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MARCH

# SMR Applications for the Saskatchewan Mining and Minerals Industry

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Authored by:

L. McGilp, P.Eng., MBA
J. Cousins, P.Eng., M.Sc.
O. Adesola, E.I.T., M.Sc.

# Acknowledgements

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# Outline

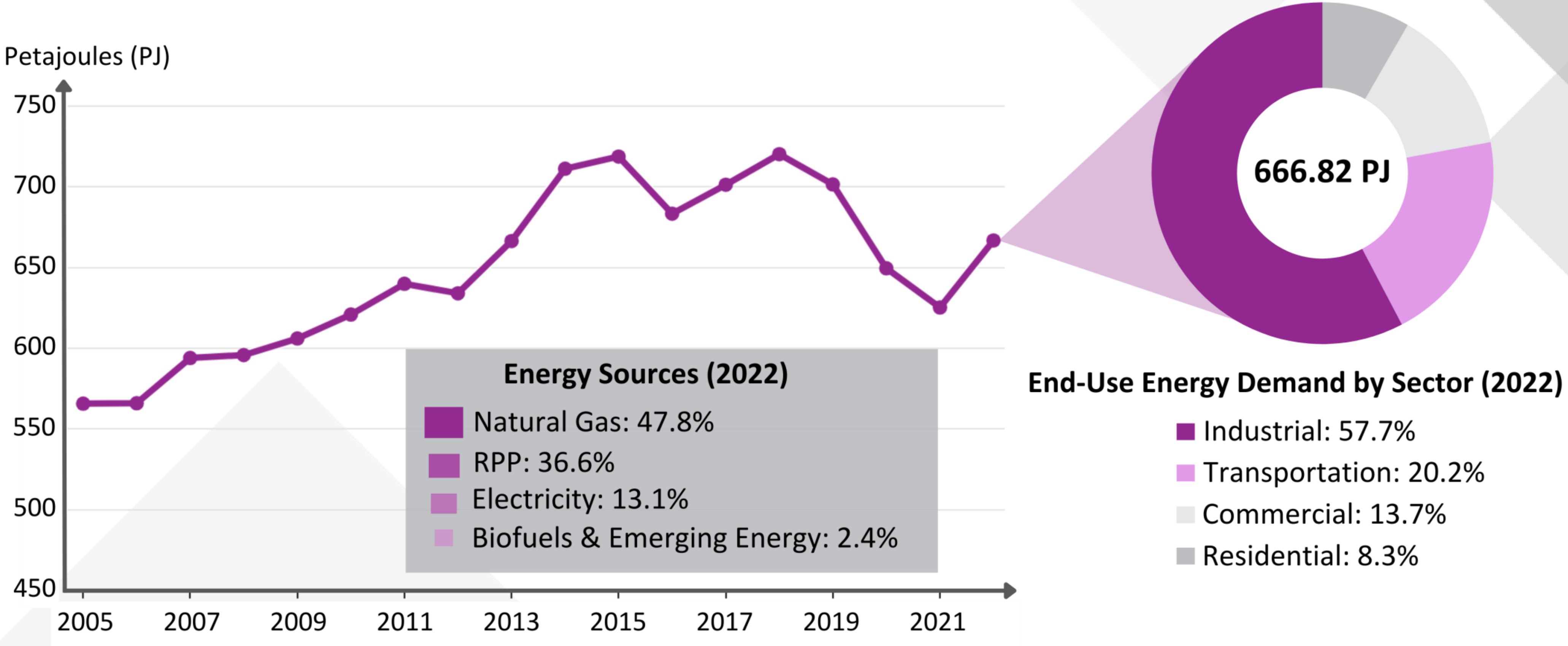
1. Project Goals
2. Energy Use in Saskatchewan
3. Primary Energy Uses in the Mining Sector
4. Impacts of SMR-sourced Heat
5. Potential SMR Technologies for Heat Applications
6. Heat Media Trade-Off Analysis
7. SMR Deployment and Heat Integration
8. Deployment and Adoption Considerations
9. Deployment Pathways – Next Steps

# Section 1: Project Goals

1. **Heat and power requirements for mining applications**
    - Overall energy requirements
    - Requirements for sub-processes
    - Temperature and heat medium of sub-processes
    - Future forecasted demand
2. **SMR technologies and relative fit for these applications**
3. **Opportunities and strategies for deployments**
    - Synergistic sites
    - Specific equipment or processes that could be targeted in a phased approach (ex. product drying)
4. **High-level economics, environmental impacts and project risk factors of a short-list of 3 technology-applications scenarios**
5. **Road map of next steps including regulatory and deployment processes and timelines, and operating model options**

# Section 2: Energy Demand in Saskatchewan

## End-Use Energy Demand for Saskatchewan, 2005 -2022



**Energy Sources (2022)**

- ■ Natural Gas: 47.8%
- ■ RPP: 36.6%
- ■ Electricity: 13.1%
- ■ Biofuels & Emerging Energy: 2.4%

**End-Use Energy Demand by Sector (2022)**

- ■ Industrial: 57.7%
- ■ Transportation: 20.2%
- ■ Commercial: 13.7%
- ■ Residential: 8.3%

