(Small) Nuclear Energy and the Path (Race) to Net Zero

with thoughts on the So What for Saskatchewan

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The Climate Emergency and the Path (Race) to Net Zero - Context

- Lessons from the COVID-19 Pandemic
- Transitions within Transitions
- Energy System Transition
- Conversations

Canada is a Tier 1 Nuclear Nation

Cigar Lake Uranium Mine

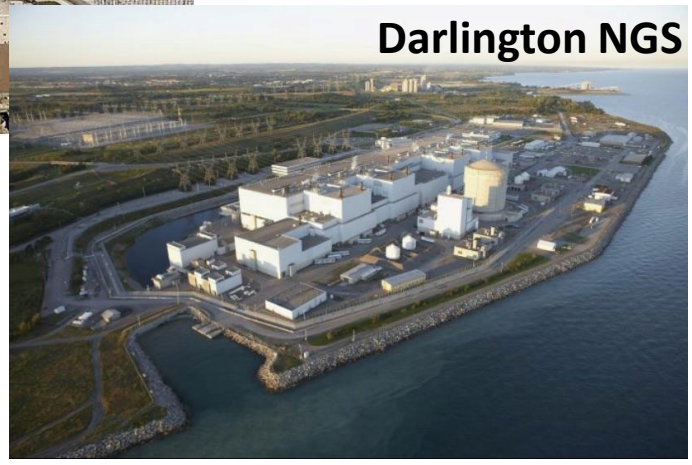
Bruce Power NGS

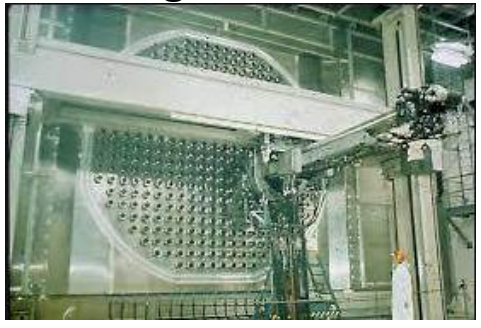
Point Lepreau NGS

Pickering NGS

Canadian Nuclear Safety Commission

Darlington NGS





CANDU Reactor

Canadian Nuclear Laboratories

Nuclear (Fission) Energy Today

- ~440 nuclear reactors worldwide in ~ 30 countries. ~10% of global electricity generation, ~400 GWe installed.
- Canada has 19 reactors providing ~17% of the country's electricity, ~ 60% in Ontario.
- ~50 reactors under construction worldwide, primarily in Asia, led by China, India and Russia.
- New Builds in Asia are largely on budget and on schedule.
- The refurbishment of Ontario's CANDU fleet, at >$25B, is the largest clean-energy project in North America.
- Data show that nuclear energy is among the lowest Green House Gas (GHG) emitting, most affordable, most scalable and safest (including accidents) energy source.

Nuclear (Fission) Energy Today

… but

- Some nuclear nations are exiting nuclear energy, e.g. Germany, Belgium, Switzerland, Taiwan.
- US is seeing nuclear plants in unregulated markets shutting down before end of their operational life because they are no longer economical.
- First-of-Kind (Generation III) New Builds, primarily in the US and EU are over budget and behind schedule.
- Three Mile Island, Chernobyl and Fukushima accidents continue to shape public perceptions of risk.
- Public polling shows persistent high levels of ***nuclear energy hesitancy***.

Nuclear Energy Today – Elephants in the Room

Ionizing Radiation

- ***Nuclear power plants release harmful radiation.***
- Ionizing radiation is naturally occurring. Nuclear power plants release a very small fraction of these normal background levels.
- Science shows there is a threshold below which harmful effects have not been detected. Science cannot yet explain why.

Nuclear Waste

- ***Nuclear waste is dangerous; there is no proven solution for its disposal.***
- A Deep Geological Repository (DGR) is a viable solution; geosphere disposal provides effective barriers. Natural DGRs work.
- Used nuclear fuel has very low volume compared to (toxic) waste from all other forms of energy generation.
- Nuclear energy is the only generating technology where waste costs are factored into its pricing.

Accidents

- ***There have been severe accidents; they will occur again.***
- UN studies assess that the total number of deaths attributable to ionizing radiation from all nuclear accidents at ~ a couple hundred.
- Taking into account all risks to human life in the life cycle of an energy technology, nuclear is the safest means of electricity generation.

