--
3:15 pm	4:15 pm	Discussion: What can this mean for MN? Planning and Implementation Challenges and Solutions	Ellen Anderson and Janice Lin
4:15 pm	5:00 pm	Reflection from participants on Day 1	All
5:00 pm	5:15 pm	Meeting close and what to expect on Day 2	Ellen Anderson

5:30 pm		Reception and Dinner	Guest Speakers: Senator David Senjem (MN Senate) and Representative Melissa Hortman (MN House of Representatives)

Day 2: January 11th 2017

Start	***Stop***	***Agenda Item***	***Led By***
8:00 am	9:00 am	Breakfast Available	--
9:00 am	9:30 am	Recap of Day 1	Ellen Anderson
9:30 am	10:30 am	Application 2: Solar + storage for a distribution cooperative	Brian Burandt (Connexus) and Ed Burgess
10:30 am	10:45 am	Break	--
10:45 am	11:45 am	Discussion: What can this mean for MN? Planning and Implementation Challenges and Solutions.	Ellen Anderson and Janice Lin
11:45 am	12:30 pm	Reflection from participants on Day 2	All
12:30 pm	2:00 pm	Closing Remarks (15 min) followed by Grab Bag Lunch	Ellen Anderson

11 Appendix C – Minnesota Energy Landscape (UMN Energy Transition Lab)

Minnesota Energy Landscape

Energy Transition Lab

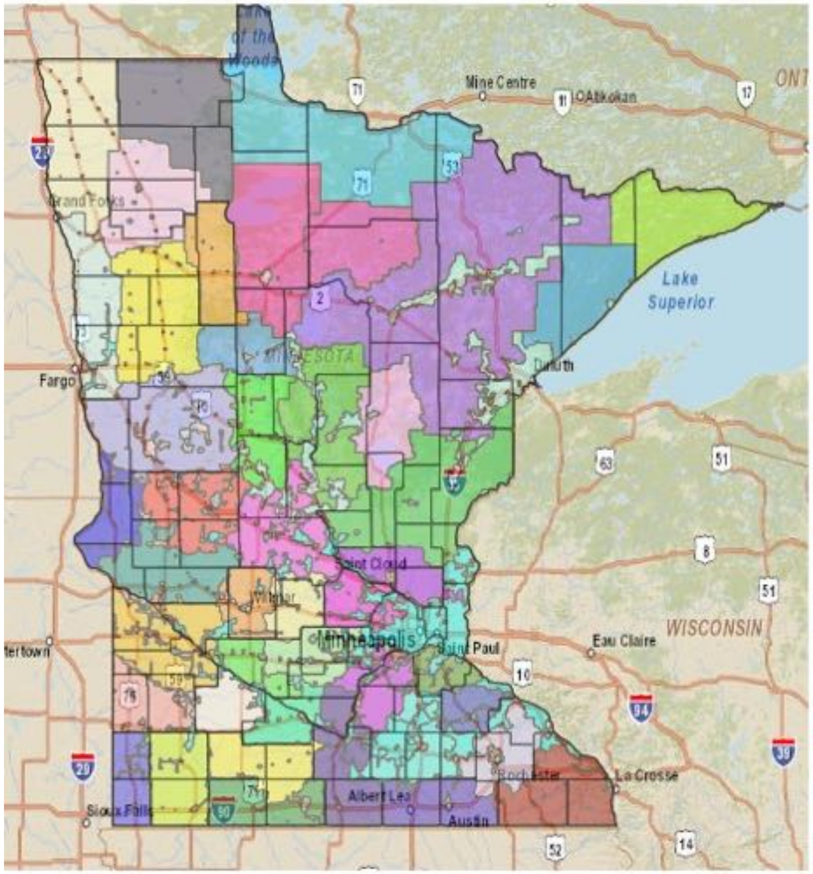
UNIVERSITY OF MINNESOTA

Driven to Discover℠

Christine L. Andrews,
Energy Storage Project Manager,
Energy Transition Lab,
University of Minnesota

A Postcard from the Future

I.Overview



Source: http://www.mngeo.state.mn.us/eusa/#

Utilities by the Numbers:

-3 IOUs: Northern States Power (Xcel), Allete Inc (MN Power), Otter Tail Power

-45 Distribution Co-ops

-6 G&T Co-ops

-126 municipal electric and 31 municipal gas utilities

Source: PUC

Total Generation Capacity 17,707 MW

Source: EIA

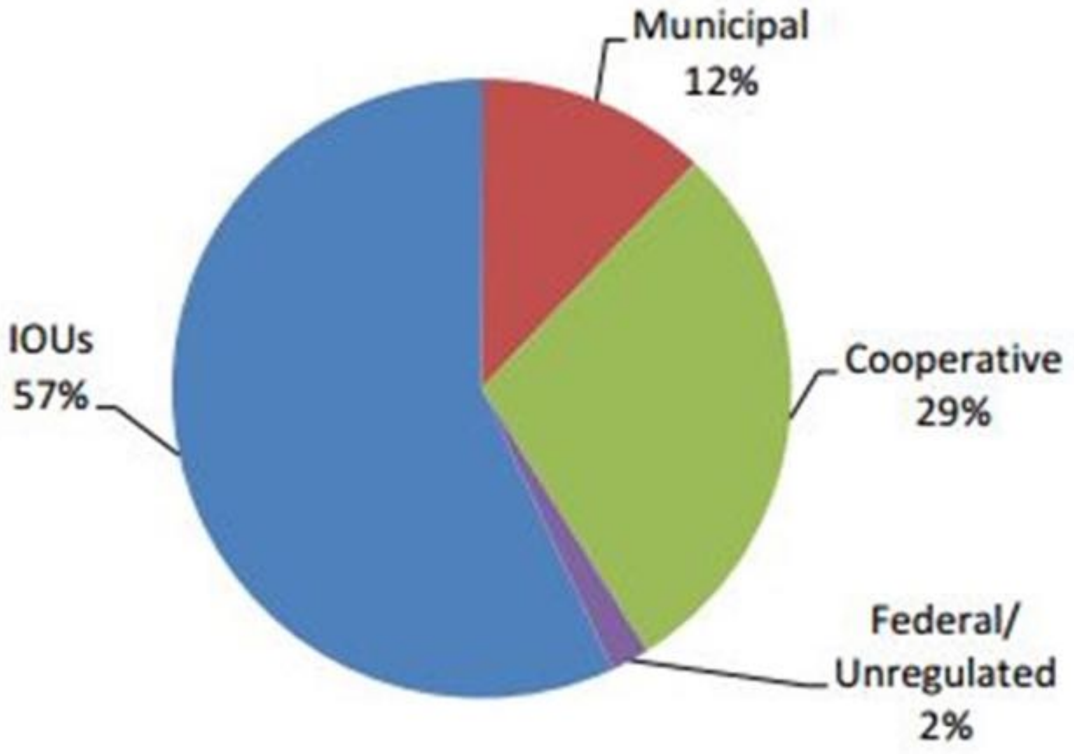
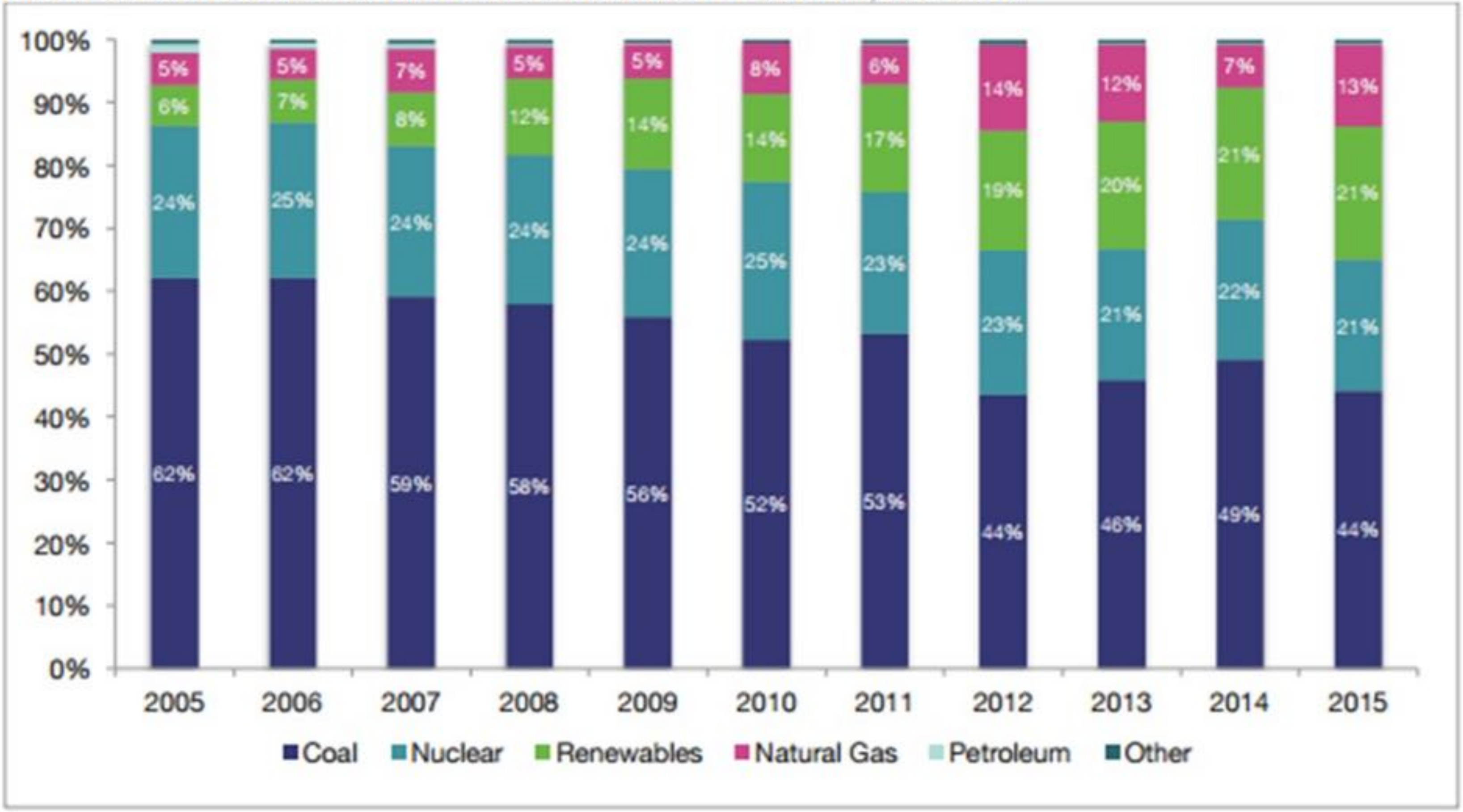


Figure 4: Proportion of IOUs, Municipal Utilities, and Cooperatives[11]

Source: DOC/Strategen White Paper, EIA data varies slightly from the 2012 Minnesota Utility Data Book, with Co-op being 21%, Muni 14%, and IOU 65% (source: November 22nd, 2013 email from Lise Trudeau of MN Commerce to Strategen)

FIGURE 3: MINNESOTA ELECTRICITY NET GENERATION BY SOURCE, 2005–2015



Source: Minnesota 2025 Energy Action Plan, citing EIA data

FIGURE 5: TOTAL MINNESOTA ENERGY CONSUMPTION, 1960–2013

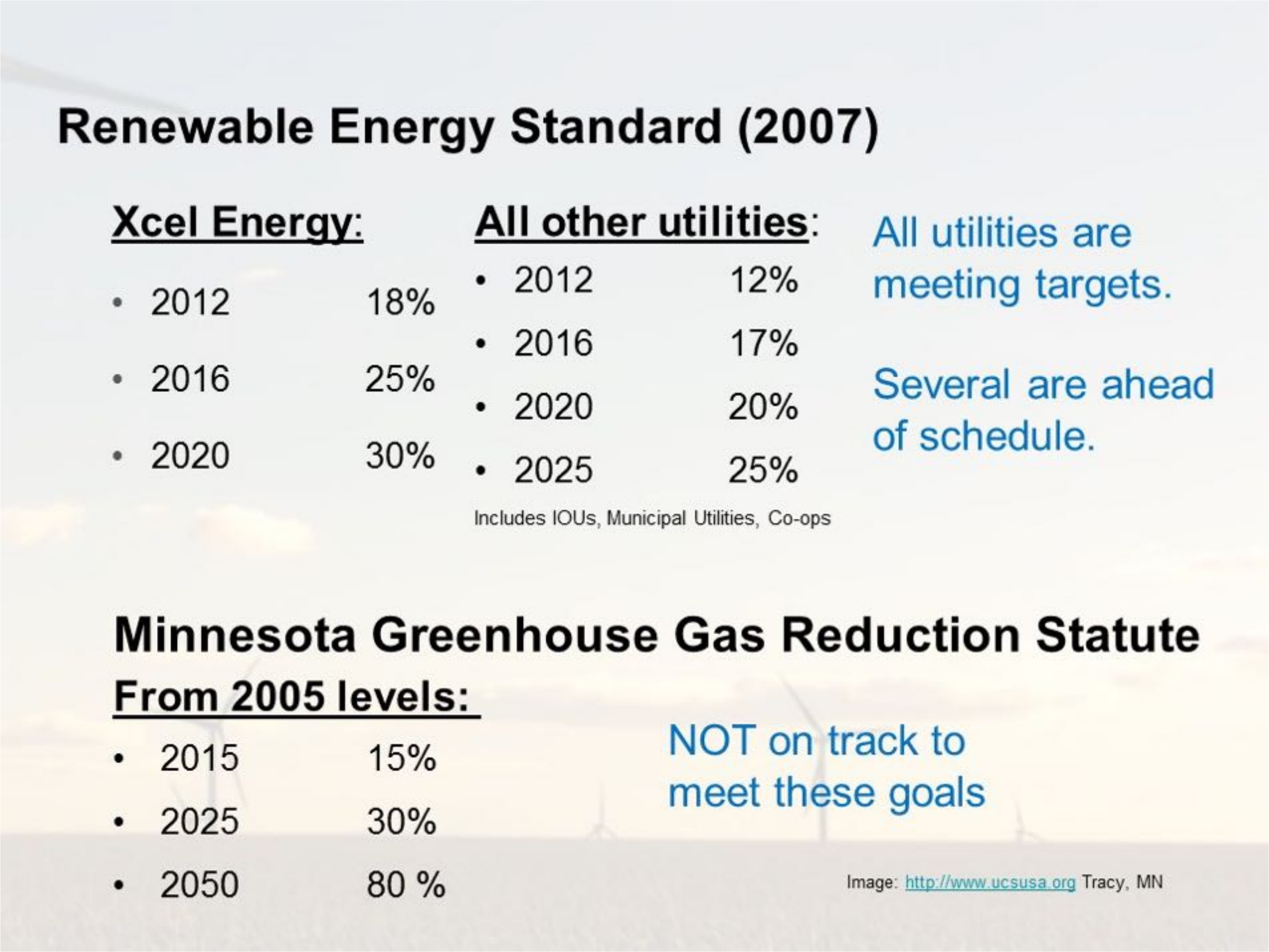
Source: U.S. Energy Information Agency: Primary Energy Consumption Estimates, 1960–2013, Minnesota

Minnesota Energy Landscape Summary

- No indigenous fossil fuel supply
- Import 26% of electricity used
- Abundant wind, solar, and bio-based energy resources
- 4th in nation in ethanol production
- A top 10 state in wind generation
- Per capita energy consumption ranks 18th despite third-coldest winters in U.S.

Source: Minnesota 2025 Energy Action Plan, Photo source: goodmedicineapothecary.com

II. Key Minnesota Energy Policy Drivers



Renewable Energy Standard (2007)

Xcel Energy:	
2012	18%
2016	25%
2020	30%

All other utilities:	
2012	12%
2016	17%
2020	20%
2025	25%

Includes IOUs, Municipal Utilities, Co-ops

All utilities are meeting targets.

Several are ahead of schedule.

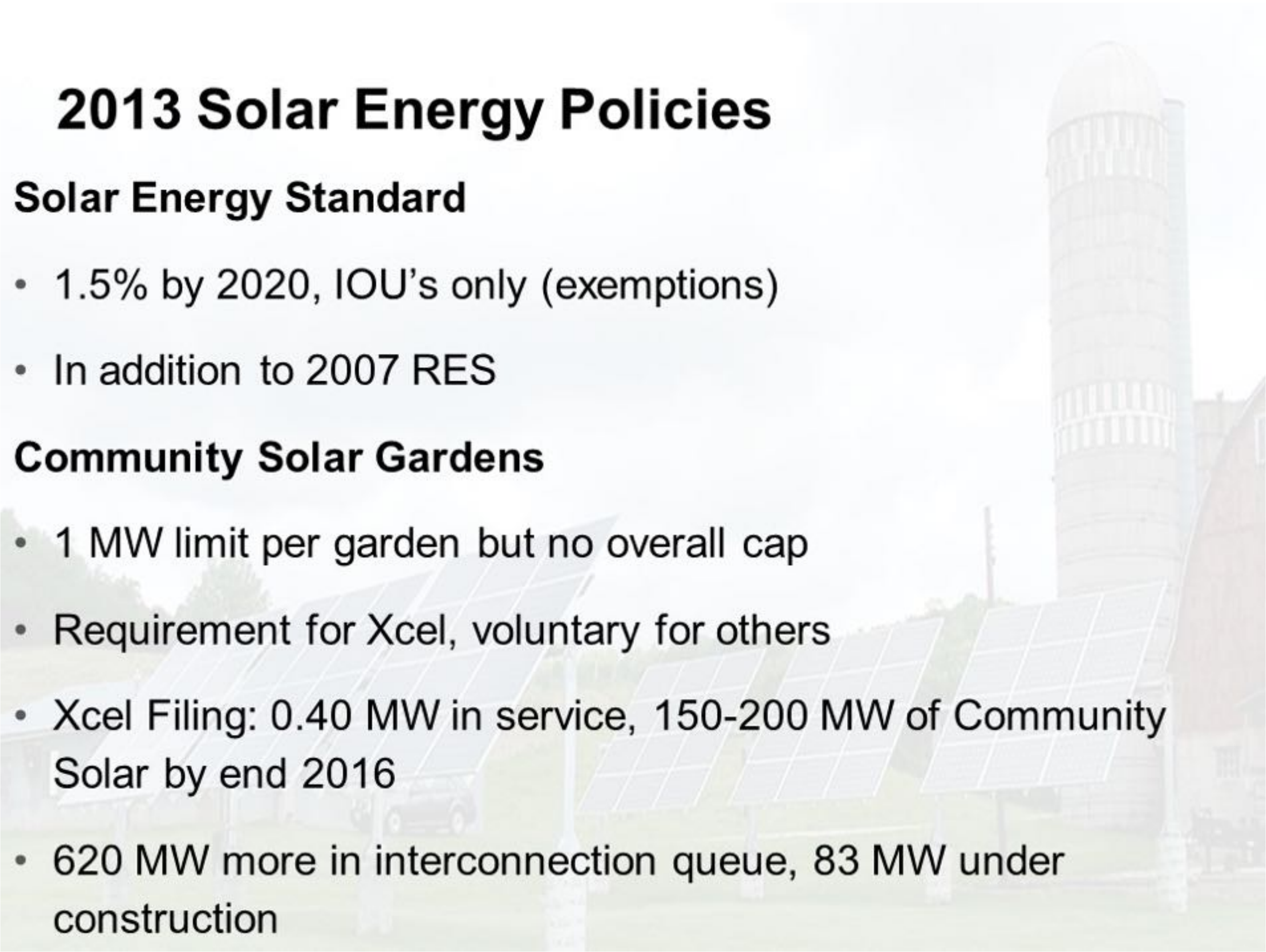
Minnesota Greenhouse Gas Reduction Statute

From 2005 levels:	
2015	15%
2025	30%
2050	80 %

NOT on track to meet these goals

Image: http://www.ucsusa.org Tracy, MN

2013 Solar Energy Policies



Solar Energy Standard

- 1.5% by 2020, IOU's only (exemptions)
- In addition to 2007 RES

Community Solar Gardens

- 1 MW limit per garden but no overall cap
- Requirement for Xcel, voluntary for others
- Xcel Filing: 0.40 MW in service, 150-200 MW of Community Solar by end 2016
- 620 MW more in interconnection queue, 83 MW under construction

Other Clean Energy Policies

Energy Efficiency Requirement: 1.5% reduction of retail sales per year

Made in Minnesota incentives for Solar PV and Solar Thermal

Value of Solar Tariff

State Goal of 10% Solar by 2030

Grid Modernization & Distribution Planning Law

MN Renewable Energy Integration and Transmission Study

(MRITS, 2014)

40% Renewables in Minnesota:

- Can be reliably accommodated with upgrades to existing transmission
- Wind and solar increase by 8.5 TWh, balanced by decrease in imports;
- Very little change in conventional generation
- **MN-Centric region goes from net importer to net exporter**

50% Renewables in Minnesota, 25% RPS in MISO North/Central

- Can be accomplished with more substantial transmission upgrades;
- Increase in MN wind and solar balanced by decrease in coal, increase in exports
- Gas-fired, combined-cycle generation declines from 5.0 TWh to 3.0 TWh
- 2% of Minnesota wind curtailed in this scenario

II. Energy Storage To Date in Minnesota

Smaller Battery Energy Storage:

Smaller Projects Totaling 311 kw

Hartley Nature Center, Duluth, MN
Solar + storage creates resilient emergency center. 6kw/2:22.50 hour

Univ. of St. Thomas, St. Paul
Solar + storage microgrid project. 50 kw.

Rural Co-op (Jackson and Litchfield)
Utility office buildings for demand charge reduction and backup power. 5kw/2 hr

Wright-Hennepin Co-op
Demand charge reduction and backup power. 51kw/2 hr.

Wright-Hennepin Solar Community, Rockford
31 kw solar array + 37 kw/2 hr.

Wright-Hennepin Solar Community

Jordan Residential storage project

Residential Storage Project, Jordan
Eleven 5kw and six 10kw units installed at co-op member locations. 115kw/3 hr

MN Valley Electric Co-op, Jordan
Demand charge reduction and backup power. 33kw/2:30 hr

Austin Municipal Utilities
Sited in municipal bldg for peak demand mgmt. 37kw/2 hr

Brainerd Public Utilities
Utility Office Bldg for demand charge reduction and backup power. 5kw/2 hr

Shakopee Public Utilities
Solar + ES at high school environmental learning center. 9kw/2hr.

Larger Energy Storage

Xcel's Luverne, MN Wind-to-Battery Project

Xcel MN Wind-to-Battery, Luverne
First U.S. application as direct wind storage, move to grid as needed. 1MW 7:12 hr

Proposed Xcel Belle Plaine Battery Project
Proposed dist. deferral project. 6MWh, 2MW battery + 1MW solar. Volt/Var, loss impact analysis, reg, power quality, DER smoothing.

Minnesota Power with Manitoba Hydro
PPA with Manitoba Hydro to store wind energy from N.D. and transmit 250MW of resulting hydroelectric power to MN via the Great Northern Transmission Line(in process)

Otter Tail Power Thermal Storage
18,000 customers = 20 MW thermal battery for peak shifting. Thermal in-floor storage

Great River Energy Thermal Storage
60,000 utility-controlled residential electric hot water heaters, shift 1 GW to off-peak

Minnesota Energy Storage Legislative Initiatives

In Law:

2013 Value of On-Site Energy Storage
Required state analysis of costs and benefits of utility-managed, grid-connected on-site energy storage

Proposed:

2015 Made in MN Energy Storage Bill
Proposed to expand energy conservation improvement plan program eligibility to include E.S. systems; Made in MN E.S. systems rebate program

2016 MN Energy Storage Tax Credit Bill
Proposed state income tax credit of 30% of cost (up to $5,000 residential, $25,000 commercial/agriculture) for E.S. systems

Minnesota Dept. of Commerce

White Paper Analysis of Utility-Managed, On-Site Energy Storage in MN

Prepared by Strategen with EPRI (modeling & technical support)
Dec. 2013

Investigated 4 use cases for energy storage:

1. Customer controlled for bill savings
2. Utility controlled for distribution system benefits
3. Utility controlled for distribution & market benefits
4. Shared customer & utility controlled for bill savings and market revenue

Results: Case 3 has positive benefit:cost

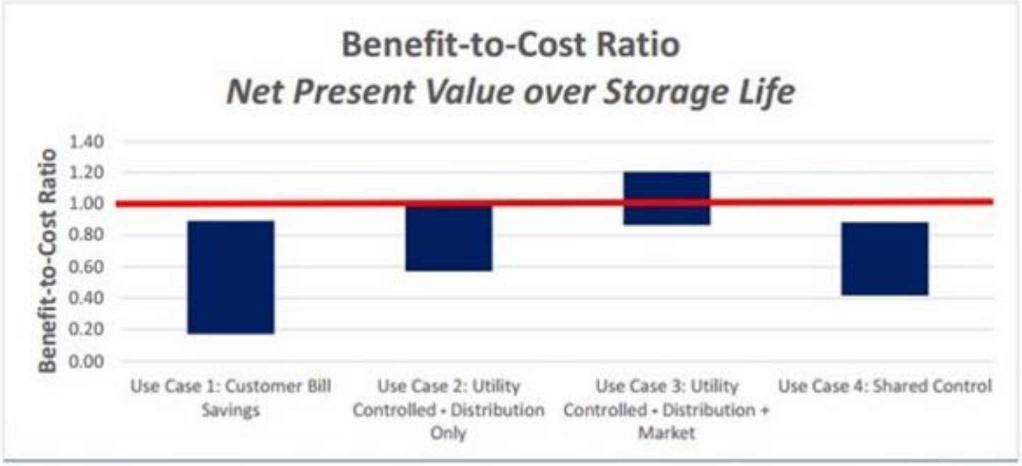


Figure 1: Summary of Customer-Sited Energy Storage Project Cost-Effectiveness in Minnesota

MINNESOTA ENERGY STORAGE ALLIANCE

- Energy Transition Lab held Energy Storage Summit in July 2015 with 200 attendees
- Led to MESA formation.
- More than 150 stakeholders involved from all sectors

MESA Activities:

- Knowledge sharing: Hot Topics Events, Upcoming Summit II
- Submitting comments on market opportunities and barriers to FERC, MISO, PUC
- Energy Storage Strategy Workshop

MISO and Energy Storage

- MISO Convened Energy Storage Stakeholder Process Jan. 2016
- ES Issues Identified by Stakeholders - In Committee Process

Market Subcommittee

Market Roadmap prioritization process includes storage-related items

Resource Adequacy Subcommittee

How to credit storage as a capacity resource

Interconnection Process Task Force

How storage assets go through interconnection queue process

Planning Subcommittee

Considering storage as a Non-Transmission Alternative; deferred to FERC on how a storage asset can be considered a transmission asset

III. Challenges and Opportunities for the Future

Energy System Efficiency

Aging Infrastructure

Cost & Affordability

Meeting Future System Needs:
Minnesota, MISO Region

Grid Modernization

Electrification of Transportation

New Utility Business Models (e21)

Growth of Distributed Energy Resources

Reliability & Resiliency

Growth of Renewable Energy

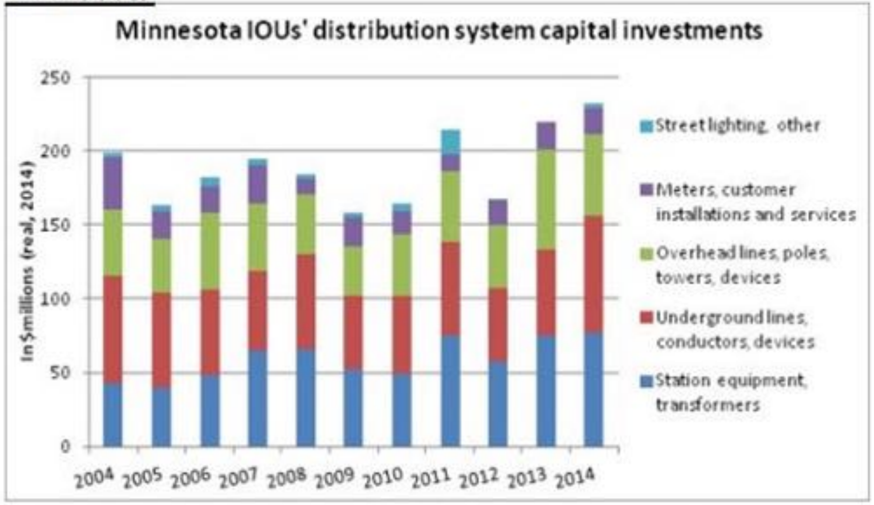
Climate Change & Regulatory Framework

Managing Peak Demand

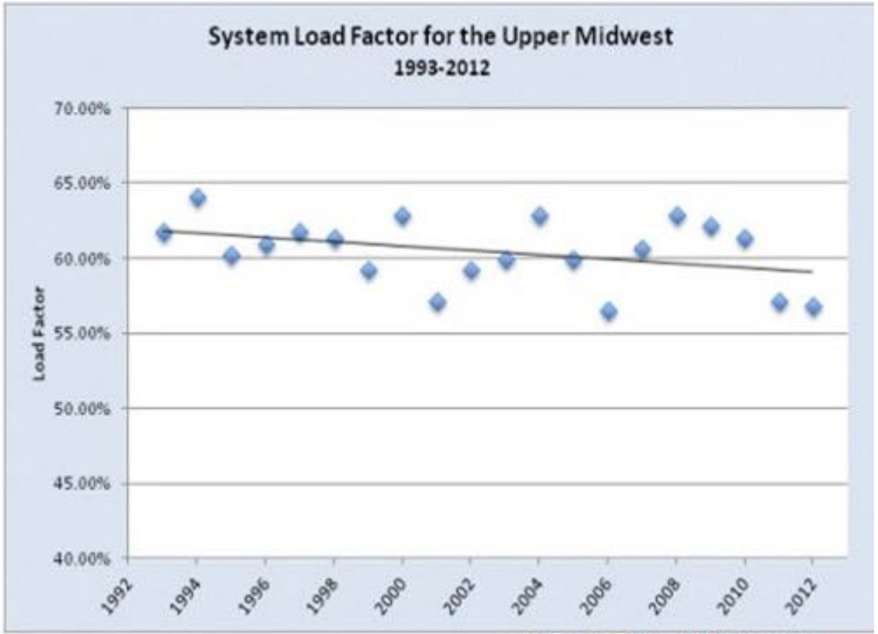
Infrastructure Investment & Utilization

- Utilities spend hundreds of millions on infrastructure
- Much of system (generators, transmission, distribution) underutilized
- Opportunity to reduce system costs by better utilizing system assets

Minnesota

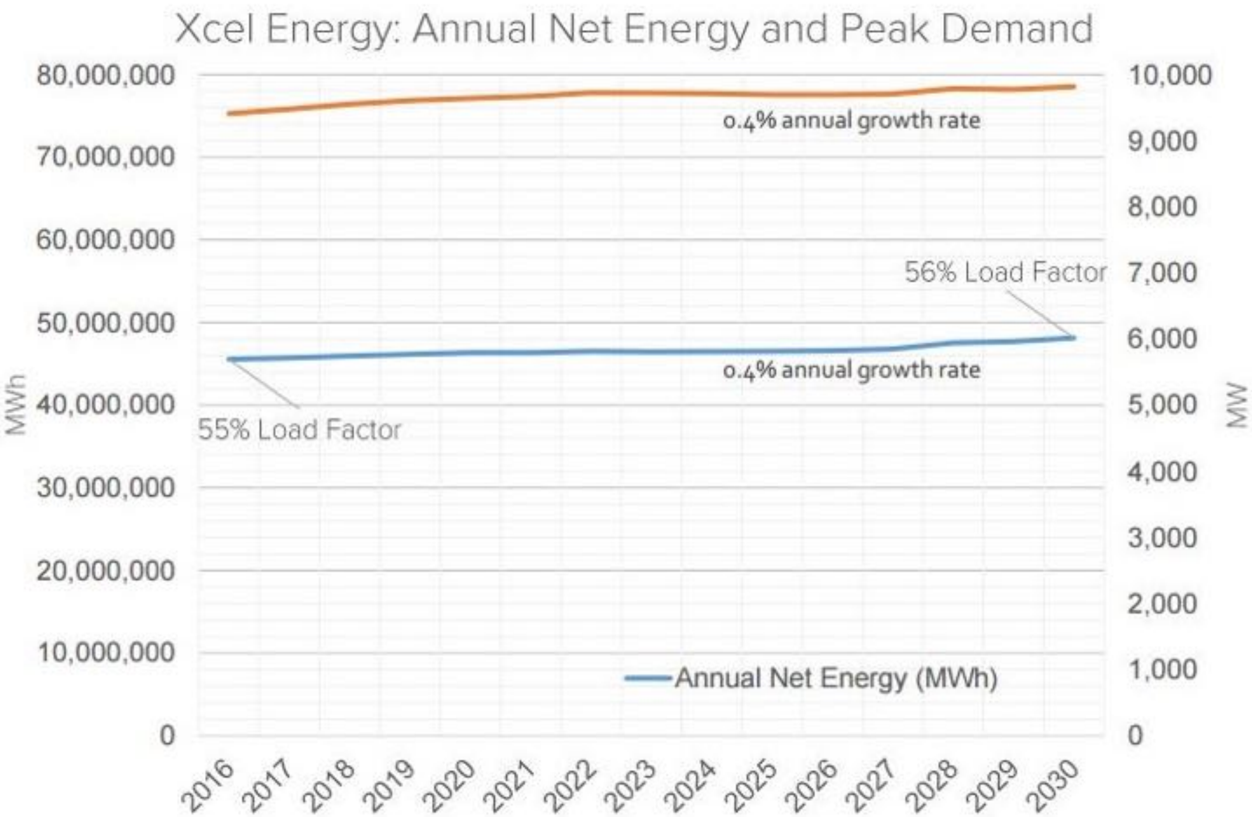


Source: PUC Filings, as presented by Commissioners Lange & Schuerger



Source: EIA – MISO region

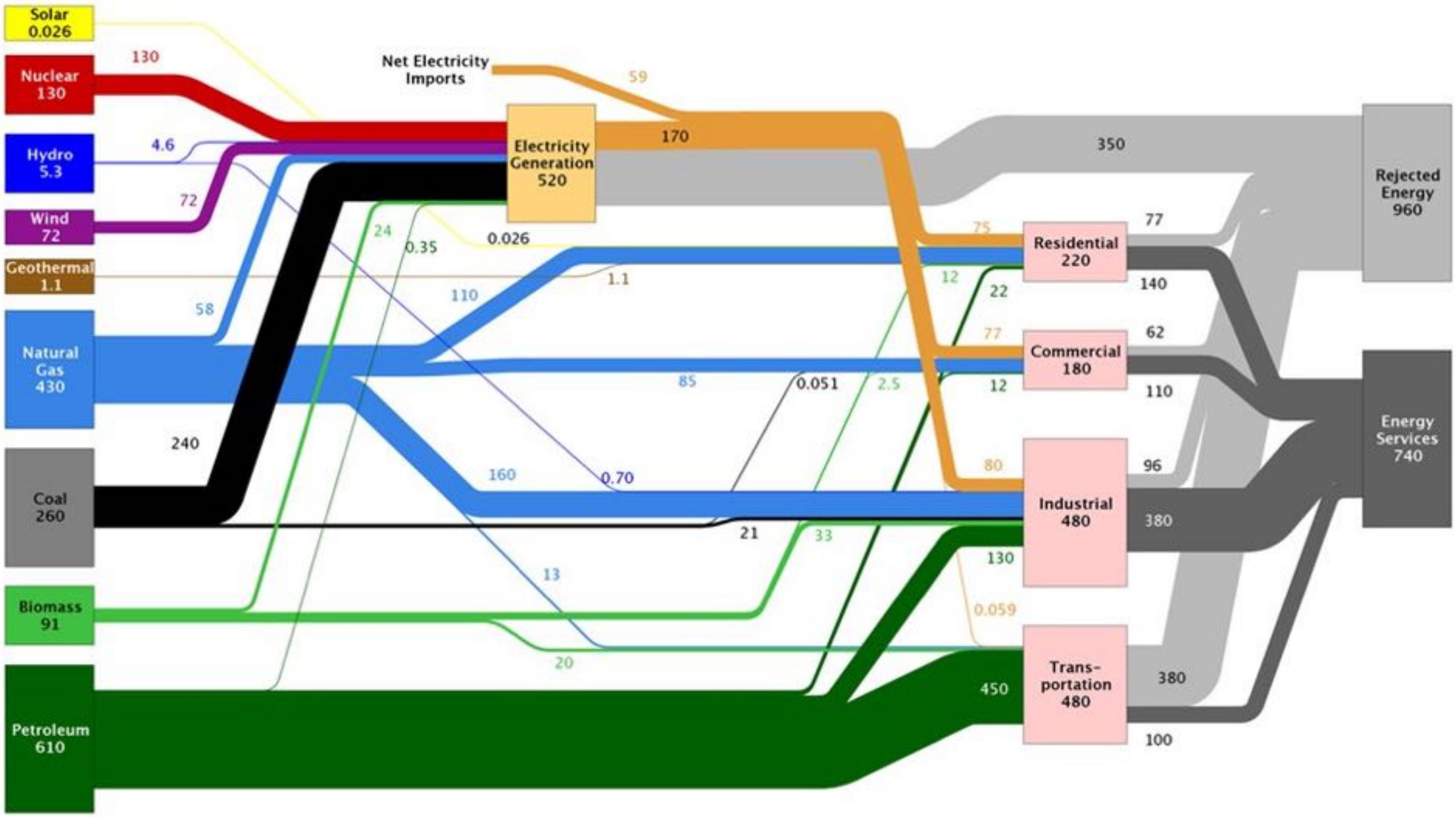
Xcel Energy: 2016-2030 Energy and Demand Forecast



Source: Xcel Energy, 2016-2030 Upper Midwest Resource Plan, Appendix I, Forecast Methodology, Tables 1 & 2
https://www.xcelenergy.com/staticfiles/xe/PDF/Regulatory/12-App-I-Forecast-Methodology-January-2015.pdf

Estimated Minnesota Energy Use In 2012
~1700 Trillion BTU

Lawrence Livermore National Laboratory



Source: LLNL 2013. Data is based on DOE/EIA-0214(2011), June 2013. If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. Distributed electricity represents only retail electricity sales and does not include self-generation. EIA reports flows for non-thermal resources (i.e., hydro, wind and solar) in BTU-equivalent values by assuming a typical fossil fuel plant "heat rate." The efficiency of electricity production is calculated as the total retail electricity delivered divided by the primary energy input into electricity generation. Interstate and international electricity trade are lumped into net imports or exports and are calculated using a system-wide generation efficiency. End use efficiency is estimated for each sector as 65% residential, 65% commercial, 80% industrial and 21% transportation. Totals may not equal sum of components due to independent rounding. LLNL-MI-410527

Aging Infrastructure

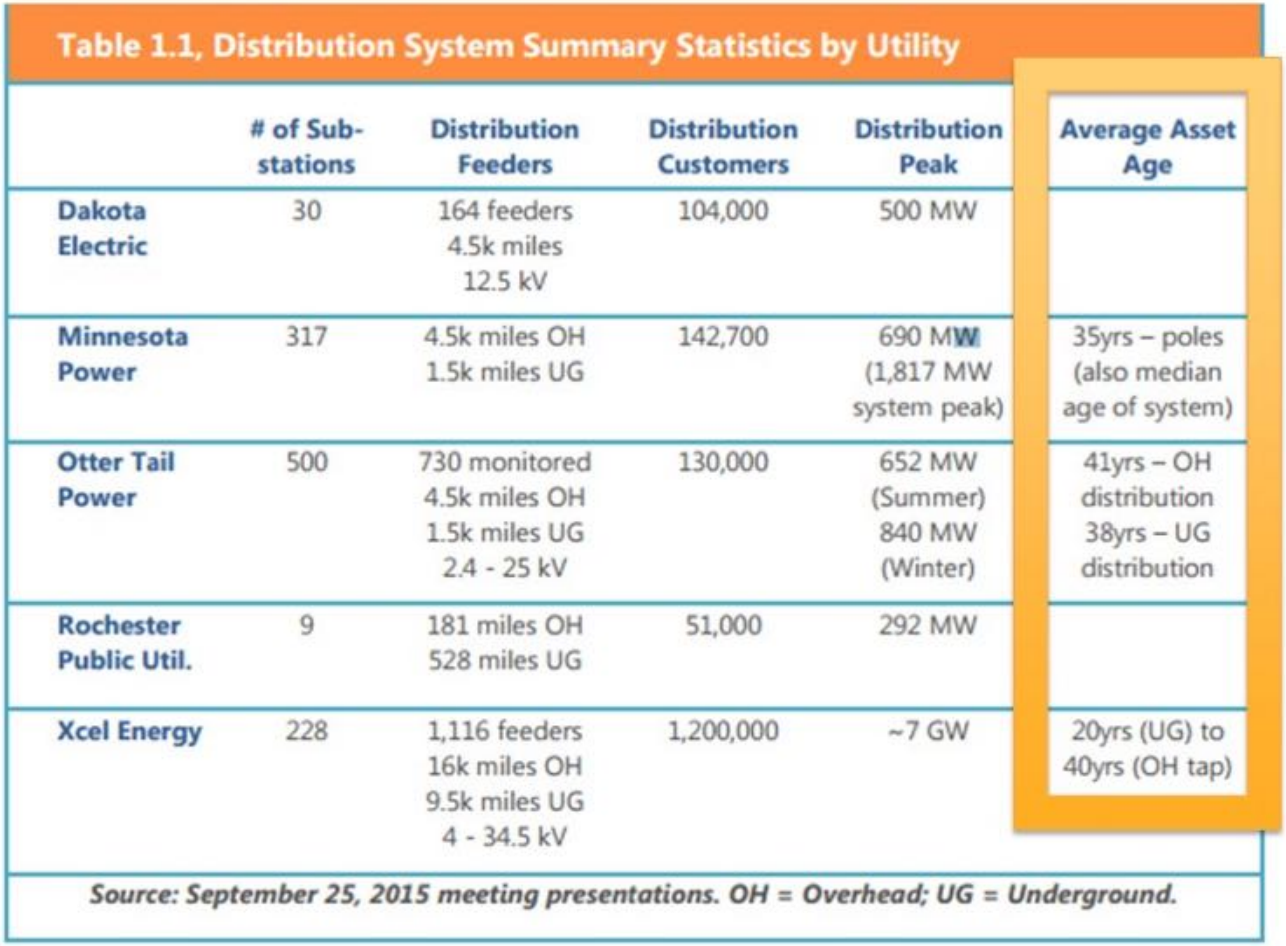


Table 1.1, Distribution System Summary Statistics by Utility

	# of Sub-stations	Distribution Feeders	Distribution Customers	Distribution Peak	Average Asset Age
Dakota Electric	30	164 feeders 4.5k miles 12.5 kV	104,000	500 MW	
Minnesota Power	317	4.5k miles OH 1.5k miles UG	142,700	690 MW (1,817 MW system peak)	35yrs – poles (also median age of system)
Otter Tail Power	500	730 monitored 4.5k miles OH 1.5k miles UG 2.4 - 25 kV	130,000	652 MW (Summer) 840 MW (Winter)	41yrs – OH distribution 38yrs – UG distribution
Rochester Public Util.	9	181 miles OH 528 miles UG	51,000	292 MW	
Xcel Energy	228	1,116 feeders 16k miles OH 9.5k miles UG 4 - 34.5 kV	1,200,000	~7 GW	20yrs (UG) to 40yrs (OH tap)

Source: September 25, 2015 meeting presentations. OH = Overhead; UG = Underground.

Source: PUC Staff Report on Grid Modernization

Reliability & Resiliency

The 7 largest MN utilities were below national median on SAIDI/SAIFI scores (excluding major event days) (2014)

Cost of U.S. electric outages was $112 billion (2013)

From 1997-2013: 32 severe weather natural disasters cost MN nearly $500 million

In 2013, Minnesota had some of the highest weather-related disaster claims in the country

PUC Staff Report on Grid Modernization:

Potential Near Term Action Items

Integrated Distribution Planning

Smart Inverters

DG Interconnection Order

Hosting Capacity Analysis

Advanced Metering Infrastructure

Volt/VAR Optimization

Customer Energy Usage Data

Time-Varying Rates

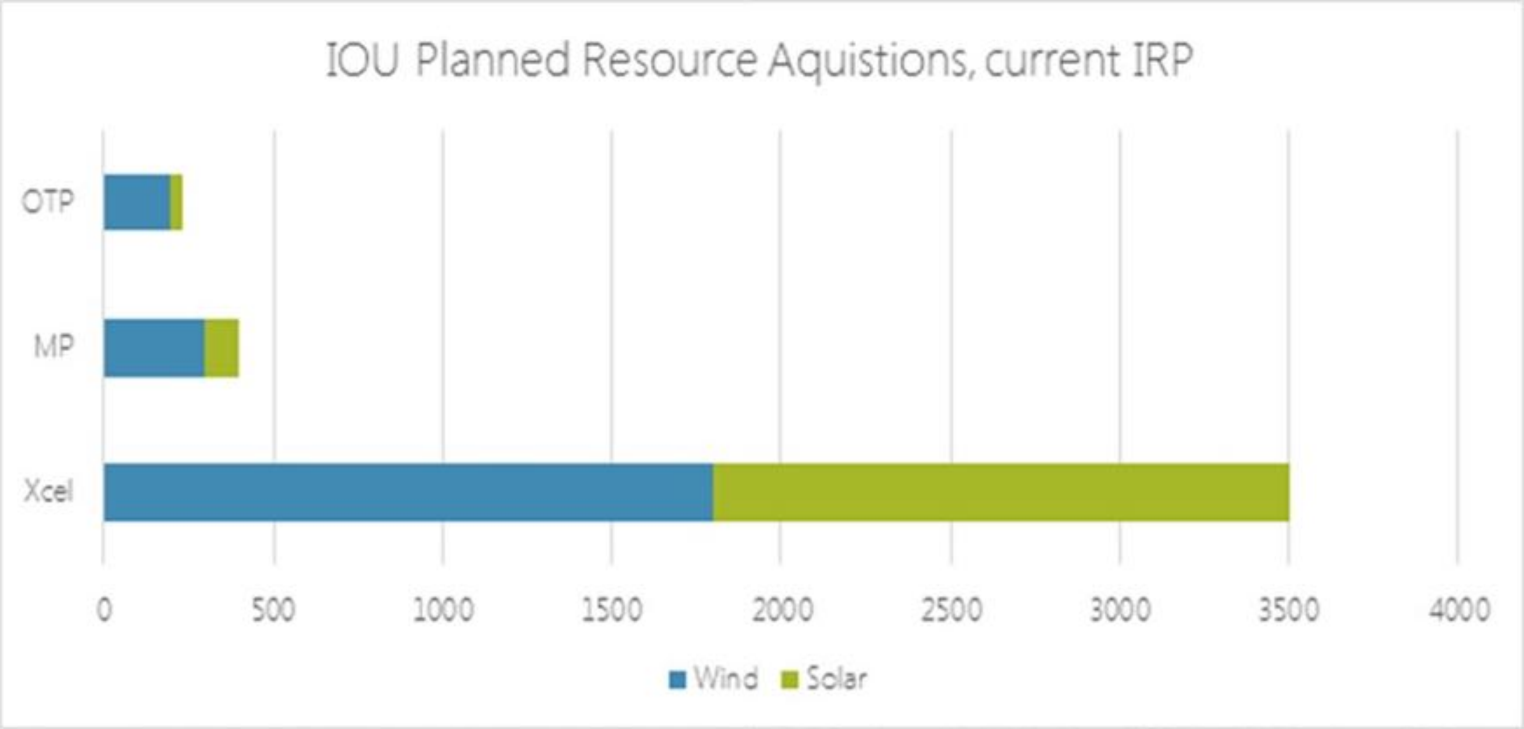
Third-Party Aggregation

Expansion of Renewable Energy

Governor Dayton and others support raising RES to 40-50%

MRITS study shows Minnesota could be net energy exporter

Utilities adding renewable energy and natural gas and reducing coal

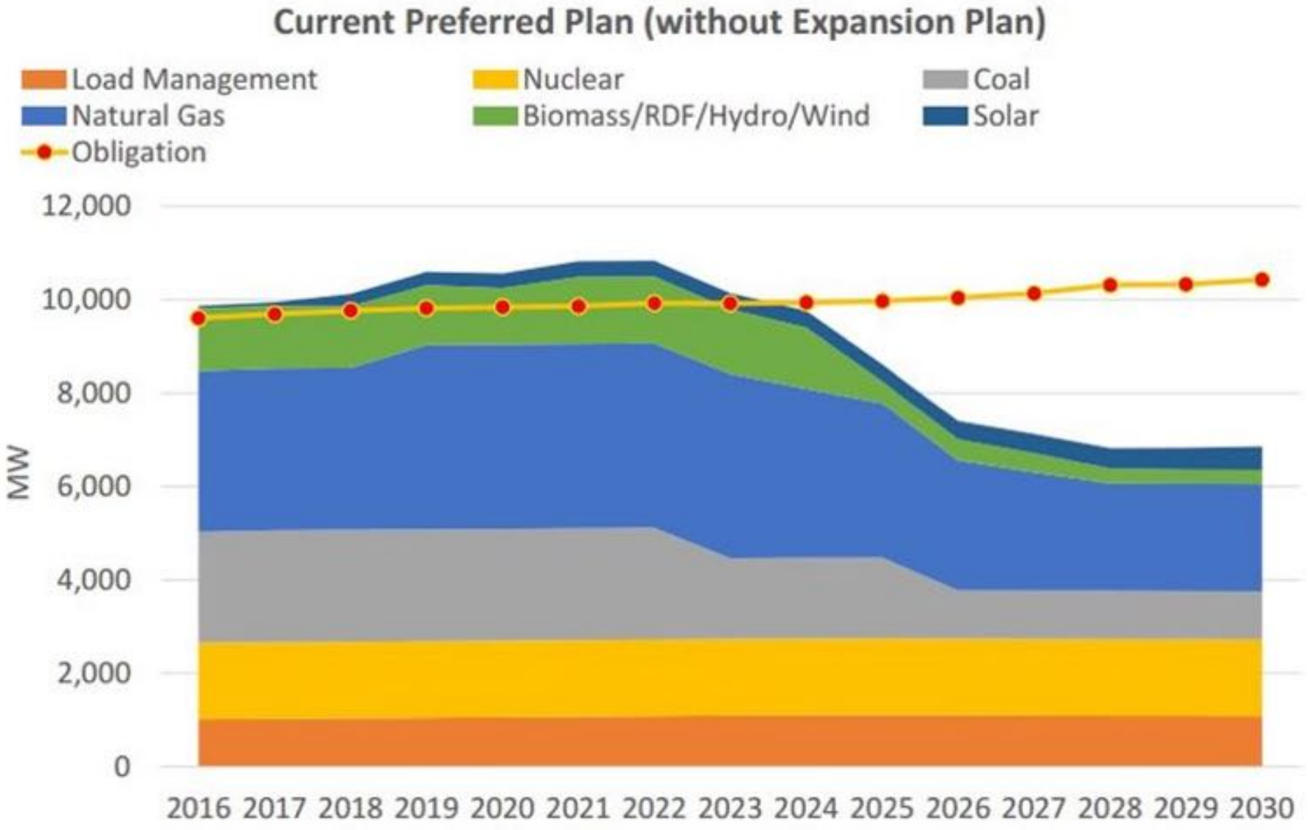


Source: OTP IRP (PUC Docket 16-386); MP IRP (PUC Docket 15-690); Xcel IRP (PUC Docket 15-21)

Electric Vehicles

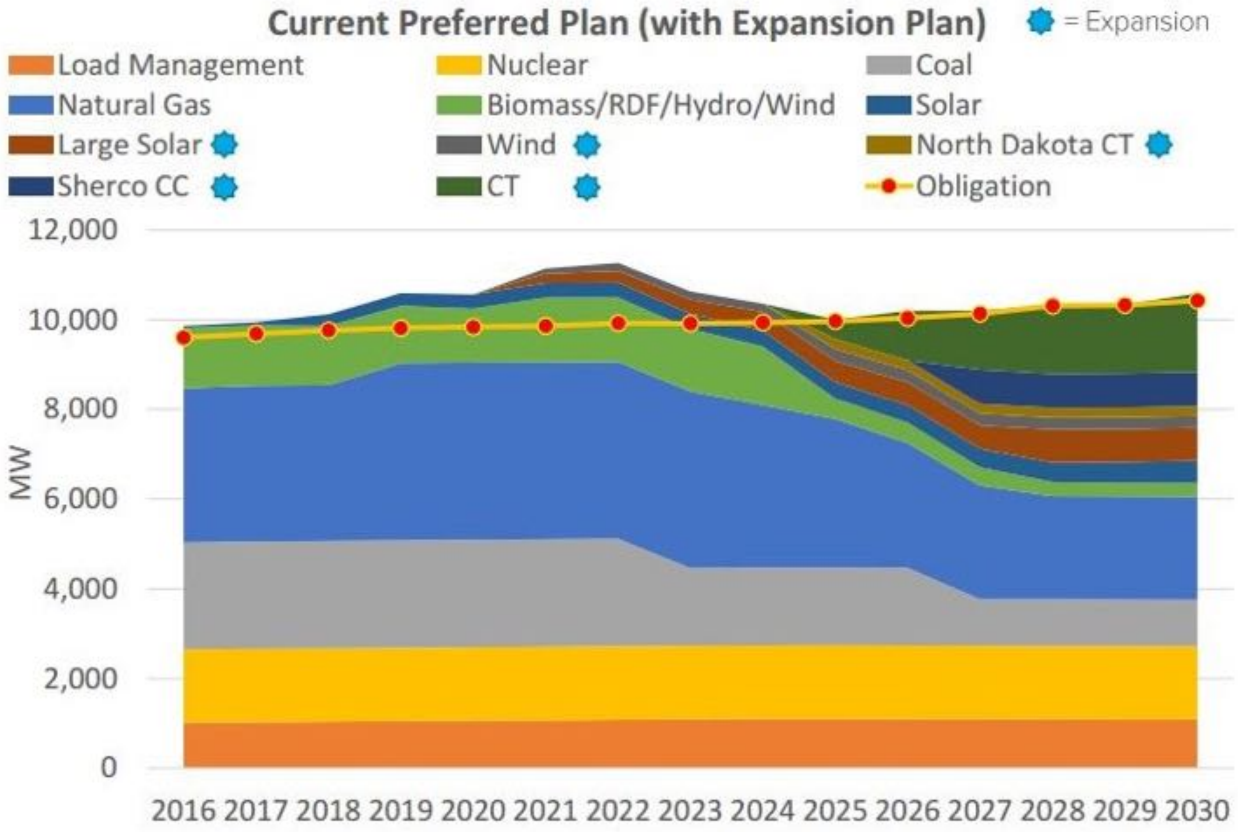
- Over 50% of MN EV drivers surveyed use renewable energy-sourced electricity rate
- EV present new market for utilities and opportunity as storage
- 3,888 Plug-ins in MN, Aug BEV sales up 123% [per zevfacts.com]
- Drive Electric MN Bulk Buy Program
  - +54 Leafs in 2016
- 242 public electric charging stations with 542 charging outlets
- EV Charging Tariff

Xcel Energy: Future Load and Resource Mix

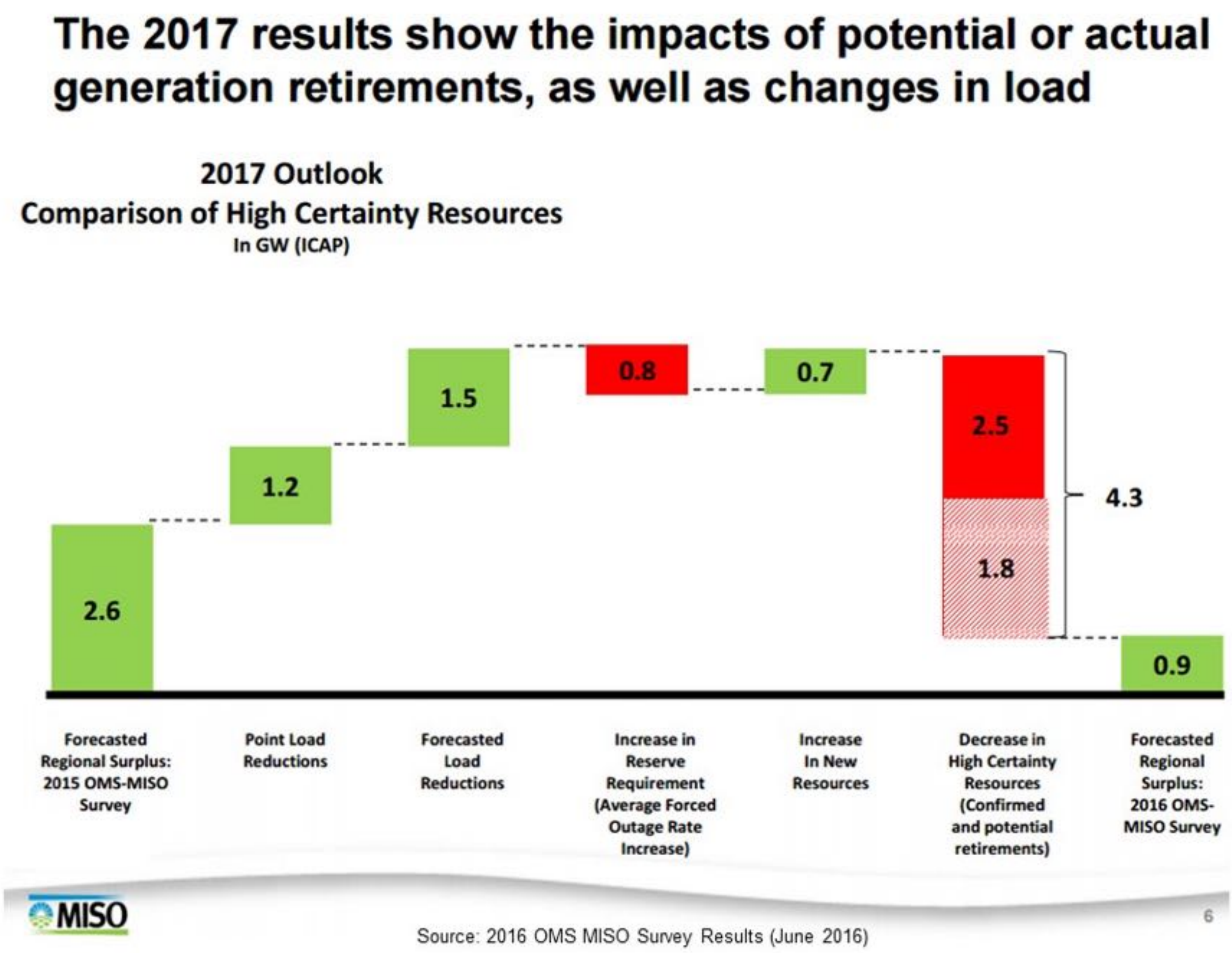


Source: Xcel Energy 2016-2030 Upper Midwest Resource Plan, Docket No. E002/RP-15-21 (Current Preferred Plan, filed Jan. 29, 2016), https://www.xcelenergy.com/staticfiles/xe/PDF/Regulatory/MN-Resource-Plan/MN-Resource-Plan-03-Supplement.pdf
Capacity reflects Unforced Capacity Values (UCAP); Current Preferred Plan includes retirement of Sherco Units 1 & 2

Xcel Energy: Future Load and Resource Mix



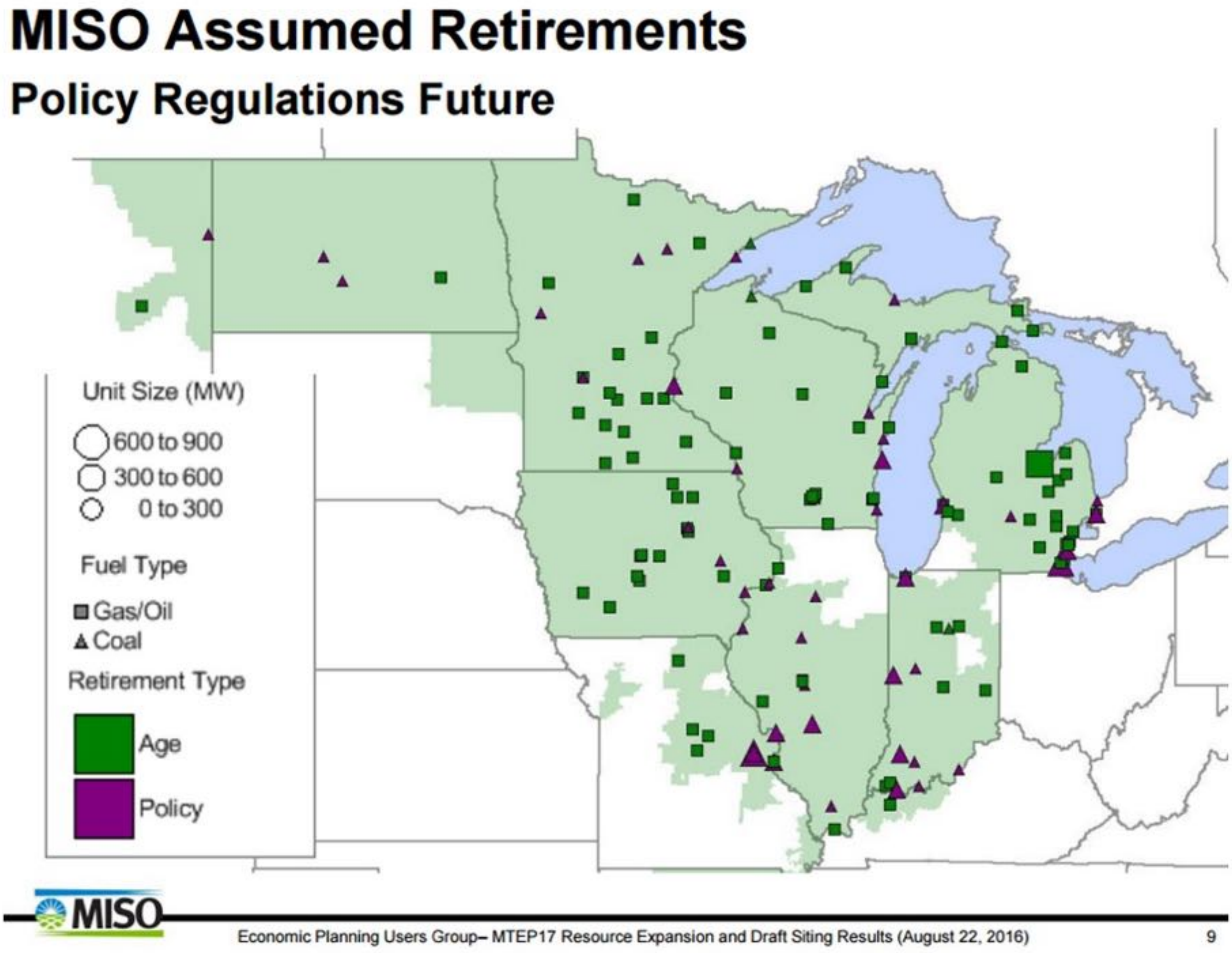
Source: Xcel Energy 2016-2030 Upper Midwest Resource Plan, Docket No. E002/RP-15-21 (Current Preferred Plan, filed Jan. 29, 2016), https://www.xcelenergy.com/staticfiles/xe/PDF/Regulatory/MN-Resource-Plan/MN-Resource-Plan-03-Supplement.pdf
Capacity reflects Unforced Capacity Values (UCAP)



The 2017 results show the impacts of potential or actual generation retirements, as well as changes in load

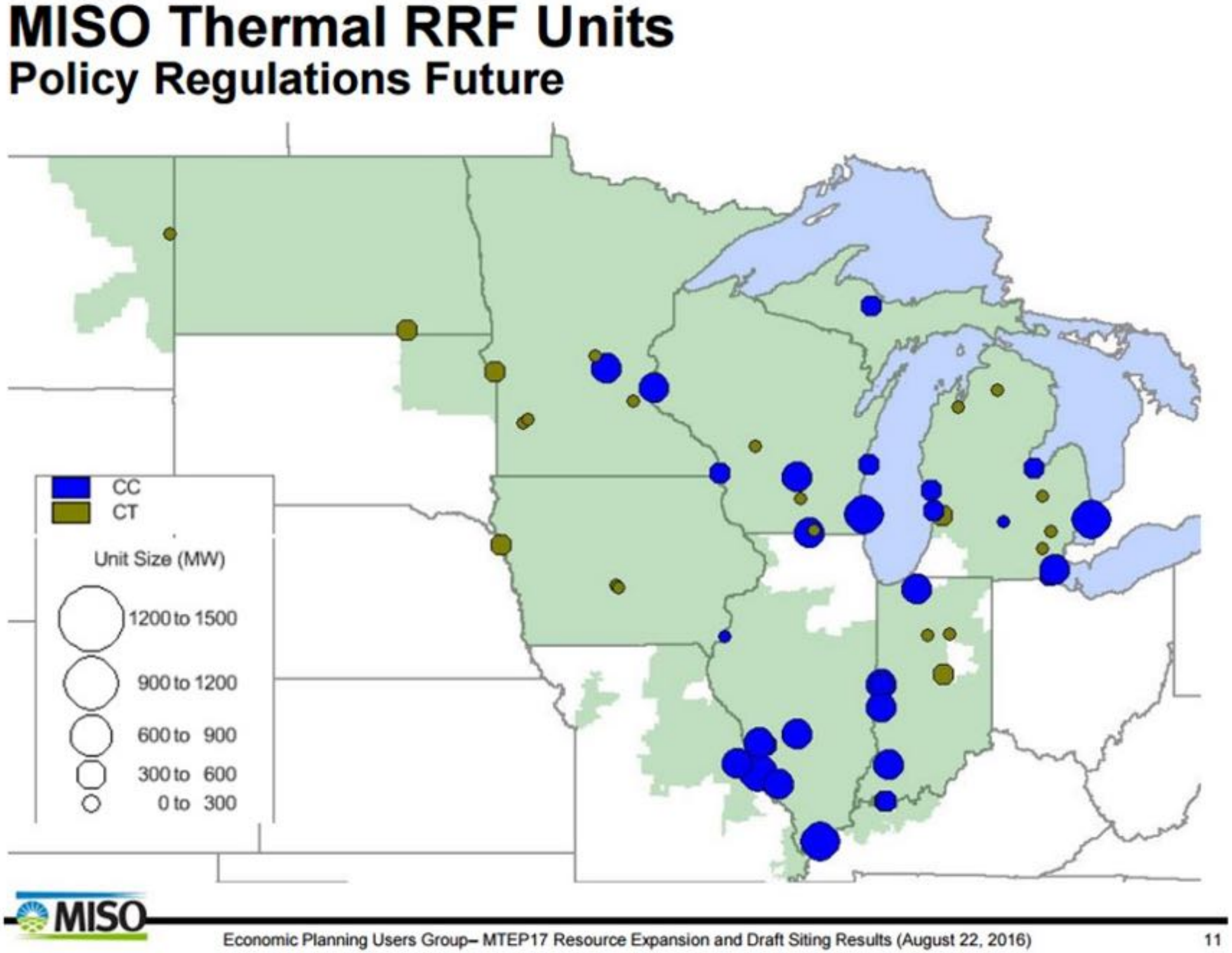
2017 Outlook
Comparison of High Certainty Resources
In GW (ICAP)

Source: 2016 OMS MISO Survey Results (June 2016)



MISO Assumed Retirements

Policy Regulations Future



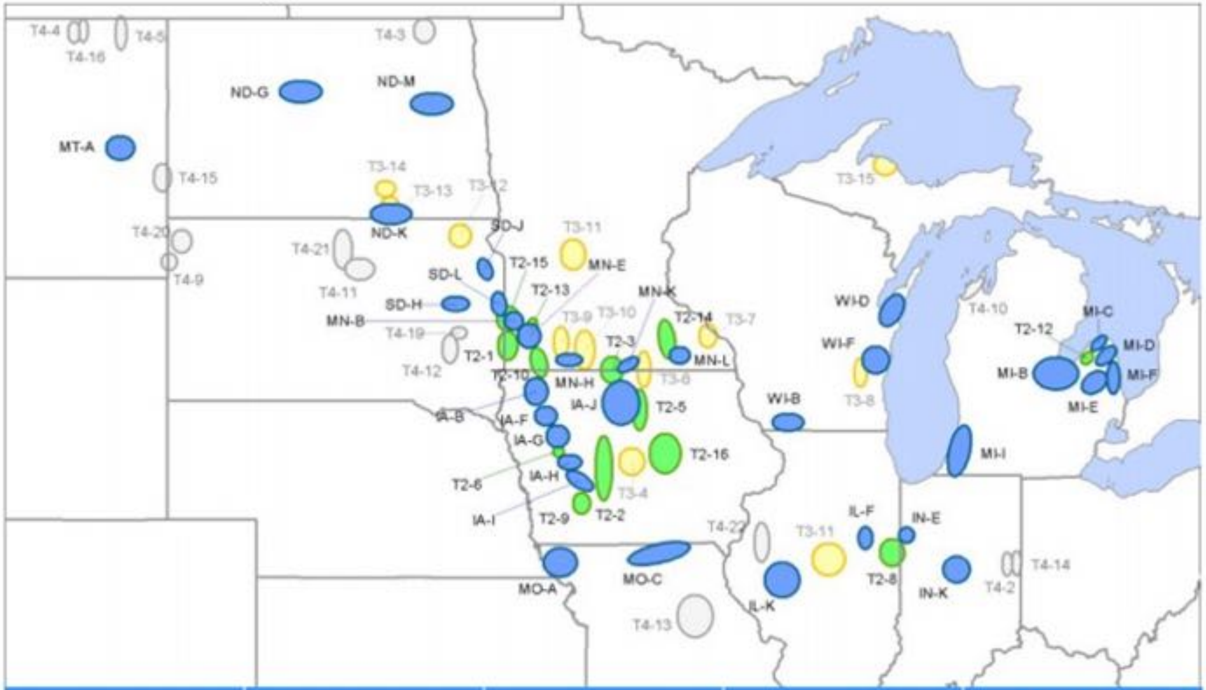
MISO Thermal RRF Units

Policy Regulations Future

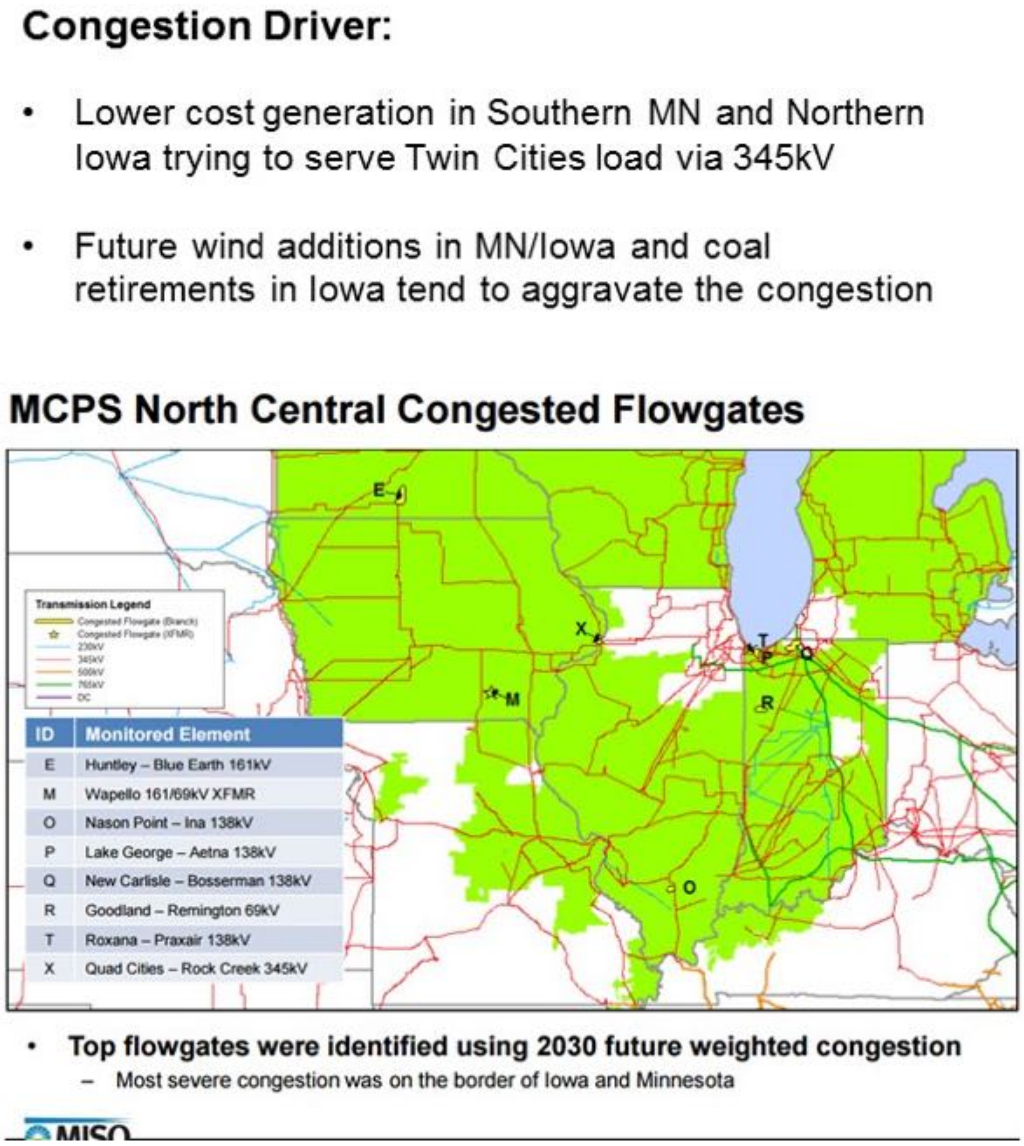
Economic Planning Users Group– MTEP17 Resource Expansion and Draft Siting Results (August 22, 2016)

11

MISO Wind Siting



Wind Tier	Total Available Tier Capacity (MW)	Existing Fleet (MW)	Policy Regulations (MW)	Accelerated Alternative Technologies (MW)
Tier 1: RGOS Zones	15,810	2,400	15,810	15,810
Tier 2	15,795	--	990	14,190
Total	**31,605**	**2,400**	**16,800**	**30,000**



Congestion Driver:

- Lower cost generation in Southern MN and Northern Iowa trying to serve Twin Cities load via 345kV
- Future wind additions in MN/Iowa and coal retirements in Iowa tend to aggravate the congestion

MCPS North Central Congested Flowgates

ID	Monitored Element
E	Huntley – Blue Earth 161kV
M	Wapello 161/69kV XFMR
O	Nason Point – Ina 138kV
P	Lake George – Aetna 138kV
Q	New Carlisle – Bosserman 138kV
R	Goodland – Remington 69kV
T	Roxana – Praxair 138kV
X	Quad Cities – Rock Creek 345kV

- **Top flowgates were identified using 2030 future weighted congestion**
  - Most severe congestion was on the border of Iowa and Minnesota

MISO

Resources

"White Paper Analysis of Utility-Managed, On-Site Energy Storage in Minnesota." Prepared for: Minnesota Department of Commerce. Prepared by: Strategen (Dec. 2013)

"Minnesota Renewable Energy Integration and Transmission Study: Final Report." Prepared for : The Minnesota Utilities and Transmission Companies and the Minnesota Dept. of Commerce. Prepared by: GE Energy Consulting, with contributions by: The Minnesota Utilities and Transmission Companies, Excel Engineering, Inc., and MISO (Oct. 31, 2014)

"Minnesota Clean Energy Economy Profile: How Industry Sectors are Advancing Economic Growth." Prepared for: Minnesota NGA Policy Academy Team, including MN Dept of Employment and Eco. Dev., Dept. of Commerce, Dept. of Ag, and Env. Quality Board. Prepared by: Collaborative Economics, Inc. (Oct. 2014)

"Minnesota and Climate Change: Our Tomorrow Starts Today." Minnesota Environmental Quality Board.