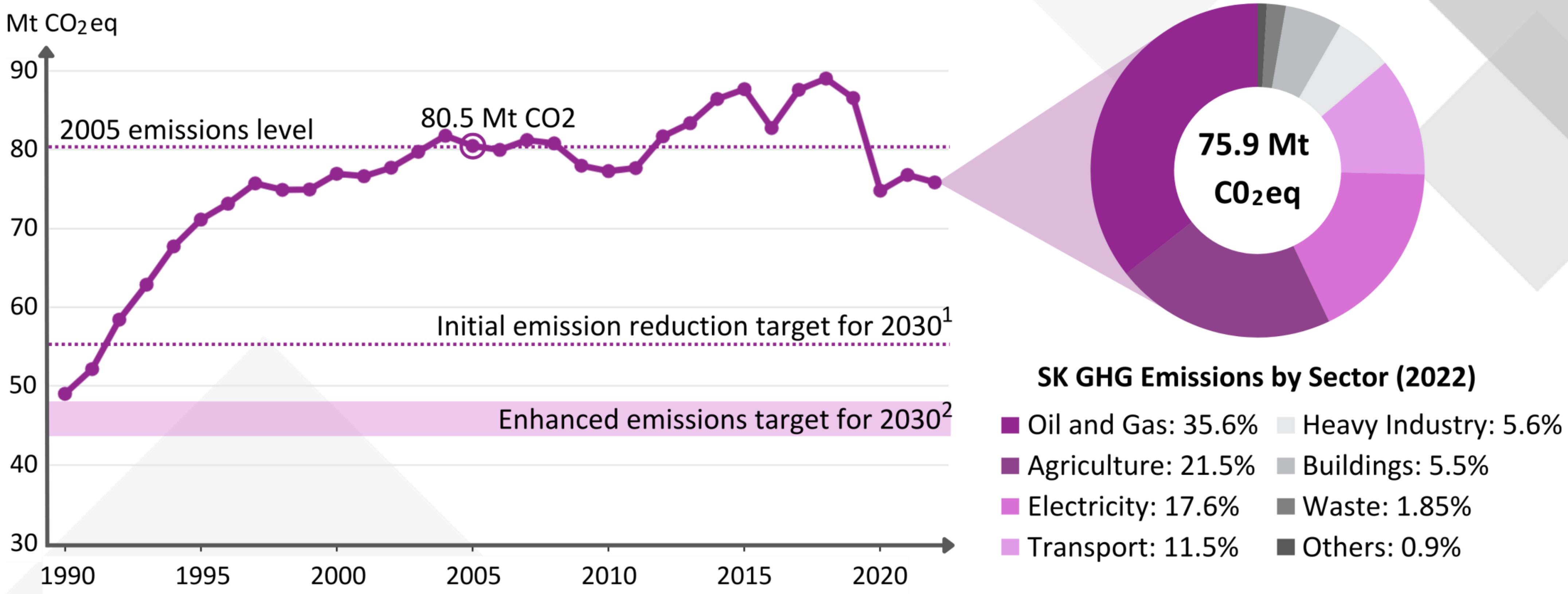
*RPP is Refined Petroleum Products. RPP includes aviation fuel, diesel, gasoline, heavy fuel oil, liquified petroleum gases (LPG), oil, etc.

Biofuels and Emerging Energy includes biomass (wood), solar, geothermal, hydrogen, ethanol and biodiesel.

Source: Canada Energy Regulator. Canada’s Energy Future Data Appendices: 2023 Report - End-Use Demand (Current Measures).

