414 Nicollet Mall
Minneapolis, Minnesota 55401

October 23, 2018 **—Via Electronic Filing—**

Daniel P. Wolf
Executive Secretary
Minnesota Public Utilities Commission
121 7th Place East, Suite 350
St. Paul, Minnesota 55101-2147

RE: 2020-2034 UPPER MIDWEST RESOURCE PLAN
OCTOBER 22, 2018 WORKSHOP MATERIALS
DOCKET NO. E002/RP-15-21

Dear Mr. Wolf:

Northern States Power Company, doing business as Xcel Energy, submits to the Minnesota Public Utilities Commission the materials presented at our October 22, 2018 workshop, Preliminary Results – Part 1. This workshop was the sixth in a series leading-up to our 2020-2034 Upper Midwest Integrated Resource Plan filing in 2019.

We have electronically filed this document with the Commission, and copies have been served on the parties on the attached service list. Please contact Amber Hedlund at 612-337-2268 or amber.r.hedlund@xcelenergy.com or Bria Shea at (612) 330-6064 or bria.e.shea@xcelenergy.com if you have any questions regarding this filing.

Sincerely,

/s/

BRIA SHEA
DIRECTOR, REGULATORY AND STRATEGIC ANALYSIS

Enclosures
cc: Service list

Xcel Energy's IRP Stakeholder Workshop 6:

Preliminary Results – Part 1

October 22, 2018

Agenda

1:00 – 1:30 pm	Xcel Energy and E3 Modeling Overview
1:30 – 3:00 pm	E3 Resolve & Recap Modeling – Preliminary Results
3:00 – 3:15 pm	Break
3:15 – 4:00 pm	Small Group Exercise
4:00 pm	ADJOURN

IRP Workshop 6

E3 and Xcel Energy Modeling Overview

October 22, 2018

Petition to Extend Filing Date:

- Xcel Energy filed a request with the MPUC to extend the filing date for our IRP from February 1 to July 1.
- Comment period closes November 19, 2018.
- Extending the filing date will provide additional time for ongoing efforts including:
  - Further opportunity to incorporate stakeholder feedback on the resource plan modeling analysis being conducted by E3 and Xcel Energy.
  - Further analysis or modeling of addition mitigation scenarios to meet statewide GHG goals.
  - Additional opportunity for workshops in the coming months.
  - A study overseen by Center for Energy and the Environment (CEE) which will analyze the economic impacts of our baseload generators on the host communities.
  - A statewide DSM Potential Study conducted by CEE, Optimal Energy Seventhwave.

Preliminary Extended Timeline

Timeline	Activity
November/December	Workshop and individual stakeholder meetings Possible Topic: Panel Discussion of Stakeholder Questions
January	Workshop and individual stakeholder meetings Possible Workshop hosted by CEE on Host Community Study
February	Workshop and individual stakeholder meetings Possible Topic: Near-Final Results from E3
March	Workshop and individual stakeholder meetings Possible Topic: Near-Final Strategist Results – Updated results for all scenarios
April	Prepare Filing Individual Stakeholder meetings
May	Prepare Filing Individual Stakeholder meetings
June	Prepare Filing Individual Stakeholder meetings
July	FILE

Modeling Efforts Underway

- E3 Resolve Modeling (Preliminary Results Today)
- E3 Recap Modeling (Preliminary Results Today)
- E3 Pathways Modeling (Updated Results Tomorrow)
- Xcel Energy Strategist Modeling (Preliminary Base Case Results Tomorrow)

E3 Modeling

- Xcel Energy engaged E3 to provide analysis to inform the Company's IRP.
- E3 is undertaking three distinct workstreams:
  - Decarbonization (Pathways) Study,
  - Portfolio (Resolve) Analysis,
  - Resource Adequacy (Recap) Analysis.
- The analysis underway by E3 will:
  - Provide context for the role of the electricity sector in reducing statewide carbon emissions (Pathways),
  - Analyze the impact of deep decarbonization scenarios on Xcel Energy's Upper Midwest System (Resolve and Recap),
  - Provide independent modeling and analysis to inform Xcel Energy's modeling efforts.

Pathways Impact on IRP

- The Pathways study develops economy-wide energy and GHG scenarios statewide through 2050.
- Not a least-cost optimization model; allows for exploration of scenarios to achieve 80% reduction in GHGs by 2050.
- Pathways provides context for the role of the electricity sector in reducing statewide carbon emissions.
  - Includes assumptions on the decarbonization of the electricity sector and the impact of electrification
  - Provides high-level sector by sector analysis to achieve the statewide goal of 80% reduction in GHGs by 2050
  - The high electrification scenario can by used to inform a high load scenario in the Company’s Strategist modeling

Pathways vs. RESOVE/Strategist

Pathways

- Analysis of economy-wide GHG emissions for Minnesota
- Focus on impacts through 2050
- Does not include cost impacts
- Not an optimization
- Not a policy prescription

RESOLVE/Strategist

- Analysis of Xcel Energy's Upper Midwest System
- Focus on impacts in IRP planning period (2020-2034)
- Cost optimization subject to constraints

RESOLVE Impact on IRP

- The RESOLVE model analyzes impacts of deep decarbonization scenarios on Xcel Energy's Upper Midwest System.
- Like Strategist, Resolve is a capacity expansion model that optimizes capacity expansion with constraints for reliability, GHG emissions, or renewable energy requirements.
- The preliminary analysis relies the data available when the model was built this past summer.

RESOLVE Impact on IRP (continued)

- The RESOLVE model will be updated prior to performing final runs, including:
  - Most recent load forecast
  - Updated cost and operating characteristics of existing units
  - Most recent fuel forecasts
  - Updates based on stakeholder feedback

- The RESOLVE model can by used to verify the Strategist modeling and provide additional insights into the impacts of deep carbonization on Xcel Energy’s System.

RESOLVE vs. Strategist – Model Comparison

RESOLVE	Strategist
• Performs optimal dispatch over a representative set of operating days in each year.	• Performs optimal dispatch based on a representative week for each month.
• Uses a chronological hourly dispatch	• Uses a load duration curve.
• Investment decisions are made in five year intervals between 2020 and 2040.	• Simulates dispatch and allows for resource investments in each year of planning period and beyond.

Methodology Comparison

RESOLVE

- RECAP informs capacity credit for renewables.
- Optimized to meet GHG or Clean Energy Standard targets.
- Chronological Hourly Dispatch captures ramping impacts.
- Market Interaction modeled through dispatch of MISO Zones 1, 2, and 3.

Strategist

- Relies on current MISO construct for capacity credit for new renewables (wind ~15%, solar 50%, DR & 4-Hour storage 100%)
- Cost optimized by including the cost of emissions.
- Integration costs are developed outside of Strategist.
- Market Interaction modeled based on forecasted market prices.

RECAP Model

- The RECAP model evaluates the resource adequacy of a high renewable system.
- Used to check the reliability of a RESOLVE portfolio.
- Can be used to calculate the Effective Load Carrying Capability (ELCC) of wind, solar, storage and DR.

Strategist Impact on IRP

- The Company's Strategist modeling will be the primary modeling tool, along with other considerations, used to support the size, type, and timing of resource additions and retirements during the planning period.
- Base assumptions for load, EE, DG, DR, fuel costs, characteristics of existing units and costs of new resources will be consistent across the Strategist and RESOLVE models.
- The RESOLVE modeling provides a different analytical framework to evaluate deep decarbonization scenarios.

What if the models conflict?

- We do *not* expect that different models will produce outputs that will perfectly match.
- We do expect the models to support the same general conclusions (i.e. that the preferred plan is a reasonable and prudent approach to meeting Xcel Energy's needs over the planning period.)
- If the models conflict, the Company will work with E3 to understand the different outcomes and make adjustments as necessary.

Energy+Environmental Economics

Xcel Energy Upper Midwest Portfolio Optimization Study

Stakeholder Workshop

Draft Results

October 22, 2018

Arne Olson, Sr. Partner
Nick Schlag, Director
Gerrit De Moor, Consultant
Femi Sawyerr, Sr. Associate
Vivian Li, Sr. Associate
Charlie Duff, Associate

Agenda

- Study Introduction
- RESOLVE Model Overview
- Reference Case Analysis
- Low Carbon Portfolio Analysis
- Zero Carbon Portfolio Analysis
- Preliminary Learnings

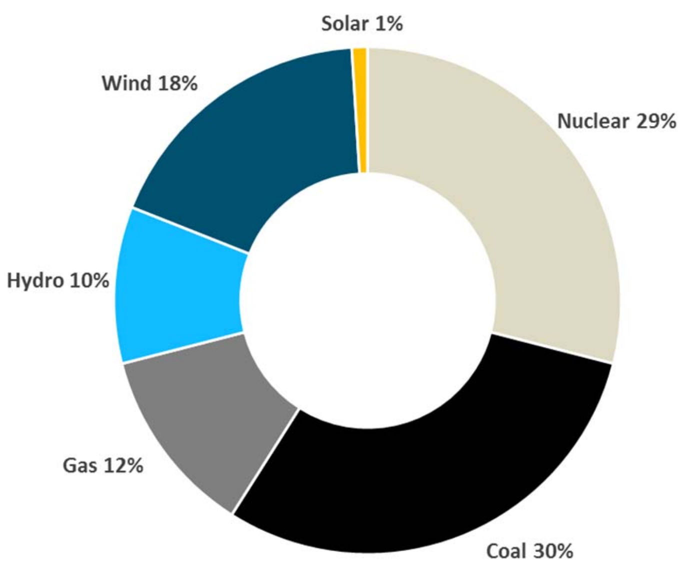
Energy+Environmental Economics

STUDY BACKGROUND

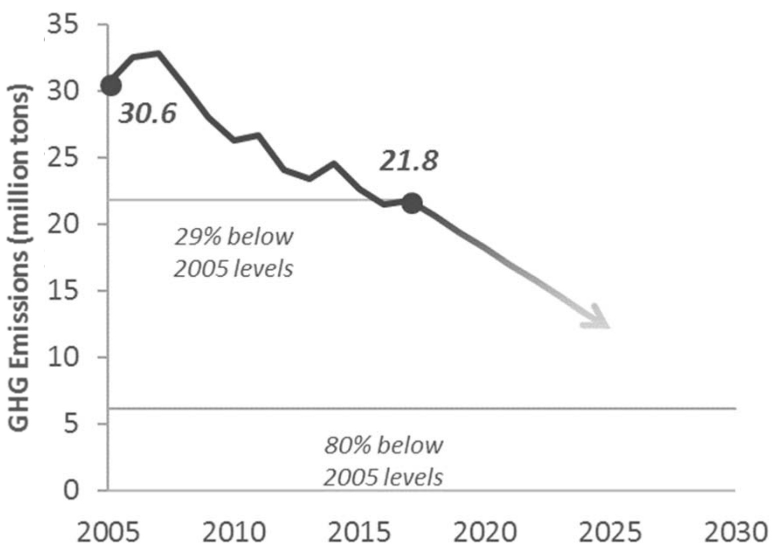
About This Study

+ In its Vision Plan, Xcel Energy has committed to reducing the GHG emissions from their electric generating fleet
+ Minnesota has set targets to reduce statewide GHG emissions for 2015, 2025, and 2050
+ Xcel Energy retained E3 to conduct independent, parallel analysis to inform its future resource strategy and Vision Plan through analysis of emissions reductions in the state of Minnesota and in the Xcel portfolio

Xcel Energy 2017 Energy Supply

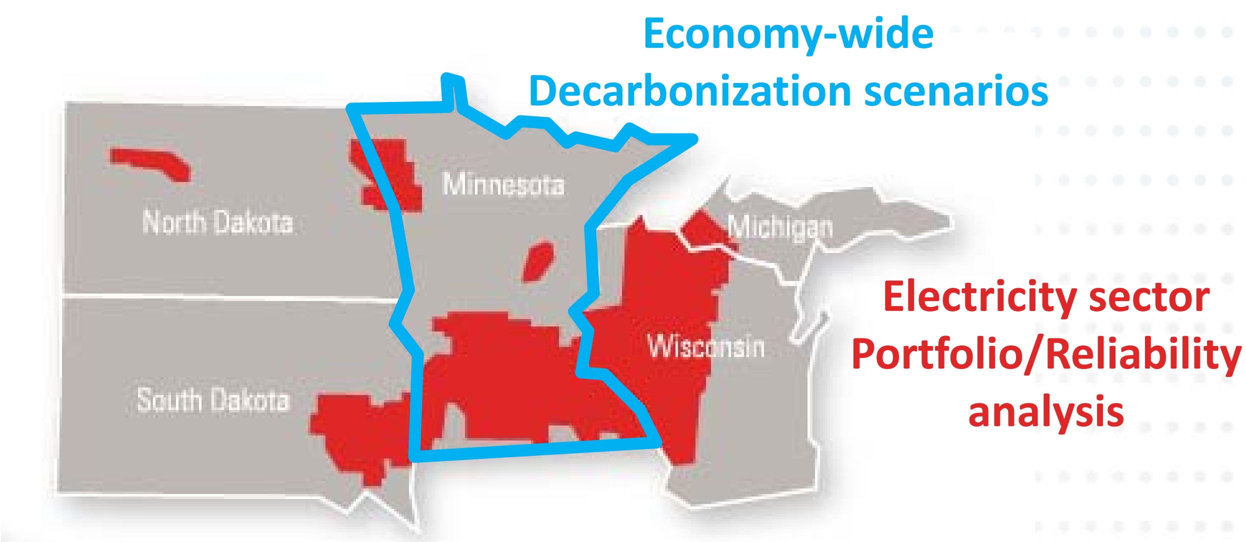


Xcel Energy Historical Emissions

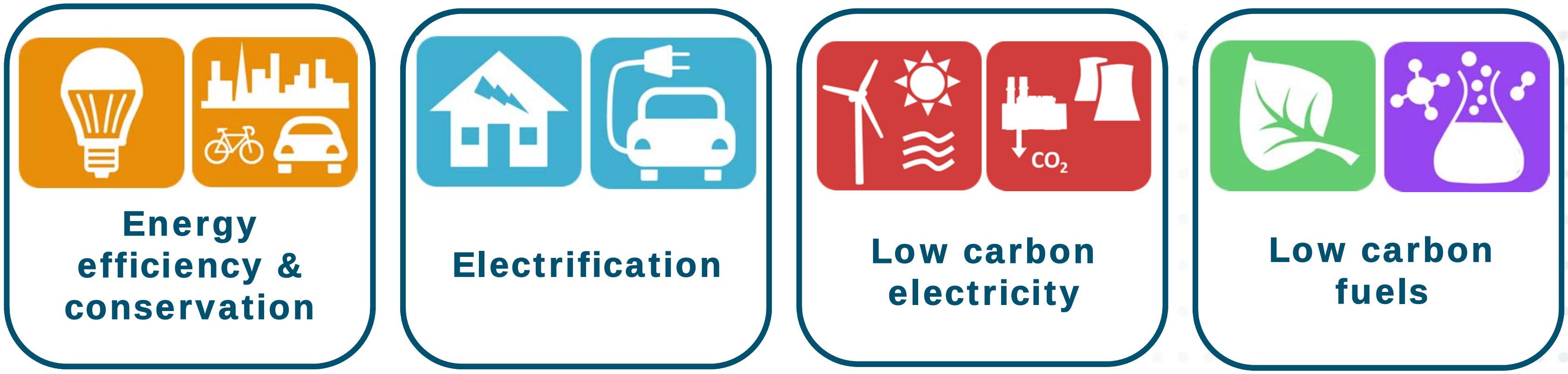


Xcel Energy IRP Support
Analysis Footprint

- **Minnesota decarbonization analysis is statewide and economy-wide**
- **Xcel electricity portfolio and reliability analysis models the electricity sector only, across the footprint of the Xcel Energy Upper Midwest region**
  - Same footprint as Xcel IRP; includes loads in MI, MN, ND, SD, WI



Four "Pillars" of Decarbonization to Meet Long-Term Goals

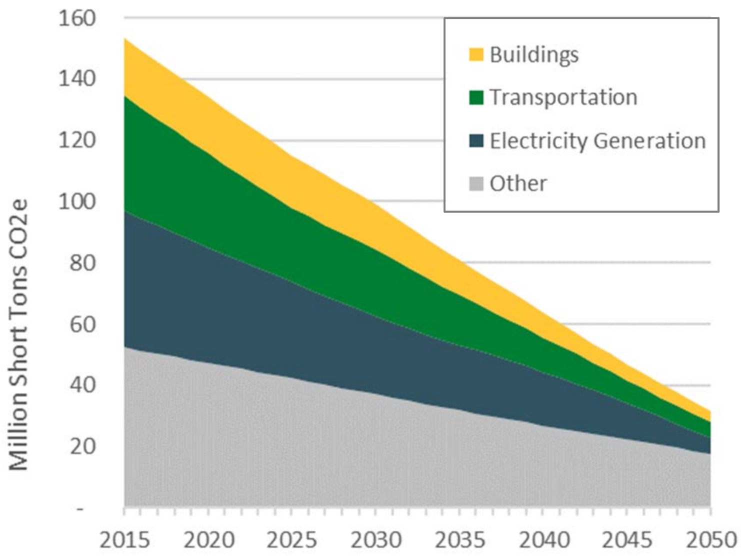


- **Four foundational elements are consistently identified in studies of strategies to meet deep decarbonization goals**
- **Across most decarbonization studies, electric sector plays a central role in meeting goals**
  - Through direct carbon reductions
  - Through electrification of loads to reduce emissions in other sectors