"e2 Initiative Phase I Report: Charting a Path to a 21st Century Energy System in Minnesota." (Dec. 2014)

"Electric System Reliability and EPA's Clean Power Plan: The Case of MISO." Analysis Group. (June 8, 2015)

"Climate Solutions and Economic Opportunities (CSEO): A foundation for Minnesota's state climate action planning." Minnesota Environmental Quality Board (March, 2016)

Minnesota Public Utilities Commission Staff Report on Grid Modernization (March, 2016)

"Evaluating the Economics for Energy Storage in the Midcontinent: A Battery Benefit-Cost Analysis." Great Plains Institute (July 2016)

"Minnesota's 2025 Energy Action Plan: Stakeholder-Driven Strategies for Success." Prepared for: MN Dept. of Commerce and MN Legislative Energy Commission. Prepared by: Rocky Mountain Institute (August 2016)

"Integrated Distribution Planning." Prepared for: MN PUC. Prepared by: ICF International. (Aug. 2016)

Keep your eyes open for: CEE's Energy Storage Report (soon), GPI e21 Initiative Phase II and white papers (soon), Xcel Hosting Capacity Analysis(Dec)

III. Challenges and Opportunities for the Future

Energy System Efficiency

Aging Infrastructure

Cost & Affordability

Meeting Future System Needs:
Minnesota, MISO Region

Grid Modernization

Electrification of Transportation

New Utility Business Models (e21)

Growth of Distributed Energy Resources

Reliability & Resiliency

Growth of Renewable Energy

Climate Change & Regulatory Framework

Managing Demand (?)

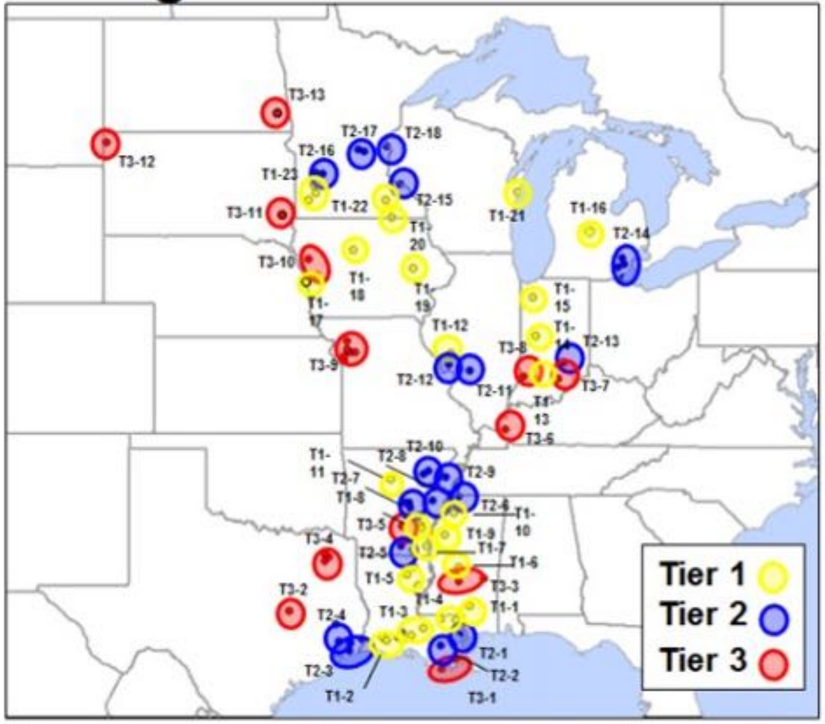
End

Definition of Grid Modernization

PUC Staff Proposal

"A modernized grid assures continued safe, reliable, and resilient utility network operations, and enables Minnesota to meet its energy policy goals, including the integration of variable renewable electricity sources and distributed energy resources. An integrated, modern grid provides for greater system efficiency and greater utilization of grid assets, enables the development of new products and services, provides customers with necessary information and tools to enable their energy choices, and supports a standards-based and interoperable utility network."

MISO Solar Siting

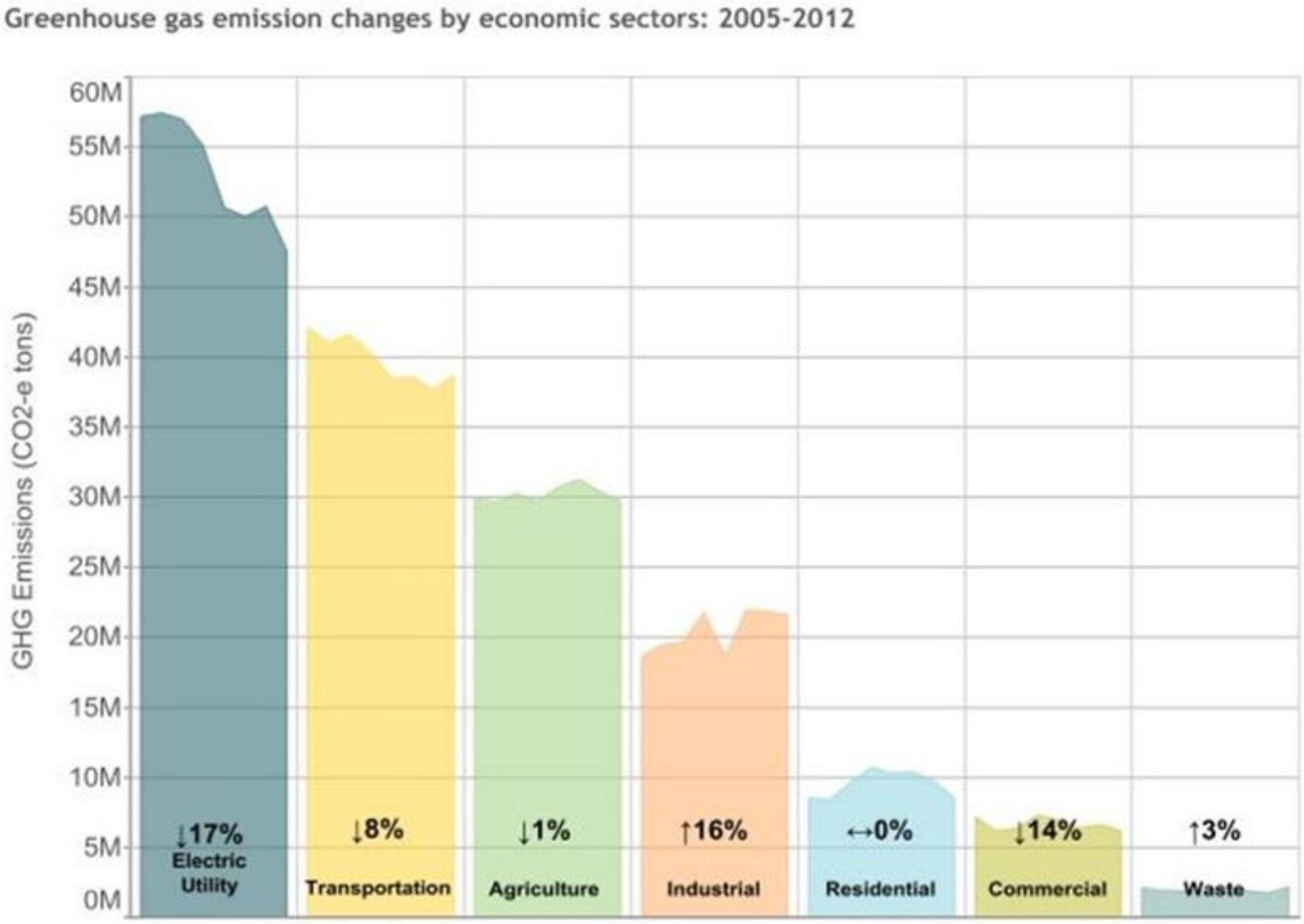


Note: Table represents capacity sited in solar tiers. Solar capacity additions split between tier and demand-side siting.

Solar Tier	Total Available Tier Capacity (MW)	Existing Fleet (MW)	Policy Regulations (MW)	Accelerated Alternative Technologies (MW)
Tier 1	4,600	1,600	4,600	4,600
Tier 2	5,400[1]	--	1,000	5,400
Tier 3	4,550[1]	--	--	4,400
Total	**14,550[1]**	**1,600**	**5,600**	**14,400**

[1] Total capacity scaled to accommodate solar capacity expansion in Accelerated Alternative Technologies future.

Sources of Greenhouse Gas Emissions in Minnesota



Source: MPCA 2015 Greenhouse Gas Emissions Reduction report

MN Renewable Energy Integration and Transmission Study (MRITS, 2014)

40% RPS in Minnesota

- Can be reliably accommodated with upgrades to existing transmission
- Wind and solar increase by 8.5 TWh, balanced by decrease in imports
- Very little change in conventional generation
- **MN-Centric region goes from net importer to net exporter**

50% RPS in Minnesota, 25% RPS in MISO North/Central

- Can be accomplished with more substantial transmission upgrades
- Increase in MN wind and solar balanced by decrease in coal, increase in exports
- Gas-fired, combined-cycle generation declines from 5.0 TWh to 3.0 TWh
- 2% of Minnesota wind curtailed in this scenario

Grid Modernization & Distribution Planning Law

H.F.3 (2015)

1. Applies to IOUs operating under a multi-year rate plan (Xcel)
2. Incorporates distribution grid modernization investment and planning into biennial transmission plan filing requirements
3. Utility must conduct distribution study to identify points for distributed generation and needed upgrades for DG
4. Xcel will file EPRI Hosting Capacity Analysis in December 2016
5. Utility must identify investment needed to modernize Transmission & Distribution to:
    - Improve reliability, security, conservation, and two-way communication between utility and customers
    - Through technology including energy storage

New Utility Business Models: e21 Initiative

Stakeholder-driven process

Led by Great Plains Institute & Center for Energy and Environment

Goal: "to develop a more customer-centric and sustainable framework for utility regulation, better aligning utility revenue with public policy goals, changing customer expectations, and the changing technology landscape."

Phase I Report (Dec. 2014)

Phase II Report (by end 2016): White papers on Grid Mod, Performance-Based Compensation, Integrated System Planning

Key White Paper Findings

Energy storage value driven primarily by:

- Distribution upgrade deferral
- Frequency regulation
- System capacity
- ITC and accelerated depreciation (MACRS)

1. Study limited in scope to certain distribution-connected use cases
2. Benefit to cost ratio could increase assuming: storage costs continue to decline & increased need for flexibility with more solar and wind
3. Storage has potential to provide multiple sources of value for customers and utilities—both economic value and in grid reliability.
4. Results subject to change based on tax policy changes, tariff changes, expansion of time-of-use energy prices, substantive changes in cost of storage, renewable energy, or conventional energy

White Paper Recommendations

1. Encourage cost recovery for storage + solar projects to defer distribution upgrades
2. Utility-controlled, customer-sited distribution upgrade deferral considered mitigation study under MRITS Study
3. Establish pilot projects to demonstrate benefits
4. Ensure projects can capture ITC benefits
5. Encourage MISO to establish clear process to value frequency regulation, other storage market products
6. Consider rate designs and demand response programs accounting for value of behind the meter storage
7. Utilities should define multiple options for control of systems and valuation metrics.

PUC: Grid Modernization

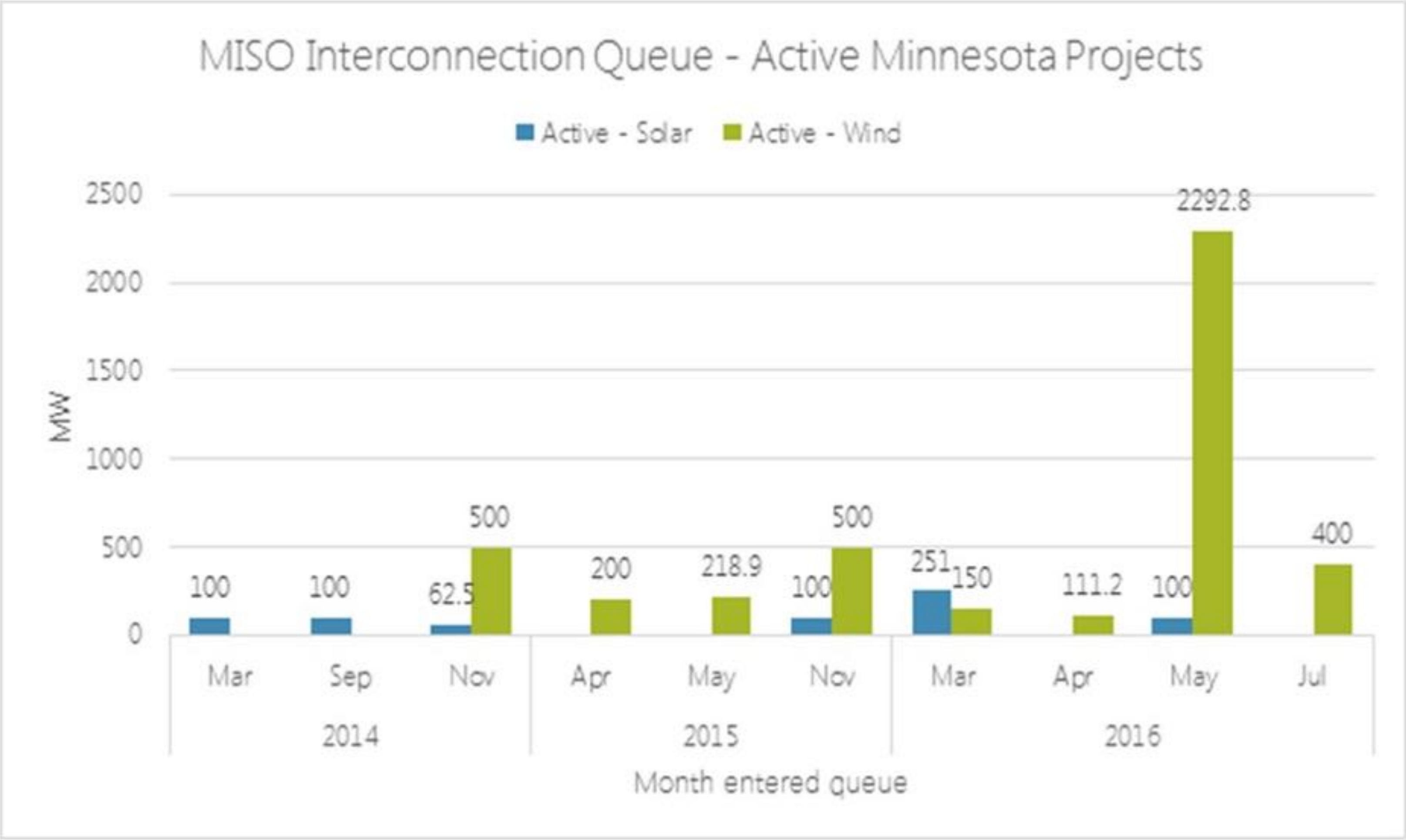
2015 Grid Modernization & Distribution Planning Law (June 2015)

PUC Initial Inquiry: Grid Modernization Presentation at May 12, 2015 meeting

PUC Grid Mod Stakeholder Meetings: 9/25/15, 10/30/15, 11/20/15

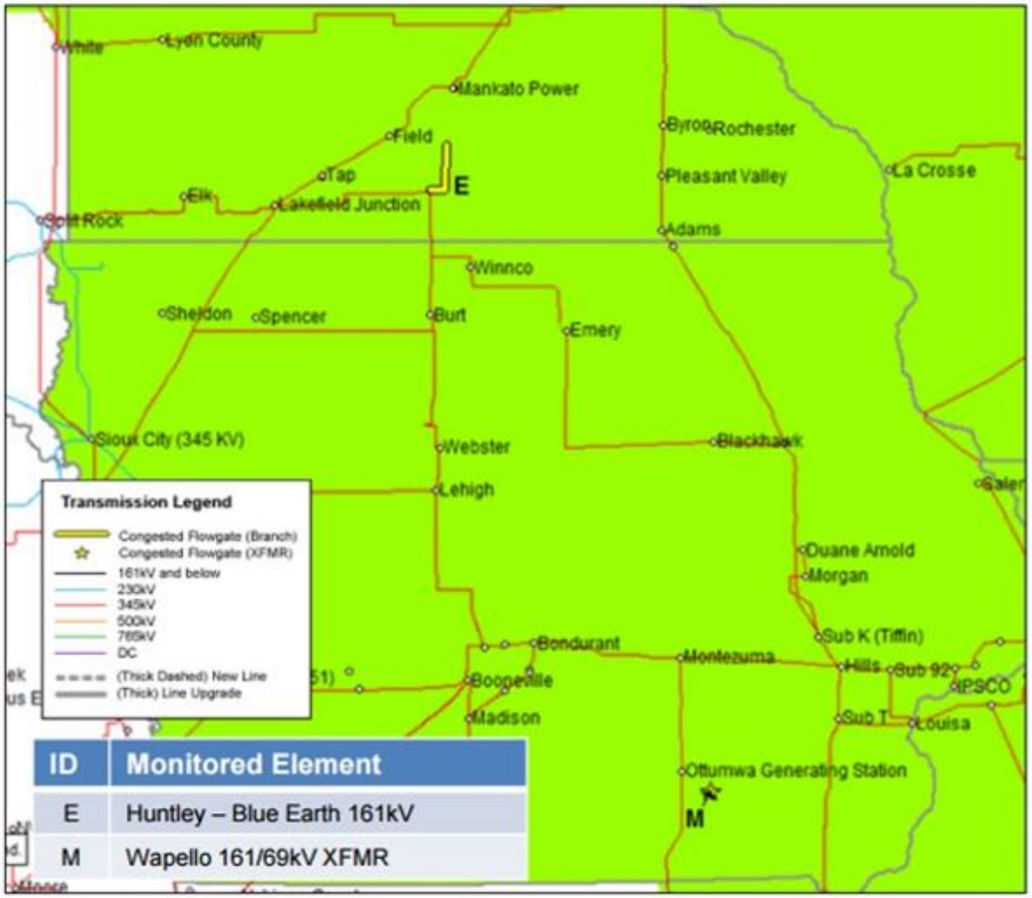
PUC Staff Report on Grid Mod (March 2016) Proposed Three-Phased Approach:

- Adopt Definition and Principles
- Potential Action Items
- Long-term Vision for Grid Mod



Source: MISO Interconnection Queue

Iowa/Minnesota Congestion



ID	Monitored Element
E	Huntley – Blue Earth 161kV
M	Wapello 161/69kV XFMR

- **Congestion driver for FG E**
  - Lower cost generation in Northern IA and Southern MN trying to serve Twin Cities load via Lakefield to Wilmarth 345kV
  - Future wind additions in IA/MN and coal retirement in MN tend to aggravate the congestion

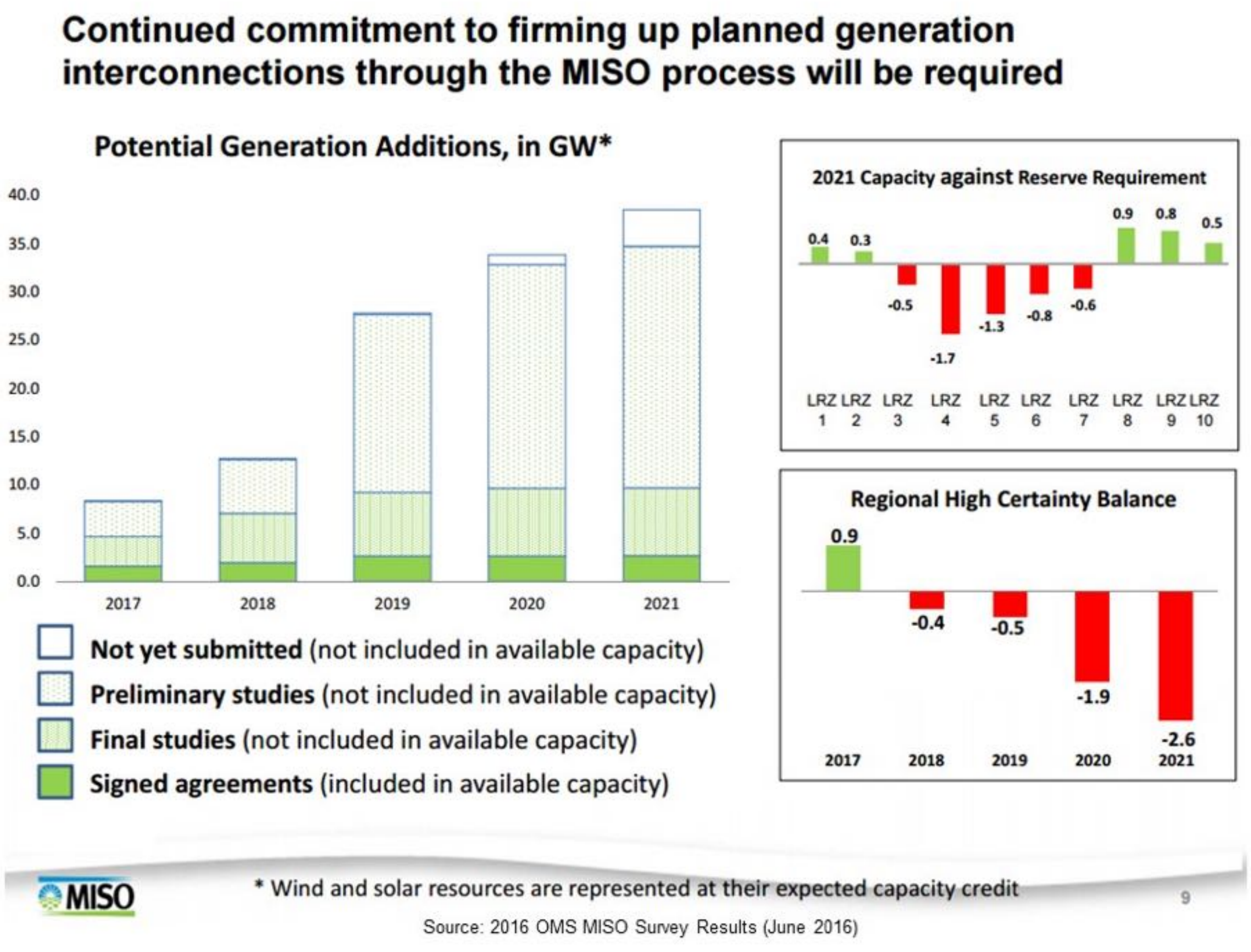
IRP Plans

Xcel 2015 Upper Midwest Resource Plan (Docket 15-21)(Before PUC)

- 1000-1,500 MW wind by 2020
- 650 MW solar by 2020
- First Sherco coal retire 2023
- Second Sherco coal retire 2026
- Analyze older CT's on system to avoid impact of forced outages
- Add CT in N.D. by end of 2025
- 3,200 MW new renewables by 2030

MN Power IRP (approved w/ modif. 7/18/16)

- 100-300 MW wind by end 2017
- 33 MW solar by 2025 (11 MW 2016, 12 MW 2020, 10 MW 2025)
- PUC: up to 100 MW solar by 2022 likely economic resource for MN Power must account for this in competitive acquisitions
- Wind + Manitoba Hydro (storage)



Continued commitment to firming up planned generation interconnections through the MISO process will be required

Potential Generation Additions, in GW*

☐ **Not yet submitted** (not included in available capacity)

▨ **Preliminary studies** (not included in available capacity)

▨ **Final studies** (not included in available capacity)

🟩 **Signed agreements** (included in available capacity)

2021 Capacity against Reserve Requirement

Regional High Certainty Balance

MISO

* Wind and solar resources are represented at their expected capacity credit

Source: 2016 OMS MISO Survey Results (June 2016)

12 Appendix D – Global Trends in Energy Storage (Strategen Consulting)

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Topics

What is energy storage?

Current state of energy storage (U.S. and globally)

Key trends and drivers

The rise of batteries

"Behind the meter" energy storage

Energy storage is a very broad asset class

Electro-Chemical

(Flow battery / Lithium Ion)

Mechanical

(Flywheel)

Bulk Mechanical

(CAES)

Thermal

(Ice / Molten Salt)

Bulk Gravitational

(Pumped Hydro)

Transportation

(Electric Vehicles)

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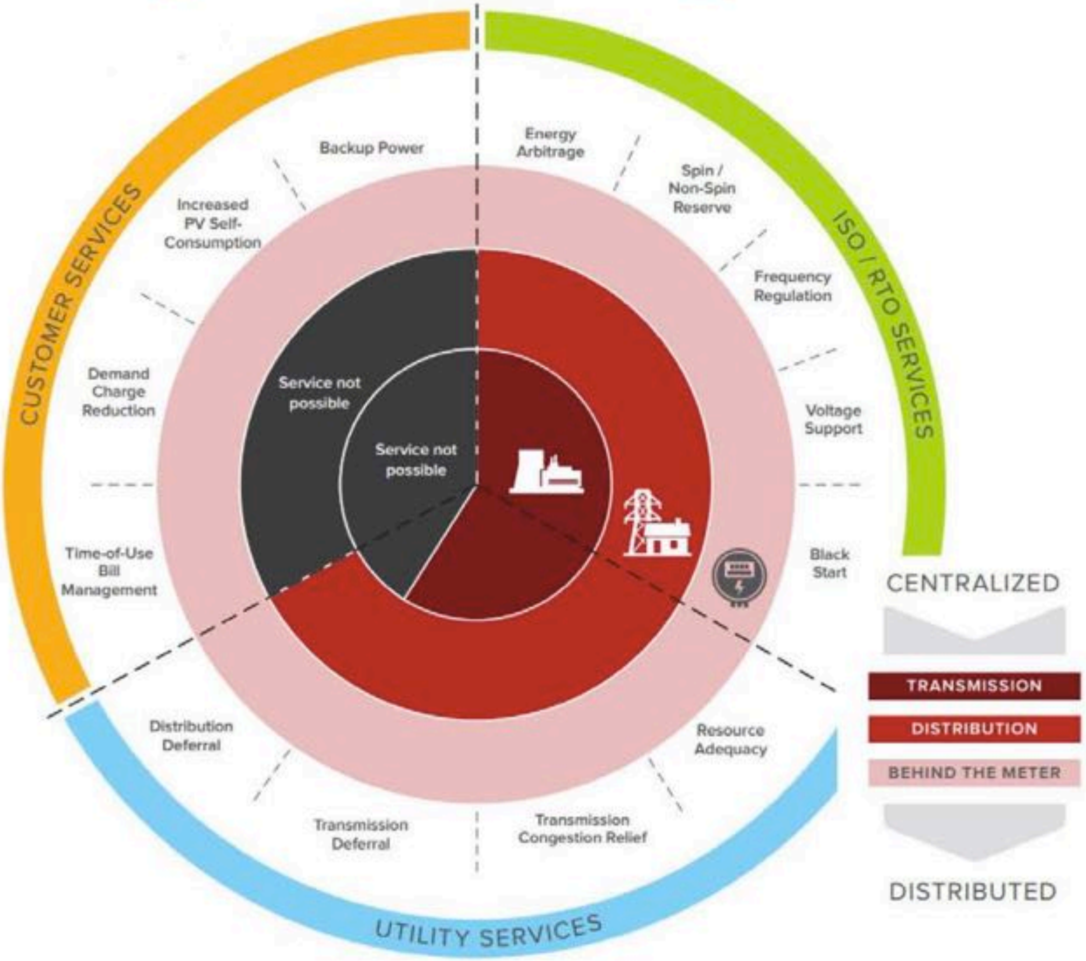
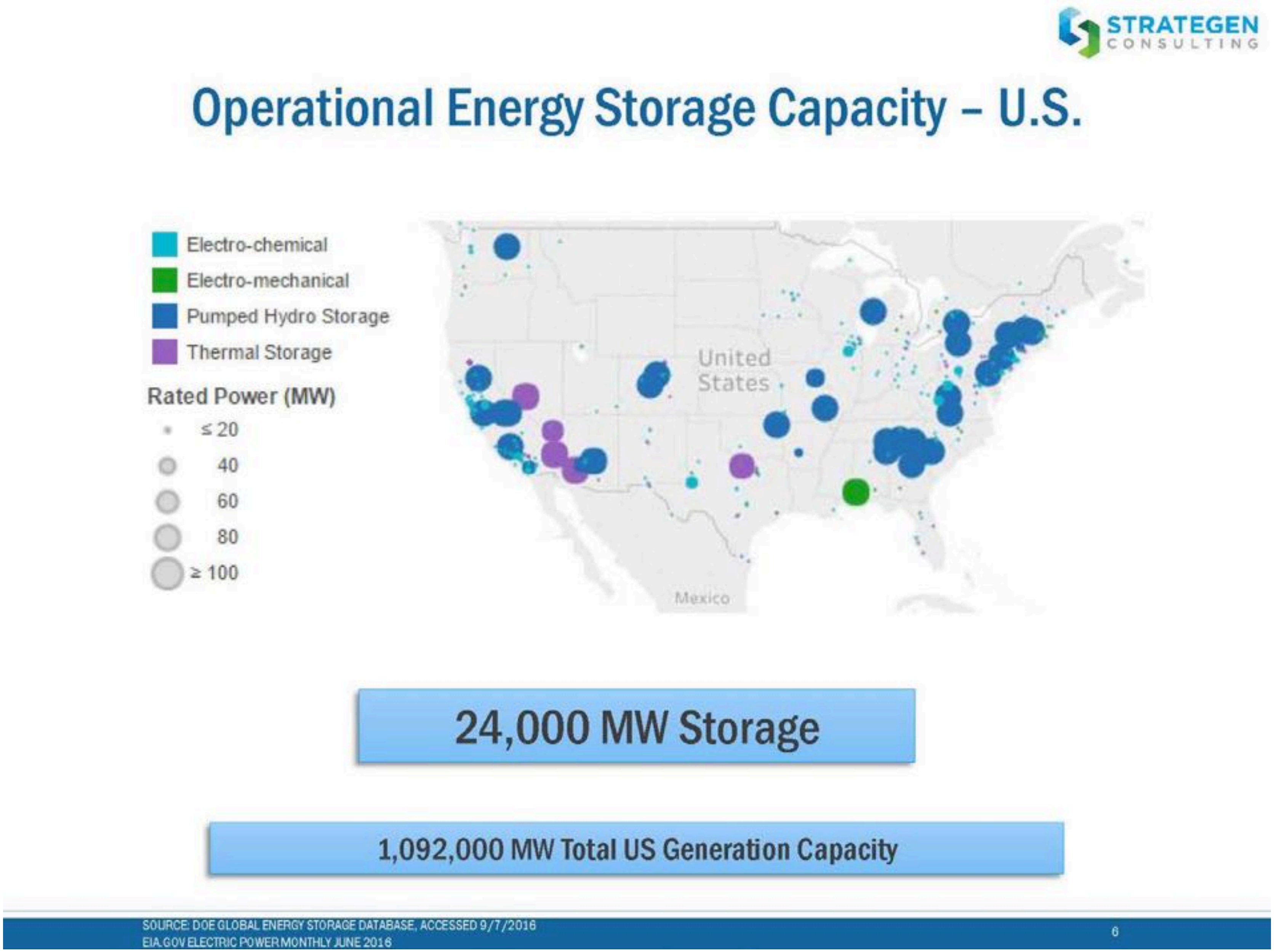
Storage can provide a range of services



SOURCE: HTTP://WWW.RMI.ORG/CONTENT/FILES/RMI-THEECONOMICSOFBATTERYENERGYSTORAGE-FULLREPORT-FINAL.PDF



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Operational Energy Storage Capacity – U.S.

24,000 MW Storage

1,092,000 MW Total US Generation Capacity

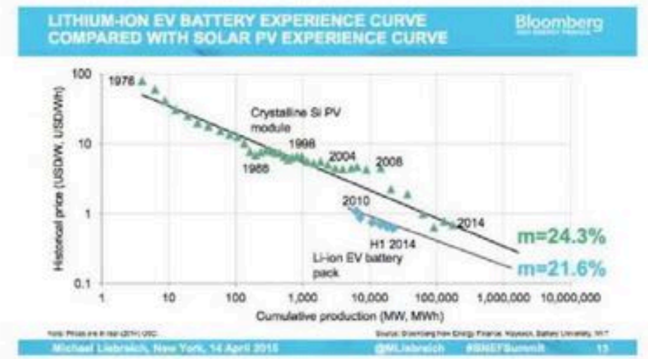
SOURCE: DOE GLOBAL ENERGY STORAGE DATABASE, ACCESSED 9/7/2016
EIA.GOV ELECTRIC POWER MONTHLY JUNE 2016

Where are we headed?

Chapter 1:
Demonstrations & Pilots

(most states are still here)

Many utilities are gaining "real-world" experience with storage deployment



Chapter 2:

Niche use case deployment

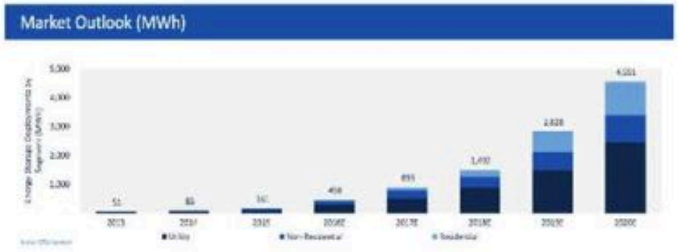
(some states are here now)

Special T&D deferral cases, high renewable penetration, load pocket constraints

Batteries Gaining Favor Over Gas Peaker Plants in California

Chapter 3:
Full deployment + Wholesale Market Opportunities

Widespread adoption and opportunities for wholesale market participation



Utility Investment Priorities

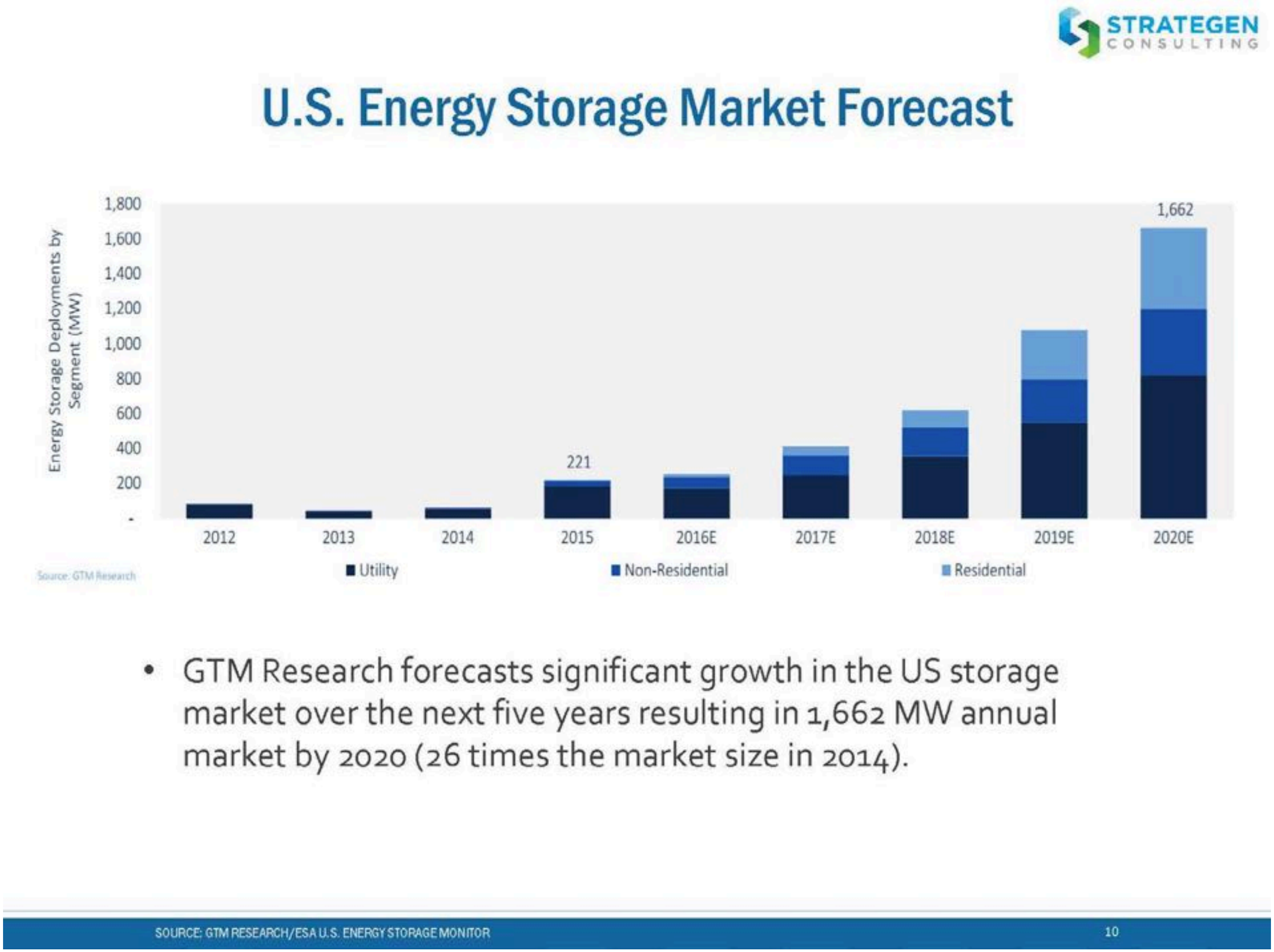
Survey: In which technologies do you think your utility should invest more?

65%	Energy storage
52%	Distibution generation
47%	Utility-scale renewables (solar & wind)
35%	Demand-side management
34%	Electric vehicle infrastructure

HTTP://WWW.UTILITYDIVE.COM/NEWS/THE-SECTOR-FAVORITE-STORAGE-TOPS-UTILITY-TECH-PICKS-FOR-SECOND-YEAR-RUNNIN/414304

*As much as **77% of utility executives** are already investing or plan to invest in storage solutions in the next 10 years.*

SOURCE: HTTP://SOLARINDUSTRYMAG.COM/UTILITY-EXECS-WEIGH-IN-ON-ENERGY-STORAGE-AND-SOLAR



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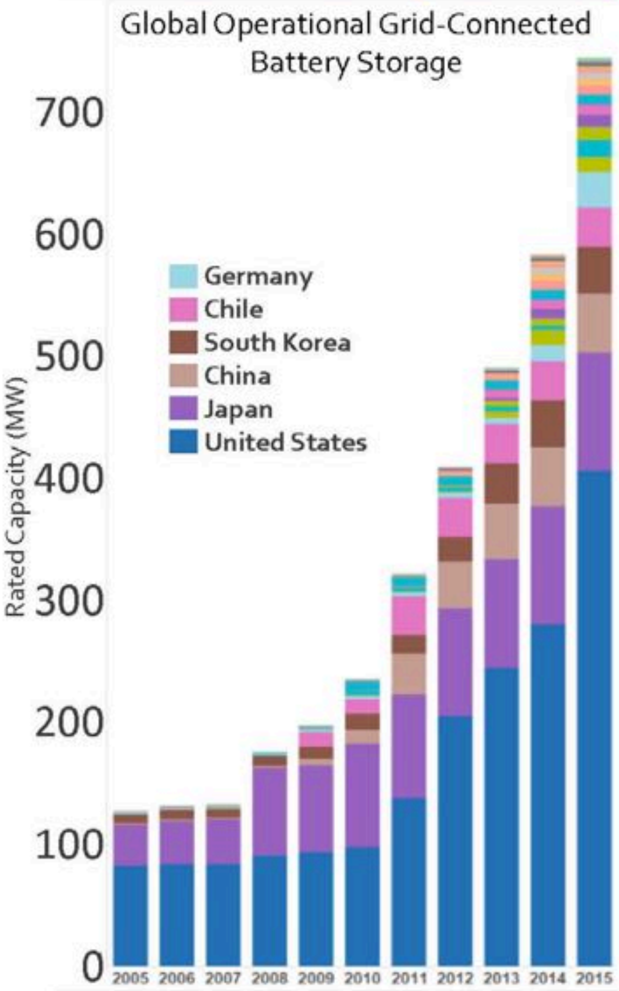
U.S. Energy Storage Market Forecast

Source: GTM Research

- GTM Research forecasts significant growth in the US storage market over the next five years resulting in 1,662 MW annual market by 2020 (26 times the market size in 2014).

SOURCE: GTM RESEARCH/ESA U.S. ENERGY STORAGE MONITOR

Global Battery Storage Market Trends



Japan & South Korea

- Ongoing issues with nuclear fleet; large installations of variable resources
- Both countries have storage targets and substantial development underway

China

- Substantial growth in renewables; rapid growth in storage since 2013
- Rapid growth in system capacity needs

EU

- Germany leads based on supportive regs, $260 MM funding, and nuclear decommissioning

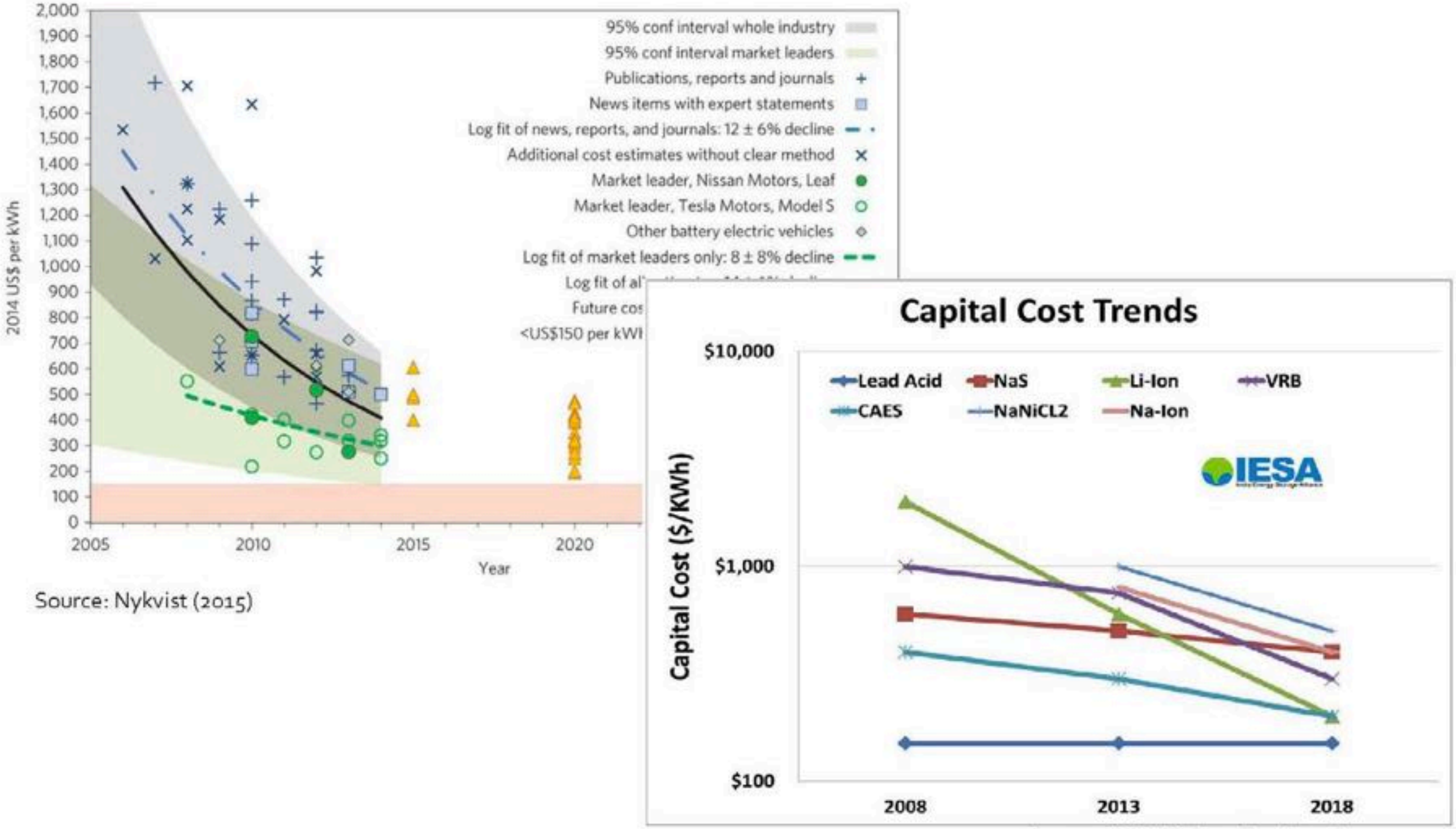
Australia

- Top global market for distributed storage
- Highest retail electricity rates in the Organization for Economic Cooperation and Development (OECD)

India

- Rapid "leapfrogging" of conventional grid with solar PV for grid electrification
- Like other industrializing nations, large opportunity for solar + storage / microgrids

Battery Technology Costs



Source: Nykvist (2015)

Source: IESA, Walawalkar (2014)

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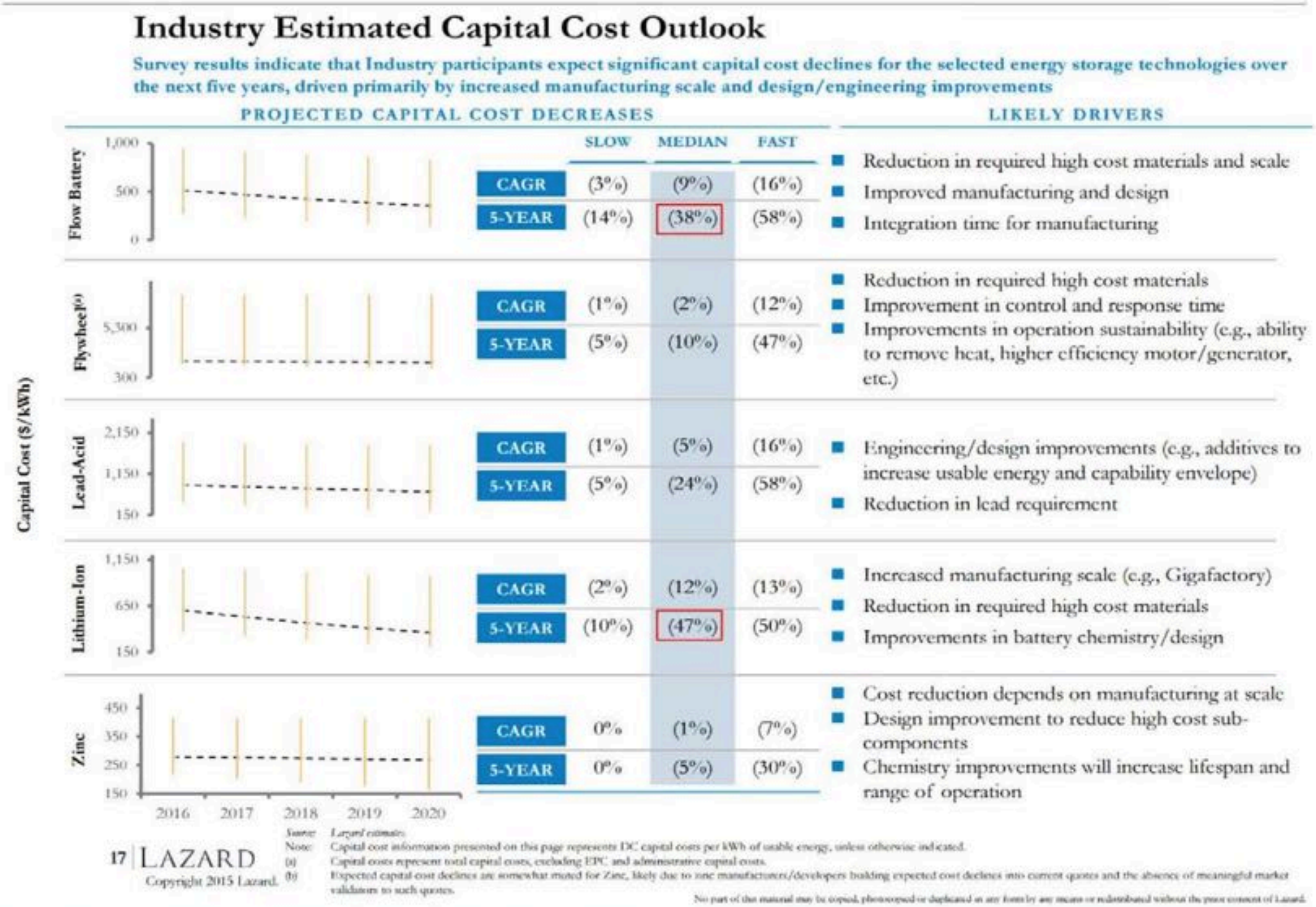
Five Year Outlook

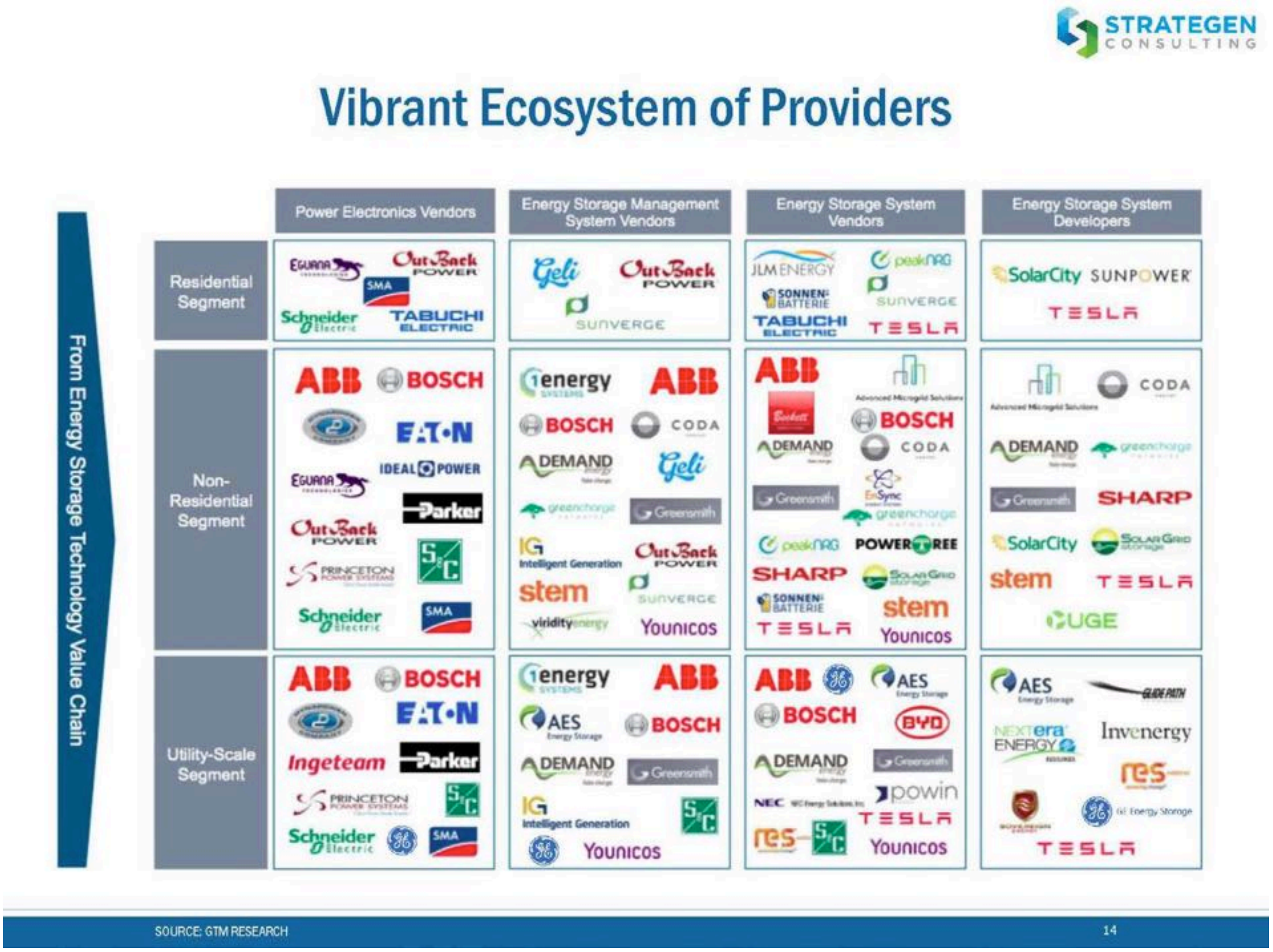


Industry Estimated Capital Cost Outlook

Survey results indicate that Industry participants expect significant capital cost declines for the selected energy storage technologies over the next five years, driven primarily by increased manufacturing scale and design/engineering improvements

		SLOW	MEDIAN	FAST	LIKELY DRIVERS
Flow Battery	CAGR	(3%)	(9%)	(16%)	■ Reduction in required high cost materials and scale ■ Improved manufacturing and design ■ Integration time for manufacturing
	5-YEAR	(14%)	(38%)	(58%)	
Flywheel(a)	CAGR	(1%)	(2%)	(12%)	■ Reduction in required high cost materials ■ Improvement in control and response time ■ Improvements in operation sustainability (e.g., ability to remove heat, higher efficiency motor/generator, etc.)
	5-YEAR	(5%)	(10%)	(47%)	
Lead-Acid	CAGR	(1%)	(5%)	(16%)	■ Engineering/design improvements (e.g., additives to increase usable energy and capability envelope) ■ Reduction in lead requirement
	5-YEAR	(5%)	(24%)	(58%)	
Lithium-Ion	CAGR	(2%)	(12%)	(13%)	■ Increased manufacturing scale (e.g., Gigafactory) ■ Reduction in required high cost materials ■ Improvements in battery chemistry/design
	5-YEAR	(10%)	(47%)	(50%)	
Zinc	CAGR	0%	(1%)	(7%)	■ Cost reduction depends on manufacturing at scale ■ Design improvement to reduce high cost sub-components ■ Chemistry improvements will increase lifespan and range of operation
	5-YEAR	0%	(5%)	(30%)	

Source: *Lazard estimates.*
Note: Capital cost information presented on this page represents DC capital costs per kWh of usable energy, unless otherwise indicated.
(a) Capital costs represent total capital costs, excluding EPC and administrative capital costs.
(b) Expected capital cost declines are somewhat muted for Zinc, likely due to zinc manufacturers/developers building expected cost declines into current quotes and the absence of meaningful market validators to such quotes.



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Vibrant Ecosystem of Providers

From Energy Storage Technology Value Chain

	Power Electronics Vendors	Energy Storage Management System Vendors	Energy Storage System Vendors	Energy Storage System Developers
Residential Segment	Eguana Technologies OutBack Power SMA Schneider Electric Tabuchi Electric	Geli OutBack Power Sunverge	JLM Energy peakNRG Sonnen Batterie Sunverge Tabuchi Electric Tesla	SolarCity SunPower Tesla
Non-Residential Segment	ABB Bosch Eaton Ideal Power Eguana Technologies Parker OutBack Power S&C Princeton Power Systems Schneider Electric SMA	1energy Systems ABB Bosch Coda Demand Energy Geli greencharge networks Greensmith IG Intelligent Generation OutBack Power stem Sunverge viridity energy Younicos	ABB Advanced Microgrid Solutions Bosch Demand Energy Coda Greensmith EnSync greencharge networks peakNRG Power Tree Sharp SolarGrid Storage Sonnen Batterie stem Tesla Younicos	Advanced Microgrid Solutions Coda Demand Energy greencharge networks Greensmith Sharp SolarCity SolarGrid Storage stem Tesla UGE
Utility-Scale Segment	ABB Bosch Eaton Ingeteam Parker Princeton Power Systems S&C Schneider Electric GE SMA	1energy Systems ABB AES Energy Storage Bosch Demand Energy Greensmith IG Intelligent Generation S&C GE Younicos	ABB GE AES Energy Storage Bosch BYD Demand Energy Greensmith NEC Energy Solutions, Inc. powin Tesla res S&C Younicos	AES Energy Storage Glide Path NextEra Energy Resources Invenergy res GE Energy Storage Tesla

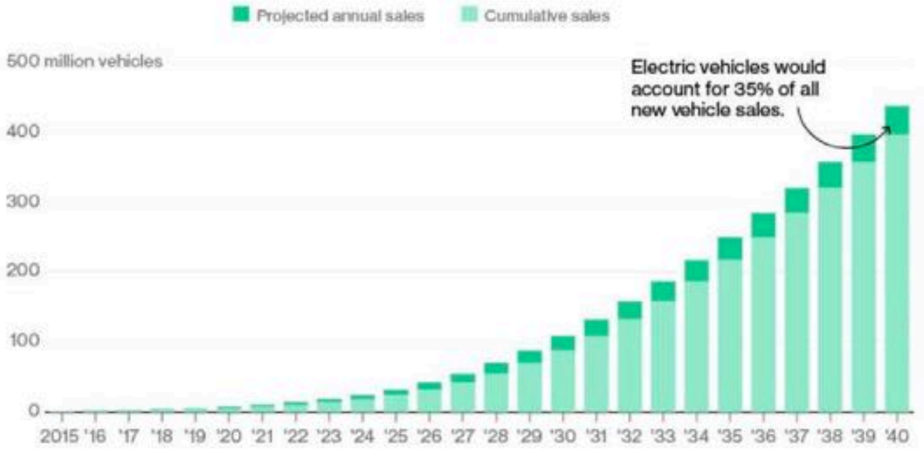
SOURCE: GTM RESEARCH

The Importance of Demand

- Modest sales of EV/hybrids can have significant impact on global cell production.

The Rise of Electric Cars

By 2022 electric vehicles will cost the same as their internal-combustion counterparts. That's the point of liftoff for sales.



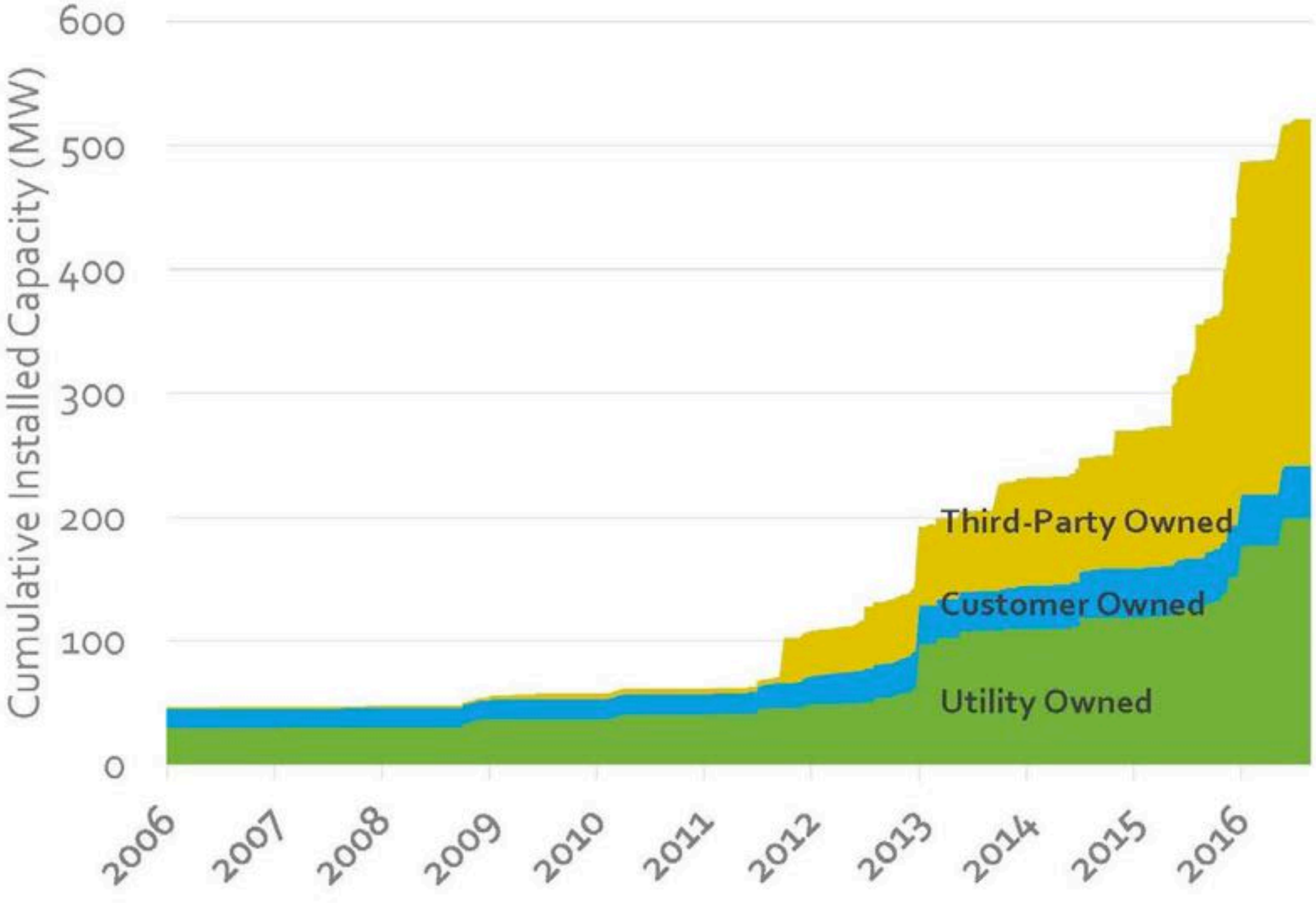
Sources: Data compiled by Bloomberg New Energy Finance, Marklines

Bloomberg

- If just 1 in 10 cars have hybrid/electric capability the demand will be equal to all 2015 global cell demand
- 2015 EV/hybrid demand equates to 2.6 million Powerwalls
- Currently, significant underutilization in global cell production

SOURCE: CEMAC REPORT TO DOE

Grid-Connected Battery Storage Projects in the U.S.

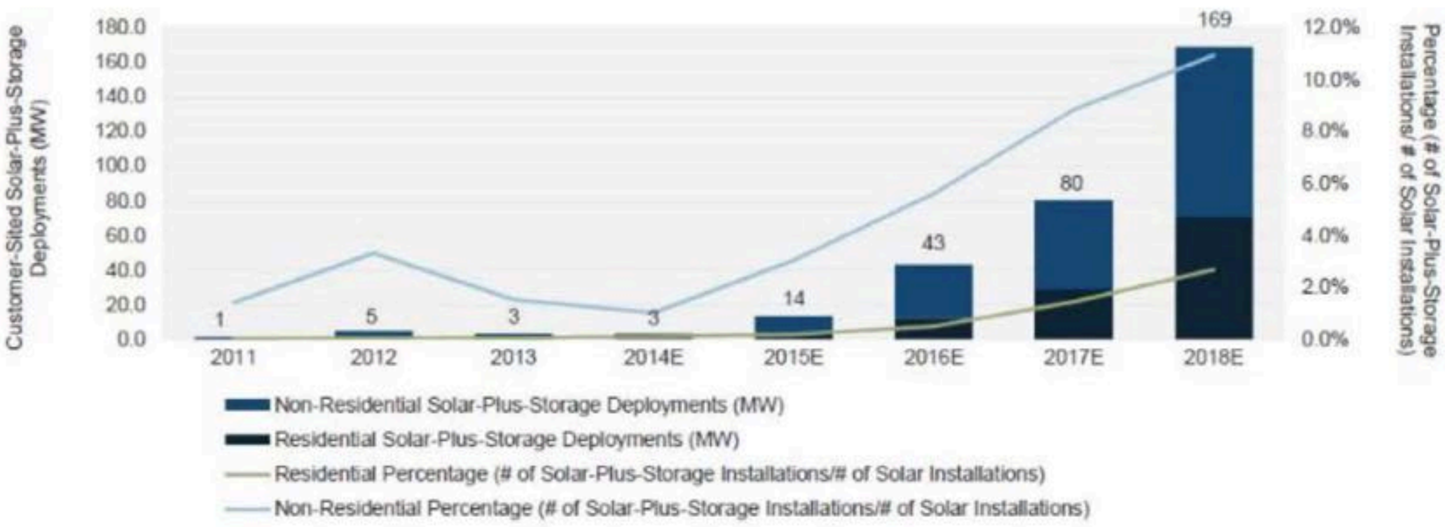


SOURCE: DOE GLOBAL ENERGY STORAGE DATABASE ACCESSED 9/7/2016

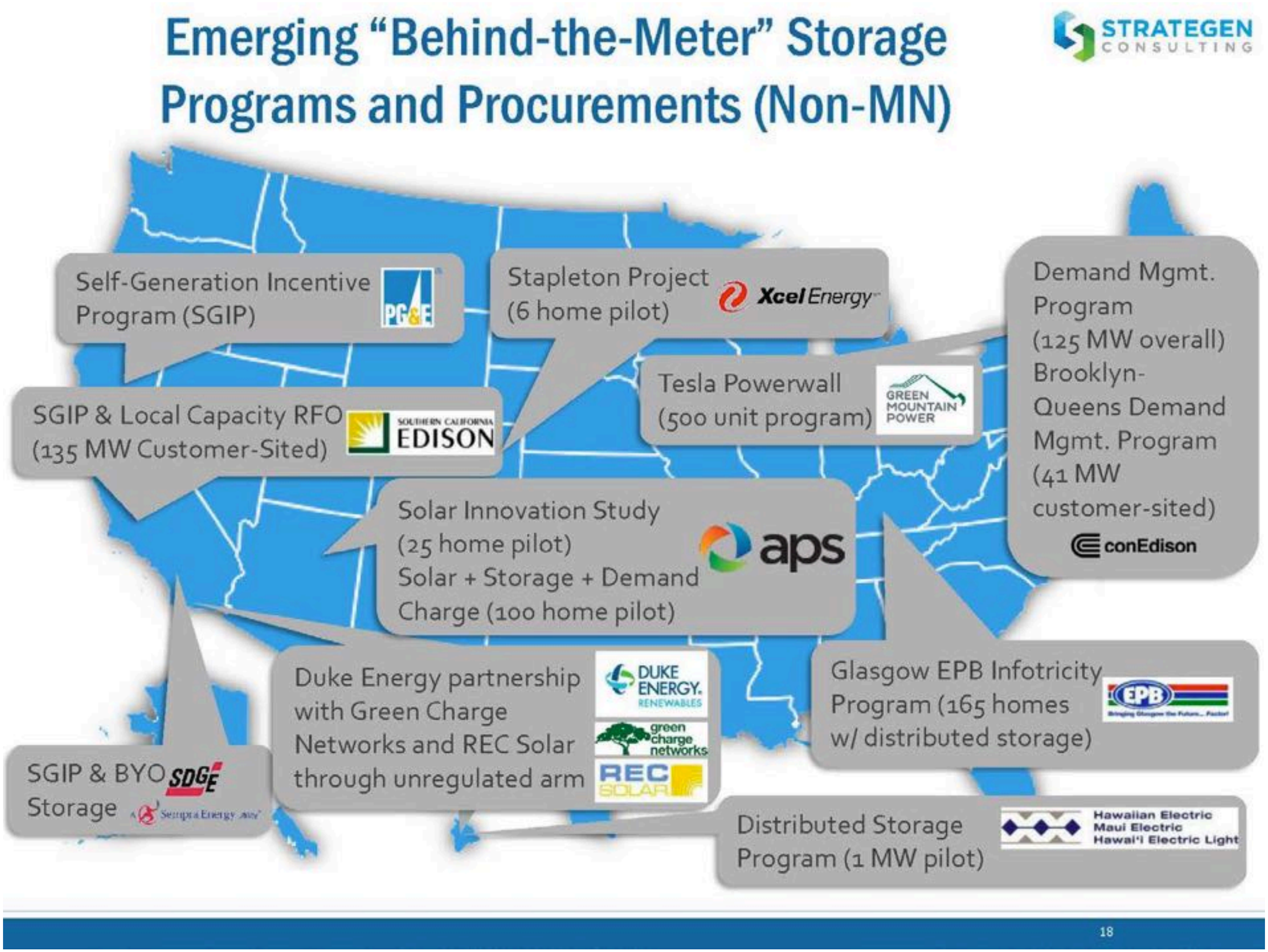
BTM Technologies are Merging

Customer-Sited Solar-Plus-Storage Forecasts

Annual U.S. Market to Reach 170 MW by 2018



Source: GTM Research Q2 2015 U.S, Energy Storage Monitor



Emerging "Behind-the-Meter" Storage Programs and Procurements (Non-MN)

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Self-Generation Incentive Program (SGIP) PG&E

Stapleton Project (6 home pilot) Xcel Energy

Demand Mgmt. Program (125 MW overall) Brooklyn-Queens Demand Mgmt. Program (41 MW customer-sited) conEdison

Tesla Powerwall (500 unit program) GREEN MOUNTAIN POWER

SGIP & Local Capacity RFO (135 MW Customer-Sited) SOUTHERN CALIFORNIA EDISON

Solar Innovation Study (25 home pilot)
Solar + Storage + Demand Charge (100 home pilot) aps

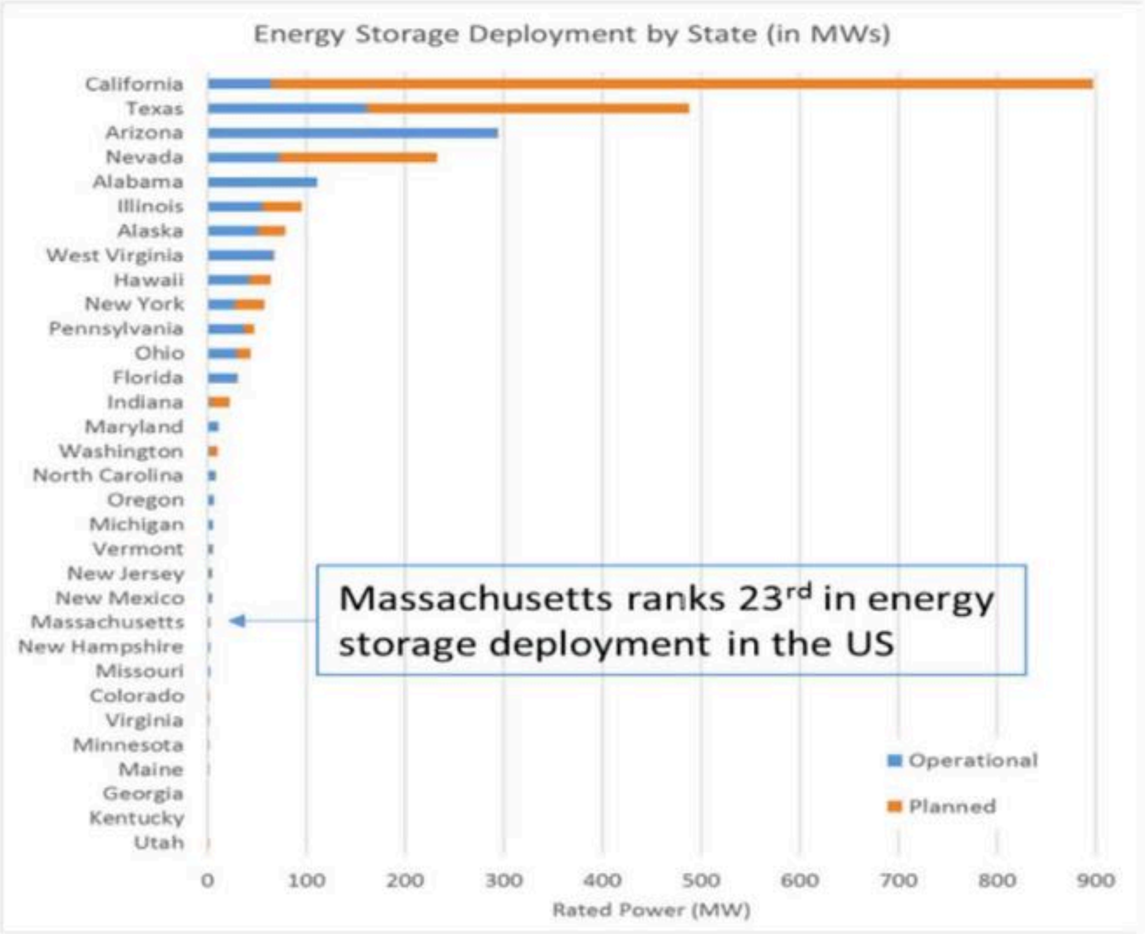
Duke Energy partnership with Green Charge Networks and REC Solar through unregulated arm DUKE ENERGY. RENEWABLES green charge networks REC SOLAR

Glasgow EPB Infotricity Program (165 homes w/ distributed storage) EPB

SGIP & BYO Storage SDG&E A Sempra Energy utility

Distributed Storage Program (1 MW pilot) Hawaiian Electric Maui Electric Hawai'i Electric Light

Massachusetts



Energy Storage Deployment by State (in MWs)

Massachusetts ranks 23rd in energy storage deployment in the US

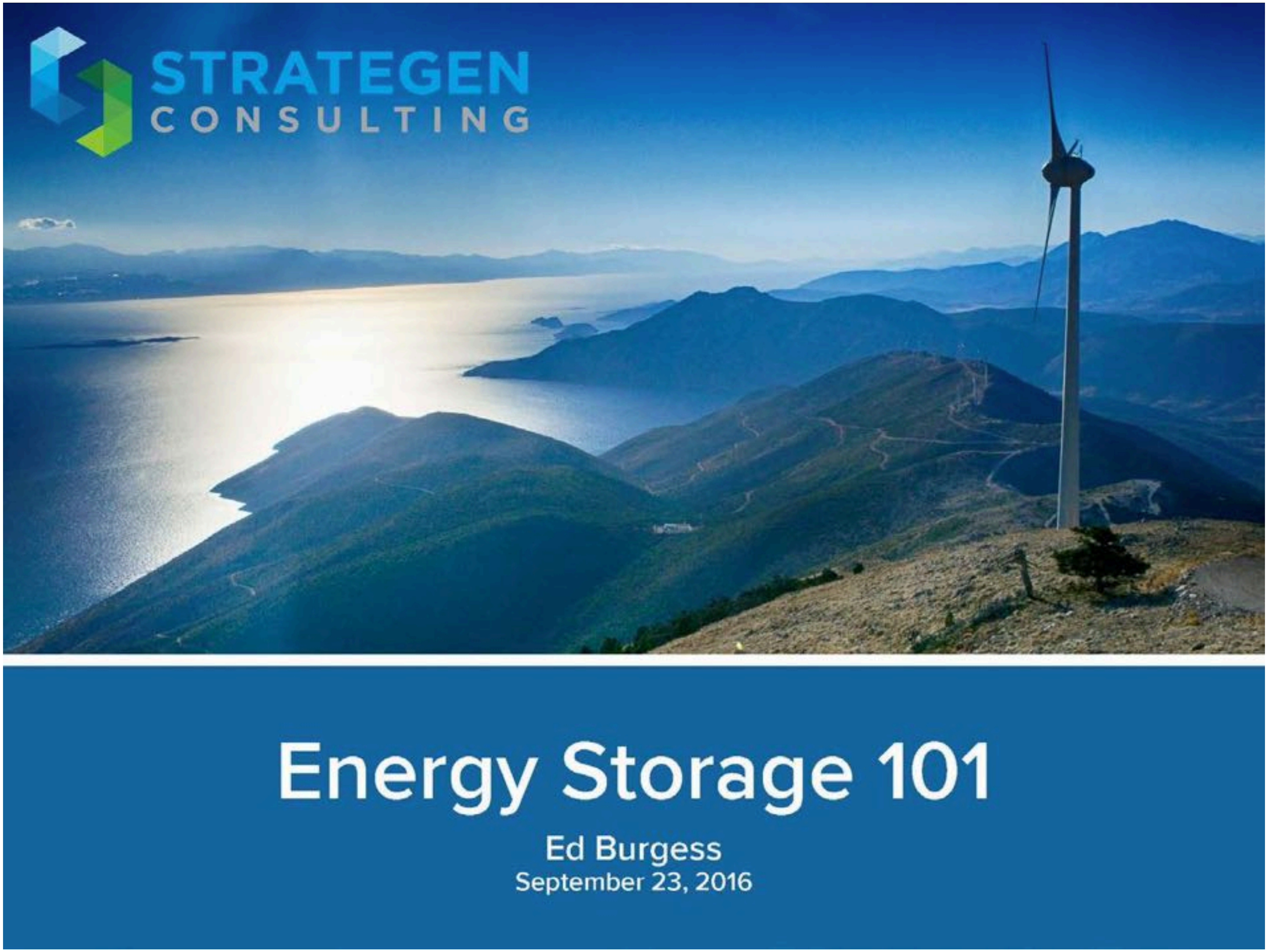
More Information

Thank you!