# Emissions in Saskatchewan

## GHG Emissions for Saskatchewan, 1990 -2022

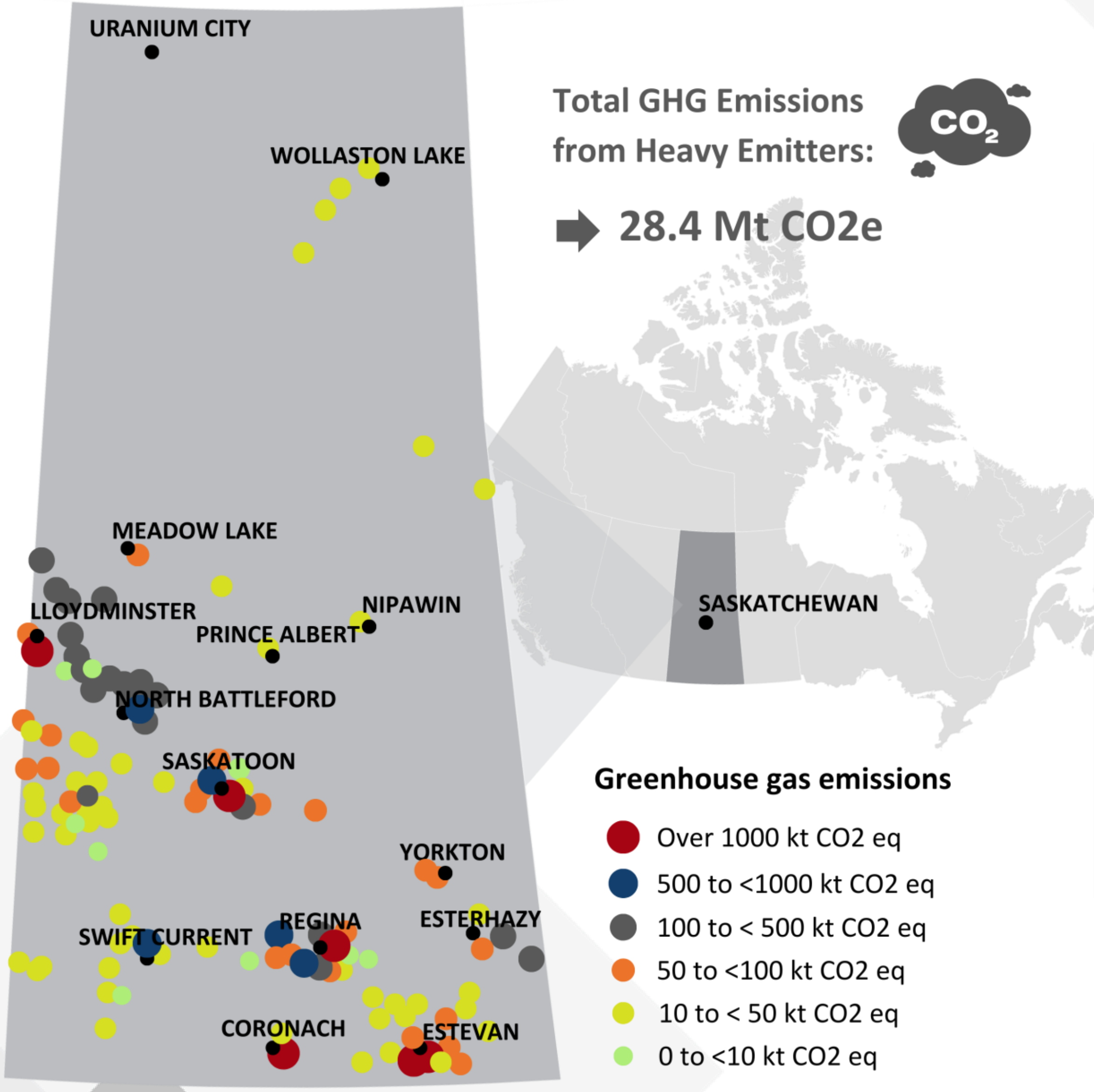


Note:

1. Canada’s commitment to reducing GHG emissions by 30% below 2005 levels by 2030 under the Paris Agreement.
2. Canada’s enhanced Paris Agreement Plans with new goal of reducing emissions by 40-45% below 2005 levels by 2030.

Source: Canada.ca; Environment and Climate Change Canada - National Inventory Report 1990 - 2022: GHG Sources and Sinks in Canada.

# Heavy Emitters in Saskatchewan



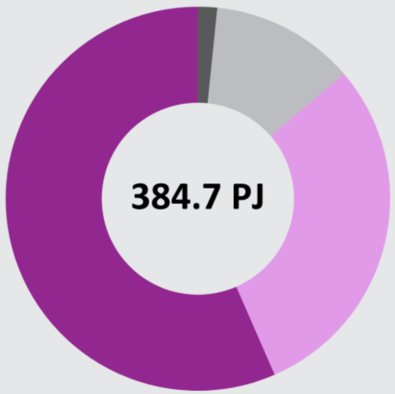
Total GHG Emissions from Heavy Emitters:

➡ 28.4 Mt CO2e

**Greenhouse gas emissions**

- ● Over 1000 kt CO2 eq
- ● 500 to <1000 kt CO2 eq
- ● 100 to < 500 kt CO2 eq
- ● 50 to <100 kt CO2 eq
- ● 10 to < 50 kt CO2 eq
- ● 0 to <10 kt CO2 eq

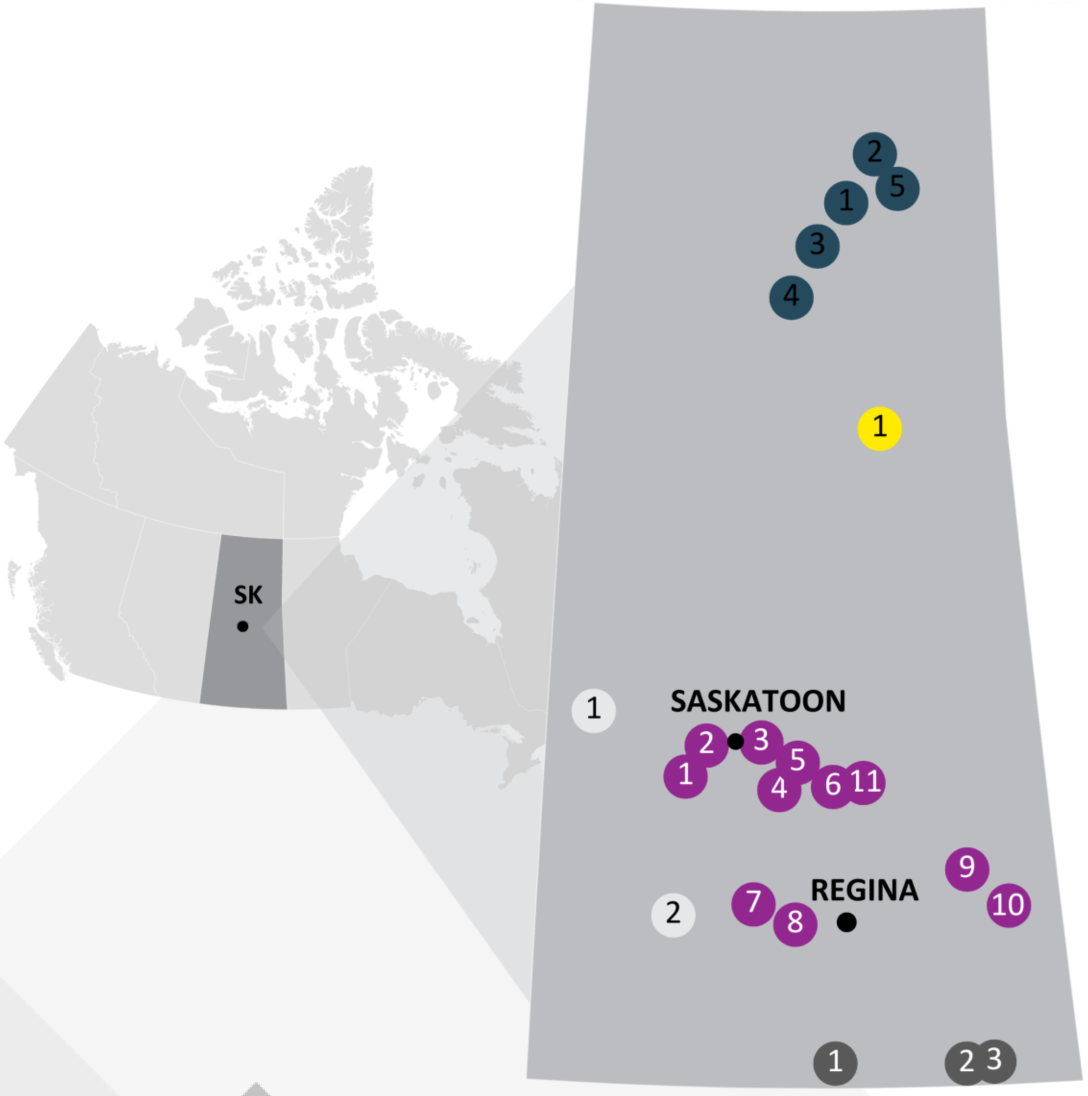
**End-Use Energy Demand by Industrial Sector (2022)**