Cost to Build

- ***Nuclear power plants are very expensive and take very long to build.***
- Costs to build a conventional (>1GWe) plant are very expensive and schedules are very long, yes.
- Nuclear power plants are also relatively inexpensive to operate, last for a very long time (~40-80 years), and have high capacity factors (operate ~90% + of the time).
- All considered, nuclear power plants are very competitive economically.

All points are true / likely true.

Who to trust/distrust?

But why take the risk?

Are there alternatives?

Why (More/Small) Nuclear Energy? (4x4)

Yesterday/Today

- Electricity Grid Reliability/Security
- Cost to Ratepayers
- VERY low GHG Emissions
- Reduced Air Pollution

Tomorrow - Today + …

- Dispatchable – enabling variable renewables
- Fit for smaller grids
- Beyond electricity
- Clean energy security

Nuclear Energy and the Global Energy System Transition – Evolving Perspectives

- **2015 Paris Climate Agreement – A Commitment to Action**
  - Variable Renewables will lead the way.
  - No/little mention of the role of nuclear energy.
- **2018 Clean Energy Ministerial** launches its Nuclear Innovation for a Clean Energy (NICE) Future initiative
  - Focus placed on renewables and nuclear energy working together.
- **2018 Report of the Intergovernmental Panel on Climate Change**
  - All IPPC Scenarios require lots more variable renewables and more nuclear energy.
  - 1/2 of IPPC scenarios postulate a 60% growth in nuclear energy.
- **2019 World Energy Outlook of the International Energy Agency**
  - A sustainable energy future needs all low-carbon solutions, including lots more variable renewables and more nuclear energy.
  - The IEA's 2050 Net Zero scenario postulates a 36% growth in nuclear energy.

Nuclear Energy and the Path (Race) to Net Zero

Nuclear Energy Priorities (IPCC, IEA)

- Extend the life of the conventional nuclear fleet where possible.
- Deliver planned conventional nuclear New Builds with Generation III (passive safety) designs.

… ***and***

- Transition rapidly to ***New Nuclear Energy*** that
  - *greatly reduces construction costs and time,*
  - *uses simpler and safer designs,*
  - *Provides the dispatchable solution to enable scale-up of Variable Renewable Energy,*
  - *looks beyond grid-level electricity markets, and*
  - *reduces nuclear waste streams.*

New Nuclear Energy: Innovation Goals

~ 70 companies worldwide are presently developing SMR solutions for market readiness within ~2-10 years

Fourth-Generation Reactor Technology

Small Modular Reactors

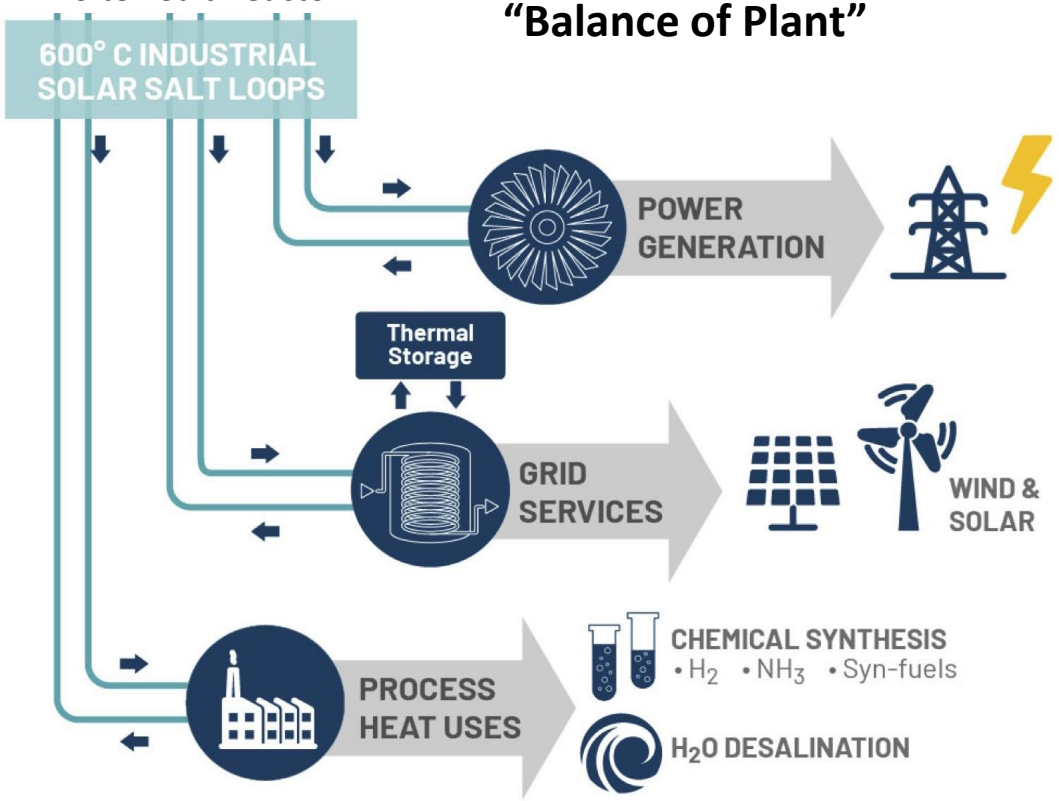
Competitive Energy Pricing (w/o carbon tax)	Competitive Time to Market	Reduced Capital Requirements	Access to Energy Markets Beyond Electricity
Improved Safety, Security, Safeguards Margins	Electricity/ Heat Co-Generation	(Near) Closed Nuclear Fuel Cycles	No/Minimal Very Long-Term Radioactive Waste
Compatibility with Renewables	Load Following	Reduced Environmental Footprint	Enabler of the Hydrogen Economy

