Load Forecast Uncertainty: Dynamic Reserves at MISO

2026 MRO Reliability, Security and CMEP Summit

May 13, 2026

Purpose & Key Takeaway

Purpose

Share recent and ongoing work at MISO to enhance operating reserve products with dynamic reserves to prepare for increased uncertainty and variability with more weather-dependent generation

Key Takeaways

- Operational challenges are magnifying as the resource mix evolves and has materialized on discrete days
- In response, reserves for each operating day will no longer be static quantities and, instead, will change daily
- AI/ML will be used to calculate reserves based upon forecasted uncertainty and variability for each operating day

Meet MISO

MISO's reliability footprint and regional offices

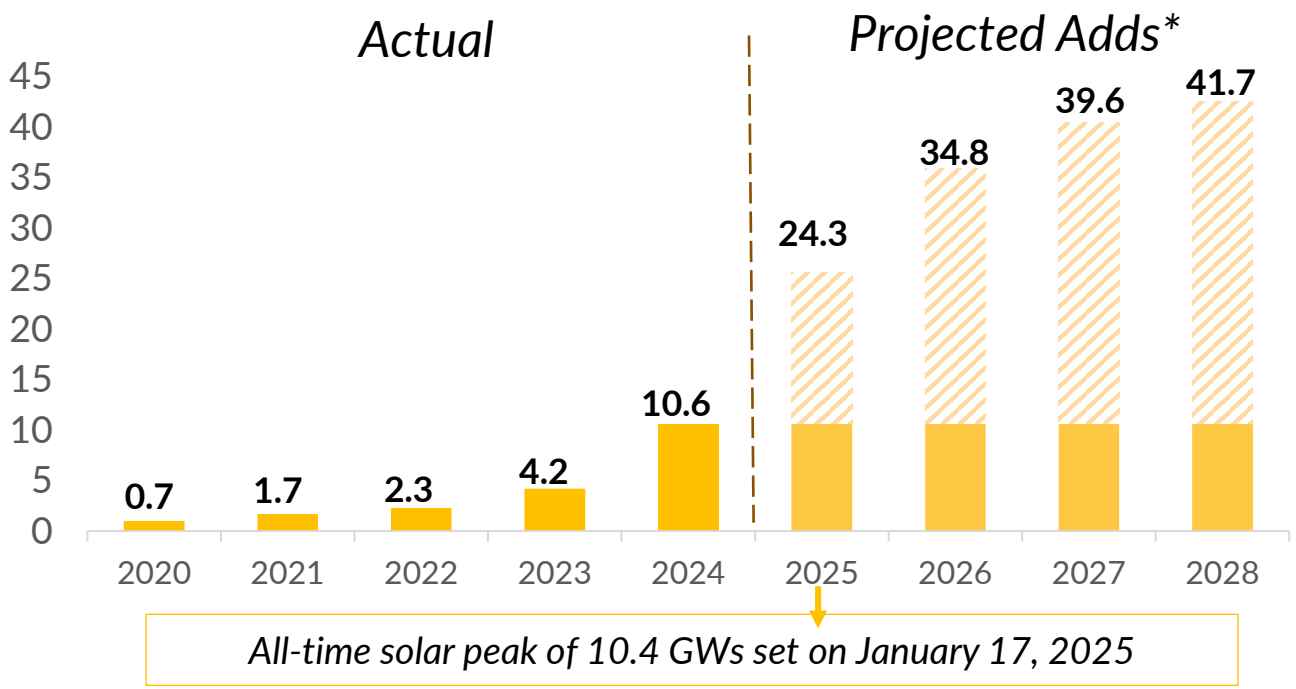
KEY FACTS

Area Served	15 U.S. States and Manitoba, Canada
Population Served	45 Million
Transmission Line	79,000 Miles
Generating Units	Approximately 2,000
Record Demand	127.1 GW 7/20/2011
Wind Peak	26.6 GW 1/3/2026
Solar Peak	18.6 GW on 4/20/2025
Total MISO Members	230+
Market Participants	550+
Market Transactions	Over $53 billion in 2025
Carbon Reduction	Approximately 32% since 2014

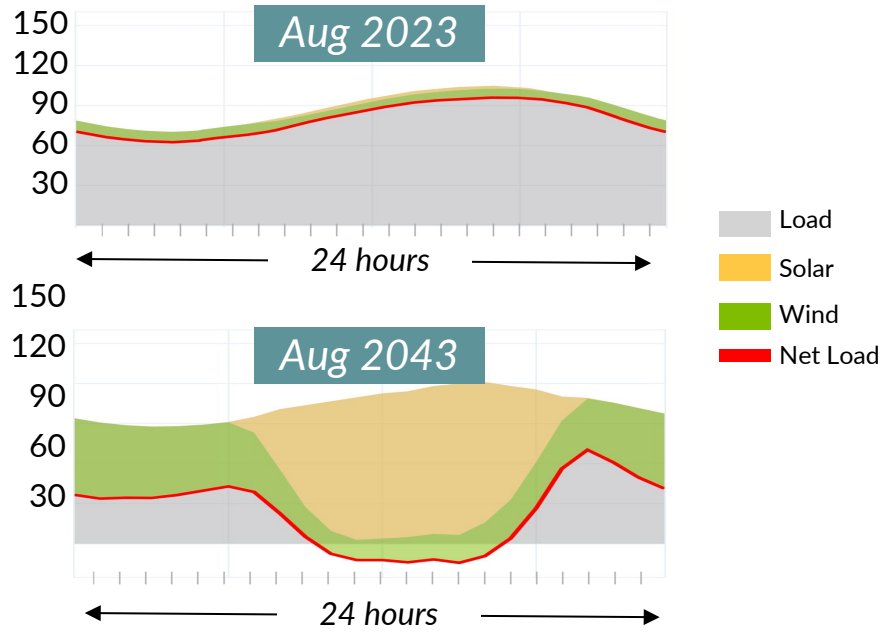
Data as of 4/23/2026

The solar growth trend will result in increasing net load ramps, potentially exceeding 100 GW by 2043

Installed Solar Capacity (GW)



System Net Load (GW)



MISO IS MEETING THIS EVOLVING NEED BY

- Dynamically determining ramp capability reserve needs
- Enhancing how we commit and dispatch generation
- Evaluating need for market products to manage longer-term ramp

*Signed Generator Interconnection Agreements Only

Coordinating and executing on the priorities within the Reliability Imperative is required to address challenges to reliability

MARKET REDEFINITION	Forecast risks and provide market signals to address changing grid reliability needs
TRANSMISSION EVOLUTION	Develop transmission plans and align new generation interconnection with member-driven plans
OPERATIONS OF THE FUTURE	Modernize MISO's operational capabilities to ensure a reliable, efficient and resilient grid amidst the evolving energy landscape
SYSTEM ENHANCEMENTS	Advance digital tools and architecture to securely drive grid and market evolution

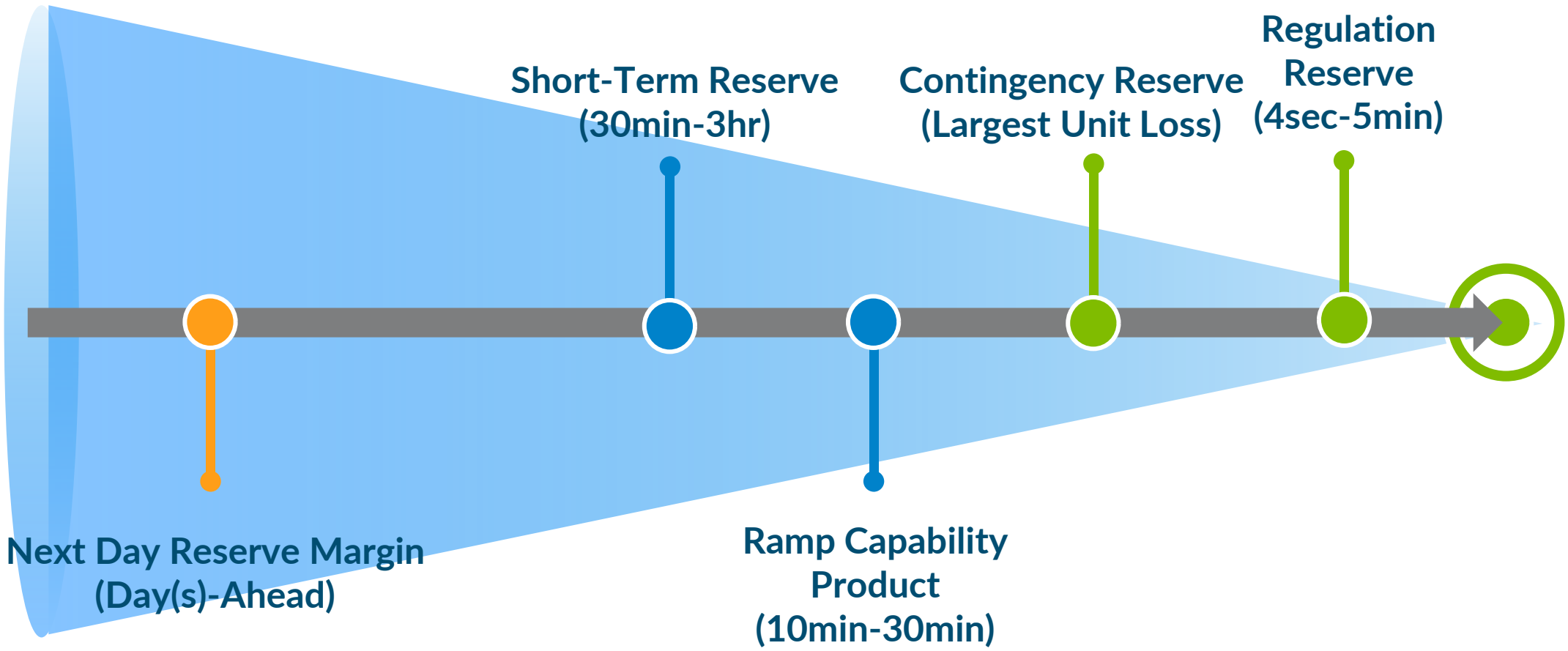
MISO operates Day-Ahead and Real-Time Energy and Ancillary Service markets with reliability commitments in-between

Forecast Inputs	Hourly forecast up to 7-day ahead	Market Participant (MP) Offer	Hourly forecast Day-Ahead	Hourly and 5 min forecasts hours ahead	5min forecast by MISO or MP
Market & Reliability Processes	Multi-Day Forward RAC	Day-Ahead Market	Next-Day Forward RAC	Intra-Day RAC and LAC	Real-Time Market and UDS

- In addition to the operating horizon, MISO also administers markets in the planning horizon
  - Planning Resource Auction (PRA)
  - Auction Revenue Rights (ARR) and Financial Transmission Rights (FTR)
- After Real-Time market, Automated Generation Control (AGC) ensures generation is balanced with actual load every four seconds

*Notes: RAC: Reliability Assessment Commitment; LAC: Look Ahead Commitment; UDS: Unit Dispatch System

The Energy and Ancillary Service markets co-optimize Energy and reserve products that cover uncertainties across different timeframes



MISO is making Next Day reserve margin, Short-Term Reserve, Ramp Capability Product and Regulation Reserve "dynamic"

Net Uncertainty Forecast and Dynamic Reserve process includes two key design features

1. **Set different levels of Reserve Requirements (Normal /High)**
   - This is similar to having different insurance coverage
   - Normal/High requirements are derived from quantified net uncertainty from historical market days
   - Reserve Requirements are updated every season

2. **Mechanism to *forecast* uncertainty and *dynamically change* Reserve Requirements in advance**
   - Different reserve products require separate forecast mechanisms/models
   - When forecast models predict HIGH uncertainty for any of the reserve products, reserve requirements are overwritten to High level*