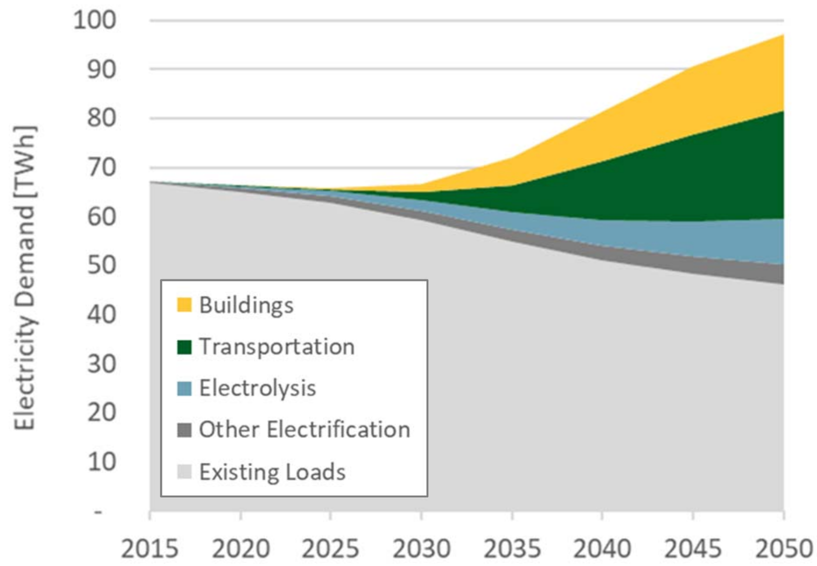
Minnesota PATHWAYS Key Results & Conclusions

- **Aggressive action is needed across all sectors to meet a statewide goal of 80% reduction below 2005 levels**
  - Reaching 80% GHG reductions by 2050 is challenging and not a given
- **Increased reliance on low-carbon electricity is needed to meet goals and enables emission reductions in other sectors**
- **Transportation and building electrification drive electric load growth, especially after 2025, particularly in a future with less biofuels**

Minnesota GHG Emissions

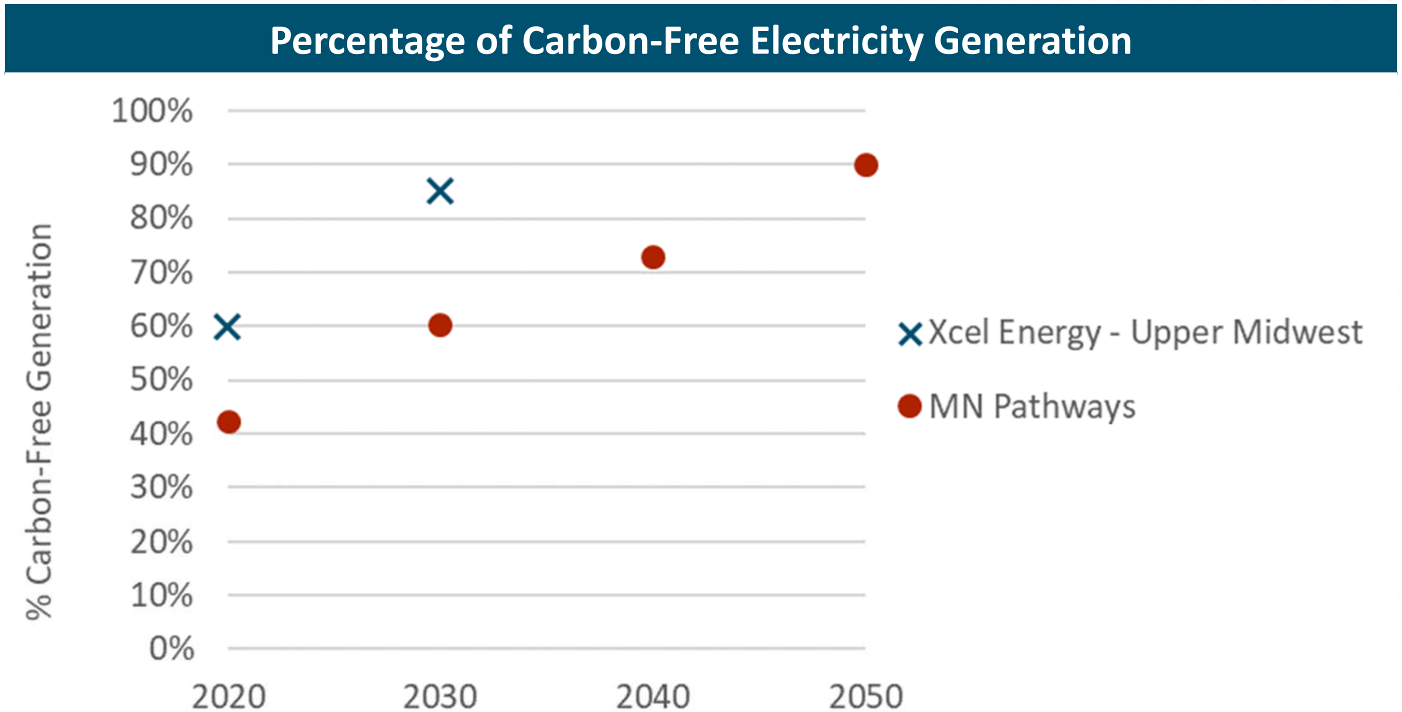


Minnesota Electricity Demand



How do Xcel Energy's commitments compare to MN electricity decarbonization scenarios?

+ **Xcel Energy has a lower-carbon generation mix than the state as a whole today, and lower carbon electricity commitments than the Minnesota Pathways mitigation scenarios assume**



Three Key Study Questions

1. **What does the Xcel Energy portfolio look like under a "Reference Case"?**
2. **How can Xcel further reduce emissions from this point, and at what cost?**
   - Measures considered include: renewables portfolio standard (RPS), clean energy standard (CES), greenhouse gas cap, early coal shutdown, prohibition on new natural gas
3. **What would it take to fully decarbonize the Xcel system using only carbon-free resources**
   - Includes nuclear, wind, hydro, solar, storage

\+ **Results presented today are DRAFT, as assumptions are not yet fully aligned with current Xcel IRP assumptions**

RESOLVE MODELING OVERVIEW

Defining the New Planning Problem

+ **Introduction of variable renewables has shifted the capacity planning paradigm**

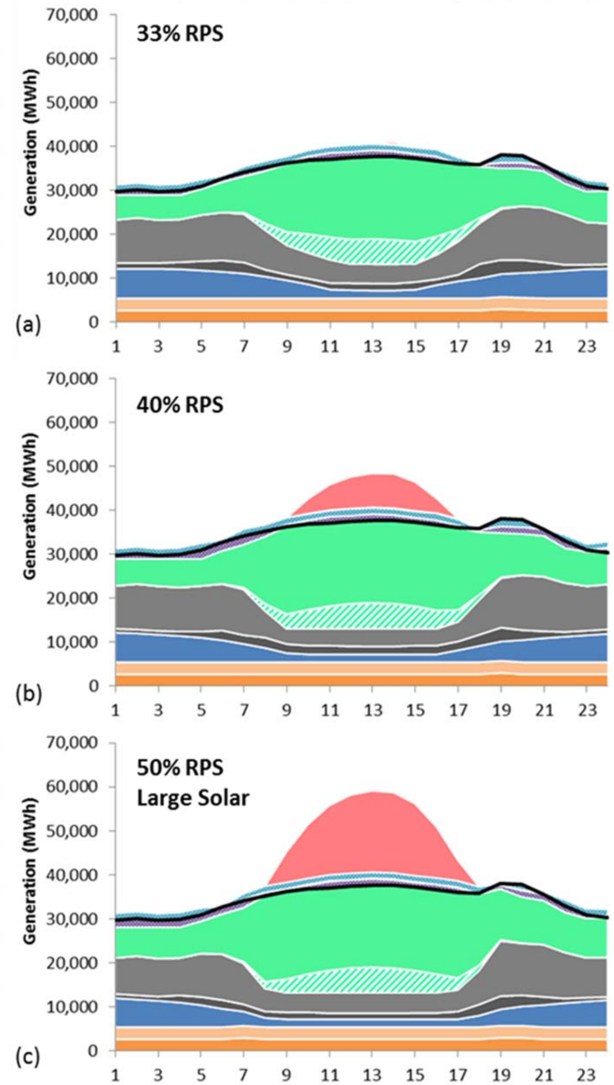
+ **The new planning problem consists of two related questions:**

  1. How many MW of <u>dispatchable</u> resources are needed to (a) meet load, and (b) meet flexibility requirements on various time scales?

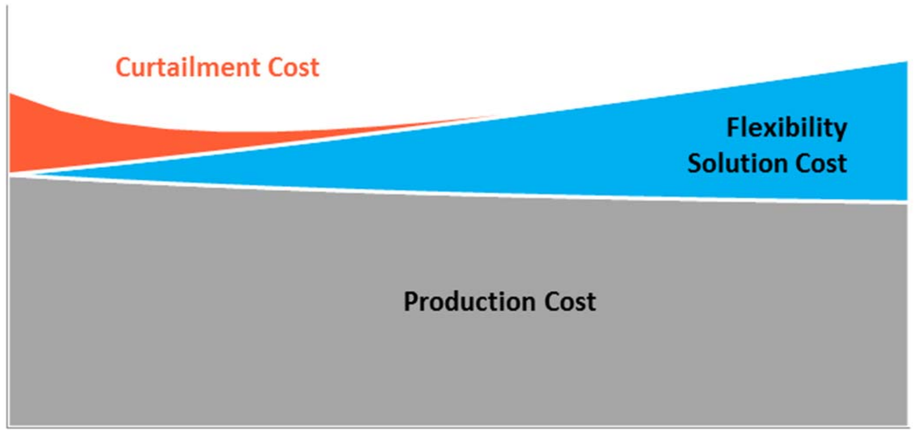
  2. What is the optimal mix of new resources, given the characteristics of the existing fleet of conventional and renewable resources?

The Renewable Integration Challenge

- **Primary drivers of renewable integration challenges at high penetrations:**
  - Renewable oversupply during low load periods
  - Inflexible conventional generation
    - Must-run resources
    - Technical constraints on ramping, minimum stable levels, minimum up and down times
    - High costs associated with cycling
  - Small balancing areas or constrained interactions with neighboring regions
- **Research has shifted to focus on grid integration solutions**



Flexibility Planning Balances Costs of Renewables and Integration Solutions

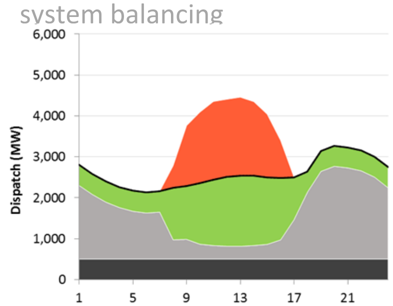


All three systems can be operated reliably but differ on cost

System Flexibility

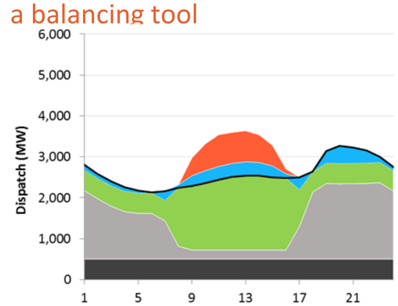
Highly Inflexible System

- No investments made in flexibility solutions
- Curtailment is frequent and occurs in large quantities, is needed for system balancing



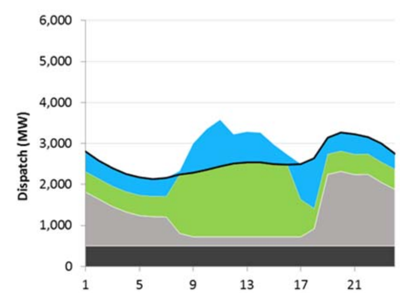
Optimal System

- Some investments made in flexibility solutions to limit curtailment
- Curtailment still occurs routinely as a balancing tool



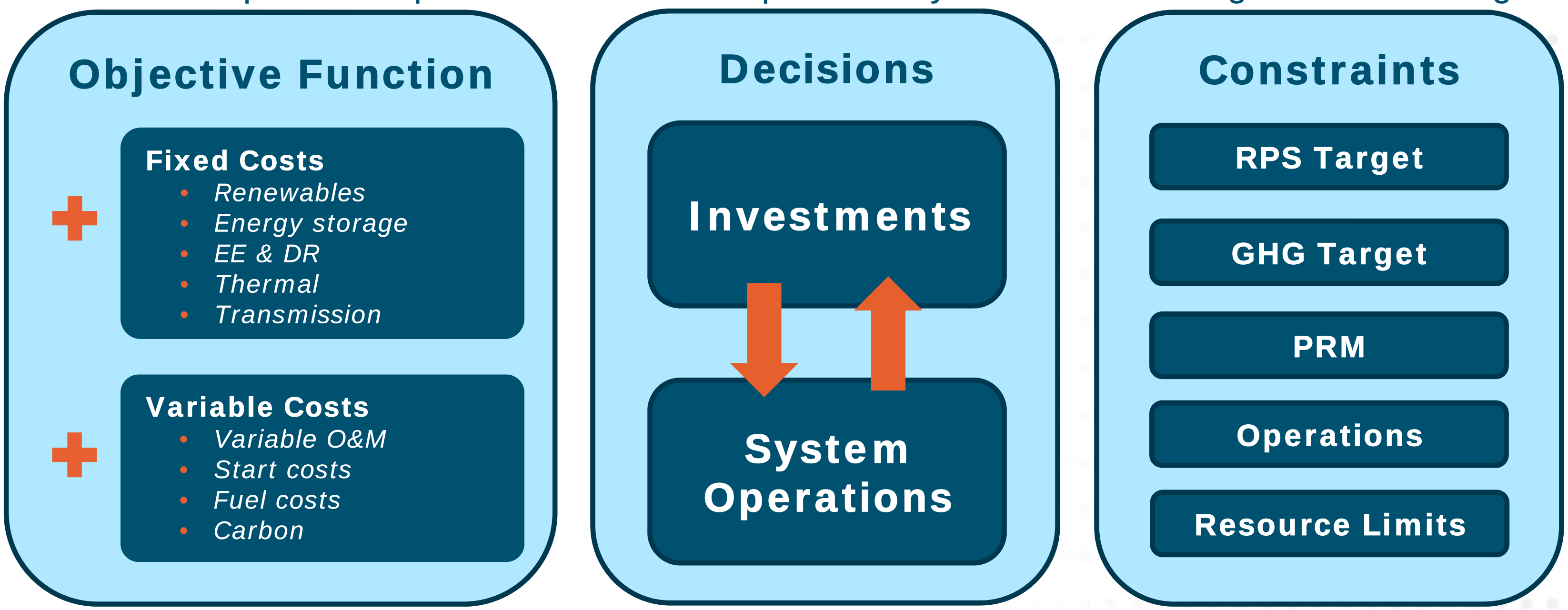
Highly Flexible System

- Significant investments made in flexibility solutions
- Curtailment does not occur due to large amounts of flexibility



Investment and Operational Decisions in RESOLVE

+ **RESOLVE co-optimizes investments and operations to minimize total NPV of electric system cost**
  - Investments and operations optimized in a single stage to capture tradeoffs between fixed & variable costs
  - Simplified dispatch simulation captures key renewable integration challenges



+ **RESOLVE is supplemented with analysis using RECAP, a detailed loss-of-load-probability model**

Key Differences Between Strategist & RESOLVE

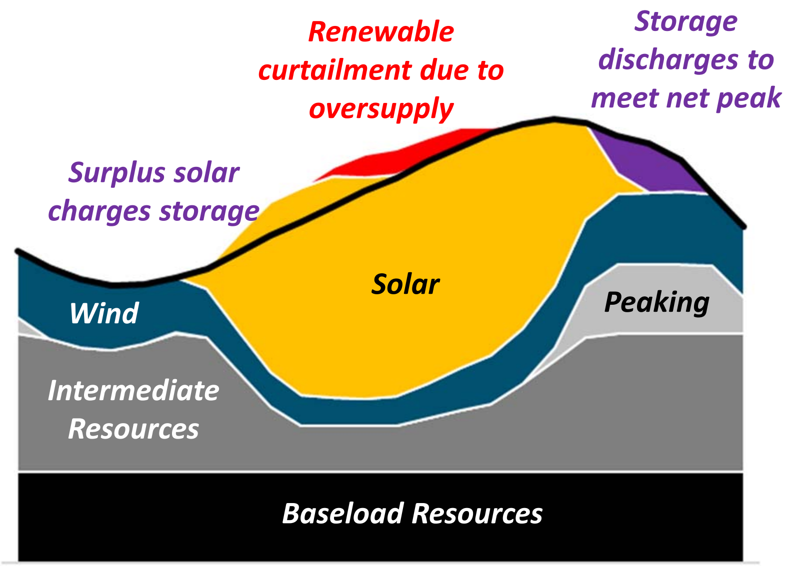
- RESOLVE & Strategist belong to the same family of models, but have important differences in how investments are evaluated

Input	Strategist	RESOLVE
System Operations	Load duration curve heuristic	Chronological hourly dispatch with simplified unit commitment
Day Sampling	Representative weeks for each month	Smart sample of ~40 representative days
Market Interactions	Purchases & sales determined based on exogenous wholesale price forecast	Market interactions simulated endogenously with representation of external loads & resources
Resource Adequacy	Planning reserve margin with deemed credits for each resource	Planning reserve margin with dynamically updating ELCC values for renewables

Hourly Dispatch Simulated in RESOLVE

- To capture renewable integration effects at increasing penetration, RESOLVE simulates hourly dispatch of the electric system
- Linearized unit commitment model captures key characteristics of system flexibility
- Increasing renewable penetration and resulting operational challenges drive need for investment in new flexible resources