Lon Huber
Director
Strategen Consulting, LLC

- Email: lhuber@strategen.com
- Phone: 928-380-5540

13 Appendix E – Energy Storage 101 (Strategen Consulting)



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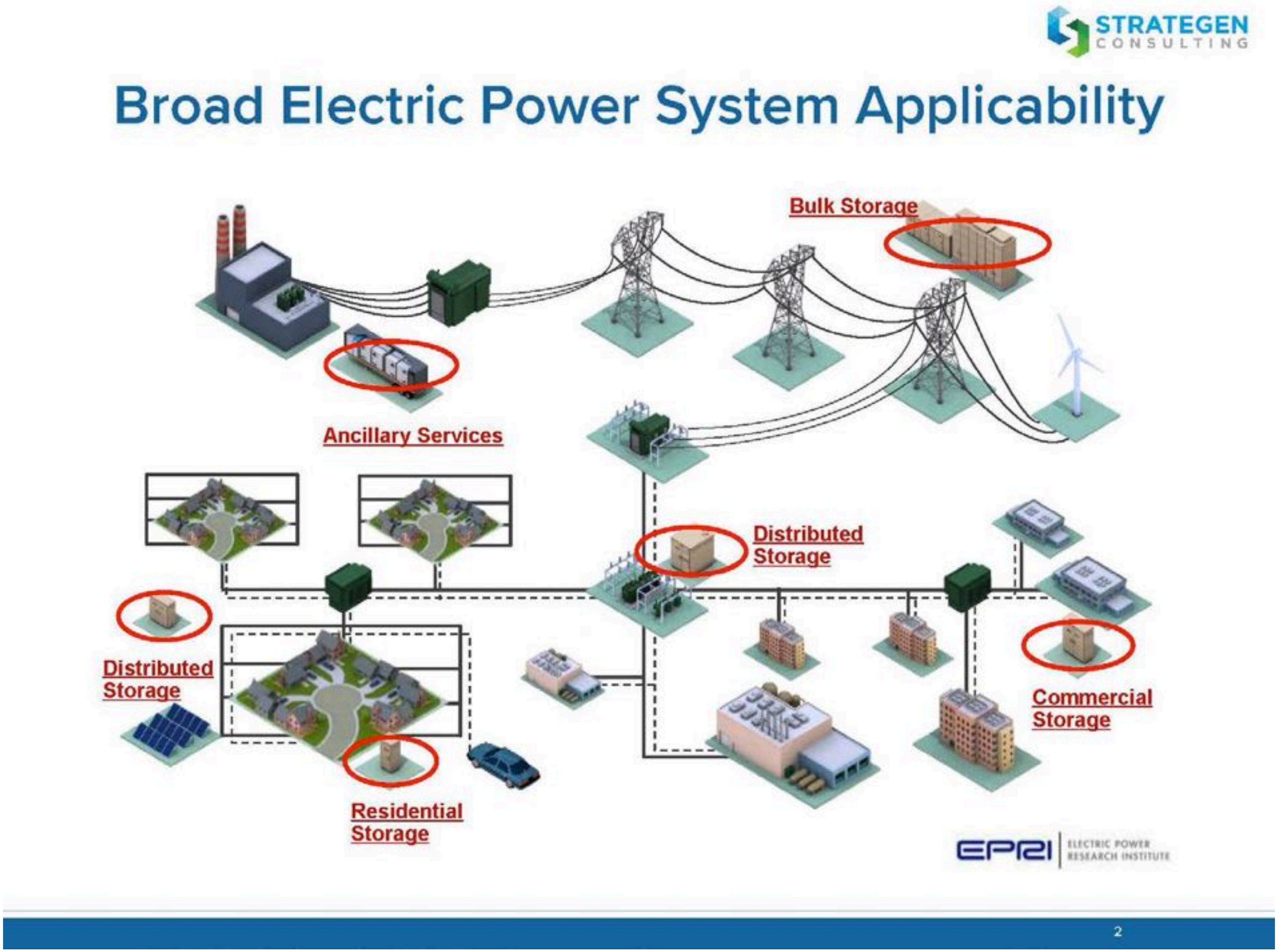
Energy Storage 101

Ed Burgess
September 23, 2016



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Broad Electric Power System Applicability

EPRI ELECTRIC POWER RESEARCH INSTITUTE

Energy Storage Can Cut Across Multiple Silos

T&D Planning

- Transmission Asset Deferral
- Distribution Asset Deferral

Resource Planning

- System Capacity
- Flexibility / Ancillary Services
- Fleet Optimization

Customer Programs

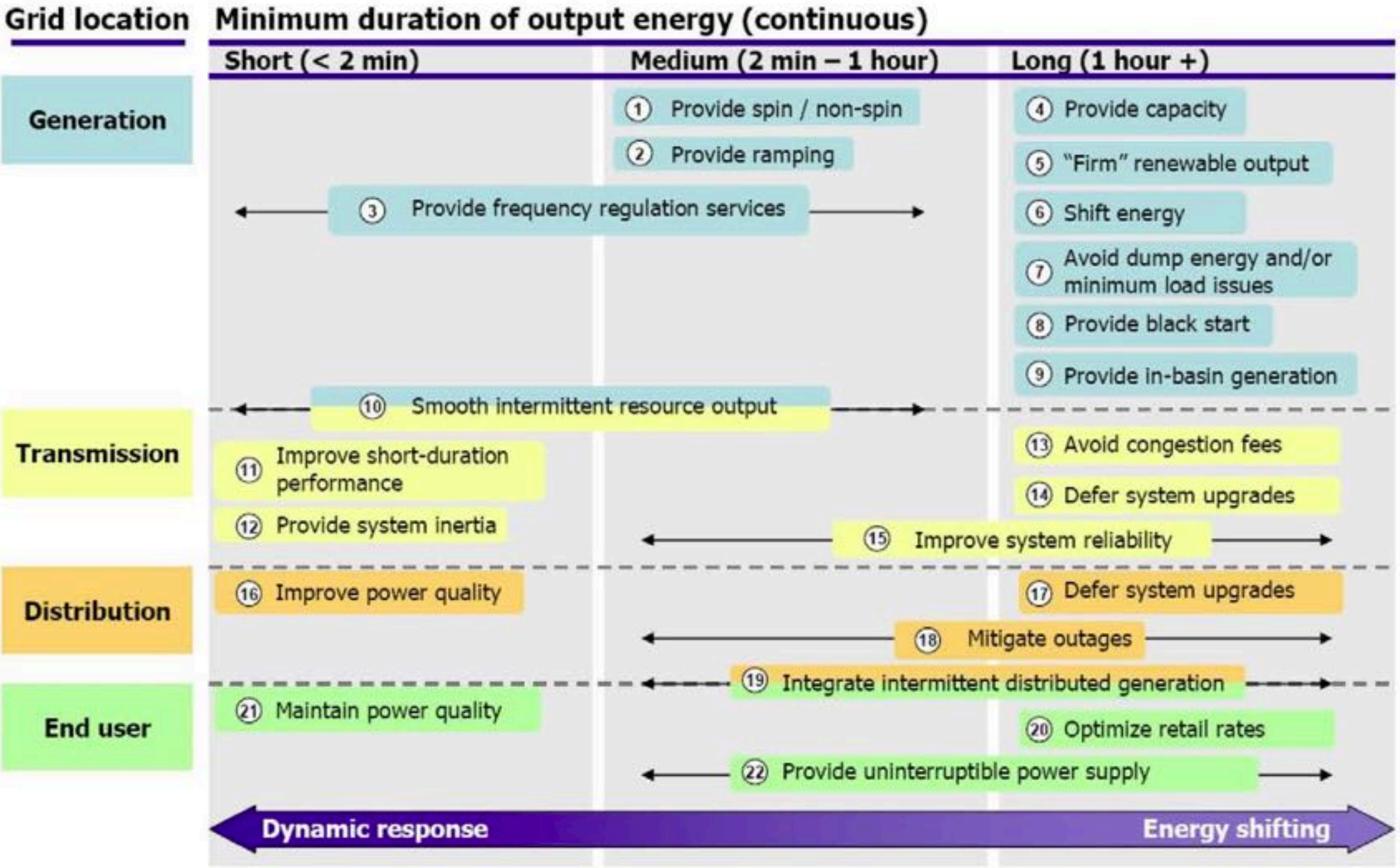
- Customer Bill Management
- Demand Response Participation
- DER/EV interconnection cost management

» Storage has potential to lower ratepayer costs and to increase grid reliability.

» Storage is not always cost effective based on a single use case, however stacking multiple benefits can increase cost effectiveness.

» Key challenge: identifying primary system need, then identifying secondary benefits that storage can also provide.

Operational Use Cases For Storage Systems



Minimum duration of output energy (continuous)

Grid location	Short (< 2 min)	Medium (2 min – 1 hour)	Long (1 hour +)
Generation	← ③ Provide frequency regulation services →	① Provide spin / non-spin ② Provide ramping	④ Provide capacity ⑤ "Firm" renewable output ⑥ Shift energy ⑦ Avoid dump energy and/or minimum load issues ⑧ Provide black start ⑨ Provide in-basin generation
Transmission	← ⑩ Smooth intermittent resource output → ⑪ Improve short-duration performance ⑫ Provide system inertia	← ⑮ Improve system reliability →	⑬ Avoid congestion fees ⑭ Defer system upgrades
Distribution	⑯ Improve power quality	← ⑱ Mitigate outages →	⑰ Defer system upgrades
End user	㉑ Maintain power quality	← ⑲ Integrate intermittent distributed generation → ← ㉒ Provide uninterruptible power supply →	⑳ Optimize retail rates

SOURCE: SCE 2011, HTTPS://WWW.EDISON.COM/CONTENT/DAM/EIX/DOCUMENTS/INNOVATION/SMART-GRIDS/ENERGY-STORAGE-CONCEPT-TO-REALITY-EDISON.PDF

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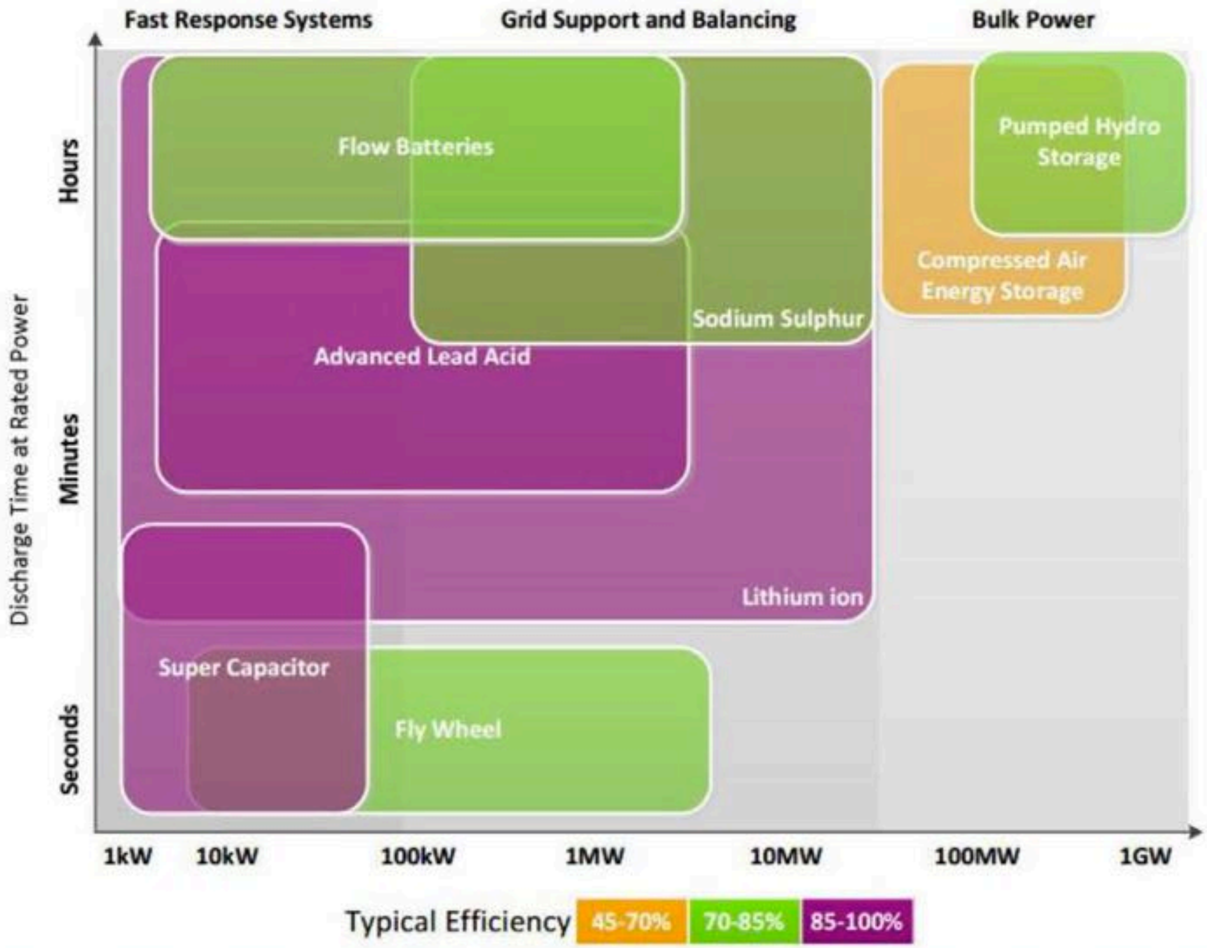
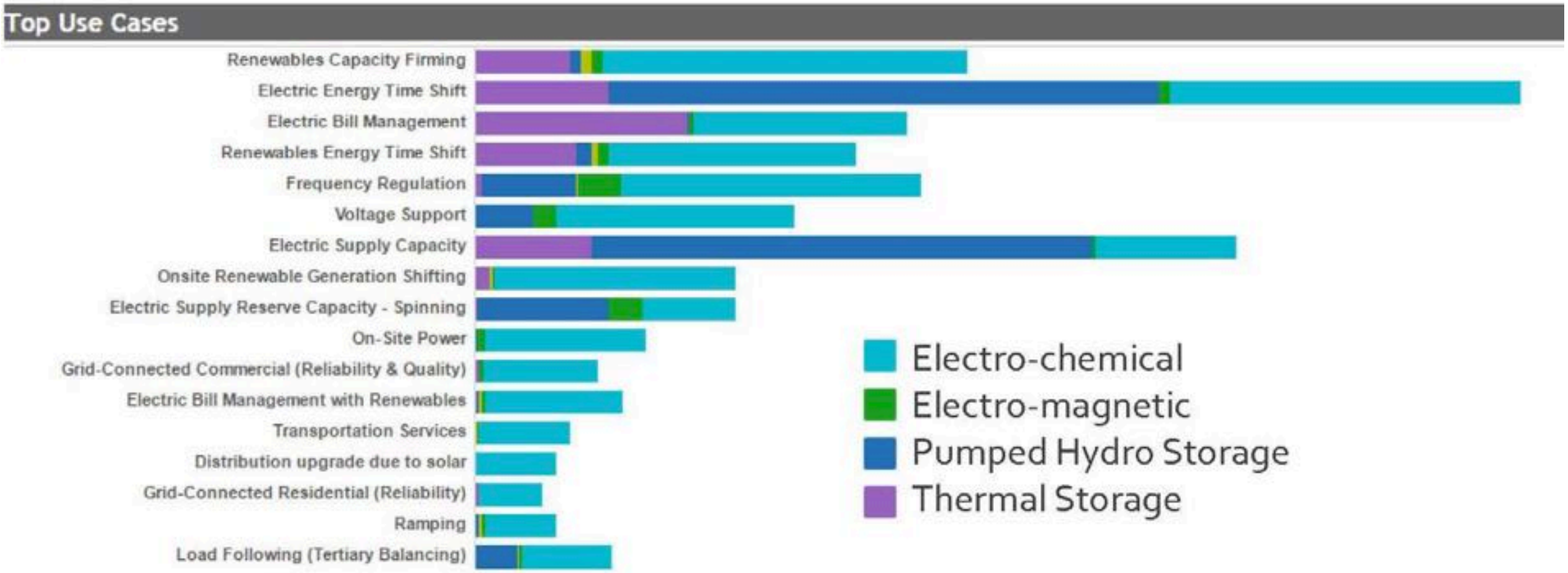
Size and Duration by Technology/Application



Source: Australian Renewable Energy Agency (7/2015): *Energy Storage Study Funding and Knowledge Sharing Priorities*

Energy Storage Use Cases (2010 – 2015)*

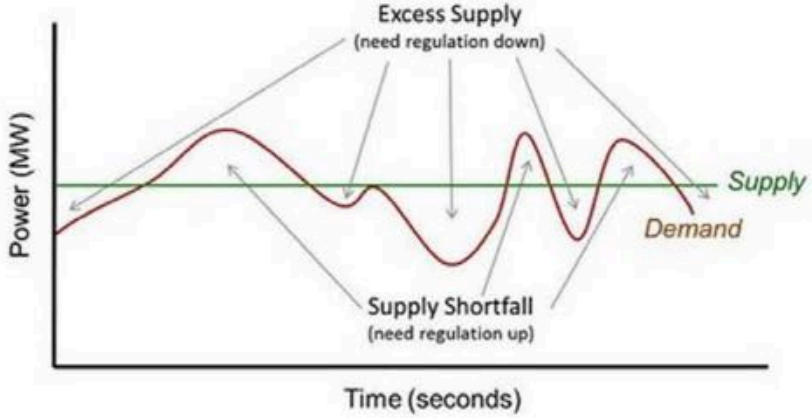


** - Chart reflects data collected from the DOE Global Energy Storage Database Accessed 2/16/2016. Database entries are self reported and use case categories are not mutually exclusive.*

SOURCE: DOE ENERGY STORAGE DATABASE ACCESSED 9/7/2016

Use Case Example #1: Frequency Regulation

- In order to synchronize generation assets to the AC grid, frequency must be held with tight tolerance bounds around 60 Hertz.



- ***Inverter-based resources such as energy storage can respond more quickly than conventional resources.***

Service	Response time	Resources
Frequency Regulation	Dispatched to correct ACE; **Response time up to 5 minutes**	**Thermal generation,** demand response
"Fast" Frequency Regulation	Dispatched to correct ACE; **Typical response time is 1-30 seconds**	**Storage,** some demand response

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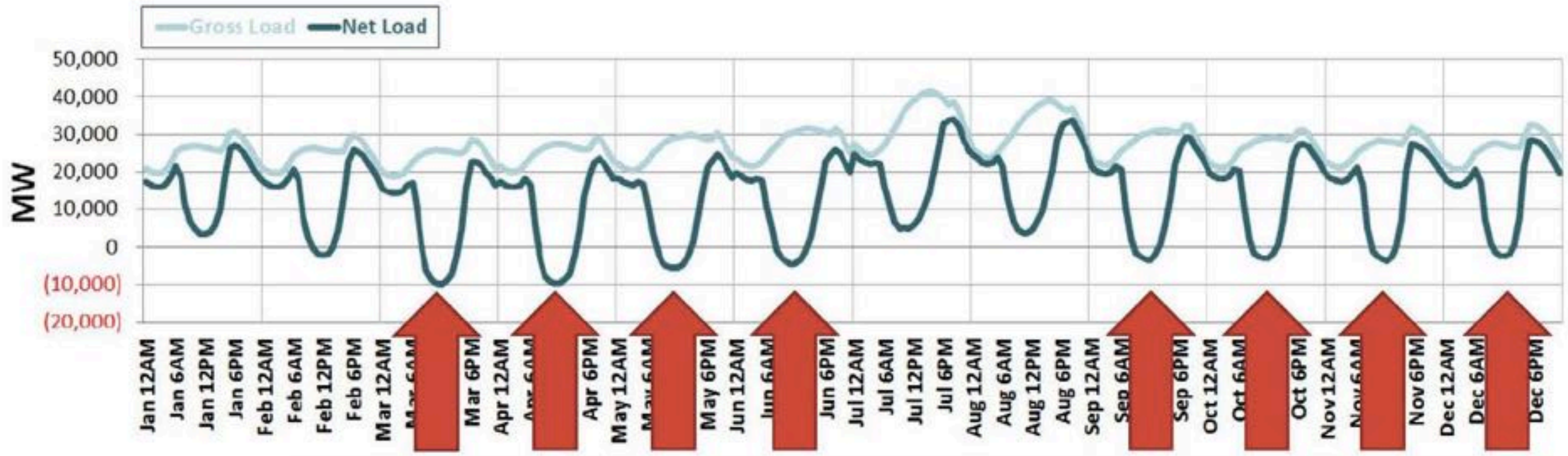
Use Case Example #2: Avoid Curtailment/Overgeneration

Figure 17: Illustration of Average Load, Renewables, and Reserve Profiles in CAISO

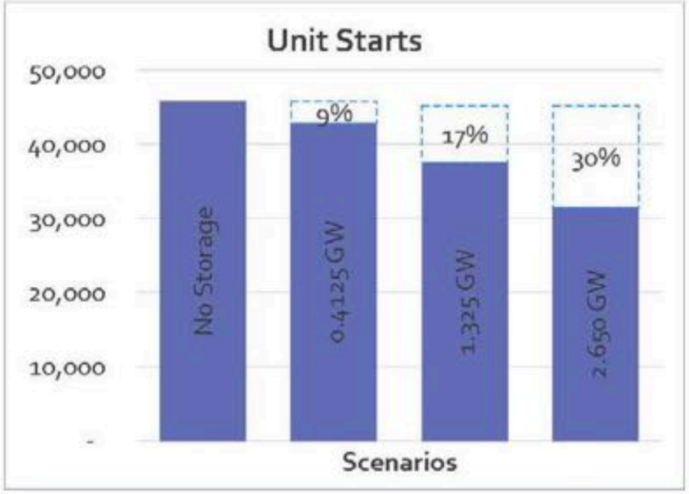
(2030, by Month and Hour of Day)



Potential Over-generation

Source: https://www.caiso.com/Documents/SB350Study-Volume5ProductionCostAnalysis.pdf

Results of CA Grid Model with Storage



- Small amounts of energy storage equivalent to 0.5% to 3.4% of peak capacity results in 9% to 30% reduction in unit starts
- Unit starts tend to be emissions intensive as well as costly

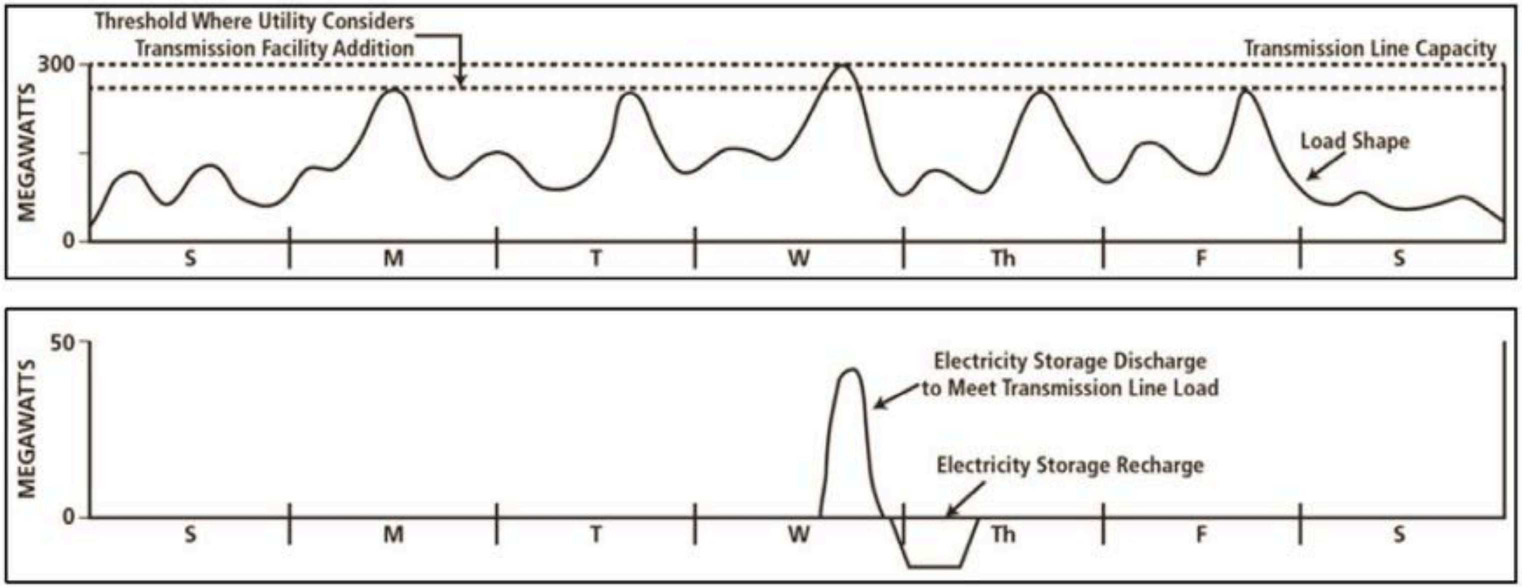
	Only 2 hour storage	2, 4, & 6 hour storage	2, 4, & 6 hour storage
% of total CA Generation Capacity	0.5%	1.7%	3.4%
Curtailment Reduction in CA (kWh)	8.1%	23.3%	40.0%

Source: California Energy Storage Alliance

Use Case Example #3: T&D Upgrade Deferral

Incremental amounts of storage can defer the need for new T&D equipment

Dispatch for Transmission Deferral



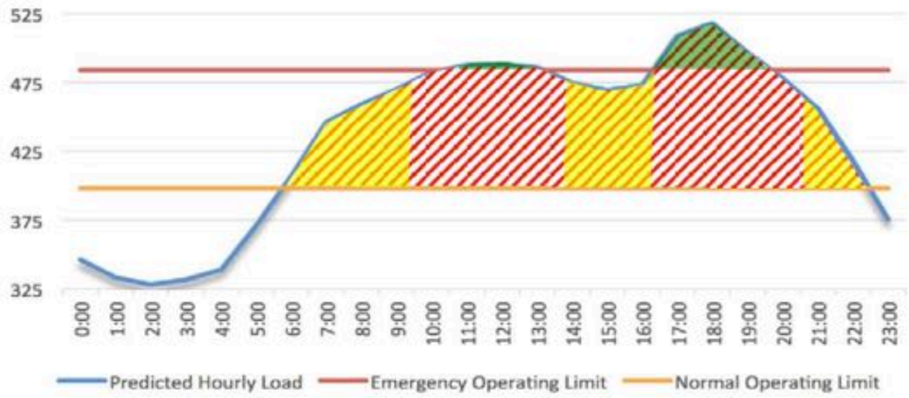
» Storage is only a fit for T&D deferral in specific circumstances – recent examples:

- Con Edison Brooklyn-Queens Initiative
- PG&E Distribution Deferral Solicitation
- Boothbay Maine Pilot Project

SOURCE: DOE/EPRI 2013 ELECTRICITY STORAGE HANDBOOK IN COLLABORATION WITH NRECA, 2013 (FIGURE 11. STORAGE FOR TRANSMISSION AND DISTRIBUTION DEFERRAL)

Case Study: Puget Sound Energy Non-Wires Alternative

Graphical Representation of Eastside Overload Scenario, 2021-2022 Winter Case (in MW)*



Baseline Configuration
- Solves for Green + Yellow

Alternate #1
- Solves for Green only

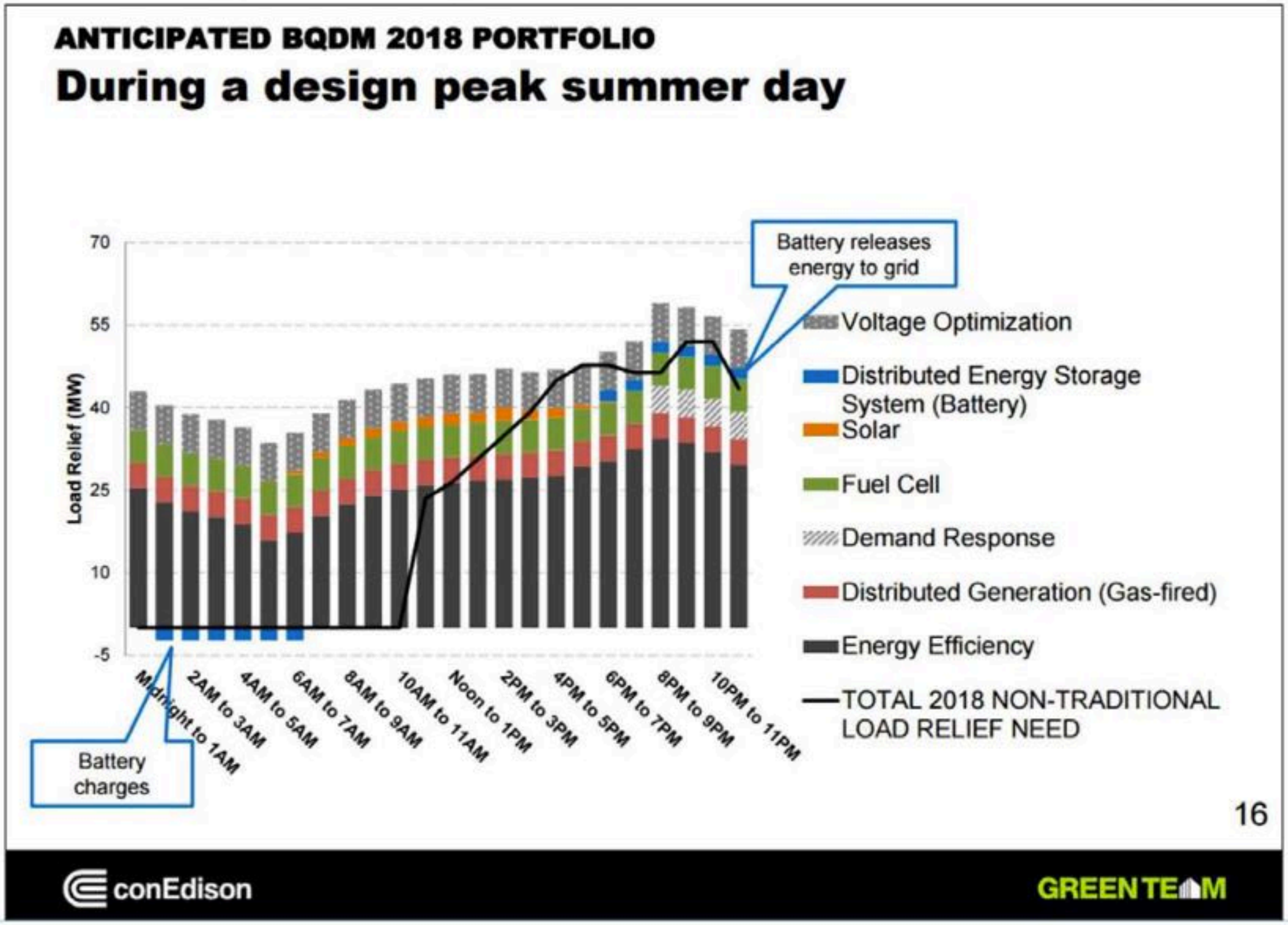
Alternate #2
- Solves for Green + Yellow + Red

*Shading represents ESS net injection requirements to meet overload scenarios: Green - *Emergency Overload Elimination*; Yellow - *Normal Overload Reduction*; and Red - *Normal Overload Elimination*

Storage Configurations Considered

Storage Configuration	Solves for	Power (MWp)	Energy (MWh)	Duration (hours)	Est. Cost ($MM)	Includes Non-Wires Alternatives	Technically Feasible	Meets Requirements
Baseline	Eliminates Emergency (Green) + Reduces Normal Overload (Yellow)	328	2,338	7.1	**$1,030**	✓	×	✓
Alternate #1	Eliminates Emergency Overload Only (Green)	121	226	1.9	**$184**	✓	✓	×
Alternate #2	Eliminates All Normal + Emergency Overloads (Green, Yellow and Red)	545	5,771	10.6	**$2,367**	✓	×	✓

Case Study: Brooklyn-Queens Demand Management

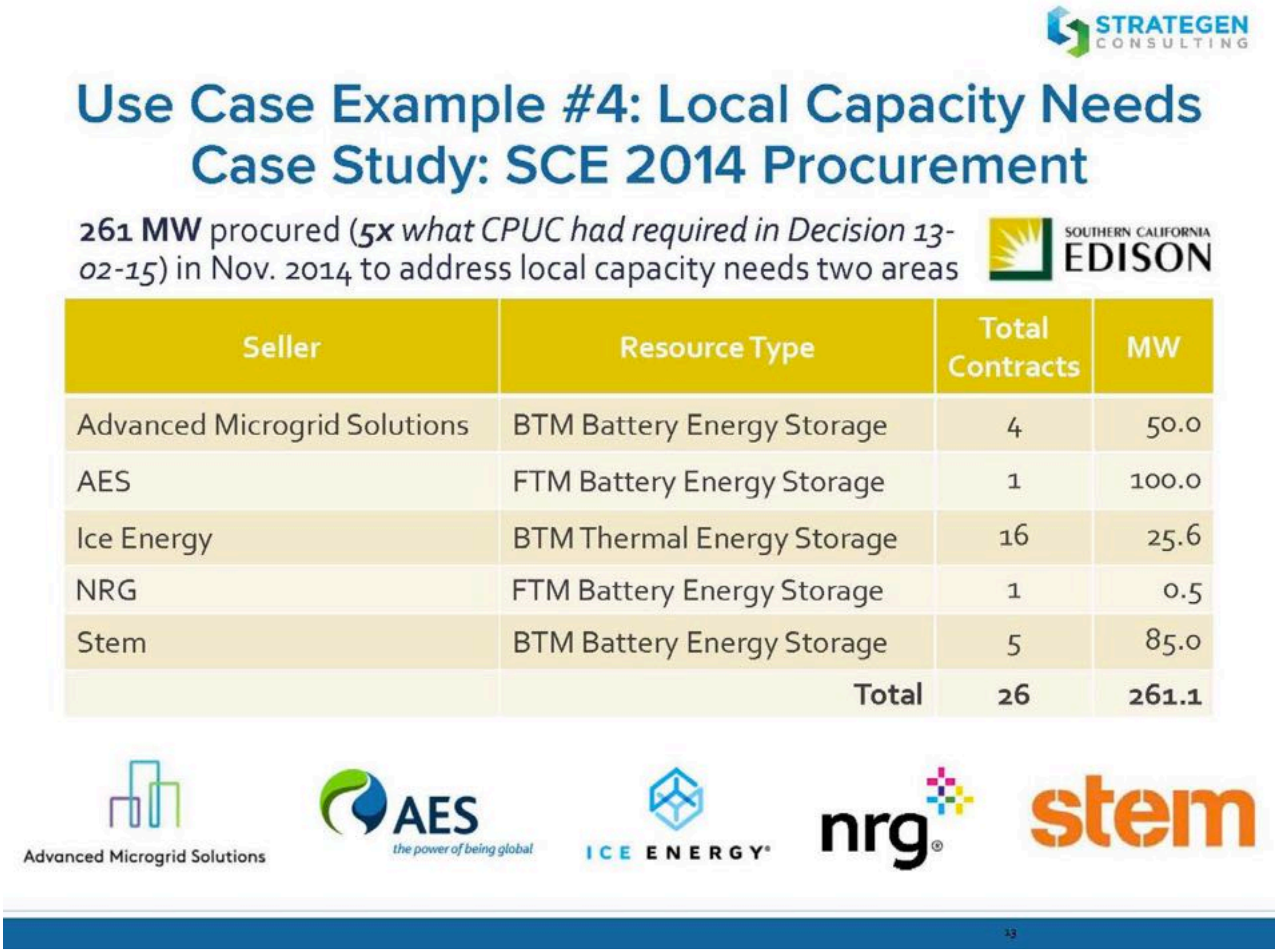


ANTICIPATED BQDM 2018 PORTFOLIO

During a design peak summer day

Battery releases energy to grid

Battery charges



Use Case Example #4: Local Capacity Needs
Case Study: SCE 2014 Procurement

261 MW procured (***5x*** *what CPUC had required in Decision 13-02-15*) in Nov. 2014 to address local capacity needs two areas

Seller	Resource Type	Total Contracts	MW
Advanced Microgrid Solutions	BTM Battery Energy Storage	4	50.0
AES	FTM Battery Energy Storage	1	100.0
Ice Energy	BTM Thermal Energy Storage	16	25.6
NRG	FTM Battery Energy Storage	1	0.5
Stem	BTM Battery Energy Storage	5	85.0
	Total	**26**	**261.1**

14 Appendix F – WIS:dom Model Description and Input Assumptions

WIS:dom Initialization

The Weather-Informed Systems: for design, operations and markets (WIS:dom) optimization model is specifically designed to incorporate initial states from which to process. For the present study, the WIS:dom optimization model was initialized for the MISO footprint, as depicted in Figure 10. The LRZs 1-7 represent MISO north and MISO south comprises LRZs 8-10.

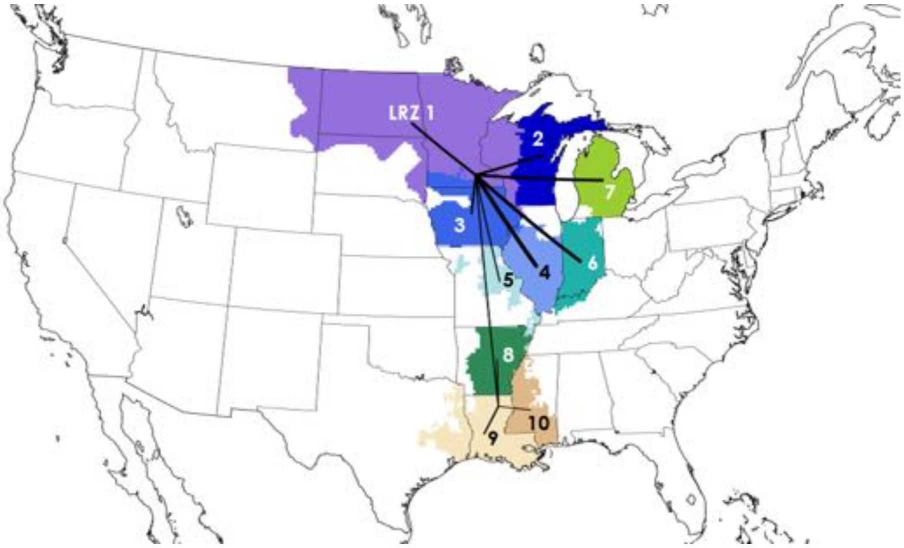


Figure 10. The geographic extent of the MISO footprint. The WIS:dom optimization model for the present study will only process data within the boundaries of LRZs 1-10. The black lines represent the high-voltage transmission links between the LRZs and the hubs.

The representation of MISO given in Figure 10 is how the WIS:dom optimization model has projected the LRZs into model space. It can be seen from Figure 10 that Minnesota resides mostly within LRZ 1, but the south-west region is within LRZ 3.

In Figure 10, the transmission links between the LRZs and the hubs for the North and South can be seen. The transmission representation follows the procedure outlined by MISO using their lines and bubbles method. The width of the lines denotes the combined relative transmission capacity between nodes.

The LRZs are the defined regions where the WIS:dom optimization model will balance generation and demand. They will also represent the areas between which high voltage transmission exists and can be expanded; beyond the intra-LRZ transmission for existing and new generation. It should be noted that the lines for transmission expansion between regions are aggregate values.

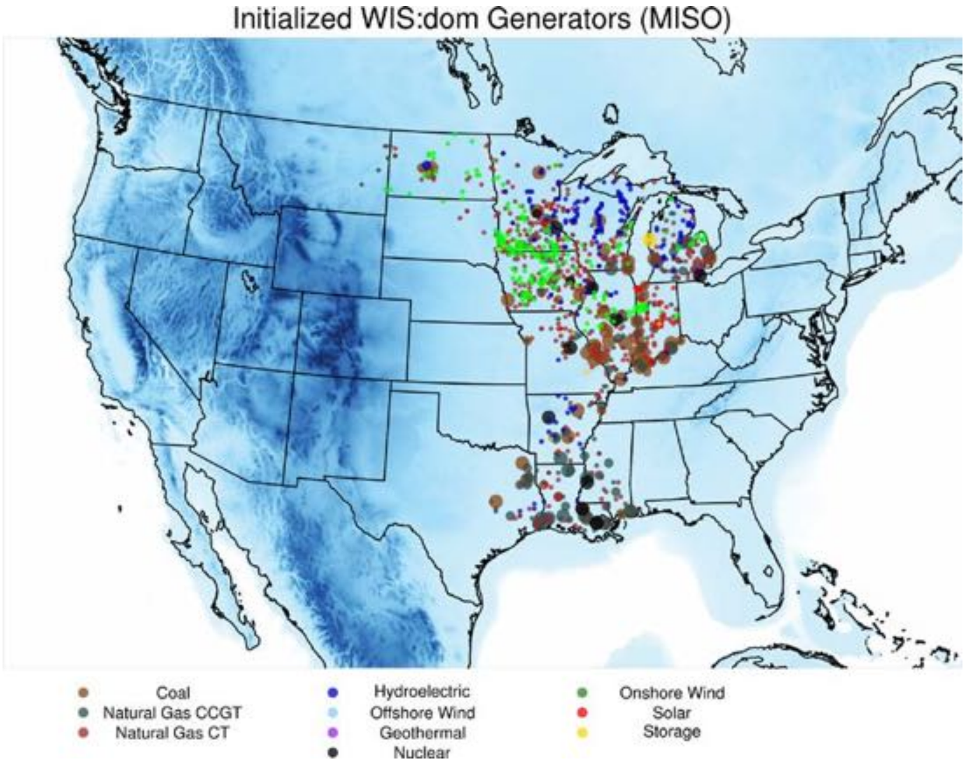


Figure 11. The initialization state of generators for WIS:dom within the MISO footprint. The initialization includes all generation that is existing and in queue as of December 2016. The metadata for each plant is also stored within WIS:dom.

To initialize the WIS:dom optimizations existing generators (unless a free initial state is warranted) are required. WIS:dom stores the generator locations, age, the minimum and maximum stable generation (P_{min} and P_{max}), retirement date, heat rates (if available), fuel type, and power factor. Of course, the optimization will not need all the generators that it is initialized with; since it contains in queue generators. In the initialization phase WIS:dom will combine existing generators with those required in queue to meet its requirements before selecting new locations. The initialization generator data was collected from the EIA in December 2016.[45]

The present study considers the following generator technologies: Coal power plants, natural gas combined cycle turbines (NG CCGT), natural gas combustion turbines (NG CT), nuclear power plants, hydroelectric power plants, utility-scale wind turbines (80 m hub height), utility-scale solar photovoltaic (PV) [flat panel, tilted at latitude], solar PV rooftop, concentrated solar power (CSP), geothermal power plants, and utility-scale electric storage. The initialized total capacity for the entire MISO footprint is 236,507 MW and the share by technology is displayed in Figure 12.

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[45] http://www.eia.gov/maps/layer_info-m.php

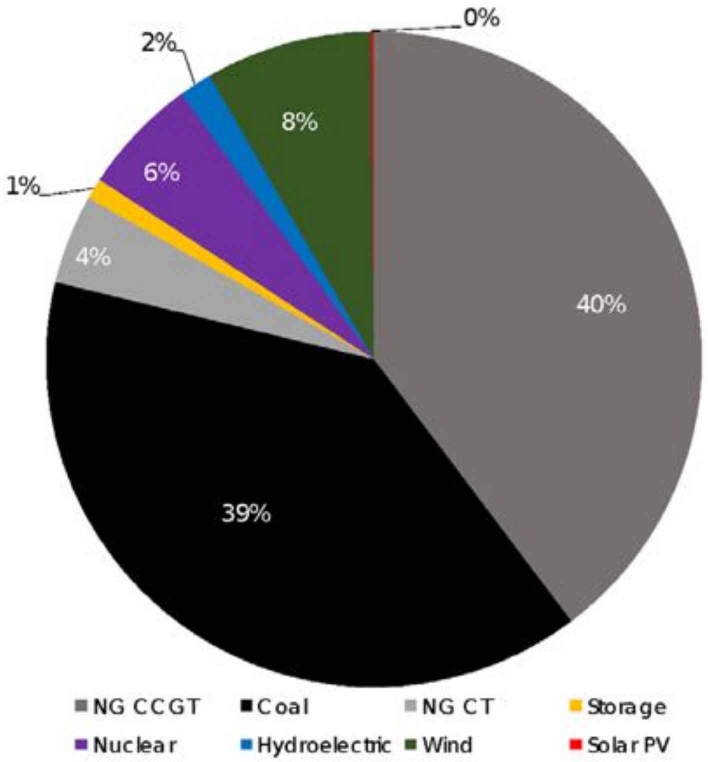

Figure 12. The share of MISO generator capacity by technology. The total capacity is 236,507 MW. The total capacity includes in-queue generators for construction as of December 2016.

All the generator types mentioned in the previous paragraph are eligible to be expanded or contracted within the capacity expansion portion of the WIS:dom optimization model. More generator types are available, for example different hub heights for wind turbines, but for complementation to the previous MISO studies, we have limited the set above.

The conventional generation can be expanded at existing locations (shown in Figure 11) or at new locations for the same cost. Within WIS:dom the expansion of existing sites or new sites must pay for transmission upgrades to connect with the AC transmission infrastructure. Retirement of sites do not pay for removing transmission. Therefore, replacement after retirement may cost less within WIS:dom than construction at a new site (up to the retired capacity at that location).

For variable generators (wind and solar PV) sorting algorithms were utilized to remove areas of population, protected lands and military facilities. Further, terrain was factored into the computation of available space for technologies. The maximum density of wind turbines within a model grid cell was restricted to no more than one per km^2 (< 2.5 W / m^2). Solar PV was restricted to a maximum installed capacity of 15 MW per km^2. The resulting upper bounds for potential deployment were input into WIS:dom to ensure that generation is not overbuilt in single grid cells.

Each resource site is assigned a distance from its LRZ demand center; which facilitates a cost and loss function to be applied within WIS:dom if that resource site is chosen to be connected to the electric grid within that LRZ. The loss function then removes power from generator power output before it reaches the LRZ demand center.

Electric storage is treated slightly differently in WIS:dom compared with the conventional and variable generators. The electric storage can be constructed in any location that can have generators built within its footprint. Further, storage can also be constructed at the demand centers.

For WIS:dom to understand the spatial constraints of numerous generators within a single grid cell (the above limits are only placed upon each generator individually) a computation is performed for each expansion for each location. The calculation estimates the space used by all the generator selected and ensures that no more space is used than is available within that location. If the combination of generators is too high for the available space, generators are removed and the co-optimization routine must find other location(s). This constraint avoids duplication of space when considering the individual generator spatial availability.

Load profiles for each of the LRZs were provided by MISO from actual historic data. The MISO standard reference year is 2006. WIS:dom co-optimizes each of the LRZs individually, while computing the transmission and power sharing between the LRZs. Therefore, it is important to have load profiles for each hour that is synchronized between the LRZs. Figure 13 shows a single week of hourly demand in winter and summer for each of the LRZs stacked upon each other.

With each LRZ having a unique load profile the WIS:dom optimization model must consider each LRZ as a balancing area where generation and demand are kept in harmony. The LRZs can communicate with each other in the WIS:dom optimization model via the transmission lines, using them for power sharing when there is arbitrage possible.

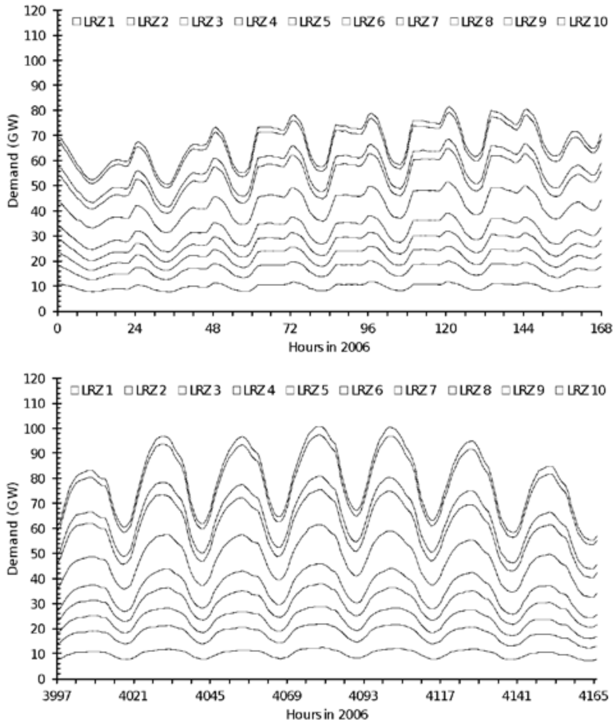

Figure 13. Hourly load profiles for each LRZ. Each LRZ has a unique load profile for the entire year of 2006 and here only a week for winter (left) and summer (right) is shown. The shape of the demand changes constantly throughout the year, and the generation with transmission must fit this perfectly every hour for the entire year.

Figure 13 is not the complete picture for demand profiles. In Figure 14, we show the normalized (to peak demand) aggregated load profile for MISO. It shows that the peak demand is 118,101 MW, with a mean normalized demand 60% of the peak value (70,917 MW). The total electric demand was estimated as 594,497,683 MWh. Figure 13 illustrates the variation in the total demand between seasons, weekdays, weekends and federal holidays. All of the variability is present in the LRZ load profiles.

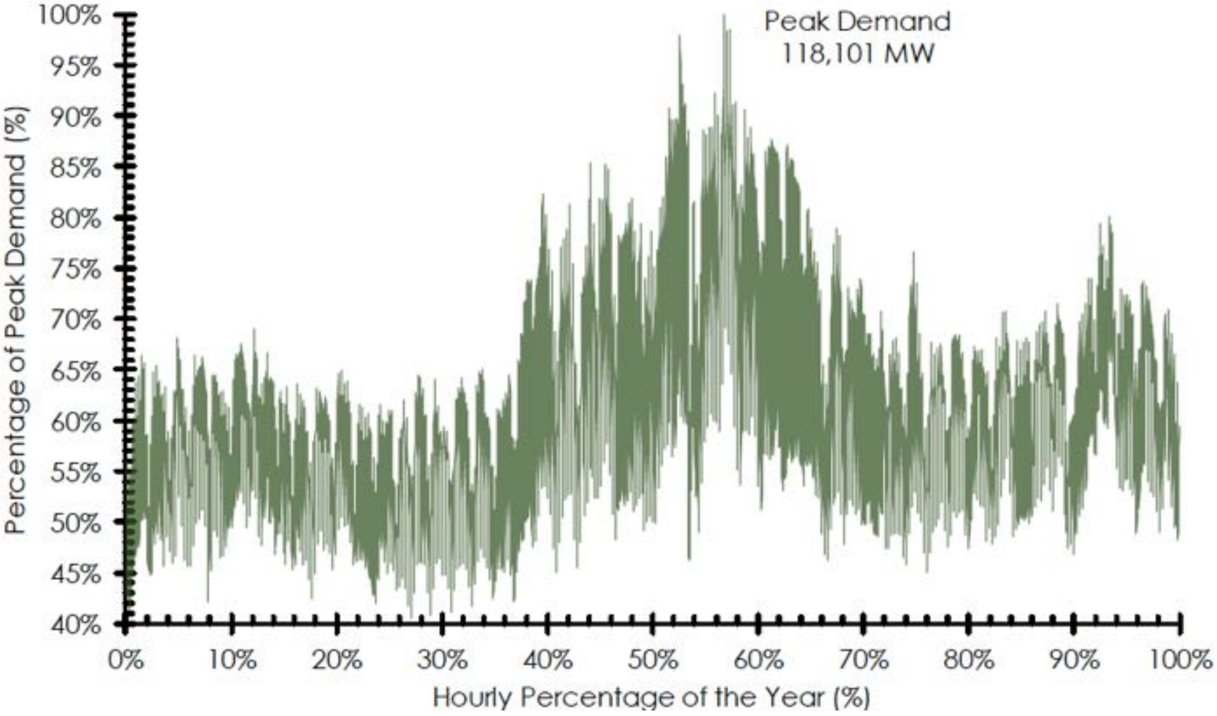

Figure 14. The normalized aggregate hourly load profile for all of MISO for 2006. The load profiles are all aligned to UTC to match the weather resource dataset (shown later). The peak demand in 2006 was 118,101 MW.

The aggregate load profile in Figure 14 illustrates an important fact. During the summer, the electric load is primarily driven by air-conditioning demand. In the middle of the year in 2006, there was a cooler period of weather that resulted in a significant reduction in electricity consumption for a couple of weeks. This can be seen in the aggregate profile at 54% of the year. The normalized values dropped to 45% of the maximum, and then within a few weeks the value increases to 90% of the maximum. The weather is the main driver to this signal, and thus it is important to synchronize the weather data and demand data.

The present study has time horizons ranging from 2017 to 2050. The demand profiles shown above are for 2006. Therefore, assumptions need to be made with regards to the changes in the demand profiles through time. To replicate previous studies for MISO, it was decided that a simplistic expansion constant would be applied to all of the hourly demand profiles. The value of the expansion constant was +0.8% per year. That resulted in a modeled increase of electricity consumption as shown in Table 10.

The increase in peak demand is approximately 50 GW by 2050 compared with 2006, which can be seen in Table 10. The additional electrical energy consumed in MISO within the WIS:dom model in 2050 is approximately 250 million MWh, which represents the electrical energy used by 23 million homes in

2015[46]. The WIS:dom optimization model must expand capacity to keep pace with increasing demand, both total consumption and peak power.

Table 10. The increase in demand estimated within WIS:dom for the entire MISO footprint from 2006 to 2050. The same percentage increases are applied to each of the LRZs. The peak demand is approximately 50 GW greater in 2050 compared with 2006, an increase of about 0.8% annually.

	Increase	Peak Load (MW)	Total Electricity (MWh)
2017	09.16%	128,920	648,957,147
2020	11.80%	132,039	664,657,050
2025	16.35%	137,405	691,672,130
2030	21.07%	142,990	719,785,240
2035	26.00%	148,802	749,041,013
2040	31.12%	154,850	779,485,890
2045	36.45%	161,144	811,168,203
2050	41.99%	167,694	844,138,249

The increase in total electricity consumption is an important assumption because all of the LRZs demand profiles expand at the same rate (using our assumption). It may be that the electricity consumption growth is different in each of the LRZs, and the growth may be more complex than a simplistic expansion. For example, the demand may increase in summer and reduce in winter, altering the load profiles further. Another example would be the addition of electric vehicles, where charging will increase the electricity consumption; but the charging profiles may alter the overall demand profiles diurnally. However, the purpose of the present study is to look at the overall alteration in the structure of the electricity grid, while anticipating increases in total electricity demand.

Two further steps are required to initialize the WIS:dom optimization model that are related to the demand profiles. They are the spinning and planning reserve requirements. WIS:dom assumes a 15% planning reserve capacity for each of the LRZs. WIS:dom must supply enough capacity to meet this constraint within each investment period. For each hour of the year WIS:dom supplies load-following (operating) reserves equal to 7% of the load at that hour. WIS:dom decides whether to provide the reserve capacity as “spinning” reserves provided by thermal generation, down-dispatched wind and solar generation, or fast-on combustion turbines. WIS:dom cannot fail to meet demand for any hour throughout the year.

Since the wind and solar generators rely on the weather as their “fuel” it is important to establish robust estimates of the potential from atmospheric numerical weather assimilation models. The weather data is required for each hour of 2006 to synchronize with the demand data. It was decided that the wind resource would be computed at 80m above ground level (AGL) and the solar PV resource would be created for flat panels that are tilted at latitude (no tracking). The load profiles are at hourly resolution; thus, the variable power resource potential was calculated for the concurrent 60-minute intervals.

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[46] Each residential home uses, on average, 10,812 kWh per year.

The analysis fields from the operational Rapid Update Cycle (RUC) were downloaded from NOMADS[47]. To assist with the creation of the solar irradiance model data, GOES satellite reflectance were obtained from NOAAs CLASS database for each three-day period for the entirety of 2006[48] and images were also checked using the SSEC Data Center Archive[49].

Using the publicly available atmospheric data, proprietary algorithms were developed to mimic the behavior of wind turbines and solar PV panels. The wind power algorithms took into account shear, veer and turbulence across the rotor diameter (100 m) for turbines at 80 m above ground level (AGL). The algorithm also estimates icing and temperature shutdowns. The solar PV power algorithms consider clouds, temperature, and the components of irradiance. Both algorithm suites incorporate reductions in final power output to account for downtimes, maintenance, and inverter/wiring inefficiencies.

The proprietary algorithms output power for each of the model resource locations at each hour for 2006. Each resource location was assigned to an LRZ, where it added to that regions potential portfolio. The resource is assumed to be "as is" by WIS:dom. That means that WIS:dom has perfect foresight throughout each of the investment periods. The weather resource is assumed to be the same for each investment period because the same load profile is utilized. Some sensitivities in the future would be warranted to predict how the system changes under different weather and demand scenarios. However, since the present study is focused on the system-level adoptions on the electric grid as storage is considered, a single year of hourly data is appropriate.

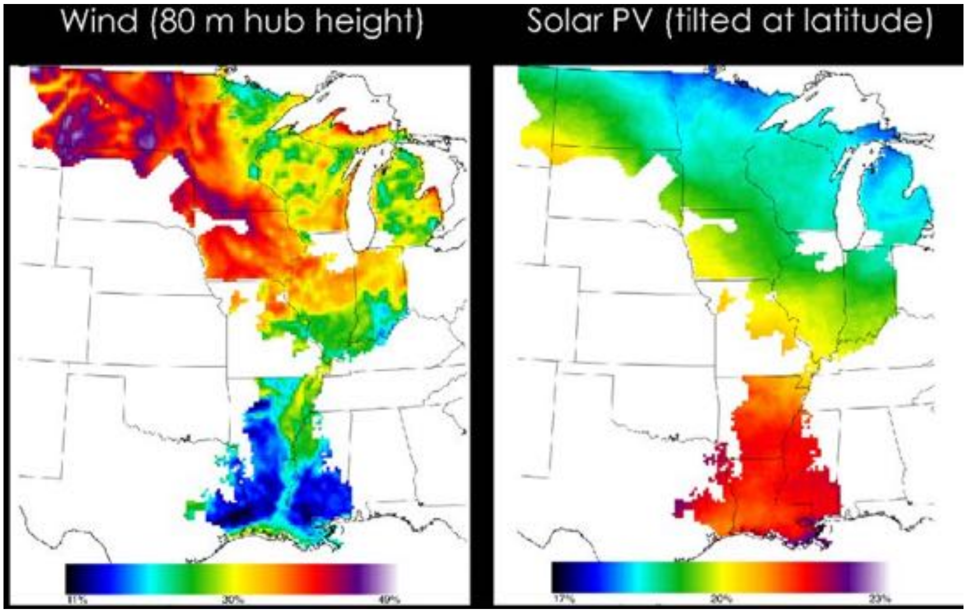

Figure 15. The estimated capacity factor maps for wind (left) and solar PV (right) for the entire MISO footprint. The capacity factor is calculated for 2006 from the hourly data. WIS:dom computes decisions from the hourly data as well as the capacity factors. The north-west region of MISO is the best for wind and the deep south is the best for solar PV.

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[47] ftp://nomads.ncdc.noaa.gov/RUC/analysis_only/

[48] http://www.class.ncdc.noaa.gov/saa/products/search?datatype_family=GVAR_IMG

[49] http://www.ssec.wisc.edu/datacenter/archive.html

The capacity factor maps for wind and solar PV are shown in Figure 15. The maps clearly show that the north-west region of MISO (LRZ 1) contains the highest capacity factor wind resources, while the MISO south (LRZs 8-10) have the best capacity factors for solar PV. The hourly variable power data allows WIS:dom to determine portfolio mixes of wind and solar PV that can work in concert to provide power when it is needed. Thus, WIS:dom can combine the different scales of variable generation: the hour-by-hour fluctuations and covariance with the yearly capacity factors to determine the optimal combination of generation to meet the estimated demand profiles.

Since the present study is centered upon Minnesota, a more detailed assessment was made of the Minnesota wind and solar PV resource. In Figure 16, we show the MN footprint capacity factor maps for wind and solar PV. The higher-resolution estimation of resource allows WIS:dom to layer data for MN that calibrates siting decisions with the highest resolution data. The way WIS:dom does this is by performing a nested co-optimization. If a site is selected in MN for development by the MISO wide co-optimization, another co-optimization is performed within MN only to determine the best placement in terms of cost and power output.

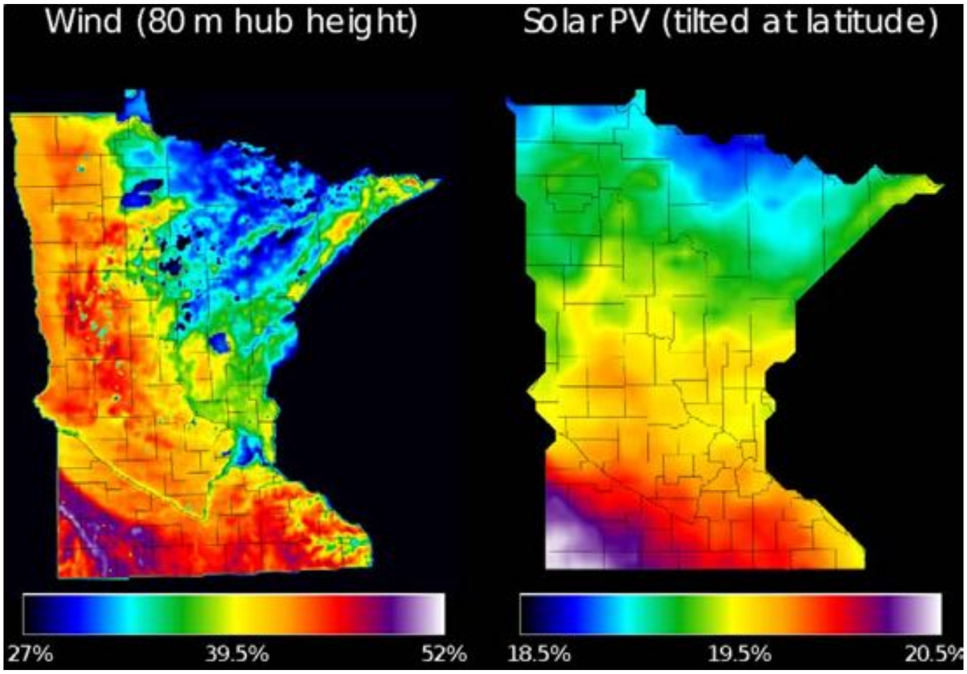


Figure 16. The higher-resolution assessment of Minnesota for wind (left) and solar PV (right). The highest capacity factor wind and solar PV are co-located in the south-west of MN.

When Figure 16 is compared with Figure 10, it can be seen that some of the most valuable wind sites in the south-west of MN have already been developed. Indeed, there is also some solar PV development in the south-west part of MN. WIS:dom can compute additional locations for generation that will complement existing and planned generators by determining the cumulants of variable generation and seeking the most valuable additional assets.

The final component necessary to initialize the WIS:dom optimization model is to provide the costs for technologies along with additional costs and information required for the model to process properly. Fundamentally, WIS:dom is a cost-optimal seeking algorithm. That is, WIS:dom will relentlessly seek the lowest-cost decisions regardless of the constraints imposed within it.

The capital costs for conventional generators (coal, NG CCGT, NG CT, nuclear, and hydroelectric) are considered to be mature for the present study. That has the implication of WIS:dom considering these technologies as having static real costs for all of the investment periods. The capital costs that WIS:dom uses for these technologies is shown in Figure 17 .

For the variable generation and storage, the capital costs are not considered mature. Therefore, WIS:dom accepts changing values for these technologies for each of the investment periods. These capital costs are displayed in Figure 18.

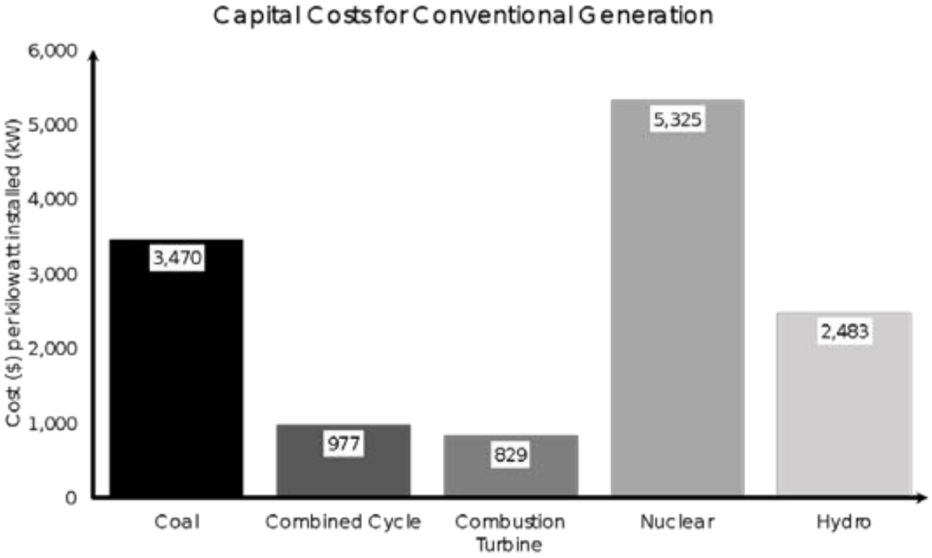


Figure 17. The capital costs for conventional generators. The costs are assumed overnight and are in real $ / kW installed.

The capital costs for wind are more mature than for solar PV, therefore the cost decreases with time are less than for solar PV. Even more dramatically, the storage capital costs are the least mature and, thus, the cost decreases with time are estimated to be even more dramatic.

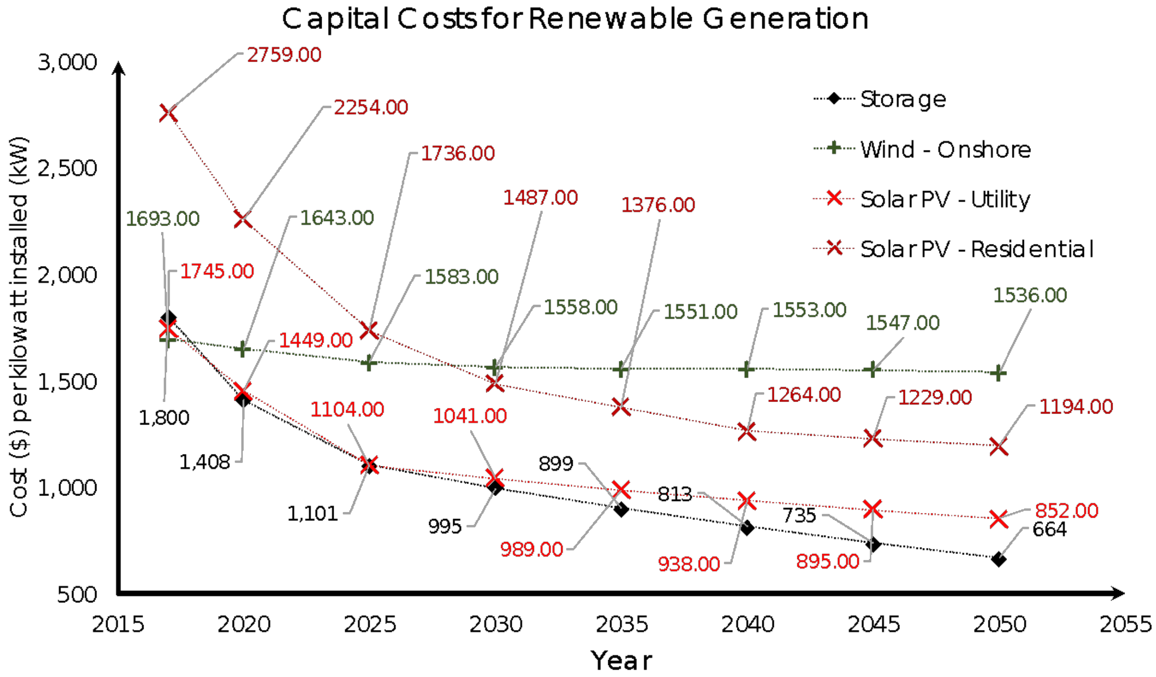


Figure 18. The capital costs for renewable generation. Since renewable technologies are less mature than conventional generation, WIS:dom accepts changing costs with investment periods. All costs are in real $ / kW installed.

The capital cost influence on the cost-optimal solution is altered by two main factors. First, the discount rate for the cost of capital. The discount rate assumed for the present study is 6.6% (real) per annum for all technologies. WIS:dom has the capability to apply different discount rates to all the technologies and investment periods, but for simplicity a single value was chosen. The second factor is the economic lifetime of the asset. The longer the lifetime, the lower the annual payments for that asset. Within WIS:dom, each technology has a different economic lifetime, as shown in Figure 19.

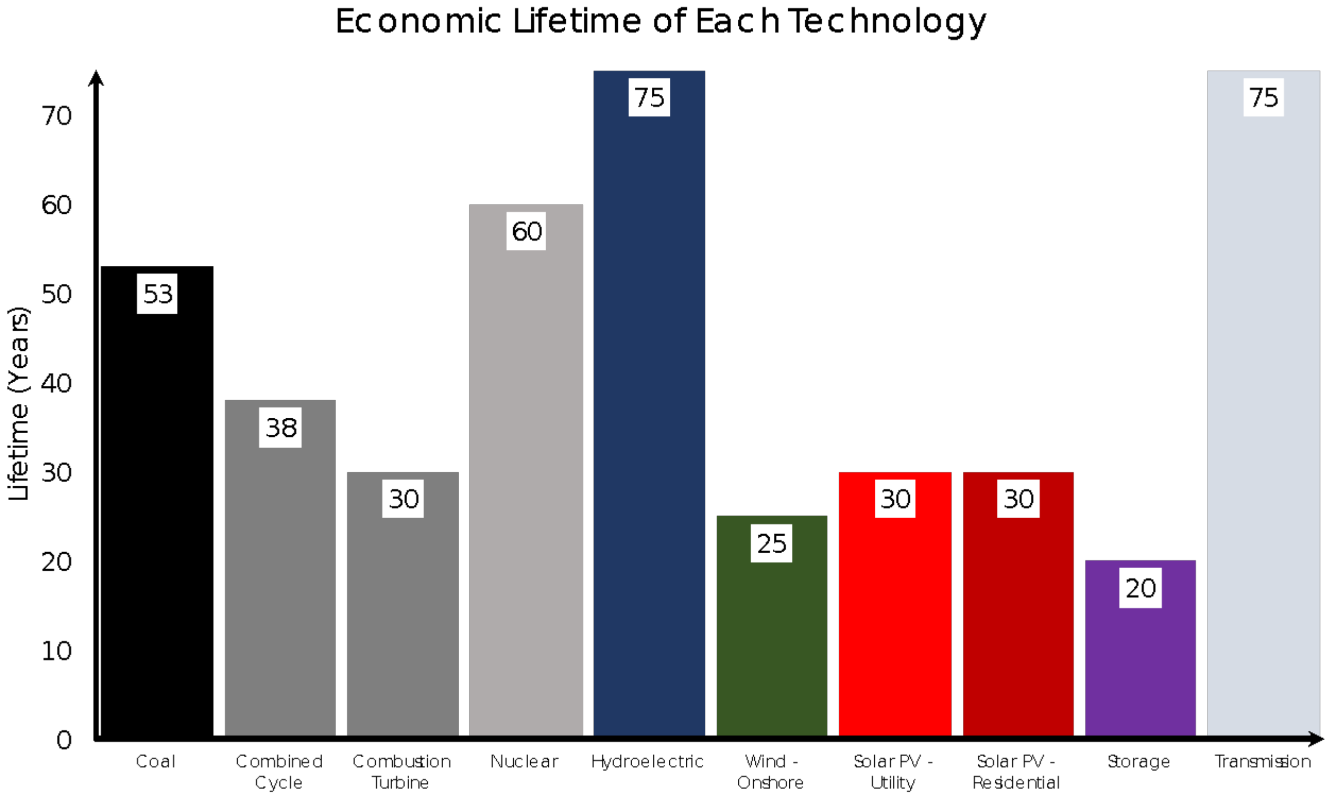
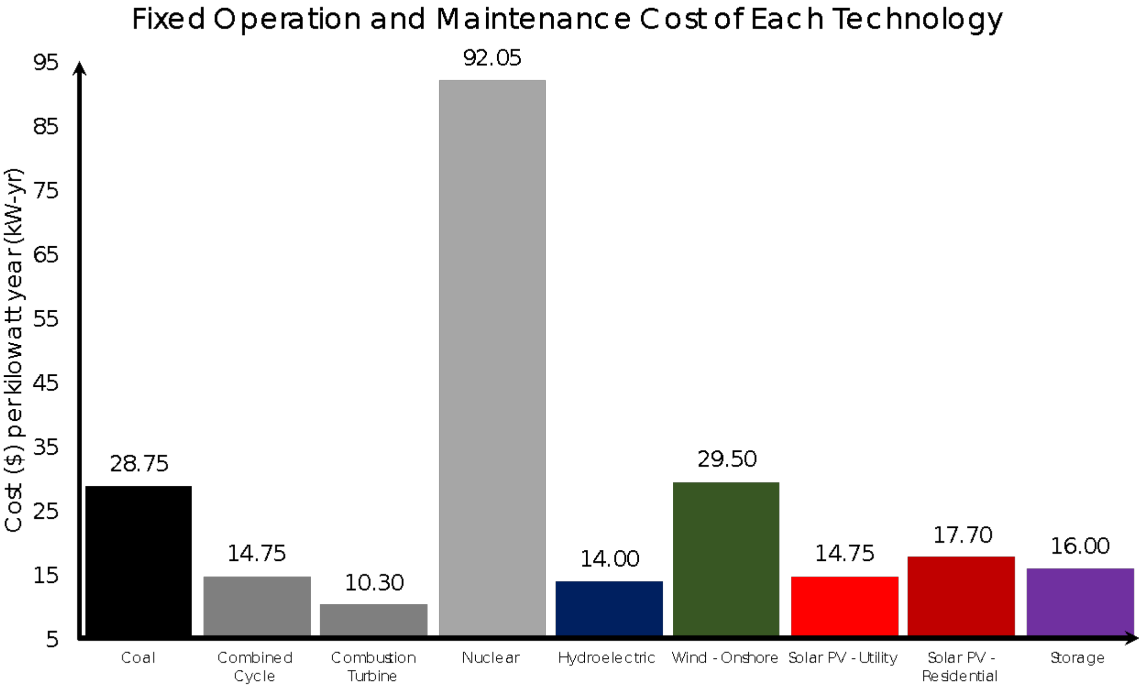


Figure 19. The economic lifetime of each technology considered in the present study. The economic lifetime represents the time to repay the debt for that particular asset. The longer the economic lifetime, the lower the annual payments.