- ■ Natural Gas: 56.5%
- ■ RPP: 29.7%
- ■ Electricity: 12.1%
- ■ Biofuels & Emerging Energy: 1.6%

**Source:** Canada.ca – Canadian Environmental Sustainability Indicators (GHG Emissions)

# Saskatchewan's Mining and Minerals Sector



## Saskatchewan Mines (2022)

**● Potash Mines**

1. Nutrien Vanscoy
2. Nutrien Cory
3. Nutrien Patience Lake
4. Nutrien Allan
5. Mosaic Colonsay
6. Nutrien Lanigan
7. K+S Potash Bethune
8. Mosaic Belle Plaine
9. Mosaic Esterhazy
10. Nutrien Rocanville
11. BHP Jansen

**● Gold Mine**

1. SSR Seabee

**● Uranium Mines**

1. Cameco Cigar Lake
2. Orano McClean Lake
3. Cameco McArthur River
4. Cameco Key Lake
5. Cameco Rabbit Lake

**● Lignite Coal Mines**

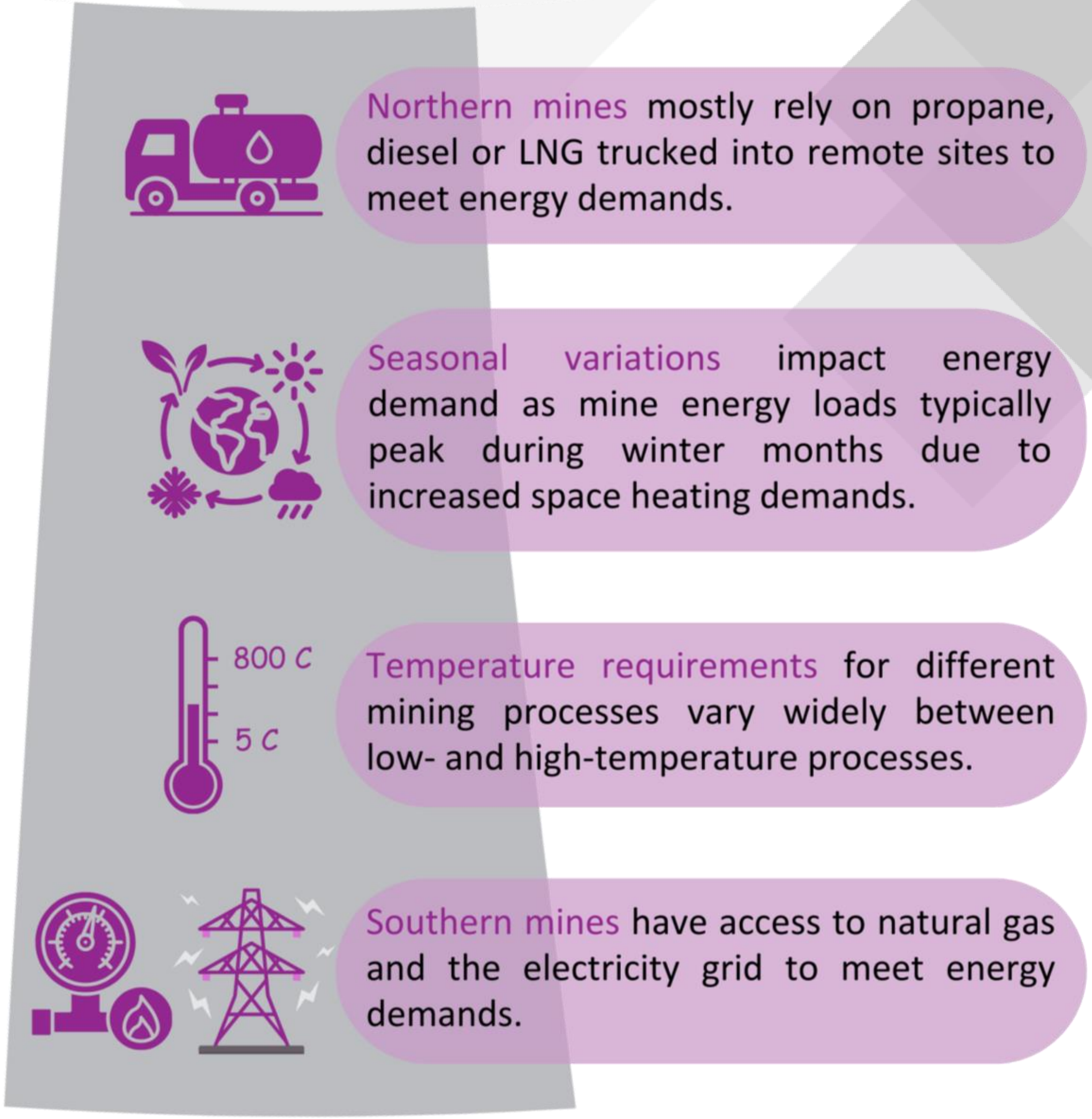
1. Poplar River
2. Boundary Dam
3. Beinfait

**○ Salt Mines**

1. Unity Plant
2. Chaplin

# Section 3: Primary Energy Uses in the Mining Sector

- Mining operations consume energy primarily in the form of heat and electricity.
- Energy (heat and electricity combined) consumption in Saskatchewan mines varies from 50 – 500 MW, depending on the mine size and type of operation.
- Heat energy uses in Saskatchewan mines are broadly categorized based on temperature requirements:
  - Process heat – Low-temperature (≤ 120 $^{o}$C)
    High-temperature (>120 $^{o}$C)
  - Mine/building space heat (5 – 20 $^{o}$C).