RESOLVE Representative Day

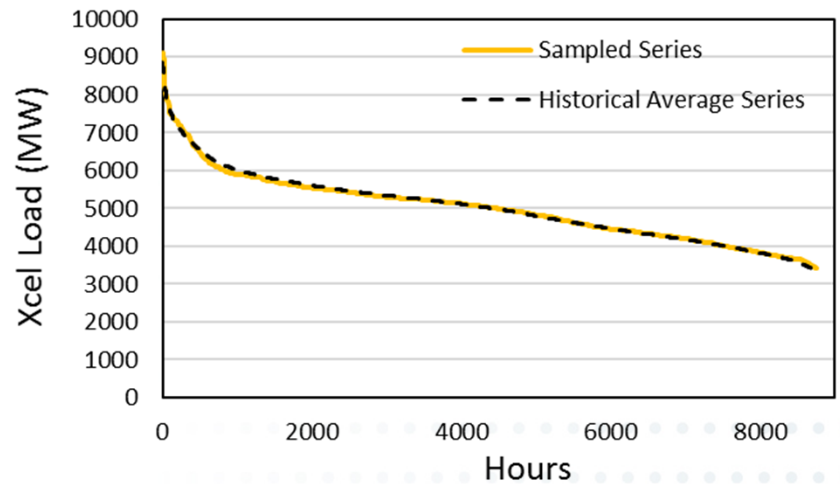


- **Key constraints on dispatch:**
  - Load & renewable hourly profiles
  - Hourly reserve requirements
  - Thermal unit Pmin & Pmax
  - Thermal unit min up & down time
  - Storage duration capacity

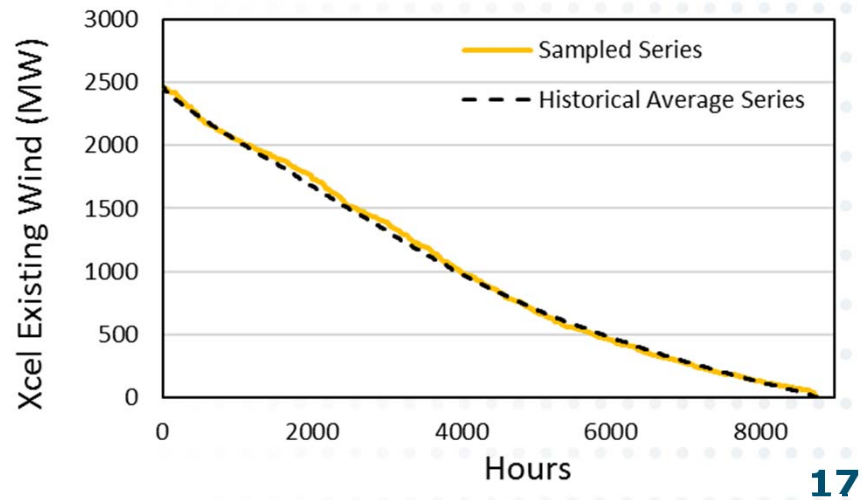
Smart Sampling of Days Captures Full Range of Operating Conditions

- **RESOLVE simulates dispatch across a sample of ~40 days in each year**
  - Weighted sample of days represents a full calendar year
- **Dispatch days selected through optimization to match full range of conditions experienced on the system**
  - Hourly load, wind, and solar
  - Number of days per month
  - Nuclear maintenance schedules

Hourly Load: Historical vs. Sampled



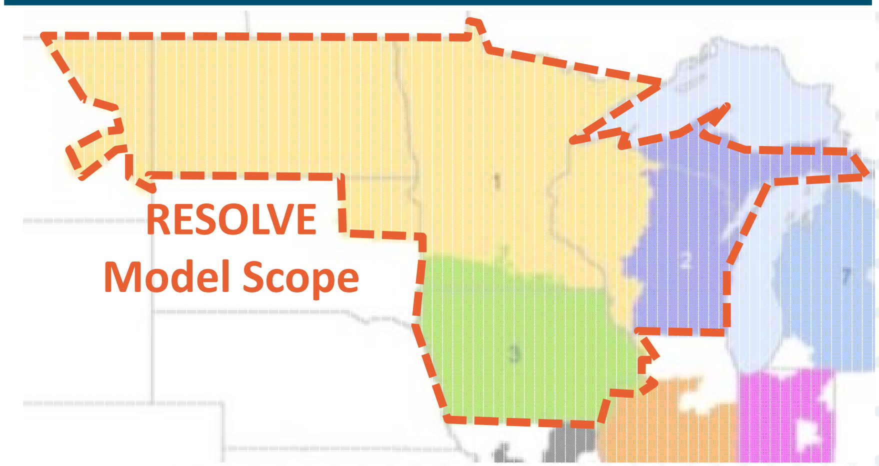
Hourly Wind Output: Historical vs. Sampled



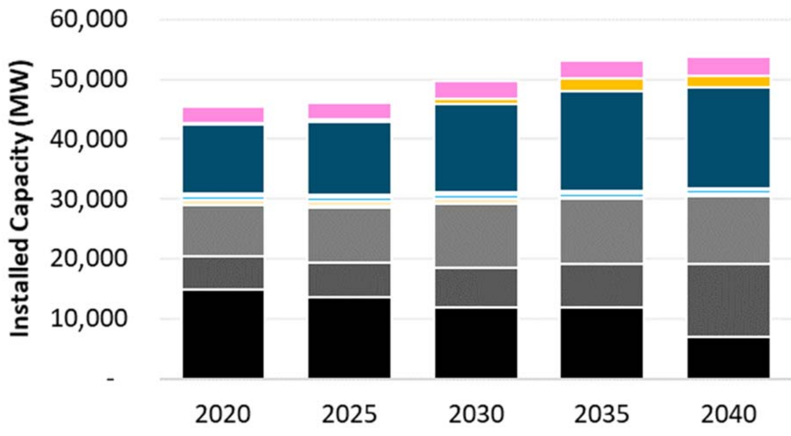
Xcel Energy RESOLVE Model Scope

- **To capture interactions of Xcel portfolio, RESOLVE simulates the operations of generation resources across the broader MISO footprint**
  - RESOLVE selects optimal **investments** for the **Xcel portfolio**
  - RESOLVE simulates **optimal dispatch** across the **entire footprint**
- **Broader operational simulation allows RESOLVE to capture changing MISO market dynamics with evolution of the generation fleet outside of Xcel portfolio:**
  - Retirement of aging baseload resources
  - Large additions of new wind generation capacity

RESOLVE Model Footprint



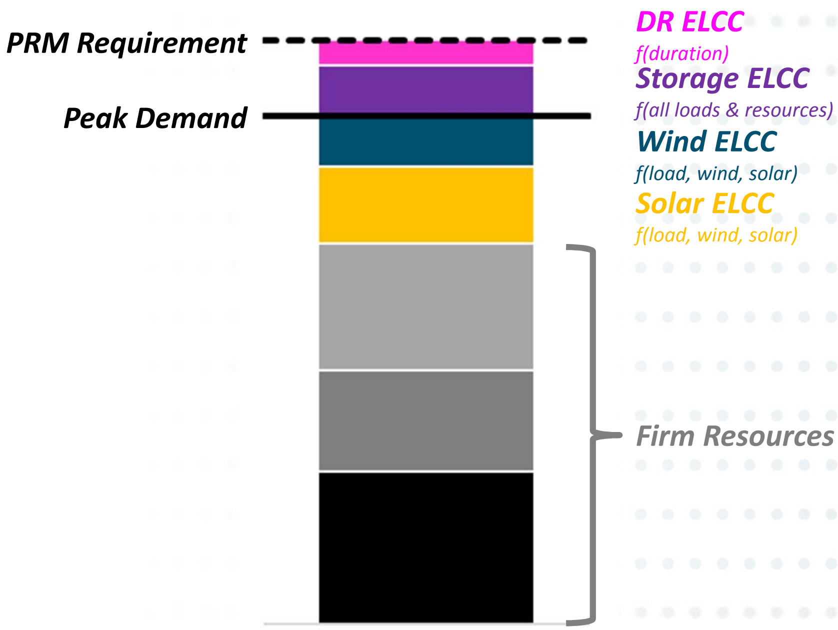
Non-Xcel Resources in MISO LRZ 1-3



Resource Adequacy in RESOLVE

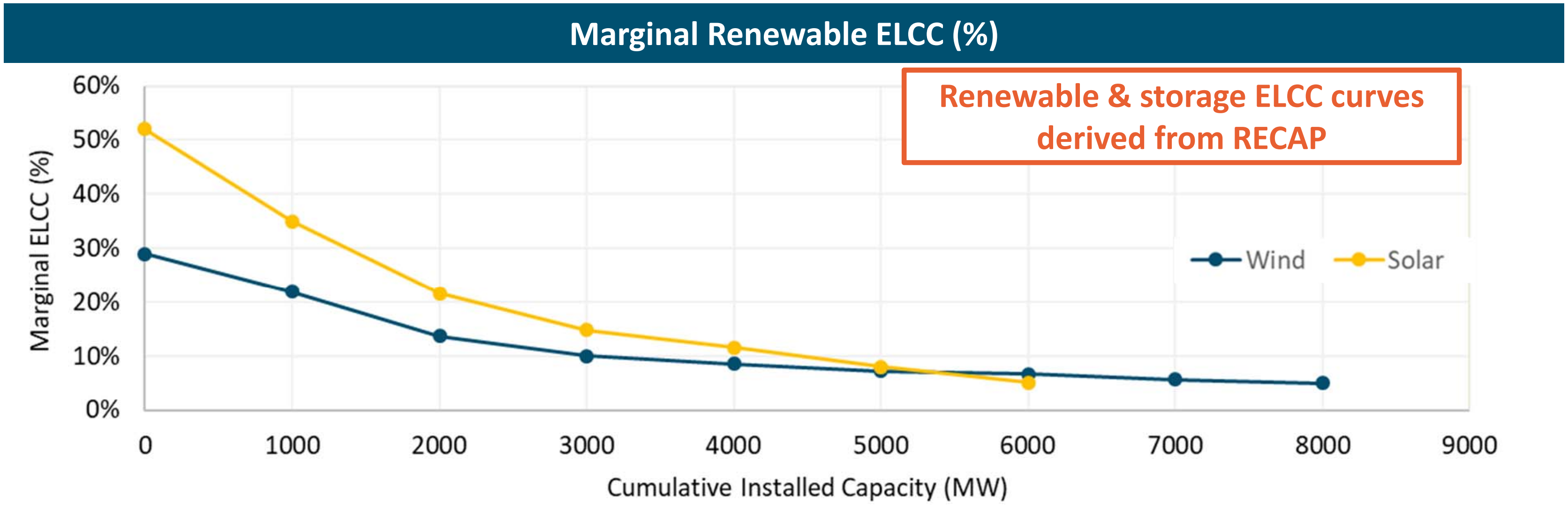
+ **Each portfolio is required to meet a planning reserve margin requirement to ensure resource adequacy**
  - PRM of 2.4% represents Xcel's obligation as a MISO member
+ **As a system shifts towards variable and use-limited resources, capacity accreditation becomes a major challenge**
+ **RESOLVE's representation of renewable ELCC is designed to capture declining marginal ELCC with increasing penetration**

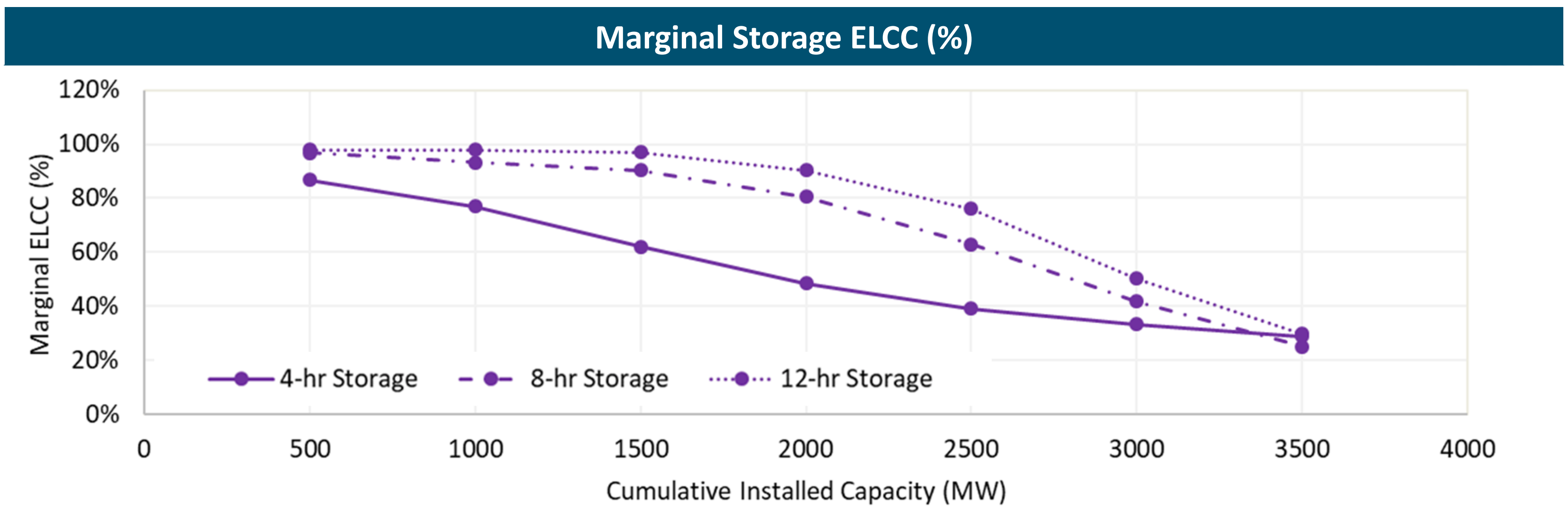
RESOLVE PRM Requirement



+ **Key assumptions for PRM**
  - Full capacity credit for firm resources
  - Renewable ELCC updates dynamically with penetration
  - Storage & DR value as a function of duration

Renewable & Storage ELCC Curves





Key Metrics Calculated by RESOLVE

- **RESOLVE produces useful outputs for resource planning:**
  - Resource additions in each investment period (MW)
  - Annual generation by resource (GWh)
  - Annual renewable curtailment (%)
  - Annual RPS/CES level achieved (%)
- **Each portfolio is also characterized by its impact on Xcel Energy's costs and emissions:**

Cost Metric

- **Includes fixed and variable costs associated with generating resources in each scenario:**
  - **Ongoing fixed O&M** for existing resources
  - **All-in fixed costs** for new resources
  - **Variable & fuel costs** of generation for all resources
  - **Net cost (or revenue)** associated with purchases (or sales) from MISO market

Emissions Metric

- **Includes all emissions attributed to Xcel portfolio in each scenario:**
  - **Physical emissions** produced by plants owned and operated by Xcel
  - Emissions attributed to market purchases from MISO at a **deemed rate (~0.40 tons/MWh)**
  - **No emissions credit** for sales to MISO market

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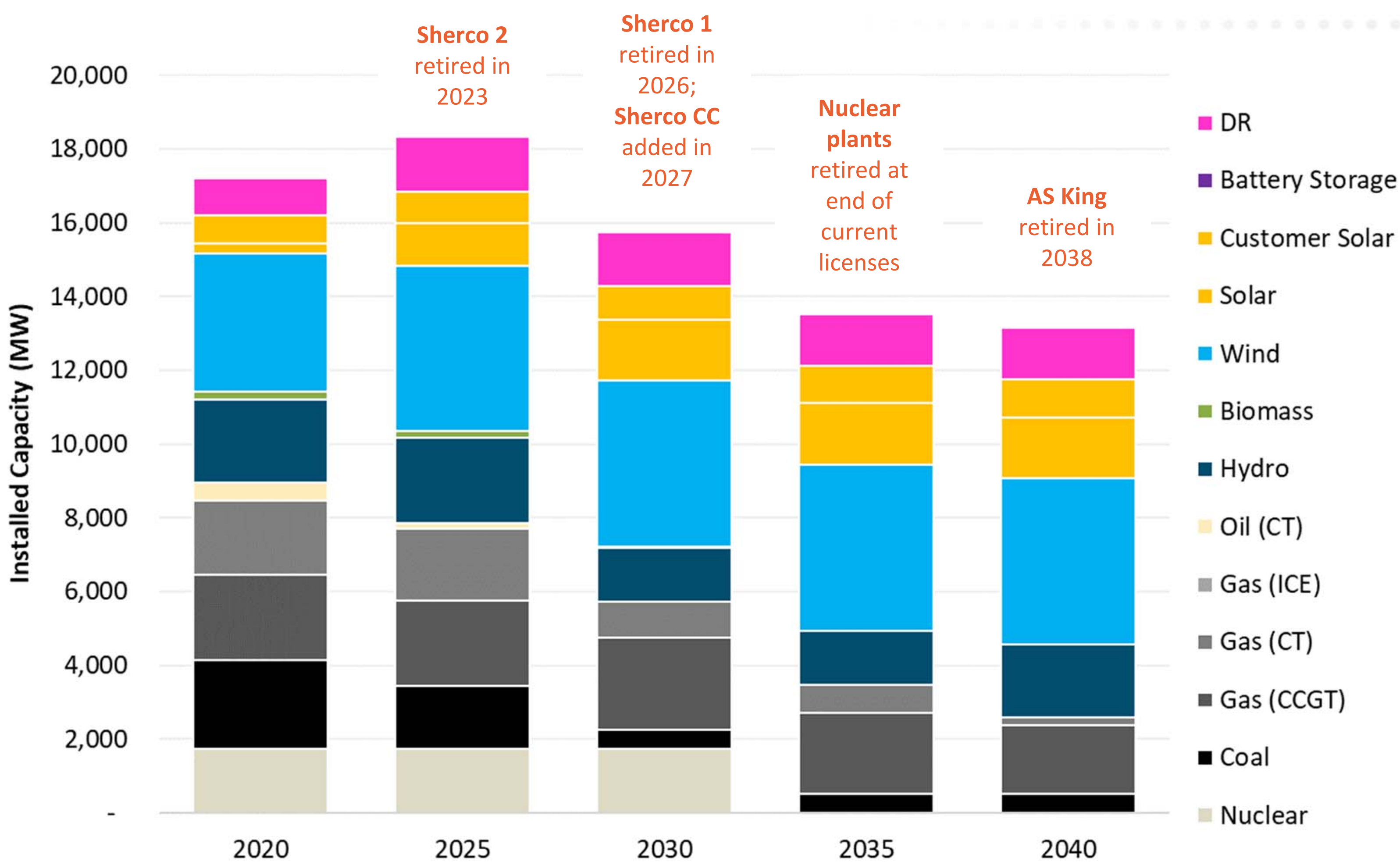
REFERENCE CASE SUMMARY