Et cetera …

Almost all designs are based on designs prototyped decades ago, updated with novel engineering approaches

View 1: The SMR Value Proposition - the Energy System's Multi-tool

e.g. Terrestrial Energy's Integrated Molten Salt Reactor



On Grid Power (~150-300 MWe)

- Fossil fuels (on-site) replacement
- Electrification growth
- Dispatchable energy solution
- Variable Renewables enabler

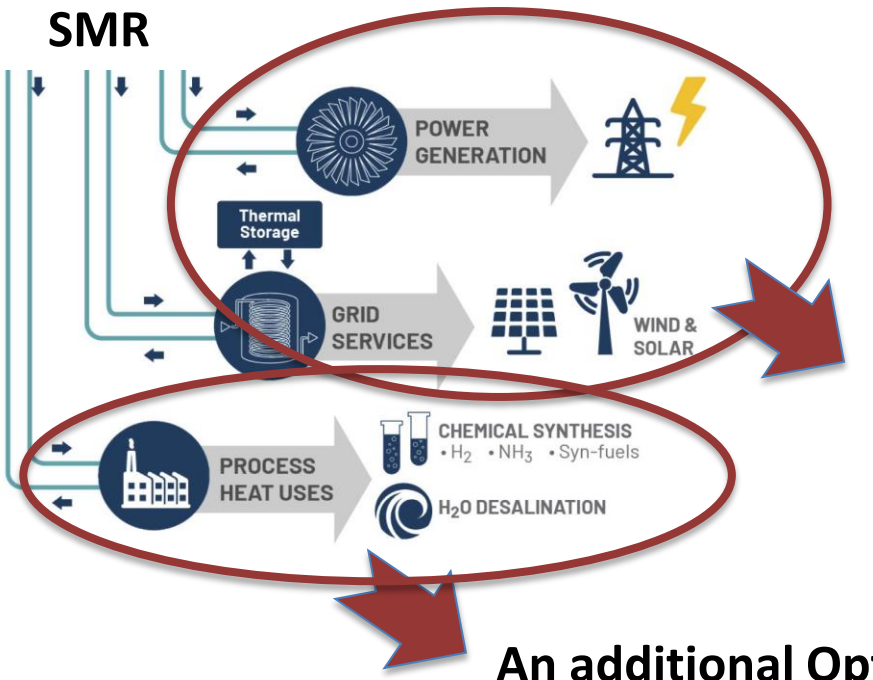
Resource Extraction and Heavy Industry (~10-80 MWe)

- Combined heat & power
- On and Off Grid
- Synthetic fuels, clean chemicals
- Hydrogen economy

Remote Communities (~1-10 MWe)

- Electricity
- District heating
- Desalination, food production

View1: The SMR Value Proposition
Helping Saskatchewan's Path to Net Zero?



