Potential of Advanced Reactors/SMRs for Decarbonization - beyond Electricity in Canadian Context

NEA Workshop
Electricity System (R)Evolution
What Role for Baseload and Dispatchable Technologies

NEA Headquarters, Boulogne-Billancourt, France

2019 September 4

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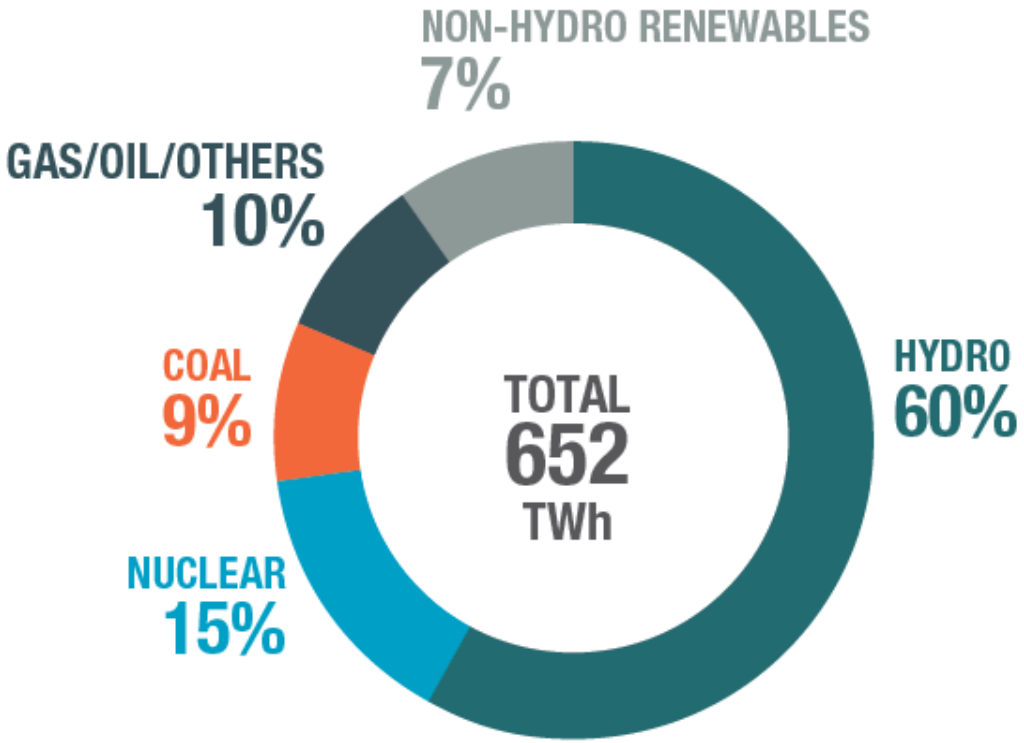
Outline

- **GHG Emissions –** electricity and beyond
- **Canada's SMR Roadmap**
- **CNL's SMR Initiative**
- **Potential opportunities for AR/SMR**
- **Integration with wind, hybrid system**
- **Past experience with nuclear cogeneration**
- **Concluding remarks**