In addition to the capital costs, generators are subject to fixed and variable operations and maintenance (O&M) costs. WIS:dom has to ability to take these O&M costs into account. The O&M costs can be changed for each investment period; however, for the present study they are assumed to remain the same for each investment period. The fixed and variable O&M costs are shown in Figure 20.



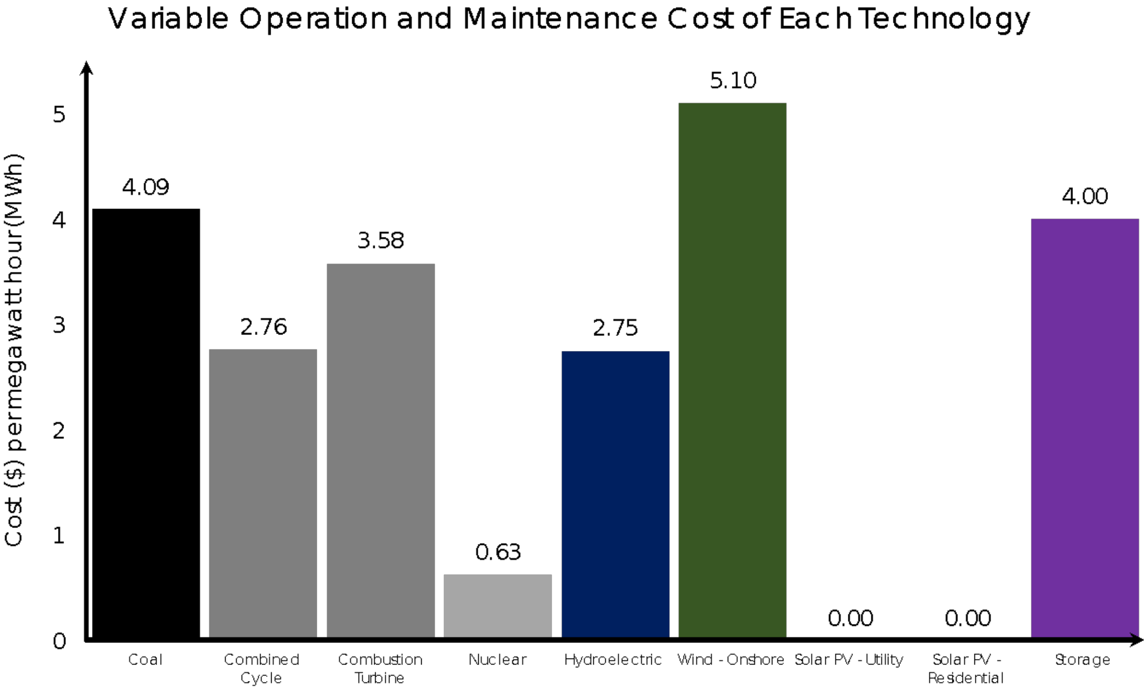
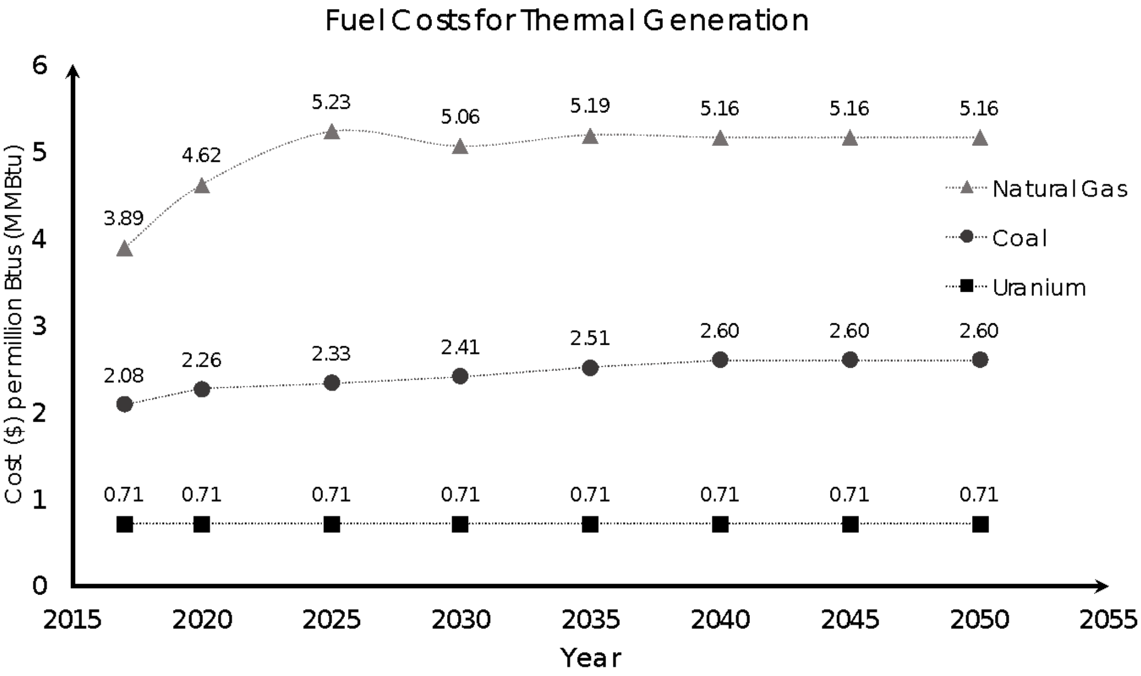


Figure 20. The fixed (top) and variable (bottom) O&M costs for each of the generator types considered by WIS:dom in the present study. The O&M costs are in real dollars, and are assumed to be constant through investment periods.

A substantial cost component for thermal generators is the fuel that they burn. The cost of the fuel burned is a combination of two factors. First, the cost of the commodity of the fuel itself. Second, the heat rate of the thermal power plant. The heat rate is the number of British Thermal Units (BTUs) required to be consumed to produce 1 kWh (3,412 BTUs). The efficiency of a power plant is computed by dividing 3,412 by the power plants heat rate. Therefore, a higher heat rate represents a less efficient power plant. The less efficient a power plant, the more fuel it must burn to create a kWh of electricity; therefore, its fuel costs will increase. Figure 21 displays the commodity fuel costs for each investment period of the present study and the heat rates for the thermal generators.



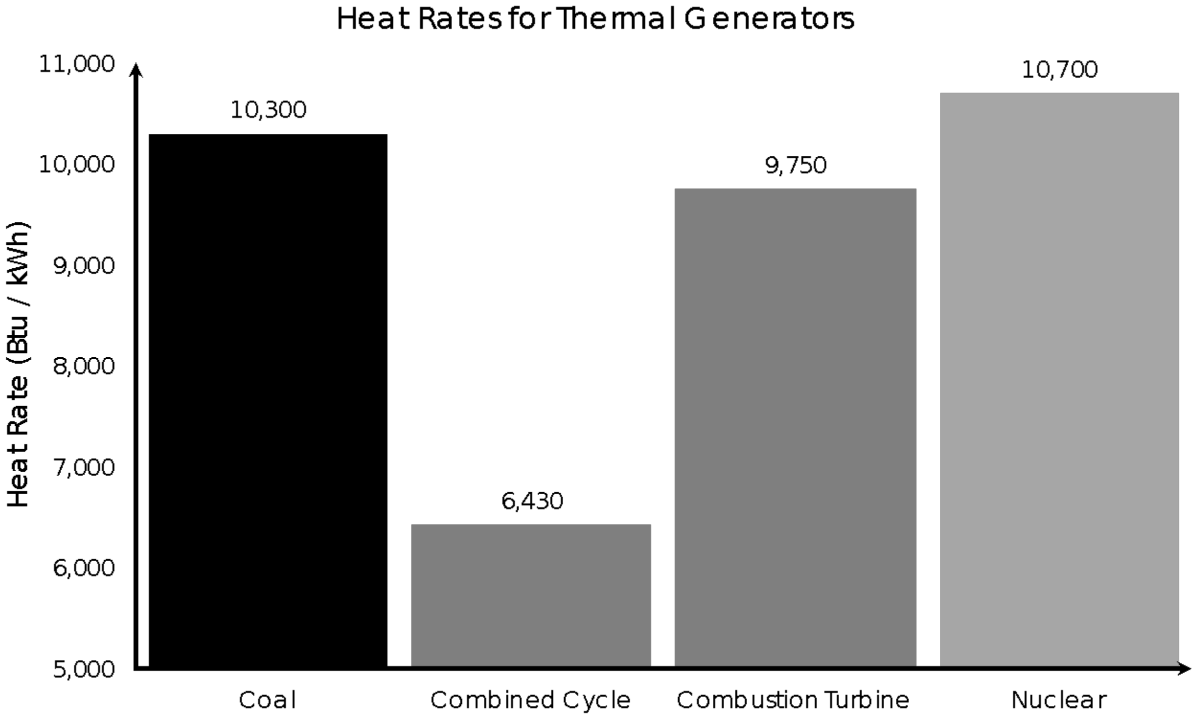


Figure 21. The cost of fuel (top) and the heat rates for the thermal generators (bottom). WIS:dom has the ability to accept and process heat rates and fuel costs for each individual generator, but for simplicity a single value was chosen for each type of generator.

For Figure 21, it can be seen that the efficiency of a coal power plant (in WIS:dom) has an efficiency of 33.1%, while NG CCGT power plants have an efficiency of 53.1%. The efficiency of the power plants impacts WIS:dom computations when considering emissions or constrained fuel sources and the total cost of generating electricity at each power plant. WIS:dom has the ability to accept and process unique fuel costs and heat rates for each individual power plant; however, for simplicity a single value was chosen for each generator type. The co-optimization would be less degenerate if unique values were set for each individual plant, because with all generators of a single type having the same fuel costs and heat rates results in numerous options that appear very similar to WIS:dom.

The cost of transmission is assumed to be the same for each LRZ. Transmission lines are priced at $701.36 / MW-mile. There is a further capital charge of $365,712.22 / MW for the transmission built between the LRZs and the Hubs. The charge is assumed to be for either HVDC stations (if transmission is direct-current) or the cost of Alternating Current (AC) connections. Within the LRZs the cost is simply assumed to be just for the transmission lines.

WIS:dom Implementation

WIS:dom is a mathematical optimization software package that determines the capacity expansion of a pre-defined geographic electric grid while simultaneously dispatching generation and transmission at the temporal resolution of the demand profiles. WIS:dom can be run in Linear Programming (LP) or Mixed Integer Programming (MIP) modes.

When using the LP mode, the unit commitment is more simplistic than in the MIP version (linear relaxation). The LP version is much more computationally efficient, and since WIS:dom is provided with true weather and demand data, unit commitment is less sensitive – WIS:dom has knowledge of the entire range of load and weather conditions for the entire year period, thus units are committed perfectly for the entire time horizon. In other words, the electricity system is dispatched in the most economically efficient way, and as such can be considered as an upper bound for the dispatch available.

The objective function is minimized to find the least-cost non-trivial solution, while providing the services of an electric grid. The services that the WIS:dom must provide for an electricity grid include:

a. The demand profiles must be satisfied in each of the ten LRZs each hour for the entire time horizon, without fail.
b. To satisfy the demand profiles, transmission may be utilized. The transmission capacity must always be greater than the power flowing along the lines.
c. WIS:dom contains a transmission power flow matrix that computes the network flows within the transmission. It further calculates and updates itself with the losses associated with the power flowing between end points.
d. The possible generation reaching each LRZ must include a load-following reserve.
e. Over the time horizon WIS:dom must provide the electric grid with planning reserve for each of the LRZs.
f. The combined area of generators deployed by WIS:dom in each model grid cell cannot exceed the area available for energy production.
g. Each generator must perform within its tolerance levels provided to it. In particular ramp rates and minimum/maximum operating levels are adhered to.
h. The generators must adhere to their P_{min} and P_{max} values.

i. Retired generation cannot be brought back online at a later time horizon.
j. New capacity must be paid for or retired at economic cost.
k. The hydroelectric can only be dispatch up to the levels that it reached in that meteorological year (2006). That level is ~41% of the nameplate capacity.
l. The maintenance schedule for the nuclear power plants must be upheld.
m. The load is expanded between each investment period.

WIS:dom is not currently built to be a full and complete grid integration model, rather an estimation of grid operation while conducting capacity and transmission expansion. Additional features can always augment the ability of WIS:dom to represent realistic operations of the electric grid. Nevertheless, WIS:dom satisfies all of the constraints a. through m. above, for each hour of a standard year for each of the investment periods within the model. For the present study, there are eight investment periods. WIS:dom optimizes at each investment period.

WIS:dom begins with the last investment period (2050) and iteratively works backwards towards the initialization investment period (2017). By working in reverse, WIS:dom can determine the future mix that is required and how to create a pathway between 2017 and that future mix, considering retirements, changing costs, emission constraints and other limits.

The WIS:dom optimization model finds the optimal way to dispatch the system for each of the investment periods as the generation mix evolves. It shifts how it operates the market to provide reliable, low-cost power for each LRZ under the scenarios given. In figure 18, we show the WIS:dom derived dispatch of the 2050 MISO grid for run 5 (reduced GHG emissions, storage allowed, transmission allowed). It can be seen in Fig. 18 that the presence of storage alters the demand profile (black line) to increase demand at times of high renewable production, and then dispatches the storage at low renewable production (like a CT plant). It can also be seen how wind and solar are complementary across MISO, this being one of the benefit of co-optimization. The energy market within WIS:dom has evolved to ensure that generators are profitable with high shares of VRE and one component of that is storage deployment that can arbitrage across the diurnal fluctuations in VREs along with flexible conventional generation and transmission.

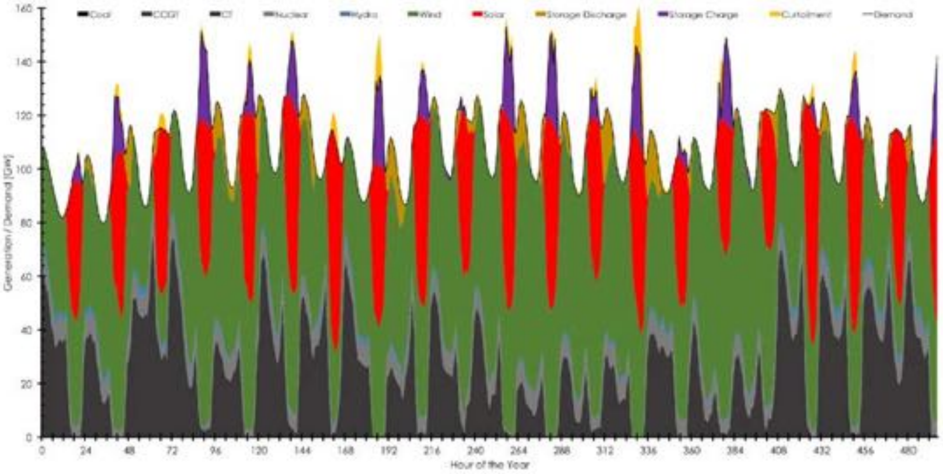
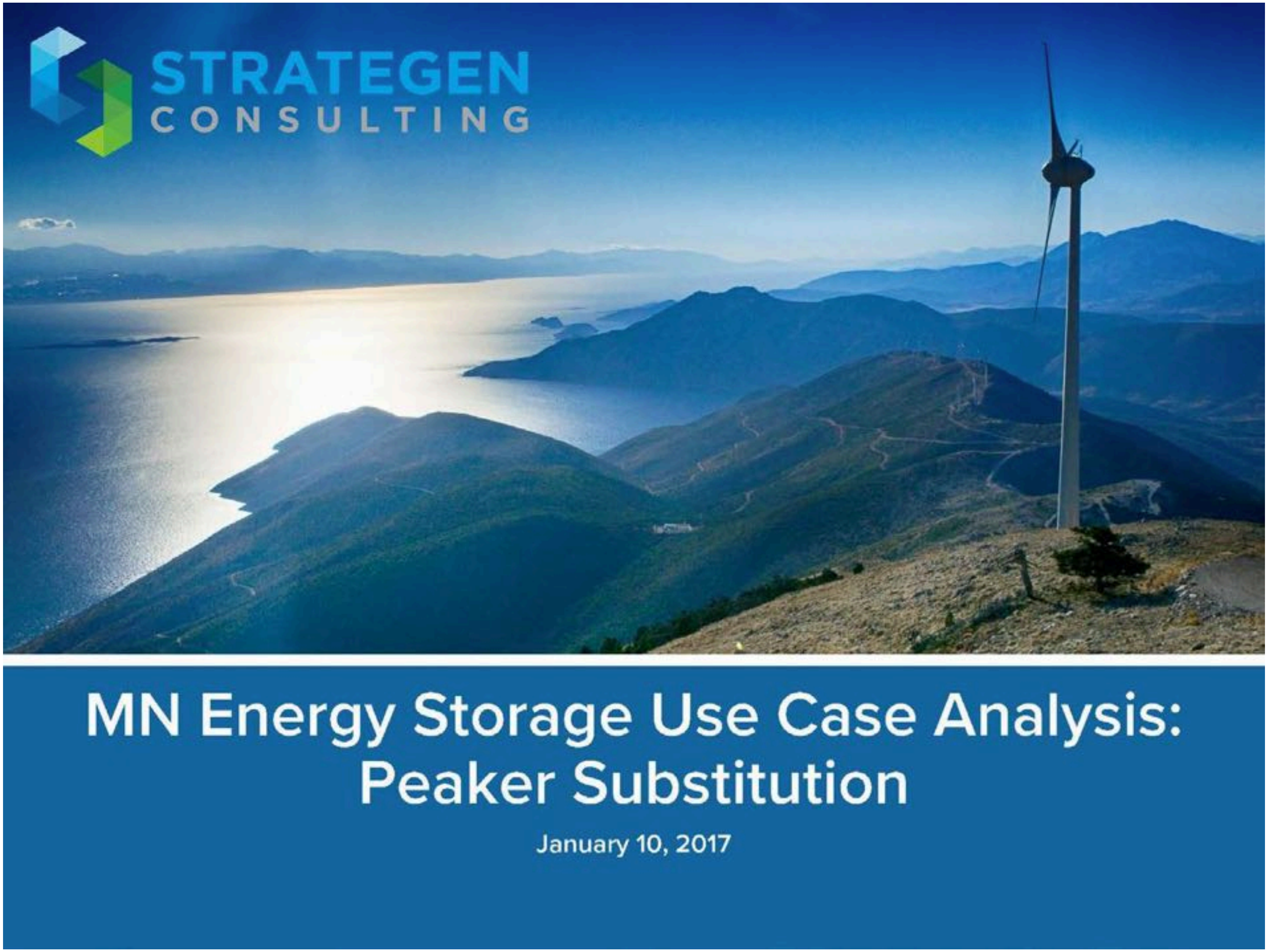


Figure 22. A snapshot of the hourly dispatch produced by WIS:dom for the 2050 MISO electric grid under "run 6". It shows the diurnal signal from wind and solar, along with how storage would be dispatched and charged. It also illustrates the fundamental shift in how the grid market would have to operate along with its diverse set of resources.

15 Appendix G – Use Case Analysis of Storage as a Peaker Alternative in Minnesota (Strategen Consulting)



STRATEGEN
CONSULTING

MN Energy Storage Use Case Analysis: Peaker Substitution

January 10, 2017

Presentation Overview

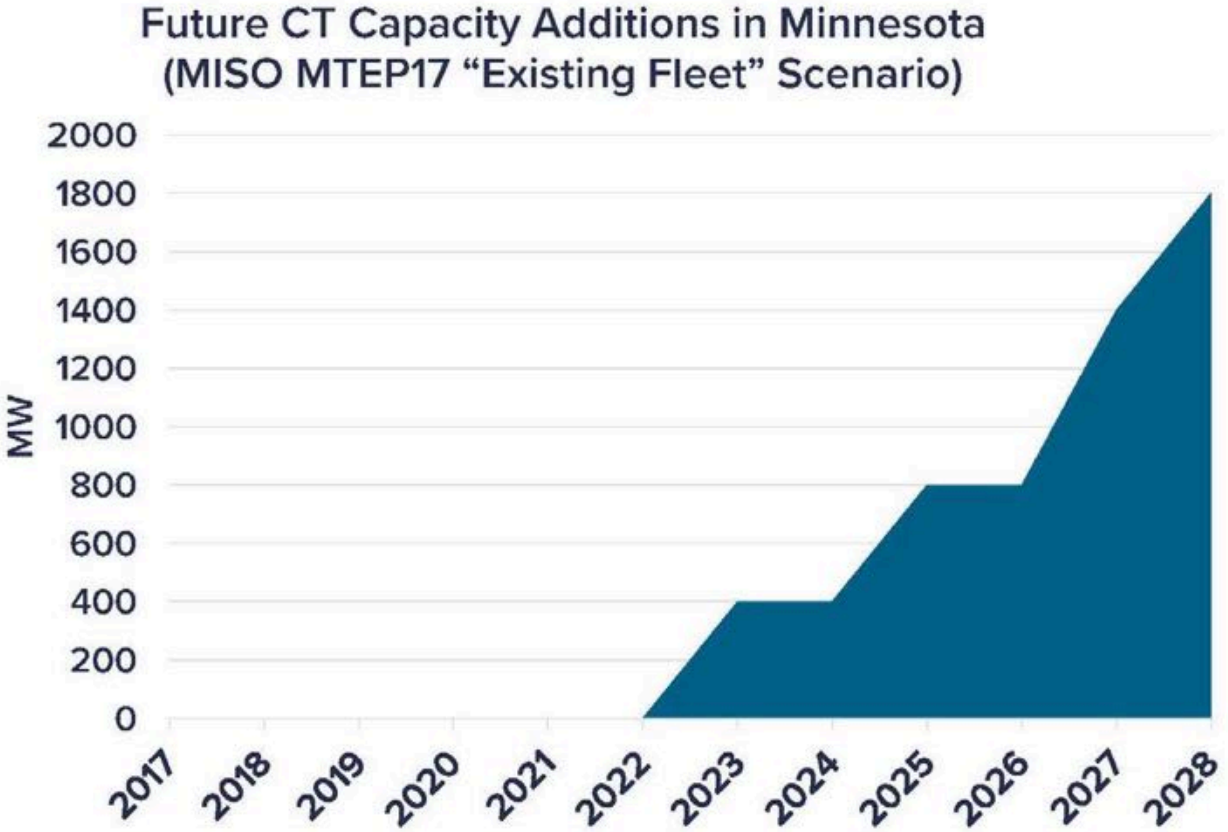
- Analysis Covered Today:
  - Storage as a Capacity Resource (vs. Peaker)
  - Solar + Storage as a Capacity Resource (vs. Peaker)
- Other Analyses in Progress:
  - Transmission Deferral Case

Presentation Outline:

1. Background & Methodology
2. Inputs and Assumptions
3. Preliminary Results

Background and Methodology

Potential Peaker Plant Additions in Minnesota



Reference:

- MISO MTEP17 Futures Siting, Planning Advisory Committee Meeting, 10-19-2016

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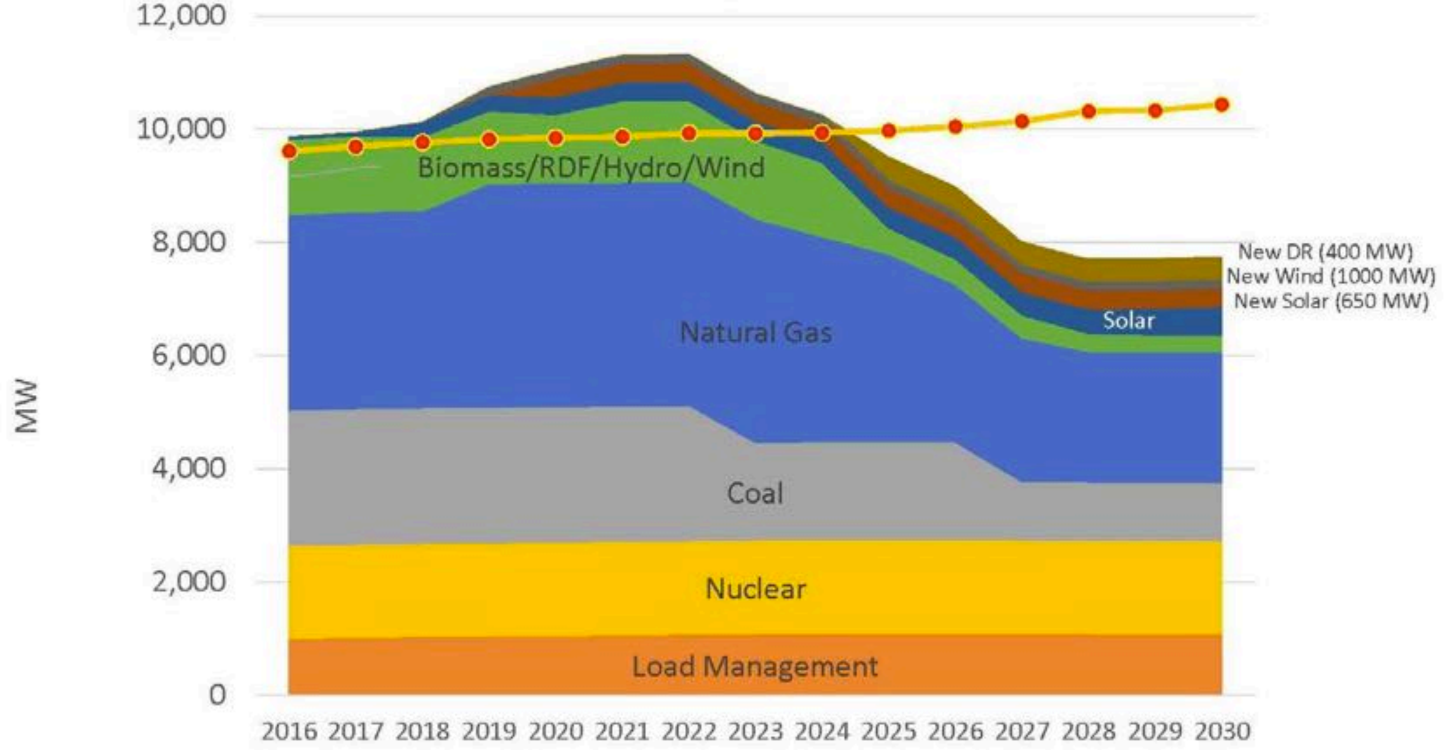
Load and Resource Forecast (Example: Xcel Energy, Upper Midwest)



Existing and Approved Resources (includes October 2016 decision)

Sources:

- Existing resources based on Xcel Energy 2016-2030 Upper Midwest Resource Plan, Docket No. E002/RP-15-21 (Current Preferred Plan, filed Jan. 29, 2016), https://www.xcelenergy.com/staticfiles/xe/PDF/Regulatory/MN-Resource-Plan/MN-Resource-Plan-03-Supplement.pdf Capacity reflects Unforced Capacity Values (UCAP); Current Preferred Plan including retirement of Sherco Units 1 & 2.
- New DR, New Wind, and New Solar based on MN PUC Docket 15-21 Second Revised Decision. UCAP contribution approximated using capacity values reported in Xcel Energy (October 2015), 2016-2030 Upper Midwest Resource Plan , Appendix J – Strategist Modeling and Outputs, Table 14

Potential Capacity Resource Options (partial list)

Credit: Duke Energy

Natural Gas Combustion Turbine

Credit: Doosan GridTech

Energy Storage System*

Credit: Solar City

Solar + Storage System*

*Can be large-scale or distributed

Peaker Substitution Use Case: Overview of Analysis

- Background:
  - MN's power system has a projected capacity need for which new resource additions are anticipated.
  - A natural gas combustion turbine (CT) is presumed to be the marginal resource type for meeting this capacity need.
- Objective:
  - Evaluate the costs/benefits from the installation of a large-scale energy storage system (ESS) or solar plus energy storage system (S+ESS) in lieu of a new CT to meet upcoming capacity needs.

Peaker Substitution Use Case: Overview of Analysis

- General Approach:
  - Calculate the net cost (NPV, net of benefits) of:
    - 100 MW, 4-hr energy storage system (ESS), with a 20-year project life.
    - 100 MW, 3-hr energy storage plus 50 MW solar system (S+ESS), with a 20-year project life.
  - Compare both to the net cost (NPV, net of benefits) of an equivalent capacity natural gas Combustion Turbine (CT).
  - The difference is considered to be the net benefit Minnesota customers (similar to a Total Resource/Societal Cost Test)
  - Quantify difference in overall impact on CO_2 emissions from both resources.

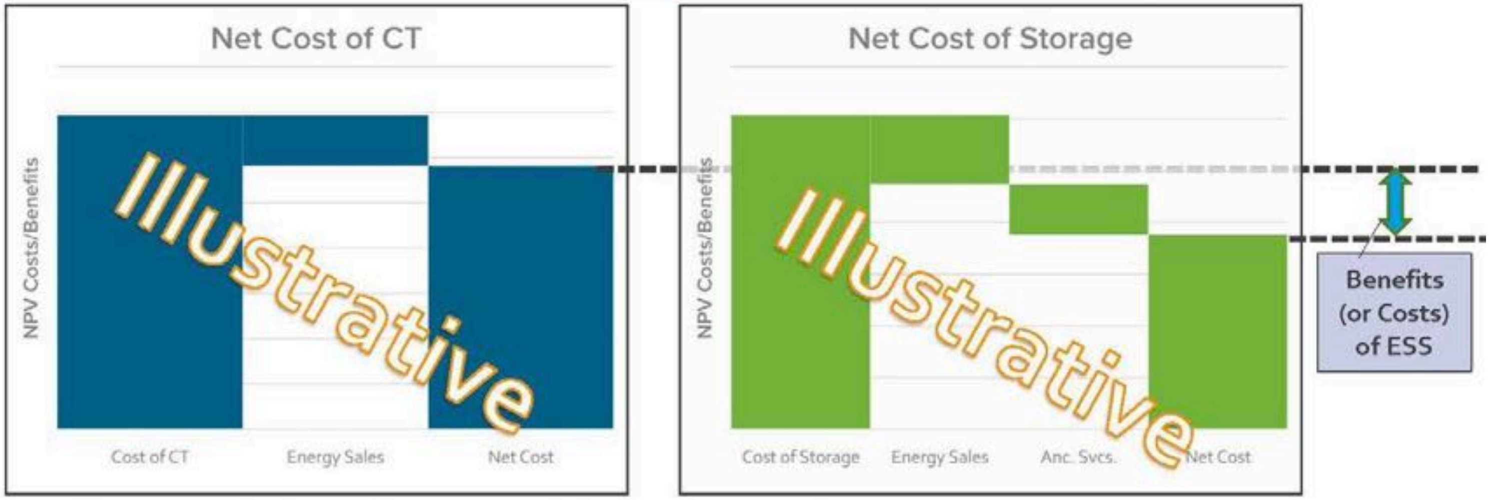
Peaker Substitution: Cost/Benefit Categories

Cost categories:

- Capital Costs
- Tax and Insurance
- O&M Costs
- Fuel or charging costs (incl. losses)

Primary Benefit Categories:

- Capacity (presumed equivalent for both resource types)
- Ancillary services revenue
- Energy sales revenue
- Avoided environmental costs (solar)



- Other benefit categories not quantified (not in scope):
  - Avoided startup and no-load costs
  - T&D deferral
  - Voltage Support

Use Case Evaluation: Methodology

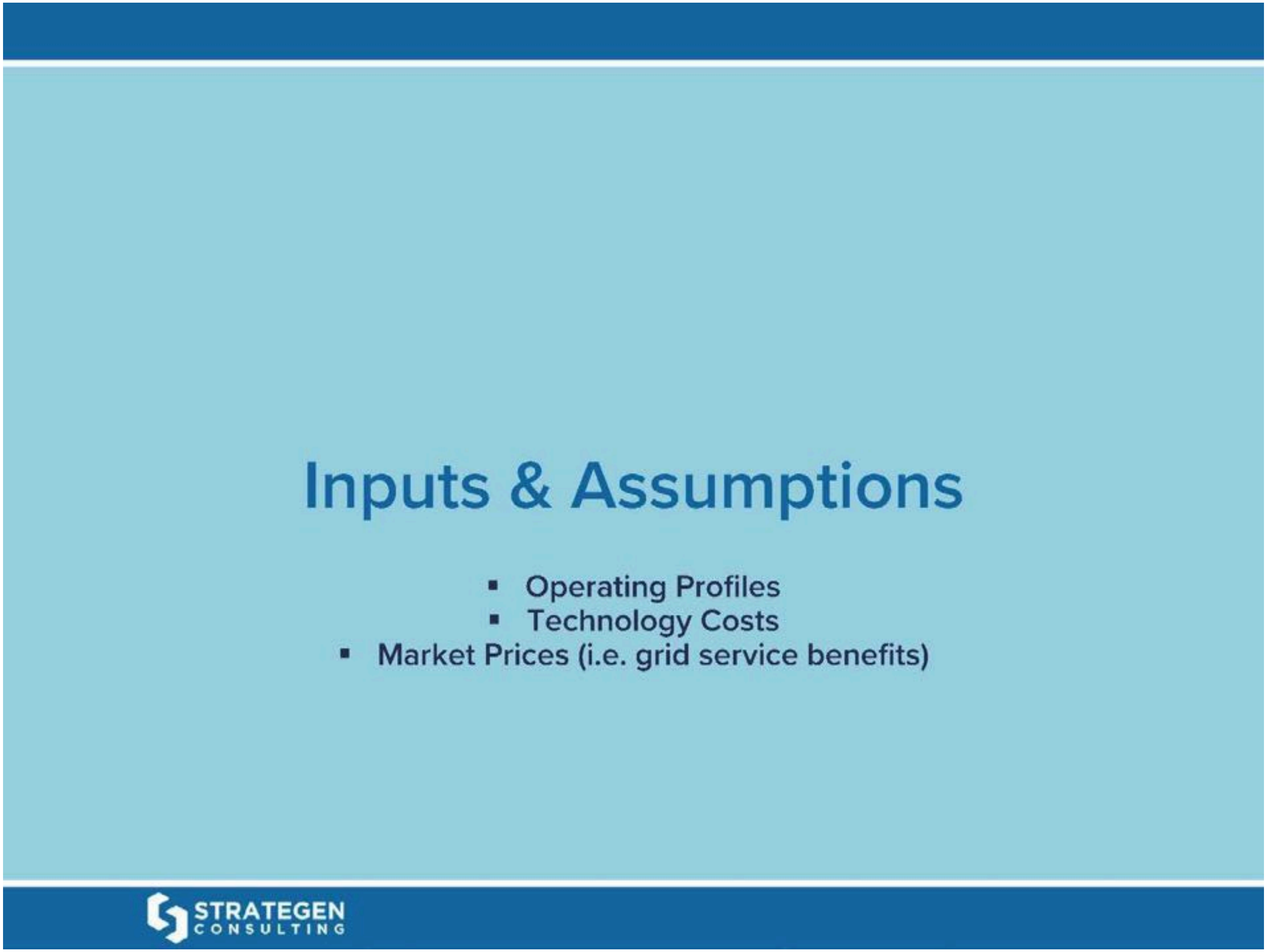
- Analysis performed using a custom Storage Resource Cost Calculator developed by Strategen.
- Inputs and assumptions customized for Minnesota.
- 4 Preliminary Scenarios Examined (plus additional sensitivities)
    1. Storage Only – 2018 (online date)
    2. Storage Only – 2023
       + High peaker cost sensitivity
    3. Solar + Storage – 2018
    4. Solar + Storage – 2023

Storage Resource Cost Calculator

Detailed Proforma
(Cost of Generation, Projected Market Benefits)

ESS + PV Dispatch Module
(Estimates Grid Charge Needs)

Marginal Resource Forecast
(Emissions Impact)



Inputs & Assumptions

- Operating Profiles
- Technology Costs
- Market Prices (i.e. grid service benefits)

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Key Assumptions: Capacity Value

- Energy storage systems (ESS) with 4 hour duration can contribute to resource adequacy in MISO as a "Use Limited Resource"
- Use Limited Resource (MISO definition):
    - "A Capacity Resource may be defined as a Use Limited Resource if it is capable of providing the energy equivalent of its claimed capacity for a minimum of 4 continuous hours each day across the Transmission Provider's peak."
- ESS capacity contribution is comparable to a new natural gas combustion turbine (CT).

References:

- MISO Market Training - Resource Adequacy https://www.misoenergy.org/_layouts/MISO/ECM/Redirect.aspx?ID=126470

Key Assumptions: ESS Operations

- **ESS Operation Assumptions:**
  - Full storage capability (i.e. 100 MW x 4 hrs) is discharged during peak hours, and charged during off-peak hours.
    - Note: MISO historical peak hours typically correspond with HE 15 through HE 18 during summer months.
  - All other hours are available to provide ancillary services (~18 hours/day). Ancillary service dispatch profile was estimated using ESVT software tool.

References:

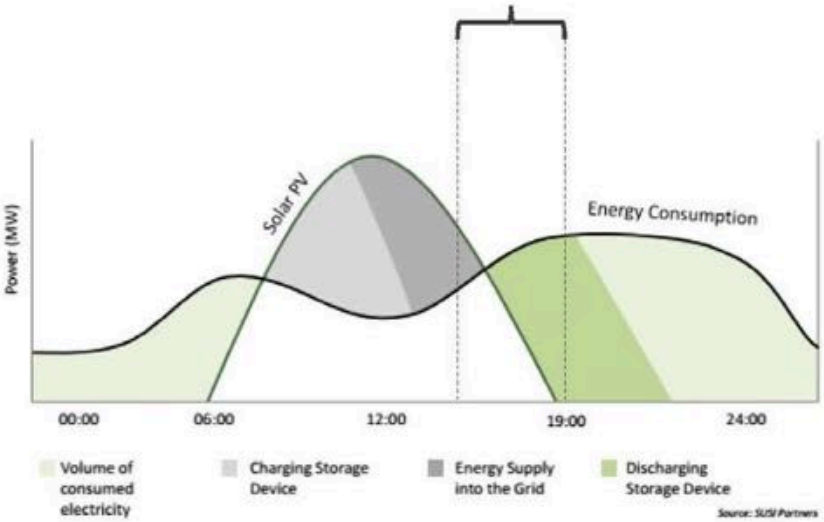
- MISO Historic Peak Load: https://www.misoenergy.org/_layouts/MISO/ECM/Redirect.aspx?ID=229498

Key Assumptions: ESS Operations (con't)

- Energy Market Revenues:
  - ESS pays and receives full LMP price for all MWh charged and discharged
  - CT receives full LMP price for all MWh generated
- Operating Reserve (Ancillary Services) Market Revenues:
  - ESS resource can receive a market award for one power or energy unit in any given time interval.
  - The highest value ancillary services product for ESS is Frequency Regulation (FR) and it is most advantageous to bid full battery capacity for FR (vs. spin, non-spin, etc.).
  - Dispatch for FR yields some additional cycling
  - CT not presumed to provide ancillary services
- For storage-only resource, IOU ownership assumed

Key Assumptions: Storage + Solar Operations

Typical Peak Hours

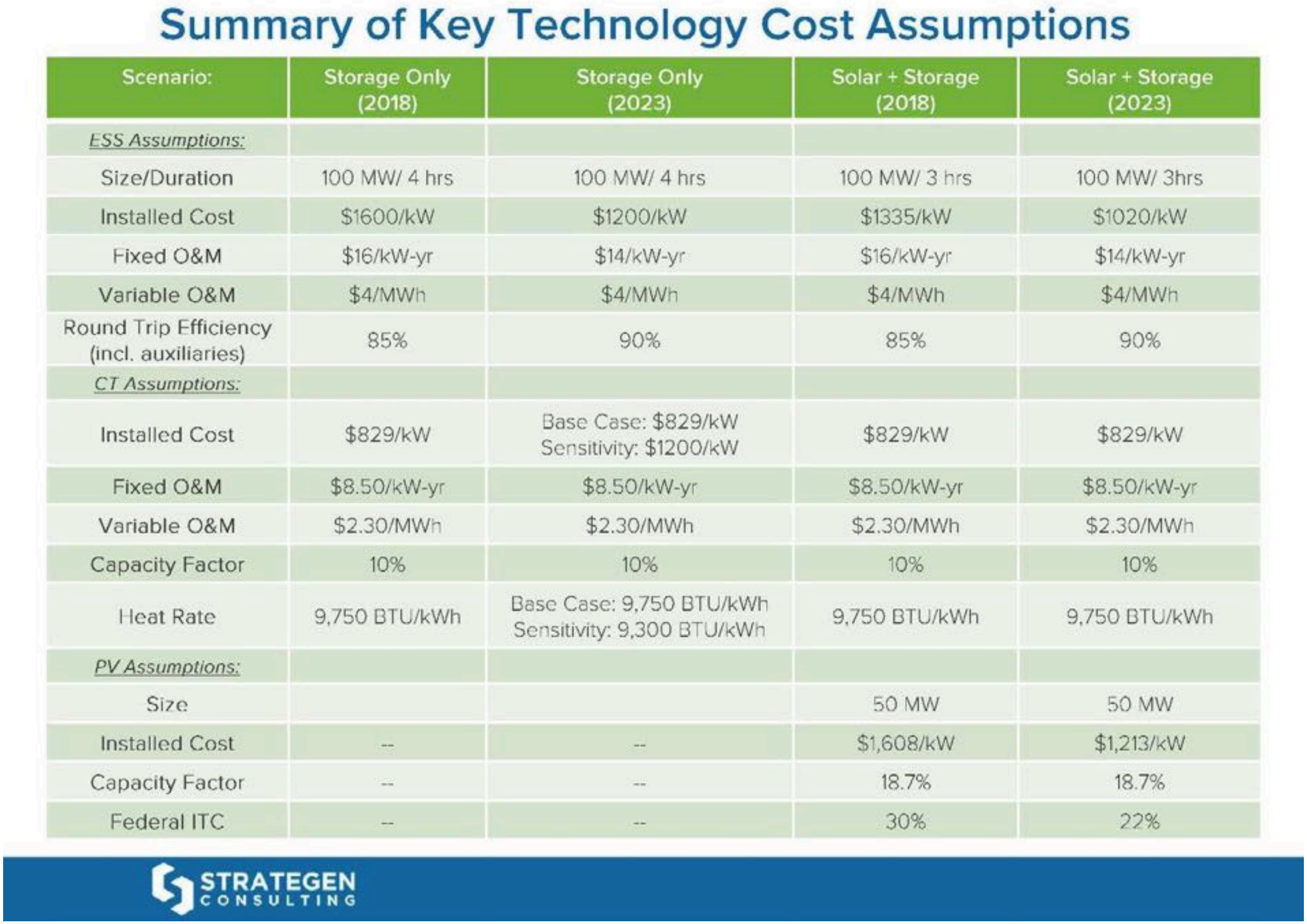


Source: SUSI Partners

Slide Credit: Connexus

Key Assumptions: Storage + Solar

- For Solar + Storage scenarios, ESS system is coupled with solar PV system as the capacity resource
- Coupled ESS+PV system is sized and operated to ensure the following:
  - High output during summer peak hours (hours ending 15 through 18, June through Sept)
  - >75% of charging energy is derived from coupled solar PV, not the grid (this is necessary for federal ITC eligibility)
  - Any excess energy produced by PV (i.e. when storage is fully charged) is exported to the grid
- Assumes financing through power purchase agreement (PPA)
- Avoided environmental costs due to PV energy are included
  - Based on most recent value of solar update (Sept 30, 2016 compliance filing in Docket No. E002/M-13-867,)



Summary of Key Technology Cost Assumptions

Scenario:	Storage Only (2018)	Storage Only (2023)	Solar + Storage (2018)	Solar + Storage (2023)
ESS Assumptions:				
Size/Duration	100 MW/ 4 hrs	100 MW/ 4 hrs	100 MW/ 3 hrs	100 MW/ 3hrs
Installed Cost	$1600/kW	$1200/kW	$1335/kW	$1020/kW
Fixed O&M	$16/kW-yr	$14/kW-yr	$16/kW-yr	$14/kW-yr
Variable O&M	$4/MWh	$4/MWh	$4/MWh	$4/MWh
Round Trip Efficiency (incl. auxiliaries)	85%	90%	85%	90%
CT Assumptions:				
Installed Cost	$829/kW	Base Case: $829/kW Sensitivity: $1200/kW	$829/kW	$829/kW
Fixed O&M	$8.50/kW-yr	$8.50/kW-yr	$8.50/kW-yr	$8.50/kW-yr
Variable O&M	$2.30/MWh	$2.30/MWh	$2.30/MWh	$2.30/MWh
Capacity Factor	10%	10%	10%	10%
Heat Rate	9,750 BTU/kWh	Base Case: 9,750 BTU/kWh Sensitivity: 9,300 BTU/kWh	9,750 BTU/kWh	9,750 BTU/kWh
PV Assumptions:				
Size			50 MW	50 MW
Installed Cost	--	--	$1,608/kW	$1,213/kW
Capacity Factor	--	--	18.7%	18.7%
Federal ITC	--	--	30%	22%

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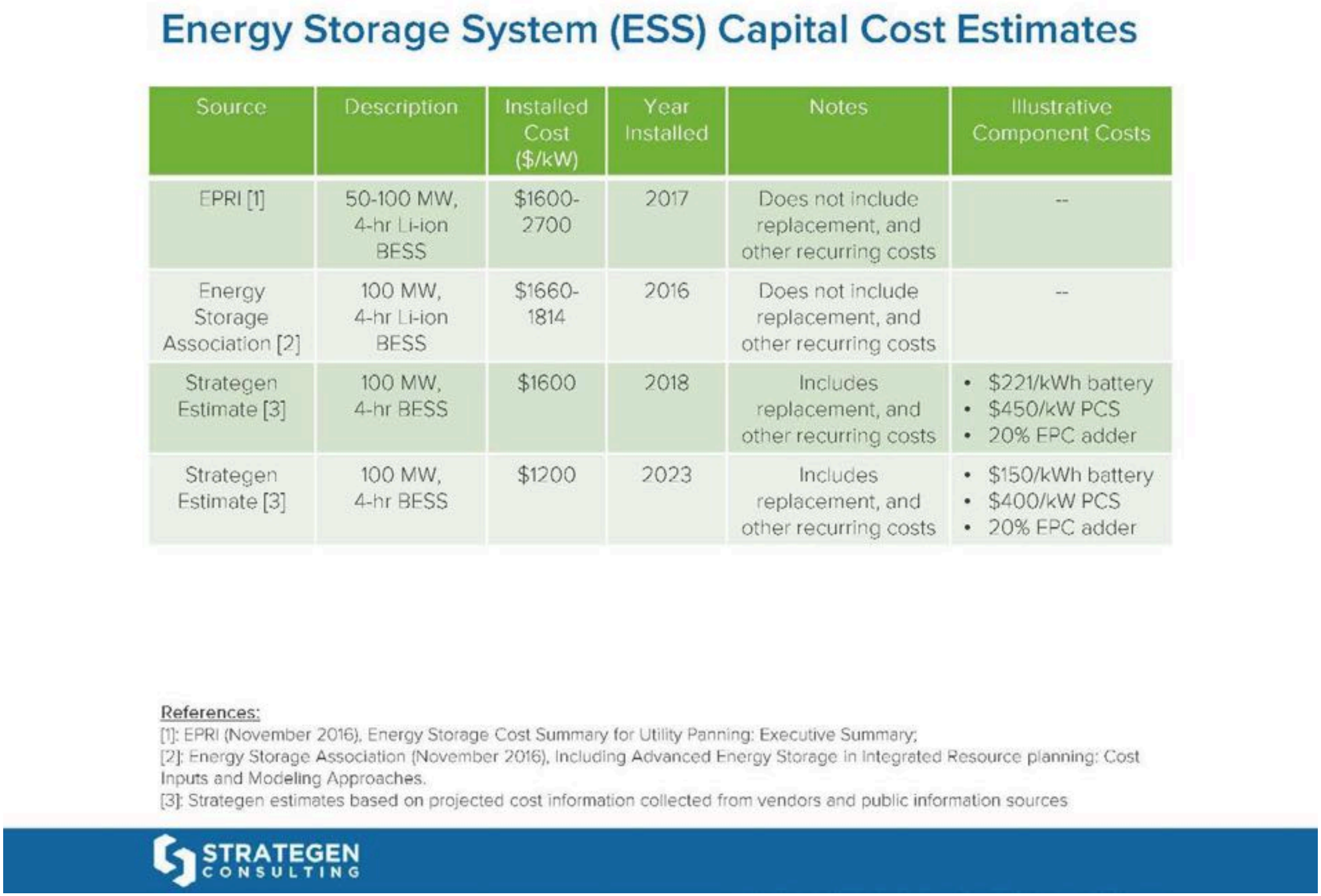

Energy Storage System (ESS) Capital Cost Estimates

Source	Description	Installed Cost ($/kW)	Year Installed	Notes	Illustrative Component Costs
EPRI [1]	50-100 MW, 4-hr Li-ion BESS	$1600-2700	2017	Does not include replacement, and other recurring costs	--
Energy Storage Association [2]	100 MW, 4-hr Li-ion BESS	$1660-1814	2016	Does not include replacement, and other recurring costs	--
Strategen Estimate [3]	100 MW, 4-hr BESS	$1600	2018	Includes replacement, and other recurring costs	• $221/kWh battery • $450/kW PCS • 20% EPC adder
Strategen Estimate [3]	100 MW, 4-hr BESS	$1200	2023	Includes replacement, and other recurring costs	• $150/kWh battery • $400/kW PCS • 20% EPC adder

References:

[1]: EPRI (November 2016), Energy Storage Cost Summary for Utility Panning: Executive Summary;

[2]: Energy Storage Association (November 2016), Including Advanced Energy Storage in Integrated Resource planning: Cost Inputs and Modeling Approaches.

[3]: Strategen estimates based on projected cost information collected from vendors and public information sources

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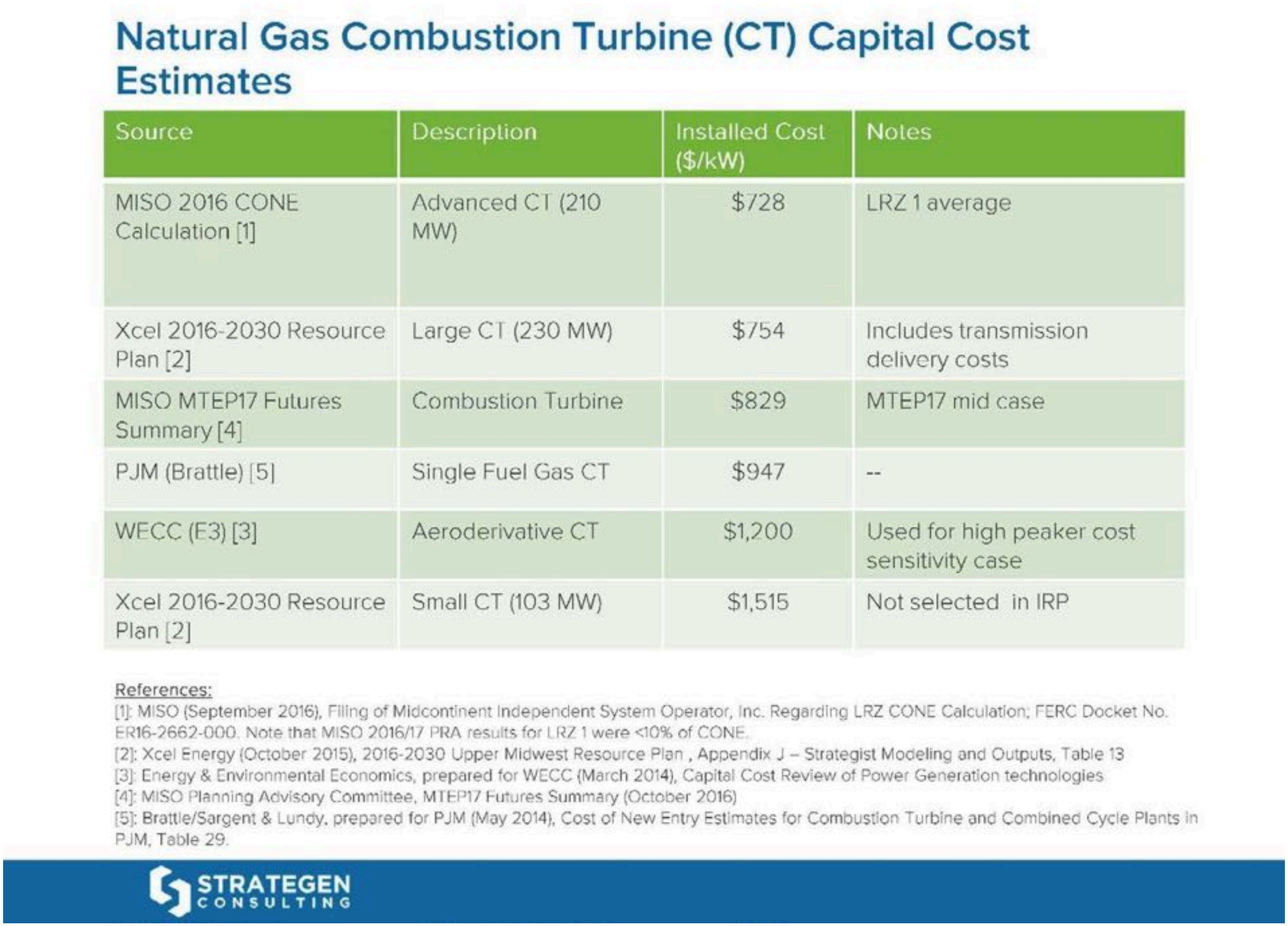

Natural Gas Combustion Turbine (CT) Capital Cost Estimates

Source	Description	Installed Cost ($/kW)	Notes
MISO 2016 CONE Calculation [1]	Advanced CT (210 MW)	$728	LRZ 1 average
Xcel 2016-2030 Resource Plan [2]	Large CT (230 MW)	$754	Includes transmission delivery costs
MISO MTEP17 Futures Summary [4]	Combustion Turbine	$829	MTEP17 mid case
PJM (Brattle) [5]	Single Fuel Gas CT	$947	--
WECC (E3) [3]	Aeroderivative CT	$1,200	Used for high peaker cost sensitivity case
Xcel 2016-2030 Resource Plan [2]	Small CT (103 MW)	$1,515	Not selected in IRP

References:

[1]: MISO (September 2016), Filing of Midcontinent Independent System Operator, Inc. Regarding LRZ CONE Calculation; FERC Docket No. ER16-2662-000. Note that MISO 2016/17 PRA results for LRZ 1 were <10% of CONE.

[2]: Xcel Energy (October 2015), 2016-2030 Upper Midwest Resource Plan , Appendix J – Strategist Modeling and Outputs, Table 13

[3]: Energy & Environmental Economics, prepared for WECC (March 2014), Capital Cost Review of Power Generation technologies

[4]: MISO Planning Advisory Committee, MTEP17 Futures Summary (October 2016)

[5]: Brattle/Sargent & Lundy, prepared for PJM (May 2014), Cost of New Entry Estimates for Combustion Turbine and Combined Cycle Plants in PJM, Table 29.

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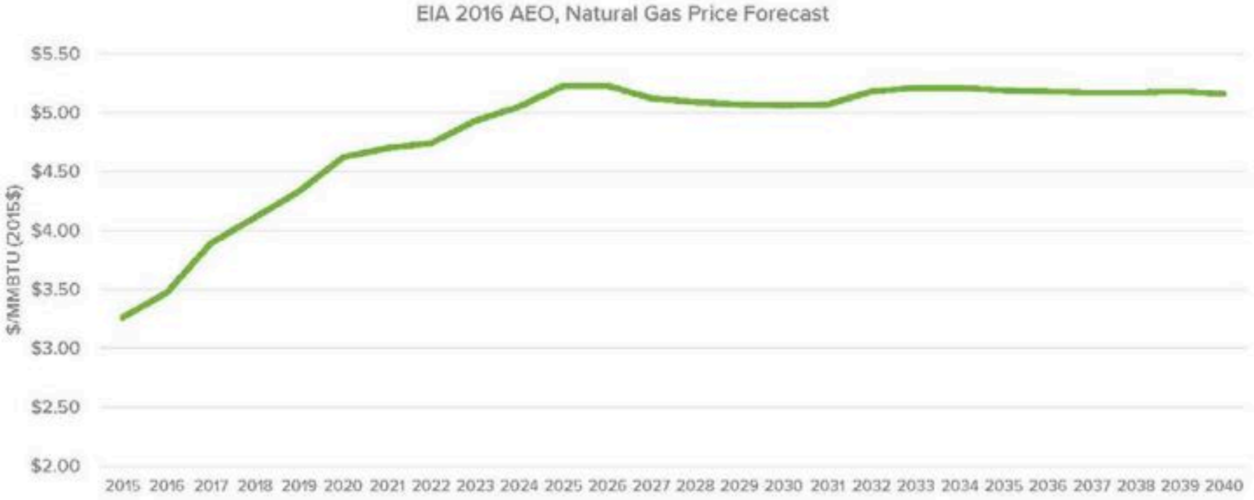
CT Heat Rate and Fuel Cost Estimates

Source	Description	Value	Notes
MISO 2016 CONE Calculation [1]	Advanced CT	9,750 BTU/kWh	Used for 2018 and 2023 cases
WECC (E3) [2]	Gas CT (Aero) Heat Rate	9,300 BTU/kWh	Used for high peaker sensitivity case


EIA 2016 AEO, Natural Gas Price Forecast

[1]: MISO (September 2016), Filing of Midcontinent Independent System Operator, Inc. Regarding LRZ CONE Calculation; FERC Docket No. ER16-2662-000

[2]: Energy & Environmental Economics, prepared for WECC (March 2014), Capital Cost Review of Power Generation technologies

[3]: EIA Annual Energy Outlook 2016, Reference Case (No Clean Power Plan)

ESS O&M Cost Estimates

Source	Description	Round Trip Efficiency (incl. aux)	O&M Costs	Notes
Strategen Estimate [1]	100 MW, 4-hr BESS, 20-years	85% (2018) 90% (2023)	Fixed: $16/kW-yr Variable: $4/MWh	Includes replacement costs

CT O&M Costs Estimates

Source	Description	O&M Costs	Notes
MISO MTEP16 [2]	Combustion Turbine	Fixed: $8.70/kW-yr Variable: $2.46/MWh	--
Xcel 2016-2030 Resource Plan [3]	Large CT (230 MW)	Fixed: $8.44/kW-yr Variable: $2.27/MWh	Fixed O&M includes ongoing CapEx.

References:

[1]: Strategen estimates based on projected cost information collected from vendors and public information sources
[2]: MISO Transmission Expansion Plan 2016, Appendix E2, EGEAS Assumptions Document (2015)
[3]: Xcel Energy, 2016-2030 Upper Midwest Resource Plan , Appendix J – Strategist Modeling and Outputs, Table 13 (October 2015)

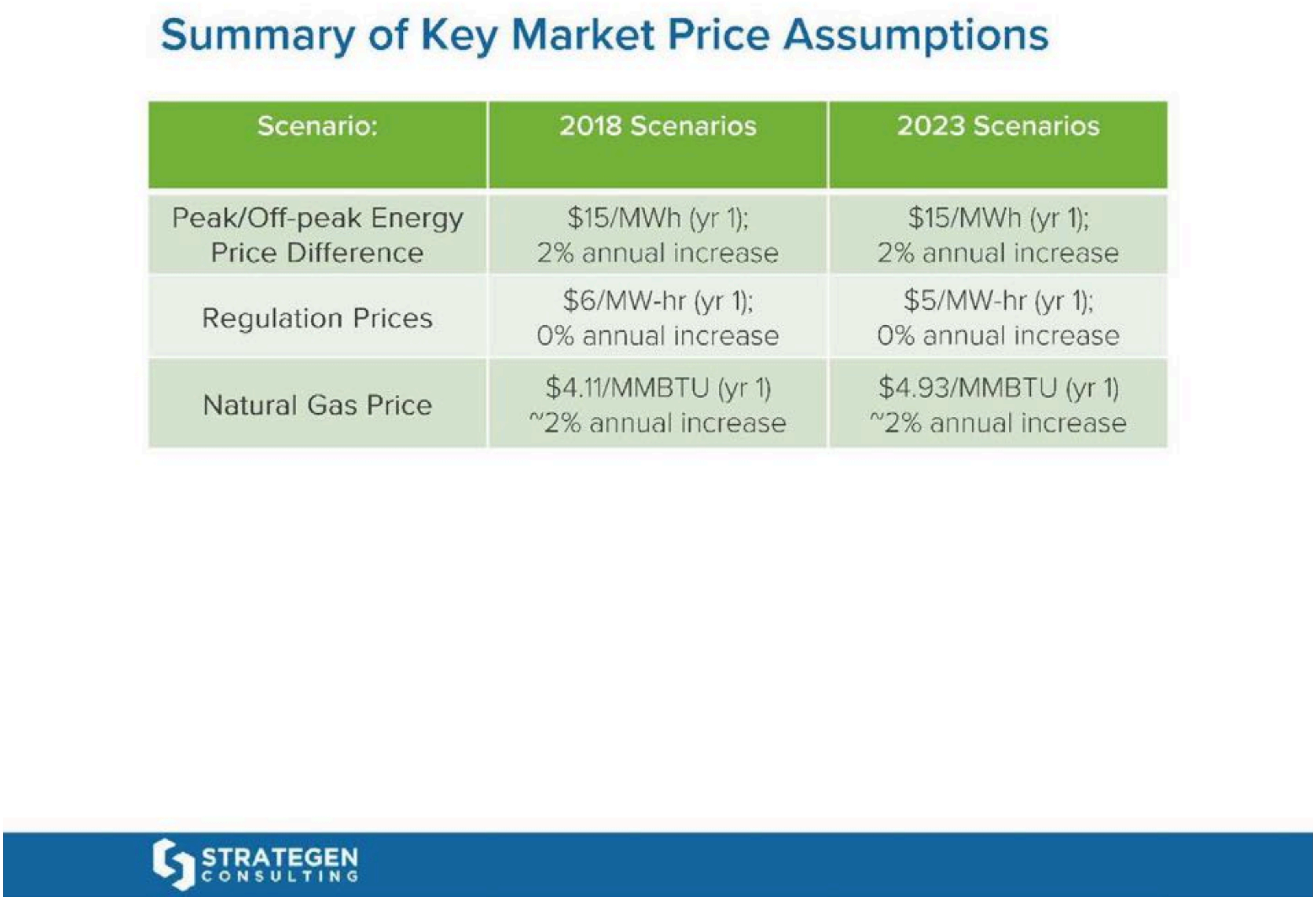
PV Cost Estimates

Source	Description	Installed Cost ($/kW)	Fixed O&M ($/kW-yr)
NREL 2016 Annual Technology Baseline	Utility PV – Mid Case, 2018	$1,608/kW	$14/kW-yr
NREL 2016 Annual Technology Baseline	Utility PV – Mid Case, 2023	$1,213/kW	$10/kW-yr

Other PV Assumptions:

- Single Axis Tracking Array
- 18.7% capacity factor (based on PV Watts simulation for St. Cloud, MN)
- Fixed O&M cost sharing with solar and storage

[1]: NREL (National Renewable Energy Laboratory). 2016. *2016 Annual Technology Baseline*. Golden, CO: National Renewable Energy Laboratory. http://www.nrel.gov/analysis/data_tech_baseline.html.

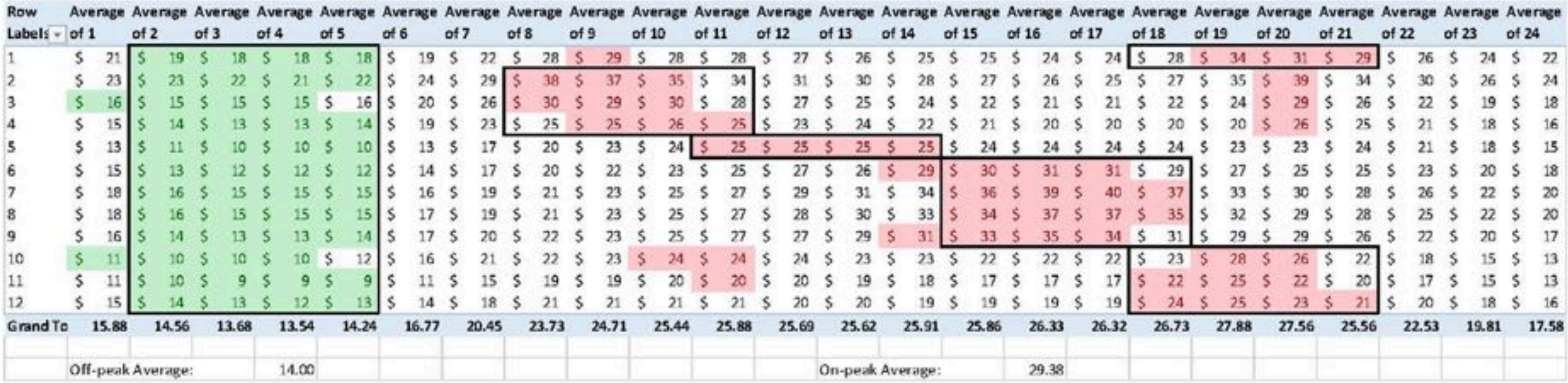


Summary of Key Market Price Assumptions

Scenario:	2018 Scenarios	2023 Scenarios
Peak/Off-peak Energy Price Difference	$15/MWh (yr 1); 2% annual increase	$15/MWh (yr 1); 2% annual increase
Regulation Prices	$6/MW-hr (yr 1); 0% annual increase	$5/MW-hr (yr 1); 0% annual increase
Natural Gas Price	$4.11/MMBTU (yr 1) ~2% annual increase	$4.93/MMBTU (yr 1) ~2% annual increase

MISO Energy Prices (for ESS arbitrage and CT output)

- MISO Minn. Hub day ahead LMP Prices for 2015 were examined.
- Daily 4-hour peak and 4-hour off-peak periods were identified for each month to determine typical peak and off-peak prices:
  - On-Peak Average =$29/MWh
  - Off-Peak Average =$14/MWh
- Higher prices, but similar price differential was observed in earlier years (e.g. 2013)
- Peak and off peak prices may diverge more in the future if new wind generation serves to suppress off-peak prices below current level



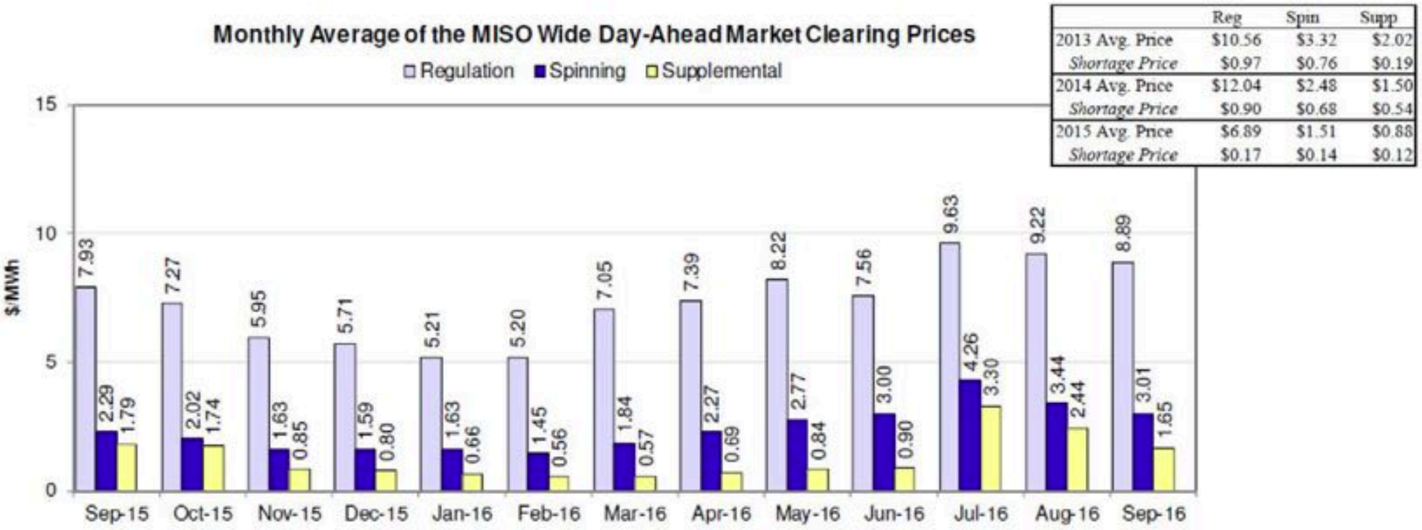
Row Labels	Average of 1	Average of 2	Average of 3	Average of 4	Average of 5	Average of 6	Average of 7	Average of 8	Average of 9	Average of 10	Average of 11	Average of 12	Average of 13	Average of 14	Average of 15	Average of 16	Average of 17	Average of 18	Average of 19	Average of 20	Average of 21	Average of 22	Average of 23	Average of 24
1	$ 21	$ 19	$ 18	$ 18	$ 18	$ 19	$ 22	$ 28	$ 29	$ 28	$ 28	$ 27	$ 26	$ 25	$ 25	$ 24	$ 24	$ 28	$ 34	$ 31	$ 29	$ 26	$ 24	$ 22
2	$ 23	$ 23	$ 22	$ 21	$ 22	$ 24	$ 29	$ 38	$ 37	$ 35	$ 34	$ 31	$ 30	$ 28	$ 27	$ 26	$ 25	$ 27	$ 35	$ 39	$ 34	$ 30	$ 26	$ 24
3	$ 16	$ 15	$ 15	$ 15	$ 16	$ 20	$ 26	$ 30	$ 29	$ 30	$ 28	$ 27	$ 25	$ 24	$ 22	$ 21	$ 21	$ 22	$ 24	$ 29	$ 26	$ 22	$ 19	$ 18
4	$ 15	$ 14	$ 13	$ 13	$ 14	$ 19	$ 23	$ 25	$ 25	$ 26	$ 25	$ 23	$ 24	$ 22	$ 21	$ 20	$ 20	$ 20	$ 20	$ 26	$ 25	$ 21	$ 18	$ 16
5	$ 13	$ 11	$ 10	$ 10	$ 10	$ 13	$ 17	$ 20	$ 23	$ 24	$ 25	$ 25	$ 25	$ 25	$ 24	$ 24	$ 24	$ 24	$ 23	$ 23	$ 24	$ 21	$ 18	$ 15
6	$ 15	$ 13	$ 12	$ 12	$ 12	$ 14	$ 17	$ 20	$ 22	$ 23	$ 25	$ 27	$ 26	$ 29	$ 30	$ 31	$ 31	$ 29	$ 27	$ 25	$ 25	$ 23	$ 20	$ 18
7	$ 18	$ 16	$ 15	$ 15	$ 15	$ 16	$ 19	$ 21	$ 23	$ 25	$ 27	$ 29	$ 31	$ 34	$ 36	$ 39	$ 40	$ 37	$ 33	$ 30	$ 28	$ 26	$ 22	$ 20
8	$ 18	$ 16	$ 15	$ 15	$ 15	$ 17	$ 19	$ 21	$ 23	$ 25	$ 27	$ 28	$ 30	$ 33	$ 34	$ 37	$ 37	$ 35	$ 32	$ 29	$ 28	$ 25	$ 22	$ 20
9	$ 16	$ 14	$ 13	$ 13	$ 14	$ 17	$ 20	$ 22	$ 23	$ 25	$ 27	$ 27	$ 29	$ 31	$ 33	$ 35	$ 34	$ 31	$ 29	$ 29	$ 26	$ 22	$ 20	$ 17
10	$ 11	$ 10	$ 10	$ 10	$ 12	$ 16	$ 21	$ 22	$ 23	$ 24	$ 24	$ 24	$ 23	$ 23	$ 22	$ 22	$ 22	$ 23	$ 28	$ 26	$ 22	$ 18	$ 15	$ 13
11	$ 11	$ 10	$ 9	$ 9	$ 9	$ 11	$ 15	$ 19	$ 19	$ 20	$ 20	$ 20	$ 19	$ 18	$ 17	$ 17	$ 17	$ 22	$ 25	$ 22	$ 20	$ 17	$ 15	$ 13
12	$ 15	$ 14	$ 13	$ 12	$ 13	$ 14	$ 18	$ 21	$ 21	$ 21	$ 21	$ 20	$ 20	$ 19	$ 19	$ 19	$ 19	$ 24	$ 25	$ 23	$ 21	$ 20	$ 18	$ 16
Grand To	15.88	14.56	13.68	13.54	14.24	16.77	20.45	23.73	24.71	25.44	25.88	25.69	25.62	25.91	25.86	26.33	26.32	26.73	27.88	27.56	25.56	22.53	19.81	17.58
	Off-peak Average:			14.00									On-peak Average:			29.38								

Starting assumptions:

- ~$15/MWh spread
- Escalation estimated to be 2% annually

MISO Operating Reserve (Ancillary Services) Markets

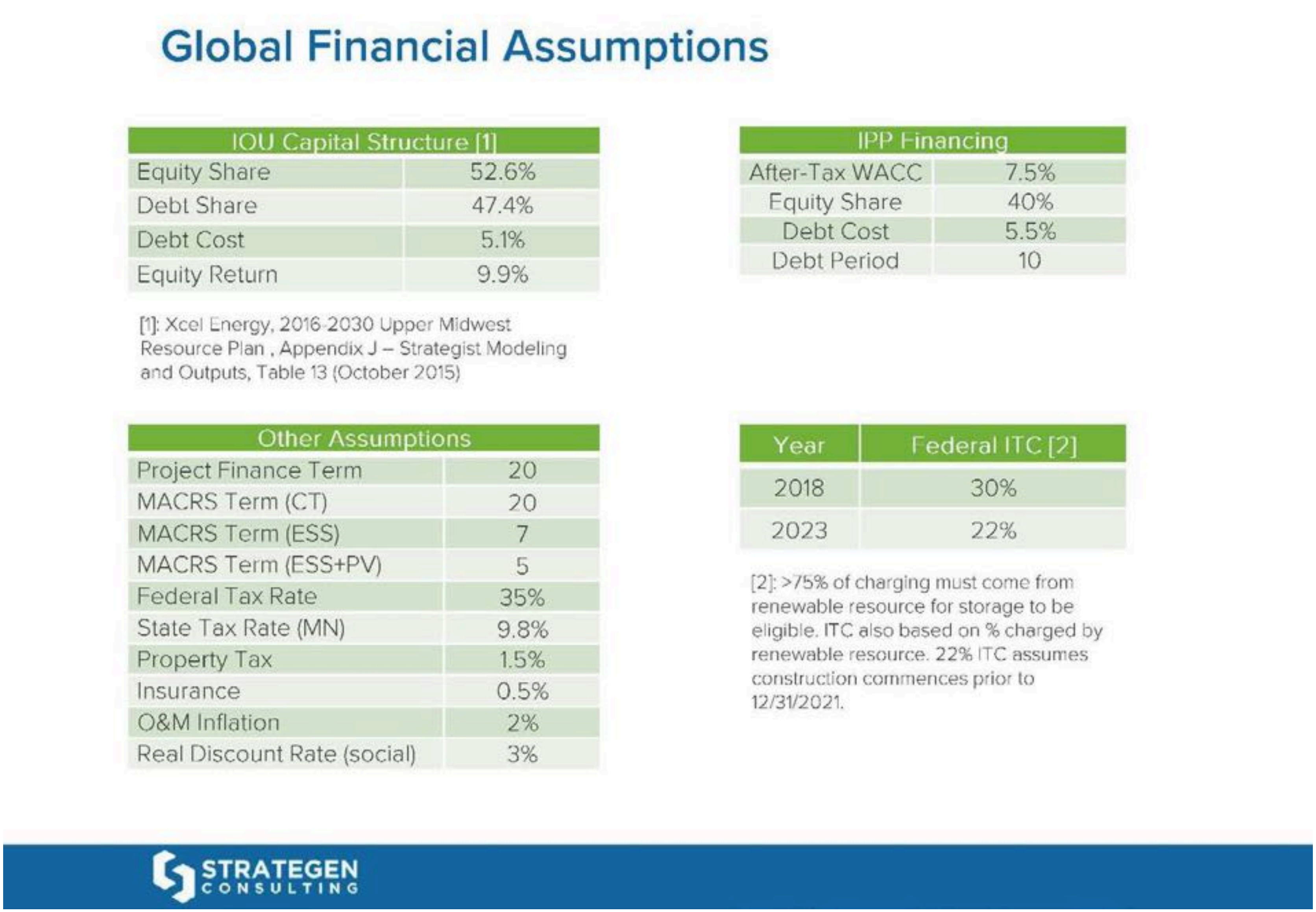
- Regulation reserves are the highest valued ancillary service product in MISO
- MISO's regulation requirement (i.e. total market size) ≈400 MW
- Regulation prices in recent months have ranged from $5.20 - $9.63 per MWh



	Reg	Spin	Supp
2013 Avg. Price	$10.56	$3.32	$2.02
Shortage Price	$0.97	$0.76	$0.19
2014 Avg. Price	$12.04	$2.48	$1.50
Shortage Price	$0.90	$0.68	$0.54
2015 Avg. Price	$6.89	$1.51	$0.88
Shortage Price	$0.17	$0.14	$0.12

- Starting assumptions:
  - $5-7/MWh (assumes minimal decrease with storage deployment)
  - No escalation assumed (offset by new hydro & storage)
  - 100 MW unit can supply 25% of MISO regulation services

Source: MISO September 2016 Monthly Market Assessment Report



Global Financial Assumptions

IOU Capital Structure [1]	
Equity Share	52.6%
Debt Share	47.4%
Debt Cost	5.1%
Equity Return	9.9%

[1]: Xcel Energy, 2016-2030 Upper Midwest Resource Plan , Appendix J – Strategist Modeling and Outputs, Table 13 (October 2015)

IPP Financing	
After-Tax WACC	7.5%
Equity Share	40%
Debt Cost	5.5%
Debt Period	10

Other Assumptions	
Project Finance Term	20
MACRS Term (CT)	20
MACRS Term (ESS)	7
MACRS Term (ESS+PV)	5
Federal Tax Rate	35%
State Tax Rate (MN)	9.8%
Property Tax	1.5%
Insurance	0.5%
O&M Inflation	2%
Real Discount Rate (social)	3%

Year	Federal ITC [2]
2018	30%
2023	22%

[2]: >75% of charging must come from renewable resource for storage to be eligible. ITC also based on % charged by renewable resource. 22% ITC assumes construction commences prior to 12/31/2021.