Reference Case Key Assumptions

+ Reference Case reflects a "business-as-usual" portfolio for Xcel Energy

Input	Assumptions
Load	Annual load CAGR of 0.3% from 2018-2040; peak load of 9,530 MW
Energy Efficiency	Historical EE programs and future EE programs in MN and SD are accounted for in load forecast
Demand Response	Existing DR programs remain in place; additional 400 MW of new DR added by 2023
Nuclear	Existing nuclear plants retire once current licenses expire • Monticello: 2030 • Prairie Island 1: 2033 • Prairie Island 2: 2034
Coal	Coal plants retire according to current Vision Plan assumptions: • Allan S King: **2037** • Sherco 1: **2026** • Sherco 2: **2023** • Sherco 3: **2040**
Natural Gas	Existing gas resources retire according to current Xcel plans; Sherco CC online by 2027; additional generic new gas resources can be built to meet capacity needs
Hydro	Manitoba contract has capacity and energy components; modeled as two separate resources
Wind and Solar	• **4.5 GW** of wind installed by 2030; additional wind available ($41/MWh in 2030) • **2.6 GW** of solar installed by 2030; additional solar available at ($41/MWh in 2030)
MISO Market	• MISO market purchases/sales limited to 1,350 MW • Pricing of market interactions determined endogenously through simulation of MISO loads & resources

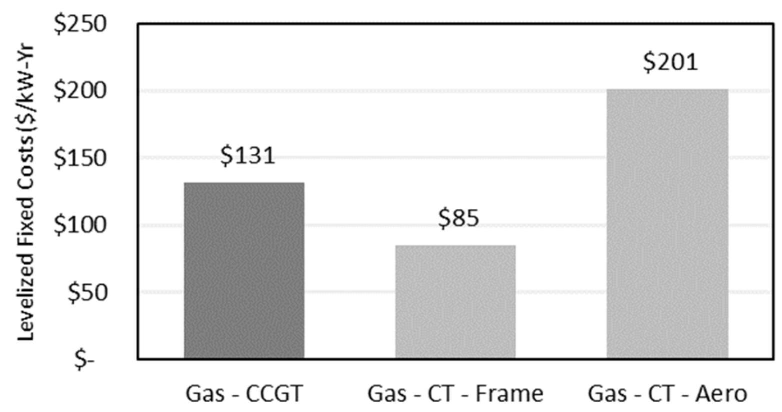
Existing Resource Assumptions



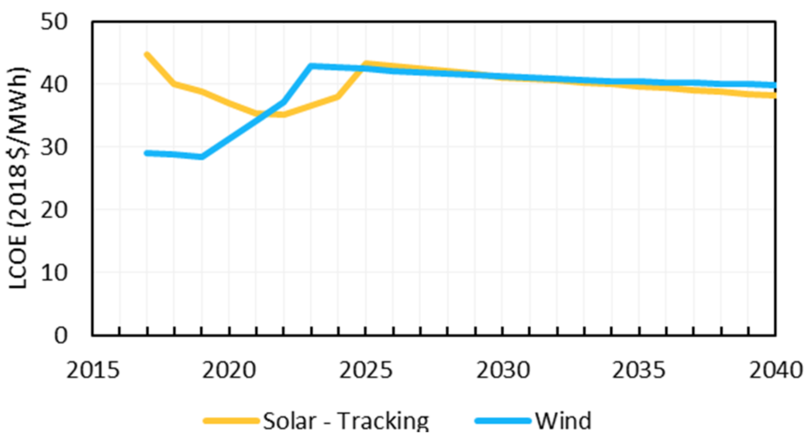
New Resource Options

- **RESOLVE selects a combination of new natural gas, renewable, and energy storage investments to meet future energy & capacity needs**
  - Conventional costs: Xcel assumptions
  - Renewable costs: NREL 2018 ATB
  - Storage costs: Lazard LCOS 3.0

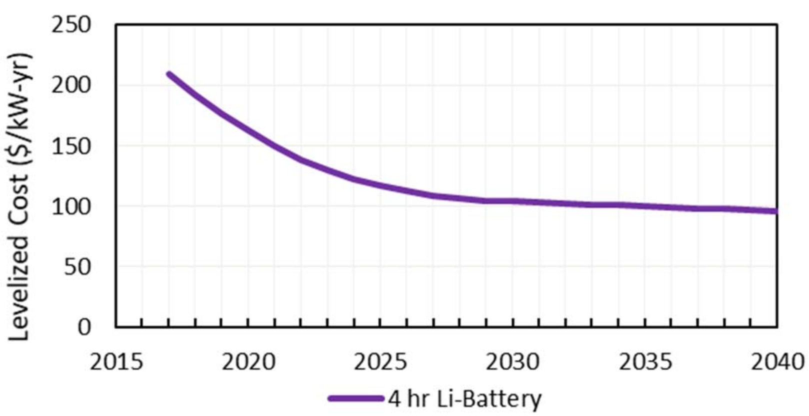
Conventional Resource Costs



Renewable Cost Projections



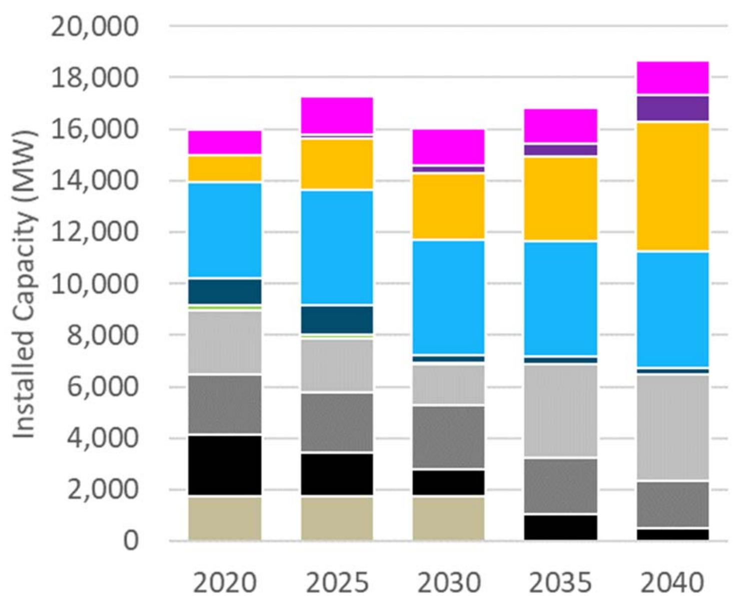
Energy Storage Cost Projections



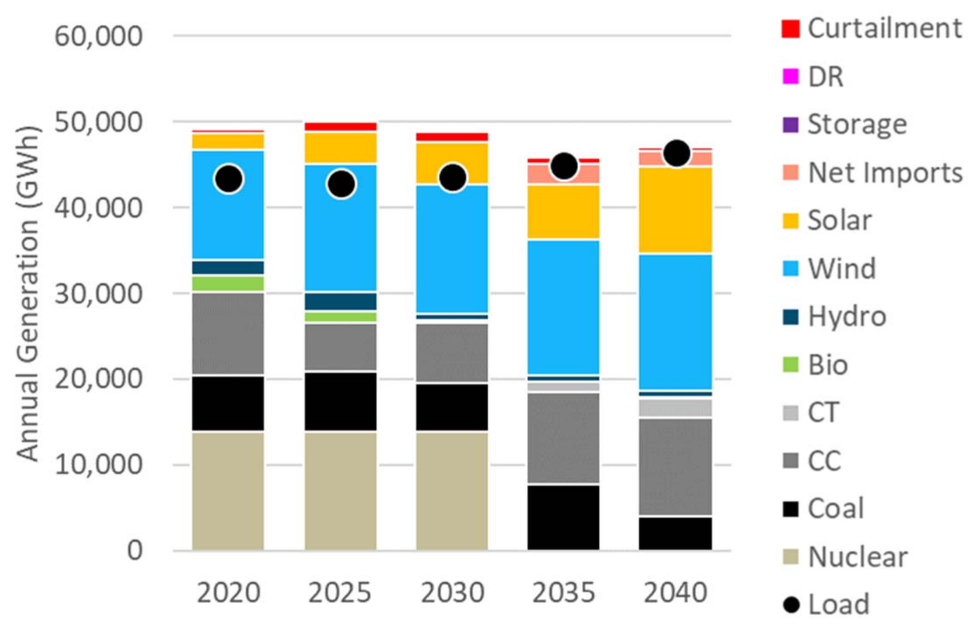
Reference Case Summary

- Planned renewable procurement results in Xcel meeting nearly 80% of 2030 loads with carbon-free generation
- Retirement of baseload resources drives increased reliance on gas generation and market purchases
- Capacity needs, driven mainly by retirements, met by a combination of gas CTs and energy storage

Total Installed Capacity (MW)

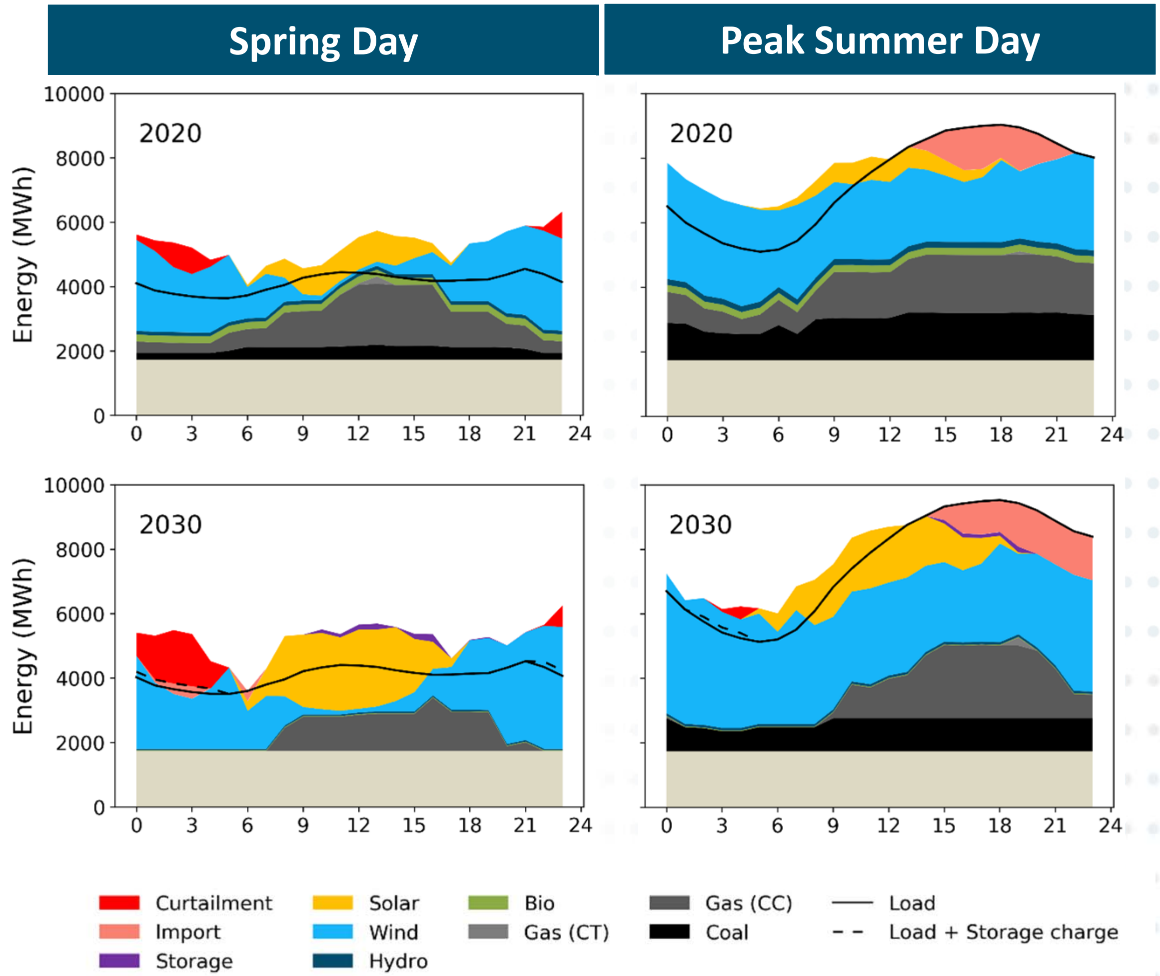


Annual Generation (GWh)



Snapshots of Operations
Peak Summer Day

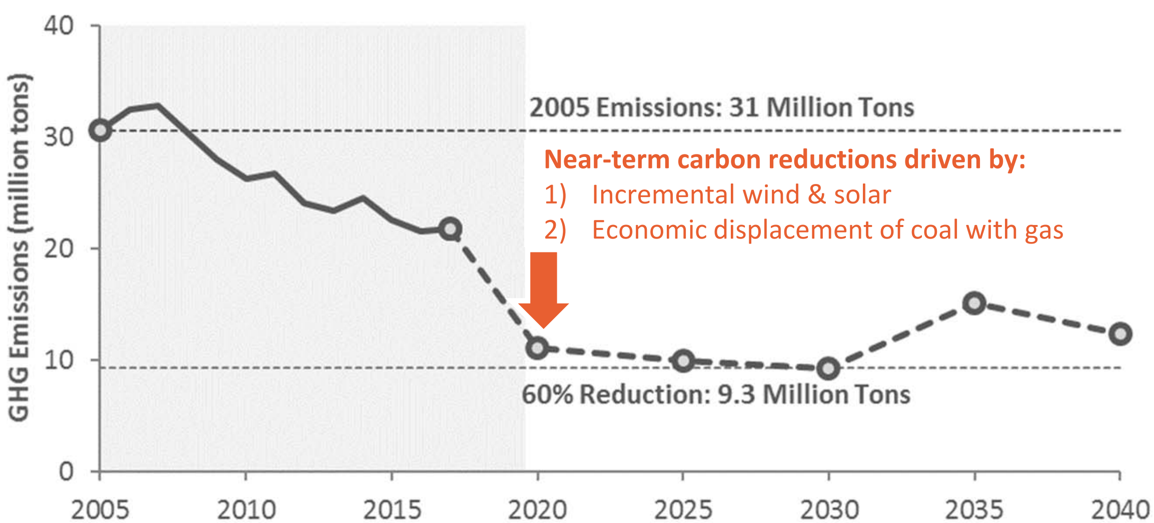
- **2020 loads served predominantly with nuclear, coal, and gas resources**
- **By 2030, fuel mix shifts towards lower carbon fuels:**
  - Retiring coal plants replaced by increased natural gas burn
  - Additional renewables displace some thermal dispatch



Emissions Trends in Reference Case

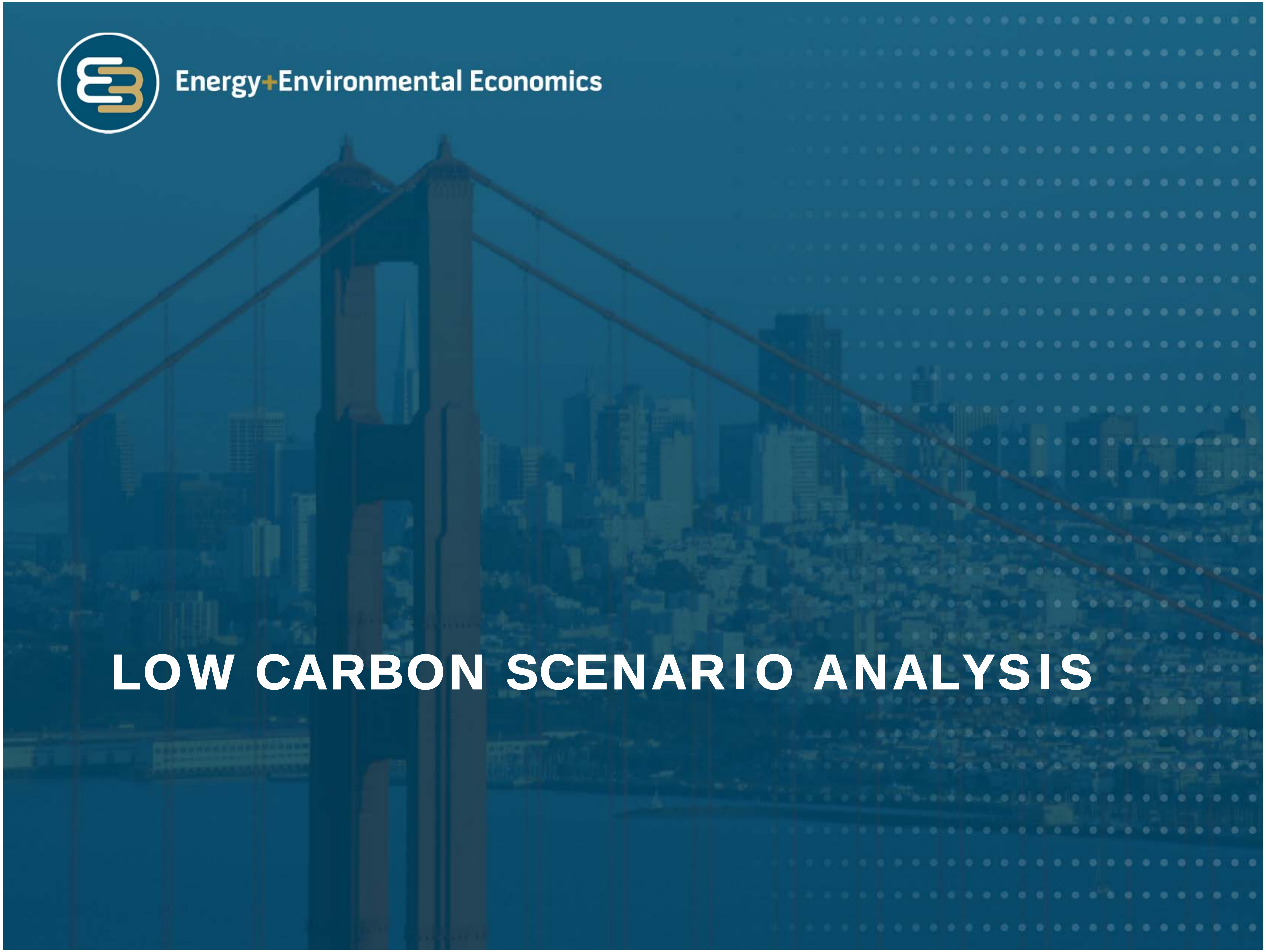
- Planned retirements of existing coal plants will result in continued emissions reductions through 2030
- Beyond 2030, assumed retirement of nuclear generators at license expiry causes a rebound in emissions