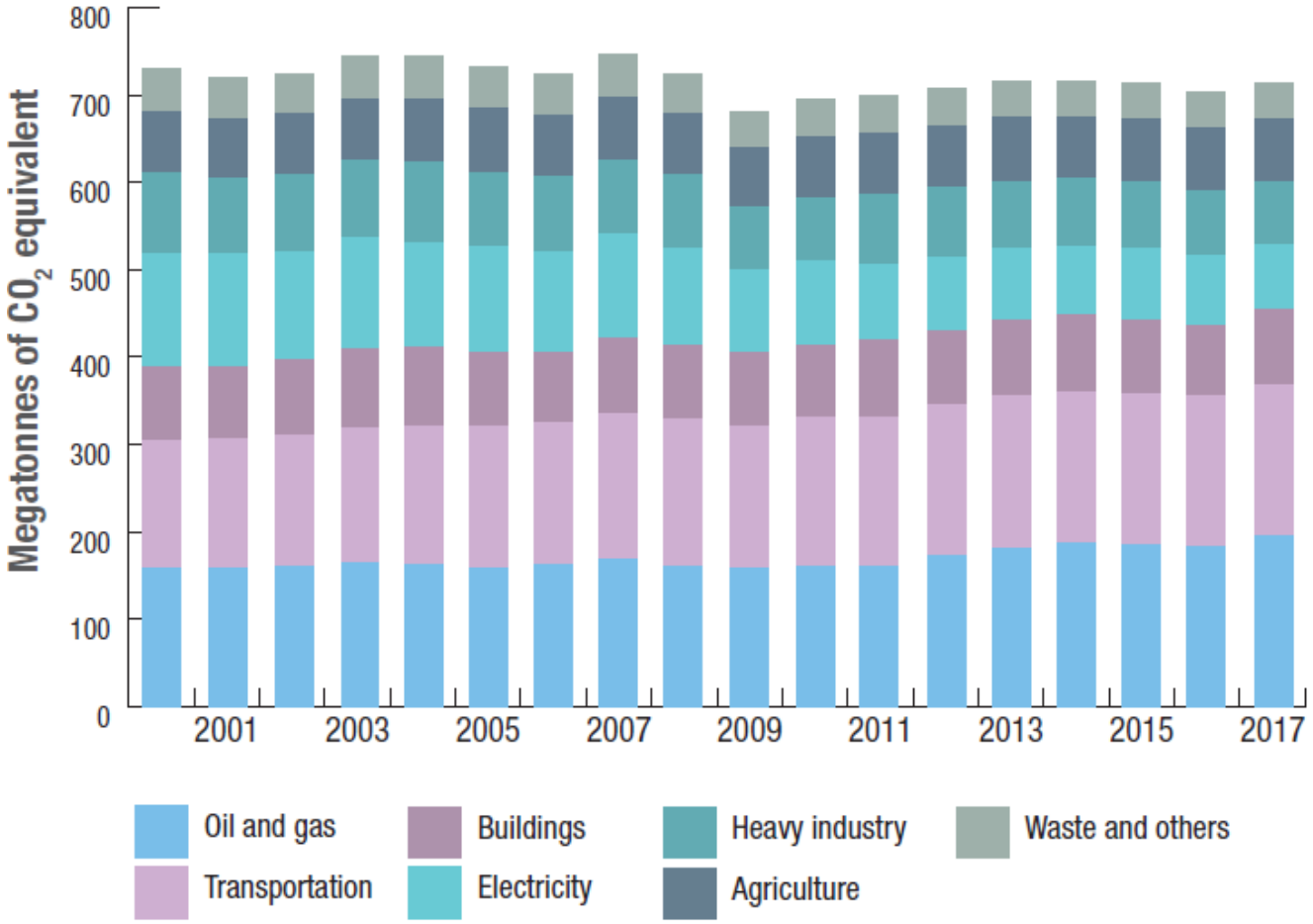
Electricity Generation in Canada



652.3 TWh in 2017

"Energy Fact Book 2019-20", Natural Resources Canada, 2019 July

GHG Emissions by Canadian Economic Sector, 2000-2017



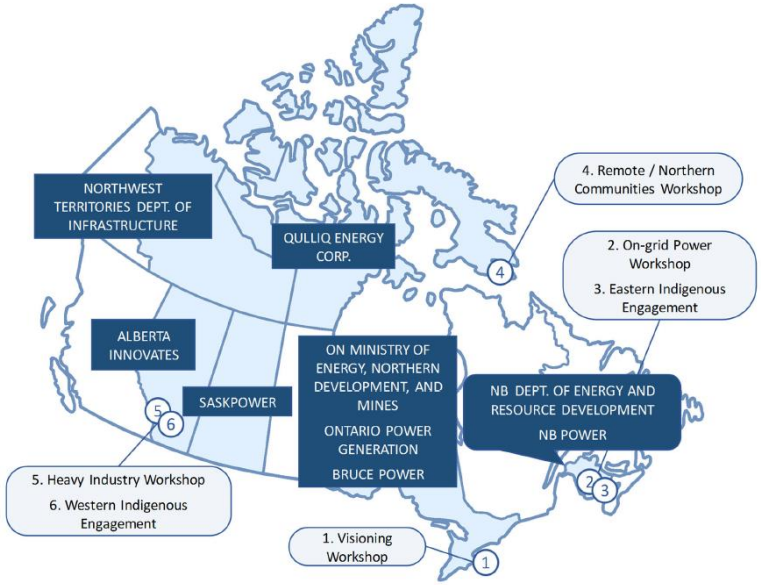
"Energy Fact Book 2019-20", Natural Resources Canada, 2019 July