* before Day-Ahead market closes at 10:30 EPT

Net Uncertainty Quantification and Seasonal Reserve Requirements

Product	ND FRAC Commitment Threshold*	Short-Term Reserve	Ramp Capability (Uncertainty Component)	Regulation Reserve
Quantified Uncertainty Component	Timeframe: Next-Day • Gen Availability • Load • Renewable • NSI • Stranded MW	Timeframe: 30min to 3hour • Netload error • Generation outage/derate • Commitment	Timeframe: 10min • Netload error • Thermal generation not following dispatch	Timeframe: 4sec to 5min • Tie Error • Regulation MW not available due to ramp sharing
Requirements	Normal / Medium / High • Four seasons • Systemwide / NorthCentral / South	Normal / High • 24 hours × four seasons • Systemwide / NorthCentral / South	Normal / High • 24 hours × four seasons • Systemwide	Normal / High • 24 hours × monthly × weekday/weekend • Systemwide
Reference		doi: 10.1109/TPWRS.2022.3200697** 20260414 RSC Item 07	20250828 RSC Item 09 20260414 RSC Item 07	20250417 RSC Item 05 20260414 RSC Item 07

* Currently managed by Next-Day (ND) Forward Reliability Assessment and Commitment (FRAC) Operating process. **Not a market product**.
** Y. Chen, "Addressing Uncertainties Through Improved Reserve Product Design," in IEEE Transactions on Power Systems, vol. 38, no. 4, pp. 3911-3923, July 2023

Net Uncertainty Forecast Models for each reserve product

Product	ND FRAC Commitment Threshold* & Short-Term Reserve	Ramp Capability (Uncertainty Component)	Regulation Reserve
Net Uncertainty Forecast Model	ND FRAC Net Uncertainty Forecast Model	Up Ramp Uncertainty Forecast/Classifier Model	Regulation Uncertainty Forecast/Classifier Model
Forecast Output	Hourly uncertainty MW (then converted to Low/Medium/High labels)	Hourly uncertainty labels (Normal / High)	Hourly uncertainty labels (Normal / High)
Implication	• Set Commitment Threshold recommendation according to L/M/H labels • Set Short-Term Reserve to High requirement for hours with High uncertainty label in next operating day	Set Ramp Capability (Uncertainty Component) to High requirement for hours with High uncertainty label in next operating day	Set Regulation Reserve to High requirement for hours with High uncertainty label in next operating day
State	• January 2024 (peak load hour full implementation) • March 2026 (all-hour uncertainty full implementation)	• June 2025 (Requirement) • Estimate June 2026 (full implementation)	• March 2026 (Requirement) • Estimate Sept 2026 (full implementation)

* Currently managed by Next-Day (ND) Forward Reliability Assessment and Commitment (FRAC) Operating process. **Not a market product**.

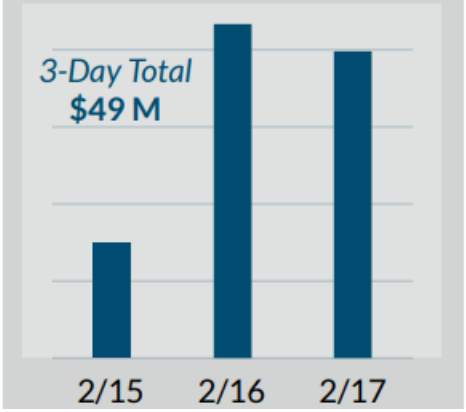
Short-Term Reserves

Operations of the Future work and dynamic STR have positioned MISO well for efficient reliability through the fleet transition, as evidenced by our performance across major storms.

URI
February 15-17, 2021
President's Day

Temperature	13˚F
Peak Demand	103 GW
Renewable Output	7 GW
Incremental Outages	21 GW

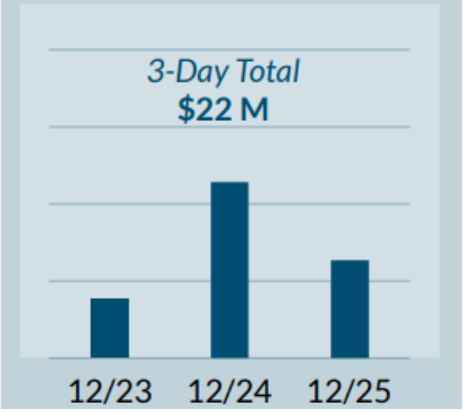
*Uplift**



ELLIOTT
December 23-25, 2022
Christmas

Temperature	3.7˚F
Peak Demand	107 GW
Renewable Output	19 GW
Incremental Outages	21 GW

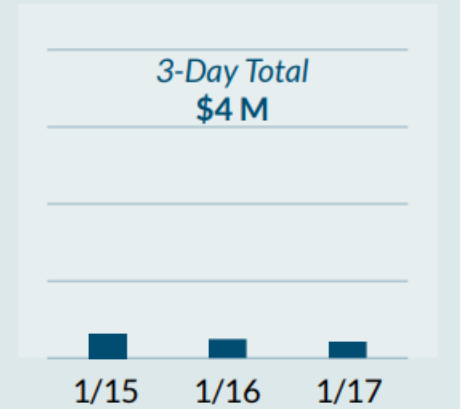
*Uplift**



HEATHER
January 15-17, 2024
Martin Luther King Jr. Day

Temperature	15.5˚F
Peak Demand	106 GW
Renewable Output	17 GW
Incremental Outages	5 GW

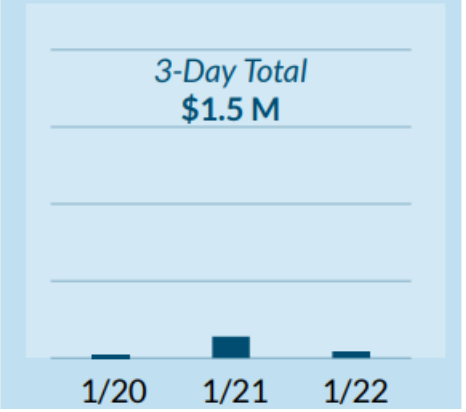
*Uplift**



ENZO
January 20-22, 2025
Martin Luther King Jr. Day

Temperature	6.5˚F
Peak Demand	108 GW
Renewable Output	19 GW
Incremental Outages	9 GW

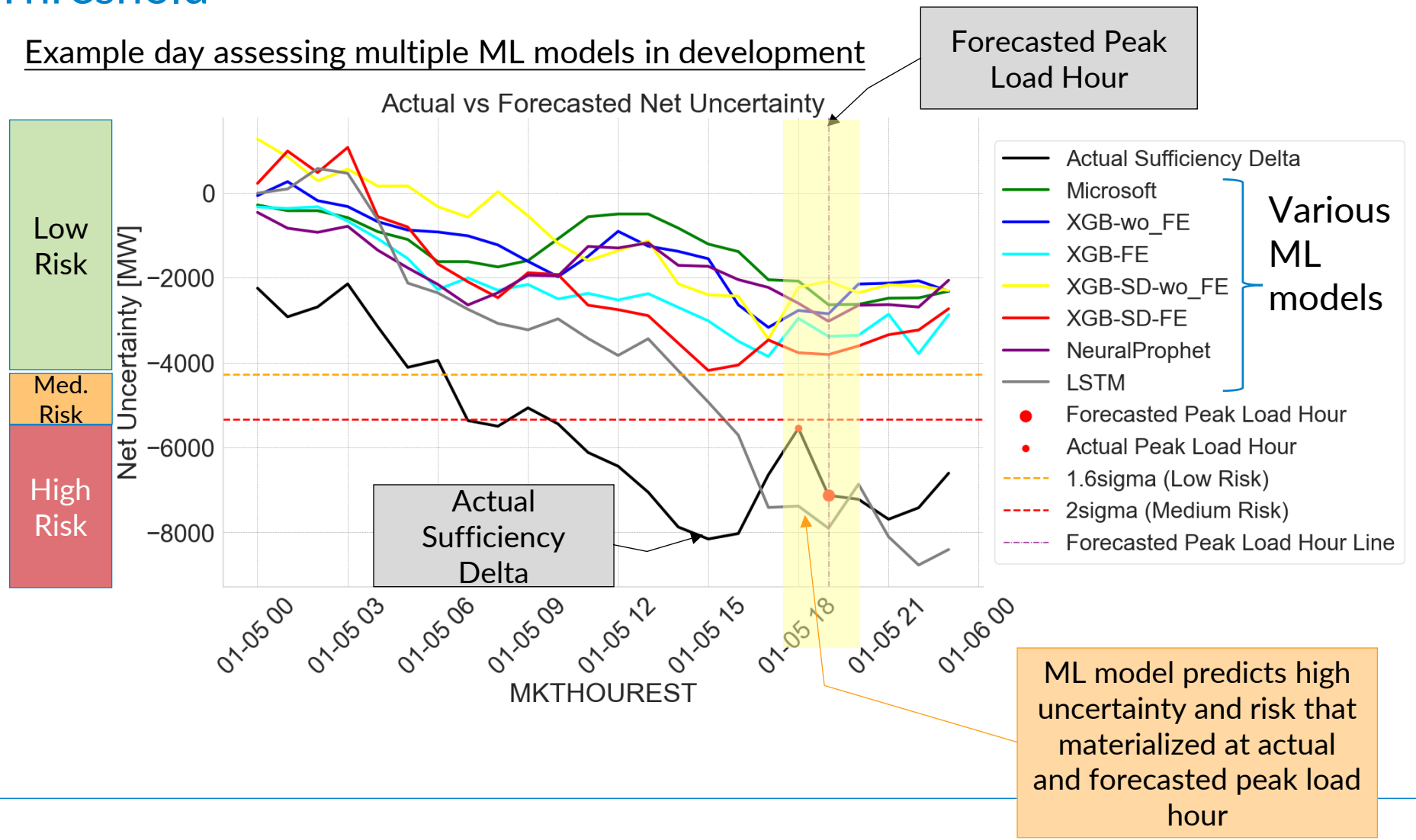
*Uplift**



Source: MISO Operations Report, Markets Committee of the Board of Directors, March 11, 2025

Day Ahead Net Load Uncertainty Prediction Machine Learning model is used to Dynamically Set Short-Term Reserve Requirement and Next-Day Reserve Margin Threshold

Example day assessing multiple ML models in development



- MISO uses deterministic day ahead net load uncertainty prediction ML model to dynamically set Short-Term Reserve requirement and Next-Day reserve margin threshold.
- Markets R&D is exploring probabilistic day ahead net uncertainty prediction models