Historical and Projected Emissions, Reference Case



DRAFT RESULTS

Energy+Environmental Economics



LOW CARBON SCENARIO ANALYSIS

Policy Scenarios to Study

Scenario Group	2030 Target		Other Assumptions
Greenhouse Gas Cap	80% 90% 95%	**GHG reduction** relative to 2005 levels	• Coal generators retained through current lifetimes • Nuclear assets retained through licenses (2030, 2033, 2034)
Clean Energy Standard	80% 90% 100%	of annual load procured from **carbon-free** resources	• Coal generators retained through current lifetimes • Nuclear assets retained through licenses
CES w/ Early Coal Retirement	80% 90% 100%	of annual load procured from **carbon-free** resources	• **All coal retired by 2030** • Nuclear assets retained through licenses
Renewables Portfolio Standard *(results forthcoming)*	80% 90% 100%	of annual load procured from **renewable** resources	• Coal generators retained through current lifetimes • **Nuclear assets retired by 2030**
No New Gas	n/a		• **No investment in new gas resources**

Preview of Key Scenario Dynamics

Scenario Group	Impact on Carbon	Impact on Cost	Key Dynamics
Greenhouse Gas Cap	**Large**	**Small**	• Scenario balances costs of greenhouse gas reductions achieved through coal-to-gas switching and investment in new renewables
Clean Energy Standard	**Small**	**Large**	• CES drives increased investment in renewables • Coal units continue to operate, but at lower capacity factors
CES w/ Early Coal Retirement	**Medium**	**Medium**	• CES drives incremental investments in renewables • Existing coal capacity and energy must be replaced
No New Gas	**Very Small**	**Medium**	• Future capacity needs must be met by energy storage & renewables

2030 Portfolio Summary
Carbon Cap Scenarios

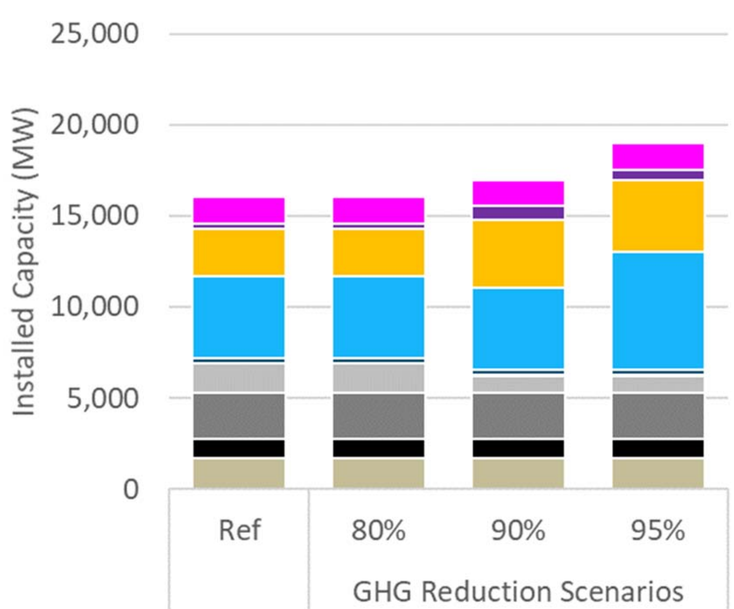
Key Findings

+ **80% GHG reductions can be achieved fairly easily through reduction in coal dispatch**
+ **To achieve 90% GHG reductions, renewables and imports displace all coal and some gas**
+ **Cost of emissions reductions beyond 90% begins to rise steeply due to renewable integration challenges**

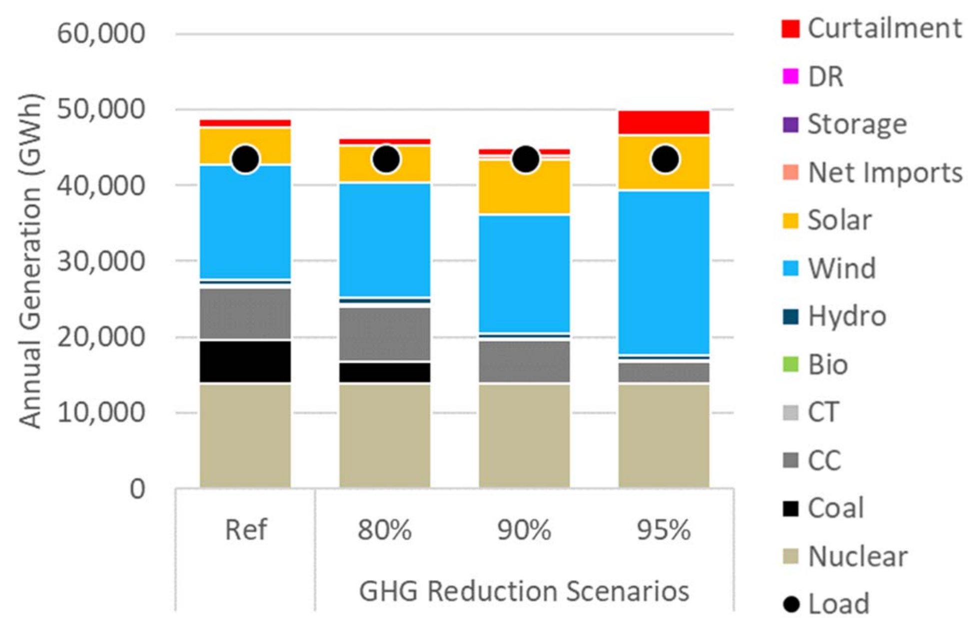
Key Metrics

Scenario	Inc Cost ($MM)	GHG Savings (Million Tons)	CES (%)	Curtailment (%)
Reference	—	—	80%	5.5%
80% GHG Red	$2	2.5	80%	4.9%
90% GHG Red	$38	5.9	86%	4.3%
95% GHG Red	$258	7.6	100%	10.0%

Total Installed Capacity (MW)



Annual Generation (GWh)



DRAFT RESULTS

2030 Portfolio Summary

CES Scenarios

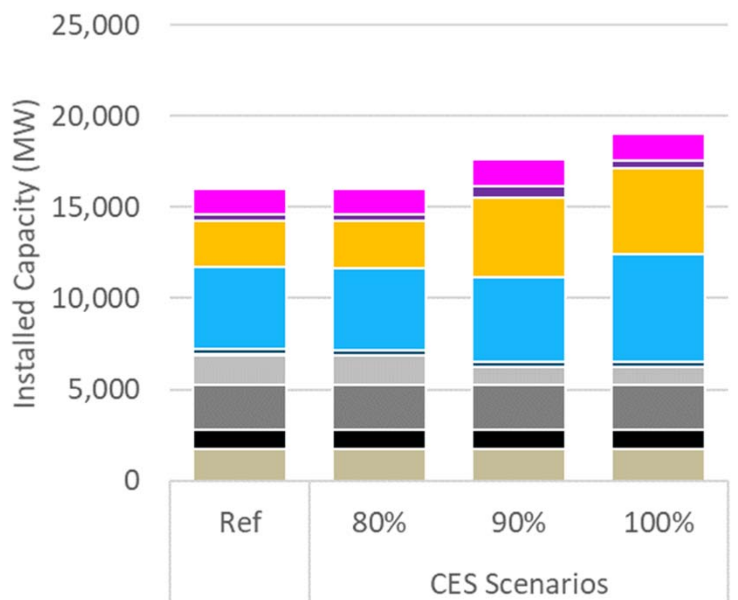
Key Findings

- Reference Case portfolio is largely aligned with an 80% CES target in 2030
- Meeting higher CES goals requires incremental investments in an additional 2 GW of renewables and batteries
- Emissions savings are not as significant as GHG optimized scenario, as coal remains one of the lowest-cost resources in the dispatch stack

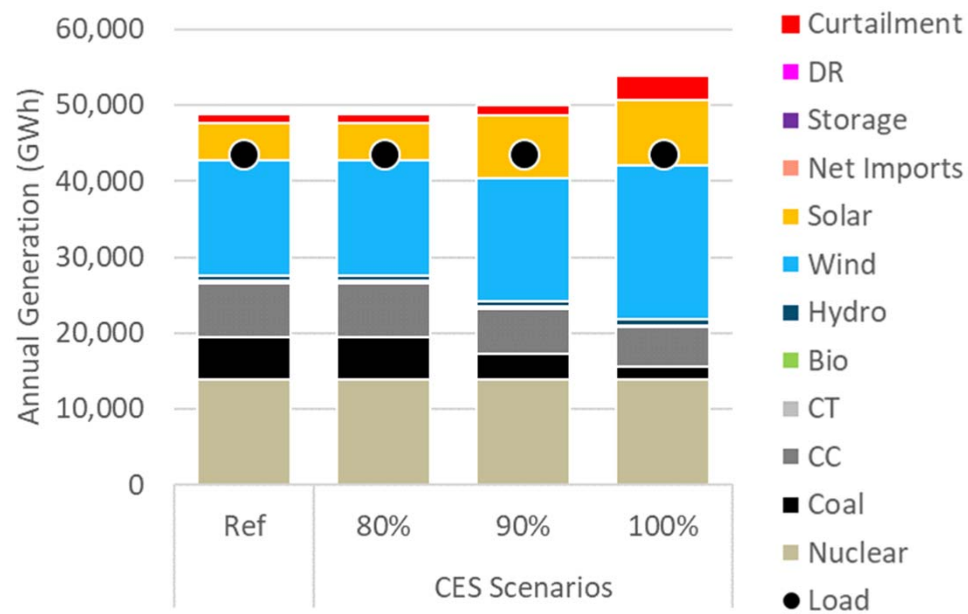
Key Metrics

Scenario	Inc Cost ($MM)	GHG Savings (Million Tons)	CES (%)	Curtailment (%)
Reference	—	—	80%	5.5%
80% CES	—	—	80%	5.1%
90% CES	$37	2.9	90%	4.4%
100% CES	$187	5.3	100%	8.4%

Total Installed Capacity (MW)



Annual Generation (GWh)



2030 Portfolio Summary

CES Scenarios (No Coal)

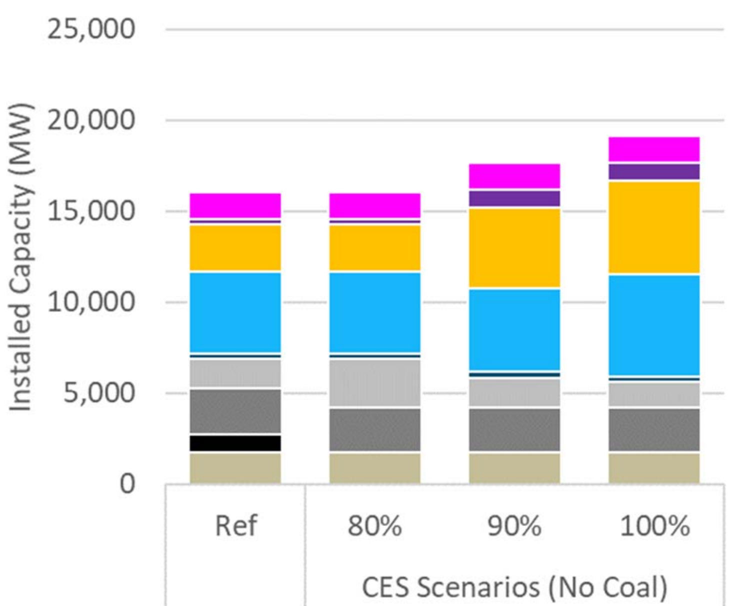
Key Findings

+ Pairing a CES with early retirement of coal generation results in increased levels of renewables and battery investment but increased emissions savings
+ Capacity from retiring coal resources replaced primarily with combination of new natural gas CTs and batteries

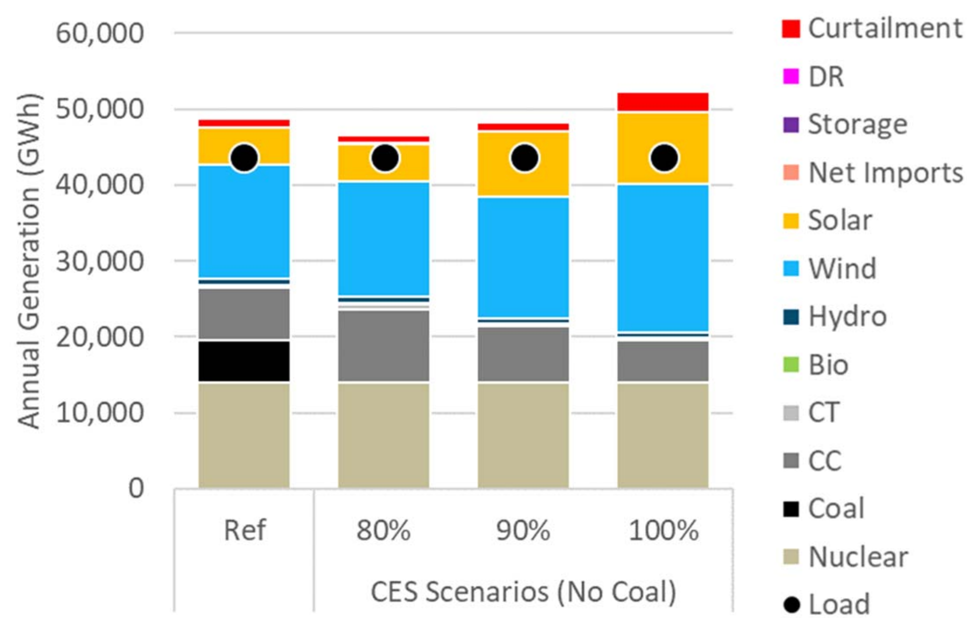
Key Metrics

Scenario	Inc Cost ($MM)	GHG Savings (Million Tons)	CES (%)	Curtailment (%)
Reference	—	—	80%	5.5%
80% CES	$59	4.0	80%	4.7%
90% CES	$84	5.3	90%	4.2%
100% CES	$206	6.5	100%	7.1%

Total Installed Capacity (MW)



Annual Generation (GWh)



2030 Portfolio Summary

No New Gas

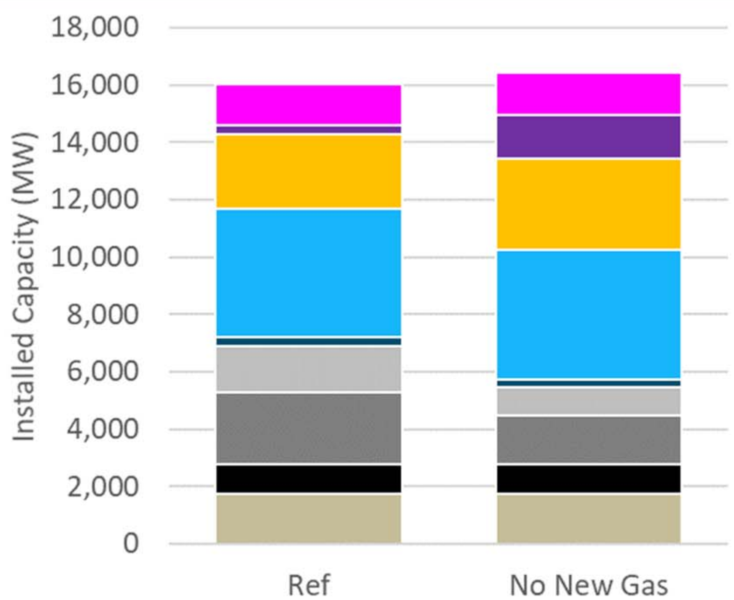
Key Findings

+ **Prohibition on new gas generation capacity requires alternative, higher cost capacity for reliability**
+ **Compared to the Reference Case, over two times more storage capacity is added by 2030**
+ **Prohibition provides limited direct greenhouse gas reduction benefit due to focus on capacity vs. energy**