Phase 1: Today to 2030: Migrate off Coal

- Natural Gas for Baseload and for Dispatchable Power
- Some Variable Renewables

Phase 2: 2030 - 2050: Migrate off Gas

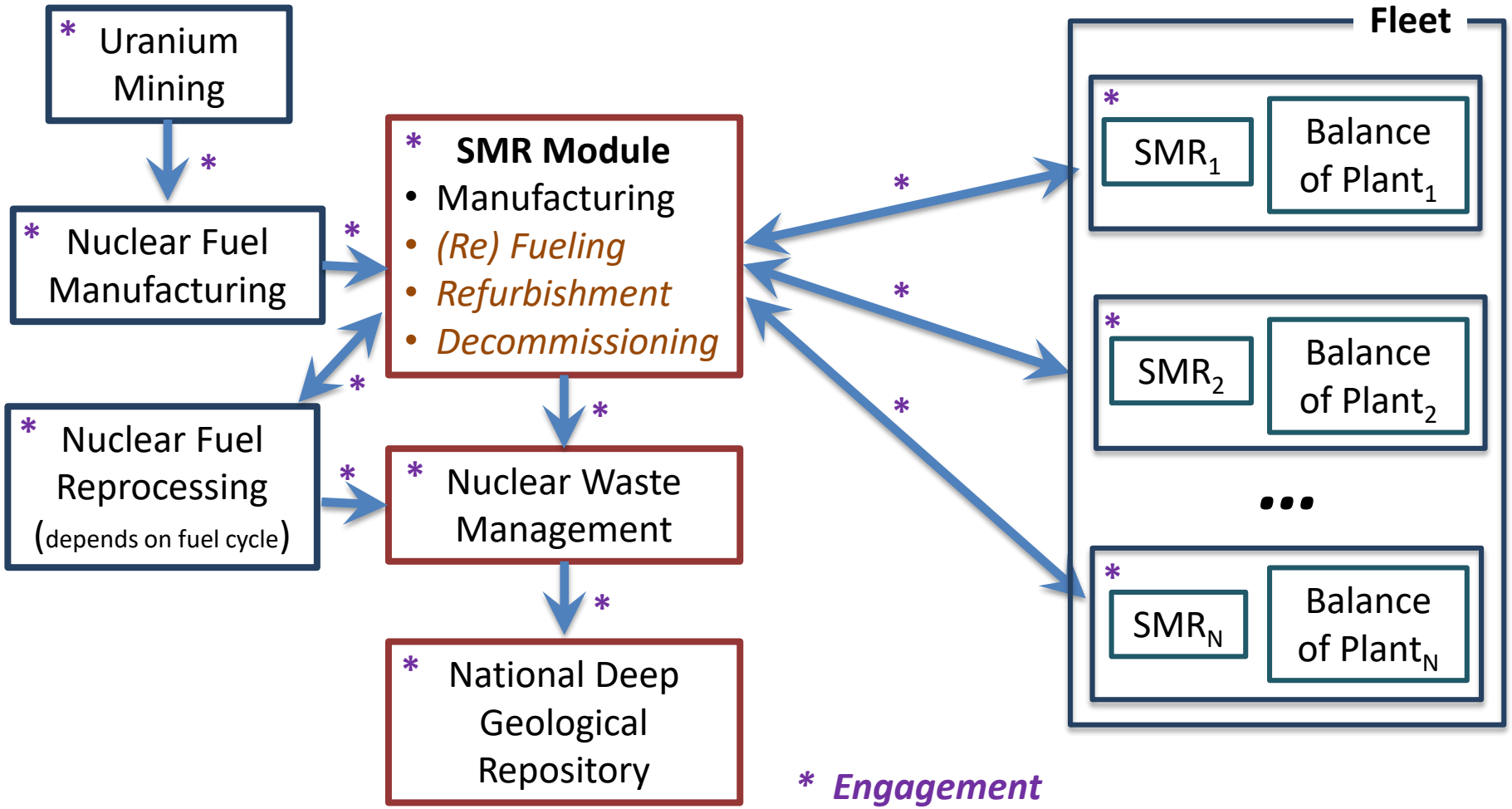
- If proven, SMR(s) for Baseload and for Dispatchable Power
- More Variable Renewables

An additional Option:

- If proven, SMRs could also enable Saskatchewan's place in synthetic fuels, clean chemicals, hydrogen economy, etc.
- Jobs!

View 2: A Notional SMR System

- **Saskatchewan Footprint?**
- National Footprint?
- International Footprint?



Transportation of Nuclear Materials

* ***Engagement***

Indigenous Rights Holders Agreements
Host / Impacted Community Agreements
Owner, Operator, Licensee Agreements
Regulatory Licenses

Canada's SMR Roadmap (2018) and Action Plan (2020)

Why Canada?

- Tier 1 Nuclear Nation
- Indicative SMR Markets
- Regulation of Nuclear Innovation

Action Plan

- Engagement is ramping up
- Partnerships are taking shape
- Demonstrations are moving forward

Key Milestones

- Early 2020's – first micro SMR demonstration at CNL, more being planned
- 2028 – first on-grid SMR built at Ontario Power Generation's Darlington NGS
- Early 2030's – planning for roll out of on-grid SMRs in New Brunswick, Ontario, Saskatchewan, Alberta