ML: Machine Learning

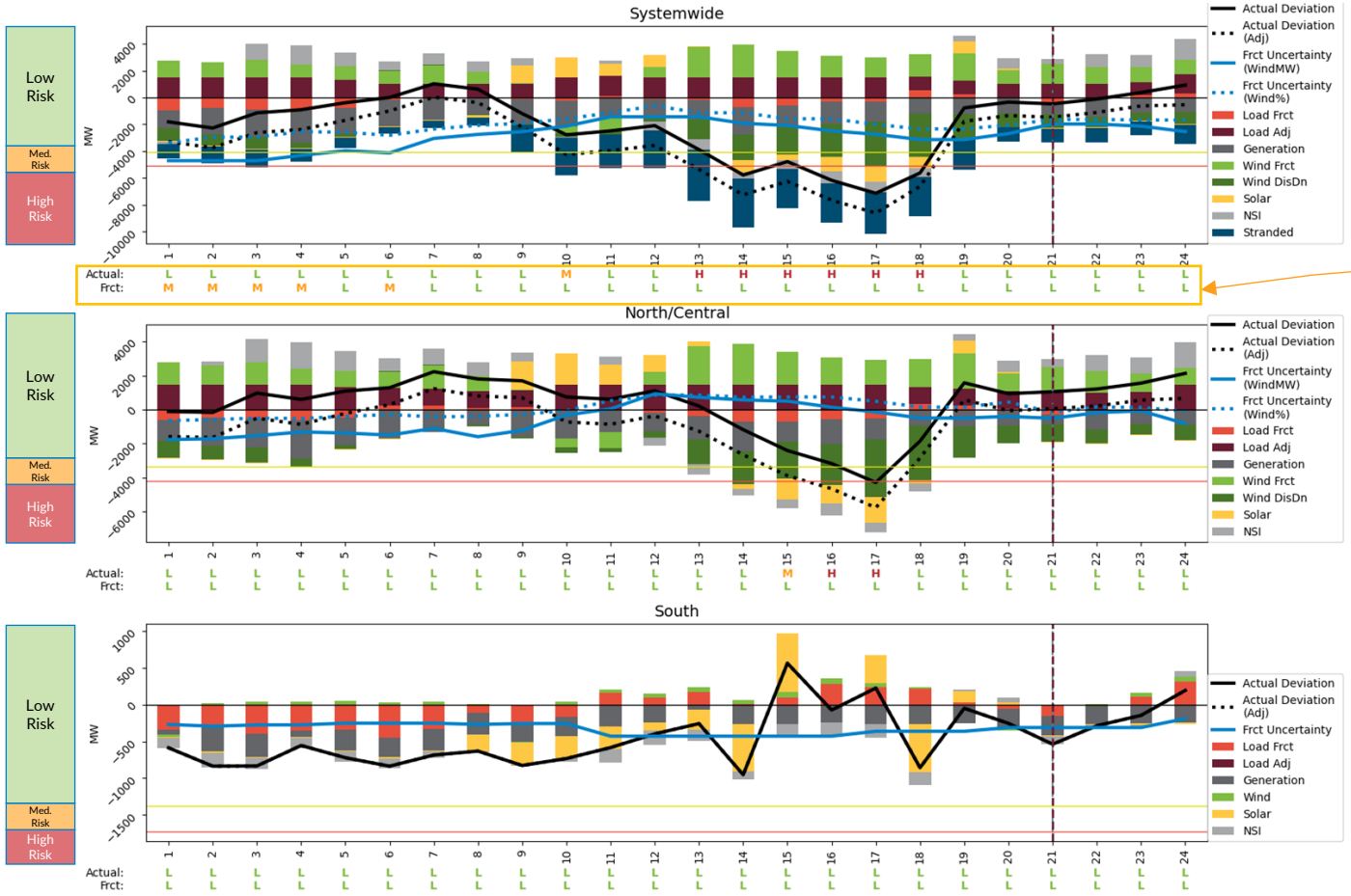
MISO begins transition to all-hour uncertainty, moving away from traditional peak-hour.

Unprecedented load growth, significant increases in renewable generation, non-conforming loads, and complex load pockets continue to challenge the complexities of load forecasting and managing uncertainty.

MISO is moving away from traditional peak-hour forecasting.

All-hours are important and it has become critical to understand the risk and uncertainty for each hour.

All-Hour Uncertainty

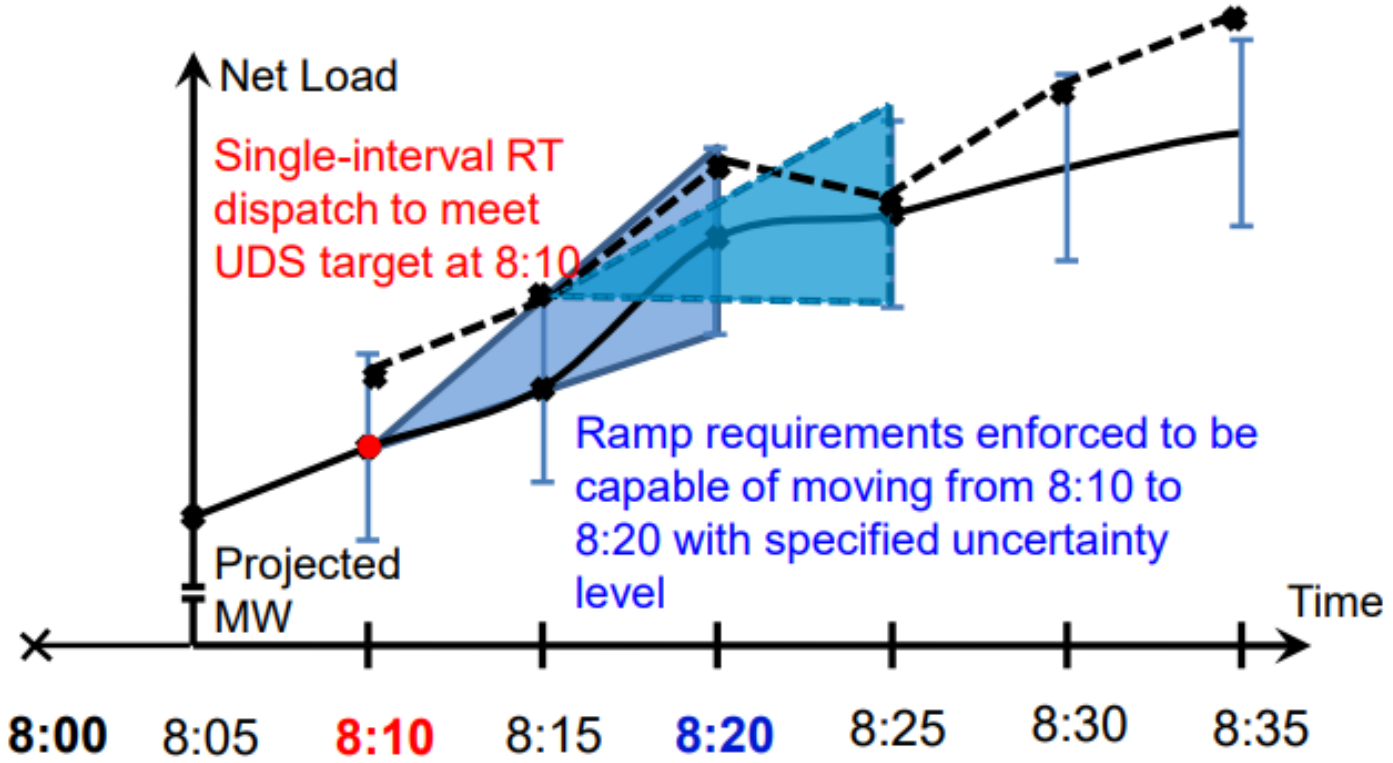


ML model predicts high, medium, or low uncertainty for each hour

Ramp Capability Product

Ramp Capability Product Requirement

- Ramp Capability Product is designed to manage both expected (variations) and unexpected (uncertainties) in the “net load”



Dynamic Ramp Capability Product Requirement (Uncertainty Component)

- 10min Ramp Net Uncertainty Quantification and Requirement for Ramp Capability Product (RCP) Uncertainty Component

Component 1: Net Load Uncertainty	Component 2: Gen Error (Thermal units not following dispatch)
For each UDS interval: 10min Net Load Uncertainty = Load Uncertainty 10min – (Wind Uncertainty 10min + Solar Uncertainty 10min), where Load Uncertainty 10min = Load Actual – Short-Term Load Forecast Wind/Solar Uncertainty 10min = (Wind/Solar Actual + Curtailment) – wind/solar short-term forecast	For each UDS interval: Track each thermal unit's dispatch MW and energy MW and calculate the difference
Hourly values are determined by 95th (Normal) and 97th (High) percentiles of Up Uncertainty	Hourly values are determined by 95th (Normal) and 97th (High) percentiles of Abs (Negative Gen Uncertainty)

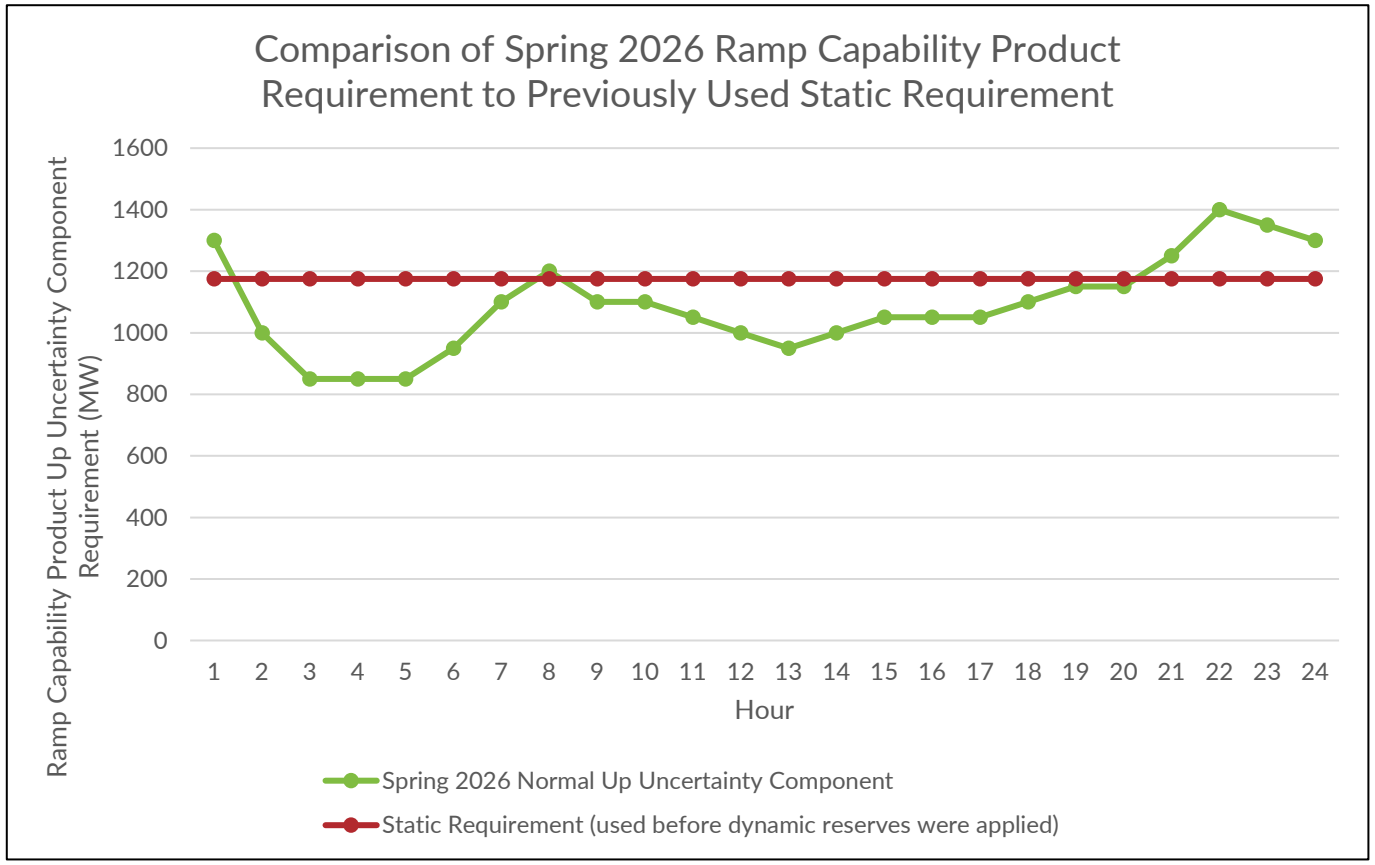
For deriving RCP Uncertainty Component:

Component 1 [(95 / 97 percentile)] +
Component 2 [(95 / 97 percentile)]

Reference: 20260414 RSC Item 07
Historical data: Same season over the last two years with 70% weight on last year