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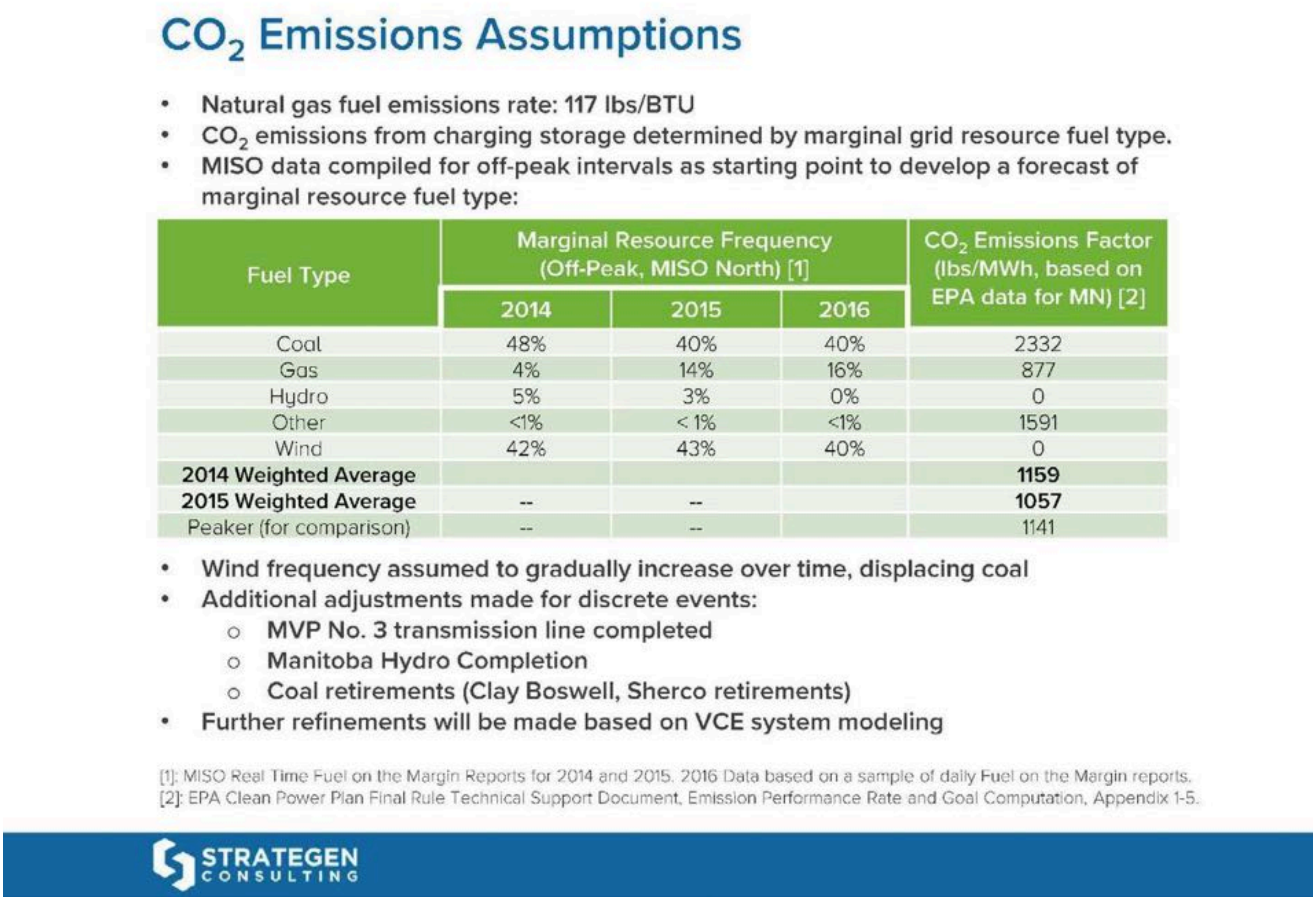

CO_2 Emissions Assumptions

- **Natural gas fuel emissions rate: 117 lbs/BTU**
- **CO_2 emissions from charging storage determined by marginal grid resource fuel type.**
- **MISO data compiled for off-peak intervals as starting point to develop a forecast of marginal resource fuel type:**

Fuel Type	Marginal Resource Frequency (Off-Peak, MISO North) [1]			CO_2 Emissions Factor (lbs/MWh, based on EPA data for MN) [2]
	2014	2015	2016	
Coal	48%	40%	40%	2332
Gas	4%	14%	16%	877
Hydro	5%	3%	0%	0
Other	<1%	< 1%	<1%	1591
Wind	42%	43%	40%	0
2014 Weighted Average				**1159**
2015 Weighted Average	--	--		**1057**
Peaker (for comparison)	--	--		1141

- **Wind frequency assumed to gradually increase over time, displacing coal**
- **Additional adjustments made for discrete events:**
  - **MVP No. 3 transmission line completed**
  - **Manitoba Hydro Completion**
  - **Coal retirements (Clay Boswell, Sherco retirements)**
- **Further refinements will be made based on VCE system modeling**

[1]: MISO Real Time Fuel on the Margin Reports for 2014 and 2015. 2016 Data based on a sample of daily Fuel on the Margin reports.
[2]: EPA Clean Power Plan Final Rule Technical Support Document, Emission Performance Rate and Goal Computation, Appendix 1-5.

Preliminary Results

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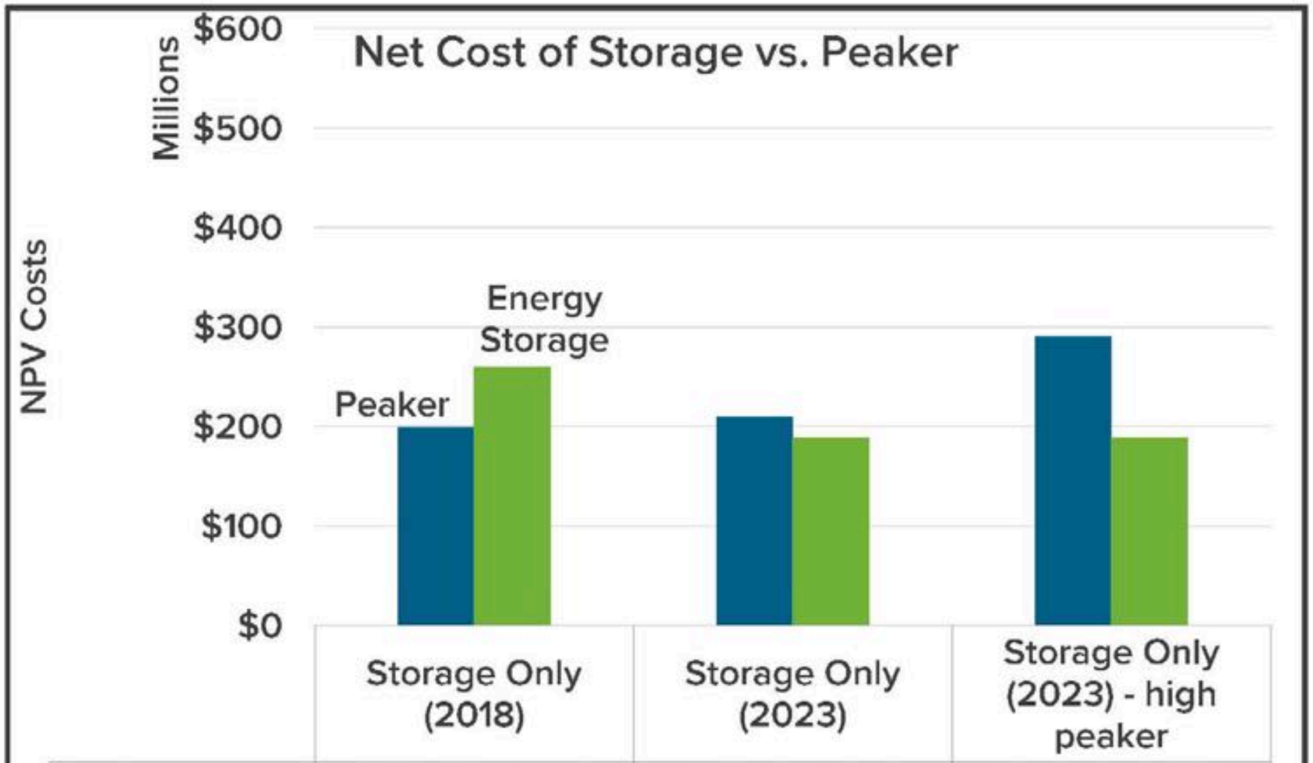
Caveats

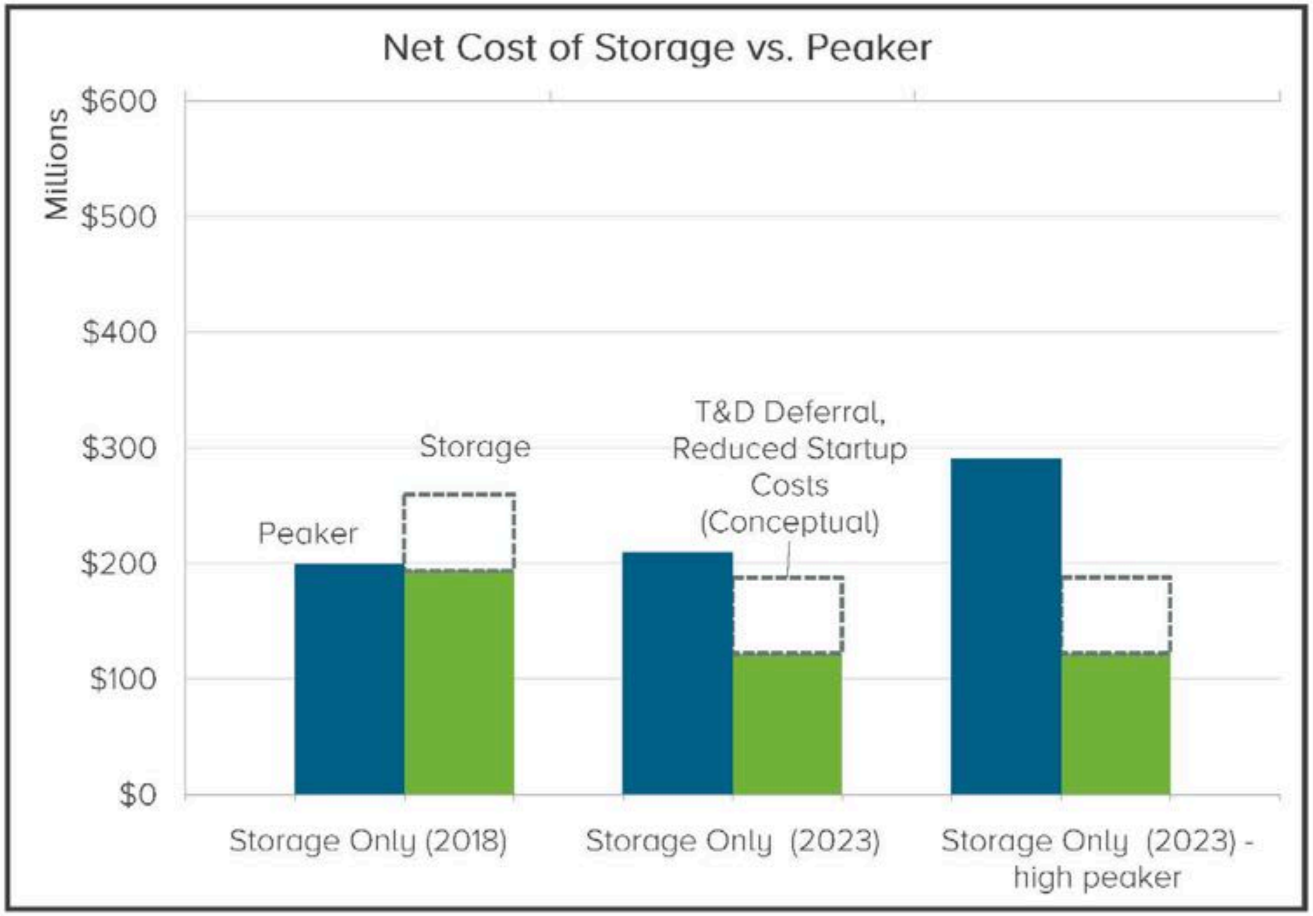
- Results shown here are *preliminary only* and will be subject to further refinement and investigation.
- Cost comparison is highly sensitive to future changes in technology costs and market prices.
- Emissions comparison is highly sensitive to the marginal grid resource used for charging and is affected by changing resource mix and transmission constraints in MISO.
- Certain monetary and/or emissions benefit categories were not quantified (e.g. possible reduced unit starts, T&D deferrals, etc).

Cost Comparison: Storage Only

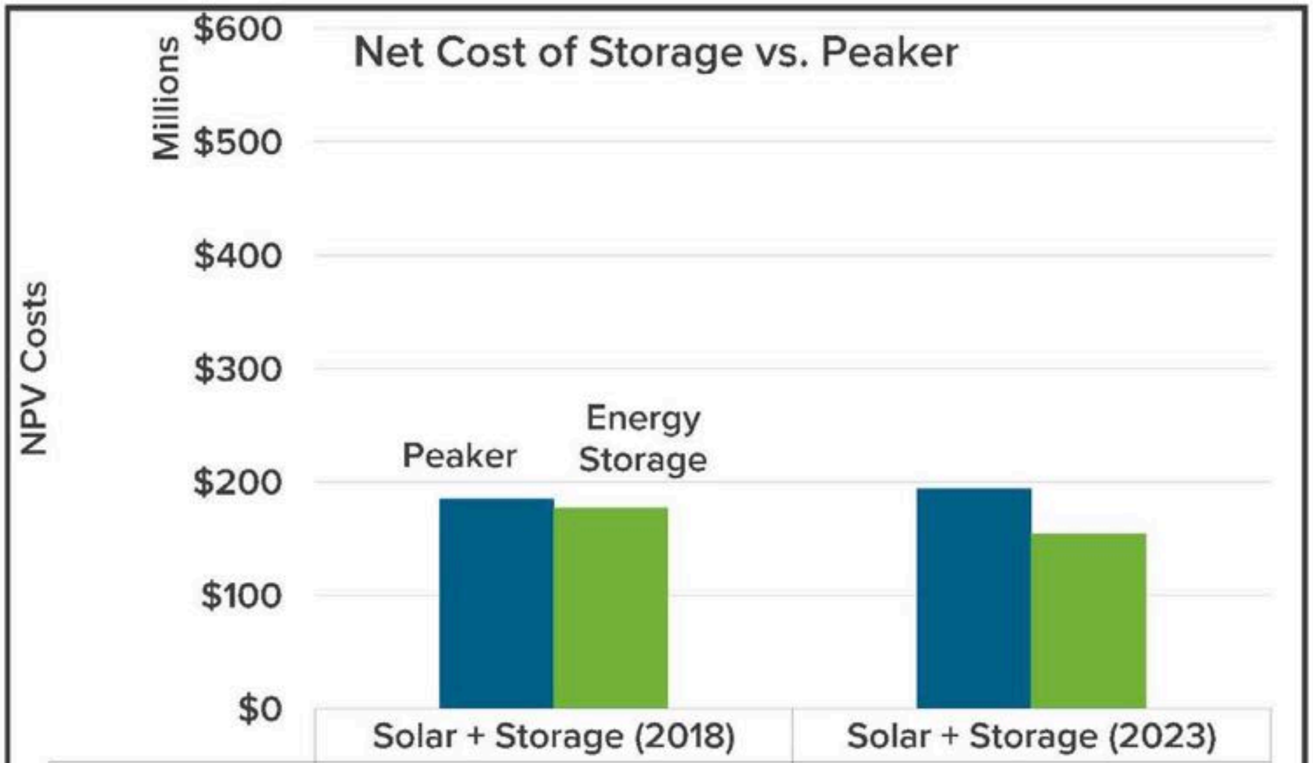


	Storage Only (2018)	Storage Only (2023)	Storage Only (2023) - high peaker
Peaker	$199,421,299	$209,625,391	$290,535,140
Energy Storage	$259,765,849	$187,939,386	$188,060,560
B/C Ratio	0.77	1.12	1.54

Locational Benefits Can Reduce Net Cost of Storage

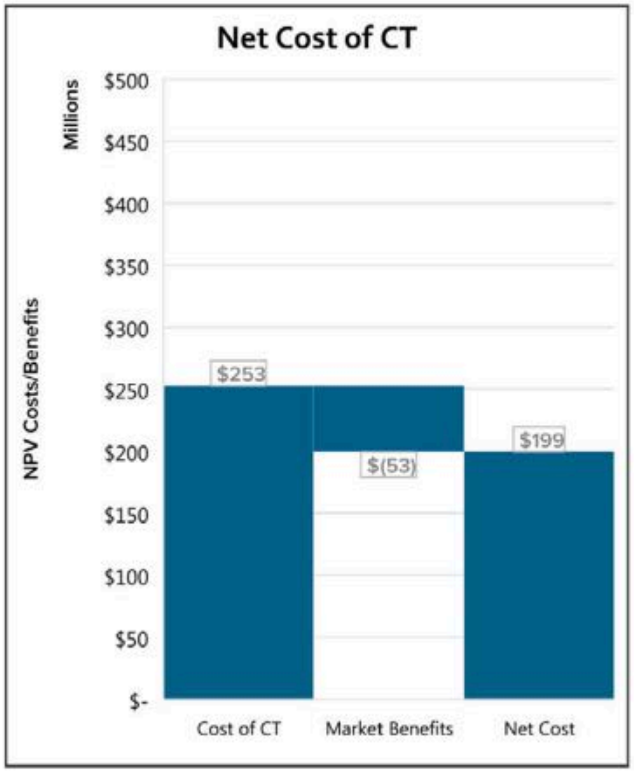


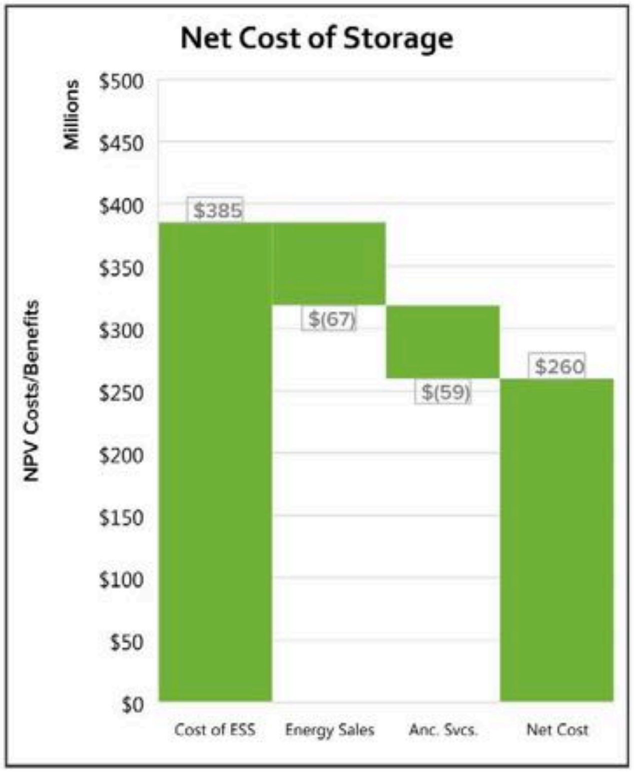
Cost Comparison: Solar + Storage



	Solar + Storage (2018)	Solar + Storage (2023)
Peaker	$184,992,561	$194,176,243
Energy Storage	$177,384,119	$154,230,487
B/C Ratio	1.04	1.26

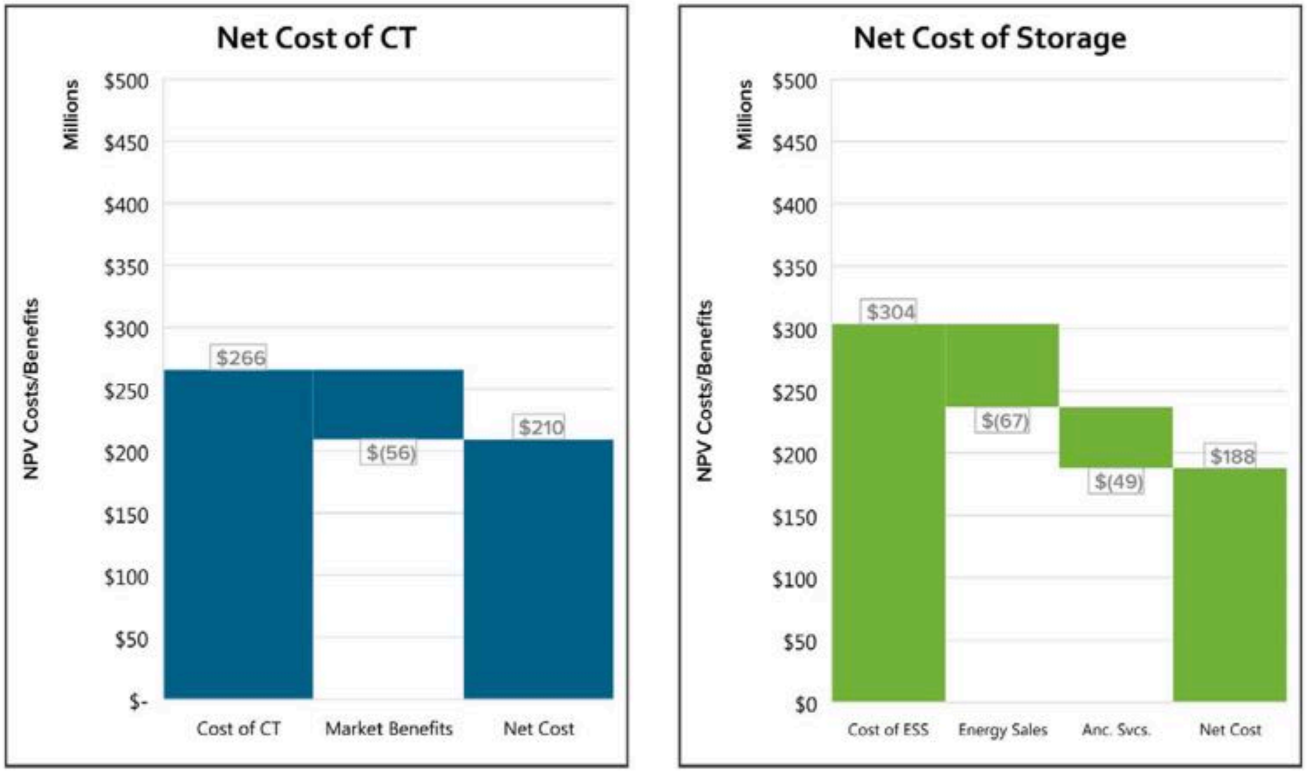
Storage Only - 2018





Net cost of storage is ~$60 M higher than CT

Storage Only - 2023



Net cost of storage is ~$22 M lower than CT

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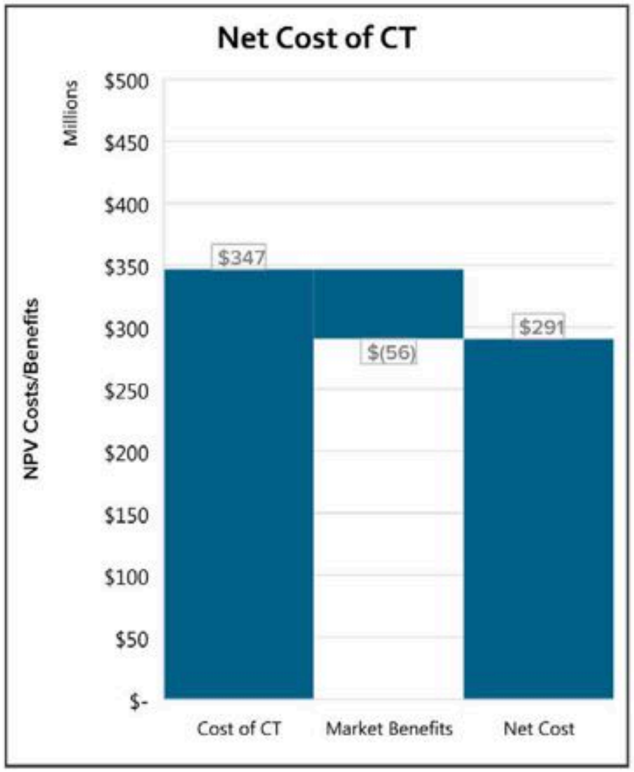
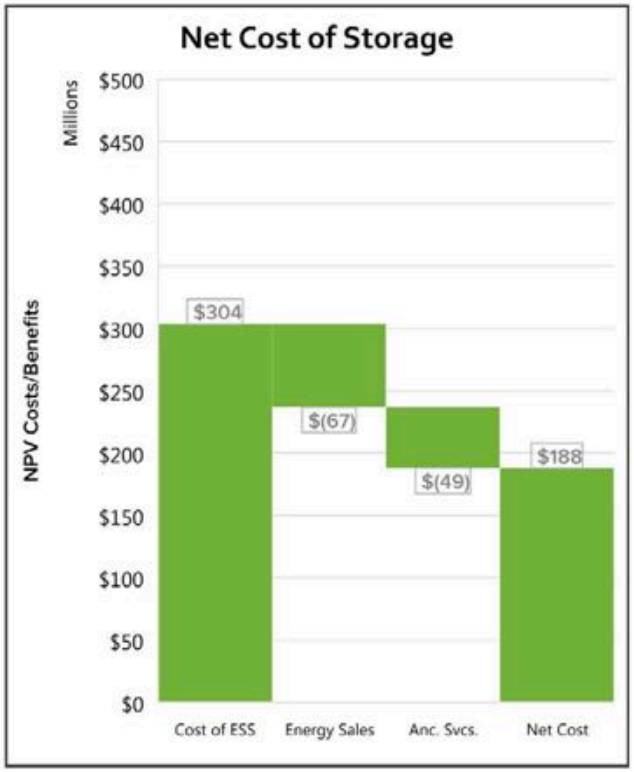
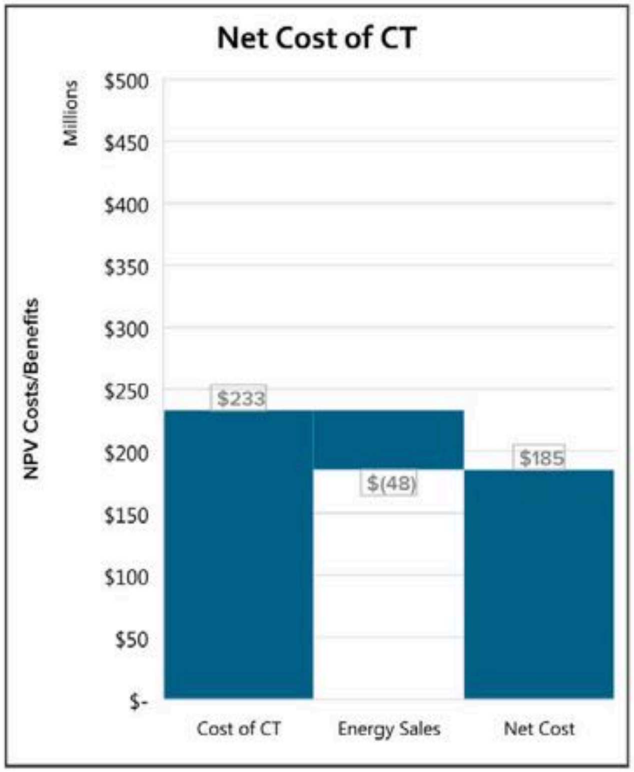
Storage Only – 2023 (high peaker cost sensitivity)



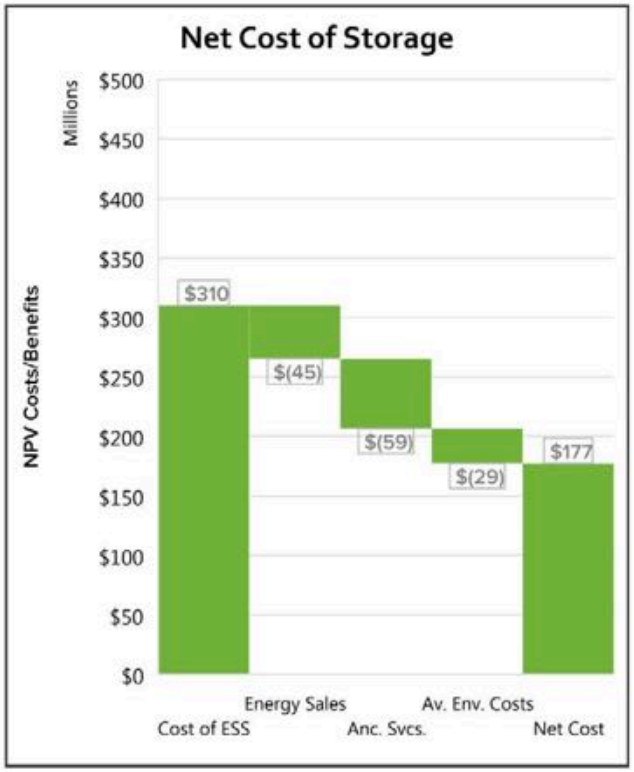


Net cost of storage is ~$102 M lower than CT

Storage + Solar - 2018



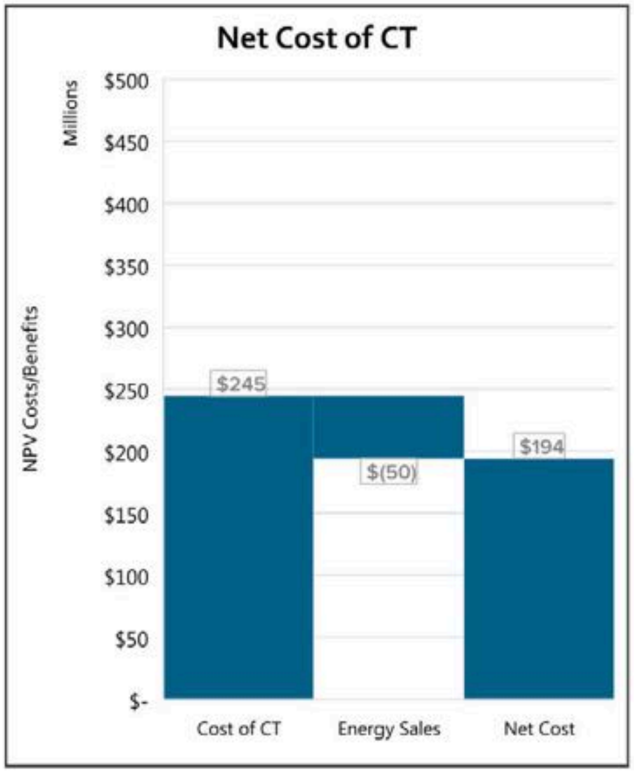
Net Cost of CT

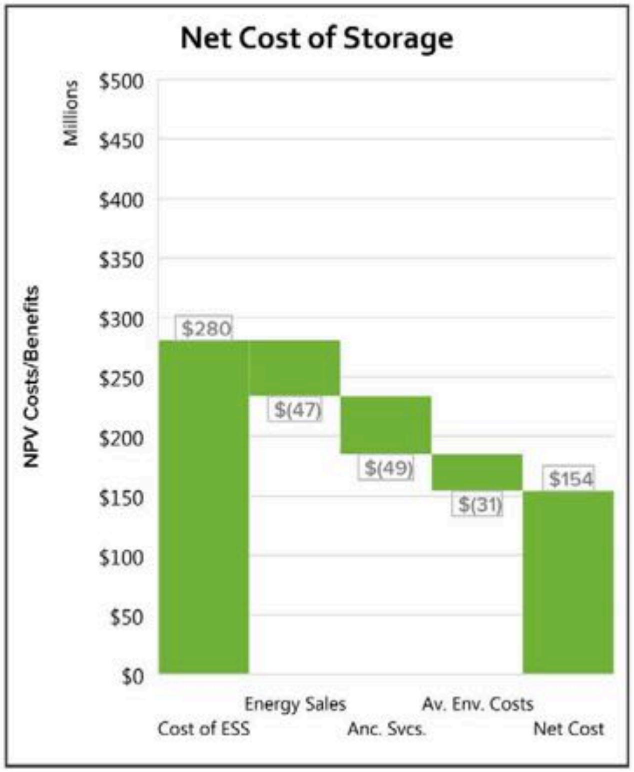


Net Cost of Storage

Net cost of storage is ~$8 M lower than CT

Storage + Solar - 2023





Net cost of storage is ~$40 M lower than CT

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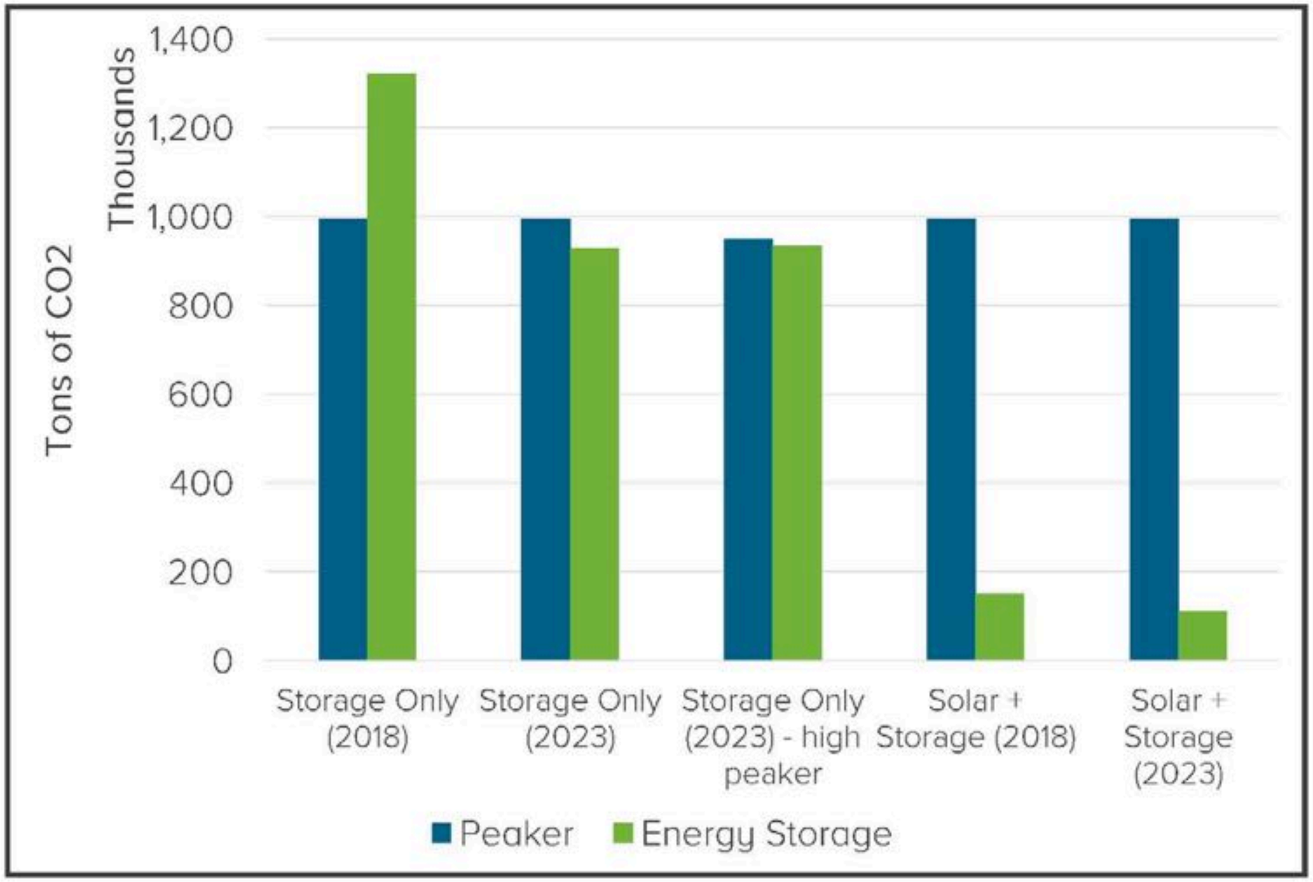
Lifetime CO_2 Emissions Comparison



STRATEGEN CONSULTING

Conclusions

- Standalone energy storage may not be cost competitive versus a new CT in the near term (2018) for MN.
- Standalone energy storage may become cost competitive within the next 5 years provided that storage technology costs decline as anticipated. This could occur sooner if:
  - Additional locational benefits (e.g. T&D deferral, etc.) can be captured
  - CT costs increase due to a need for more flexible unit types
- A coupled energy storage + solar resource may be beneficial both in the near term (2018) and long-term (2023) provided that:
  - The federal investment tax credit (ITC) is fully leveraged
  - Environmental benefits are considered
- Both standalone storage and solar + storage have the potential to reduce emissions relative to a CT:
  - Solar + storage is significantly more effective at reducing emissions
  - The relative emissions impact of standalone storage can improve over time if the frequency of wind "on the margin" increases

Questions, Discussion & Next Steps

Thank You!

Ed Burgess
Senior Manager
Strategen Consulting, LLC

Email: eburgess@strategen.com
Phone: 941-266-0017

Extra Slides

“Breakeven” Storage Costs

- Storage Only: $1336/kW (4-hr duration)
  - Representative cell costs: $175/kWh cells, $412/kW power conversion, 20% EPC
- Solar + Storage: $1092/kW (3-hr duration)
  - Representative costs: $170/kWh cells, $400/kW power conversion, 20% EPC

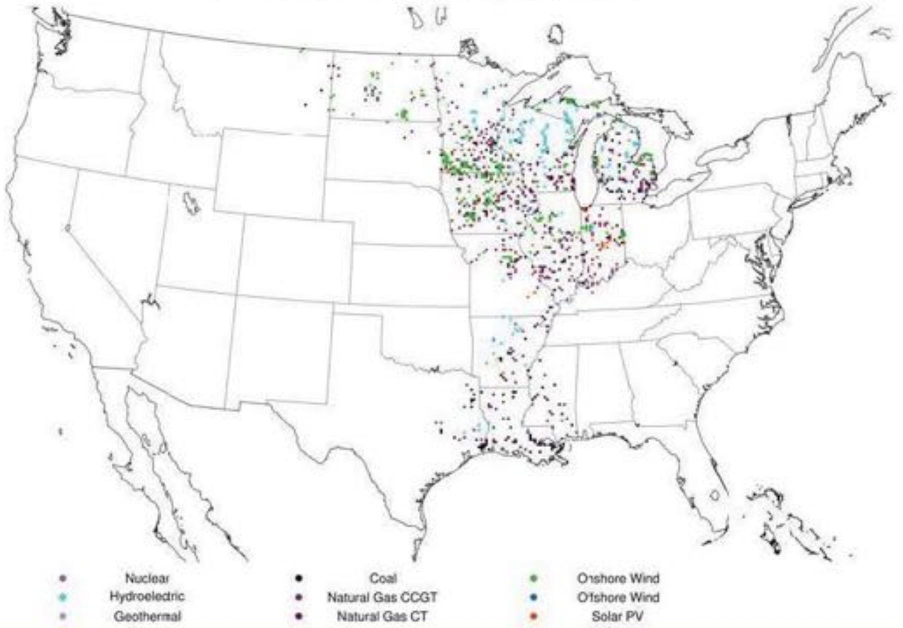
Breakout discussion (30 minutes)

1. Team up with one or two other meeting participants
2. Discuss over the extended break the following three questions:
   1. What does the analysis tell us as to what is right for MN?
   2. What are roadblocks that can be addressed together?
   3. What specific actions can be undertaken near term to make progress? And, BY WHOM?
3. Write your answers on your large format post-its (one idea/post it) Be sure to include WHO should lead the action.
4. We will reconvene in 30 minutes to discuss as a group and vote for top priorities

Note: All recommendations for specific actions are fair game!

16 Appendix H - System Level Scenario Analysis of Minnesota Energy Storage: Interim Results (Vibrant Clean Energy)

Minnesota Energy Storage:
System Level Scenario Analysis Interim Results


MISO Electric Power Plants Optimized for 2017

VCE **VIBRANT CLEAN ENERGY, LLC**

Minnesota Energy Storage:
System Level Scenario Analysis Interim Results

Caveats / Limitations that may impact Storage:

- System modeling is most helpful in considering broad, long-term system-wide trends and their impacts, however, it may not always accurately portray what resource decisions make sense in specific cases or planning decisions. A detailed look at an individual resource investments may tell a somewhat different story, especially if additional ancillary services are included (i.e. using a "net cost" perspective);
- One limitation is that the hourly modeling approach does not capture sub-hourly dispatch such as frequency regulation which is a major benefit storage can offer;
- In WIS:dom startup costs are approximated through variable costs, but may not perfectly match reality;
- WIS:dom is idealistic in that it assumes perfect economic decision-making and foresight – however we know this is not exactly how planning unfolds in the real world (especially true in vertically integrated environments, such as Minnesota);
- As WIS:dom is a least-cost model, it is sensitive to input cost values for different technologies (relative to each other) and so small changes in these costs can influence decisions on marginal assets.

VCE VIBRANT CLEAN ENERGY, LLC

Minnesota Energy Storage: System Level Scenario Analysis Interim Results

Main Take Away Points from Analysis So Far:

- For a reduction of 50% of GHG emissions by 2030, storage could play a key role. Installed capacities could be greater than nuclear and ease the transition;
- The existing storage on the MISO grid can be used to displace peaker plants;
- Higher GHG emission and water constrained scenarios are only possible with the help of storage;
- The MISO footprint has highly correlated wind patterns that suggest storage would be beneficial in large quantities to minimize curtailments;
- Storage provides more benefits that just delivery of energy – it also can help with stabilizing the grid with increased variable generation and decreased inertia creating generation.

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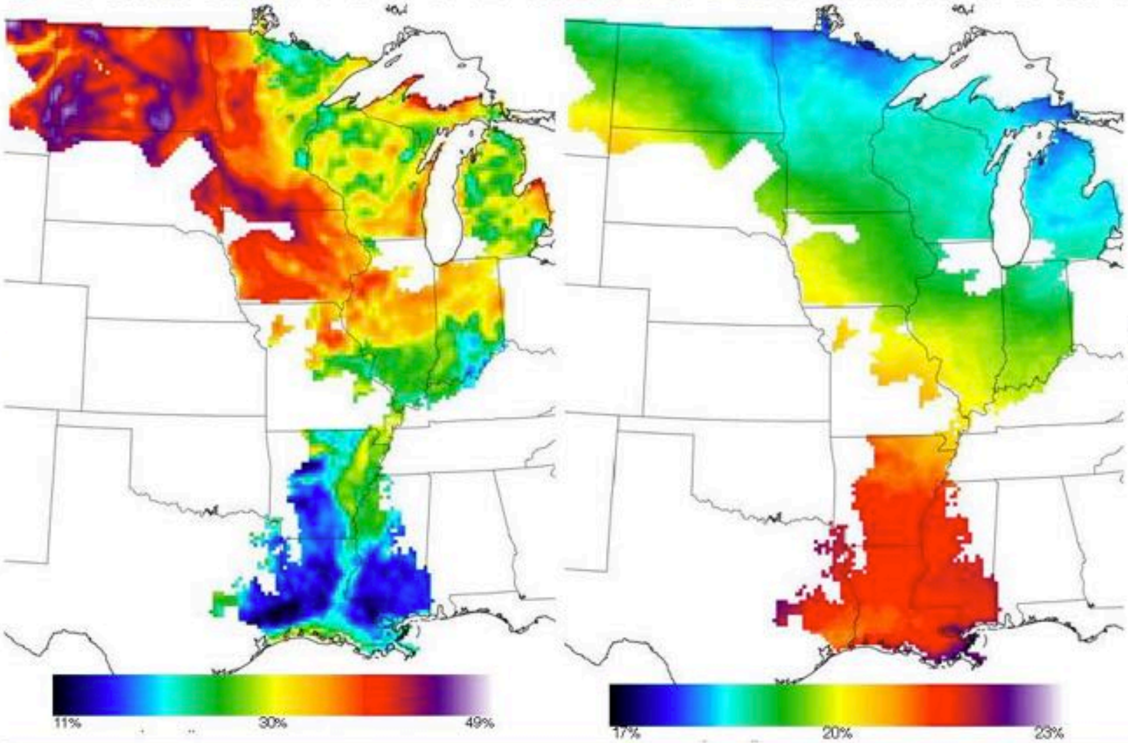
Weather Data and Power Data Across Minnesota and MISO

Wind Resource at 80 m AGL

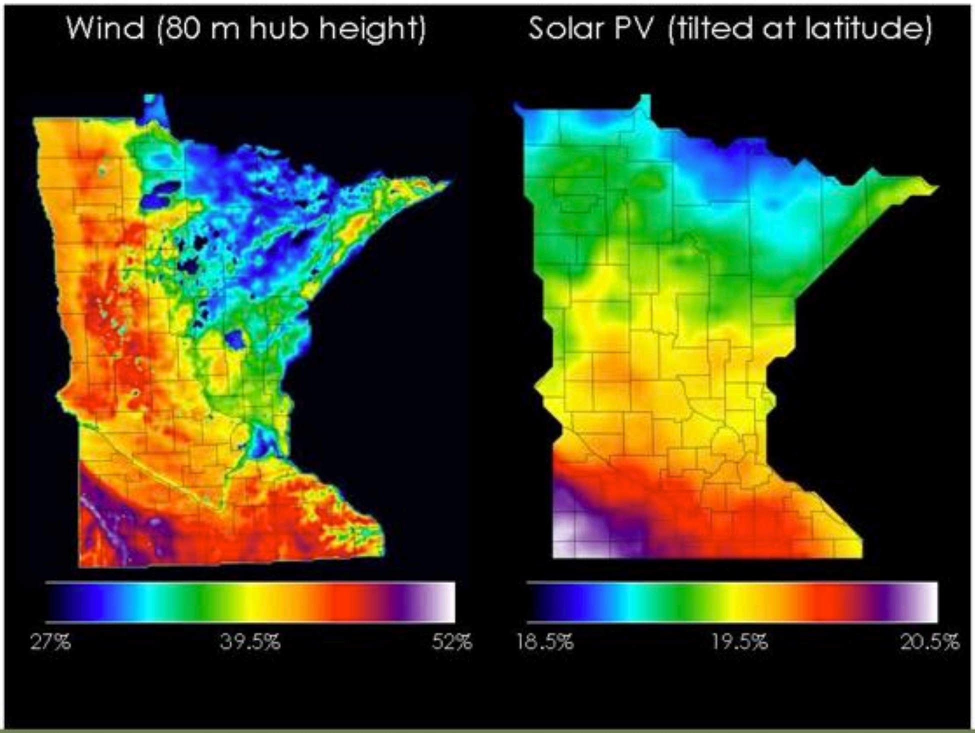


Solar PV Resource (tilted at latitude)

VCE

VIBRANT CLEAN ENERGY, LLC

Weather Data and Power Data Across Minnesota and MISO



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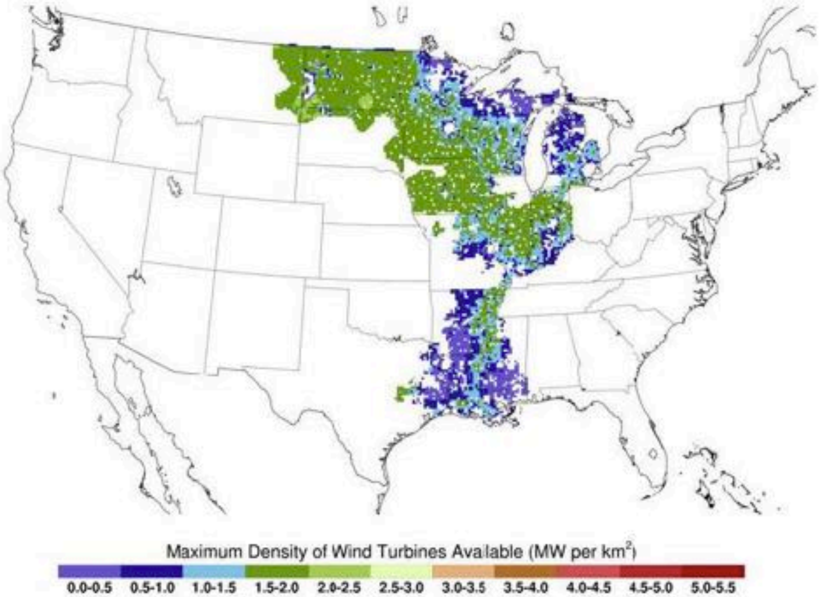
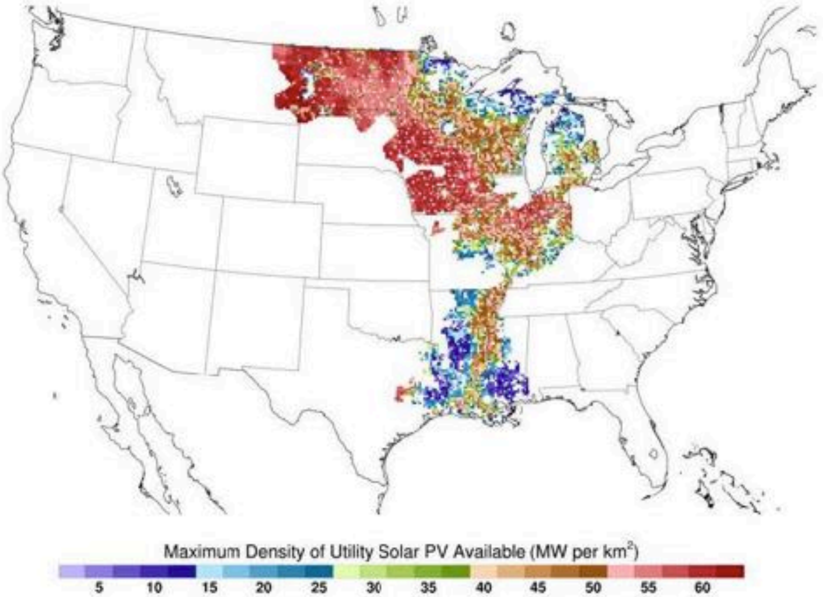
Generator Siting Constrained by Land Use Datasets





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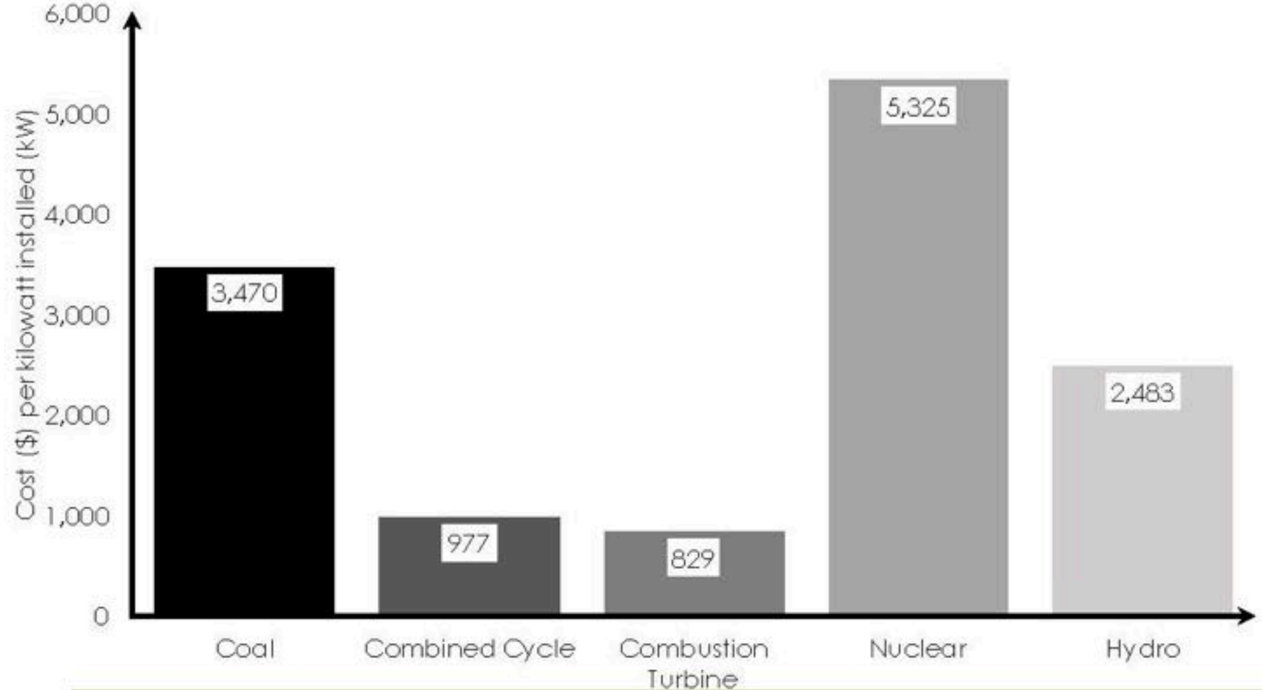
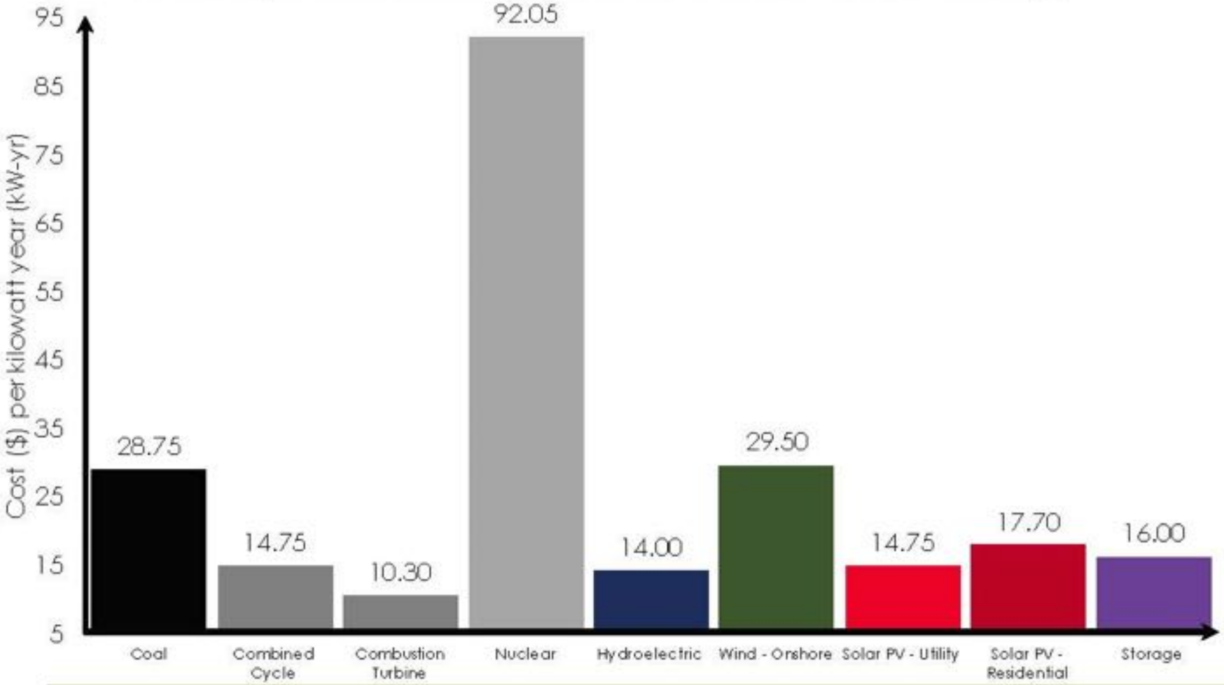
Capital Costs Are Critical Inputs

Capital Costs for Conventional Generation



VCE VIBRANT CLEAN ENERGY, LLC

WIS:dom Considers the Fixed O&M Costs



Fixed Operation and Maintenance Cost of Each Technology

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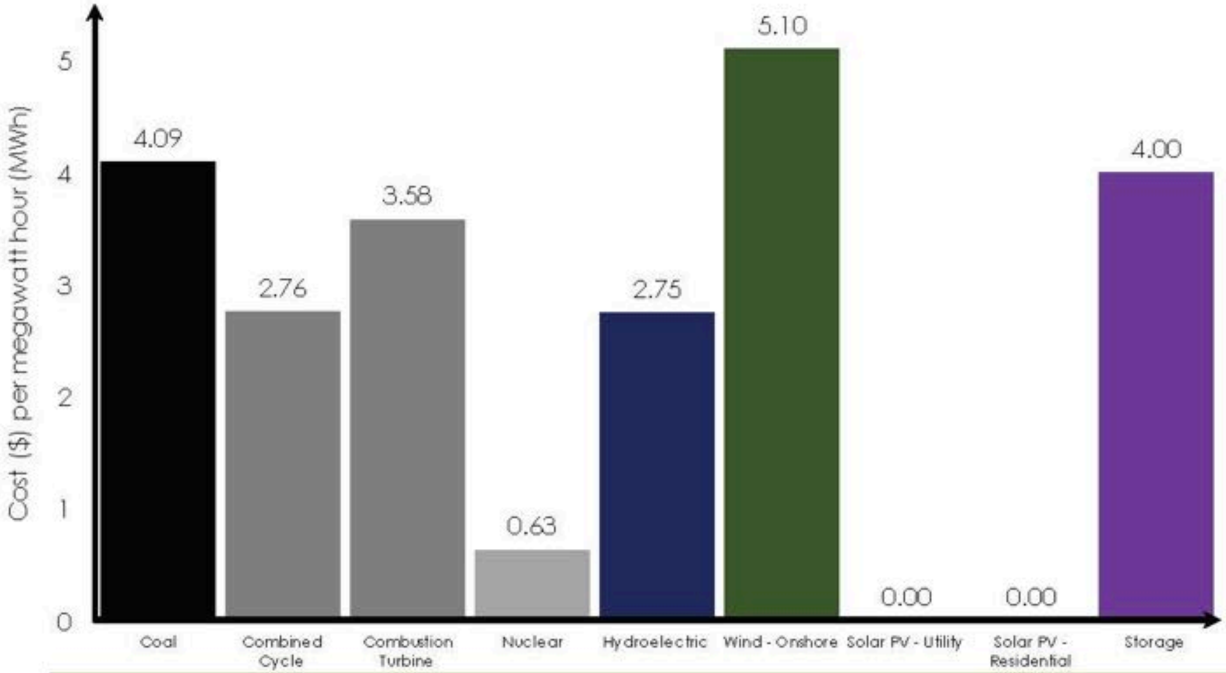
WIS:dom Considers the Variable O&M Costs



Variable Operation and Maintenance Cost of Each Technology

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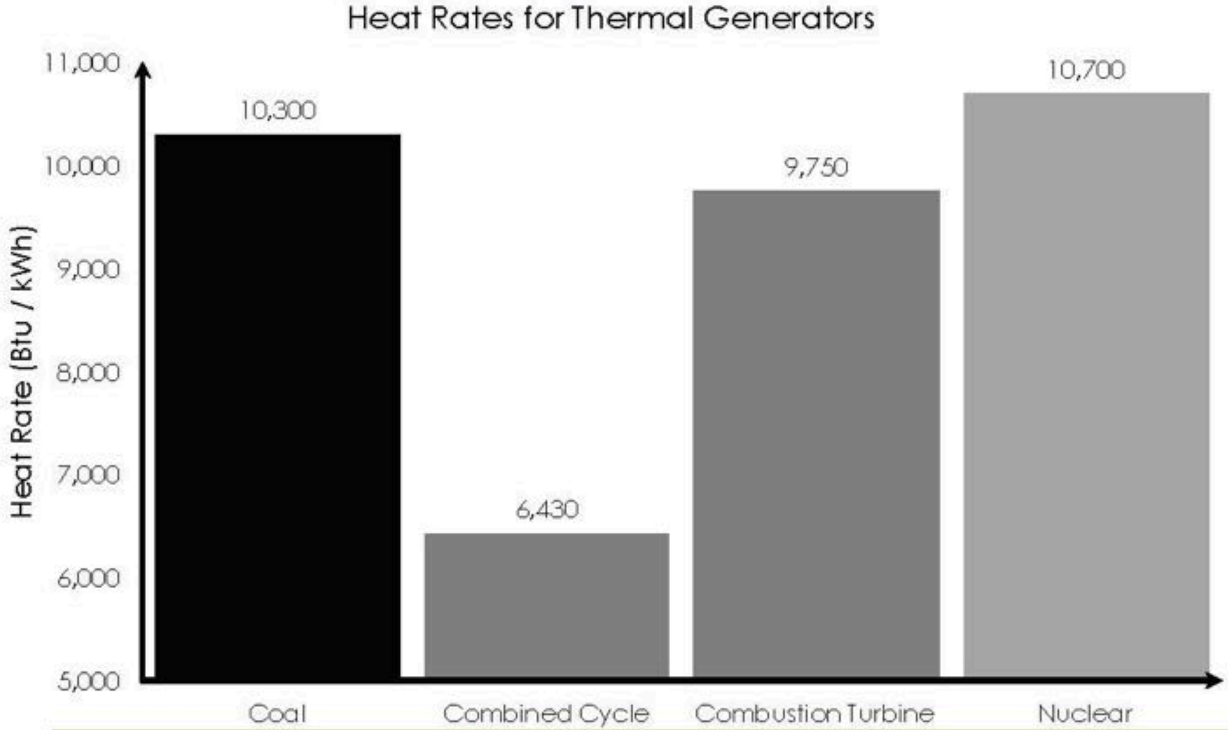
WIS:dom Considers the Heat Rates of Thermal Generation



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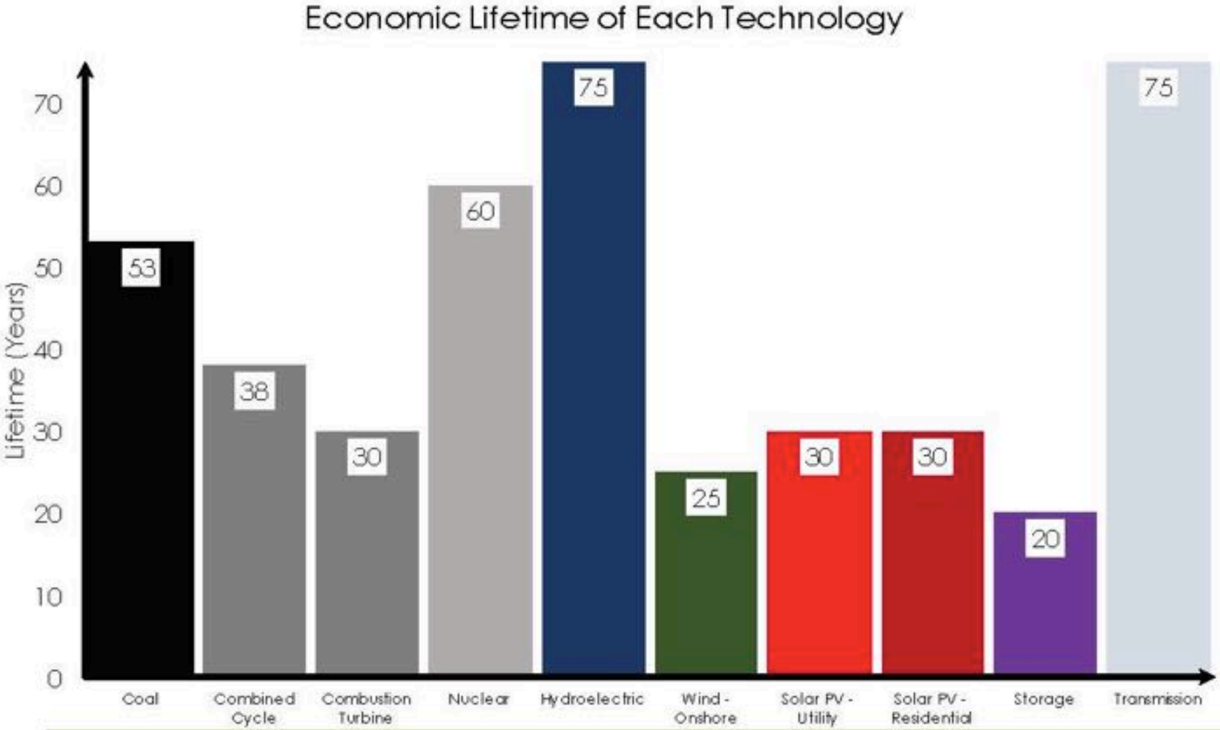
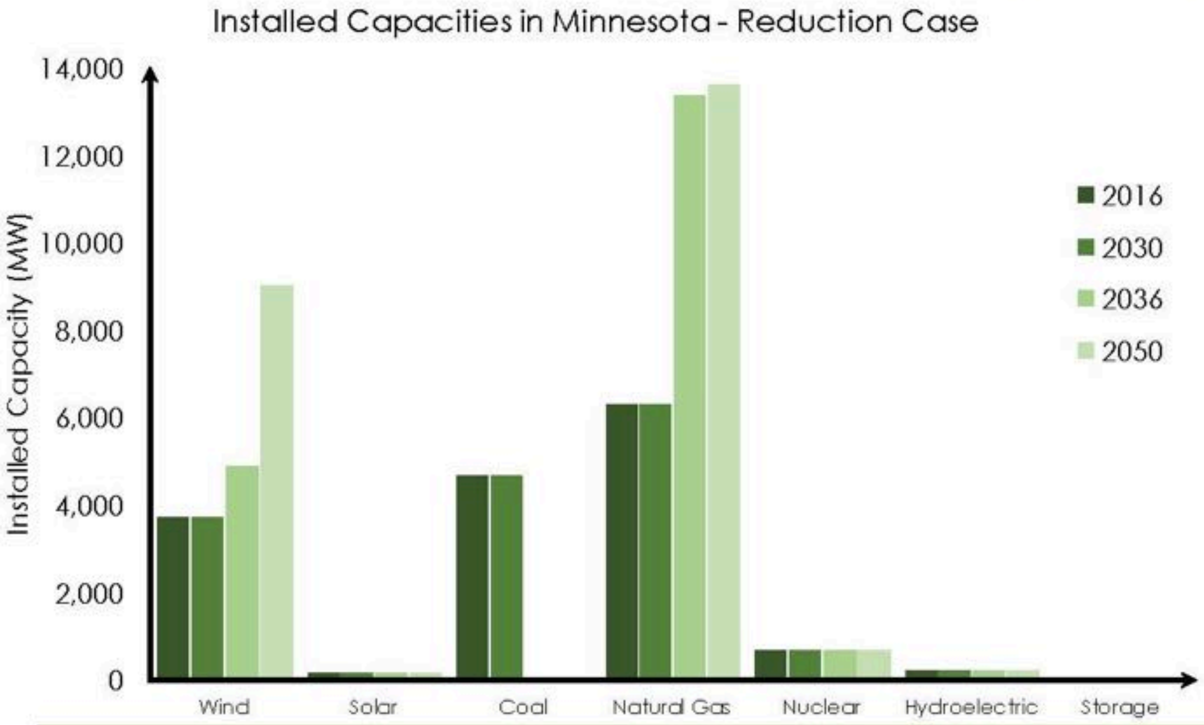
WIS:dom Takes into Account The Economic Lifetime of Technology



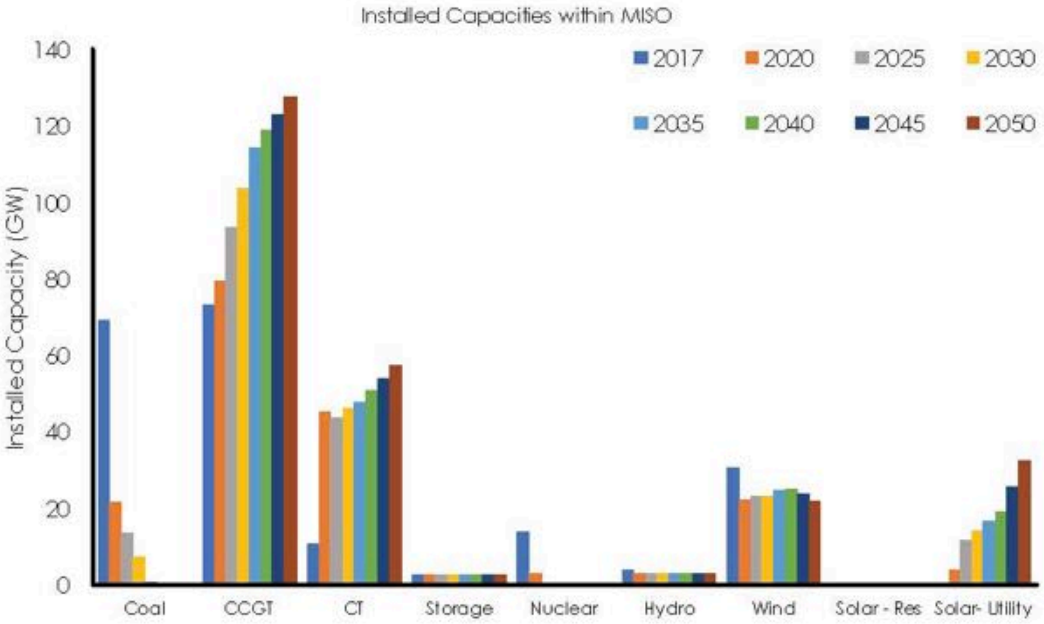
VCE VIBRANT CLEAN ENERGY, LLC

Summary Results from VCE Study for MISO [for MN]


Installed Capacities in Minnesota - Reduction Case

VIBRANT CLEAN ENERGY, LLC

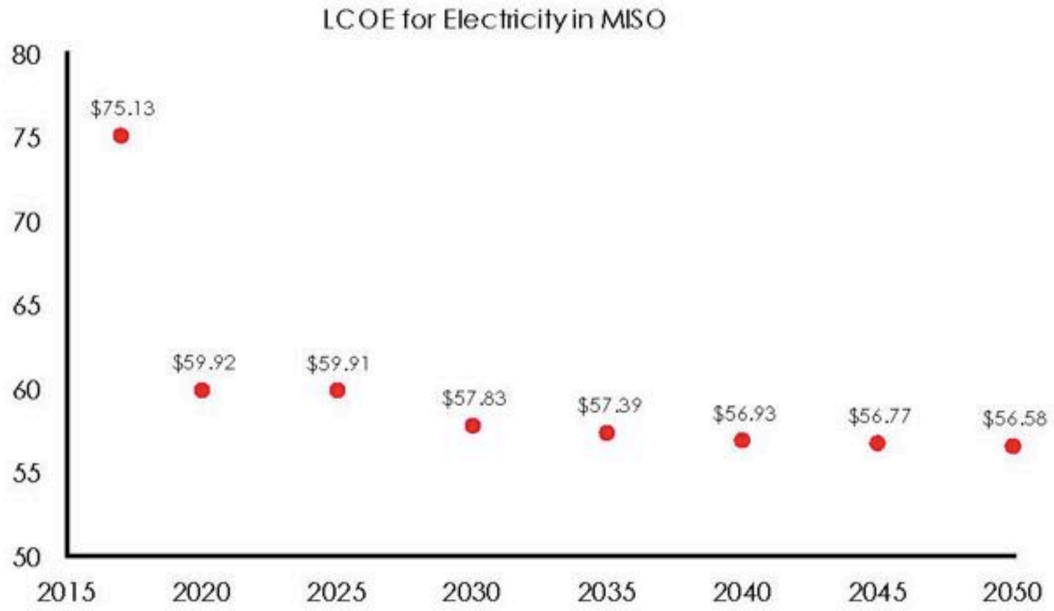
The Base Case for MISO
[No Transmission or Storage Expansion Allowed]



- All Coal is retired by 2045 in MISO;
- All Nuclear is retired by 2025 in MISO;
- Significantly more CCGT and CT power plants are installed in MISO;
- Solar PV increases capacity within MISO to over 30 GW;
- Wind initially falls in capacity before rising in 2035 to 2040, before retirements give way to natural gas and solar PV;
- By 2050, there is a 42% reduction of CO_2 from 2005 levels within MISO.