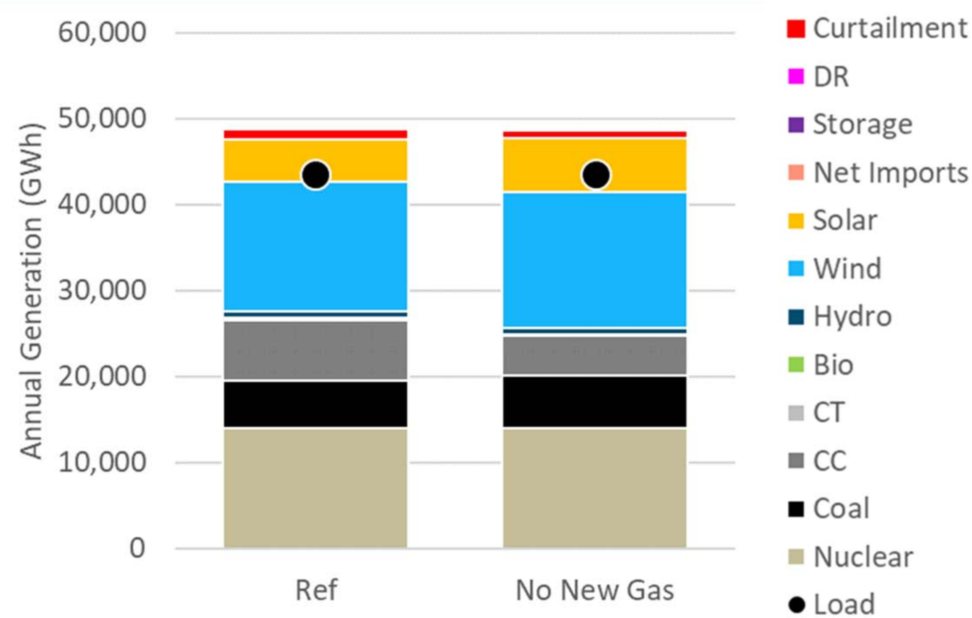
Key Metrics

Scenario	Inc Cost ($MM)	GHG Savings (Million Tons)	CES (%)	Curtailment (%)
Reference	—	—	80%	5.5%
No New Gas	$76	0.3	83%	3.7%

Total Installed Capacity (MW)

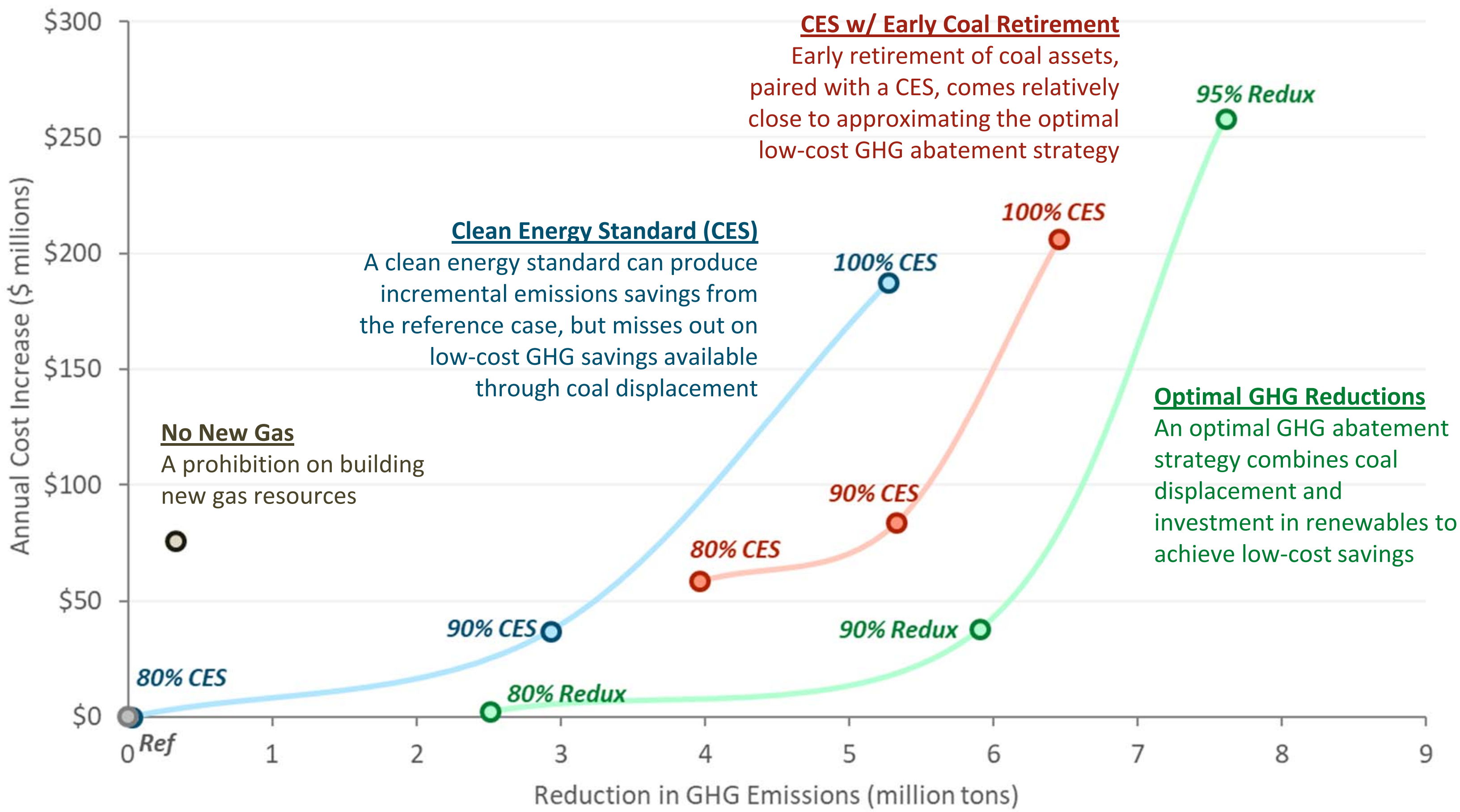


Annual Generation (GWh)



DRAFT RESULTS

2030 Costs & Emissions Impacts



DRAFT RESULTS

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ACHIEVING 100% GREENHOUSE GAS REDUCTIONS

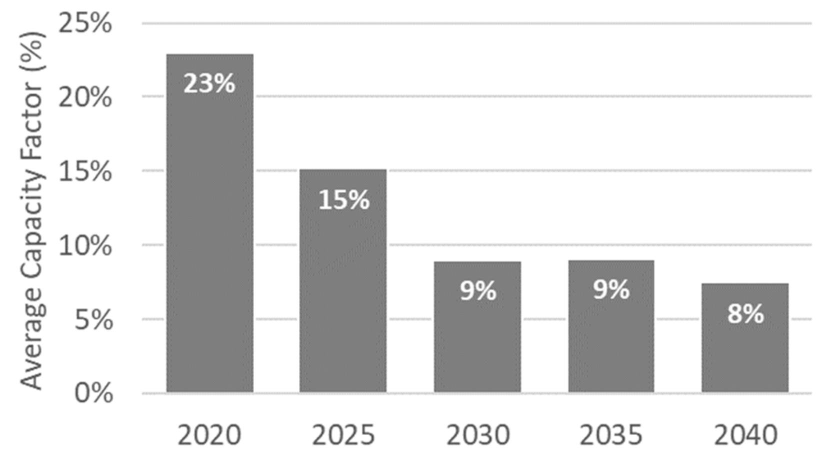
Achieving 100% GHG Reductions

- **This study is also designed to ask the hypothetical question of what it would take to achieve 100% GHG reductions on the Xcel system**
- **Achieving a zero-carbon grid presents a new challenge for system reliability: serving load over sustained periods of low renewable output (1 day to 1 week)**
- **Designing a system that can ensure reliability under these conditions will require some combination of:**
  - Very long duration energy storage
  - Large "overbuild" of renewable generation capability
  - Availability of dispatchable zero-carbon resources (e.g. biogas, CCS)
- **This analysis examines what would be needed to design a reliable carbon-free system in 2030 relying exclusively on existing nuclear, wind, solar, storage, and demand response**

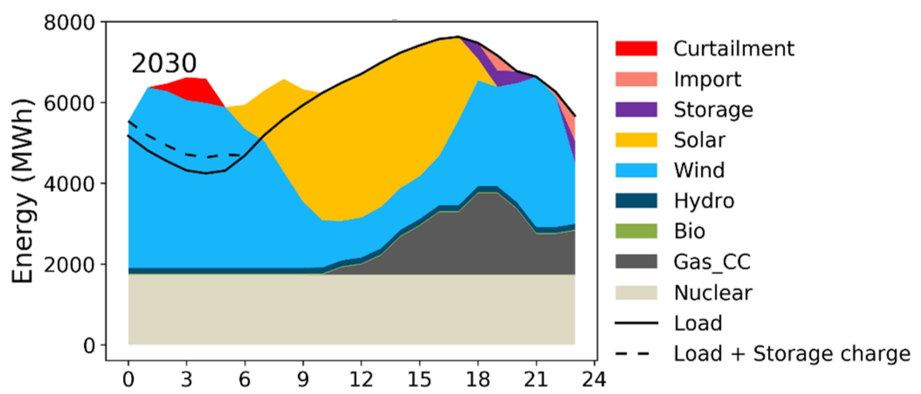
Role of Fossil Resources in the 95% GHG Reduction Scenario

- **95% GHG Reduction scenario achieves significant carbon reductions while maintaining significant installed fossil capacity**
- **In the 95% GHG Reduction scenario, fossil resources are rarely used—but play a key role in maintaining system reliability**
  - Dispatched during periods of sustained low renewable output and high loads
- **In this role, gas resources are crucial to meeting resource adequacy needs with a limited greenhouse gas footprint**

Average CCGT Capacity Factor, 95% GHG Reduction Scenario



Example High Load Day, 95% GHG Reduction Scenario



DRAFT RESULTS

Challenges of Achieving 100% GHG Reductions

+ **System can no longer rely on firm fossil resources to meet resource adequacy needs**
  - Up to ~95% GHG reductions, Xcel can meet reliability needs by retaining some natural gas generation capacity and dispatching it infrequently
+ **Achieving 100% GHG reductions would imply restricting access to the broader MISO market, creating an electrical island around Xcel and eliminating key benefits of market participation**
  - Xcel's resource adequacy needs would increase without diversity of broader loads and resources
  - Ability to rely on market for some share of real-time balancing of renewables would also be eliminated

Designing a 100% GHG Reduction Portfolio Using Reliability Models

+ **RECAP, E3's LOLP model, provides a means of constructing a reliable portfolio that relies only on carbon-free resources in 2030**
    - All existing nuclear units still in service
    - No reliance on coal or gas units
    - No purchases from MISO market
+ **System is designed to meet a resource adequacy standard of 1 day in 10 years (i.e. LOLE = 2.4 hrs/yr)**

Inputs

Load
- *Hourly load for many weather years*

Dispatchable Generation
- *Capacity*
- *FOR*
- *Maintenance*

Renewables
- *Capacity*
- *Hourly generation profiles for many weather years*

Hydro
- *Hydro availability for many hydro years*
- *Max/min constraints*

Storage
- *Capacity*
- *Duration*
- *Roundtrip efficiency*
- *FOR*

Demand Response
- *Capacity*
- *Max # of calls*
- *Duration of each call*

Outputs

LOLE
- *Loss of load expectation*
- *Hrs/yr of total expected lost load per year*

ALOLP
- *Annual loss of load probability*
- *% probability of having a single loss of load in any given year*

EUE
- *Expected unserved energy*
- *MWh/yr of energy that cannot be served*

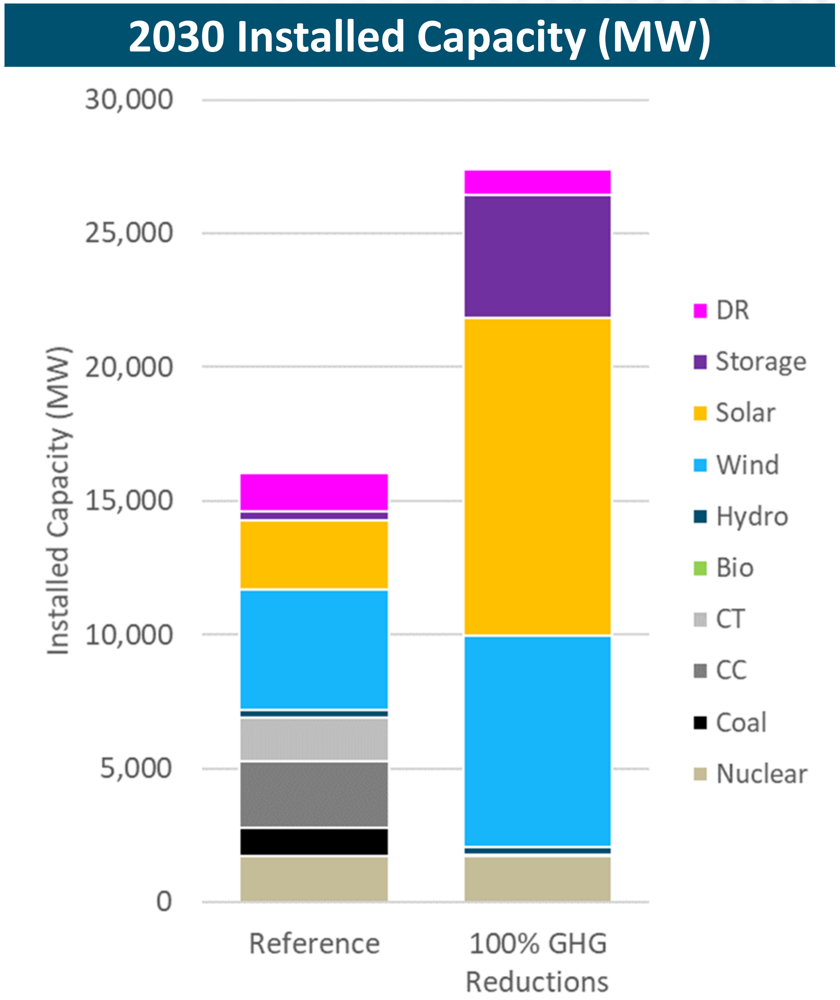
ELCC
- *Effective load carrying capability*
- *Equivalent quantity of 'perfect capacity' for a variable or energy-limited resource*

TPRM
- *Target planning reserve margin*
- *PRM required to achieve a specified reliability threshold (i.e. LOLE, ALOLP, or EUE)*

RECAP uses Monte Carlo analysis of loads, renewables, and generator outages across hundreds of years to examine the reliability of a generation portfolio

100% GHG Reductions by 2030

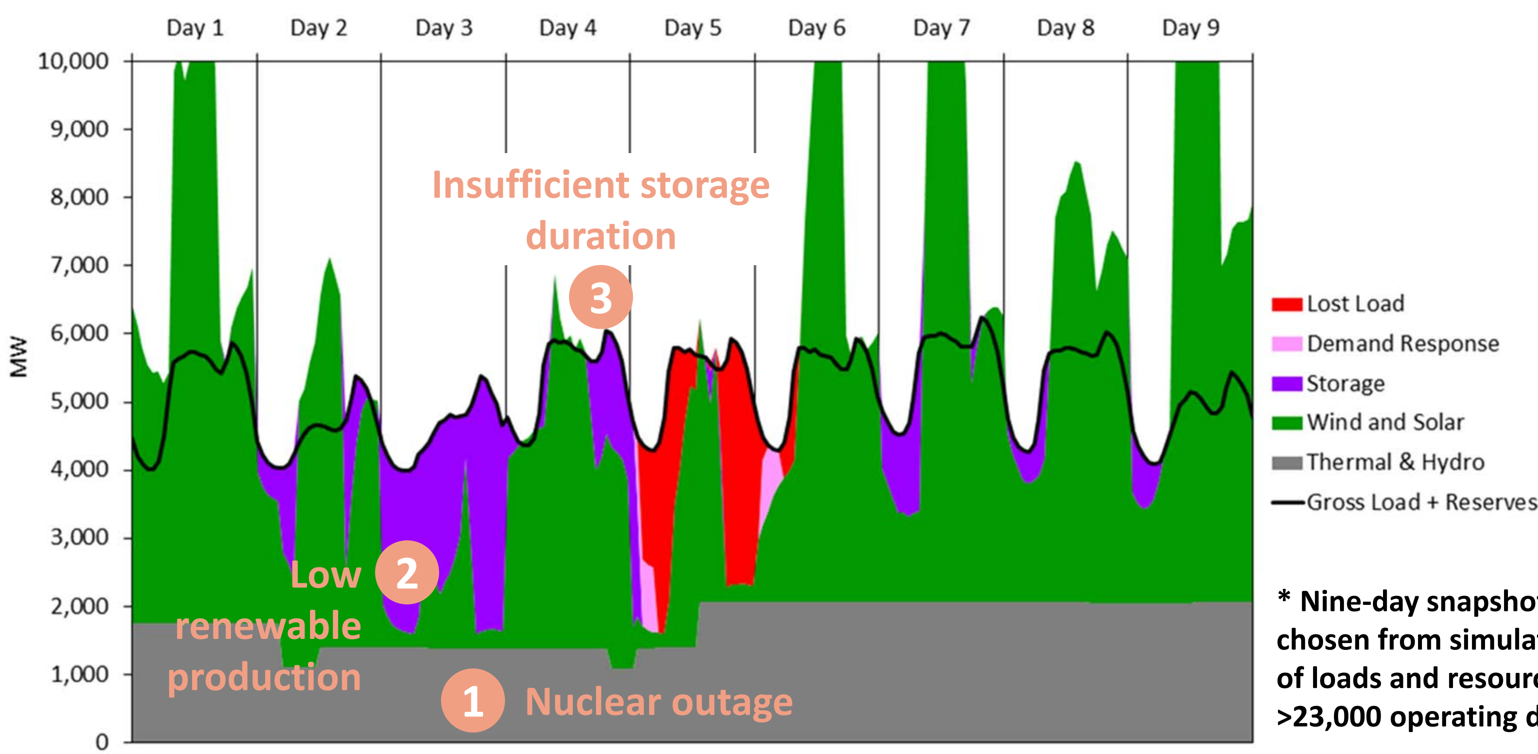
+ **In the absence of dispatchable gas and coal resources, significant new investment in renewables and storage are needed for reliability**
  - **20 GW** of wind and solar
  - **5 GW** of 17-hr storage
  - **+$2.9 billion/yr** in incremental fixed costs
+ **Meeting reliability needs results in significant "overbuild" of renewables**
  - Renewables + nuclear capable of meeting **160%** of Xcel annual energy needs—but large quantities must be curtailed
+ **Scale of investments results in exponential cost increase to achieve final 5% GHG reductions**



Anatomy of a Reliability Event in 100% GHG Reduction Portfolio

+ **On a system that relies predominantly on variable resources & storage to meet reliability needs, reliability events result from sustained energy shortages—not peak needs**

Nine-Day Snapshot* of Resource Availability, 100% GHG Reduction Scenario



* Nine-day snapshot chosen from simulation of loads and resources on >23,000 operating days

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PRELIMINARY OBSERVATIONS & NEXT STEPS

Summary of Observations

1. **The lowest cost way to reduce carbon in the Xcel system is to replace coal with a combination of renewables and natural gas**
   - Coal generation produces approximately 85% of Xcel's GHG emissions in the 2020 Reference case
   - In absence of a state-wide carbon price or changes in MISO rules, early coal retirement is likely the most cost-effective strategy to achieve significant additional emissions reductions
2. **A Clean Energy Standard (CES) will also drive down emissions, but at a higher cost and with diminishing effectiveness**
   - At very high CES levels, large amounts of generation will be exported and/or curtailed since the incentive is on delivering energy anywhere, rather than displacing fossil fuels in Xcel's territory
3. **Maintaining a large amount of firm generation capacity to meet reliability needs can help Xcel decarbonize its portfolio at reasonable cost**
   - Natural gas generators can fulfill this reliability need without producing significant amounts of greenhouse gases if operated as peakers
   - Meeting all reliability needs with a combination of wind, solar, and storage will require prohibitively large investments

Next Steps

- Align key input assumptions with Xcel Energy IRP modeling team
- Explore impacts of alternative portfolio decisions
  - Early nuclear retirement, nuclear relicensing, others?
- Test robustness of results through sensitivity analysis
  - Renewable & storage costs, fuel prices, loads, others?
- Integrate results of E3 PATHWAYS analysis on Minnesota statewide decarbonization
  - High electrification scenario, biogas availability

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Thank You!