Seasonally-updated Ramp Capability Product up uncertainty component requirement varies each hour, better reflecting the anticipated uncertainty hourly variation

- Normal uncertainty Ramp Capability Product Up requirements are calculated and published seasonally
- High uncertainty Ramp Capability Product Up requirements will be published later in 2026 when operationalized



Regulation

Dynamic Regulation Reserve Requirement

- Methodology Improvement for derive Regulation Requirement

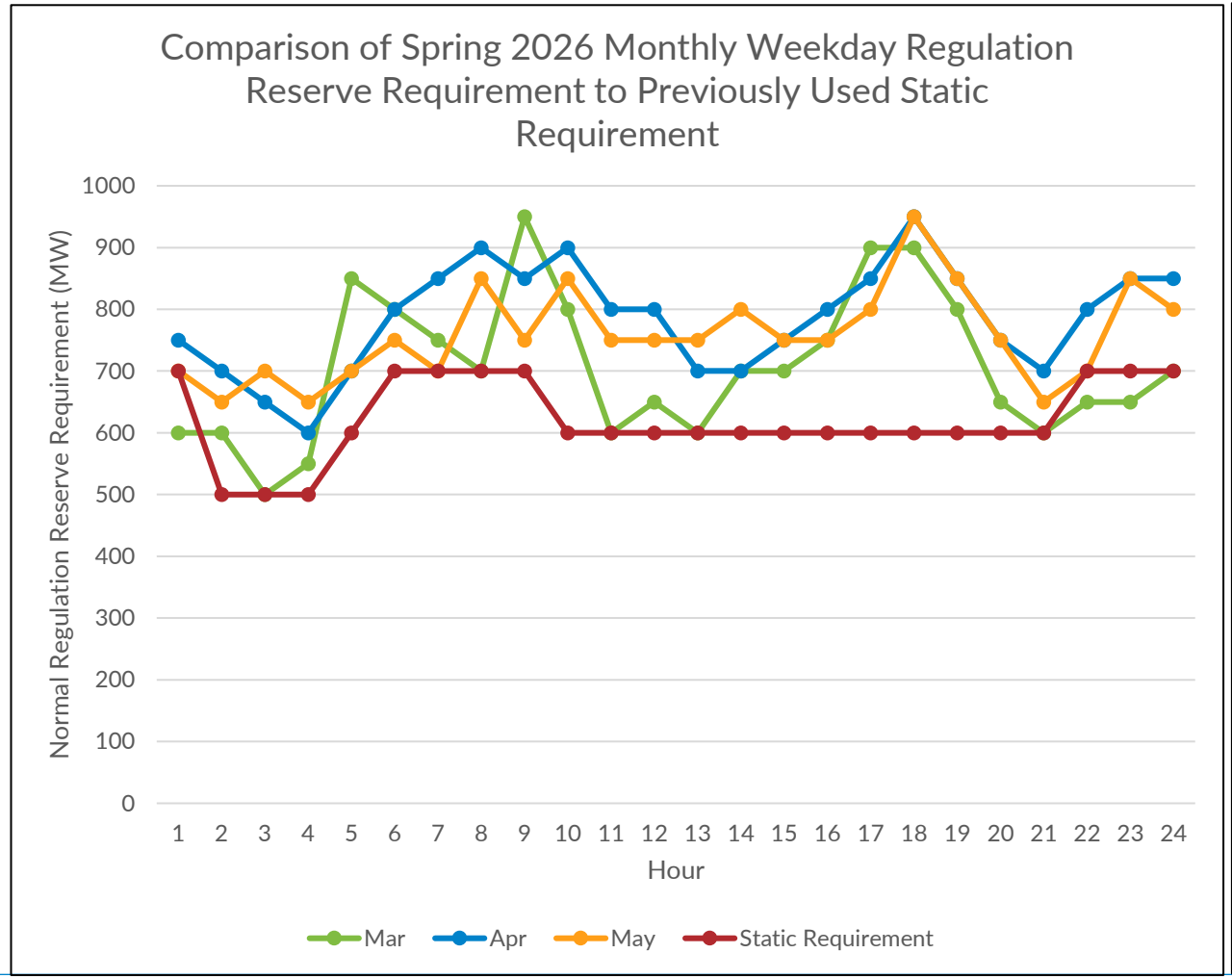
Component 1: Tie Error	Component 2: Regulation Capacity not available for deployment because of ramp sharing
Historical data: Same season over the last two years with 70% weight on last year	
Hourly values are determined by 95th (Normal) and 97th (High) percentiles plus a scaling factor to account for growth of renewable capacity	Mean of Component 2

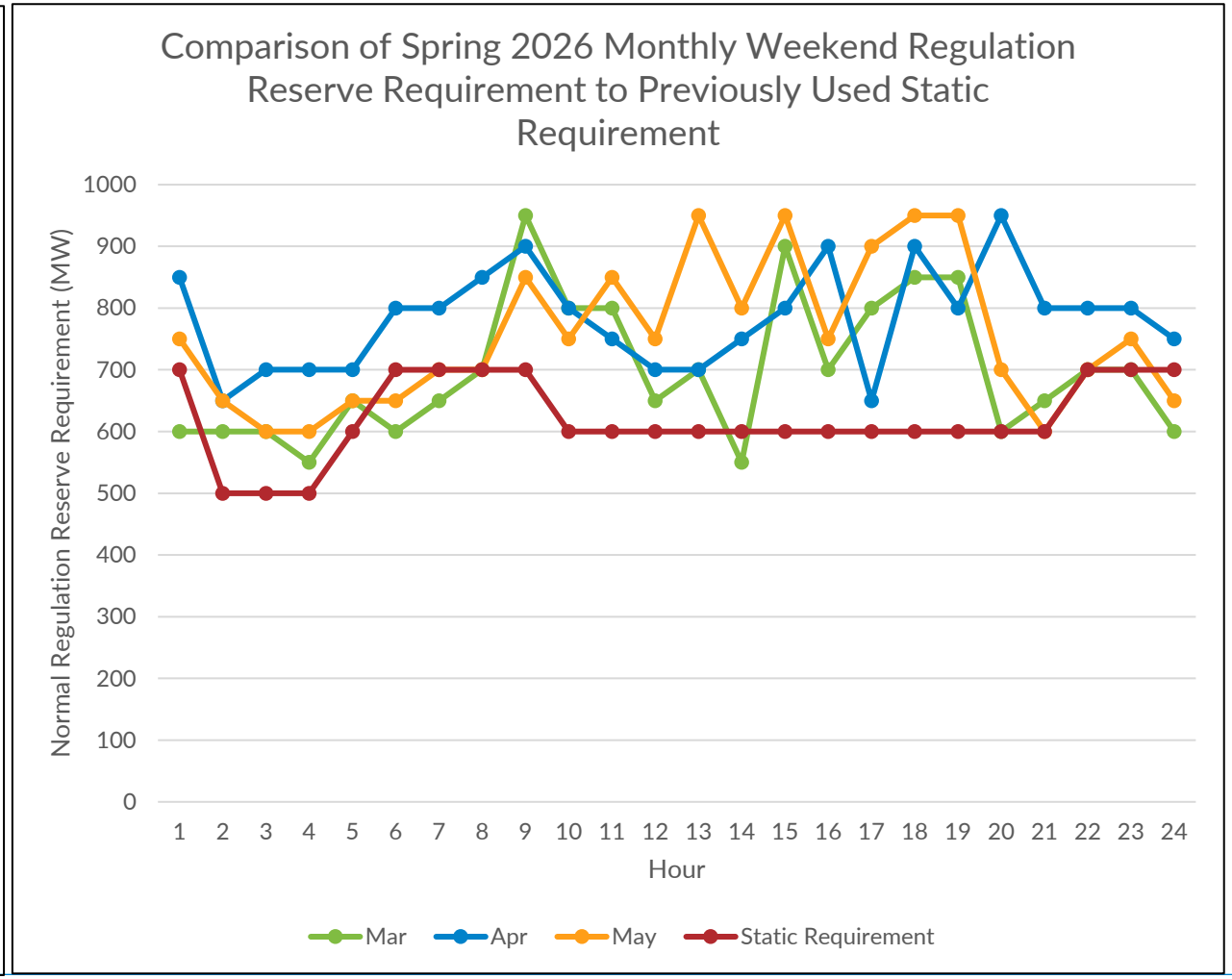
For deriving Regulation Requirement:

Component 1 [95 / 97 percentile]*scaling factor
+
Component 2 [Mean]

Reference: 20260414 RSC Item 07

Seasonally-updated monthly Regulation reserve requirement varies each month and hour, better reflecting the anticipated monthly and hourly uncertainty variation





Next Steps

- Apply the next-day process to change the Regulation and Ramp requirements dynamically based on high or normal uncertainty
  - Test Regulation and Ramp forecast uncertainty Machine Learning models
  - Apply the process
- Improve Short-Term Reserve all hours uncertainty process
  - Test all hours Short-Term Reserve uncertainty forecast classification model
  - Apply process improvements

Contact

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Appendix

Resources

- Short-Term Reserve Uncertainty design described in paper: Y. Chen, "Addressing Uncertainties Through Improved Reserve Product Design," in *IEEE Transactions on Power Systems*, vol. 38, no. 4, pp. 3911-3923, July 2023, doi: 10.1109/TPWRS.2022.3200697.

- STR, Ramp Capability, and Regulation Requirements are posted under Related Documents on the Market Subcommittee (MSC) page on the MISO website at via the URL below:

  Engage > Stakeholder Entities and Workshop > Market Subcommittee > Related Documents
  https://www.misoenergy.org/engage/committees/market-subcommittee/

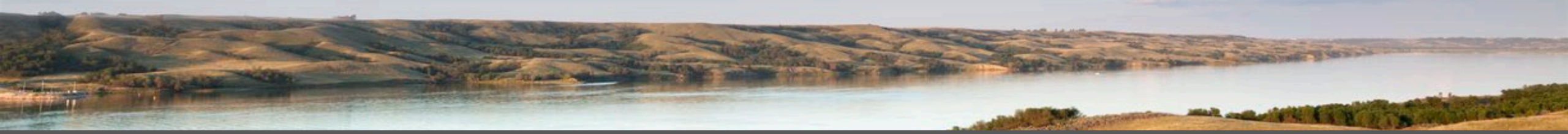
- Stakeholder materials posted for MISO Dashboard items:
  - RSC-2024-1: Dynamic Regulation Reserve Requirement
  - RSC-2024-2: Dynamic Ramp Capability Product Requirement (Uncertainty Component)

OUR FUTURE, OUR PLAN FOR NUCLEAR POWER

MRO Reliability, Security and CMEP Summit

May 13, 2026

David M. Brock



SaskPower
Powering our future®

About Saskatchewan

We have the **food, fuel, fertilizer and the critical minerals** the world needs.