Northern mines mostly rely on propane, diesel or LNG trucked into remote sites to meet energy demands.

Seasonal variations impact energy demand as mine energy loads typically peak during winter months due to increased space heating demands.

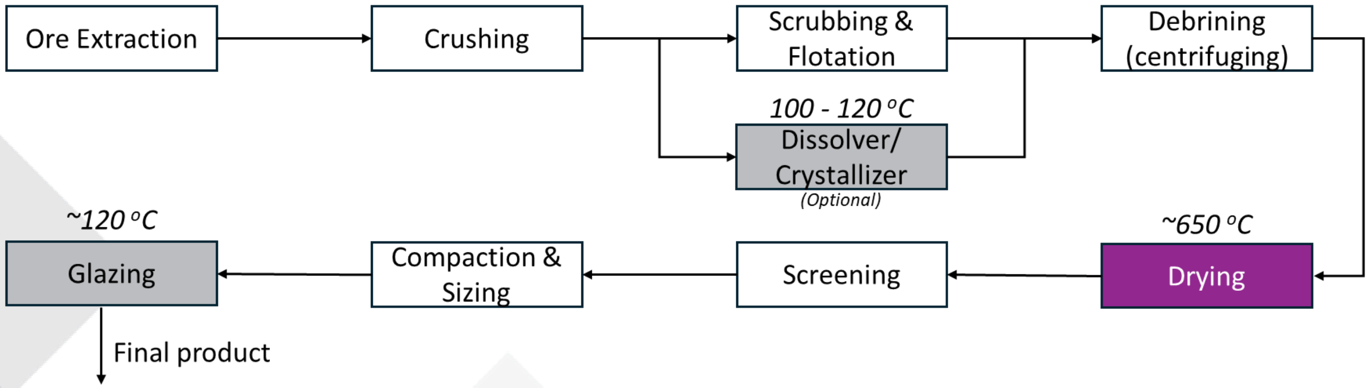
Temperature requirements for different mining processes vary widely between low- and high-temperature processes.

Southern mines have access to natural gas and the electricity grid to meet energy demands.

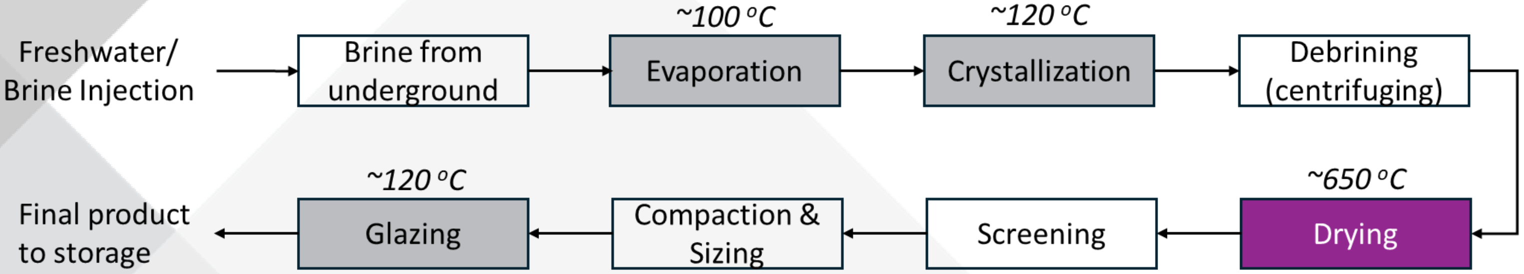
# Mining Processes and their Energy Loads

## Simplified Potash Mine Flow Block Diagram

### Conventional (Underground) Mine

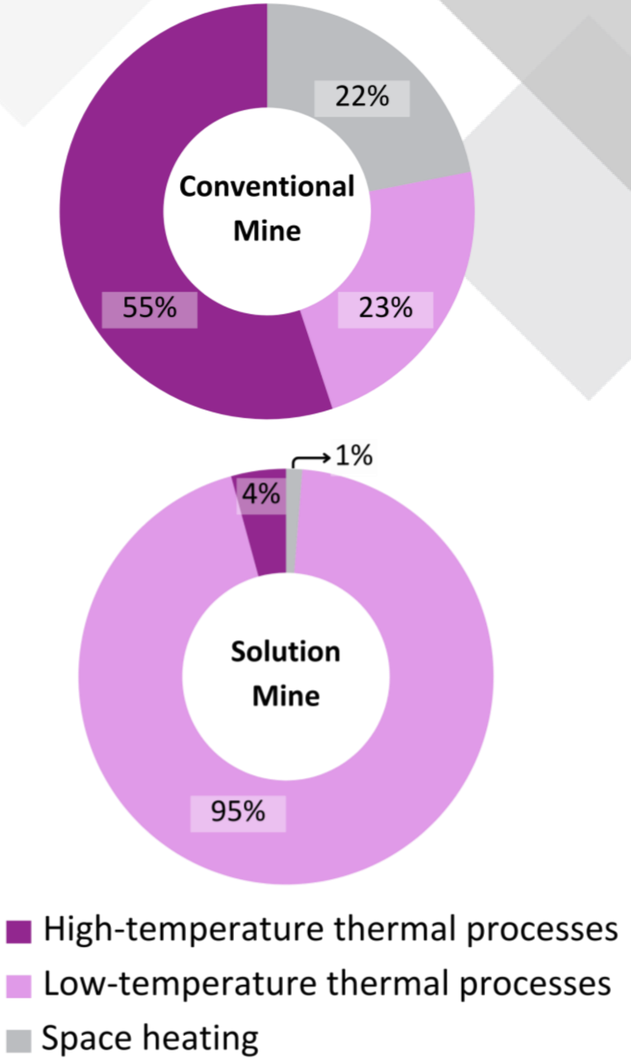

Ore Extraction
Crushing
Scrubbing & Flotation
100 - 120 °C
Dissolver/ Crystallizer
*(Optional)*
Debrining (centrifuging)
~650 °C
Drying
Screening
Compaction & Sizing
~120 °C
Glazing
Final product