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DETAILED INPUTS & ASSUMPTIONS

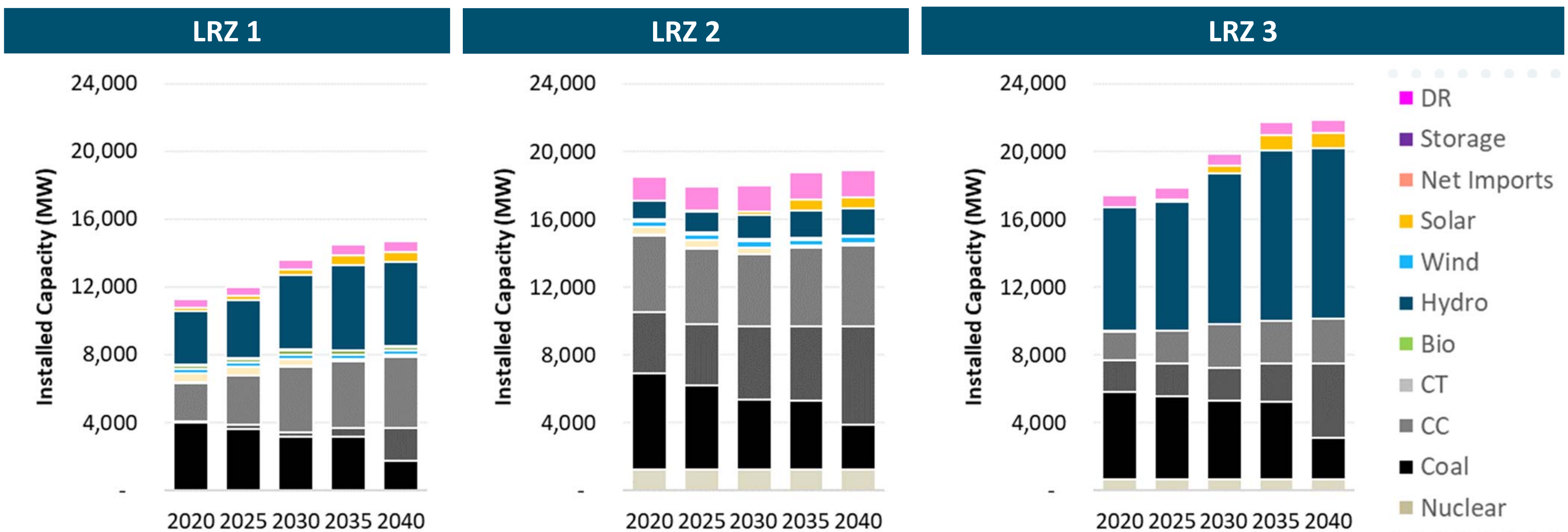
Characteristics of Xcel Energy Thermal Resources

Type	Resource ID	Nameplate Capacity (MW)	Pmin (% of Pmax)	Full Load Heat Rate (MMBtu/ MWh)	Min Load Heat Rate (MMBtu/ MWh)	Min. Down Time (hr)	Min. Up Time (hr)	Start Cost ($/MW)	Variable O&M ($/MWh)	Fixed O&M ($/kW-yr)
Nuclear	MONTI	648	100%	—	10.26	120	120	—	$5	$219
	P ISLAND_1	546	100%	—	10.31	120	120	—	$4	$209
	P ISLAND_2	546	100%	—	10.37	120	120	—	$4	$206
Coal	AS_KING	511	70%	9.91	10.36	8	14	$139	$1	$50
	SHERCO_1	680	38%	10.36	11.92	8	14	$102	$1	$29
	SHERCO_2	682	38%	10.05	11.04	8	14	$117	$0.93	$29
	SHERCO_3	515	47%	10.29	10.52	16	16	$118	$0.93	$35
Gas CCGT	BDOG_CC	298	66%	7.40	7.35	6	4	$13	$5	$28
	HB_CC	575	38%	7.11	8.13	6	4	$11	$5	$14
	RS_CC	487	27%	6.99	10.75	6	4	$16	$5	$16
	LSCOTGRV	262	44%	9.71	10.75	8	8	$13	$5	$39
	CALPMNKT	357	49%	7.67	7.78	6	4	$8	$5	$99
	CALPINE CC (add)	345	51%	7.73	7.10	6	4	$12	$5	$35
	SHERCO CC (add)	786	21%	8.38	7.71	6	4	$12	$5	$35
Gas Peaker	ANSON_2_3	218	41%	12.21	15.38	1	1	$12	$5	$14
	ANSON_4	168	54%	10.11	12.46	1	1	$11	$5	$14
	BLUELAKE_7_8	351	56%	10.08	11.89	1	1	$11	$5	$6
	FLAMBEAU	16	31%	15.78	25.09	1	1	$7	$5	$11
	GRANITE	64	25%	16.57	29.28	1	1	$9	$5	$9
	INVERHIL	370	16%	12.46	25.76	1	1	$10	$5	$7
	WHEATON_1_2_3_4	243	16%	12.90	26.37	1	1	$10	$5	$7
	INVENERG	358	58%	10.28	11.87	1	1	$12	$5	—
	BAYFRONT_4	15	67%	12.71	13.84	1	1	—	$5	$124
	BLACKDOG (add)	232	50%	12.24	10.23	1	1	$11	$5	$10
Oil Peaker	BLUELAKE_1_2_3_4	193	61%	13.58	16.67	1	1	$51	$5	$6
	FCH_ISLD	81	37%	12.89	17.02	1	1	$44	$5	$5
	WHEATON_5_6	140	36%	12.75	18.17	1	1	$37	$5	$7

External Generation Portfolio

Continued Fleet Change (CFC) Scenario

+ **Generation data obtained from MISO Transmission Expansion Planning 2018 report**
  - Xcel's generation portfolio is excluded from LRZ 1
+ **By 2050 wind will have the largest share of the generation portfolio in LRZ 3, while LRZ1 and LRZ 2 will have mostly gas**
  - Beyond 2032, we assume backstop CCGT resources are added to replace retired coal capacity and peaker resources are added to meet PRM requirements



Existing Thermal Resources – External Zones

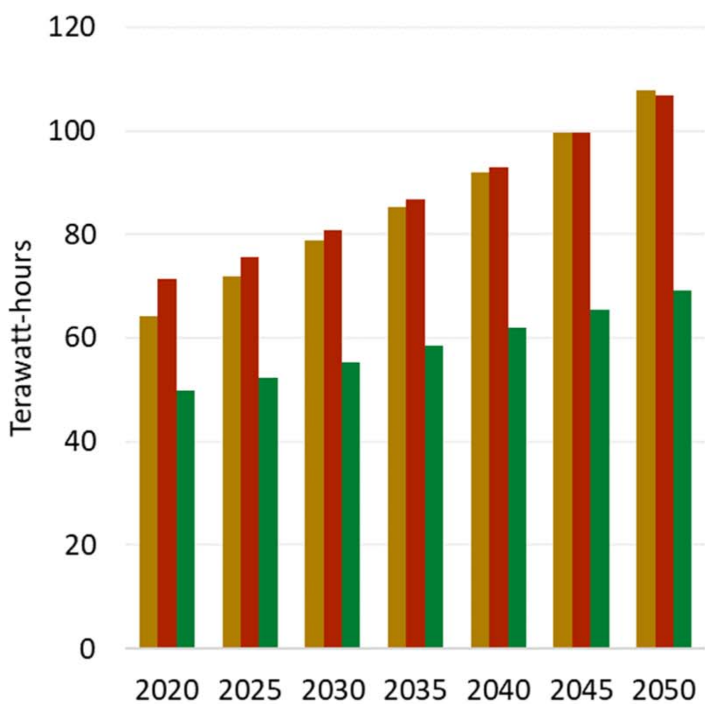
- Operating characteristics values are capacity-weighted averages for each technology type by LRZ from MTEP data

Zone	Technology	Nameplate Capacity (MW)	Full Load Heat Rate (MMBtu/MWh)	Min Load Heat Rate (MMBtu/MWh)	Pmin (% of Pmax)	Min. Down Time (hr)	Min. Up Time (hr)	Start Cost ($/MW)
LRZ1	Coal	252	10.24	10.24	41%	8	11	$98
	Gas Peaker	70	12.01	12.01	26%	1	1	$11
	Gas CCGT	391	7.40	7.40	50%	8	8	$16
	Gas - ICE	110	9.29	9.29	25%	1	1	$5
	Fuel Oil	28	12.02	12.02	19%	2	1	$36
LRZ2	Nuclear	586	10.25	10.25	100%	120	120	—
	Coal	252	10.24	10.24	40%	8	11	$95
	Gas Peaker	70	12.01	12.01	26%	1	1	$14
	Gas CCGT	391	7.40	7.40	50%	6	4	$12
	Gas – ICE	110	9.29	9.29	31%	1	1	$3
	Fuel Oil	28	12.02	12.02	26%	1	1	$39
LRZ3	Nuclear	586	10.25	10.25	100%	120	120	—
	Coal	252	10.24	10.24	40%	10	13	$112
	Gas Peaker	70	12.01	12.01	26%	1	1	$14
	Gas CCGT	391	7.40	7.40	50%	6	4	$12
	Fuel Oil	28	12.02	12.02	22%	1	1	$31

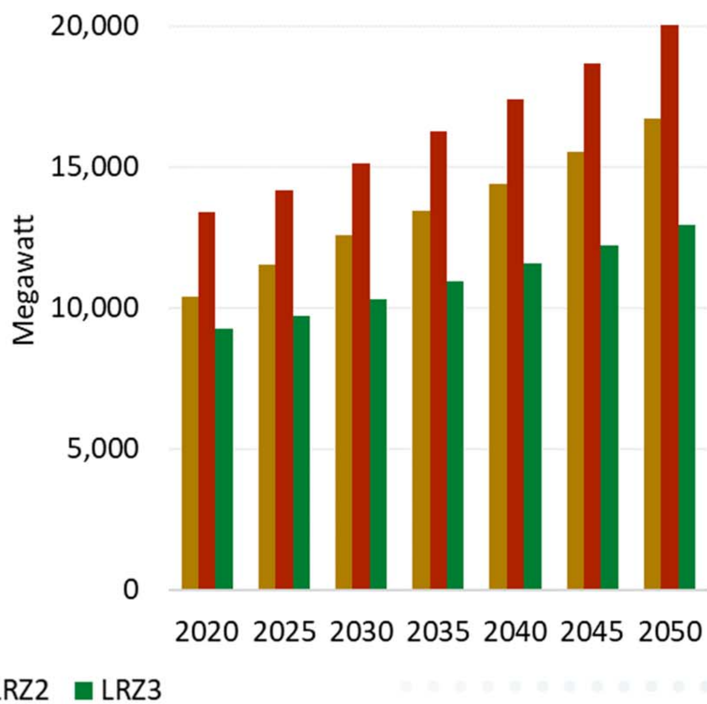
Load Forecasts
Other MISO Loads

- **Annual demand data from the 2018 MISO Independent Load Forecast**
  - Excluding NSP loads (from NSP forecast) from LRZ 1
  - Energy values account for losses and energy efficiency

External Zones Annual Energy Demand (TWh)

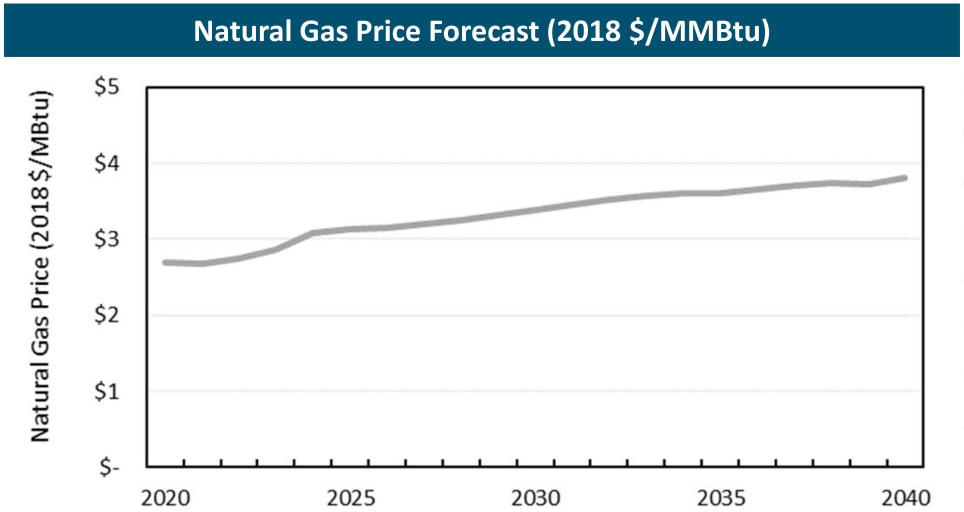


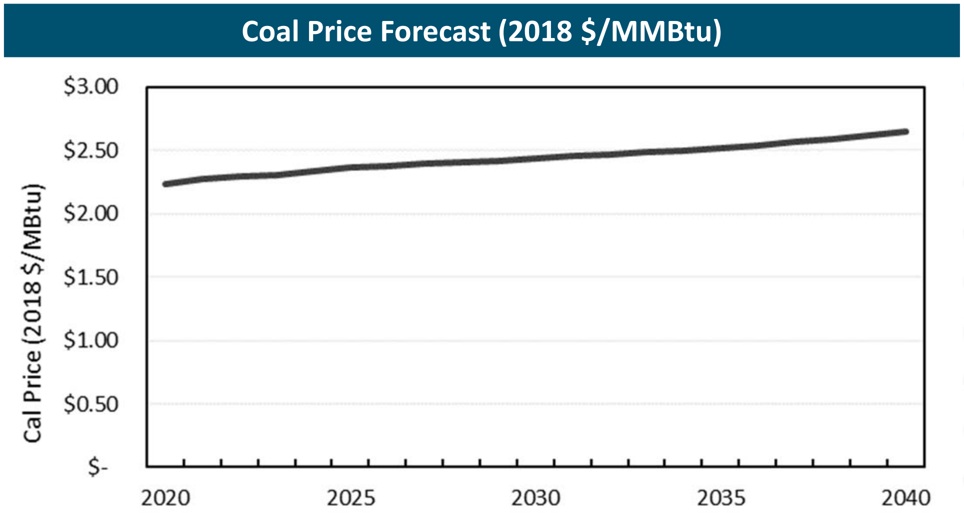
External Zones Non-Coincident Peak Demand (MW)



Fuel Price Forecasts

- Gas price forecast averages Xcel Energy fuel cost forecast for individual gas plants
- Coal price averages Xcel Energy fuel cost forecast for individual coal plants



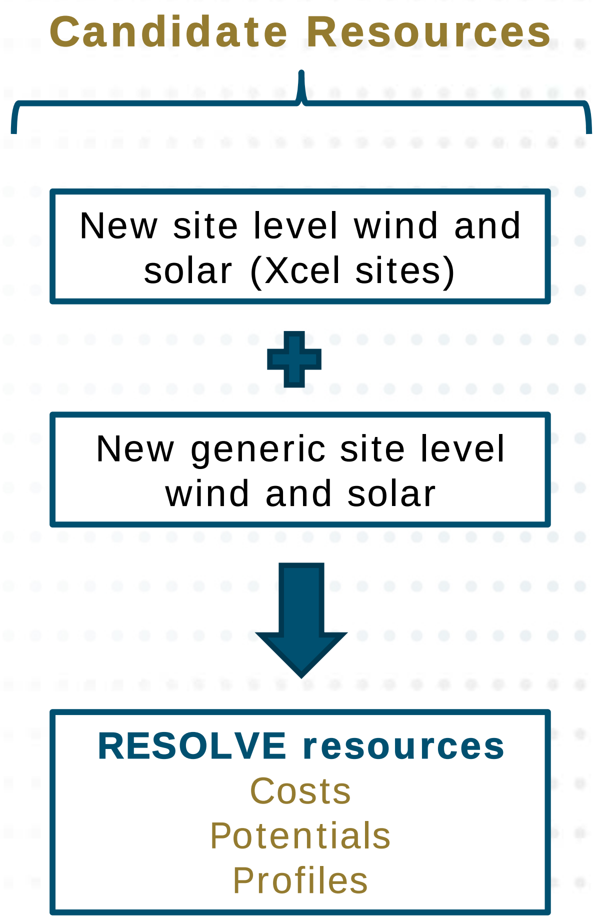


New Resource Options in RESOLVE

Resource Option	Examples of Available Options	Functionality
Natural Gas Generation	• Simple cycle gas turbines • Reciprocating engines • Combined cycle gas turbines	• Dispatches economically based on heat rate, subject to ramping limitations • Contributes to meeting reserve needs and ramping constraints
Renewable Generation	• Geothermal • Small Hydro • Solar PV (BTM, tracking, fixed) • Wind	• Produces zero-carbon generation that contributes to meeting RPS goals • Curtailable when necessary to help balance load
Energy Storage	• Batteries (>1 hr) • Pumped Storage (>12 hr)	• Stores excess energy for later use • Contributes to meeting reserve needs and ramping constraints
Energy Efficiency	• HVAC & appliances • Lighting	• Reduces load, retail sales, planning reserve margin need
Demand Response	• Interruptible tariff (ag) • DLC: space & water heating (res)	• Contributes to planning reserve margin needs