Canada's SMR Roadmap

- ***Vision:*** SMRs as a source of safe, clean, affordable energy, opening opportunities for a resilient, low-carbon future and capturing benefits for Canada and Canadians.

- ***Collaborative effort:*** pan-Canadian approach, interested provinces and territories, power utilities, 55 organizations, five experts groups.

- ***Report:*** published in 2018 November



Domestic Market Potential for SMRs

Significant domestic potential for SMRs

1. **On-grid power generation** Canada's commitment to phase out coal-fired power plants by 2030; and secure 90% non-emitting electricity supply by 2030
2. **On and off-grid combined heat and power for resource extraction and heavy industry**; oil sands facilities, heavy industries
3. **Off-grid diesel replacement** for electricity, district heating, and desalination in remote communities (<10 MWe, many <2.5 MWe)

Recommendations from SMR Roadmap

- **Demonstration and Deployment**
  - Govt funding to cost-share with private industry for demonstration
  - Govt risk sharing for first commercial deployment
- **Policy, legislation and regulation**
  - Regulatory efficiency, graded risk-informed approach, risk-sharing on waste management costs
- **Capacity, engagement and public confidence**
  - Engagement with indigenous peoples and communities
- **International partnerships and markets**
  - International enabling frameworks for technologies

Specific recommendations for governments, regulator, industry associations, utilities, vendors, research institutions
e.g. fleet approach for the industry

CNL's SMR Vision

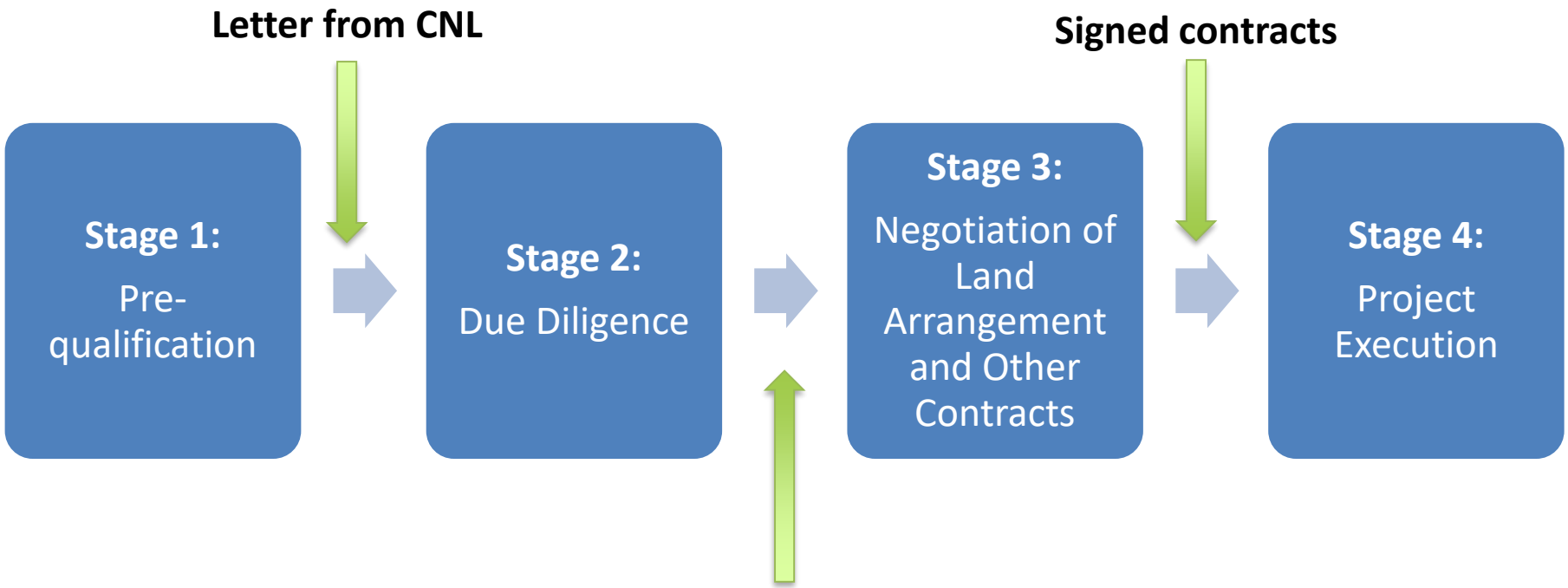
- *"demonstrate the commercial viability of the small modular reactor by 2026."*
- *"recognized globally as a leader in SMR prototype testing and S&T support."*
- *"be a recognized hub for SMRs, where multiple vendor-supported prototypes are built and tested."*
- *"in the next 10 years … host a prototype"*