### Solution Mine


Freshwater/ Brine Injection
Brine from underground
~100 °C
Evaporation
~120 °C
Crystallization
Debrining (centrifuging)
~650 °C
Drying
Screening
Compaction & Sizing
~120 °C
Glazing
Final product to storage

▨ Low-temp processes ■ High-temp processes ☐ Non-thermal processes

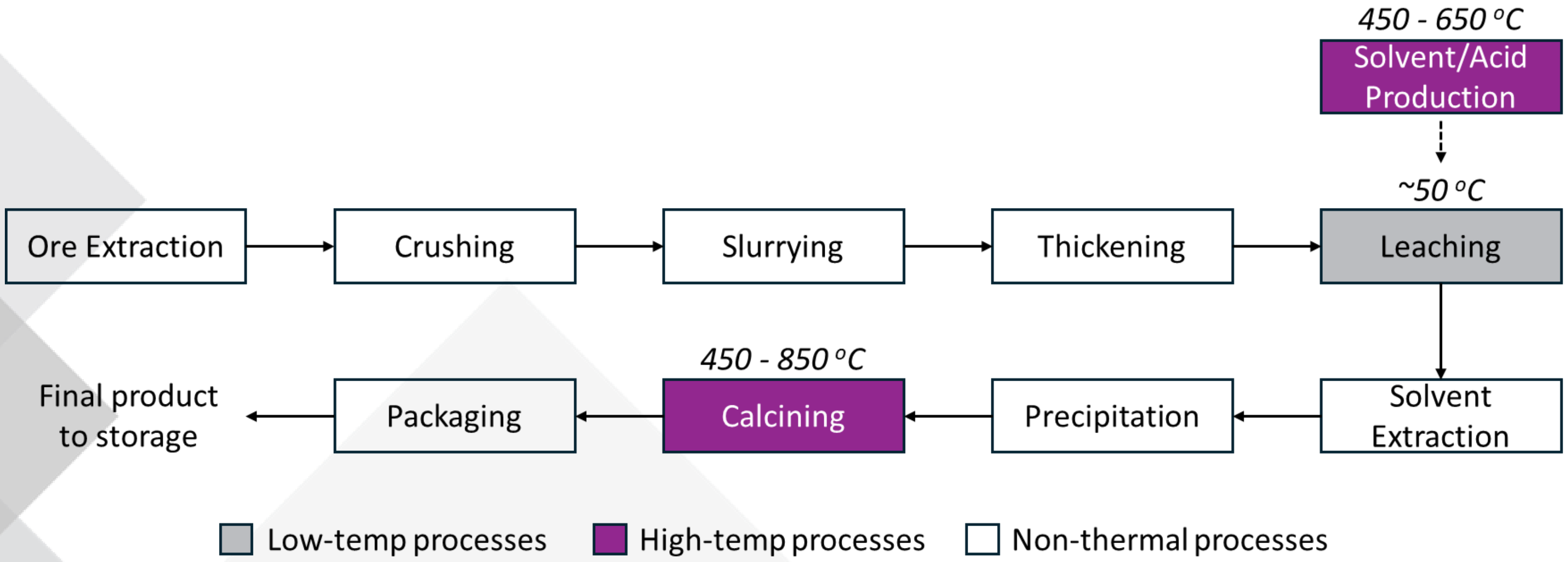
## Peak Heat Loads at Potash Mine Sites



# Mining Processes and their Energy Loads

## Simplified Uranium Mine Flow Block Diagram

### Conventional (Underground) Uranium Mine



450 - 650 °C

Solvent/Acid Production

~50 °C

Ore Extraction → Crushing → Slurrying → Thickening → Leaching

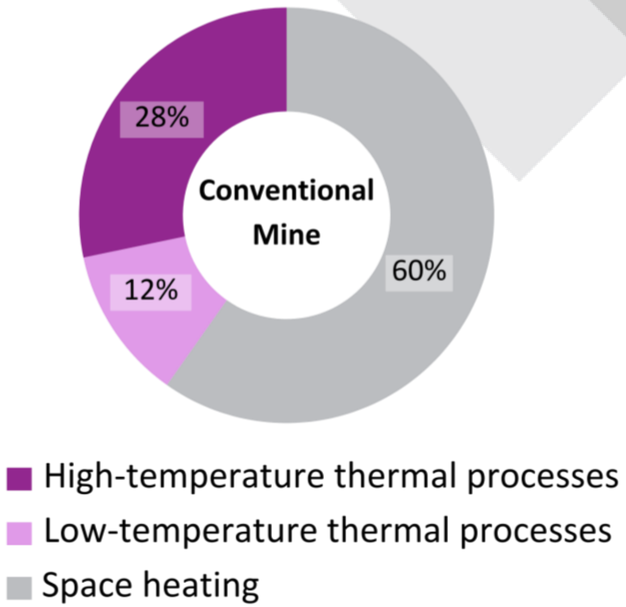
Leaching → Solvent Extraction

Solvent Extraction → Precipitation → Calcining → Packaging → Final product to storage

450 - 850 °C

▨ Low-temp processes ■ High-temp processes ☐ Non-thermal processes

### Peak Heat Loads at Uranium Mine Sites



# Section 4: Conventional vs. SMR-sourced Heat

## Fossil fuels (Natural Gas, Propane, LNG, etc.)

- Provide reliable and consistent energy
- Hydrocarbon delivered directly to process equipment for combustion (primarily gas pipeline distribution infrastructure; minimal heat loss)
- Operational flexibility; systems are easily scaled

## Nuclear energy from SMRs

Important considerations for SMR-sourced heat include: temperature limitations, risk of radioactive contamination, and reliability.