About Saskatchewan

Area: 651,036 km^2 (251,366 mi^2)

Almost the size of Texas

Home to 1.27 million people

Centre of the North American power grid

About SaskPower

STATE-OWNED ENTERPRISE

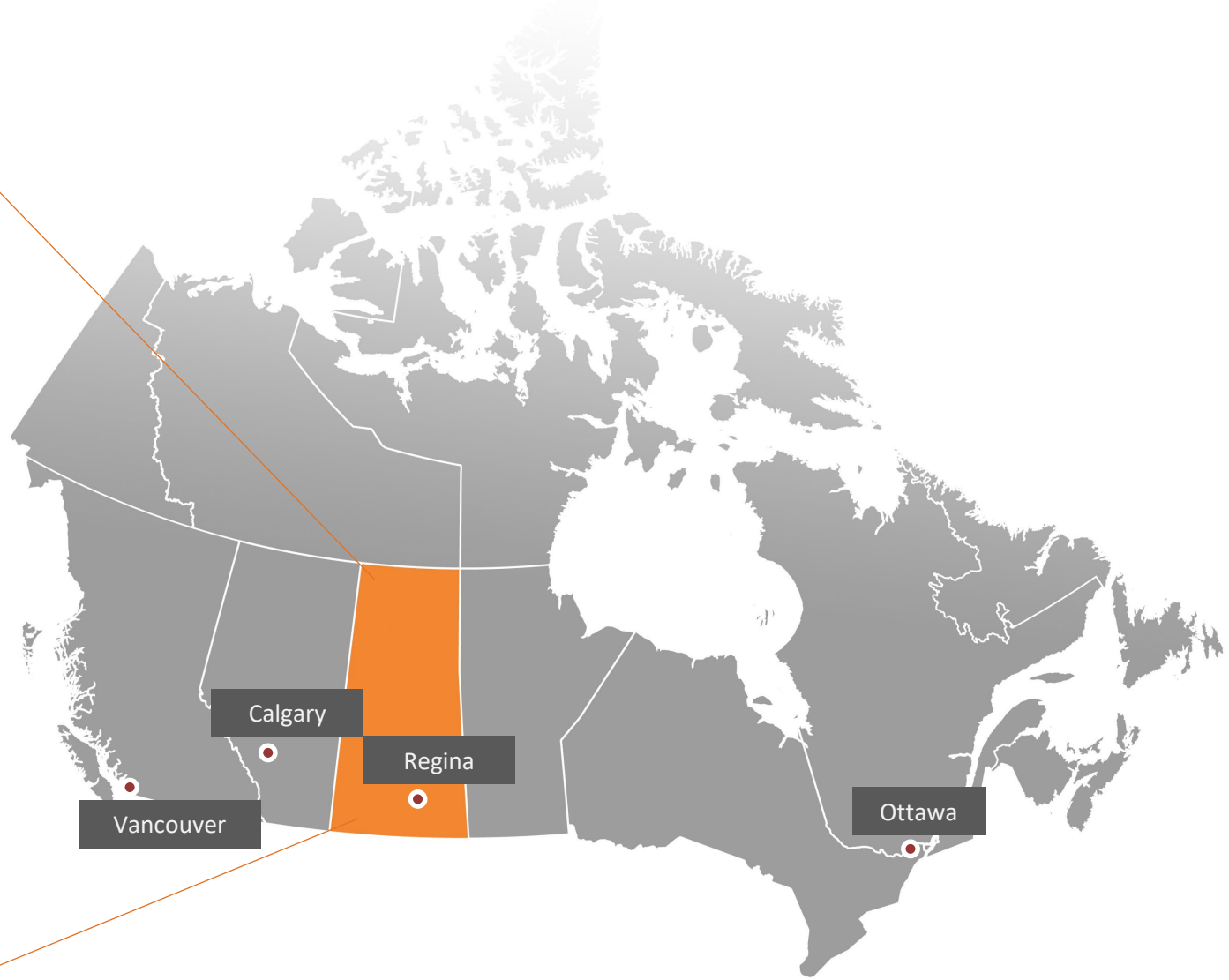
VERTICALLY INTEGRATED UTILITY

560,000 CUSTOMERS

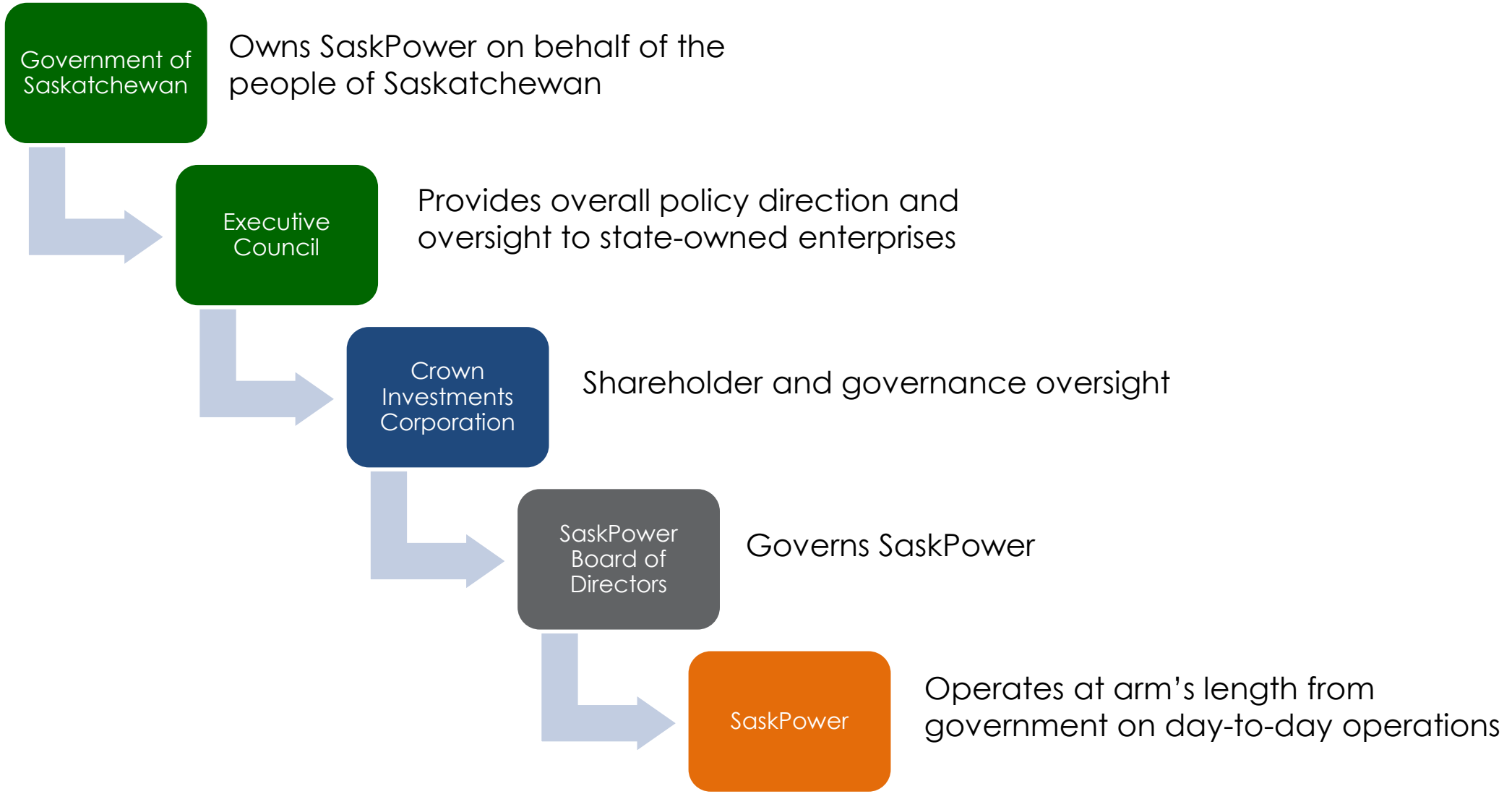
6,000 MW CAPACITY

159,000 KM OF POWER LINES

3,910MW RECORD PEAK LOAD



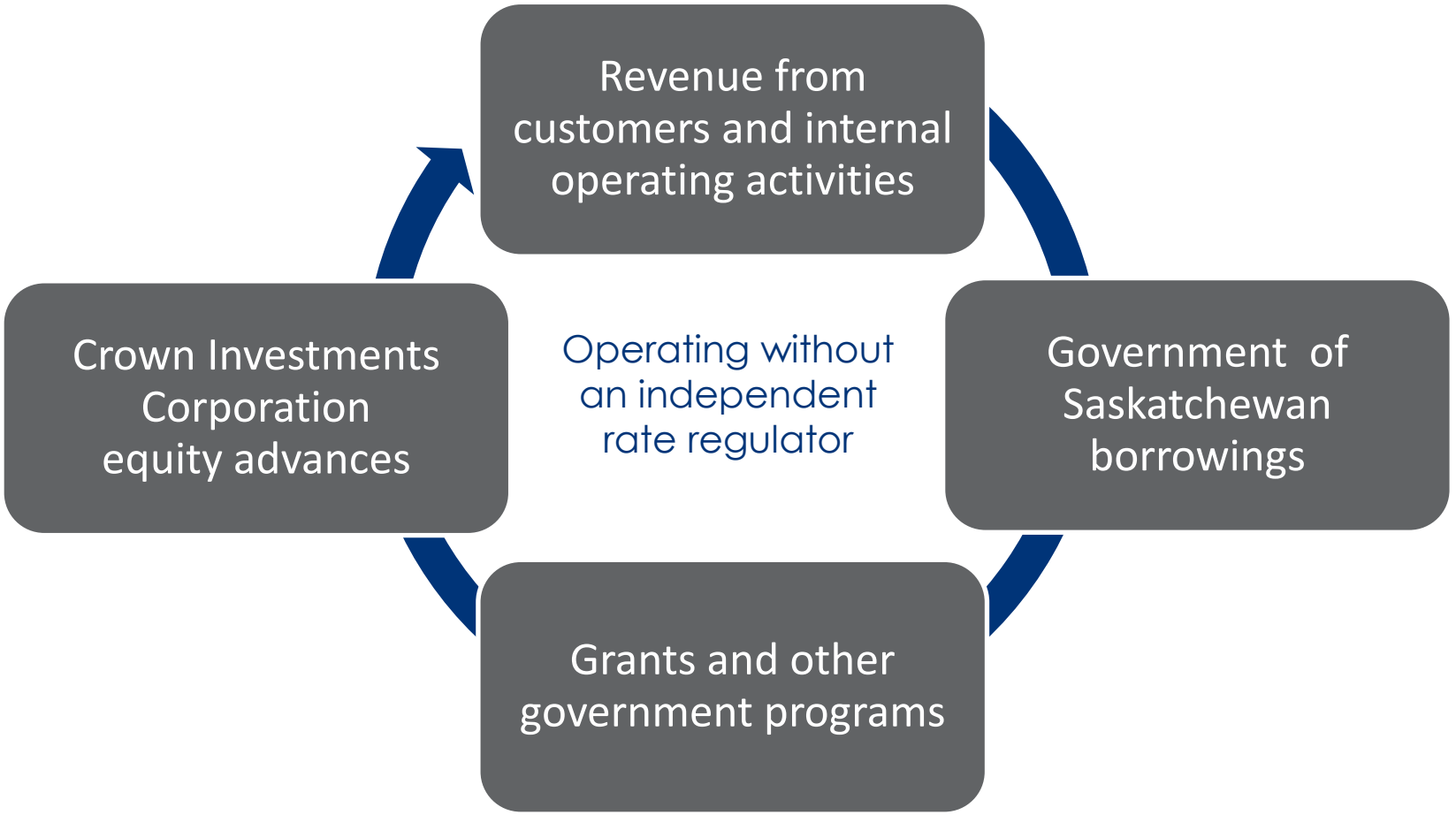
Ownership and Oversight



SaskPower's Sources of Financing

$3 billion annual operating budget

$1.5 billion annual capital spend



Saskatchewan's Nuclear Future Builds on a Strong Legacy

Strong Uranium Supply; High Fuel-Switching Costs

Home to the world's highest grade uranium deposits

2nd largest uranium producer globally (2024)

24% global production (2024)

$3.2 billion in uranium sales(2025)

#1 uranium supplier to the U.S. and Canada's only producer

36% of U.S. uranium deliveries were from Saskatchewan (2024)

World Class Research and Expertise

Sylvia Fedoruk Centre for Nuclear Innovation
Advances nuclear science by funding research, building expertise and operating Saskatchewan's state-of-the-art 24 MeV cyclotron to support medical isotopes, nuclear medicine and energy innovation.