VIBRANT CLEAN ENERGY, LLC

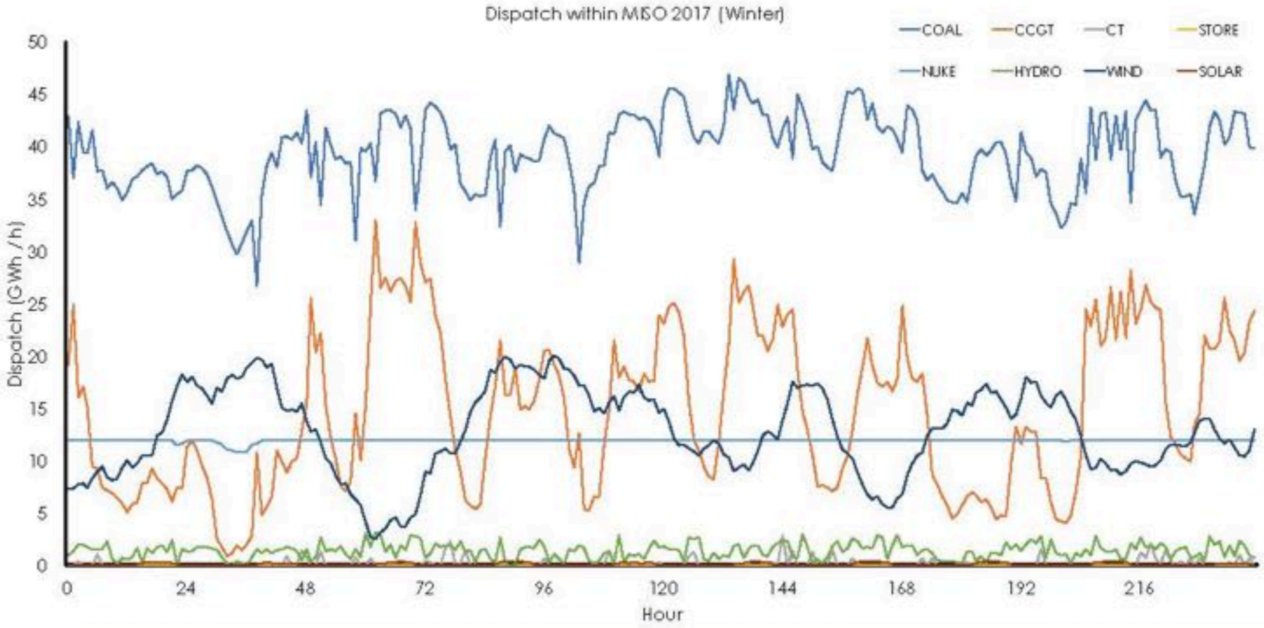
The Base Case for MISO
[No Transmission or Storage Expansion Allowed]



- By 2020 there is a sharp decrease in LCOE due to retirements and more efficient operations;
- The LCOE steadily declines are time progresses, since older units retire and newer, cheaper, units are brought online;
- These costs are in agreement with the VCE MISO study "Base Case" without reduction targets. However, there are larger emission reductions.

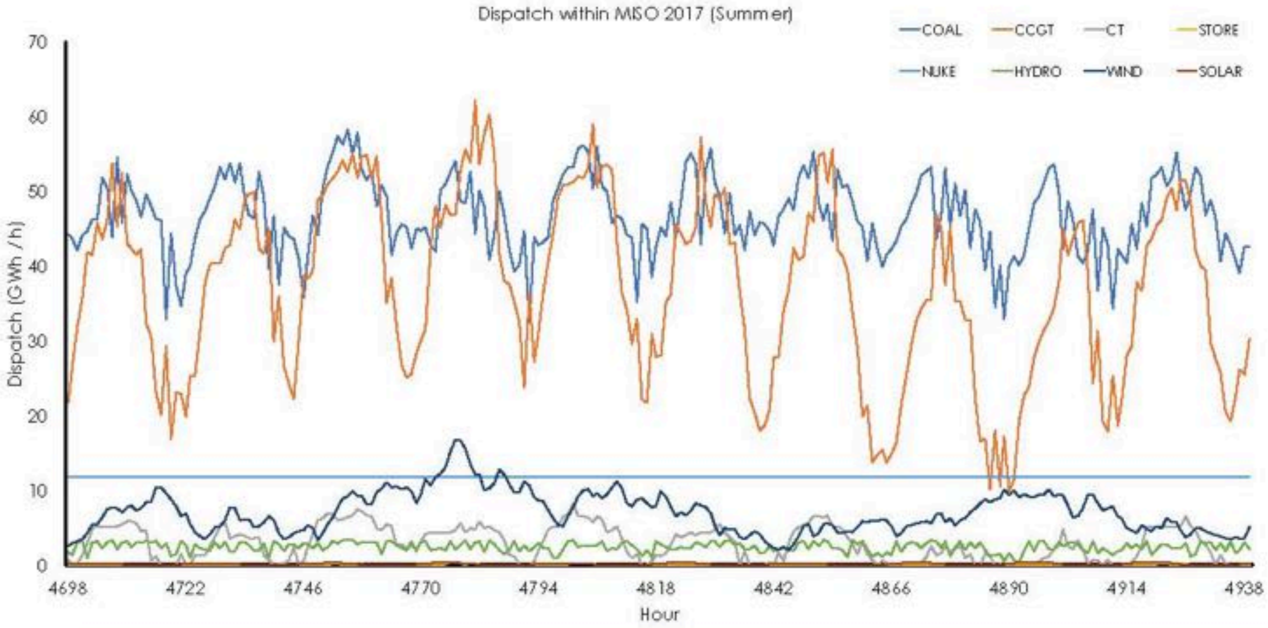
VCE VIBRANT CLEAN ENERGY, LLC

The Base Case for MISO
[No Transmission or Storage Expansion Allowed]



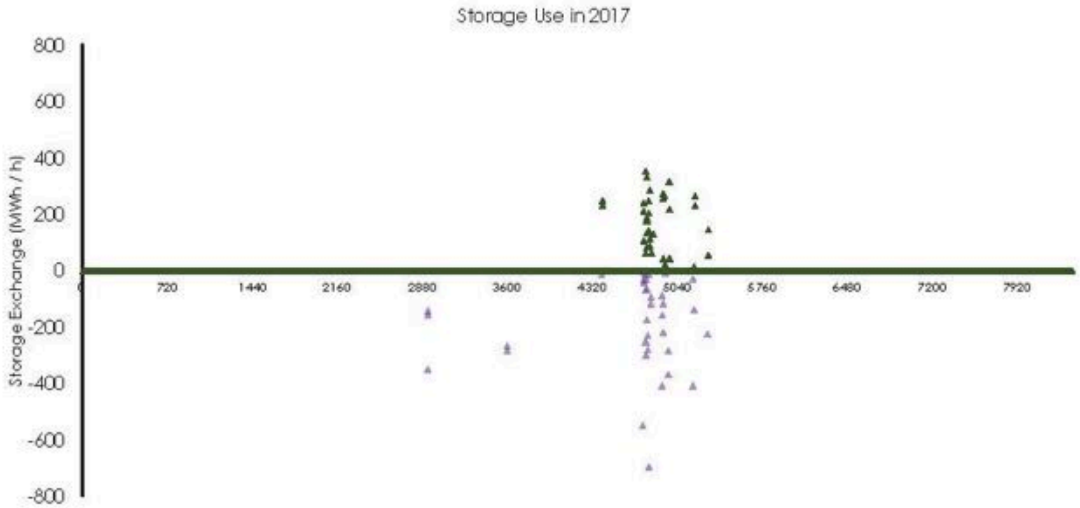
VCE **VIBRANT CLEAN ENERGY, LLC**

The Base Case for MISO
[No Transmission or Storage Expansion Allowed]



VIBRANT CLEAN ENERGY, LLC

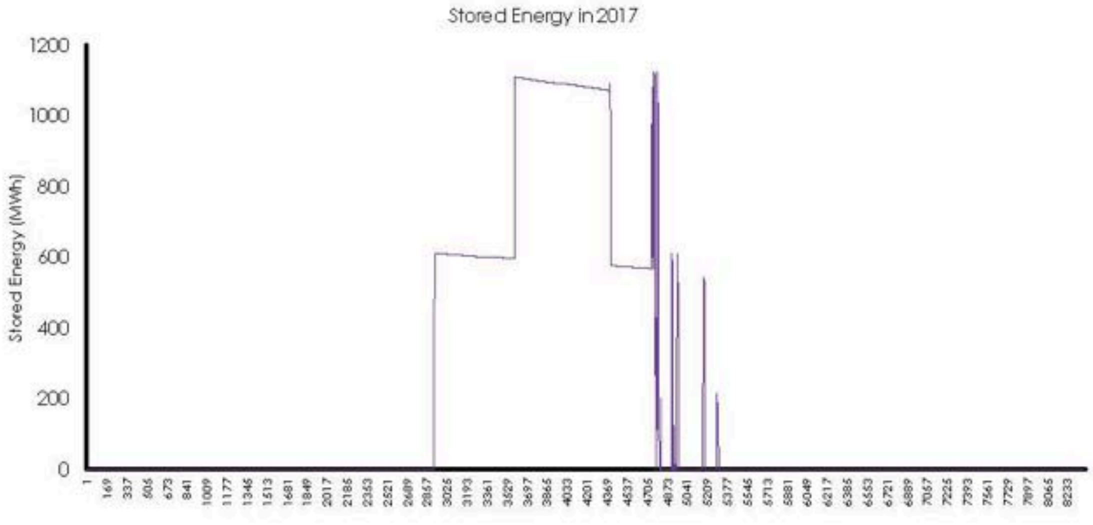
The Base Case for MISO
[No Transmission or Storage Expansion Allowed]



- WIS:dom utilizes the storage in spring and summer to remove the need for some peaking plants at high cost time periods;
- The use of storage is heavily clustered around the peak demand time periods.

VCE **VIBRANT CLEAN ENERGY, LLC**

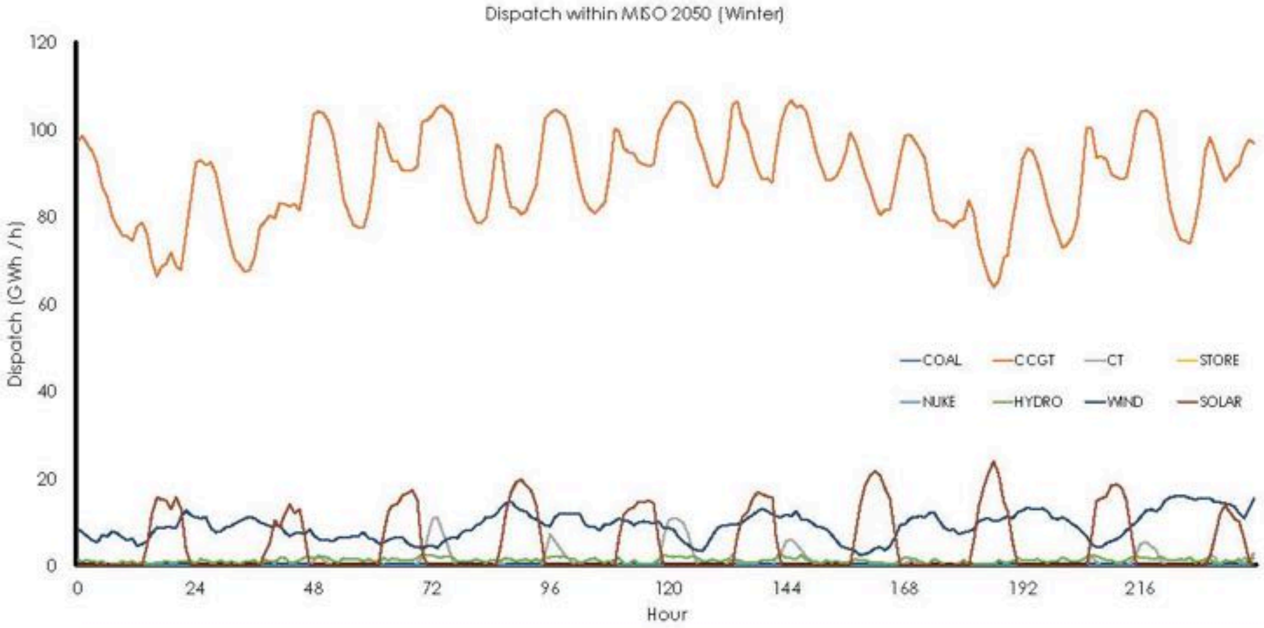
The Base Case for MISO
[No Transmission or Storage Expansion Allowed]



- The model stored energy for both long periods and short periods when it utilized the storage;
- The loss rate within the storage can be seen;
- The model uses the storage most for the peaks within summer.

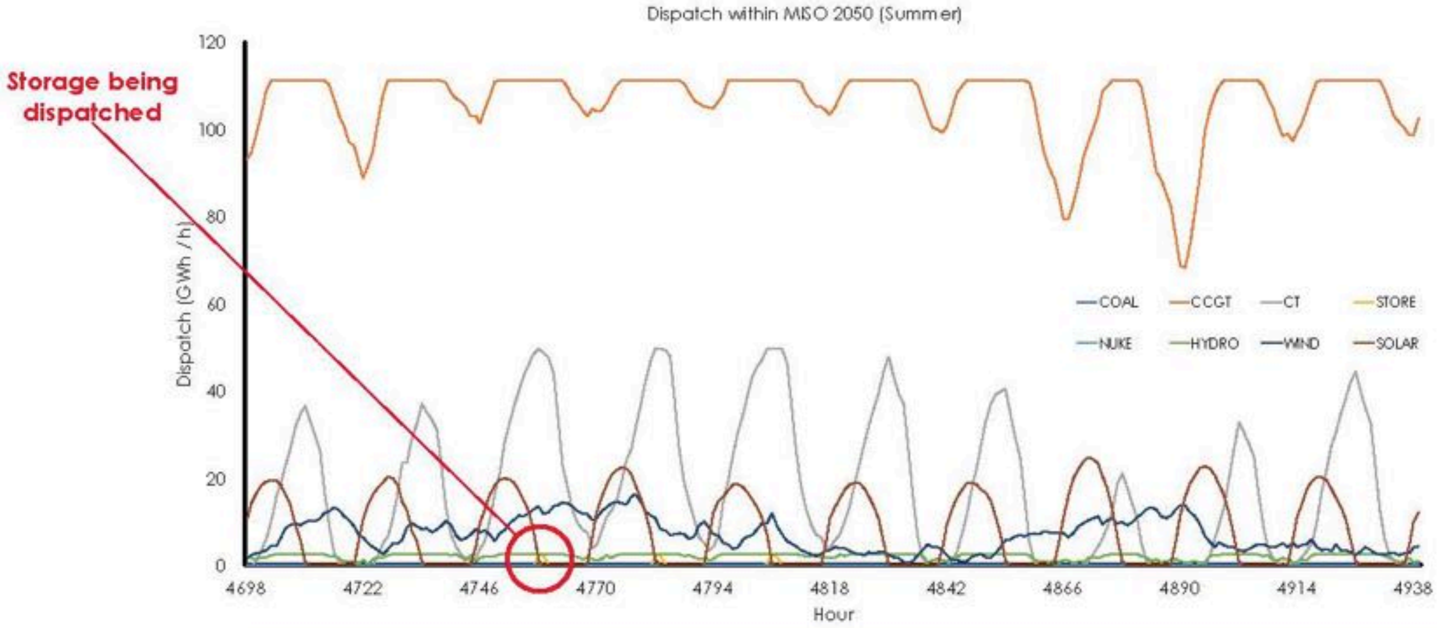
VCE VIBRANT CLEAN ENERGY, LLC

The Base Case for MISO
[No Transmission or Storage Expansion Allowed]



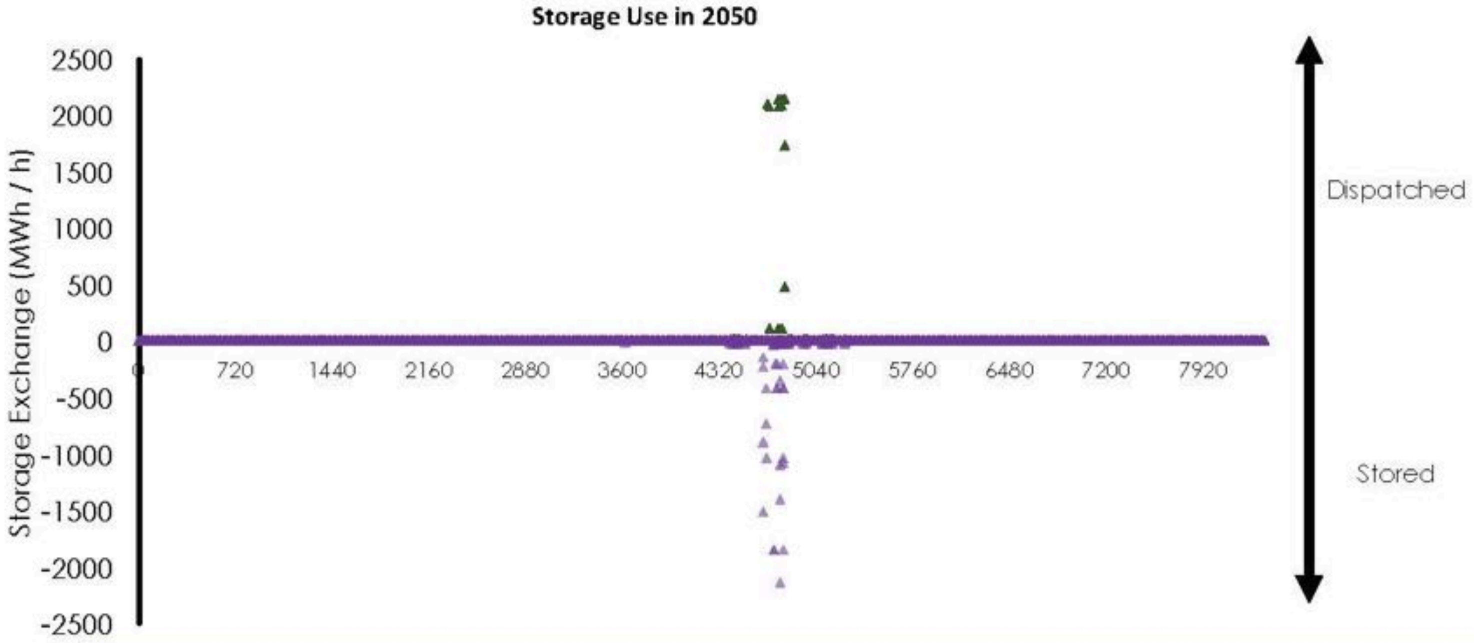
VCE **VIBRANT CLEAN ENERGY, LLC**

The Base Case for MISO
[No Transmission or Storage Expansion Allowed]



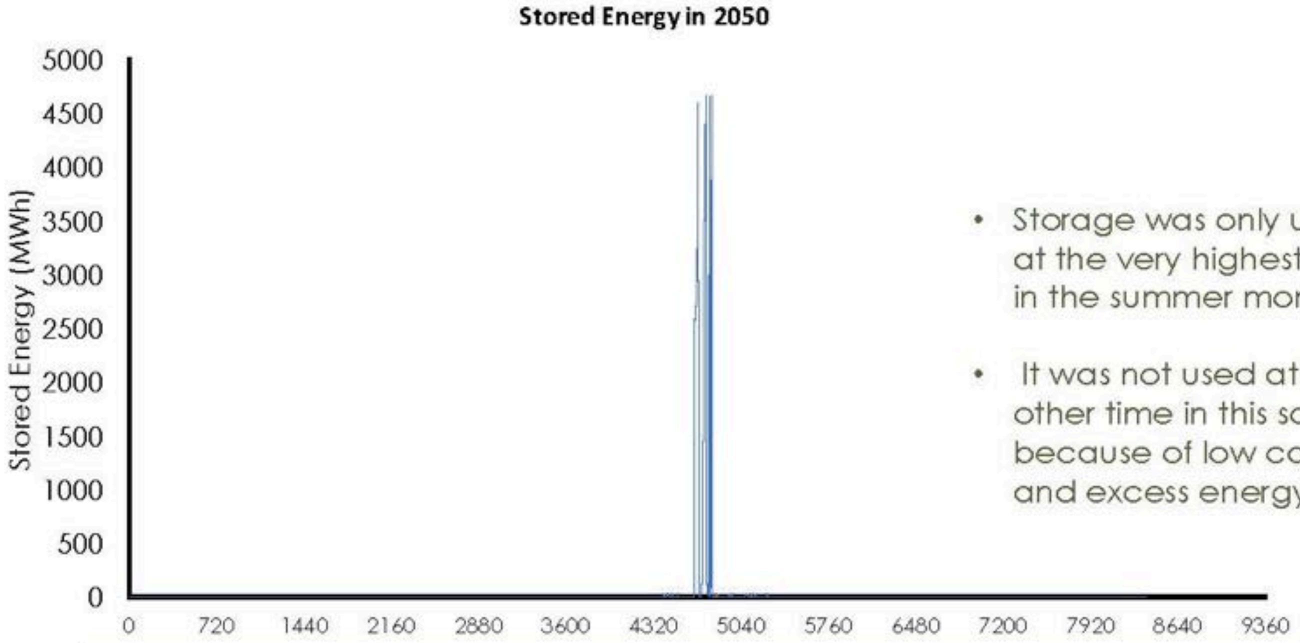
VCE VIBRANT CLEAN ENERGY, LLC

The Base Case for MISO
[No Transmission or Storage Expansion Allowed]



VIBRANT CLEAN ENERGY, LLC

The Base Case for MISO
[No Transmission or Storage Expansion Allowed]



- Storage was only utilized at the very highest peaks in the summer months.
- It was not used at any other time in this scenario because of low capacity and excess energy.

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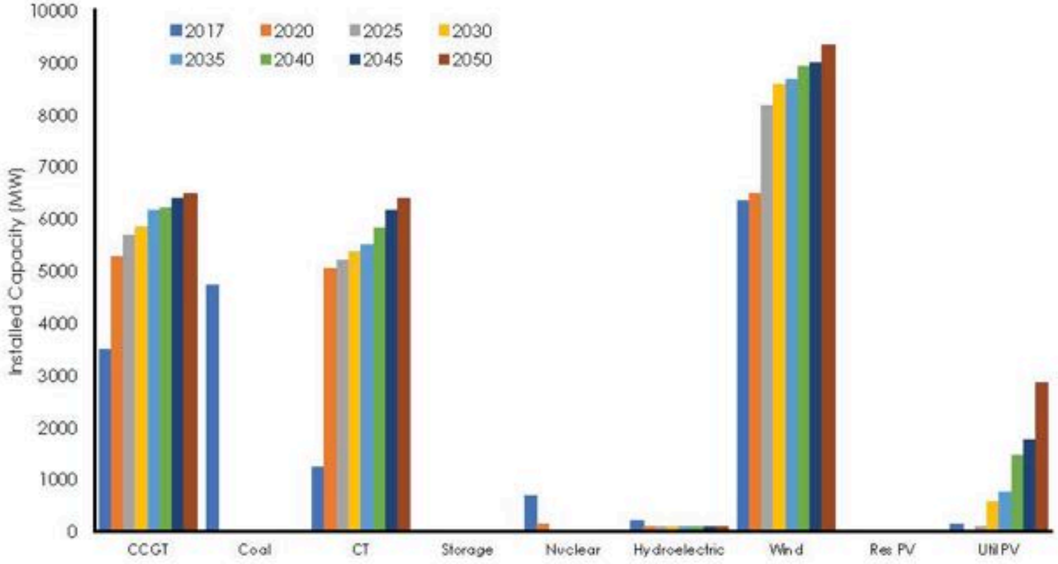
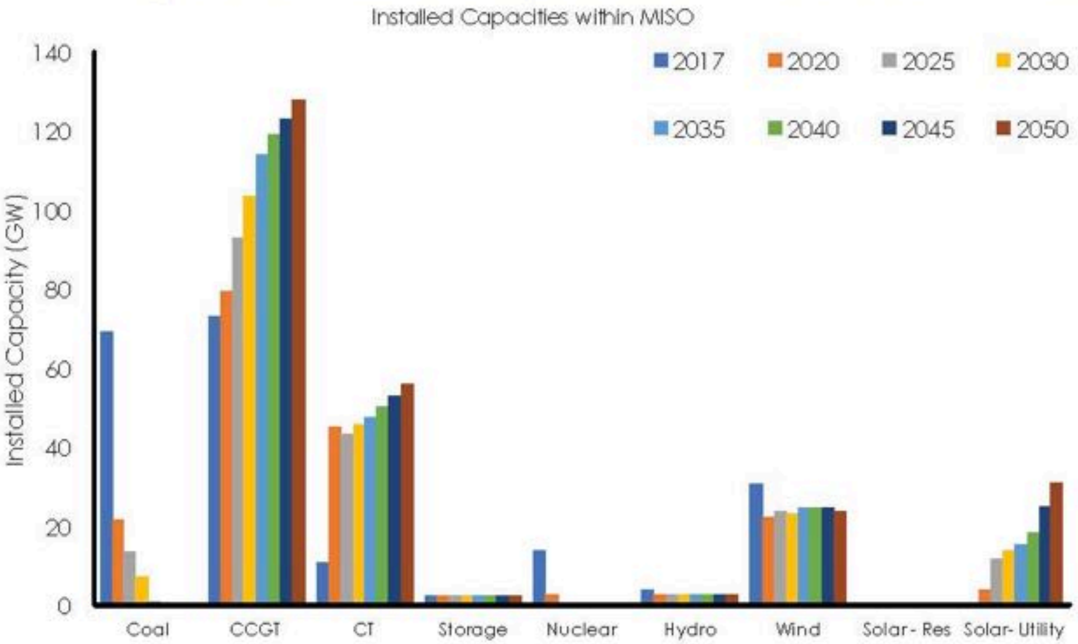
The Base Case for MISO – MN Capacities [No Transmission or Storage Expansion Allowed]



- All Coal is retired by 2020 in MN;
- All Nuclear is retired by 2025 in MN;
- Significantly more CCGT, CT, wind and Solar PV power plants are installed in MN;
- Wind reaches nearly 10 GW and solar PV is almost 3GW by 2050;
- In 2025 wind is the cheapest for of energy for MN, and so is the dominantly installed technology. Some CCGT, CT and solar PV complement the wind installations.

VCE VIBRANT CLEAN ENERGY, LLC

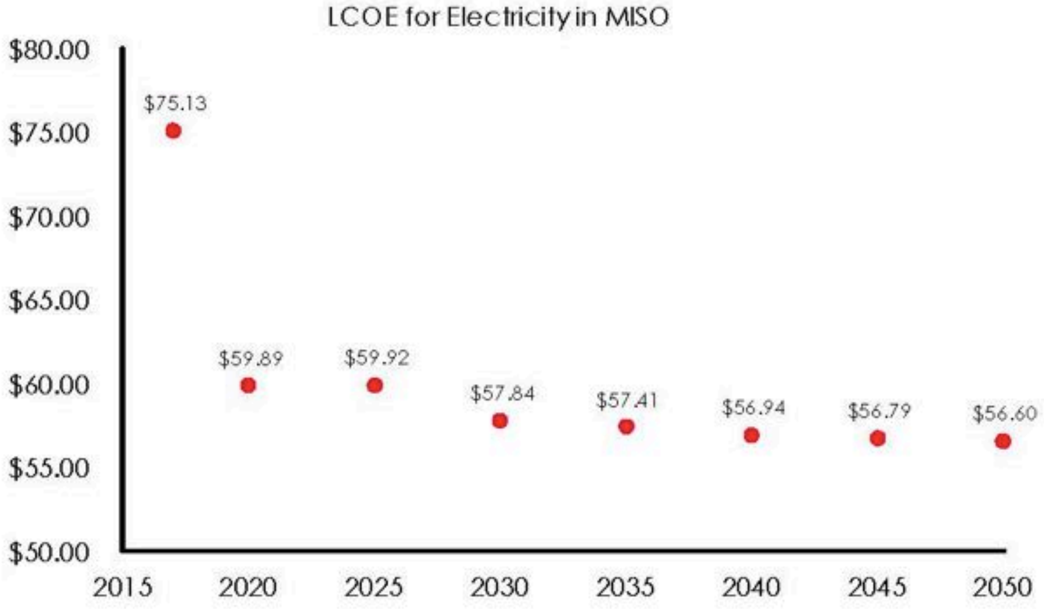
The Base Case for MISO
[Transmission Expansion Allowed, No Storage Expansion]



- All Coal is retired by 2050 in MISO;
- All Nuclear is retired by 2025 in MISO;
- Significantly more CCGT and CT power plants are installed in MISO;
- Solar PV increases capacity within MISO to over 30 GW;
- Wind initially falls in capacity before rising in 2035 to 2040, before retirements give way to natural gas and solar PV;
- By 2050, there is over a 42% reduction of CO_2 from 2005 levels within MISO – higher reductions than the no-transmission expansion scenario;
- Results strikingly similar to the no transmission expansion scenario – since natural gas dominates.

VCE VIBRANT CLEAN ENERGY, LLC

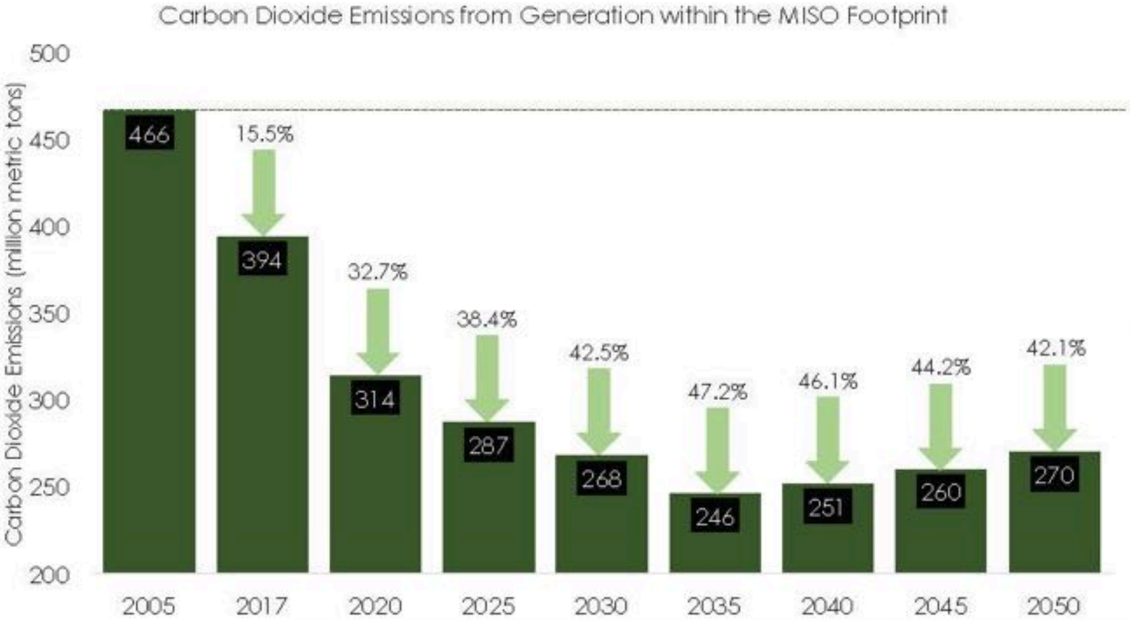
The Base Case for MISO
[Transmission Expansion Allowed, No Storage Expansion]



- By 2020 there is a sharp decrease in LCOE due to retirements and more efficient operations;
- The LCOE steadily declines are time progresses, since older units retire and newer, cheaper, units are brought online;
- These costs are in agreement with the VCE MISO study "Base Case" without reduction targets. However, there are larger emission reductions;
- The costs in this scenario are within the noise of the model compared with the no-transmission expansion scenario (within a few ¢/MWh). By 2050 there is over 1,000 MW less generation required on the MISO grid.

VCE VIBRANT CLEAN ENERGY, LLC

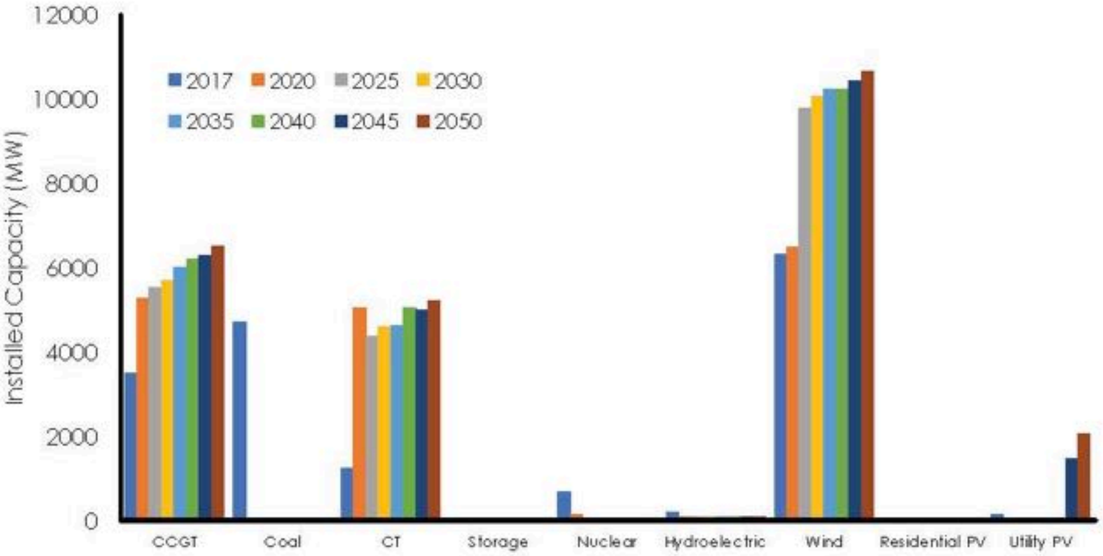
The Base Case for MISO [Transmission Expansion Allowed, No Storage Expansion]



- With no carbon emission reduction targets, the least-cost pathway results in a 42% reduction in CO_2 by 2050 compared with 2005 levels;
- The uptick of emissions from 2035 onwards is dues to natural gas being burned as a replacement to coal, and with a growing load, emissions will eventually start increasing.

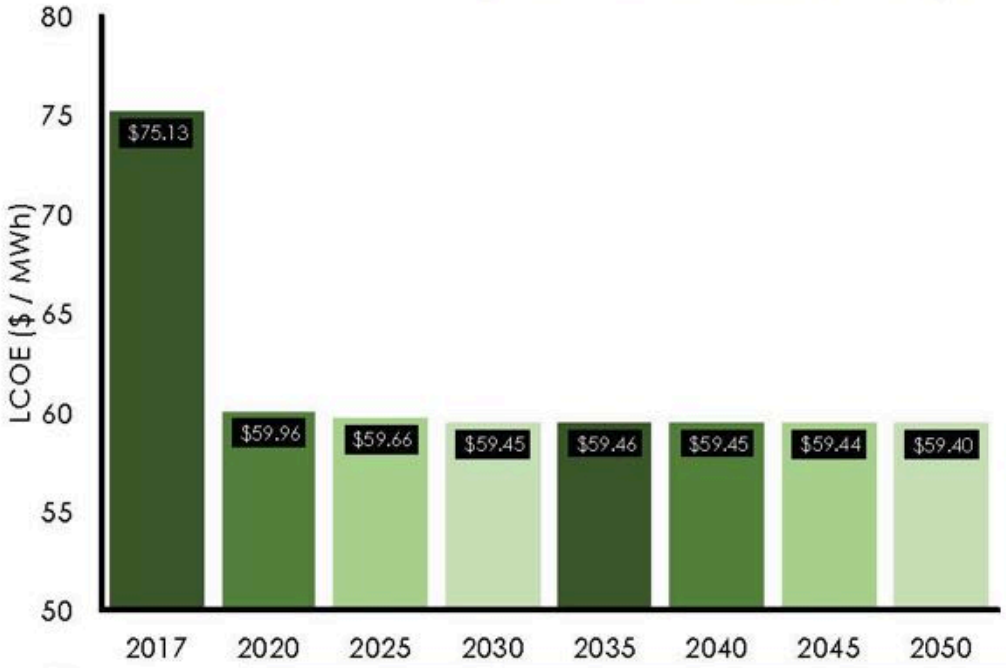
VCE VIBRANT CLEAN ENERGY, LLC

The Base Case for MISO – MN Capacities [Transmission Expansion Allowed, No Storage Expansion]



- All Coal is retired by 2020 in MN;
- All Nuclear is retired by 2025 in MN;
- Significantly more CCGT, CT, wind and Solar PV power plants are installed in MN;
- Wind reaches nearly 11 GW and solar PV is almost 2GW by 2050;
- In 2025 wind is the cheapest for of energy for MN, and so is the dominantly installed technology. Some CCGT, CT and solar PV complement the wind installations;
- Again, the generation mix is fairly similar to that of the no-transmission expansion scenario, except because of the added transmission wind is more competitive and solar PV less so.

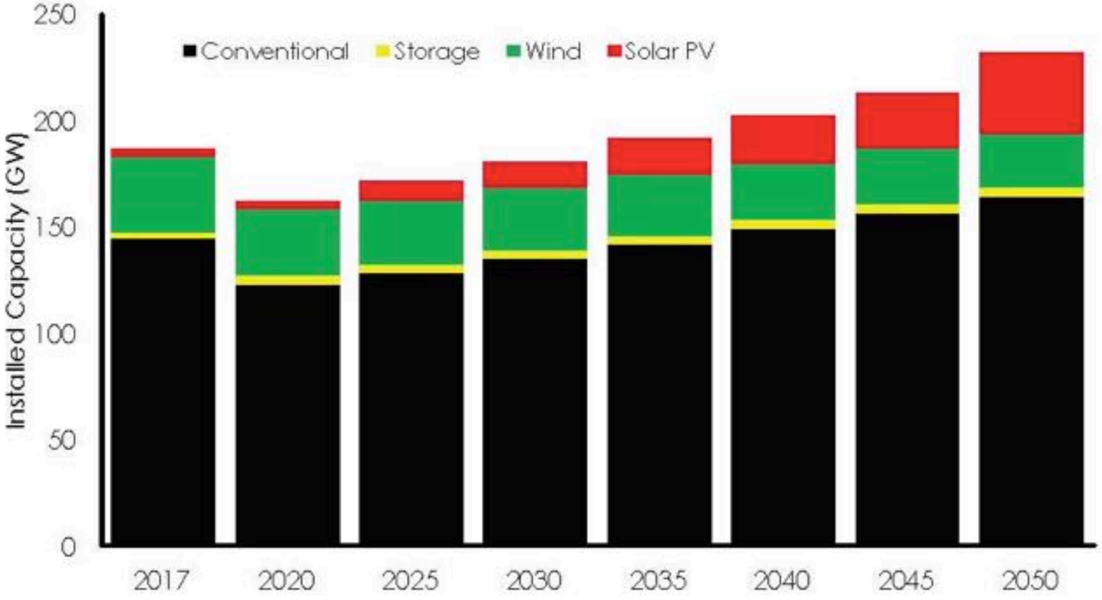
The Storage Enforced Case of 2 GW in MN for MISO [No Transmission Expansion]



- The model was forced to accept 2 GW of storage within Minnesota;
- The hours of storage were allowed to change;
- The change in LCOE is small for this large addition to storage in Minnesota, at around 30-40 ¢ / MWh;
- The additional cost is equivalent to 0.6%;
- Other generators and dispatch orders adjust to the enforced storage to help minimize the additional costs;
- Other regions of MISO benefit from storage in MN as power can move from region to region with existing transmission.

VCE VIBRANT CLEAN ENERGY, LLC

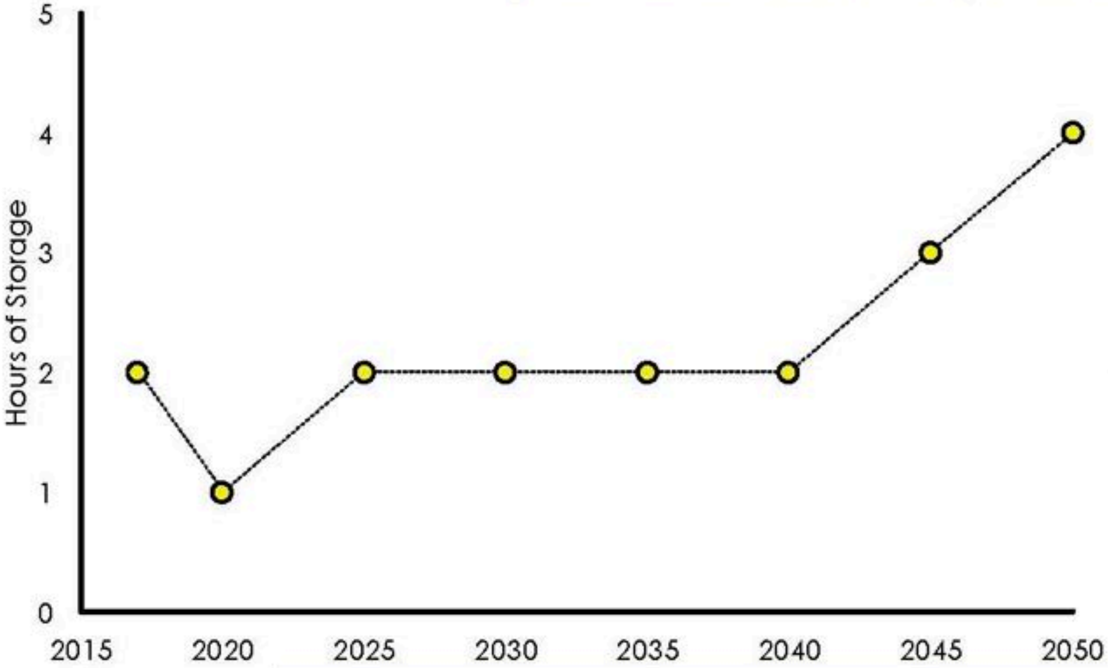
The Storage Enforced Case of 2 GW in MN for MISO [No Transmission Expansion]



- No storage was allowed to be installed in any other location other than where it is enforced within Minnesota;
- More solar PV is installed compared with the other scenarios, and this is compensated by less wind and natural gas CT.

VCE VIBRANT CLEAN ENERGY, LLC

The Storage Enforced Case of 2 GW in MN for MISO [No Transmission Expansion]



- As the cost to store energy becomes cheaper, the model installs higher amounts of capacity in terms of hours of storage;
- The additional storage hours can assist with the reserve margins, frequency regulation and reduction of CT dispatch.

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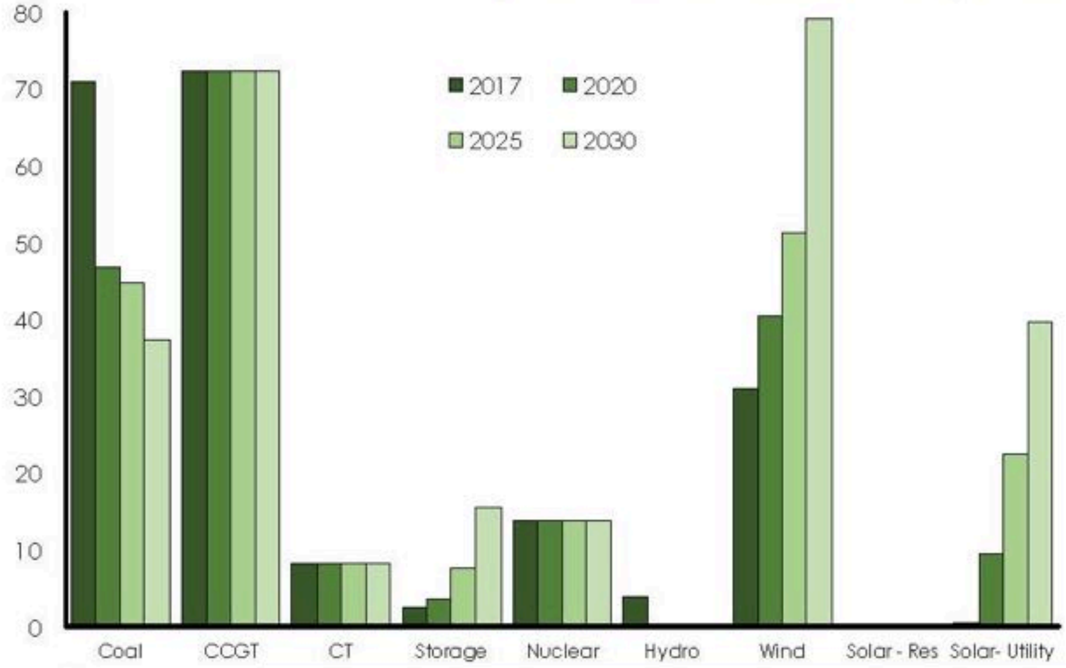
The Emission Reduction Case for MISO [No Transmission Expansion]



- To achieve a 50% reduction in GHG emissions by 2030, the cheapest pathway includes over 15 GW of storage on the MISO grid;
- The increase in storage facilitates much bigger increases in wind and solar as generation;
- The curtailment is only 3.5% of generation for wind and solar, due to the presence of storage.
- Further reduction targets would require more storage, both in power capacity and duration.

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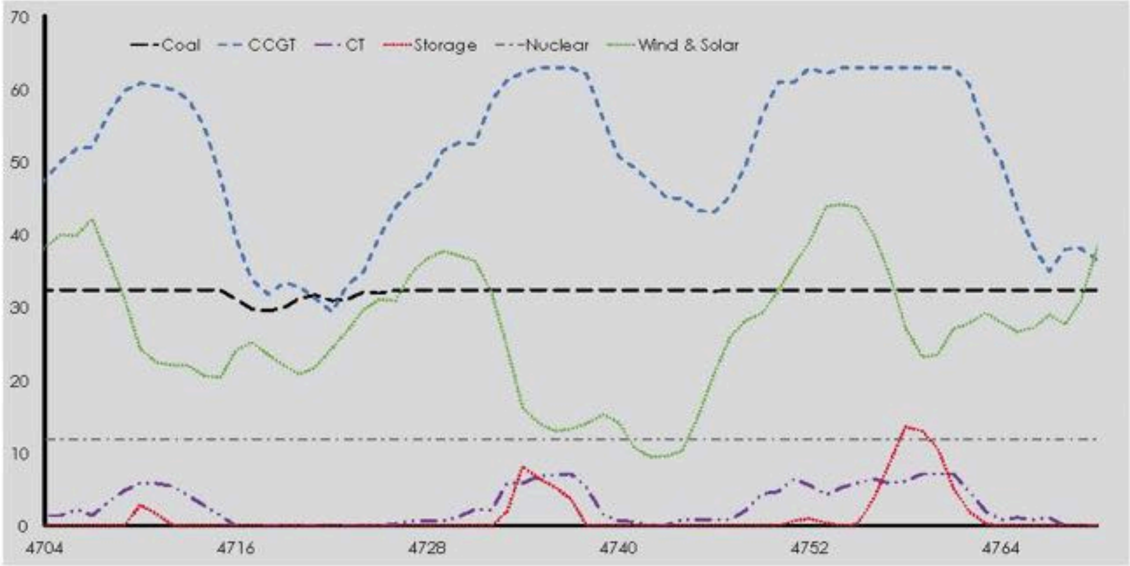
The Emission Reduction Case for MISO [No Transmission Expansion]



- Storage complements the behavior of the CTs in terms of energy production;
- The storage also provides additional load following reserves and frequency regulation (not shown);
- The storage also facilitates the reduction in use of hydroelectric power.

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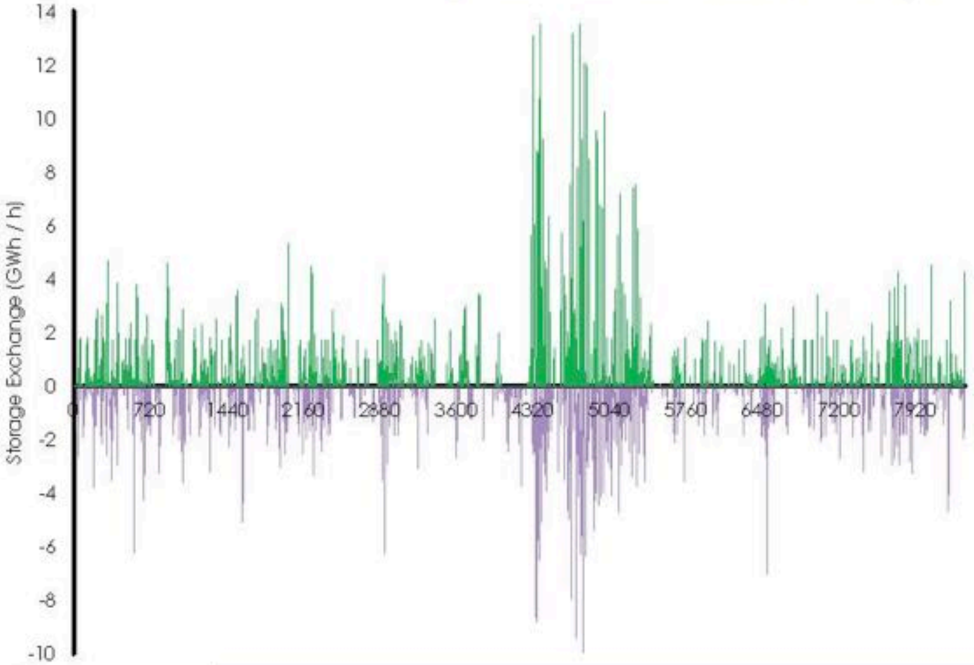
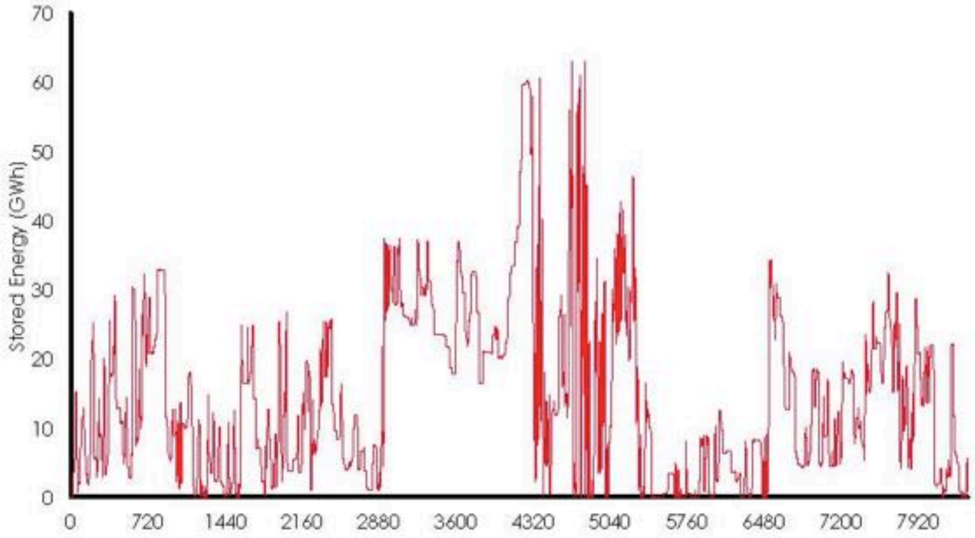
The Emission Reduction Case for MISO
[No Transmission Expansion]



- The use of storage in the reduction case becomes ubiquitous over MISO;
- The peak usage is in the summer months as expected;
- The storage allows zero new CTs from 2017 to 2030.

VCE VIBRANT CLEAN ENERGY, LLC

The Emission Reduction Case for MISO [No Transmission Expansion]



- By 2030, the storage duration remains "4-hours";
- These facilitates no new CTs from 2017;
- The 4-hours also makes it possible to reduce emissions by 50% from 2005 levels by 2030;
- Also water consumption is reduced dramatically.

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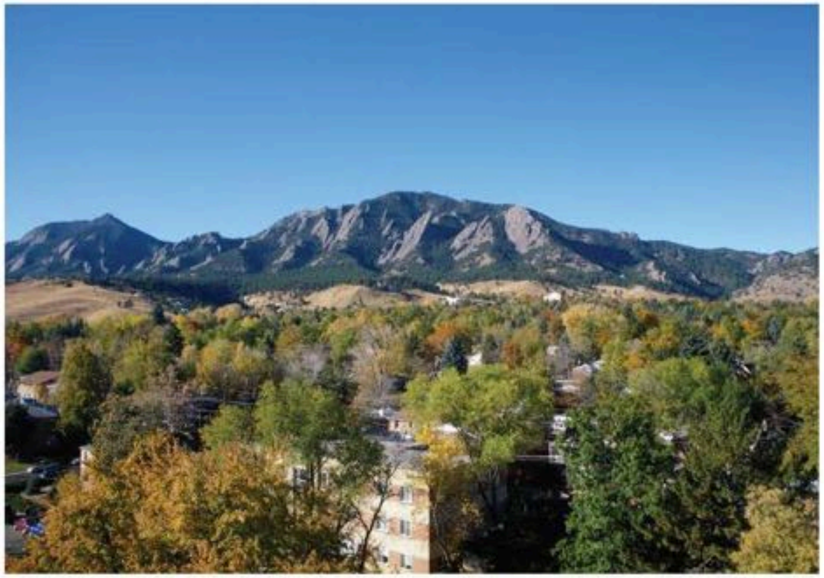
More Results will be Presented in the Final Report Coming Soon!

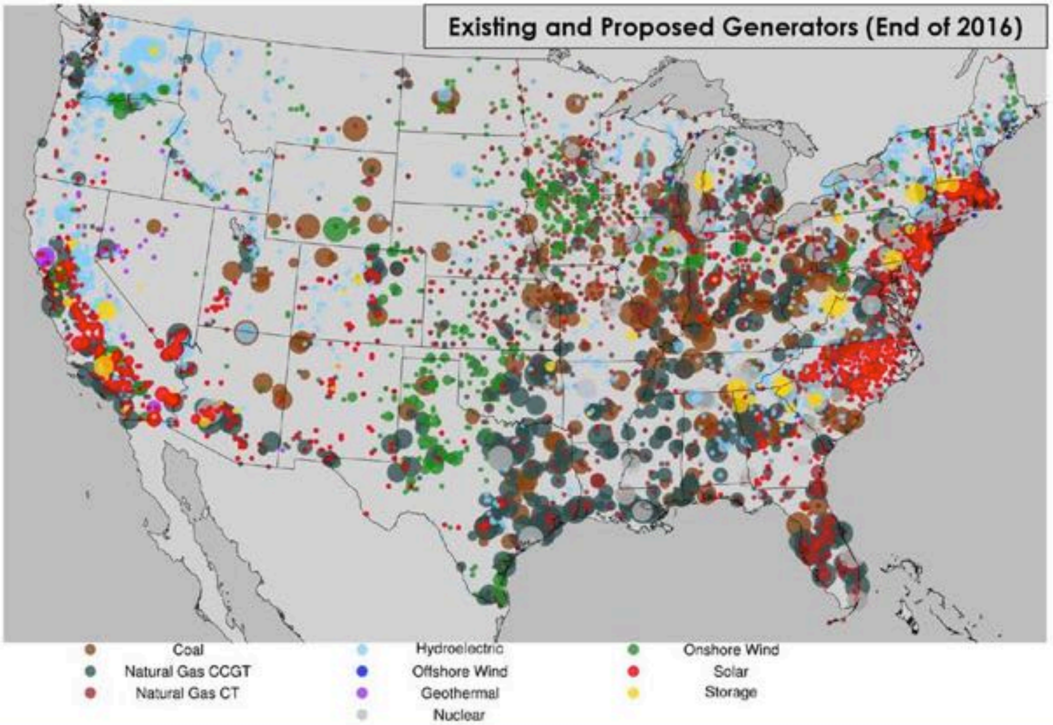


E-mail: christopher@vibrantcleanenergy.com
Telephone: +1-720-668-6873
Website: VibrantCleanEnergy.com

VCE **VIBRANT CLEAN ENERGY, LLC**

17 Appendix I - System Level Scenario Analysis of Minnesota Energy Storage: Final Results (Vibrant Clean Energy)

WIS:dom Takes Into Account Build Queue



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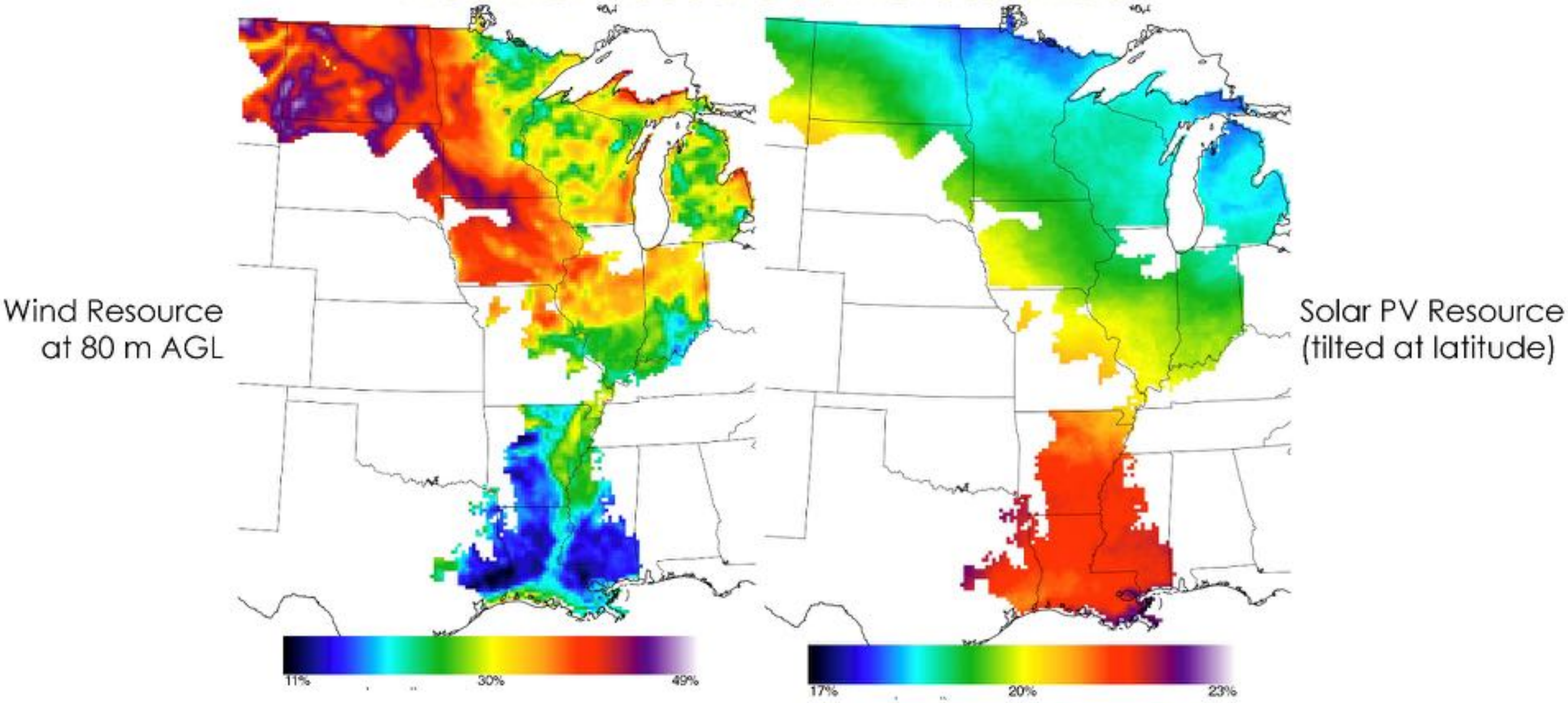
Weather Resources Across MISO



Wind Resource at 80 m AGL

Solar PV Resource (tilted at latitude)

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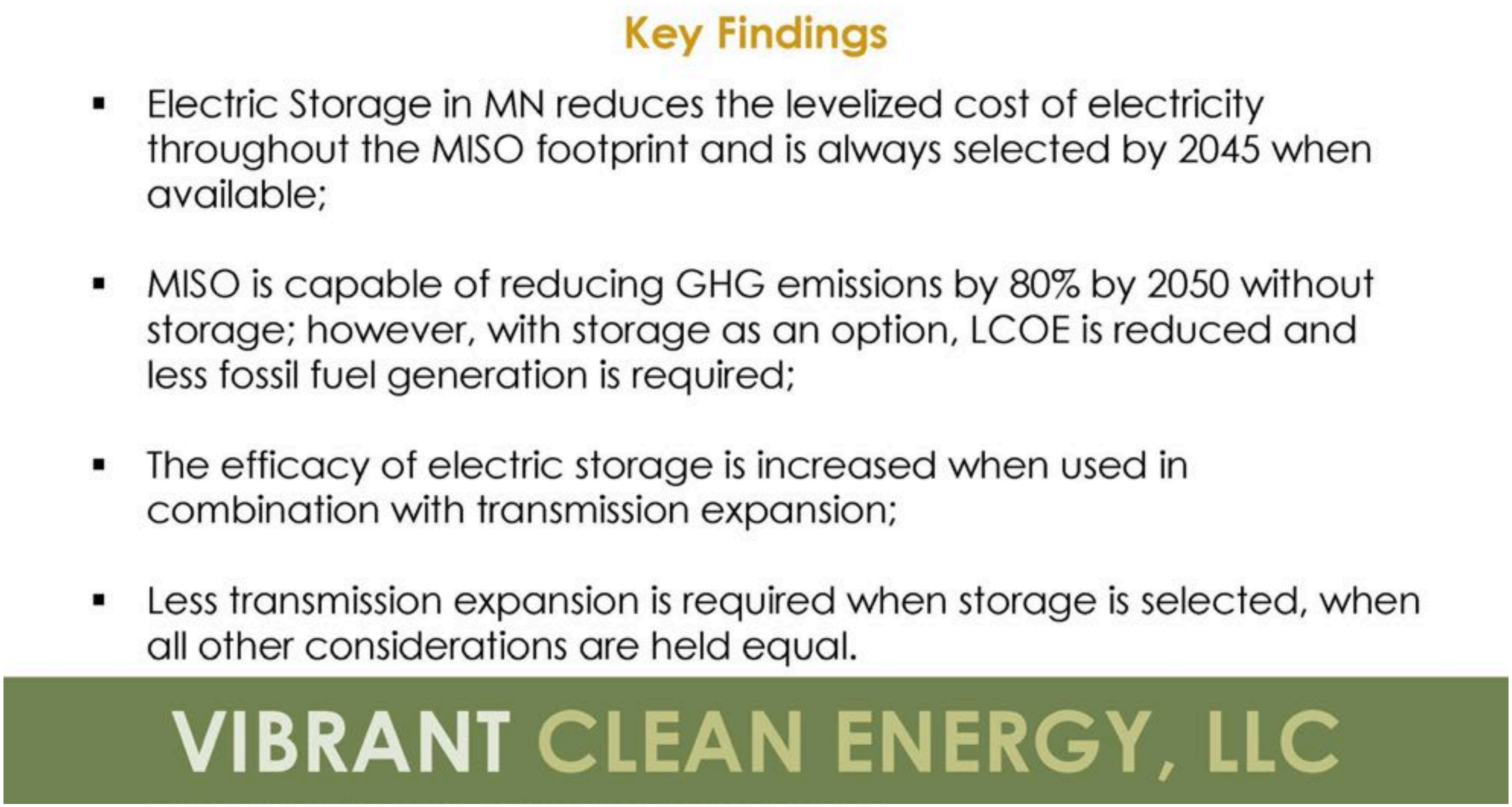

Key Findings

- Electric Storage in MN reduces the levelized cost of electricity throughout the MISO footprint and is always selected by 2045 when available;
- MISO is capable of reducing GHG emissions by 80% by 2050 without storage; however, with storage as an option, LCOE is reduced and less fossil fuel generation is required;
- The efficacy of electric storage is increased when used in combination with transmission expansion;
- Less transmission expansion is required when storage is selected, when all other considerations are held equal.

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Key Findings

- More storage is selected by the WIS:dom optimization model when the ITC is applied to storage as well as solar PV;
- Findings are consistent and supportive of the MRITS study – MN can support 40%+ variable generation.
  - ✓ *Current study finds least-cost configurations throughout MISO based upon hourly, high granularity weather data for variable renewables;*
  - ✓ *WIS:dom finds economic and constrained scenarios to determine an agnostic envelope parameter space for role of different technologies;*
- Storage provides lower costs, higher resiliency (greater portfolio diversity), reserves, sustainable resource use, and increased transmission efficiency.

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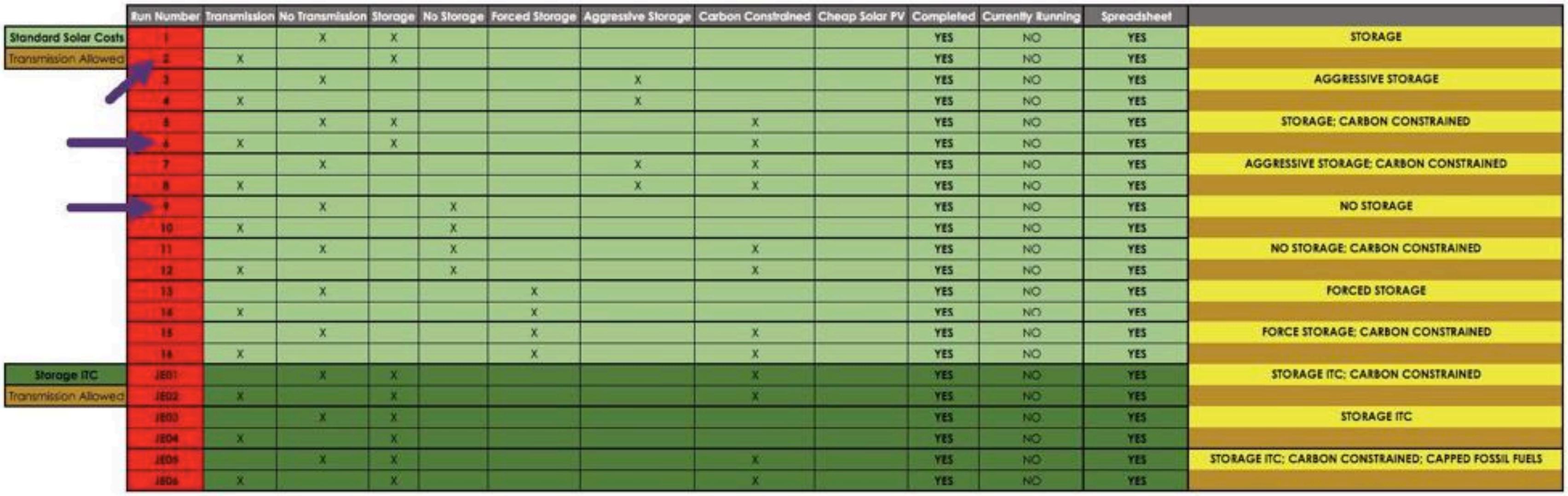
Optimization Scenarios Performed During the Study



	Run Number	Transmission	No Transmission	Storage	No Storage	Forced Storage	Aggressive Storage	Carbon Constrained	Cheap Solar PV	Completed	Currently Running	Spreadsheet	
Standard Solar Costs	1		X	X						YES	NO	YES	STORAGE
Transmission Allowed	2	X		X						YES	NO	YES	
	3		X				X			YES	NO	YES	AGGRESSIVE STORAGE
	4	X					X			YES	NO	YES	
	5		X	X				X		YES	NO	YES	STORAGE; CARBON CONSTRAINED
	6	X		X				X		YES	NO	YES	
	7		X				X	X		YES	NO	YES	AGGRESSIVE STORAGE; CARBON CONSTRAINED
	8	X					X	X		YES	NO	YES	
	9		X		X					YES	NO	YES	NO STORAGE
	10	X			X					YES	NO	YES	
	11		X		X			X		YES	NO	YES	NO STORAGE; CARBON CONSTRAINED
	12	X			X			X		YES	NO	YES	
	13		X			X				YES	NO	YES	FORCED STORAGE
	14	X				X				YES	NO	YES	
	15		X			X		X		YES	NO	YES	FORCE STORAGE; CARBON CONSTRAINED
	16	X				X		X		YES	NO	YES	
Storage ITC	JE01		X	X				X		YES	NO	YES	STORAGE ITC; CARBON CONSTRAINED
Transmission Allowed	JE02	X		X				X		YES	NO	YES	
	JE03		X	X						YES	NO	YES	STORAGE ITC
	JE04	X		X						YES	NO	YES	
	JE05		X	X				X		YES	NO	YES	STORAGE ITC; CARBON CONSTRAINED; CAPPED FOSSIL FUELS
	JE06	X		X				X		YES	NO	YES	

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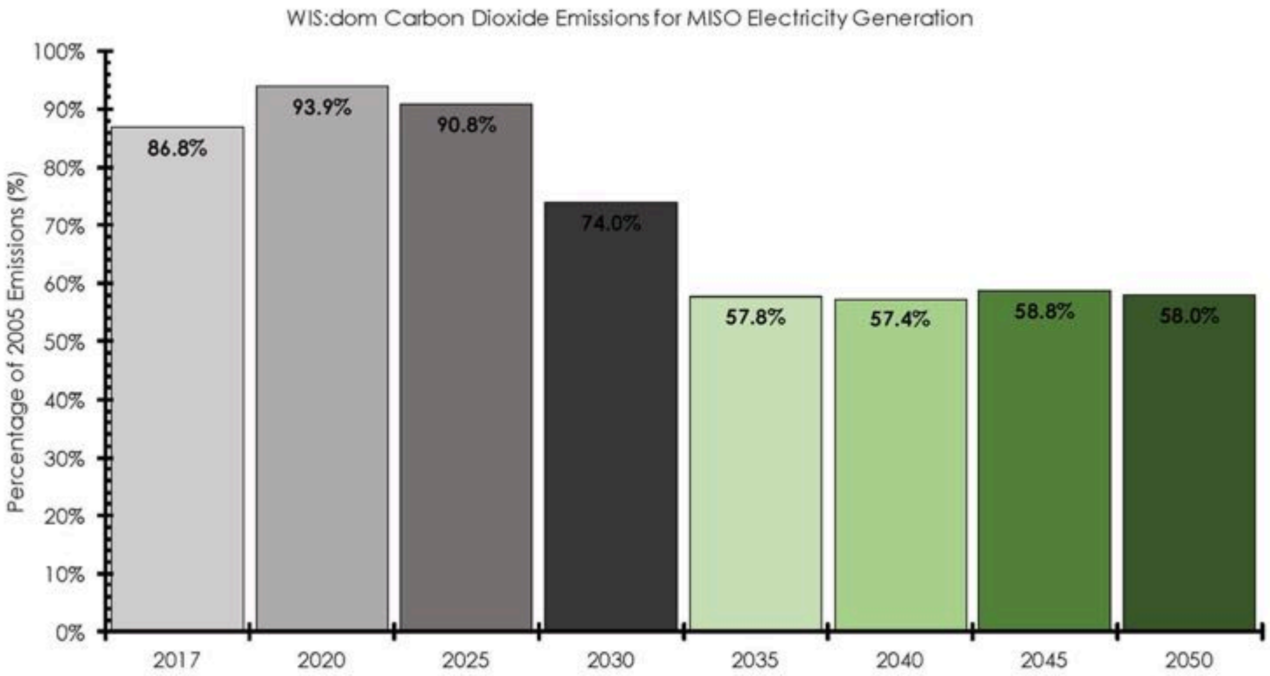
Base Case: No Transmission, No Storage, No GHG Constraints



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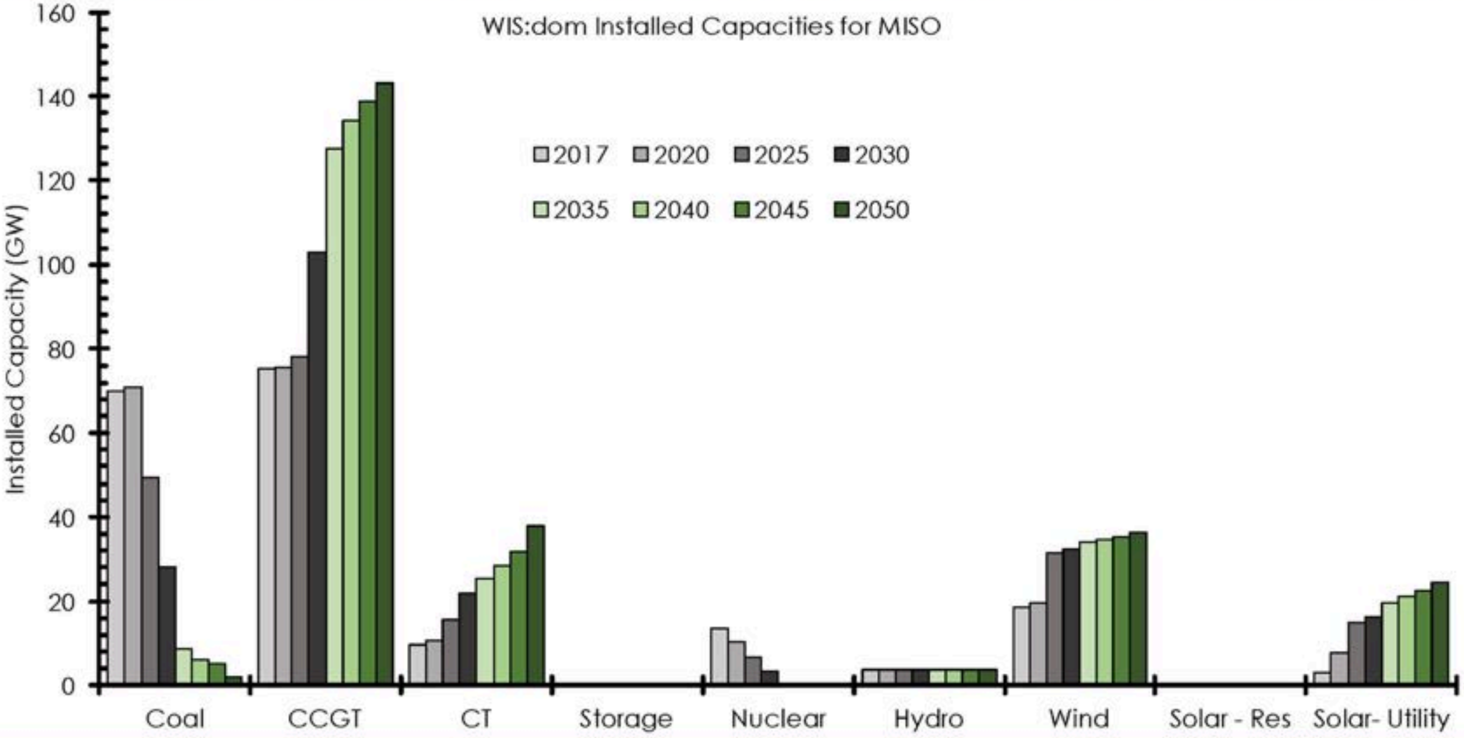
Base Case: No Transmission, No Storage, No GHG Constraints



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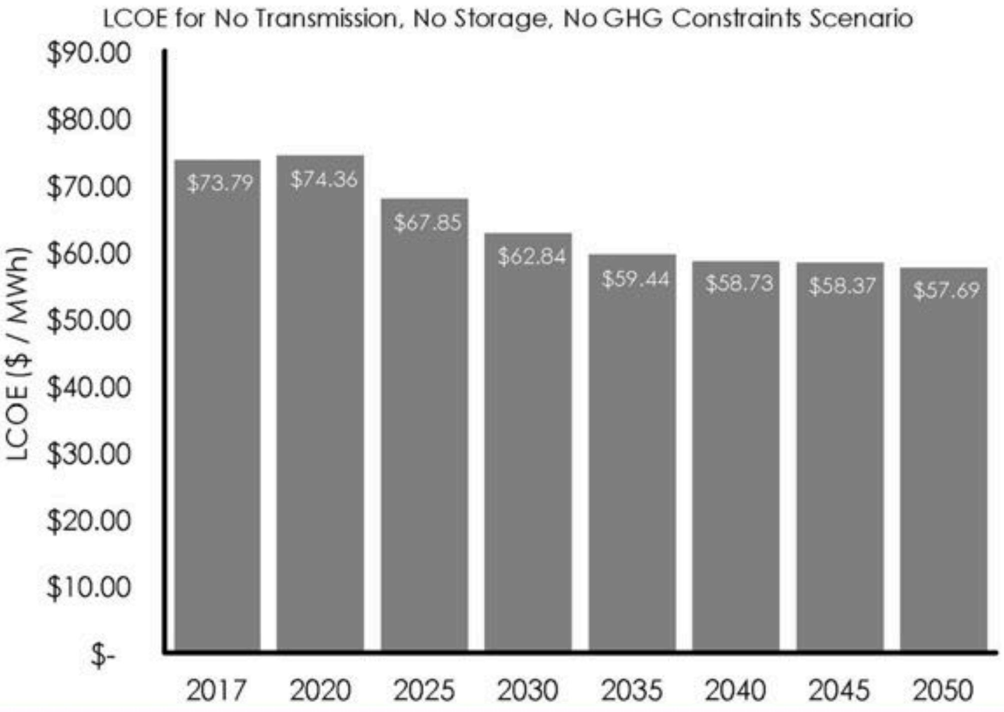
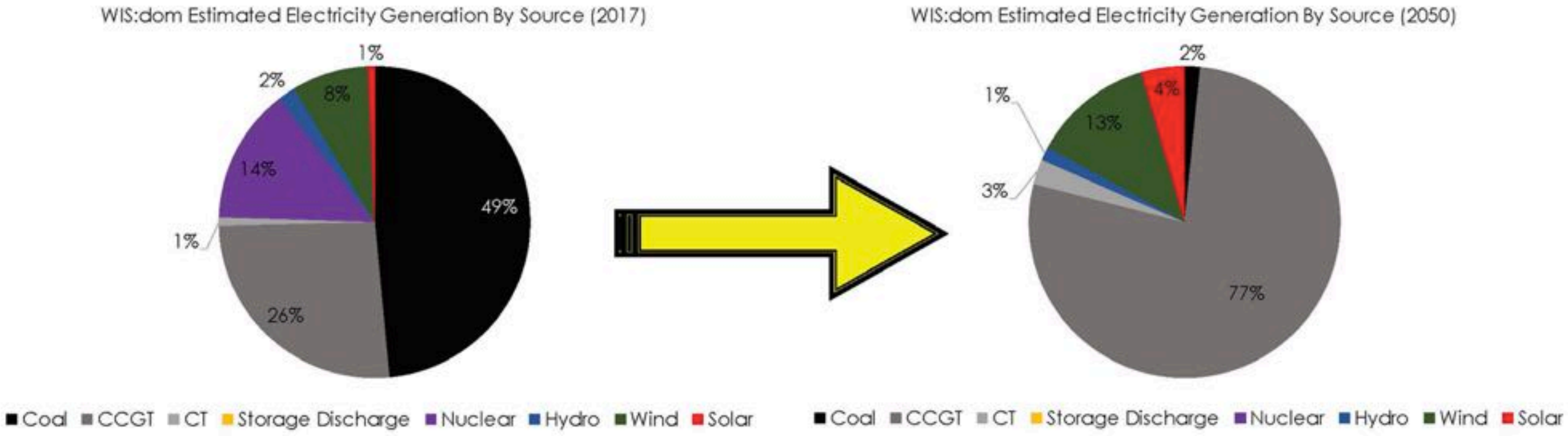
Base Case: No Transmission, No Storage, No GHG Constraints



VIBRANT CLEAN ENERGY, LLC

Base Case: No Transmission, No Storage, No GHG Constraints



- Natural Gas Combined Cycle becomes the dominant generation source by 2050;
- Wind and solar PV generation grow steadily;
- Nuclear power plants are all fully retired;
- A small amount of coal fired power remains.