- Candidate SMR reactors are not quite hot enough to directly supply heat for high-temperature processes; temperature boosting is required for some processes
- Heat Transport infrastructure required; heat losses from heat exchange steps & transport
- Intermediary heat loops are required in most cases to avoid low-level radiation contamination risks
- Integration should consider unplanned shutdowns, implications for both mine operations and nuclear power plant operations; impact of loss of heat sink and/or loss of heat source and backup options for such scenarios

# Section 5: SMR Technologies for Heat Applications

| Reactor | Reactor Type & Fuel | Output (MWe) | Output (MWth) | Heat Medium | Outlet Temp. ($^{o}$C) | Anticipated Earliest Online Target |
|---|---|---|---|---|---|---|
| **Xe-100** | HTGR;<br>TRISO pebbles | 80 | 200 | Helium | Helium: 750<br>Steam: 565 | Dow Chemical, USA (2030) |
| **ARC-100** | Sodium-cooled;<br>U-Zr (13%) | 100 | 286 | Sodium<br>(sodium loop) | Sodium: 510<br>Steam: 450 | NB Power, NB CA<br>(2031-33) |
| **eVinci** | Heat pipe;<br>TRISO pellets | 5 | 13 | Sodium heat pipes | Air: ~750 direct<br>Air: ~ 200 'waste' | Test reactor @ Idaho Nat'l Lab (2026)<br>SRC, SK CA (2029) |
| **MMR** | HTGR;<br>TRISO pellets | 3.5-15 | 10-50 | Helium<br>(Molten salt cycle) | Helium:660<br>Steam: 500-600 | Global First Power, Chalk River (2029) |
| **BWRX-300 (Gen III+)** | BWR;<br>LEU $UO_2$ | 300 | 870 | Light water | Steam: 285 | OPG, ON CA(2029) |
| **IMSR 400** | Fluoride molten salt reactor;<br>$UF_4$ | 390 | 884 | Flouride salt<br>(solar salt loop) | Primary salt: 700<br>Solar salt: 585 | No public orders yet; could deploy by 2032-35 |
| **Natrium Reactor** | Sodium-cooled;<br>HALEU U-Zr | 345 | 840 | Molten salt | 500 | PacifiCorp,<br>Wyoming Demonstration (2029-30) |
| **AP 300** | PWR;<br>LEU $UO_2$ | 300 | 900 | Light water | Steam: 272.7*<br>From AP 1000 | No public orders yet; could deploy in 2030's. |

# Section 6: Heat Media Trade-Off Analysis

- Three different heat transfer fluid (HTF) options were considered to transport heat from SMR to process equipment, space heating and underground air heating for the mine.

| Heat Transfer Fluid Options | | |
|---|---|---|
| **Molten salts** | **Steam** | **Glycol/Water mix** |
| **Nitrate salts**<br>*Solar salt*<br>*($NaN0_3/KNO_3$ - 60/40 %)*<br>**Chloride salts**<br>*MgNaK-Cl salts* | **Saturated steam**<br>*Low pressure (LP)*<br>*High pressure (HP)*<br>**Superheated steam (SHS)** | *50 wt.% ethylene glycol* |

| Relevant Factors for HTF Selection |
|---|
| Fluid properties |
| CAPEX |
| OPEX |
| Maintenance requirements |
| Safety |
| Complexity of Operations |
| Environmental Impact |

# Highlights of Heat Transfer Fluid Comparison

| | Molten Salts (MS) | Steam | Glycol |
|---|---|---|---|
| Operating Range | 150 °C – 800 °C | ≤ 550 °C | ≤ 100 °C |
| Operating Pressure | < 1 MPa | SHS & LP: 1 MPa; HP: 21 MPa | < 1 MPa |
| Pros | • Non-toxic, non-flammable<br>• Efficient heat transfer properties<br>• Low operating pressure | • Low cost and availability<br>• Moderate corrosion rates<br>• Well-established applications<br>• Material requirements: Carbon steel and stainless-steel pipes | • Established applications<br>• Easy to use<br>• Low operating pressures<br>• Material Requirements: steel piping |
| Cons | • Risk of solidification (freezes at 150–400 °C)<br>• Complex operations<br>• Novelty (for some salts)<br>• Material requirements: corrosion-resistant materials (high cost)<br>• Salt thermally decomposes above temperature limits. | • High operating pressures<br>• Limited temperature range<br>• Water chemistry monitoring regimen required to prevent corrosion | • Limited to low temperatures<br>• Toxicity |

***Note:*** *Temperatures stated in the table are representative only. A wider operating range is possible for steam and glycol.*