Canadian Light Source Synchrotron
Canada's only synchrotron. Supports nuclear power through research across the full lifecycle: from fuel source (uranium mining), to reactor materials and safety (advanced material analysis), to novel fuel forms (chemistry), and nuclear waste containment.

Radiation Safety Institute of Canada
Canada's only independent, national organization focussed exclusively on promoting and advancing radiation safety in the workplace, the environment and in the community.

Research and Training

- Western Canada's first SMR Safety, Licensing, and Testing Centre will advance nuclear research and support nuclear workforce and supply chain development.
- Nuclear research chairs being established by the Sylvia Fedoruk Centre for Nuclear Innovation and the University Network for Excellence in Nuclear Engineering

NUCLEAR POWER AS THE FUTURE

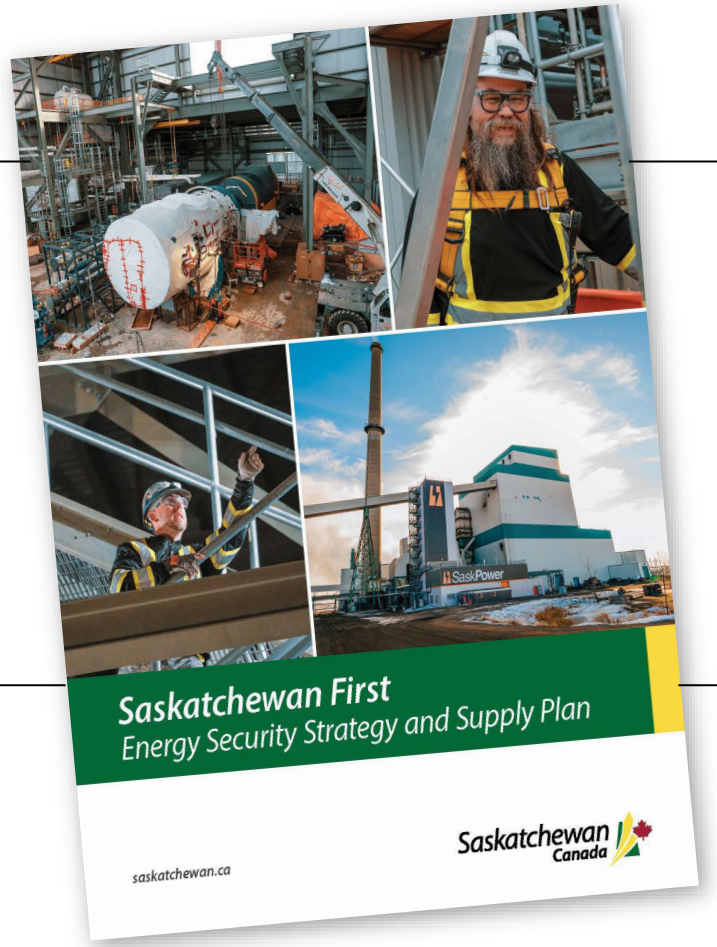
SaskPower

Energy Security Strategy and Supply Plan

Strong policy support; but building a nuclear facility takes many years.

An all-of-the-above approach

Coal as a bridge to nuclear



Nuclear power as the future

Transmission infrastructure

Energy Security Strategy and Supply Plan

An all-of-the above approach

- Coal & Natural Gas
- Hydro (in-province and imports)
- Wind & Solar
- SMR
- Other (biomass, flare gas, landfill gas, waste heat)
- Planning for a net-zero electricity system by 2050

Coal as a bridge to nuclear

- Established Coal Life Extension team
- Planning for 25-year life extensions of all seven coal units
- Planning for coal mine relocations for supply beyond 2029
- Negotiating coal supply contracts beyond 2029
- Potential for future CCS on coal units

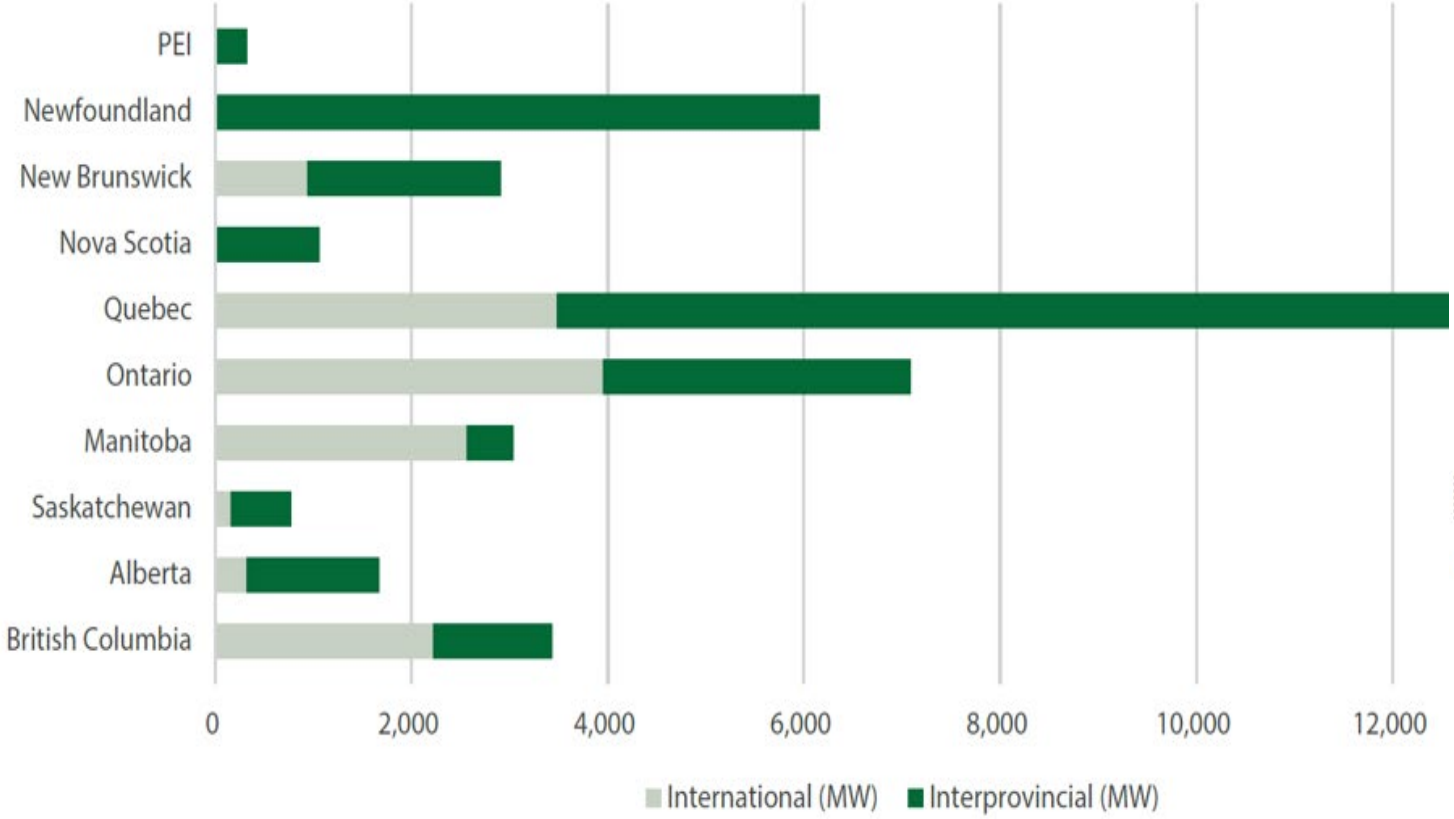
Nuclear power as the future

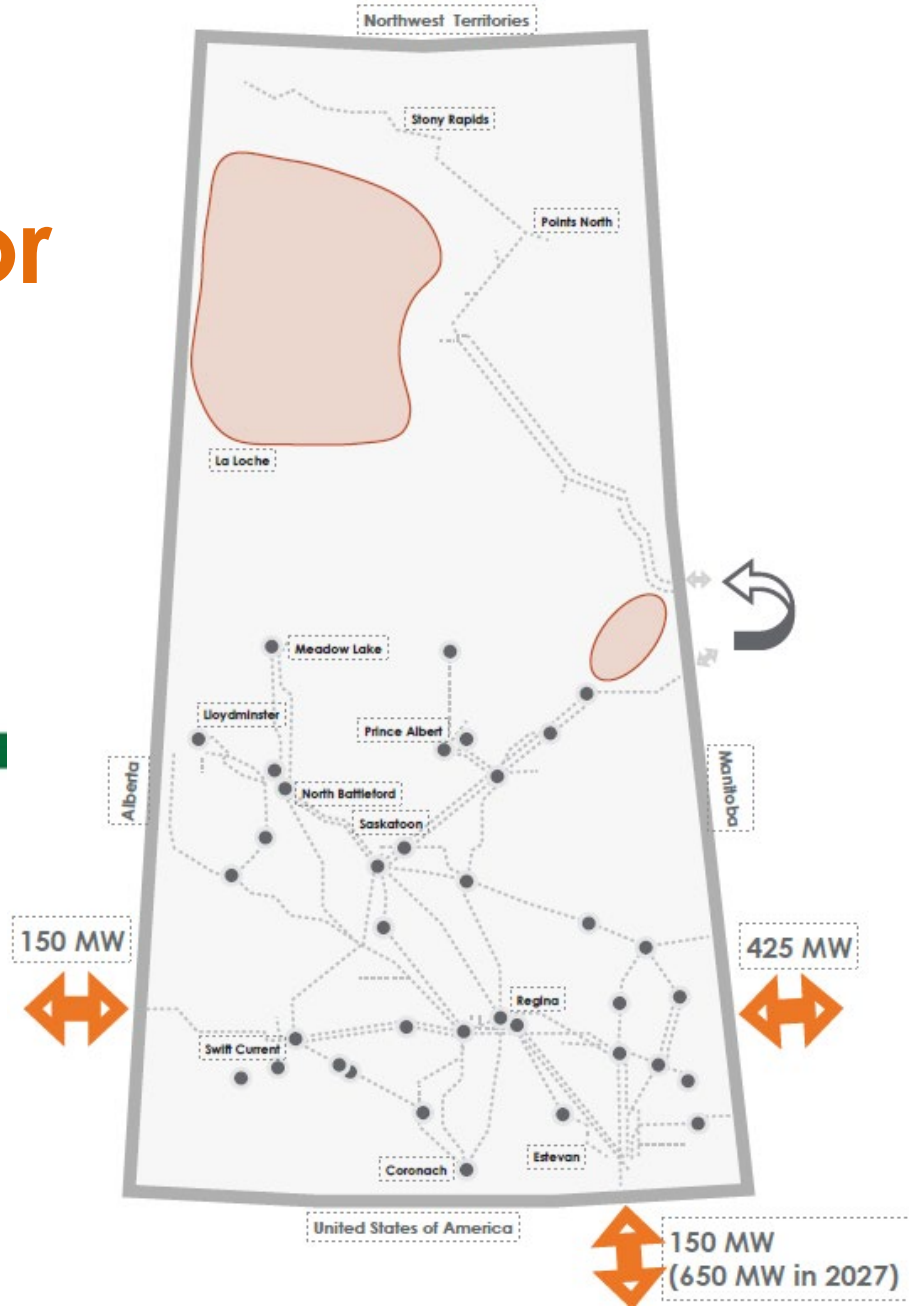
- Established SaskNuclear
- Advancing planning and licensing work for SMRs
- Final SMR site selection decision in 2026
- Supply chain development and partner selection
- Beginning evaluation of large reactor technologies

Transmission infrastructure

- SPP interconnection
- Transmission reinforcement throughout province
- North-South Systems Interconnection
- Northwest System Expansion