Developing a Renewable Supply Curve

- **Potential candidate site data for new wind and solar resources from Xcel is supplemented additional generic sites chosen by E3**
  - Goal: supplement existing sites with new potential regions for development
- **Site level data are grouped into representative resource regions**
  - RESOLVE resource costs represent capacity-weighted costs rolled up from site level data
- **RESOLVE resource potentials represent total summed site level potentials**



Renewable Cost & Potential Assumptions

- **Renewable costs and cost trajectories obtained from 2018 NREL ATB dataset**
- **Solar capacity potentials are assumed to be uncapped**
  - Regional potential = sum of capacity expansion cap of solar sites provided by Xcel
  - Generic E3 sampled solar sites are assigned values such that the minimum regional solar potentials = 1 GW
- **Past NREL analysis suggest that the technical potential of wind in the Minnesota region is effectively unconstrained**

	Source	Notes	2018 Installed Costs*	2030 Installed Costs	2050 Installed Costs
Solar - Tracking	2018 NREL ATB	Technology: "PV Utility Scale"	1092 $/kW	843 $/kW	686 $/kW
Wind		Assumed TRG2	1570 $/kW	1381 $/kW	1295 $/kW

*PV costs are reported in $/kW-DC

Energy Storage Cost Assumptions

- Energy storage cost projections derived from Lazard's *Levelized Cost of Storage 3.0*

	Source	2018 Installed Costs	2030 Installed Costs	2050 Installed Costs
Battery - Li	2017 Lazard LCOS 3.0, with E3 adjustments	Capacity: 286 $/kW Energy: 296 $/kWh Total: 367 $/kWh	Capacity: 141 $/kW Energy: 146 $/kWh Total: 181 $/kWh	Capacity: 114 $/kW Energy: 118 $/kWh Total: 147 $/kWh
Battery - Flow		Capacity: 1253 $/kW Energy: 224 $/kWh Total: 538 $/kWh	Capacity: 868 $/kW Energy: 155 $/kWh Total: 373 $/kWh	Capacity: 781 $/kW Energy: 140 $/kWh Total: 335 $/kWh

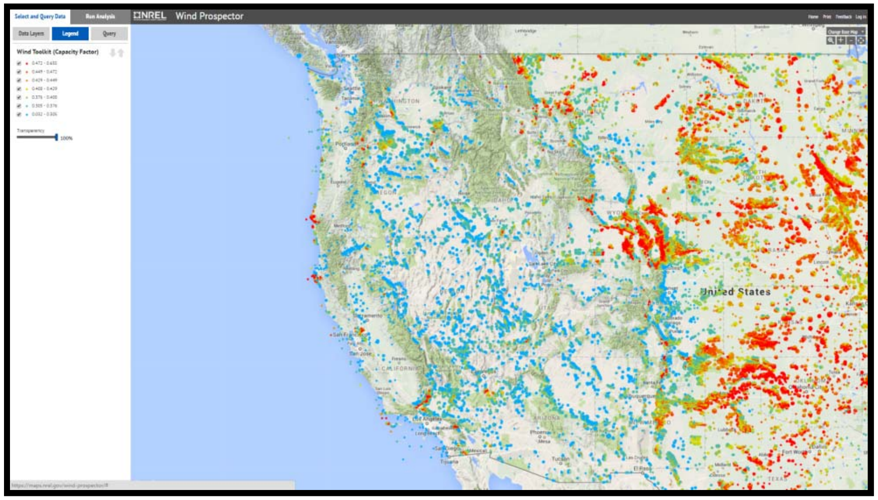
Load and Renewable Profiles

- Capturing correlations between load and variable renewables is necessary to understand operational and reliability impacts of high renewable penetrations
- This study will use weather-matched load and renewable profiles from 2007-2012 from the following sources:
  - Load: Xcel Energy recorded hourly loads
  - Wind: NREL WIND Toolkit
  - Solar: NREL National Solar Radiation Database (NSRDB)

Simulated Wind & Solar Profiles

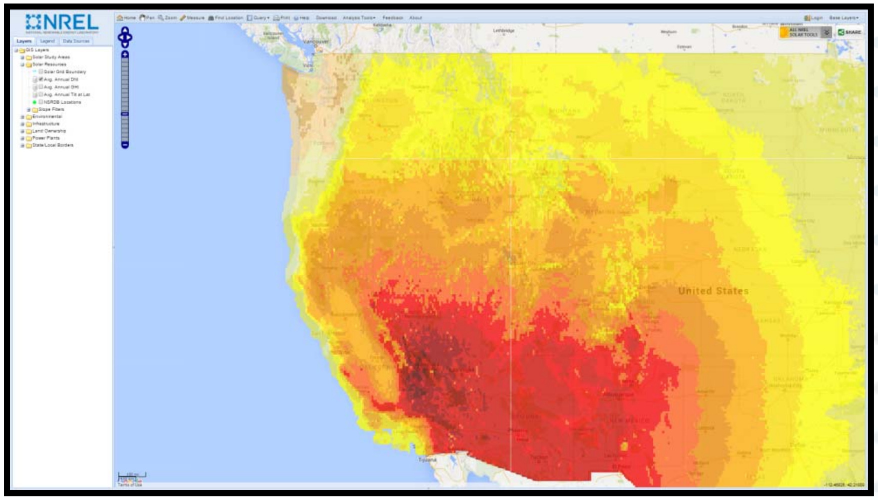
- NREL's Wind Integration National Dataset (WIND) and Solar Integration National Dataset (SIND) Toolkits provide best publicly available resource for variable renewable profiles

NREL Wind Prospector (link)



- 126,000 sites
- 5-min temporal resolution
- 2007-2013 historical period

NREL Solar Prospector (link)

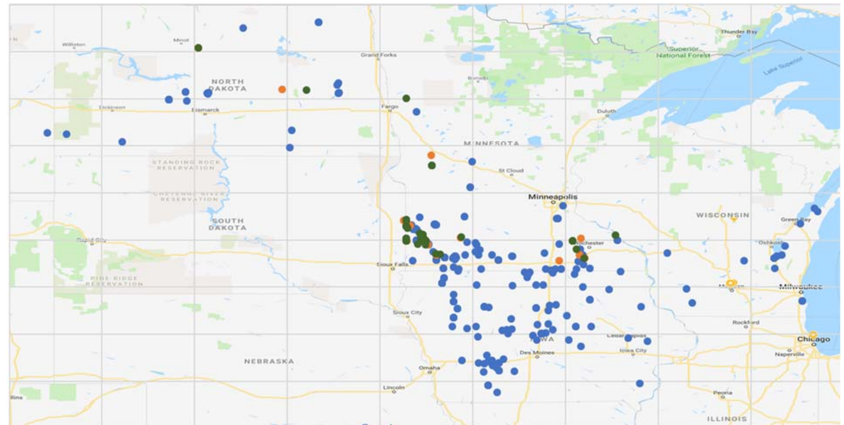


- 120,000 sites
- 1-min temporal resolution
- 2007-2013 historical period

Wind & Solar Site Selection

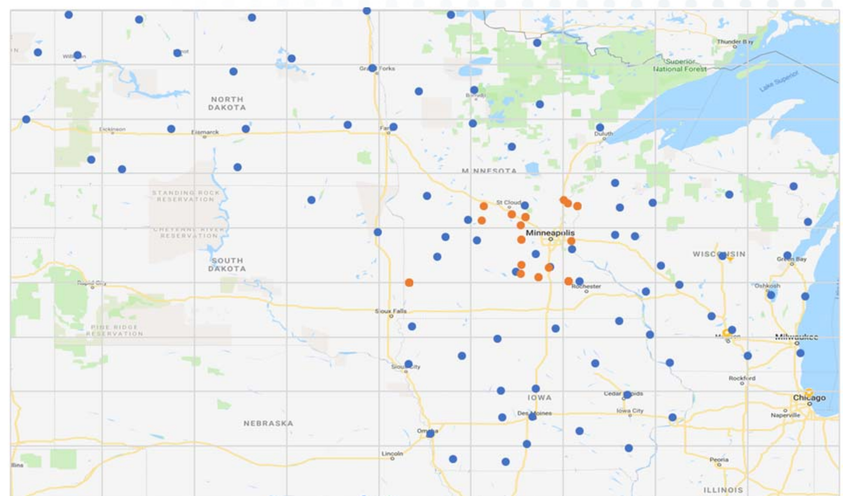
- **Three categories of wind sites:**
  - Existing Xcel wind resources (4.5 GW by 2025)
  - Prospective Xcel wind resources (4 GW)
  - Generic additional wind resources (14 GW)
- **Two categories of solar sites:**
  - Prospective Xcel solar sites (5 GW)
  - Generic additional solar sites (32 GW)

Wind Sites Modeled



• E3 Generic Wind • Xcel Prospective Wind • Xcel Existing Wind

Solar Sites Modeled

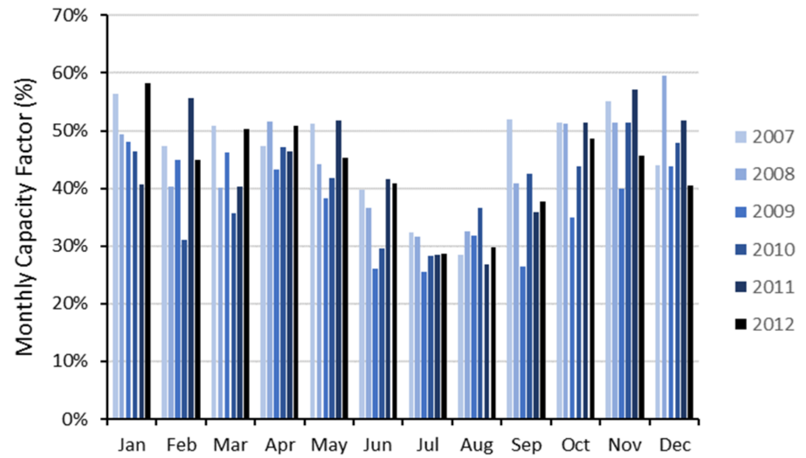


• E3 Generic Solar • Xcel Prospective Solar

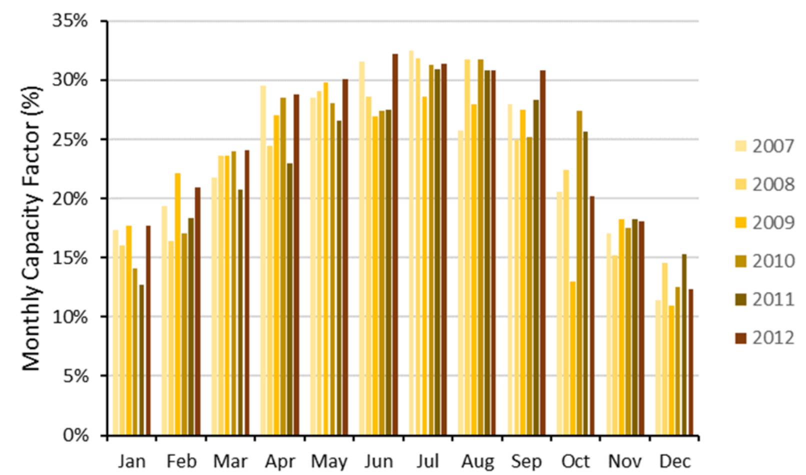
Seasonal Wind & Solar Performance

- **Wind capacity factors vary seasonally and across weather years**
  - Generally highest in winter, lowest in summer
- **Solar capacity factors show seasonal trends with less interannual variability**
  - Highest output in sprint and summer months

Simulated Wind Capacity Factor



Simulated Solar Capacity Factor



Hourly Patterns of Wind & Solar Output

Simulated Wind Capacity Factor

Month-Hour CF	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Jan	56%	56%	55%	55%	54%	54%	54%	54%	52%	44%	38%	34%	33%	34%	35%	39%	46%	54%	58%	59%	60%	59%	58%	57%
Feb	50%	49%	49%	48%	48%	48%	49%	48%	43%	35%	31%	30%	31%	32%	33%	34%	37%	44%	50%	52%	53%	53%	53%	52%
Mar	52%	51%	50%	50%	49%	49%	49%	46%	39%	34%	32%	32%	33%	34%	35%	36%	37%	39%	45%	50%	52%	53%	53%	52%
Apr	56%	56%	55%	55%	54%	54%	51%	42%	36%	36%	38%	39%	41%	42%	43%	44%	44%	44%	45%	49%	53%	55%	56%	56%
May	55%	55%	54%	54%	53%	51%	42%	33%	32%	34%	36%	38%	40%	41%	43%	44%	44%	43%	42%	46%	51%	53%	54%	54%
Jun	45%	45%	44%	43%	43%	40%	29%	23%	23%	25%	27%	28%	30%	31%	32%	33%	34%	33%	32%	36%	42%	45%	46%	46%
Jul	41%	40%	39%	38%	37%	35%	24%	16%	15%	17%	18%	19%	20%	21%	23%	24%	25%	25%	25%	32%	39%	42%	42%	42%
Aug	42%	41%	40%	40%	39%	38%	32%	22%	17%	18%	19%	20%	21%	22%	24%	24%	25%	24%	28%	36%	41%	43%	43%	43%
Sep	49%	49%	48%	47%	47%	46%	45%	37%	27%	25%	26%	28%	30%	31%	32%	32%	32%	32%	39%	45%	47%	49%	49%	49%
Oct	55%	55%	54%	53%	52%	52%	52%	50%	41%	33%	32%	33%	35%	37%	38%	39%	39%	43%	50%	54%	56%	57%	57%	56%
Nov	57%	57%	56%	55%	55%	54%	54%	54%	51%	42%	36%	34%	34%	36%	37%	39%	44%	52%	57%	60%	60%	60%	59%	58%
Dec	52%	52%	52%	52%	52%	52%	52%	52%	51%	46%	39%	34%	33%	32%	34%	38%	46%	52%	55%	56%	56%	55%	54%	53%

Simulated Solar Capacity Factor

Month-Hour CF	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Jan	0%	0%	0%	0%	0%	0%	0%	0%	18%	40%	48%	52%	54%	54%	52%	48%	23%	0%	0%	0%	0%	0%	0%	0%
Feb	0%	0%	0%	0%	0%	0%	0%	2%	33%	47%	51%	54%	56%	57%	55%	51%	43%	7%	0%	0%	0%	0%	0%	0%
Mar	0%	0%	0%	0%	0%	0%	1%	17%	45%	53%	57%	60%	62%	62%	59%	56%	48%	29%	1%	0%	0%	0%	0%	0%
Apr	0%	0%	0%	0%	0%	0%	16%	28%	53%	61%	65%	67%	68%	66%	63%	58%	50%	34%	6%	0%	0%	0%	0%	0%
May	0%	0%	0%	0%	0%	7%	24%	33%	56%	64%	66%	68%	68%	66%	63%	59%	52%	37%	13%	3%	0%	0%	0%	0%
Jun	0%	0%	0%	0%	0%	11%	25%	31%	54%	62%	65%	67%	67%	65%	63%	59%	54%	41%	16%	7%	0%	0%	0%	0%
Jul	0%	0%	0%	0%	0%	8%	27%	32%	59%	68%	71%	72%	73%	71%	69%	66%	60%	47%	18%	6%	0%	0%	0%	0%
Aug	0%	0%	0%	0%	0%	1%	22%	30%	57%	66%	70%	72%	73%	71%	69%	65%	58%	42%	12%	1%	0%	0%	0%	0%
Sep	0%	0%	0%	0%	0%	0%	8%	31%	57%	66%	70%	71%	72%	71%	68%	62%	53%	30%	2%	0%	0%	0%	0%	0%
Oct	0%	0%	0%	0%	0%	0%	0%	22%	48%	56%	60%	62%	62%	60%	56%	49%	36%	3%	0%	0%	0%	0%	0%	0%
Nov	0%	0%	0%	0%	0%	0%	0%	4%	36%	49%	54%	57%	58%	55%	50%	42%	10%	0%	0%	0%	0%	0%	0%	0%
Dec	0%	0%	0%	0%	0%	0%	0%	0%	17%	36%	40%	43%	45%	44%	43%	39%	2%	0%	0%	0%	0%	0%	0%	0%

CERTIFICATE OF SERVICE

I, Carl Cronin, hereby certify that I have this day served copies of the foregoing document on the attached lists of persons.

- xx by depositing a true and correct copy thereof, properly enveloped with postage paid in the United States mail at Minneapolis, Minnesota

- xx electronic filing

Docket No. E002/RP-15-21

Dated this 23rd day of October 2018

/s/

____

Carl Cronin
Case Specialist

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