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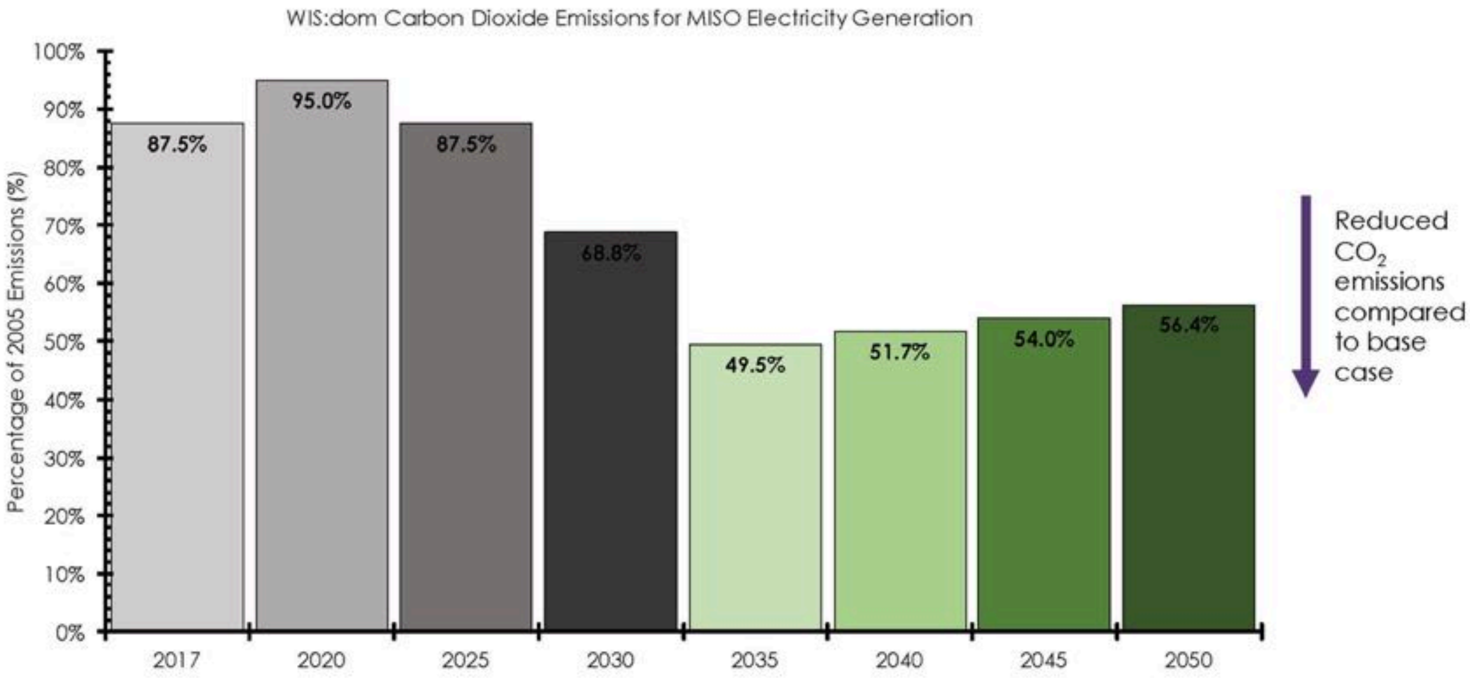
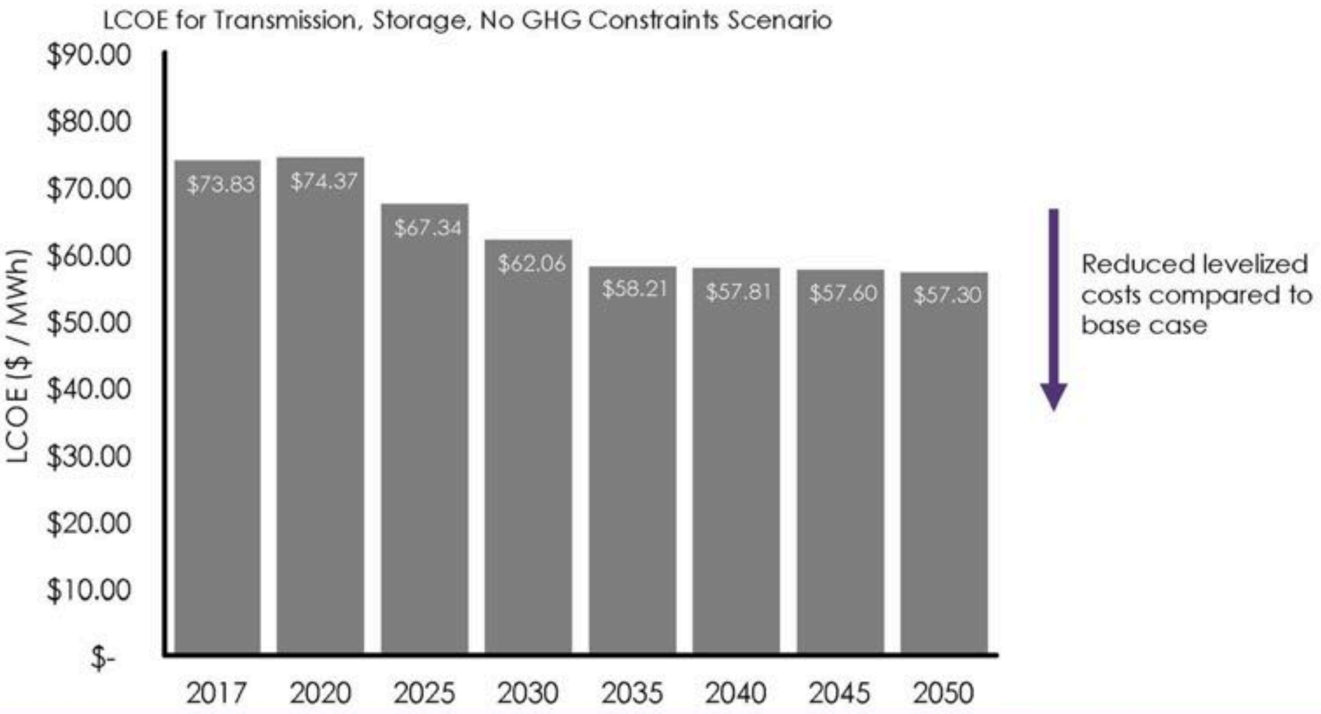
Alternative Case A: Transmission, Storage, No GHG Constraints



VIBRANT CLEAN ENERGY, LLC

Alternative Case A: Transmission, Storage, No GHG Constraints



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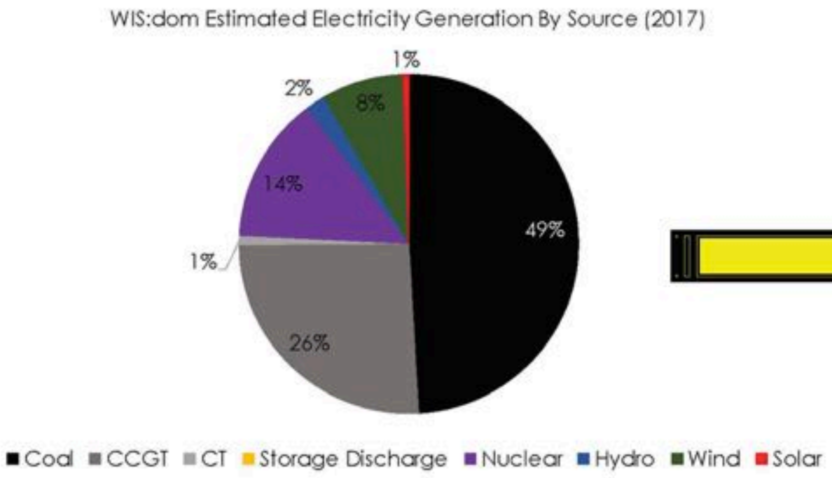
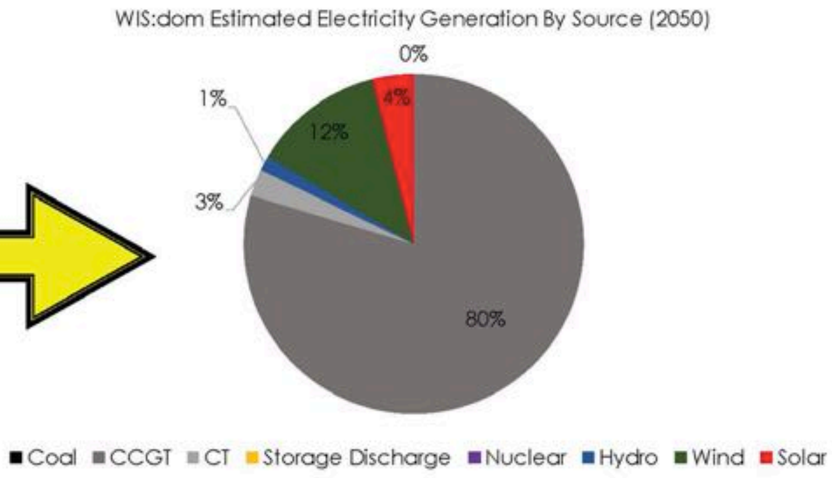
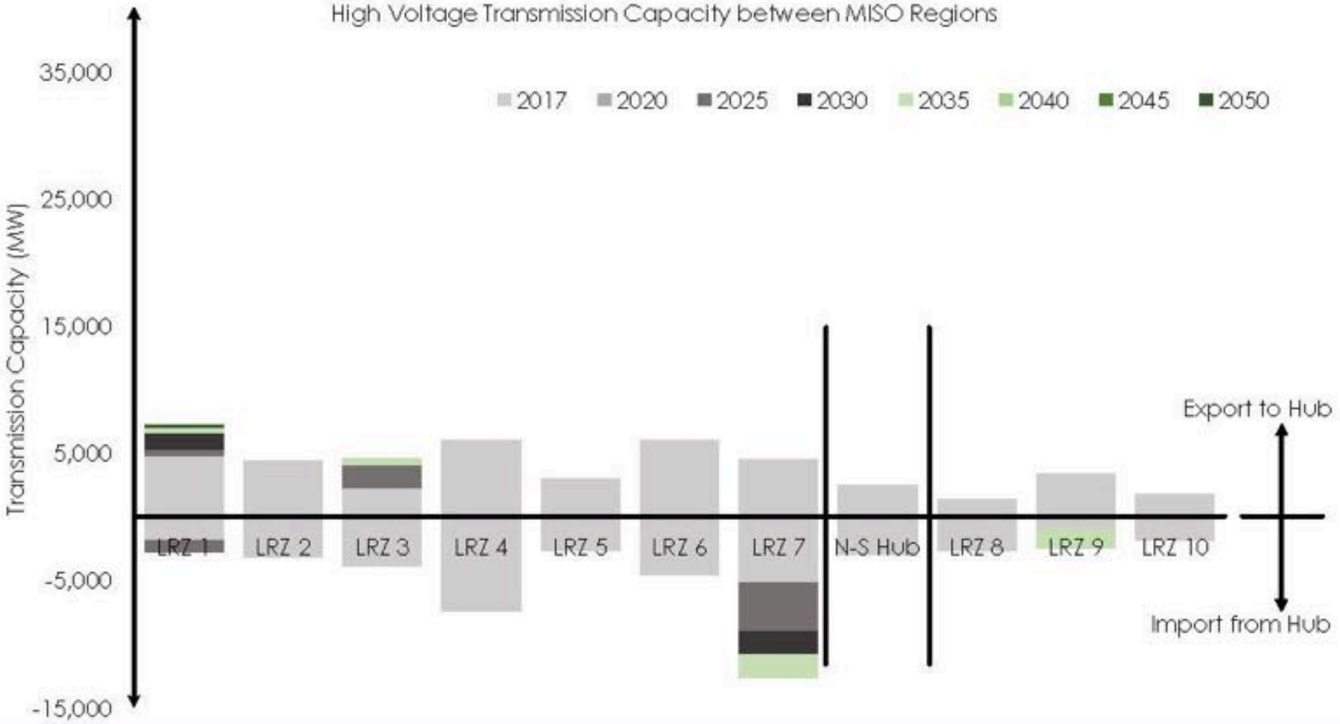
Alternative Case A: Transmission, Storage, No GHG Constraints


WIS:dom Estimated Electricity Generation By Source (2017)


WIS:dom Estimated Electricity Generation By Source (2050)

- Natural Gas Combined Cycle becomes the dominant generation source by 2050;
- Wind and solar PV generation grow steadily;
- Nuclear power plants are all fully retired;
- All coal fired power plants are fully retired.

Alternative Case A: Transmission, Storage, No GHG Constraints



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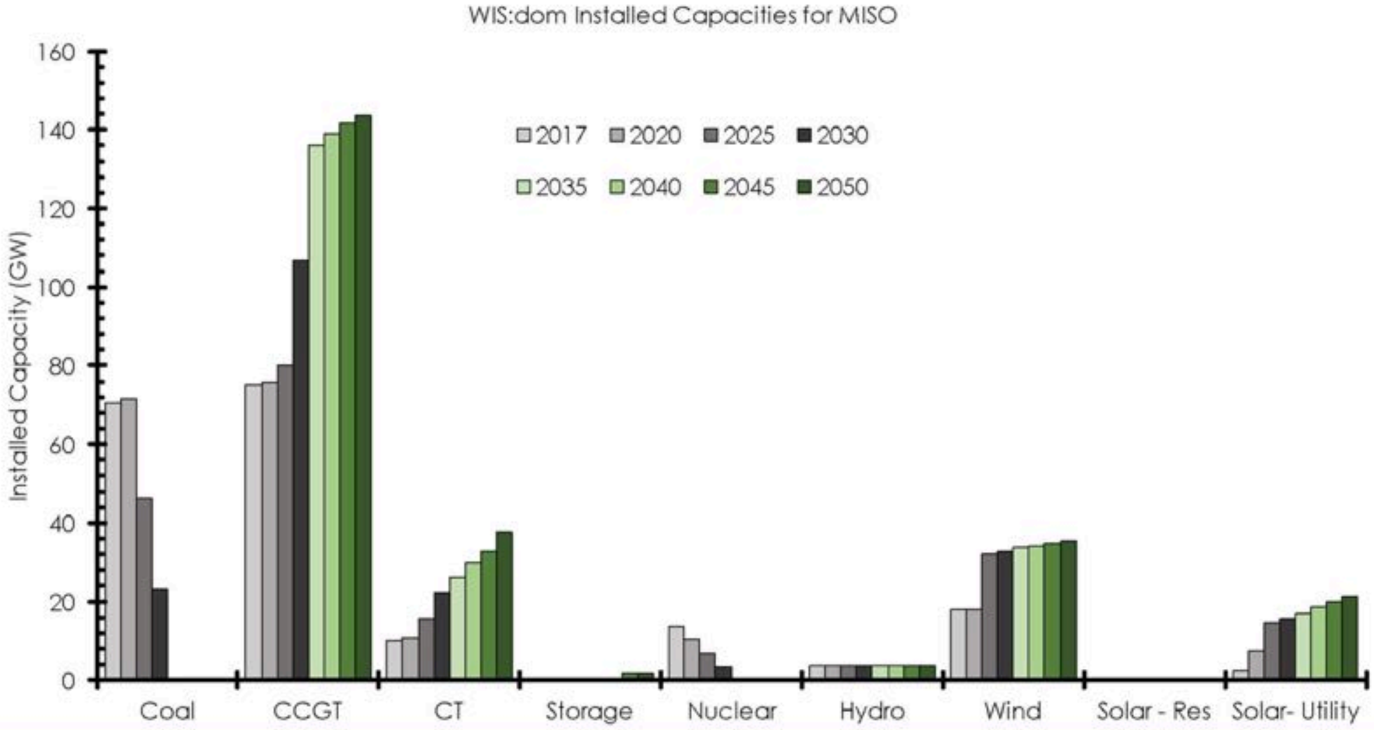
Alternative Case A: Transmission, Storage, No GHG Constraints



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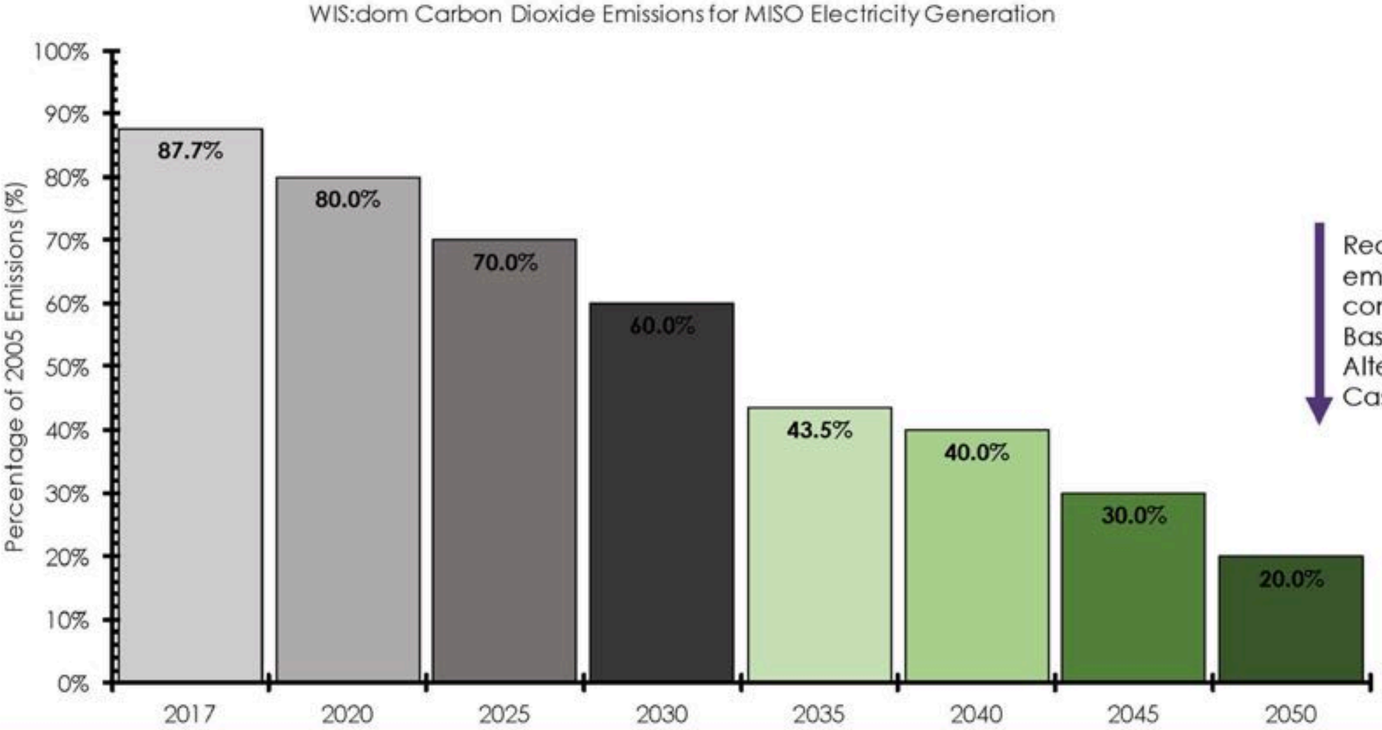
Alternative Case B: Transmission, Storage, GHG Constraints



Reduced CO_2 emissions compared to Base Case and Alternative Case A

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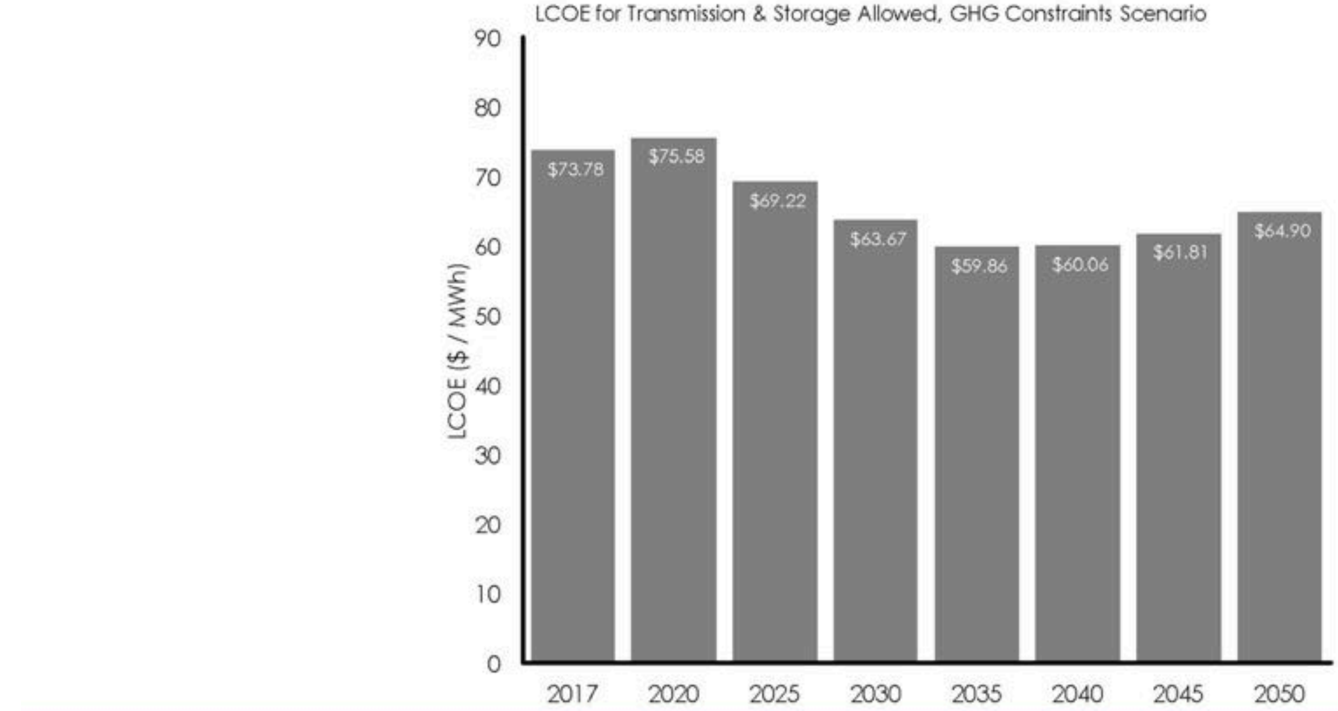
Alternative Case B: Transmission, Storage, GHG Constraints



LCOE from 2035 are higher than the Base Case and Alterative Case A due to emission constraints; but still lower than in 2017.

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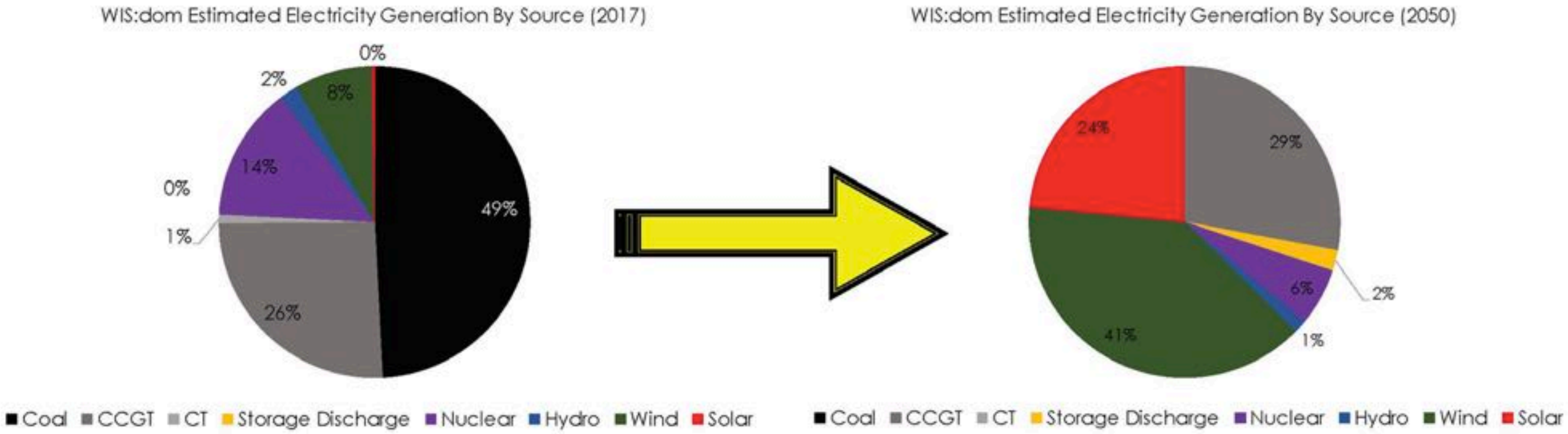
Alternative Case B: Transmission, Storage, GHG Constraints


WIS:dom Estimated Electricity Generation By Source (2017)

WIS:dom Estimated Electricity Generation By Source (2050)

- Wind and Solar PV become the dominant generation sources by 2050;
- Natural Gas combustion turbines are all retired;
- Only some of the nuclear power plants are retired;
- All coal fired power plants are fully retired;
- Storage discharge accounts for 2% of the dispatched energy.

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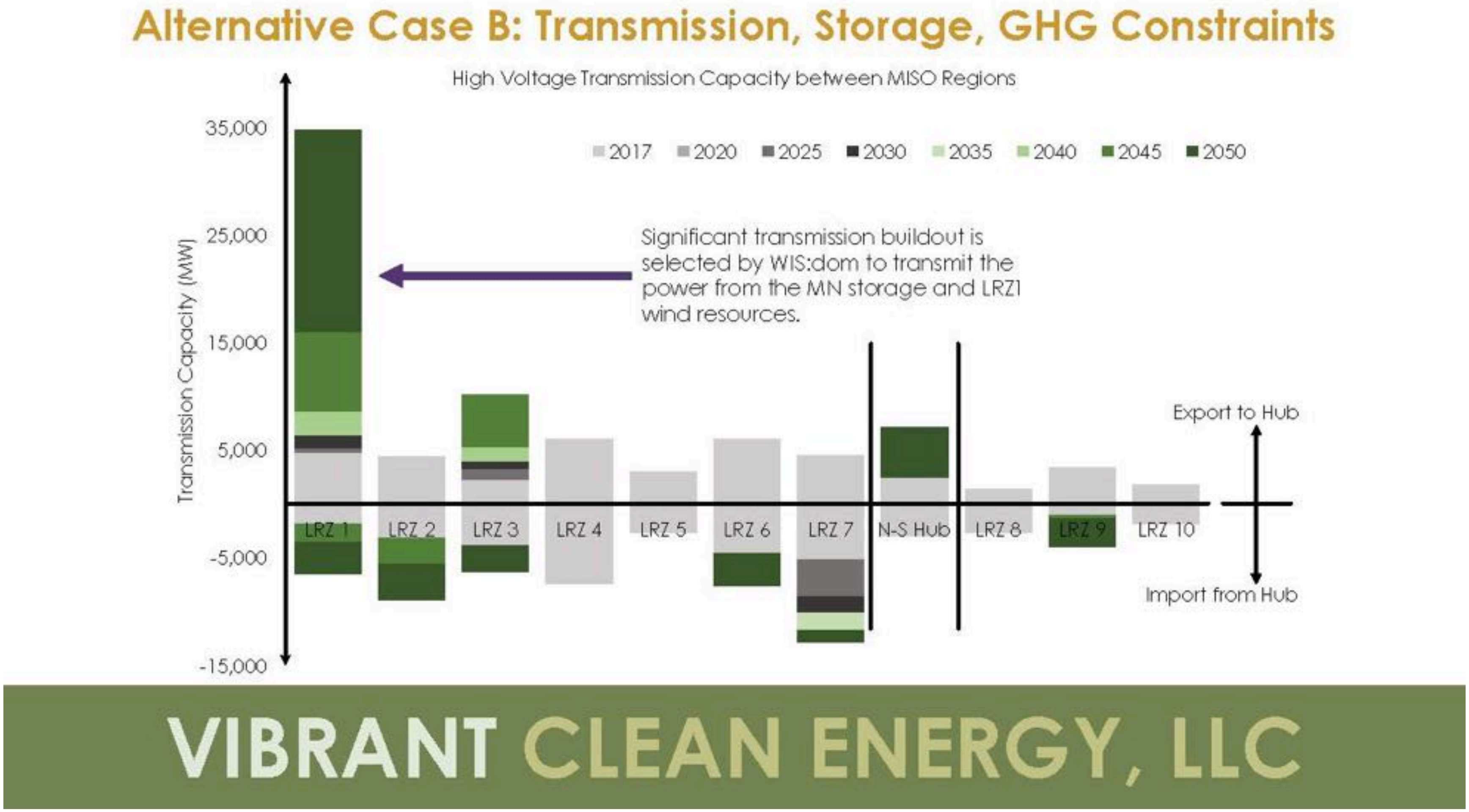

Alternative Case B: Transmission, Storage, GHG Constraints

Significant transmission buildout is selected by WIS:dom to transmit the power from the MN storage and LRZ1 wind resources.

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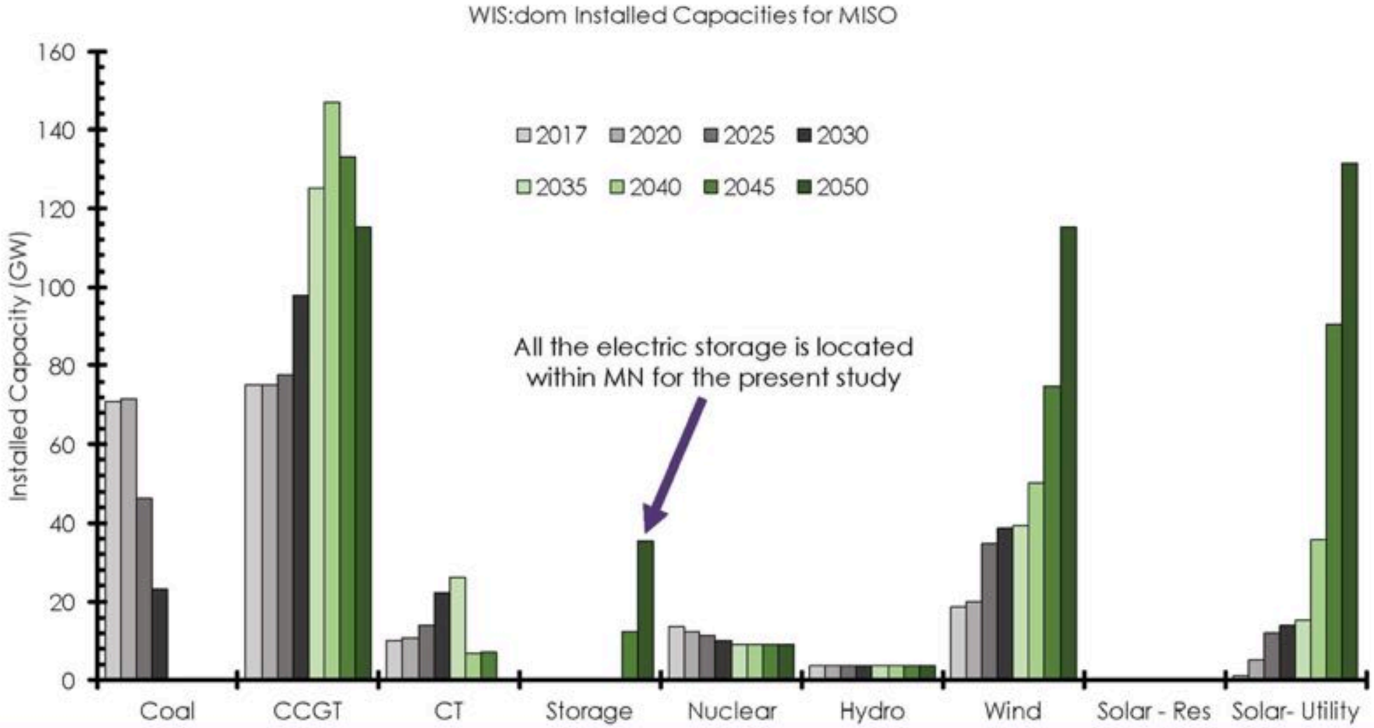
Alternative Case B: Transmission, Storage, GHG Constraints


WIS:dom Installed Capacities for MISO

All the electric storage is located within MN for the present study

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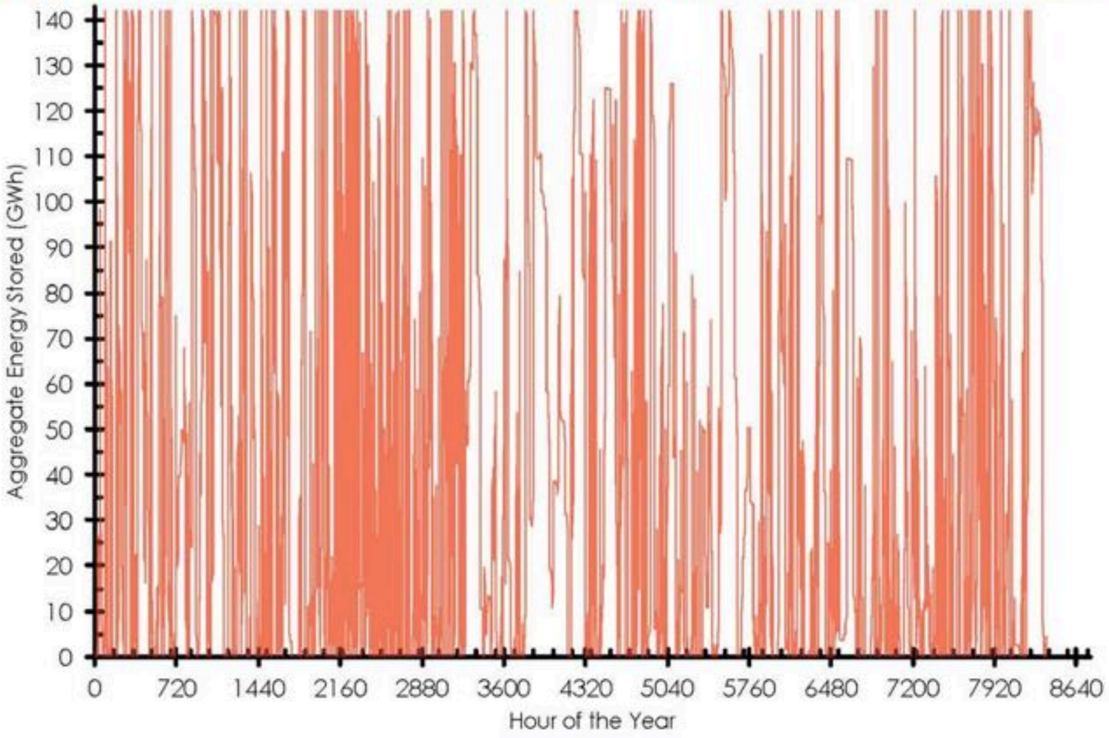
Alternative Case B: Transmission, Storage, GHG Constraints



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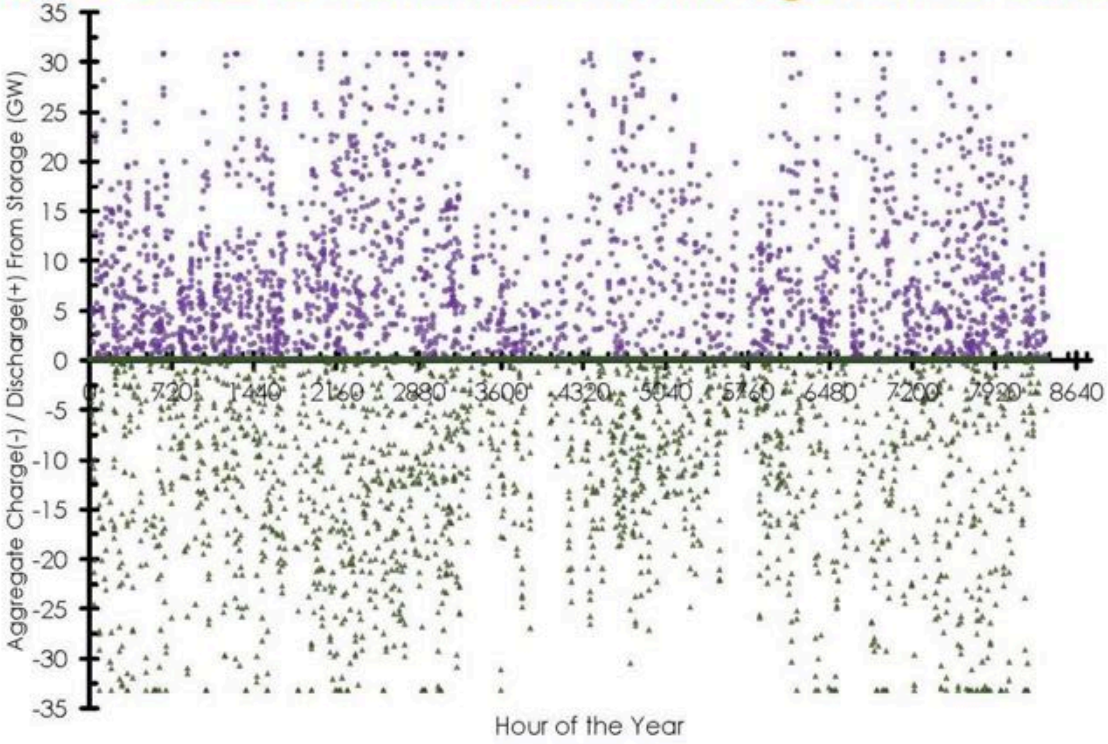
Alternative Case B: Transmission, Storage, GHG Constraints



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Other Alternative Cases

- ✓ Forced storage scenario results in an increase in LCOE of 0.2% compared with the Base Case scenario, but with 3% lower GHG emissions. Forced storage increases by 3 GW each investment period to 24 GW by 2050.
- ✓ Storage including ITC results in earlier adoption by the WIS:dom model of storage. It facilitates a reduction in LCOE of 0.5% and an additional 6 GW of storage by 2050.
- ✓ When transmission expansion is allowed, WIS:dom selects more storage than when it is not allowed.
- ✓ More solar PV is selected by WIS:dom when more storage is available.
- ✓ Storage competes with and reduces CTs in some regions of MISO as storage becomes economical. Particularly in the "forced storage" scenario.
- ✓ All other results are consistent with those shown; more transmission results in more storage deployed, emission targets increase storage deployment, increased storage promotes more solar PV deployment.

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All Results Are Available Online

https://drive.google.com/drive/folders/0BzNQOOD_tM5DWjhxbU43d05ER2M?usp=sharing

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Possible Modeling Next Steps

1. Consider modeling storage with more hours of energy, rather than just 4 hours;
2. Include more years of weather data to optimize upon;
3. Analyze more cost trajectories for technologies;
4. Include CCS and more GHG reduction standards;
5. Electric Vehicles, heating/cooling, and thermal storage;
6. Larger transmission coordination. MISO with SPP and/or PJM;
7. Multiple hub heights for wind generators.

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The WIS:dom Optimization Model System Level Analysis of Minnesota Energy Storage

Additional Slides

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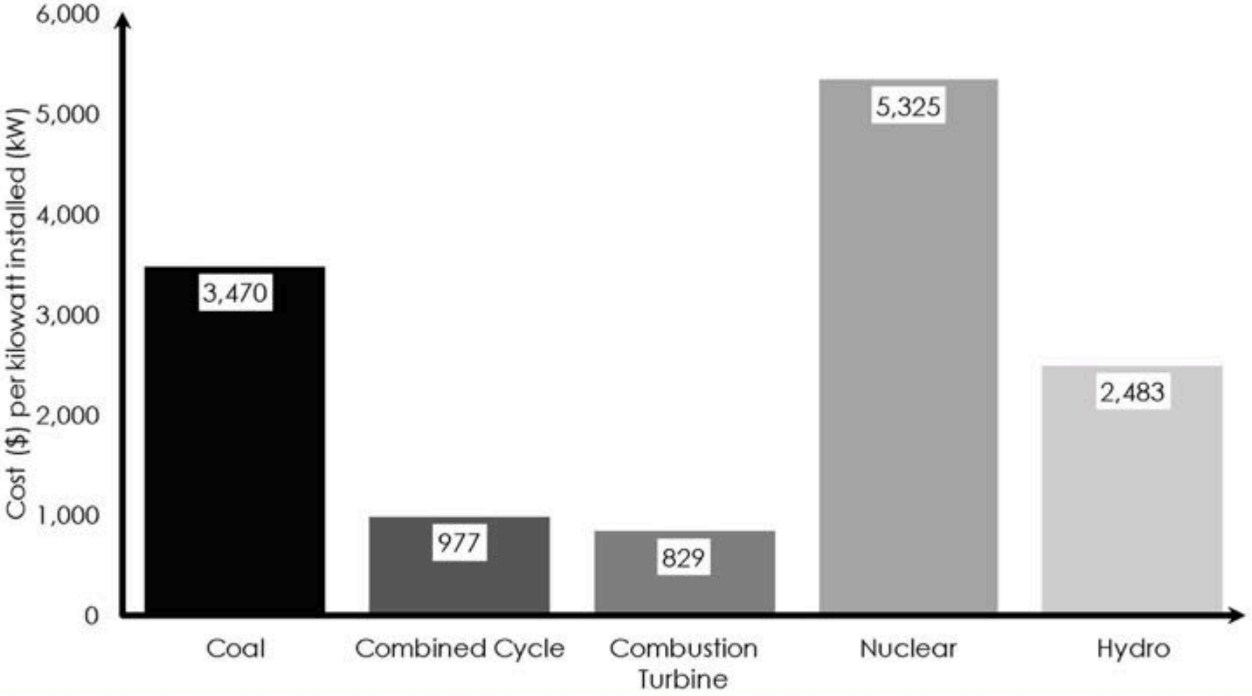
For WIS:dom Capital Costs Are Critical Inputs

Capital Costs for Conventional Generation



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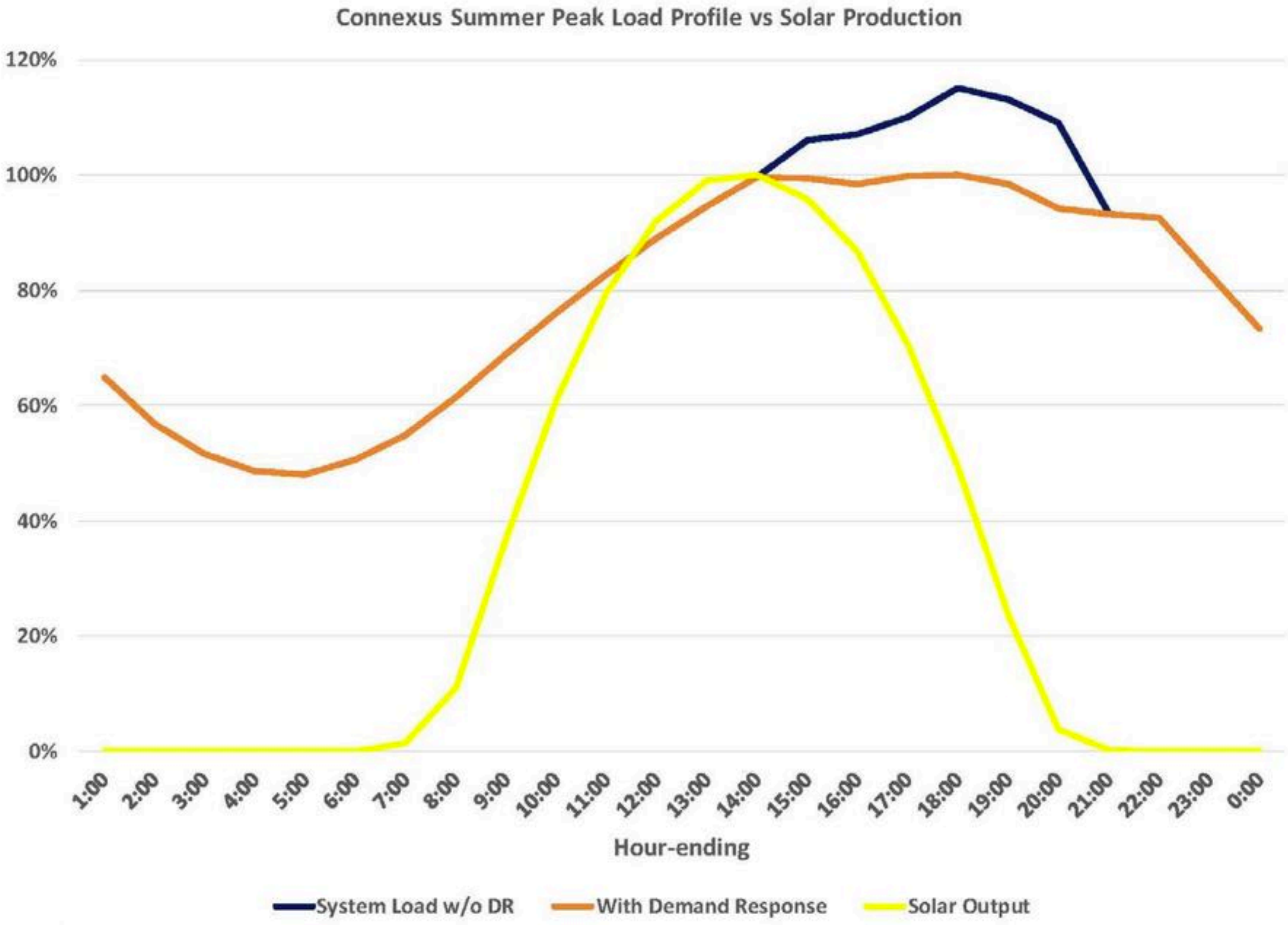
18 Appendix J – Energy Storage Use Case: Distribution Grid Interconnected Solar (Connexus)

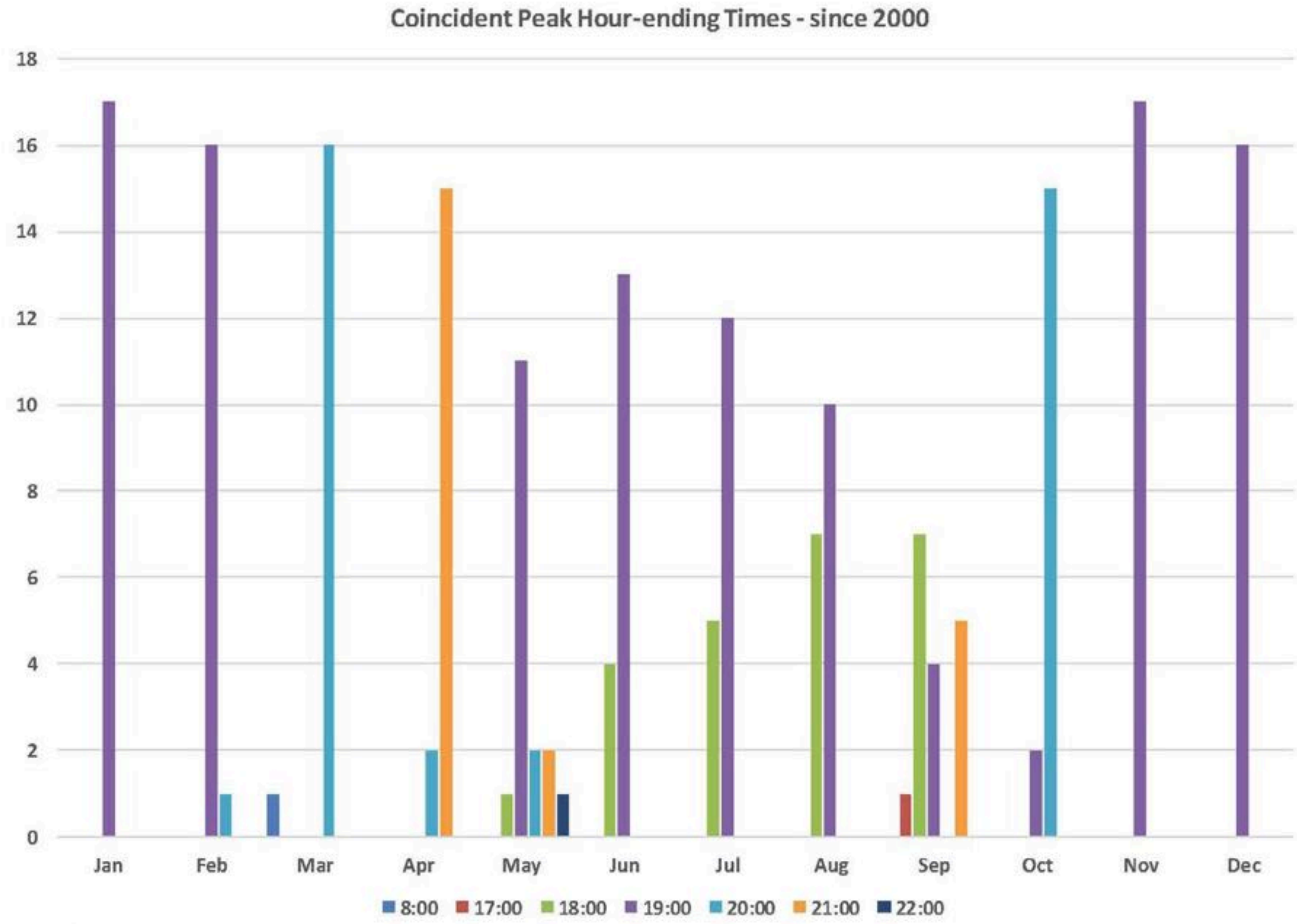
Price Signals for Solar + Storage

Monthly Rate from GRE

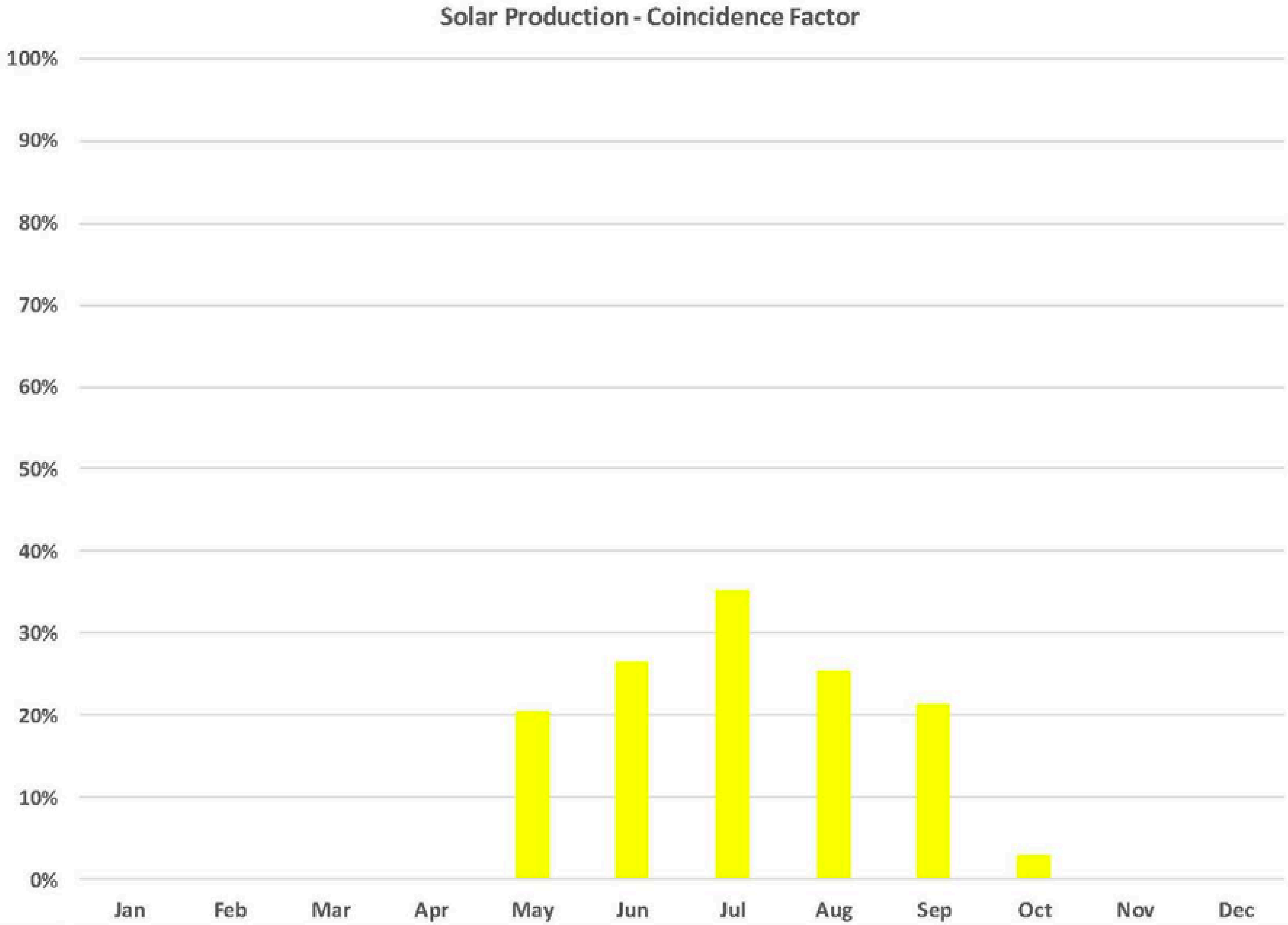
- Coincident demand charge
  - Capacity
  - Transmission
- Energy
  - On-Peak
    - 10 am – 8 pm (Mon-Fri)
  - Off-Peak
    - All other hours

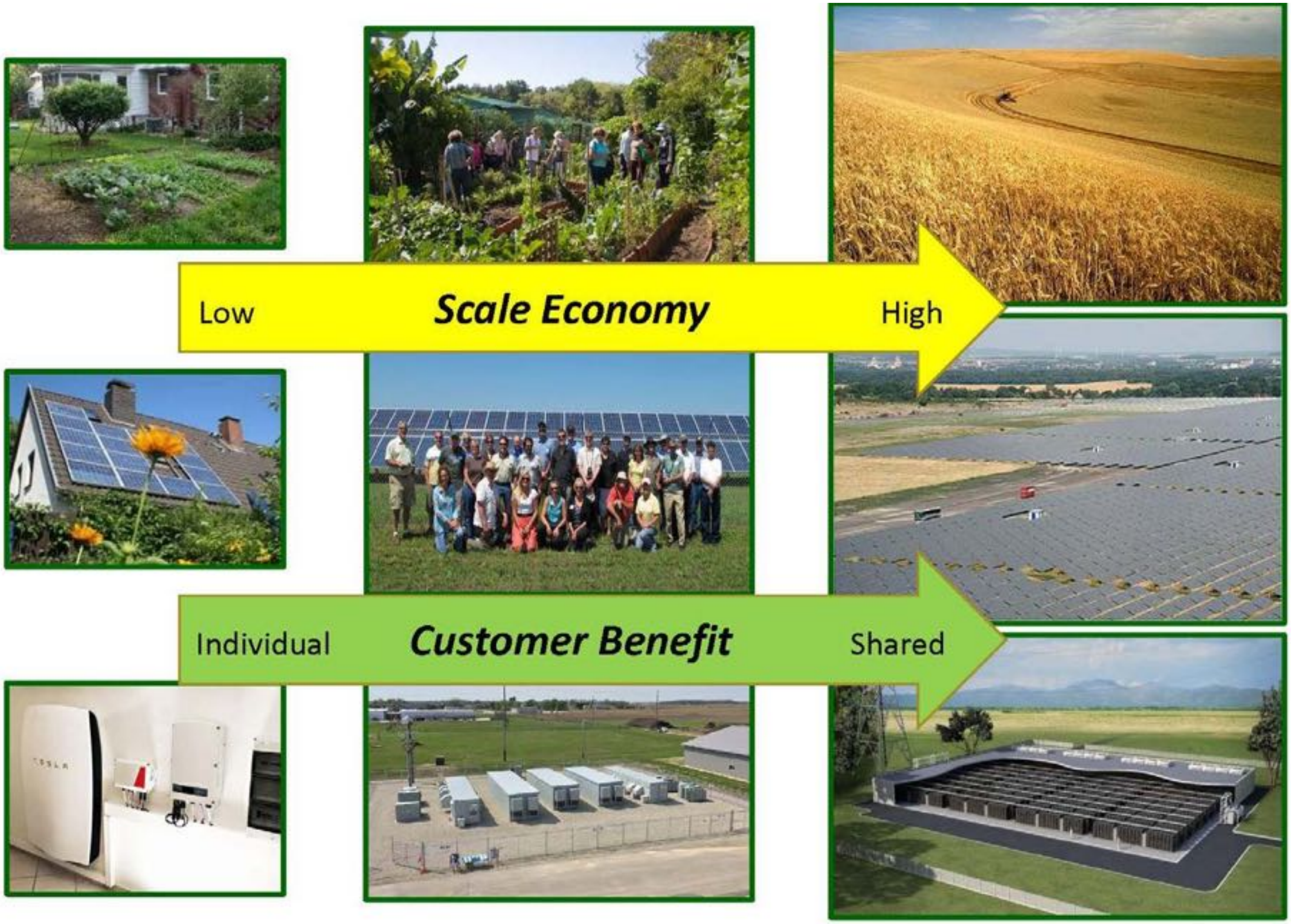


your most powerful membership



your most powerful membership


Solar Production - Coincidence Factor
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec



Low **Scale Economy** High

Individual **Customer Benefit** Shared

Scale matters

	Rooftop Solar Residential	Rooftop Solar Commercial	CE's Community Solar	Community Solar	Utility-Scale Solar
Size	< 10 kW	10-100 kW	245 kW	0.1-1 MW	1-10 MW
Capital $	$\$3.90/W_{dc}$	$\$3.46/W_{dc}$	$\$2.78/W_{dc}$	$\$2.49/W_{dc}$	$\$2.03/W_{dc}$
LCOE	$0.12/kWh	$0.11/kWh	$0.09/kWh	$0.08/kWh	$0.07/kWh

Benefit

Individual

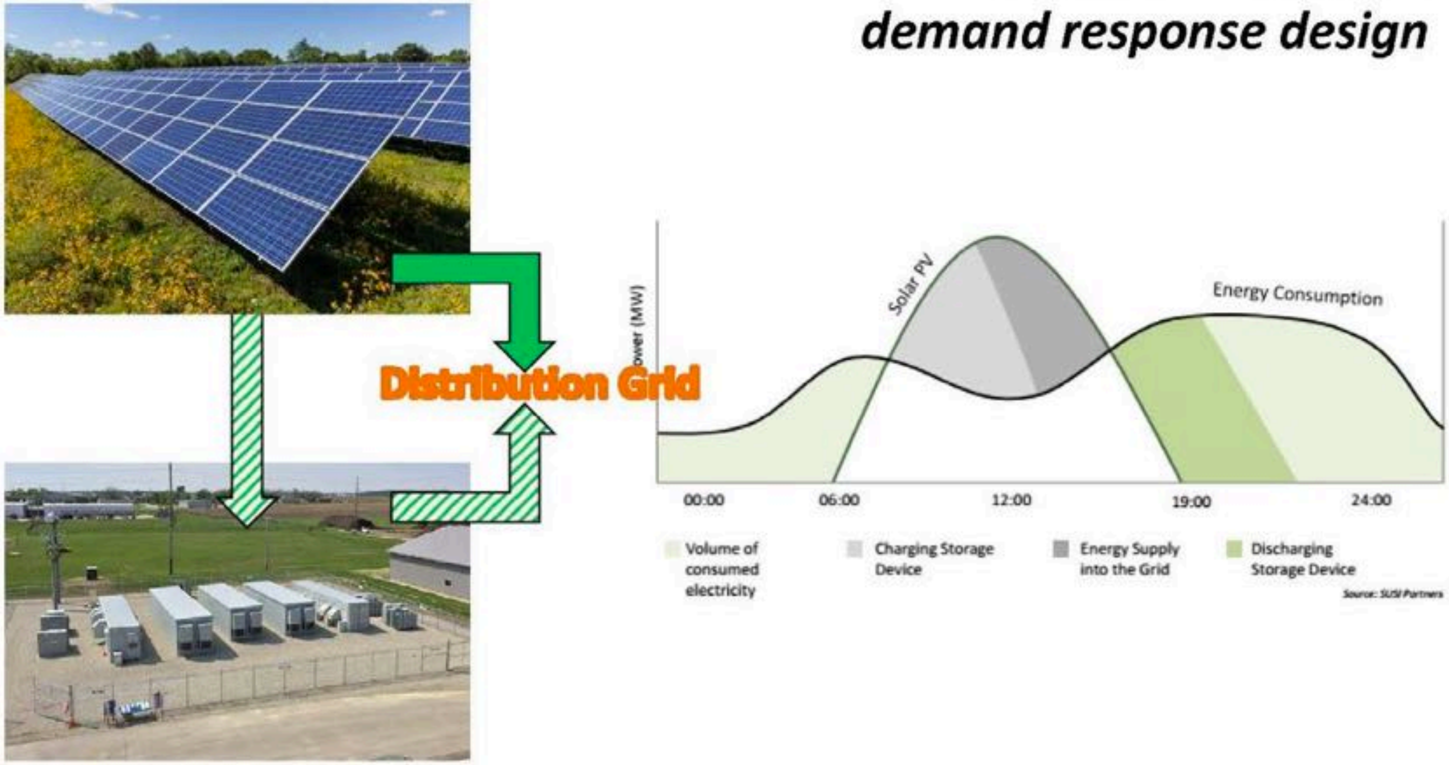
Few

Many

All

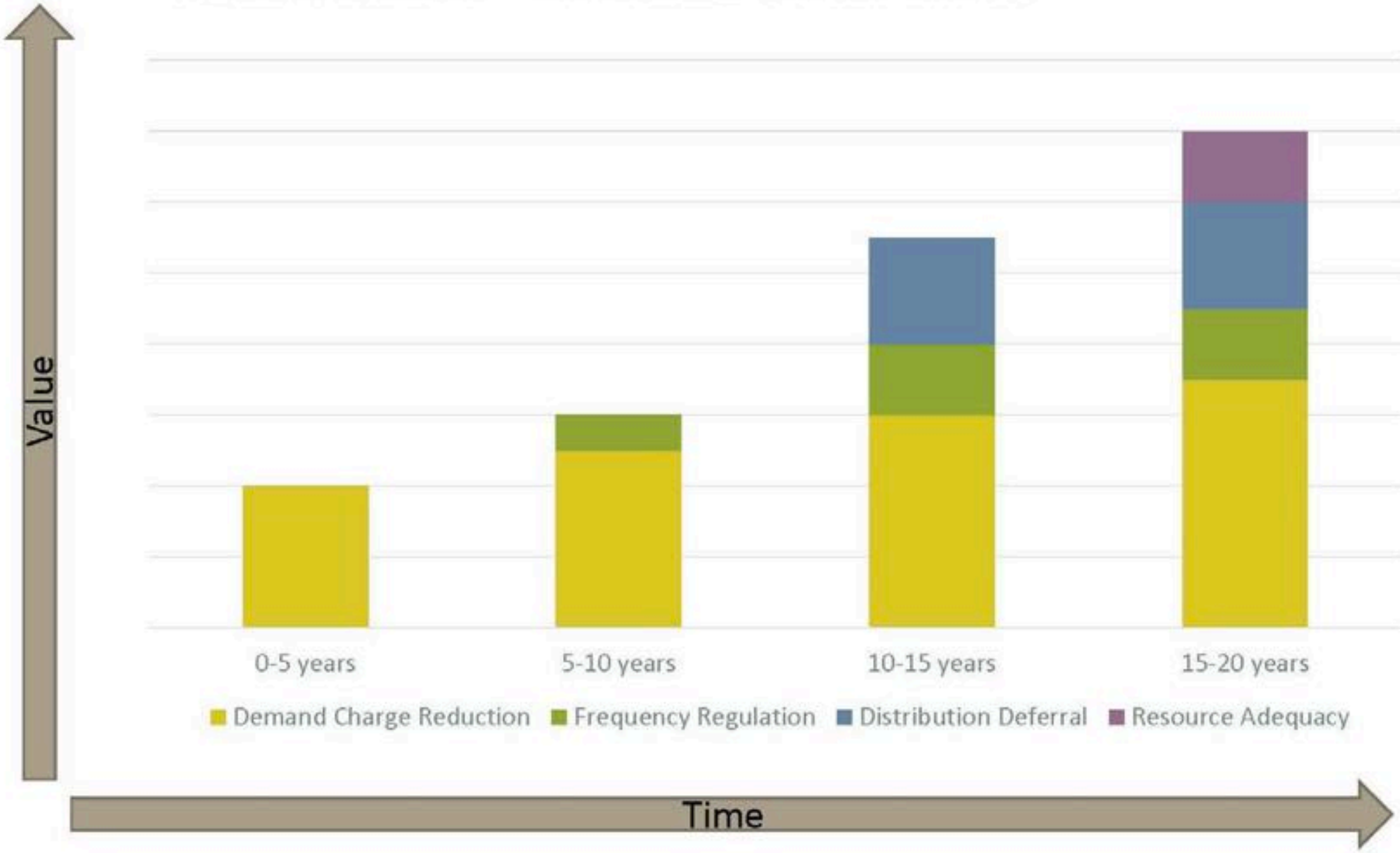
Connexus Use Case → Solar + Storage

at MW Scale
on distribution grid
demand response design



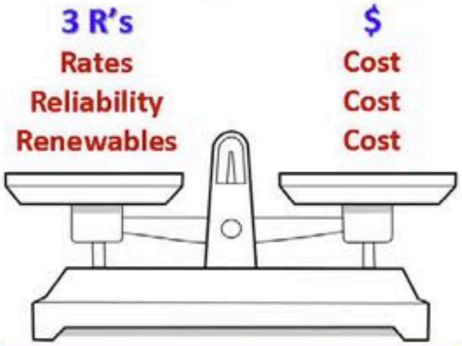
Source: SUSI Partners

At utility scale …
“value stack” evolves over time



Add Solar and Maintain the Balance

- **Pursue solar when it can lower total overall system cost**
  - Focus on realizing utility-scale economics
  - Consider permitting, distribution grid integration
  - Optimize tax credits
- **Accommodate members who want their own solar**
  - Net-metered members pay fair grid access fee (no subsidy)



3 R's
Rates
Reliability
Renewables

$
Cost
Cost
Cost

Key Messages

- **Renewables & the Energy Mix**
  - ❖ Building solar and realizing value is at distribution level
  - ❖ It is going to be part of our supply portfolio
- **Scale Matters**
  - ❖ Utility-scale outshines roof-top
- **Challenge**
  - ❖ Address range of member “wants” with cost fairness
- **Opportunity**
  - ❖ Develop solar that benefits all members

	Challenges	Approach
Technology	• Few Reference Projects • System Packaging • Performance Risk	**Modest Scale** **Keep Simple**
Siting	• Grid “Location” • Municipal Permitting • Zoning/Use of Land	**Address Early**
Financial	• Finding the Right Partners • Transaction Risks • Tax Benefit Complexity	**Realizable “Cash” Benefits**
Operations	• Grid Integration • Optimizing System • Dispatch Charge/Discharge	**Rigorous Design** **Walk Before We Run**

Observations – Large Scale Solar + Storage

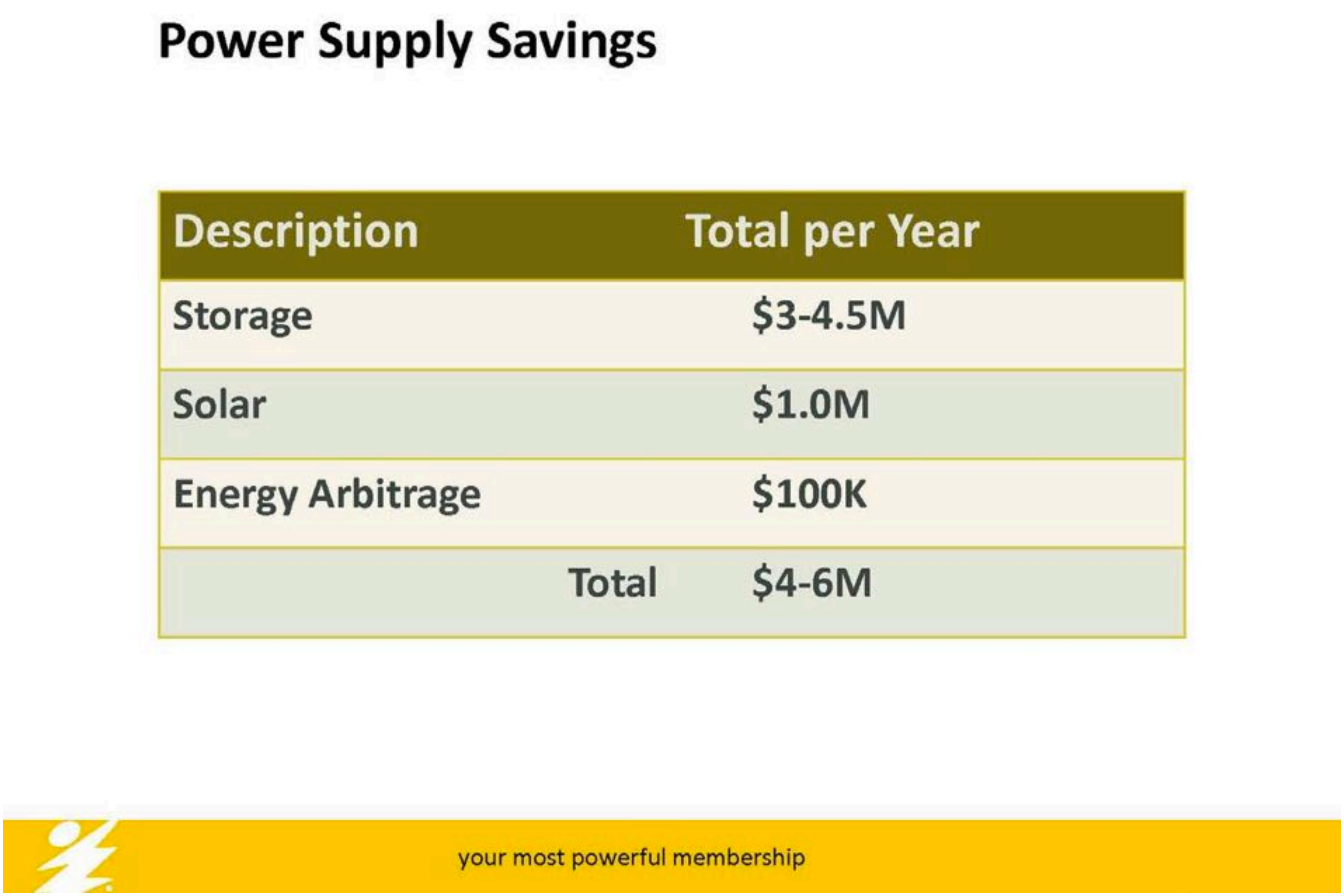
- **Technology readiness**
  - PV … "yes"
  - Batteries … "very soon"
- **MN demonstration(s) needed**
  - Key gap today … system and grid integration and operations
  - Each project will be unique … and ***not*** one-size-fits-all
  - Unique intersection of siting needs … ***not*** suited for everywhere
- **Benefit to electric customers and grid will evolve over time**

Project Overview

- **10 MW of Solar**
    - 50-60 acres of land

- **20 MW of Storage for Demand Response**
    - 40 MW (20 MW for 2 hours)
    - Lithium-ion Technology

- **~$60 million project**
    - $11-13M – Solar
    - $40-44M – Storage
    - $4-6M – land/contingency/consulting



Power Supply Savings

Description	Total per Year
Storage	$3-4.5M
Solar	$1.0M
Energy Arbitrage	$100K
Total	$4-6M

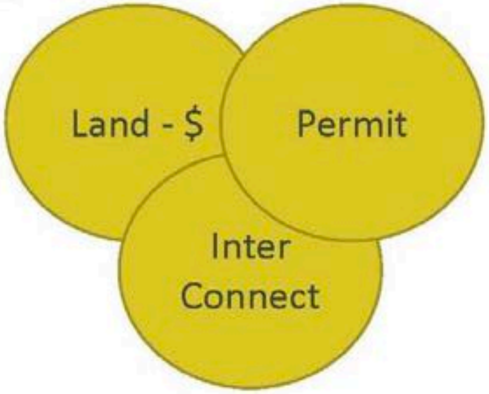
your most powerful membership

Investment Tax Credits

- Solar with storage is considered a “qualifying advanced energy project”
- 30% tax credit vested at 20% per year over 5 years
- Storage needs to be charged by solar a minimum of 75% to receive the ITC
- There is no ITC requirement for the Renewable Energy Certificates (RECs)
    - ❖ Value Stack