# Section 7: SMR Deployment and Heat Integration

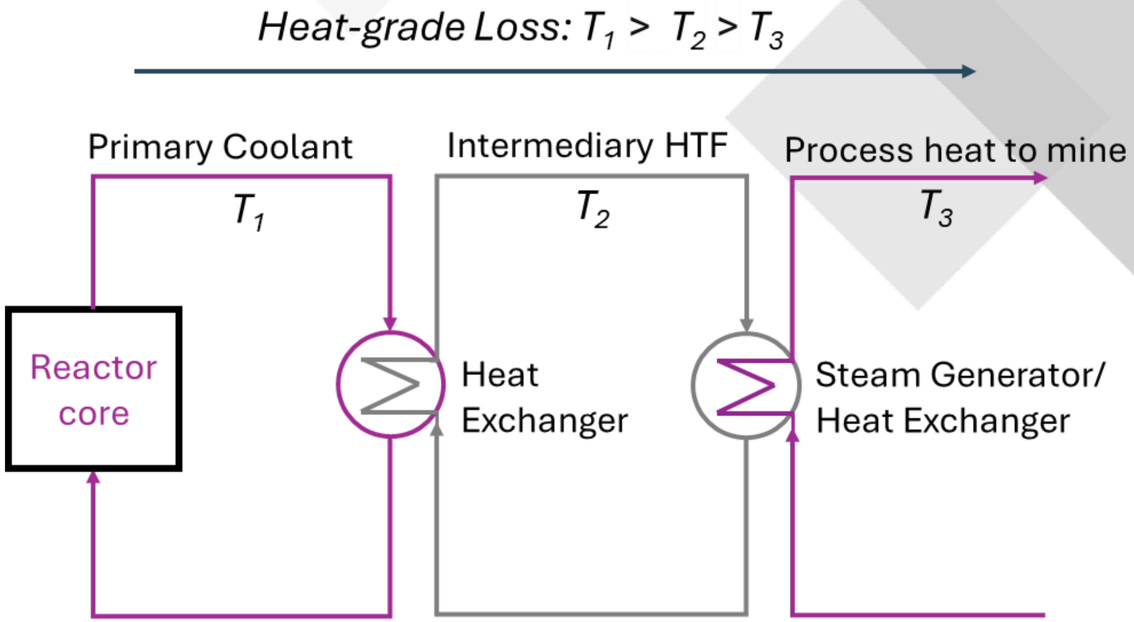
This study developed and analyzed four (4) scenarios for SMR heat integration and deployment:

| Scenario | Mine | Energy Requirements | Reactor |
|---|---|---|---|
| P1 | Conventional Potash Mine<br>3.0 MTPY, On-grid | 39 MWth, 52 MWe | Gen III+ (BWRX-300 or similar) |
| P2 | Conventional Potash Mine<br>3.0 MTPY, On-grid | 39 MWth, 52 MWe | Gen IV (High Temperature) |
| U1 | Uranium Mine (underground)<br>10.5 Mlb/yr, Off-grid | 9.2 MWth, 12 MWe | Gen IV (Micro-reactor) |
| L1 | Remote SMR - Long-distance steam transport (15 km) | - | Gen III+ (BWRX-300 or similar) |

***Note:*** *MTPY – million tonnes per year; Mlb/yr – million pounds per year*

# SMR Heat Integration Considerations

- Heat Exchange:
  - Intermediate Heat Transfer Fluid required to ensure isolation between the nuclear island and the mine
  - Required for heat media exchanges
  - Temperature losses with each exchange
- Different heat requirements benefit from different heat transfer media
  - Adds complexity, multiple configurations possible
- Heat Integration Infrastructure & Heat Media Commercial Readiness and Operability. Study used:
  - Steam for high-temperature requirements
  - Hydronic glycol for low-temperature requirements
- Process modifications could help streamline heat integration; out-of-scope for this study



# Highlights from Scenario Analysis Results

## Potash mines

Advanced Reactors with higher temperature heat provide the best match for potash sites.

Most equipment is commercially available; some semi-exotic (large) equipment required for high-heat components.

Advancements in Heat transfer fluids (ex. molten salts) and/or infrastructure, may offer improvements to heat integration systems over time.

## Uranium mines

Micro-reactors provide best fit for Northern locations.

Scenarios leveraged both direct and ‘waste’ heat from vSMRs.

## Long Distance Transport

Cost, not heat loss, greatest constraint.

# Key Learnings from Heat Integration Analysis

## Infrastructure Complexity

- Different temperature ranges of heat requirements complicate the system.
  - Separate infrastructure for different heat-ranges (glycol, steam, etc.)
  - Recovering more heat drives complexity; further work needed to assess financial viability.
- Several scenarios, options and variations; cost optimization potential.

## Design Constraints

- Cost
- Operability
- Commercial Availability/Maturity of Components

## Decarbonization

While significant emission reductions were achieved, most integration scenarios still required hydrocarbon-sourced heat for temperature boosting or backup.

# Section 8: Deployment and Adoption Considerations

**Siting/EPZs**

- Combined emergency response plans are viable.
- Mine’s impacts on the NPP (ex. corrosion) must be considered.
- Potential to leverage existing Environmental Assessment.
  - Renewed public engagement required for nuclear scope of operation.

**Reliability**

- Nuclear traditionally 95%+ capacity factor.
- Consider potential back-up requirements and infrastructure for heat.

**Adoption Timelines**

- Net zero goals vs. SMR readiness.
- Deployment timeline length.

**TRL**

- SMRs: FOAK in early 2030’s; NOAK, post 2035.
- Infrastructure: Energy Transition driving improvement in heat transfer technologies as well.

**Synergies**

- Benefits of single site multi-unit deployments.
- Potential benefit of regional common technology multi-unit deployments:
  - Operating Experience
  - Common Supply Chain, R&D

**Operating Models**

- Operator: Holds CNSC license.
- Different models and options for Owner/Operator:
  - SaskPower &/or SRC as operators &/or partners.

# Section 9: Deployment Pathways – Next Steps

## Further study to refine technical, siting and commercial factors

- Explore & Resolve Technical Issues
- Detailed Integration Cost Analysis
- Site Viability Evaluation
- Owner/Operator Structure
- Preliminary Economic Evaluation

## Develop Project

- Define Technology, Operator, Site, Fuel supply chain
- Decision-tier cost estimate

## Execute

- Public Engagement
- Siting & Licensing
- Develop Nuclear Operating Organization
- Detailed Engineering & Construction Planning
- Obtain Licenses - to prepare a site, - to construct
- Construct/Install SMR & heat integration infrastructure
- Commission
- Operate, Monitor & Optimize

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☎ 306 651-6330

✉ info@marchconsulting.com

🌐 www.marchconsulting.com

📍 201 21st St E #200, Saskatoon