Modest Provincial Demand; Growing Regional Demand For Energy Security





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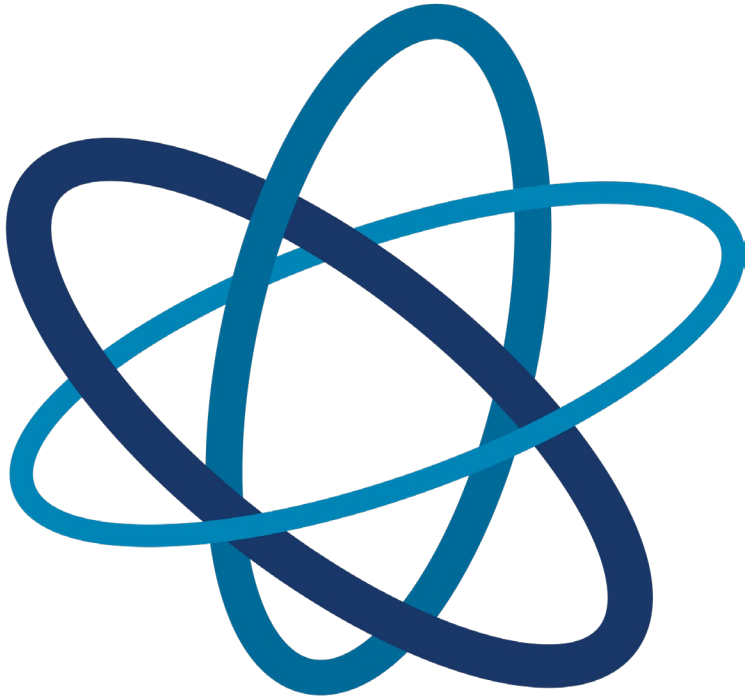
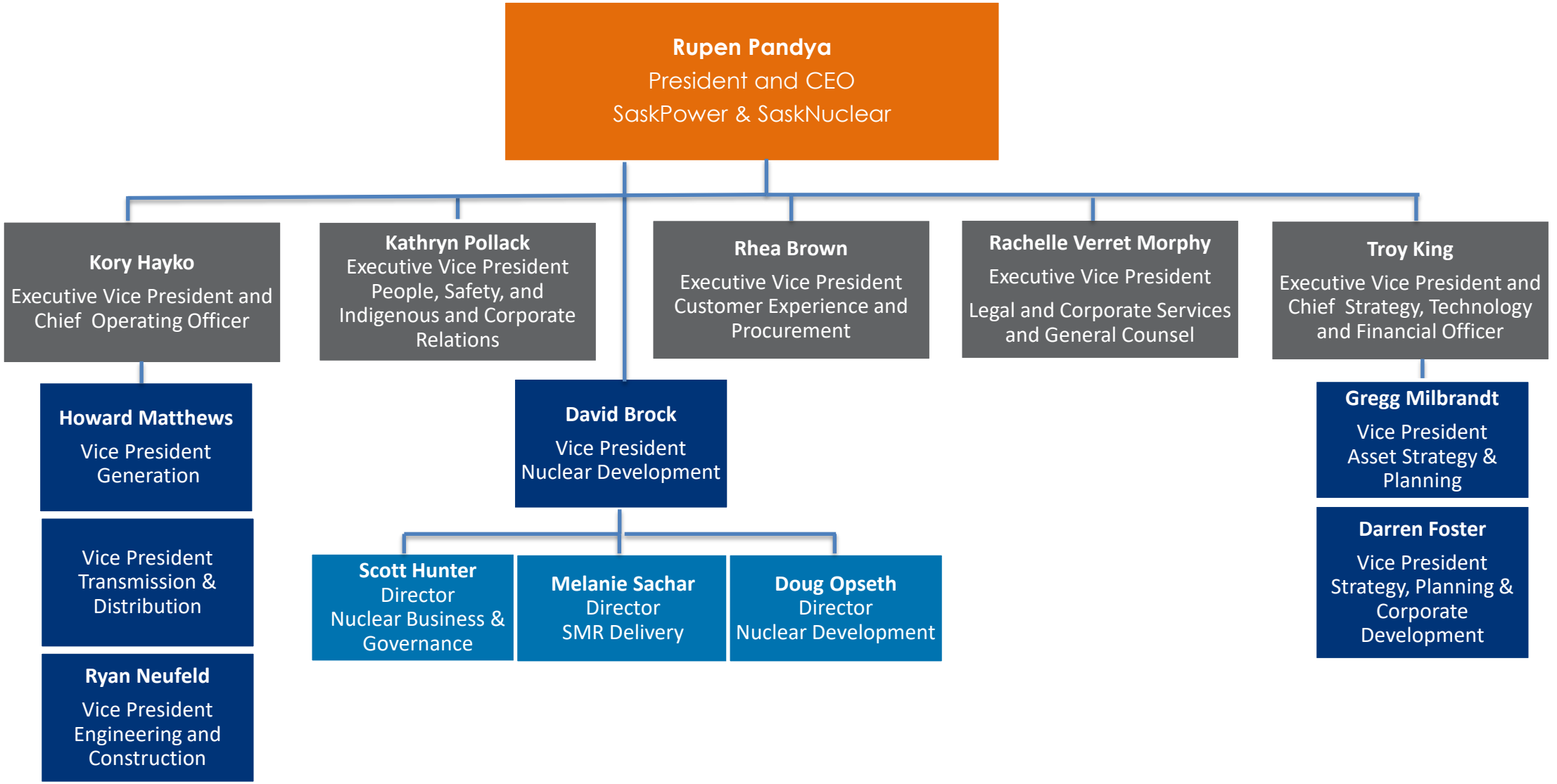
SaskNuclear

- Wholly-owned nuclear subsidiary to license and construct nuclear power plants in Saskatchewan.
- Will have autonomy in decisions and actions to build nuclear, while maintaining guidance and support from SaskPower's leadership and board.



SaskNuclear Organizational Structure

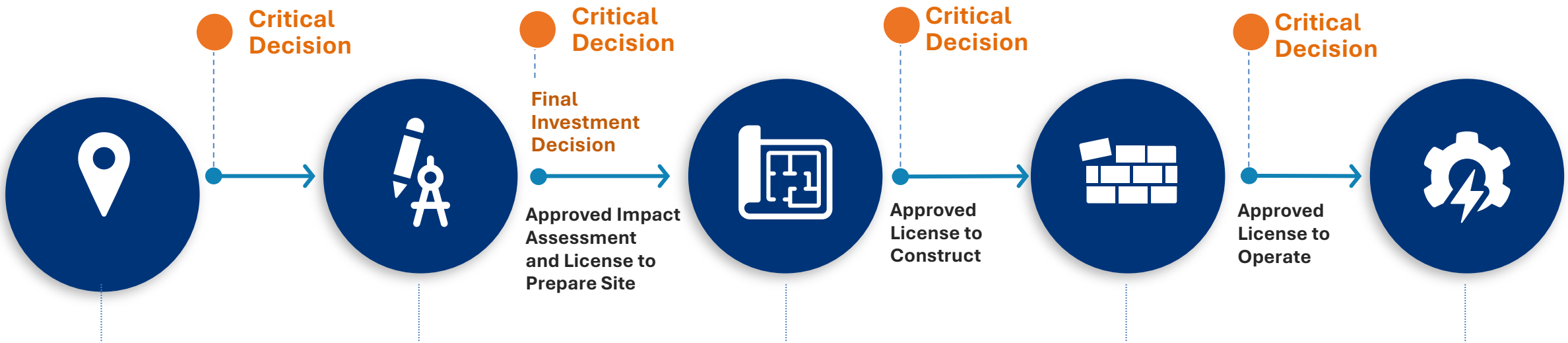


Small Modular Reactor Project

Small Modular Reactors (SMRs) are to bridge from coal-to-nuclear, adding more reliable baseload power to our grid.

We've selected the GE Vernova Hitachi BWRX-300 SMR for potential deployment in Saskatchewan.

Building a SMR Facility



Select a Site

Rigorous early studies, and Indigenous Knowledge to inform site selection

Site Evaluation

Submit the Initial Project Description to begin Impact Assessment

Continue in-depth studies to confirm the site is suitable for a nuclear facility

Apply for a license to prepare the site

Site Preparation

Clear and prepare the land, early excavation, adding basic infrastructure like roads, power, water, drainage and building support facilities

Apply for construction license

Construction

Construction of the SMR facility, install and test equipment Operations team training and readiness