Site Identification

- **Considerations**
  - ❖ Interconnection quantification per site
    - ➢ MW of solar
    - ➢ MW of storage
  - ❖ Land costs ($/acre)
  - ❖ Interconnection costs



- **Zoning/Permitting**
  - ❖ Permitting requirements vary from Pro-Solar to specifically prohibiting Community Solar

Project Next Steps

- Request for Proposal – released 1Q17
- Evaluations of Proposals – 2Q17
- Decision Process
  - Go
    - Select Project Developer
    - Exercise Land Lease/Purchase Options
  - No Go
    - Forfeit Lease/Purchase Option deposit

Questions

19 Appendix K – Additional Workshop Presentations

AES
we are the energy

Energy Storage as a Flexible Capacity Solution

Minnesota Energy Storage Workshop

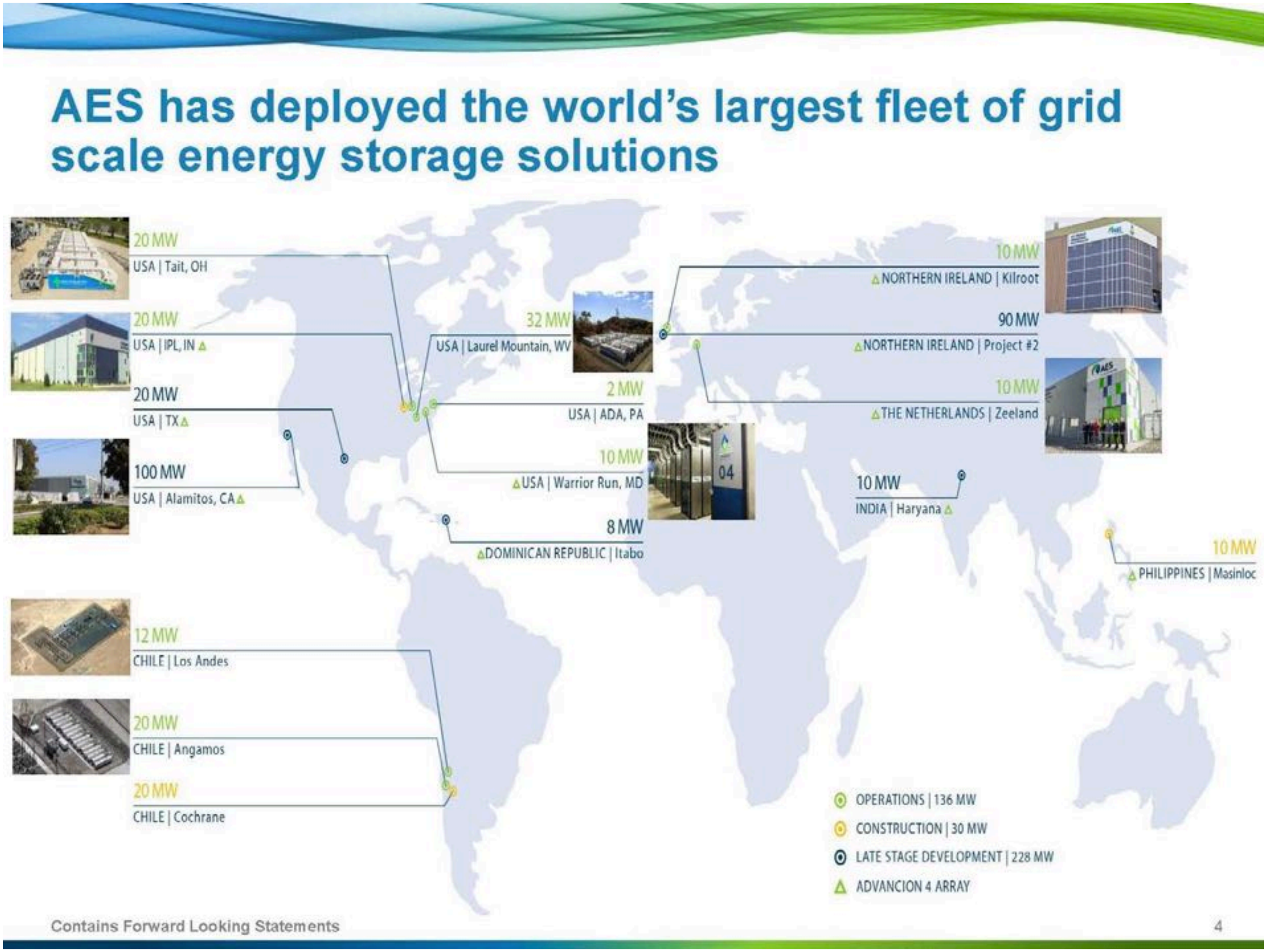
September 23, 2016

Agenda

Introduction

Meeting the growing need for flexible capacity

Discussion



AES has deployed the world's largest fleet of grid scale energy storage solutions

20 MW
USA | Tait, OH

20 MW
USA | IPL, IN △

20 MW
USA | TX △

100 MW
USA | Alamitos, CA △

32 MW
USA | Laurel Mountain, WV

2 MW
USA | ADA, PA

10 MW
△ USA | Warrior Run, MD

8 MW
△ DOMINICAN REPUBLIC | Itabo

12 MW
CHILE | Los Andes

20 MW
CHILE | Angamos

20 MW
CHILE | Cochrane

10 MW
△ NORTHERN IRELAND | Kilroot

90 MW
△ NORTHERN IRELAND | Project #2

10 MW
△ THE NETHERLANDS | Zeeland

10 MW
INDIA | Haryana △

10 MW
△ PHILIPPINES | Masinloc

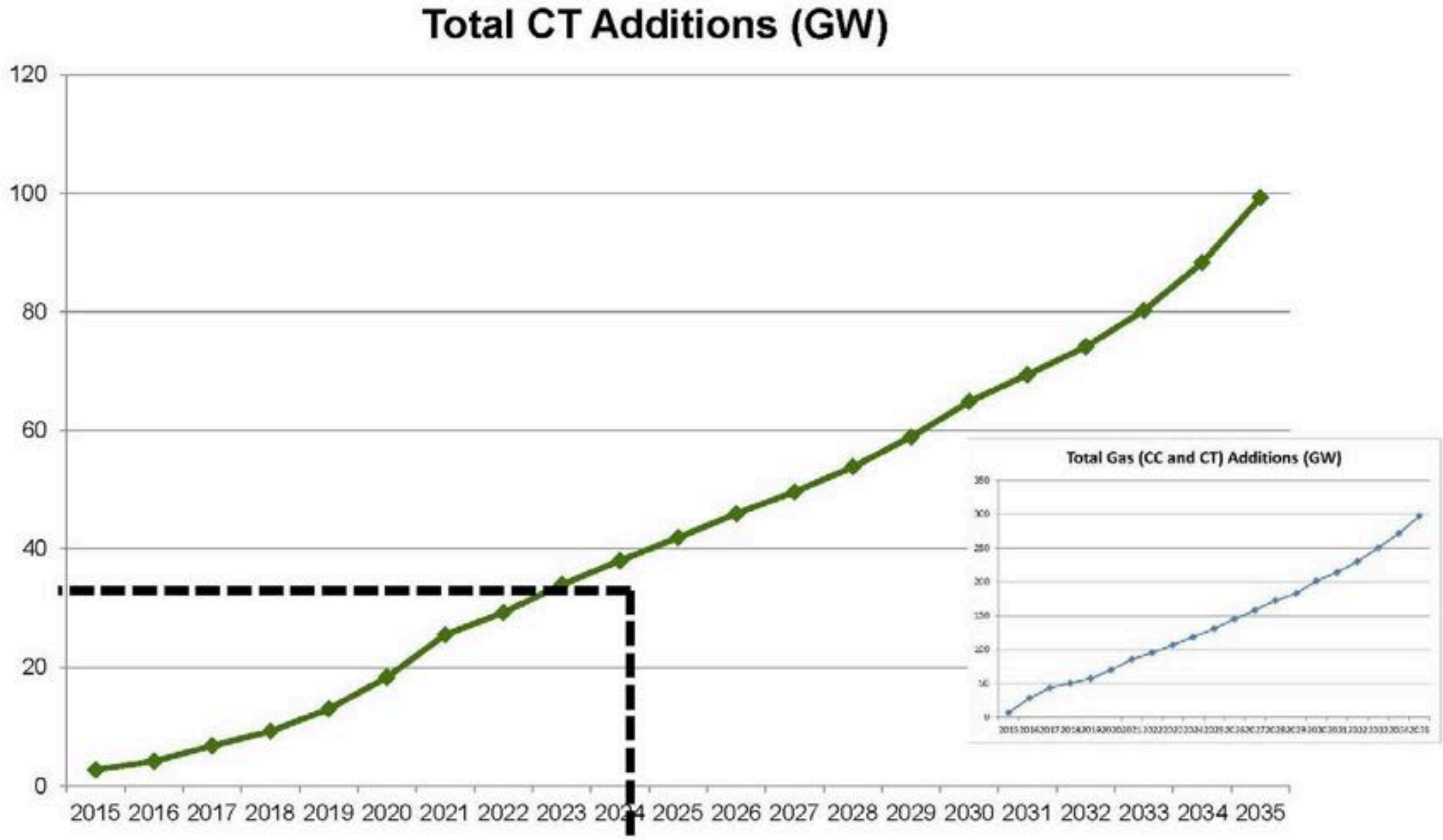
◎ OPERATIONS | 136 MW
◎ CONSTRUCTION | 30 MW
◎ LATE STAGE DEVELOPMENT | 228 MW
△ ADVANCION 4 ARRAY

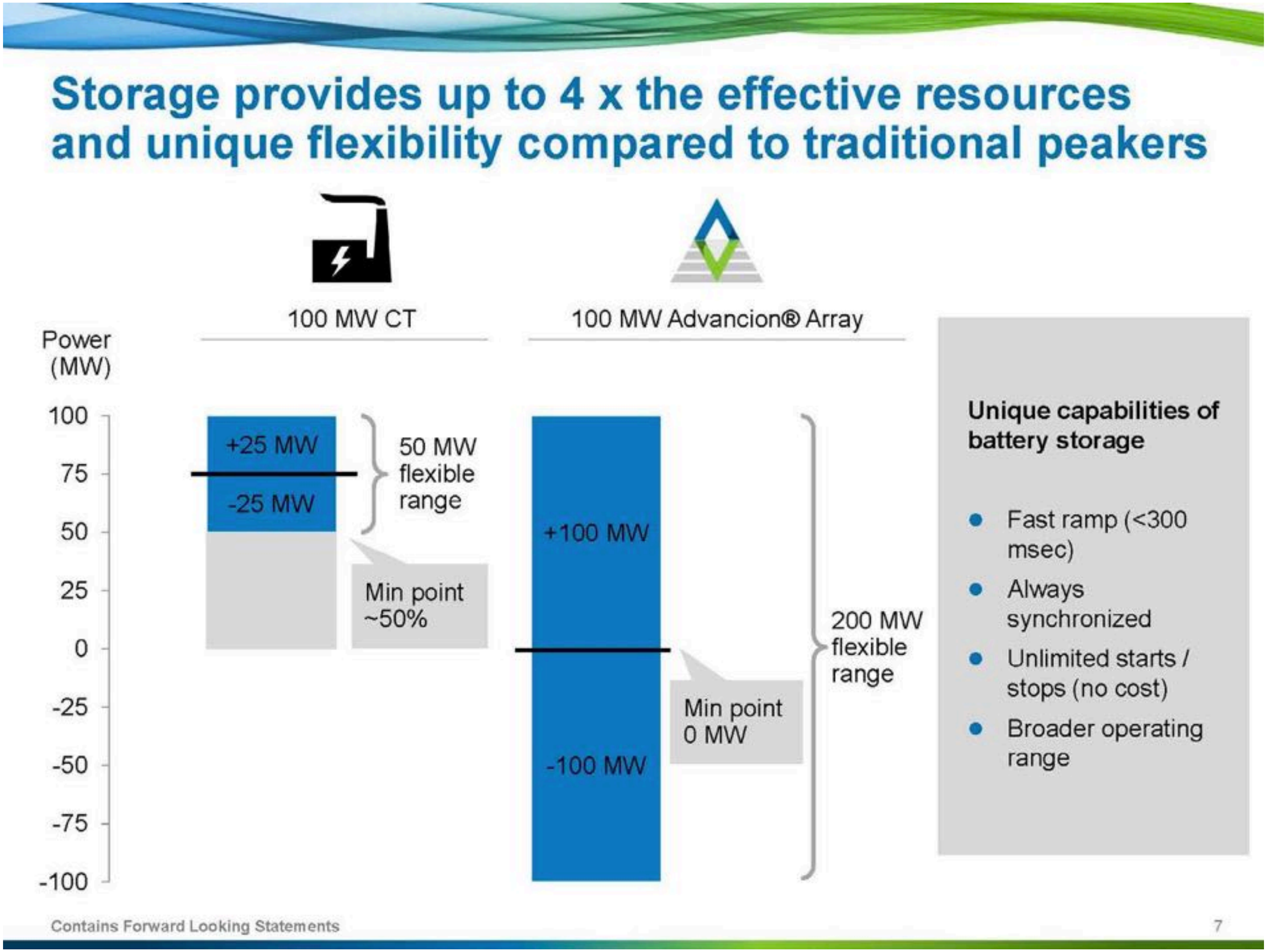
Contains Forward Looking Statements

4

IHS analysis projects 39 GW of simple cycle gas turbines and 123 GW of total gas capacity additions in the U.S. over the next 10 years.

The need for flexible capacity is growing nationally..





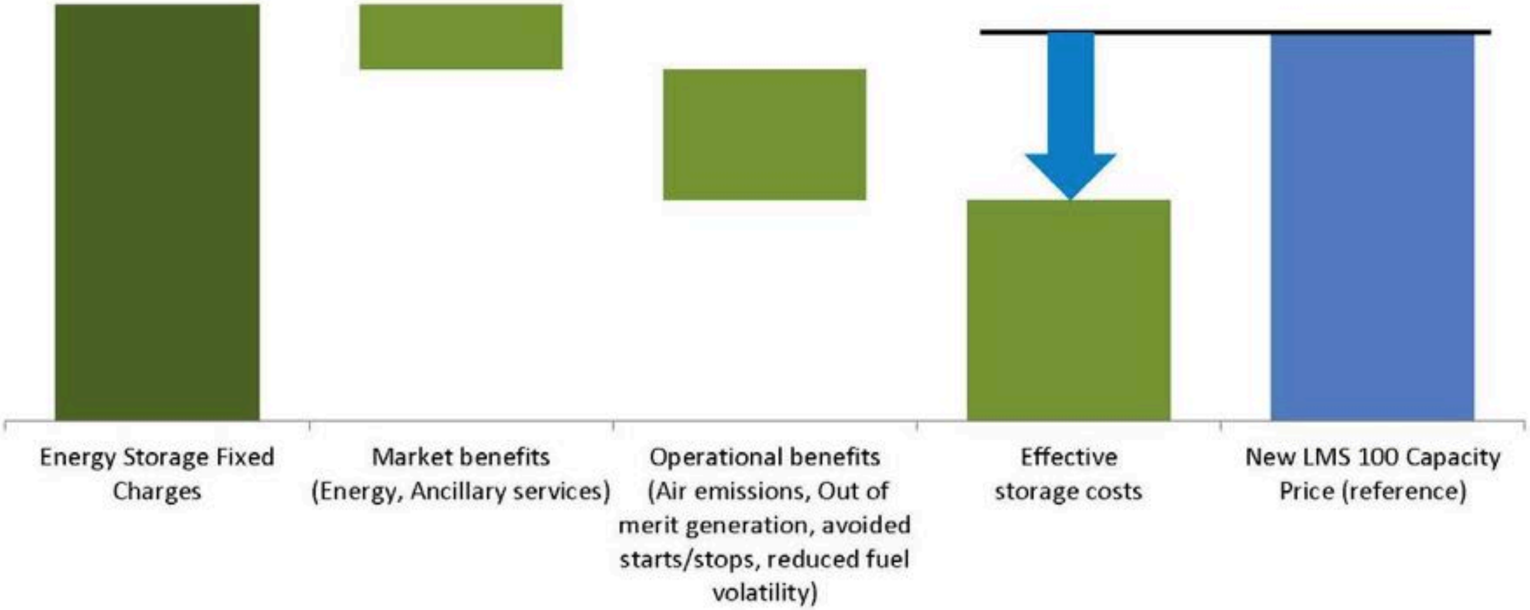
Storage provides up to 4 x the effective resources and unique flexibility compared to traditional peakers

Unique capabilities of battery storage

- Fast ramp (<300 msec)
- Always synchronized
- Unlimited starts / stops (no cost)
- Broader operating range

Storage is cost effective today

Indicative capacity cost ($/kW-month)



Contains Forward Looking Statements

Additional Benefits from Energy Storage

- Emission free with no water usage
- Rapid deployment
- No minimum generation
- Always on
- High reliability + availability
- Can perform multiple jobs, highly utilized asset

ALWAYS ON

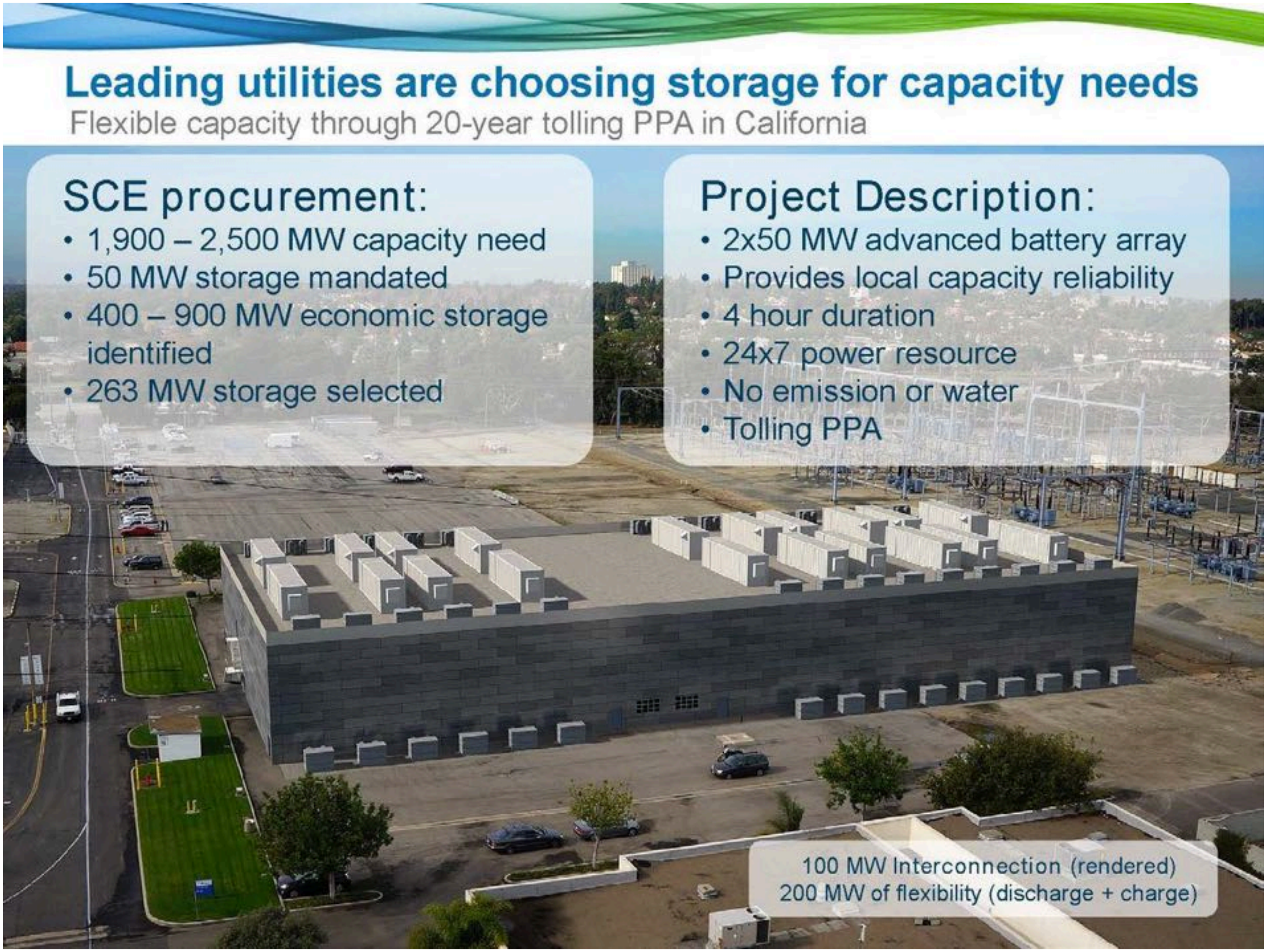
Versus Average Peaker Plant

6.6% vs. 97%

15X more service hours

FLEXIBLE ARRAYS

Parallel Array For High Availability



Leading utilities are choosing storage for capacity needs

Flexible capacity through 20-year tolling PPA in California

SCE procurement:

- 1,900 – 2,500 MW capacity need
- 50 MW storage mandated
- 400 – 900 MW economic storage identified
- 263 MW storage selected

Project Description:

- 2x50 MW advanced battery array
- Provides local capacity reliability
- 4 hour duration
- 24x7 power resource
- No emission or water
- Tolling PPA

100 MW Interconnection (rendered)
200 MW of flexibility (discharge + charge)

Agenda

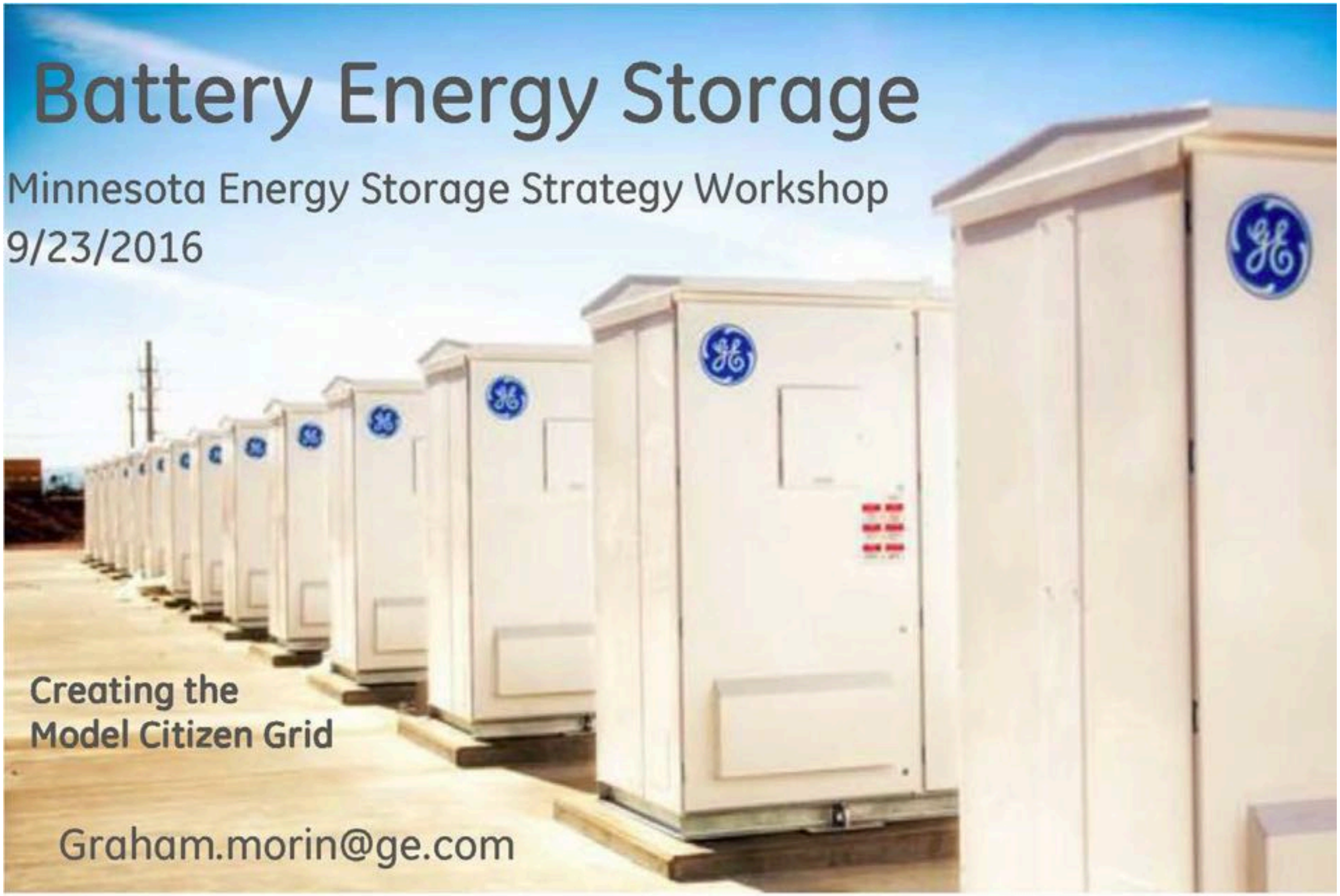
Introduction and Background

Meeting the growing need for flexible capacity

Discussion

Discussion questions

- How are you planning to meet flexible capacity needs in the system?
- How is storage being evaluated within resource planning?
- Are you opening procurements to allow all-source competition?
- Have you considered storage to meet transmission needs?



Battery Energy Storage

Minnesota Energy Storage Strategy Workshop
9/23/2016

**Creating the
Model Citizen Grid**

Graham.morin@ge.com

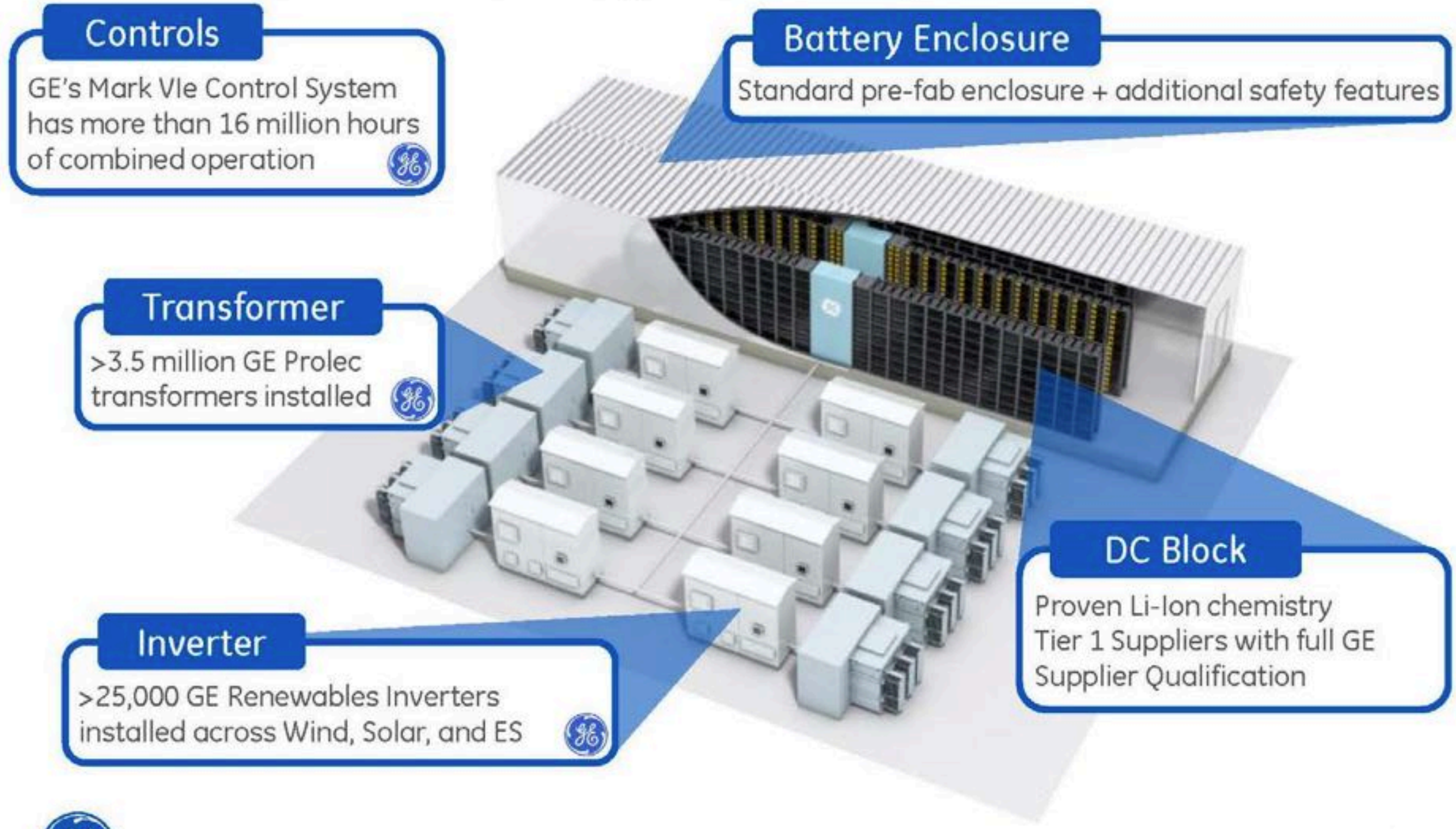
Imagination at work

Anatomy of an Energy Storage System

- Dispatch communication and Controls
- AC Front End
    - Interconnect
    - AC Collector
    - Inverters
    - Isolation Transformers
- DC Enclosure
    - Batteries
    - Fire Suppression
    - Climate Control

GE MW Class ES Platform

Custom solutions from standard, proven building blocks



Controls

GE's Mark VIe Control System has more than 16 million hours of combined operation

Battery Enclosure

Standard pre-fab enclosure + additional safety features

Transformer

>3.5 million GE Prolec transformers installed

DC Block

Proven Li-Ion chemistry
Tier 1 Suppliers with full GE Supplier Qualification

Inverter

>25,000 GE Renewables Inverters installed across Wind, Solar, and ES

Imperial Irrigation District

Publicly-owned utility

Service territory covers 6,471 square miles, from the Mexican border to Riverside county

Interties with SDG&E, SCE, WAPA and APS

Sixth-largest electrical utility in California

Over 140,000 customers

One of five balancing authorities in the state

1GW peak
300MW min load


IMPERIAL IRRIGATION DISTRICT

Headquartered in Imperial, CA. Additional locations in El Centro and La Quinta, CA.

IID/Coachella Project

PROJECT SUMMARY

Customer: Imperial Irrigation District, El Centro CA

Market Connectivity: IID / SCE

System Size: 30MW / 20MWh BESS

Applications: Distribution management system integration, ramp rate control, emergency power/black start capability, frequency response, spinning reserve

CURRENT STATUS

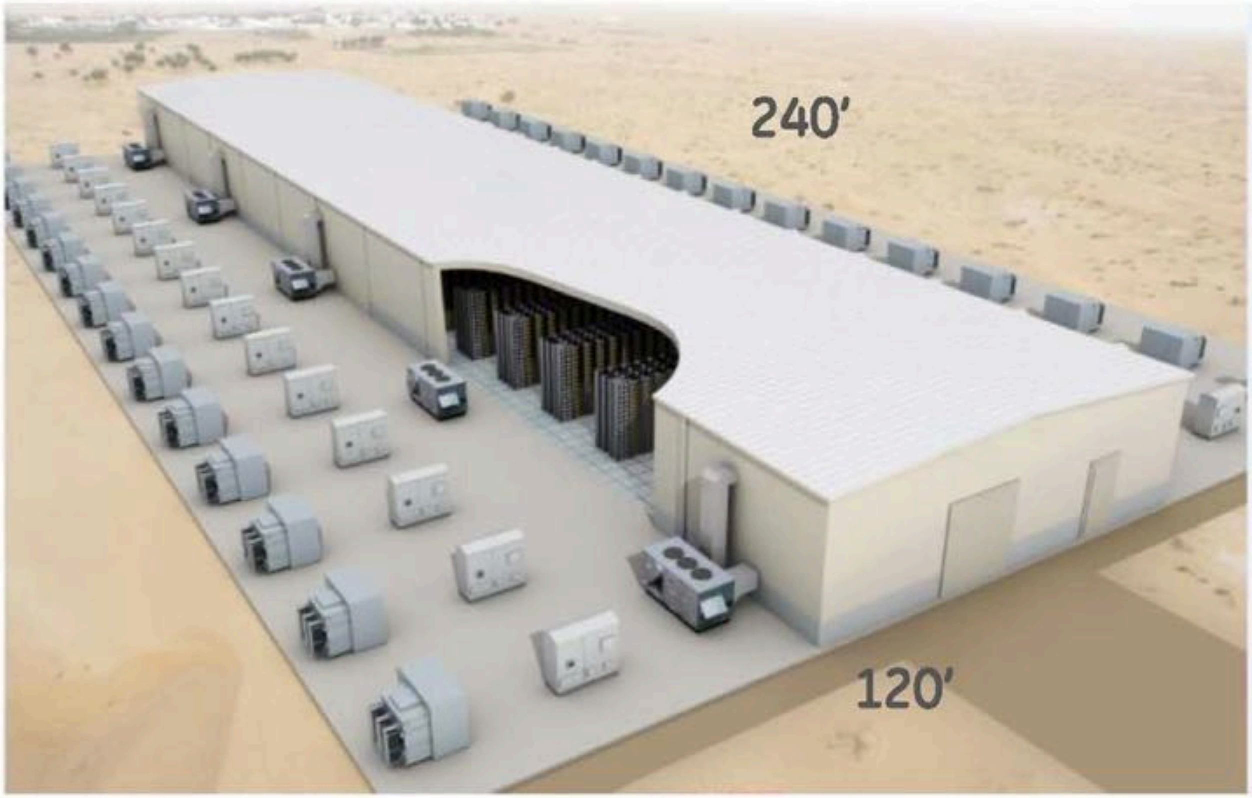
Civil And Building Works ★ Install and Connect Equipment ★ Commissioning ★

2Q2016: Start Equipment installation

Energize BESS

3Q2016: COD

30MW 20MWh BESS
Imperial Irrigation District-Ca



Imperial Irrigation District

Thank You !

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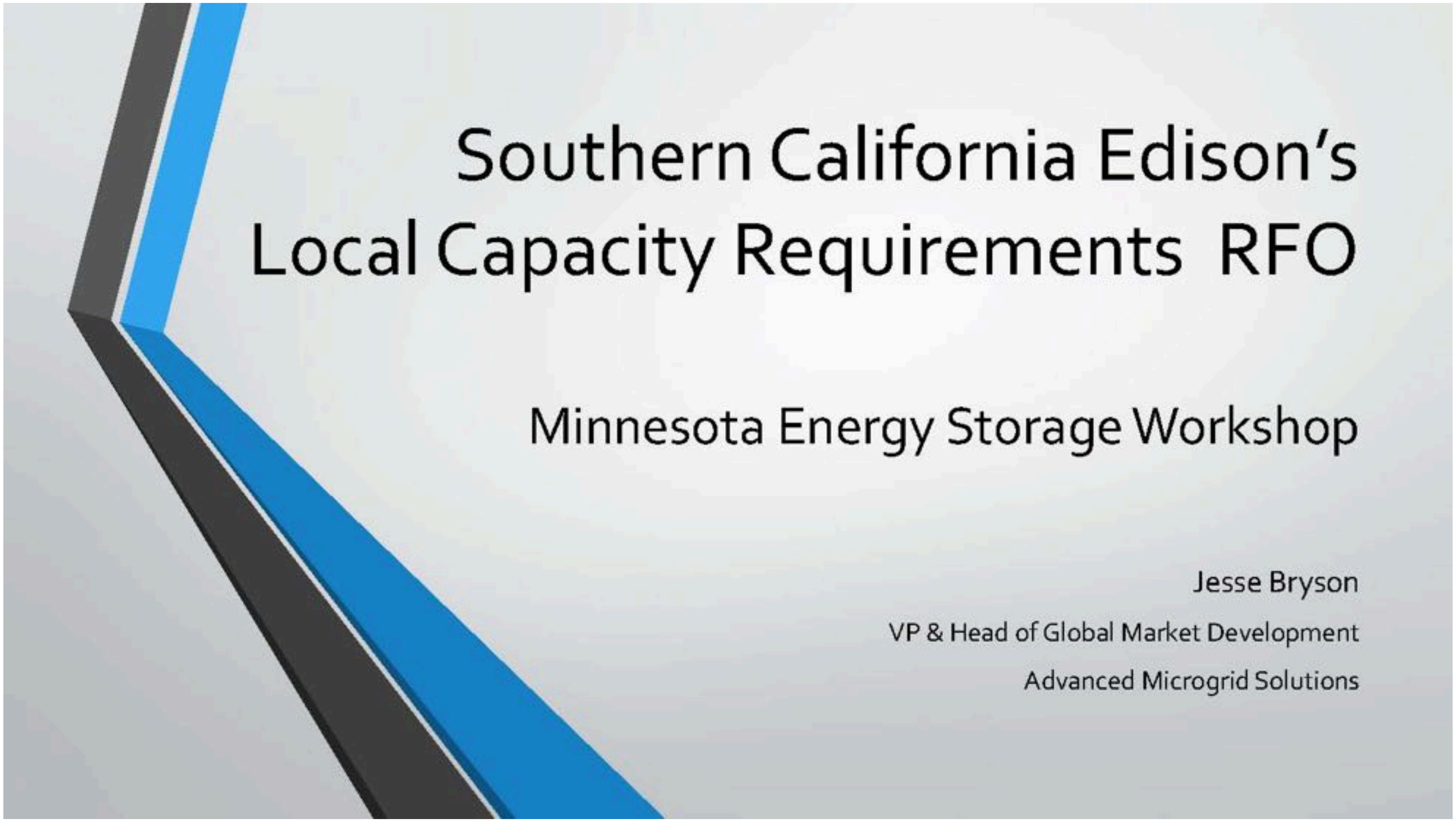


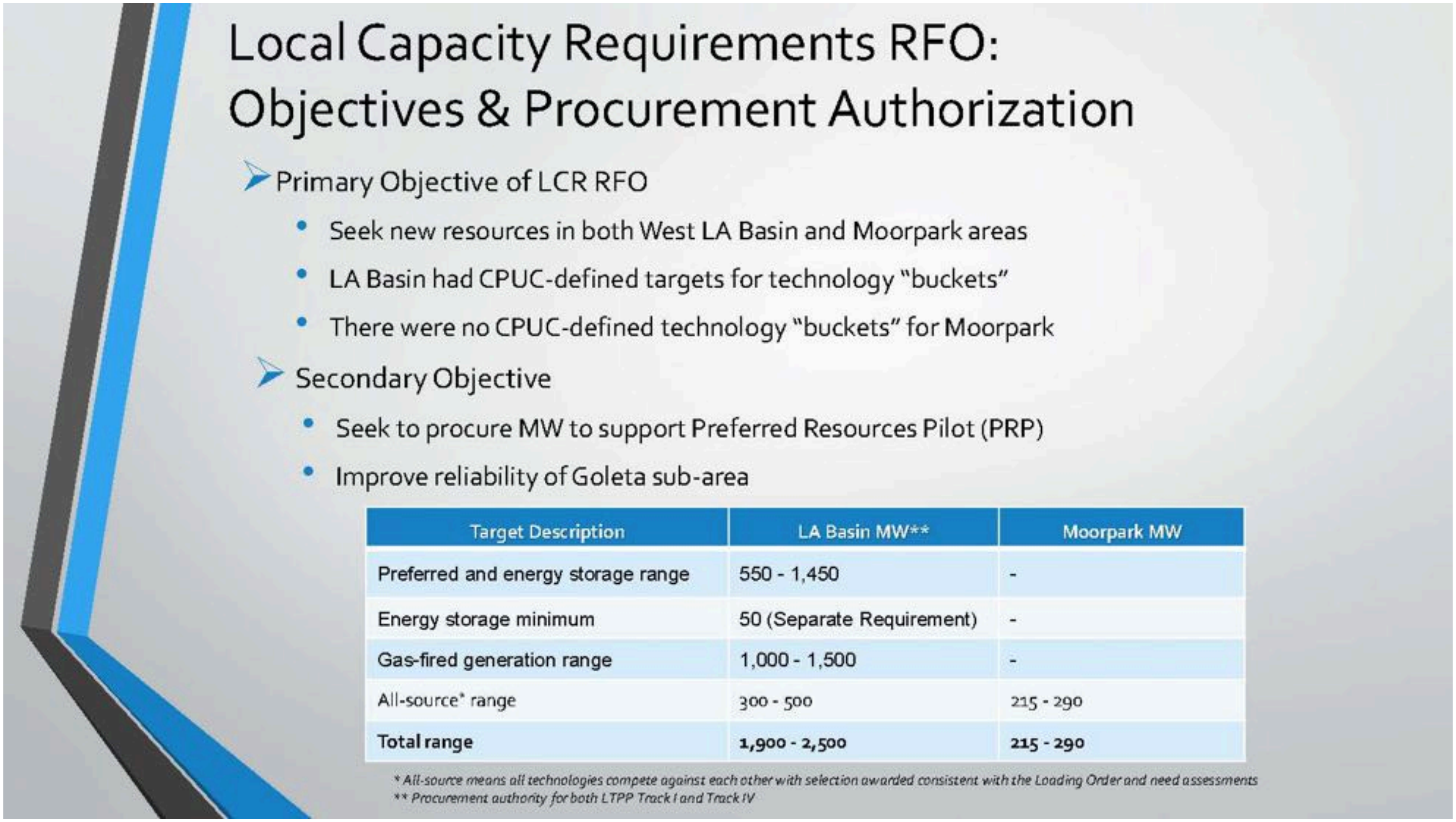
Southern California Edison's Local Capacity Requirements RFO

Minnesota Energy Storage Workshop

Jesse Bryson

VP & Head of Global Market Development

Advanced Microgrid Solutions



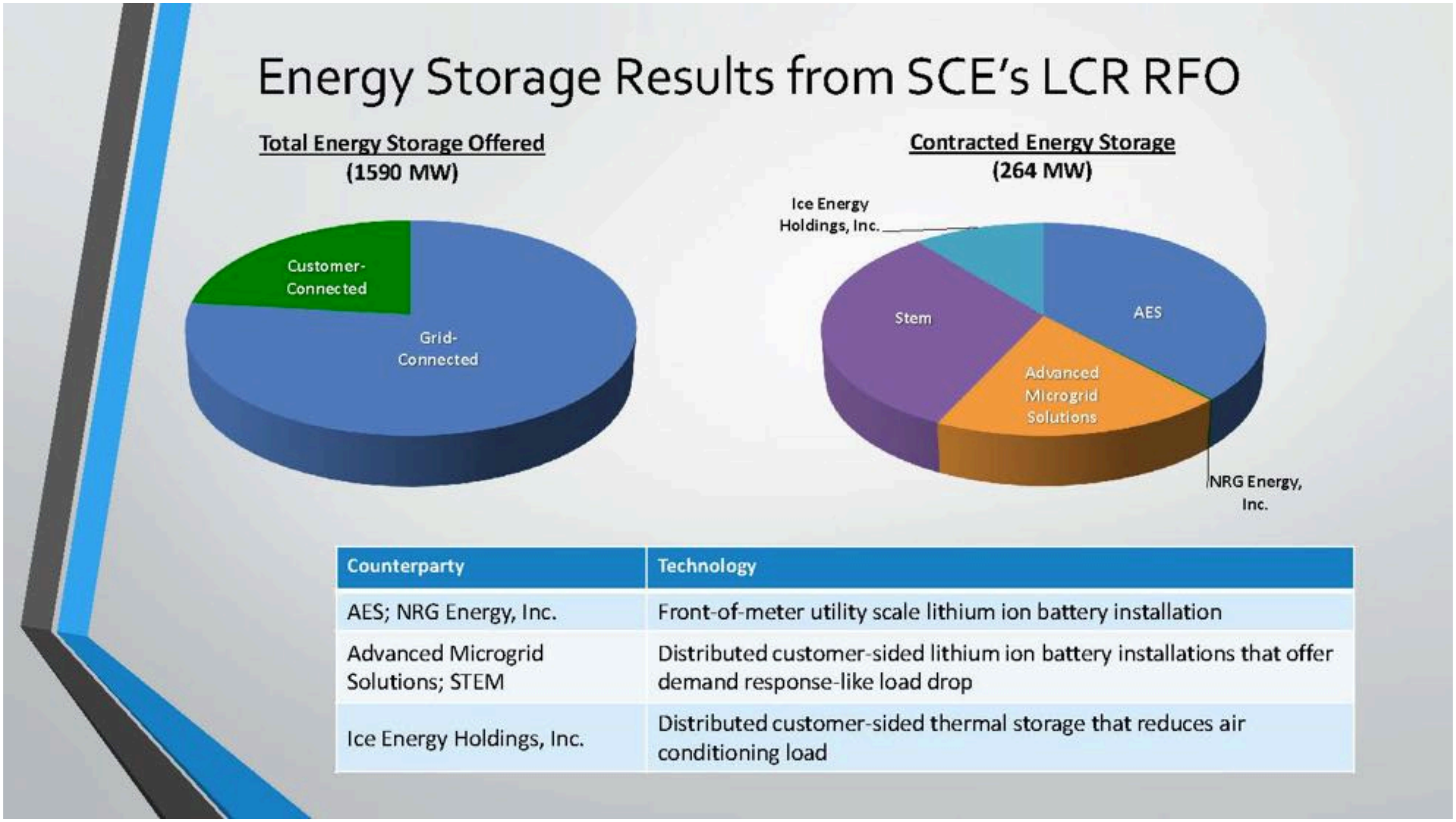
Local Capacity Requirements RFO: Objectives & Procurement Authorization

- Primary Objective of LCR RFO
  - Seek new resources in both West LA Basin and Moorpark areas
  - LA Basin had CPUC-defined targets for technology "buckets"
  - There were no CPUC-defined technology "buckets" for Moorpark
- Secondary Objective
  - Seek to procure MW to support Preferred Resources Pilot (PRP)
  - Improve reliability of Goleta sub-area

Target Description	LA Basin MW**	Moorpark MW
Preferred and energy storage range	550 - 1,450	-
Energy storage minimum	50 (Separate Requirement)	-
Gas-fired generation range	1,000 - 1,500	-
All-source* range	300 - 500	215 - 290
Total range	**1,900 - 2,500**	**215 - 290**

** All-source means all technologies compete against each other with selection awarded consistent with the Loading Order and need assessments*

*** Procurement authority for both LTPP Track I and Track IV*



Energy Storage Results from SCE's LCR RFO

Total Energy Storage Offered
(1590 MW)

Contracted Energy Storage
(264 MW)

Counterparty	Technology
AES; NRG Energy, Inc.	Front-of-meter utility scale lithium ion battery installation
Advanced Microgrid Solutions; STEM	Distributed customer-sided lithium ion battery installations that offer demand response-like load drop
Ice Energy Holdings, Inc.	Distributed customer-sided thermal storage that reduces air conditioning load

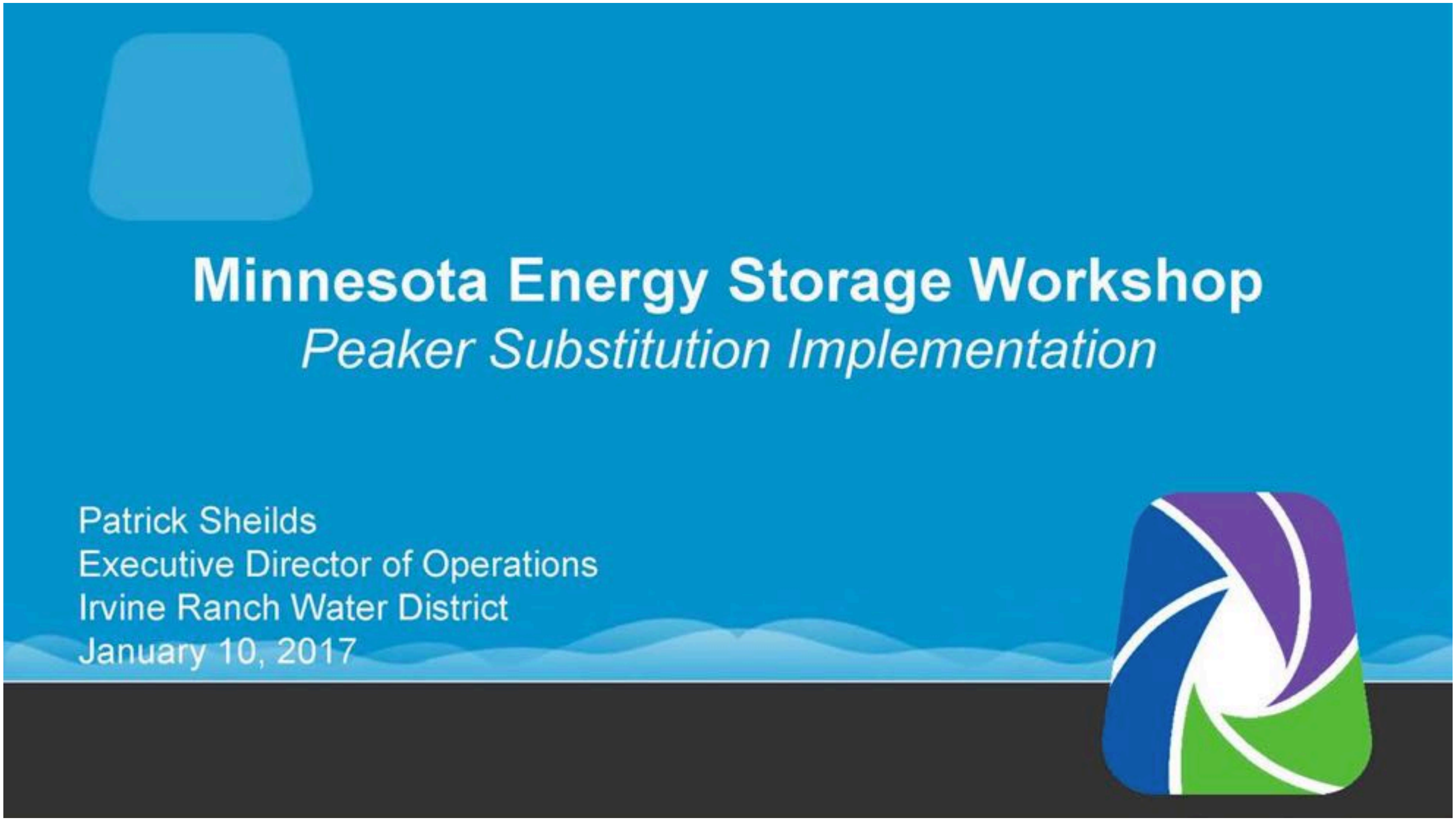
LCR Lessons Learned

Things that worked well

- Very robust market response
- Engagement of market participants
- Innovative products
- Although time consuming, flexibility to negotiate one-off contracts

Challenges

- Market rules were not known in many cases
- Uncertainty over interconnection process and potential charging constraints
- Uncertainty over charging rates
- Accounting concerns created challenges
- Effectiveness of locations on the grid changed



Minnesota Energy Storage Workshop

Peaker Substitution Implementation

Patrick Sheilds
Executive Director of Operations
Irvine Ranch Water District
January 10, 2017

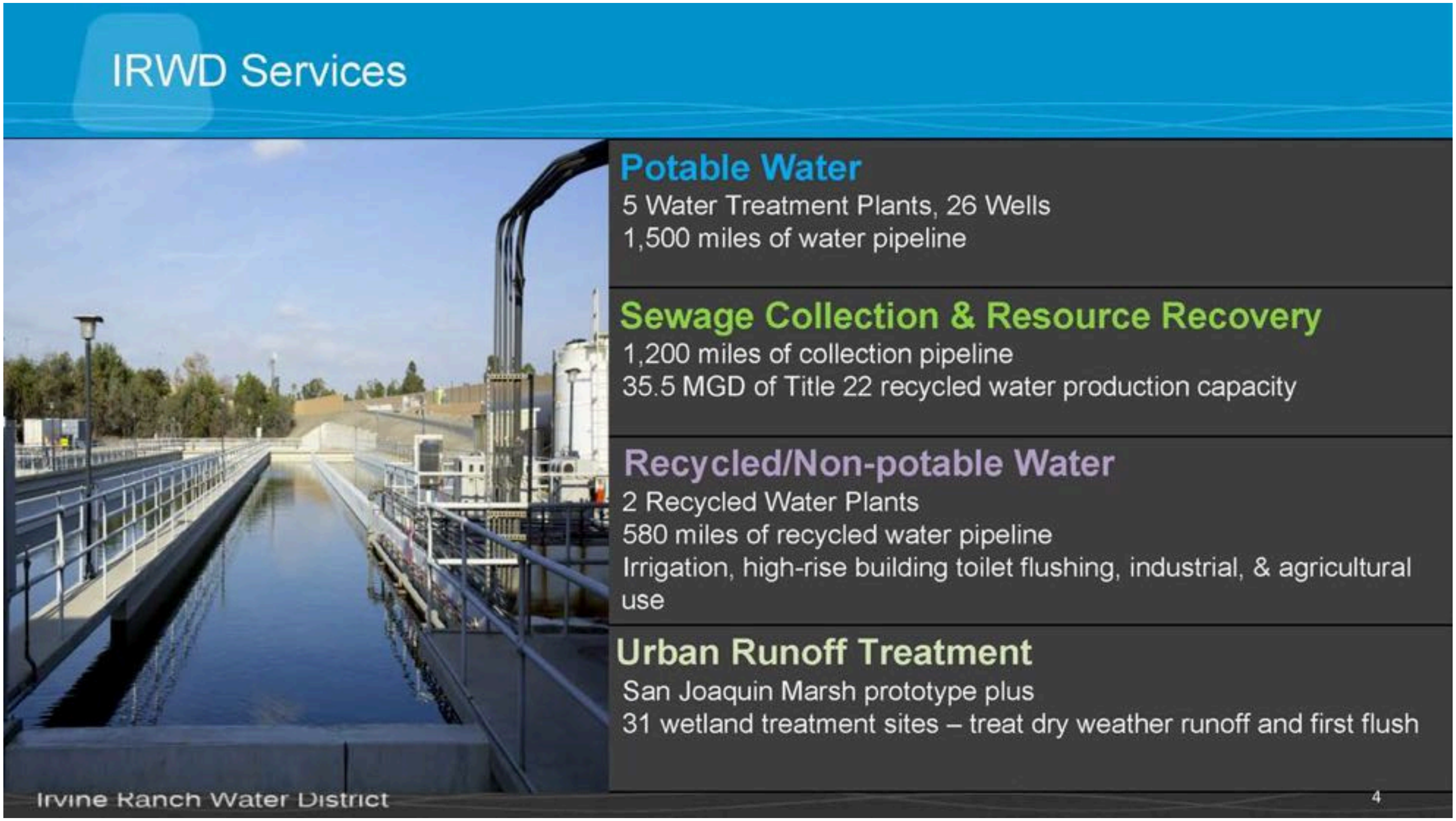
IRWD Service Area

390,000
Residential Customers

Over 500,000
District Daytime Population

181 Square Miles
20% of Orange County

6 Cities
Irvine, Tustin, Lake Forest, Orange, Newport Beach, Costa Mesa, & Unincorporated County



IRWD Services

Potable Water

5 Water Treatment Plants, 26 Wells
1,500 miles of water pipeline

Sewage Collection & Resource Recovery

1,200 miles of collection pipeline
35.5 MGD of Title 22 recycled water production capacity

Recycled/Non-potable Water

2 Recycled Water Plants
580 miles of recycled water pipeline
Irrigation, high-rise building toilet flushing, industrial, & agricultural use

Urban Runoff Treatment

San Joaquin Marsh prototype plus
31 wetland treatment sites – treat dry weather runoff and first flush

Board Adopted Strategic Planning Goal

- Goal (5.): ***"Improve electric service reliability, manage demands and control costs"***

- Target Activity (d.): ***"Pursue cost effective and proven energy storage programs through participation in Self Generation Incentive Program (SGIP)"***

Energy Management at IRWD

Steps taken:

1) Developed an Energy and Greenhouse Gas Master Plan
2) Demand response and optimization:
   - Minimizing peak time of pumping
   - Flow equalization
   - High energy efficiency equipment
   - Embedded energy pumping surcharges
3) Developed onsite generation:
   - Diesel and natural gas engines
   - Solar energy
   - Battery Storage

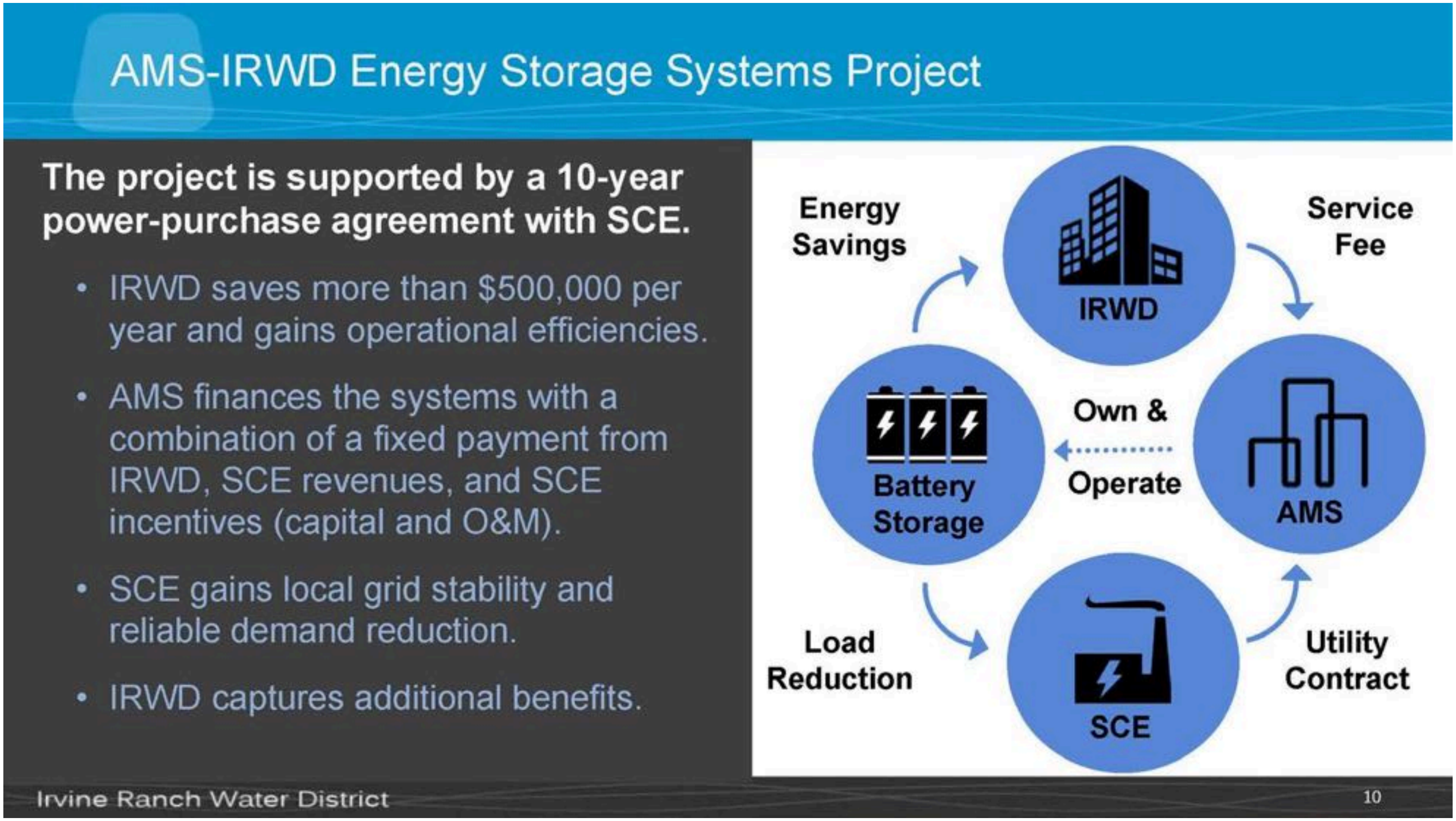
~12% of IRWD's Operating Budget is for energy expenses.

The Opportunity for Energy Storage at IRWD

- Local resources are needed to respond to the retirement of the San Onofre Nuclear Generation Station.
- Southern California Edison (SCE) has been authorized to procure more than 2,200 megawatts of new local resources, a component of which includes energy storage.
- IRWD facilities qualify as host sites due to:
  - Location
  - Energy consumption
  - Load profile

IRWD's Energy Storage Program Highlights

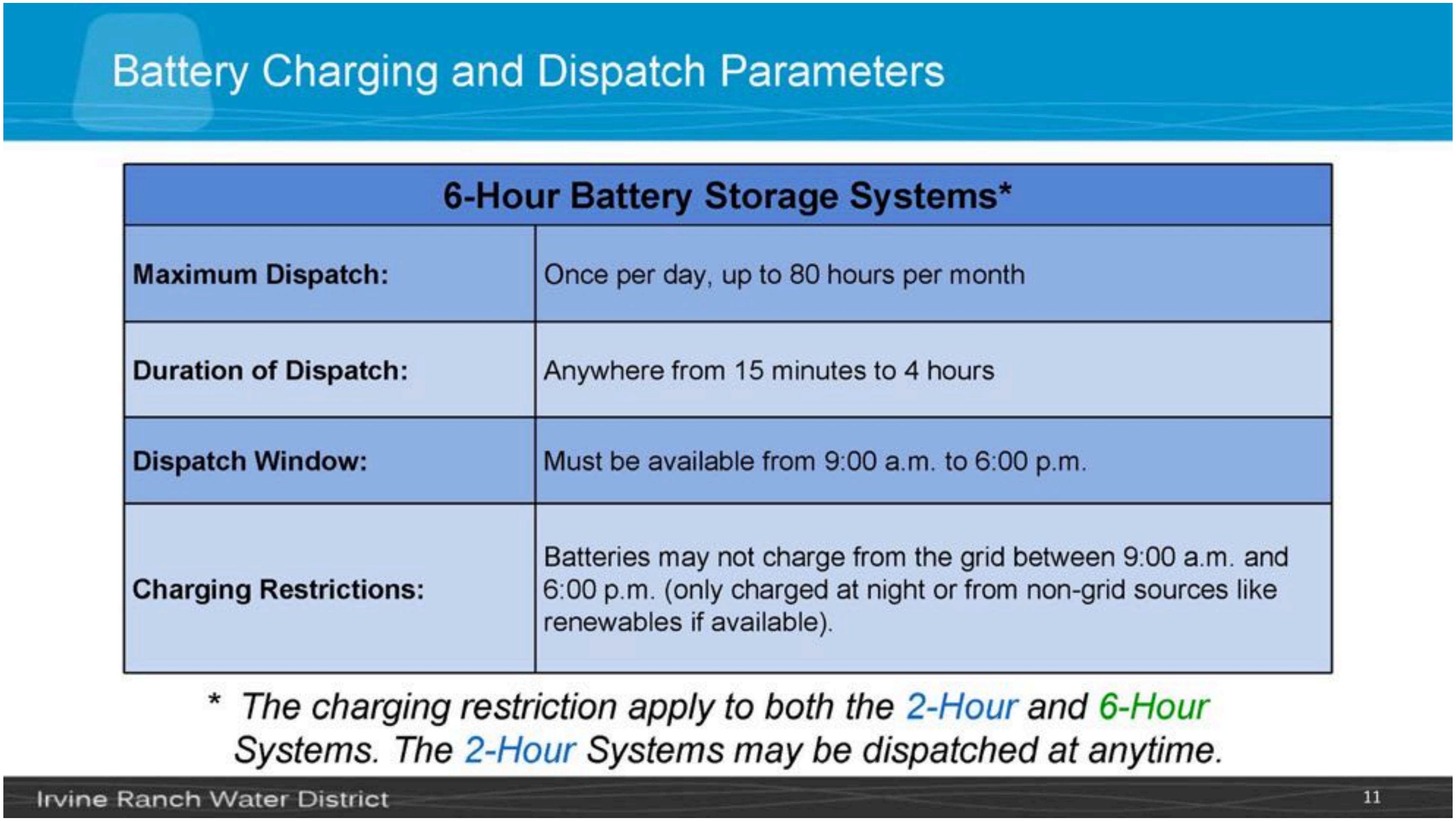
- IRWD partnered with developer Advanced Microgrid Solutions (AMS)
- 7 MW of battery storage to be installed at 11 IRWD sites
- Batteries will be charged from the grid during off-peak, lower-cost periods and be dispatched to IRWD facilities during on-peak, higher-cost periods
- 10-year power purchase agreement, co-terminus with AMS/SCE contract and Self-Generation Incentive Program (SGIP) Requirements
- SGIP grants awarded: $11.5M



AMS-IRWD Energy Storage Systems Project

The project is supported by a 10-year power-purchase agreement with SCE.

- IRWD saves more than $500,000 per year and gains operational efficiencies.
- AMS finances the systems with a combination of a fixed payment from IRWD, SCE revenues, and SCE incentives (capital and O&M).
- SCE gains local grid stability and reliable demand reduction.
- IRWD captures additional benefits.



Battery Charging and Dispatch Parameters

6-Hour Battery Storage Systems*	
Maximum Dispatch:	Once per day, up to 80 hours per month
Duration of Dispatch:	Anywhere from 15 minutes to 4 hours
Dispatch Window:	Must be available from 9:00 a.m. to 6:00 p.m.
Charging Restrictions:	Batteries may not charge from the grid between 9:00 a.m. and 6:00 p.m. (only charged at night or from non-grid sources like renewables if available).

* *The charging restriction apply to both the 2-Hour and 6-Hour Systems. The 2-Hour Systems may be dispatched at anytime.*

IRWD Contact Information

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20 Appendix L – Workshop Action Items

The following provides a complete list of potential action items generated from brainstorming sessions during Day 1 and Day 2 of the second workshop in January. During each session, workshop participants voted on priority items. Items in this list are listed in the order of votes received (highest voted items are listed first). Individual participants' additional comments are noted below each action item topic.

Day One Action Items

1. Host Technical Conference (21 total votes)

- Topics: 1. Grid Operations 2. Interconnection 3. Measurement & Verification 4. Utility Training.
- Challenges to utility
  - Economics
  - Technology
  - Ownership risks
  - Technological expertise (to allow for utility ownership)
  - Financing
- Get more granular information about loads and hosting capacity
- (Telemetry) Measurement and Verification requirements for storage
- WWSOD (what would system operators do?)
- Distribution level as well...
- Technical working group...

2. Direct All Source Procurement Including ESS (PUC): (20 total votes)

- Allowing all source procurement vs. Resource specific RFP "Manitoba?" -PUC
- Include storage in capacity procurements (all source-type RFPs) -PUC Driven
- Ensure the ability of storage resources to participate in capacity procurement proceedings
- Ensure that IRP/CON process adequately considers non-conventional generation alternatives – Utilities- -PUC
- "Request for Information" to see what storage projects bid at what price- (non binding) - Utilities w/PUC
- ACTION- all sources. RFP for energy and capacity, inel, all attributes, fes-price discovery. Who- PUC

3. Craft MISO ESS Rules and Products: (20 total votes)

- Third party ownership and aggregator of DR +DG
- Create more MISO market products
- Action – Establish market rules that compensate storage for full range of values. Who- MISO
- Policy certainty at MISO for battery and solar participation in ancillary services (qualification for providing regulation for battery and solar needs to be clear)
- Clarify who can aggregate customers for storage
- Third party aggregators (PUC)

4. Develop Utility Cost Recovery Treatment (PUC) (17 total votes)

- Action/- make clear how utility will make money on storage. Who- PUC
- Action/- Make clear how storage will be treated. RE: Cost Recovery. Who- PUC

5. (PUC) Direct MN ESS Deployment: Incl: Range of Use Cases, Price Discovery, MWs not KWs, Min 10 MW Grid Connected (15 total votes)

- Visible projects built and information and lessons learned shared (utilities) (Customers)
- Pilot of RE+ storage for critical infrastructure. WWT.
- Action: Identify opportunities to replace diesel gen sets booking of critical infrastructure where solar and storage could replace or supplement. Who: contract consultants
- E21 phase III. Storage demo focused on distribution solution.
- Need process for approving innovative "pilot" projects at PUC (PUC-Legislature-or Stakeholder process)
- Action- more pilots that demo range of "use costs" for MN and price discovery. Utilities and PUC = WHO
- Pilot to demonstrate cost/benefit with $ MISO market and distribution

6. Link MN System Needs to Storage (Utilities)(Needs Assessment)(PUC Directed): (12 total votes)

- Report with categorization of demonstrated Tx-level storage reliability solutions
    - Ideally with utility agreement
    - Could include an agreement on recommendation on cost/revenue tra__
- Tie ESS to grid modernization
- Understand state/IRP services/reliability benefits that aren't relevant to MISO, but have local read
- Mapping high value grid locations and initiatives WHO: PUC/Utilities

7. Innovate Rate (Retail) Design (11 total votes)

- Tariff options for customers willing to host energy storage
- Green tariffs... how would/does that effect energy storage
- What: advance meter infrastructure. Who: utilities.
- What: ensure rate design along with system peak. Who: PUC

8. Develop Community Storage + Solar Program (8 total votes)

- Sell a "community" storage program
- Community solar plus storage policy. Who: Leg and PUC

9. Apply ESS Modeling Tool: (5 total)

- U of M: Study interaction of DERs in the electric distribution system
- Examine modeling of emerging technology in resources planning – MCEA and clean energy groups

- Develop ability to account for storage technology in Strategist/EGEAS and other capacity product cost models

10. Conduct More Modeling: (4 total)

- Demonstrate synergy benefits solar + storage
- Mores sensitivities run in modeling
- Compare peaker scenario to DR

11. Examine MISO Interconnection Process. ESS and ESS+Solar: (4 total votes)

- MISO- do we need to reexamine resource requirements for RA? (e.g. 4-hours)
- Advocate for specific interconnection polices at MISO for battery and solar- dispatch 1 net out and capacity credit.

12. Focus on Needs of Coops: (4 total votes)

- Identify needs of different utilities to engage with grid modernization (DERs)
- Organize co-op-specific storage workshop to explore opportunities and examples (co-ops) (ETL/MESA)
- Ongoing discussion with coops and muni's about accessing wholesale market with storage

13. Create MN State of Charge Report (like MA)(Legislature) (4 total votes)

- State study like Mass

14. Direct PUC to Allow ESS as T&D Alternative (2 total votes)

- Rate base cost of battery storage procurement from IPP in place of transmission asset purchase. EG: Dakotas
    - Temporary read for OFG dev-move battery storage when not needed
- Incentivize storage investments in T&D locations for deferrals while allowing 3rd party merchant participation
    - IOU/MPUC policy/rulings
    - MISO tariff allowance
- Require utilities to issue RFP for T&D deferral investments using storage, DR or renewables (e.g. NYREV).
    - MN Legislation/MPUC

15. Measure and Value ESS GHG Benefits: what's on the margin, how storage affects GHG's (Developer action) (2 total votes)

- Value of avoided emissions ($/kw(h))? Include in IRP
- Action- value of storage (PUC-Driven). Detailed analysis to establish benefits quantitatively.

16. Clarify Wholesale Rate Design (2 total votes)

- Clarify retail vs wholesale early on treatment
    - Utilities/MISO/PUC

17. Explore Residential Applications (Education, Incentives/Rate Design) (1 total vote)

- Communicate bill impacts
- Are residential consumers ready? Education. Value prop.
- Emergency back up. Making a storage program worth it for residential consumer. Financial incentive.
- What: evaluation of storage with an incentive. Who: PUC

18. Develop Utility Value Proposition (1 total vote)

- Anchor utilities seated at all tables
- Close collaboration with utilities to evaluate & understand value proposition
    - Stakeholder CEO

19. Direct Fed to Clarify ITC Rules

- ITC clarity w/IRS for investors
    - Same site _____
    - Documentation
    - 75%

20. Create ESS IRP Carve Out

- Renewable/Storage carve out in IRP

21. Develop Model Contracts

- Develop model contract for distribution utilities to access wholesale market benefits with storage in Minnesota.

22. Incremental New Utility Business Model (PUC)

- New utility paradigm. Pay for performance vs. Today method. PUC

23. Target Micro Peak Applications/Grain Dryers

- Project Idea: DG solar/Wind + storage @ farm with grain drying operation

24. Integrate with Solar

- Project idea: add DG storage w/ aurora solar project

Day Two Action Items

1. Implement Legislator/Regulator Education (15 votes):
    - Handouts, Education Day at leg, Overnight Retreat at end of session; Business models; ConEd Price Info
    - Create 1 page info sheet on storage benefits for handling to legislators
    - Technical conference/meeting designed to highlight the benefits/use cases/values of energy storage for regulators and legislature. Objective: make them realize ES not a thing of the future
    - Legislative education day on storage highlighting analysis and stories from this meeting. Bring 1 pager

2. Engage Customers for Hosting: (8 votes):
    - Approach customers to host. Large Host Sites; Industrial (e.g. Distribution Centers. Land is cheaper); Value Proposition for Host (Retail/commercial locations don't want to lease land to storage, not cost effective. Bill Credit/Incentives); Educate MN Sustainable Growth Coalition (100% Renewable Energy Target)
    - Approaching customers to host projects (1 dot)

3. Engage Utility Distribution Engineers in Summit on ESS (IEEE, partners)(Especially IOUs) (8 votes)
    - Distribution planning engineers "summit"
    - Minnesota Power-Systems CONF- 53rd 11/7-9/2017 Sponsored by College of Continuing Education, U of M.
    - North Central Electric Association www.ncea-online.org Dale Janke
    - IOU's "leadership" are missing. TARGET THEIR PARTICIPATION
    - Educational/knowledge sharing utility-let gropu on storage.
    - Combine tech conference on storage (4 utility engineers and miso) with another conference. IE
        - Energy Storage Summit
        - Energy Design Conf

4. Develop ESS Joint Parties Proposal for Grid Mod Docket (Utilities, Big Co's, MN Sustainable Growth Coalition) (8 votes)
    - Lowcarbonusa.org
    - Grid mod outcome procurement targets
    - Ask storage project leaders to share confidential price information with commissioners (as Trade Secret)
    - Propose collaborative Grid Mod idea w/storage to PUC (all source procurement and deployment and utility cost recovery and rate payer buyin)

5. Reform Solar Gardens Program for Peak Time Option with ESS (7 votes)
    - Make community solar program opt. People time credits rate

6. Develop MN/MISO Roadmap to ESS Bankability (4 votes)

- One pager on financing storage
- How do we make BESS projects bankable in MN (one dot with RJ on it)
    - Outreach to investment/financial community

7. <u>Target Brownfield Opportunities for Solar & Storage</u> (4 votes)
    - Action: meet with head of cities. RE: workshops for their members on solar and storage.
    - Brownfield re-development
    - Action- meet US/MPCA commissioners to discuss solar or state-owned landfills
        - May require legislative change to 37.5 yr (constraint)

8. <u>Ask Organization of MISO States to Host </u>Conference (3 votes)
    - OMS role in hosting technical CONF

9. <u>Analyze Potential Existing Asset Optimization with ESS</u> (2 votes)
    - Analyze potential for existing asset optimization w ESS (GRE)
    - Draft case study on value of ESS to avoid lumpy costs
    - Joint solar + storage roadmap for co-ops and G&Ts (e.g. to address lumpy costs, future retirements, etc)

10. <u>Engage Municipalities (Resiliency, Siting, Critical Infrastructure)/First Responder Training</u> (1 vote)
    - Engage and fund GPI and CERTS to engage municipalities about solar gardens
    - Engage with municipal lenders re solar + storage siting and potential for facility critical power = waste water treatment
    - Implement NFPA First responder training (connexus)