Apply for an operation license

Operate

Nuclear fuel brought on-site

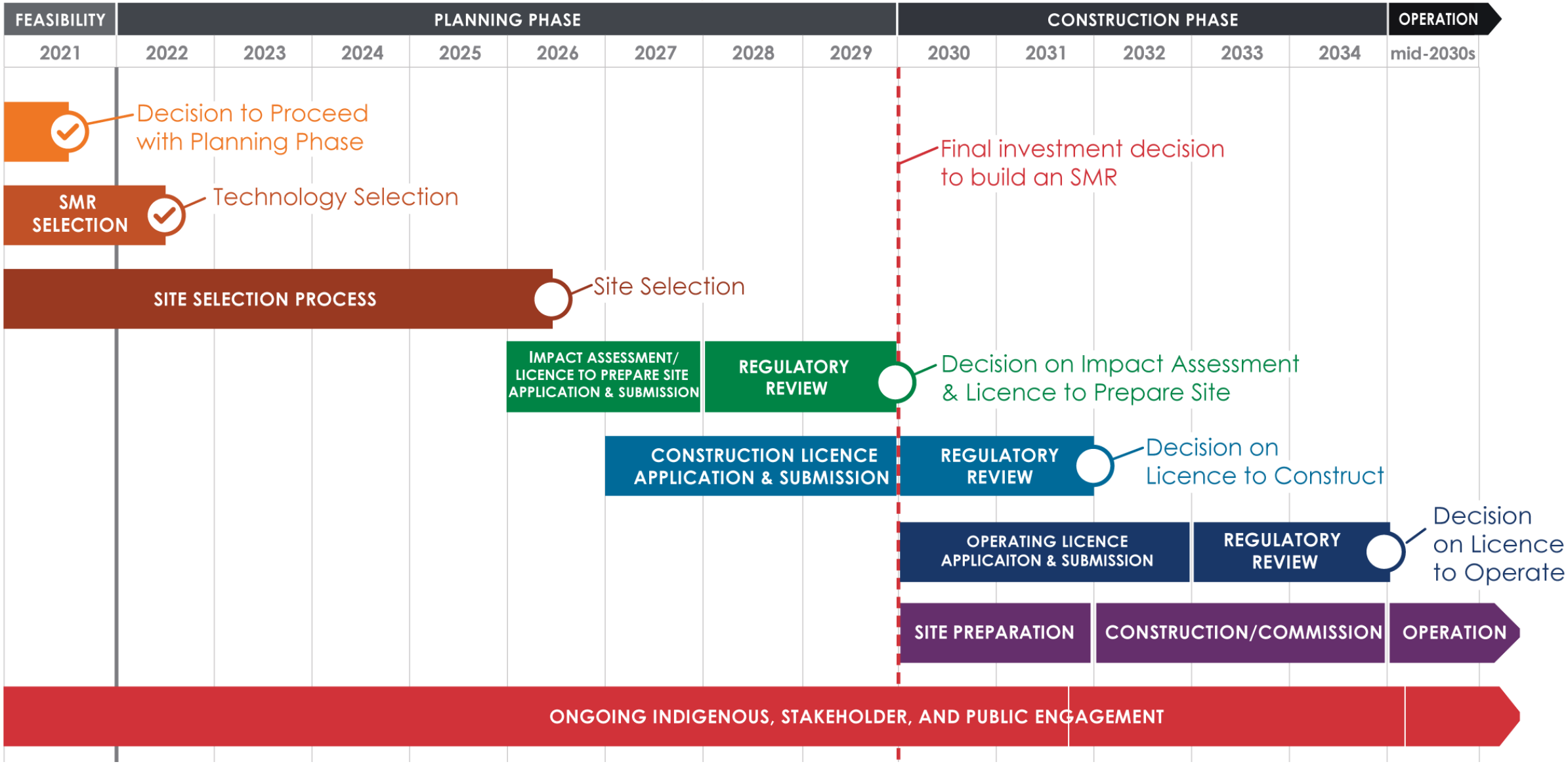
The plant starts generating power

Continuous emergency preparedness, security and environmental monitoring

Ongoing Indigenous, Stakeholder and Public Engagement

SaskPower Powering our future®

SMR Project Timeline



Selecting a Site for Further Evaluation

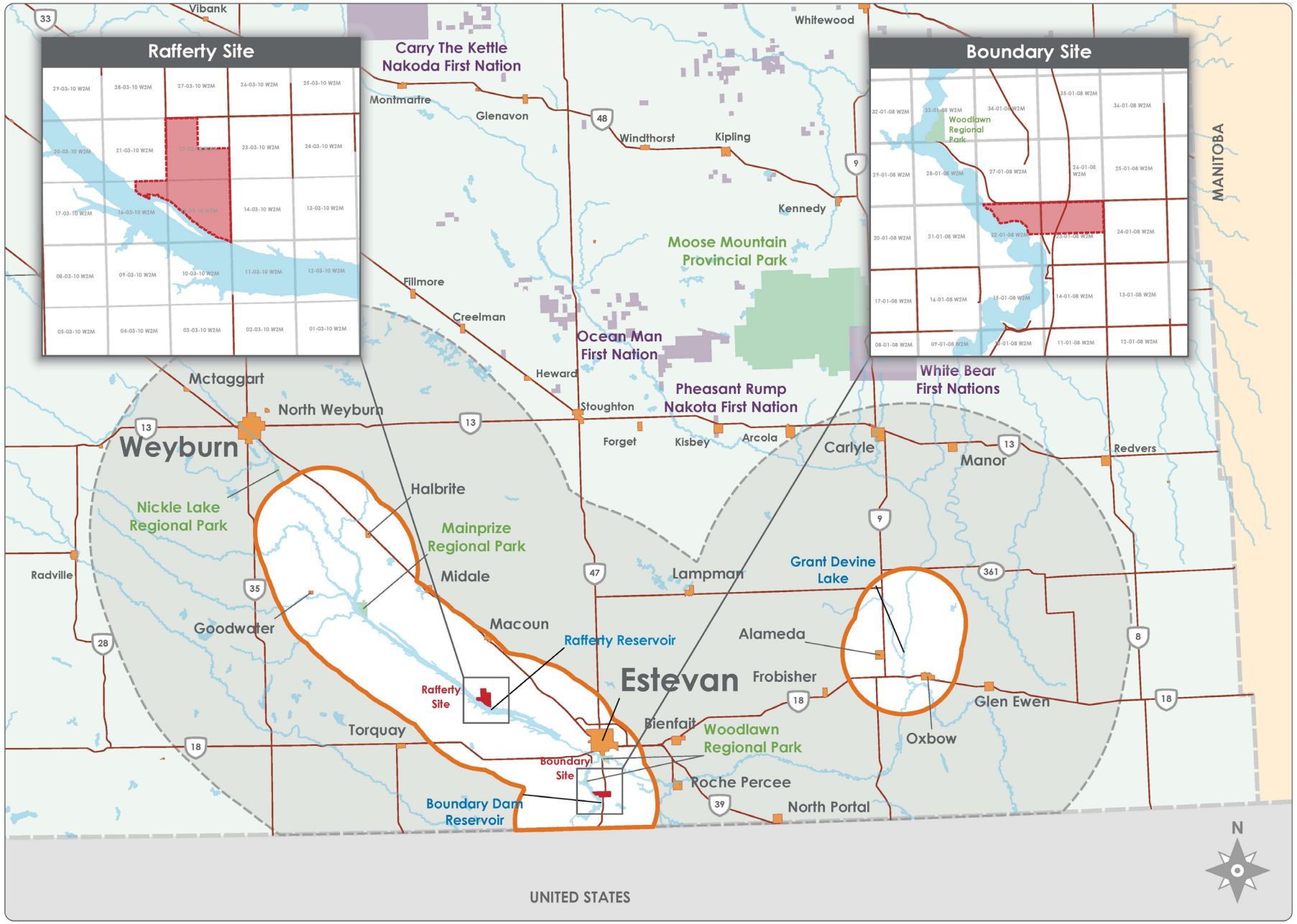
Determining the site for Saskatchewan's first nuclear power plant with capacity to host up to two SMRs.

Two Candidate Sites in Southeast Saskatchewan

(Boundaries are approximate)

- Candidate Site
- Potential siting area
- Proposed study area
- First Nation Reserves
- Protected Lands

This map encompasses the traditional territories of the First Nations and Métis peoples.



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Engagement and Consultation

- Consulted with Rightsholders
- Continue engagement with Indigenous peoples, municipal leaders and communities in the Estevan Region.
- Since 2022, we've exceeded 9,500 interactions through 200 in-person and online opportunities to share information and collect input to inform the site selection.

Site Evaluation and Characterization Planning

We're developing a comprehensive plan to begin site evaluation and characterization following site selection.

This work will support the License to Prepare Site application and will include:

- Geotechnical, hydrological and external hazard studies
- Determine environmental and socio-economic baselines
- Effects and impact assessments are required under the *Impact Assessment Act*

Federal and Provincial Regulators

Canadian Nuclear Safety Commission (CNSC)
Regulates all nuclear energy, materials, facilities and activities in Canada.

Impact Assessment Agency of Canada (IAAC)
Ensures the project won't have a potential negative impact on the environment, public health, society, local economy.

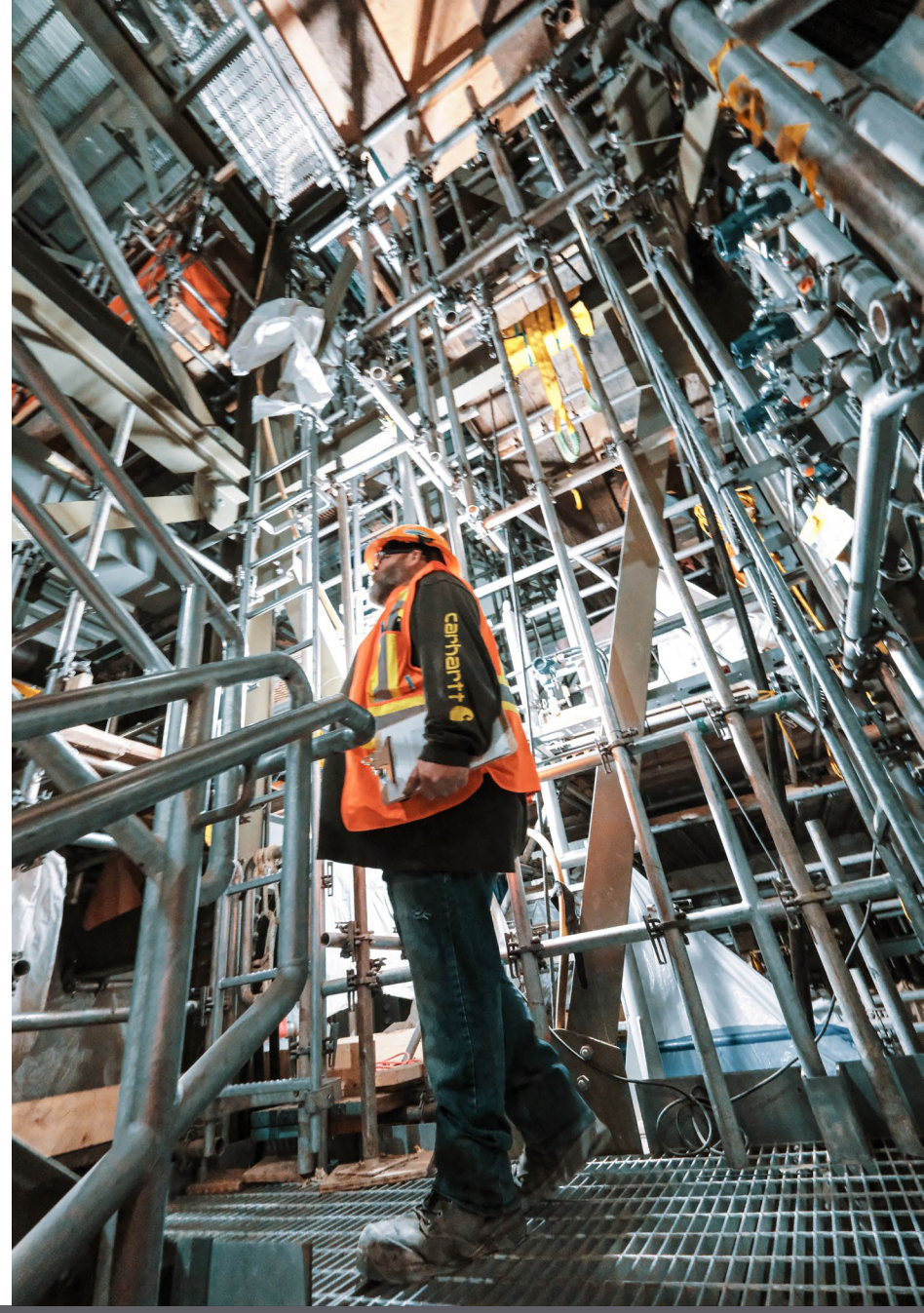
Saskatchewan Ministry of Environment
Evaluates potential environment impacts of a project before irreversible decisions are made.

Licence to Prepare Site (LTPS)	⟷	**Impact Assessment (IA)**
Licence to Construct (LTC)		
Licence to Operate (LTO)		

Decide whether project progresses.

Supply Chain

- Advancing our planning to select a nuclear-experienced construction and engineering partner to design, buy equipment and build the SMR facility
- Engaging early with our primary construction and engineering partners helps us qualify and build nuclear expertise in Saskatchewan
- Indigenous and local participation plans are an important part of the project



Workforce

- 89,000 jobs in Canada's nuclear industry
- Saskatchewan will need 2,500 to 3,500 skilled workers, largely in the trades to build and operate the SMR facility.
- Working with Indigenous partners to determine pathways for Indigenous peoples to develop the skills needed to participate in upcoming workforce needs.

Economic Growth

SMRs are a part of a wider energy transition in Saskatchewan that can provide communities and industries with reliable heat and power while creating high-quality jobs, and local economic development.

Large Nuclear Technology Evaluation

Evaluating large reactor technologies.

Commissioning a large reactor can take 15 to 20 years.

A Trusted Global Fuel Partner with Strong Nuclear Supply Chain Potential

Canada:
2nd largest global uranium producer (SK), nuclear fuel services (ON), nuclear power plants (ON & NB)

United States:
World's largest producer of nuclear power, 94 operable reactors, conversion, enrichment, and fuel fabrication capacity

United Kingdom:
Approx. 15% of electricity from nuclear; conversion, enrichment, reprocessing, and waste capacity

France:
About 70% of electricity from nuclear, 56 operable reactors, conversion, enrichment, and fuel fabrication capacity

Japan:
Hosts a full fuel cycle, including enrichment, 33 operable reactors

Poland:
Pursuing nuclear power deployment and supply diversification through international partnerships.

China:
Self-sufficient in most aspects of the fuel cycle, 56 operable reactors

A Reliable Partner at the Centre of Power in North America

Transmission: intra-provincial, inter-provincial, and international dispatch mix of reliable baseload power.

Southwest Power Pool (SPP) interties will expand export capacity to 650 MW, positioning Saskatchewan as a reliable power partner.

THANK YOU