Excerpts from our 10 Year Plan – www.cnl.ca/strategy

CNL's SMR Initiative

- **CNL issued Request for Expression of Interest in Summer 2017**
- **80 responses, 19 expressions for potential SMR demonstrations at a CNL site**
- **Results summarized in a report available at www.cnl.ca**
- **Strengths**
  1) Canadian regulatory approach is strong
  2) Favourable market demand and policy alignment
  3) Existing nuclear supply chain
  4) CNL's capabilities are a needed asset
- **CNL issued invitation for siting of SMR demonstration project (closed on 2018 June 11)**

CNL's Staged Process for Application Evaluation



CNL recommends to AECL
If successful, letter of support for licensing purposes

Update on CNL's Process to Site SMR

Two proponents completed pre-qualification stage (Stage 1)

- StarCore Nuclear – 14 MWe HTGR
- Terrestrial Energy – 195 MWe integral MSR
- U-Battery – 4 MWe HTGR

One proponent progressed through Stage 2

- Global First Power (GFP) with key partners Ontario Power Generation (OPG) andUltra Safe Nuclear Corporation (USNC) – 5 MWe HTGR
- Submitted application to Canadian Nuclear Safety Commission (CNSC)for a license to prepare site at Chalk River Laboratories
- Notice of commencement of environmental assessment posed by CNSC to the Canadian Environmental Assessment Agency – 2019 July

CNL's Canadian Nuclear Research Initiative

- **Program to enable R&D to accelerate deployment of SMRs in Canada**
- **Launched in 2019 July**
- **CNL will issue annual call for proposal in focus areas**
  - Market analysis, fuel development, reactor physics modelling, transportation
  - Access to CNL's expertise and facilities

Vendor Design Reviews by Canadian Nuclear Safety Commission (with service agreements)

Vendor	Name of design and cooling type	MWe	Applied for	Review start date	Status
Terrestrial Energy Inc.	IMSR Integral Molten Salt Reactor	200	Phase 1	2016 April	Complete
			Phase 2	2018 December	Assessment in progress
Ultra Safe Nuclear Corporation	MMR-5 and MMR-10 High-temperature gas	5-10	Phase 1	2016 December	Complete
			Phase 2	Pending	Project start pending
LeadCold Nuclear Inc.	SEALER Molten Lead	3	Phase 1	2017 January	On hold at vendor's request
Advanced Reactor Concepts Ltd.	ARC-100 Liquid Sodium	100	Phase 1	2017 September	Assessment in progress
Moltex Energy	Moltex Energy Stable Salt Reactor	300	Series Phase 1 and 2	2017 December	Phase 1 assessment in progress
SMR, LLC. (A Holtec International Company)	SMR-160 Pressurized Light Water	160	Phase 1	2018 July	Assessment in progress
NuScale Power, LLC	NuScale Integral pressurized water reactor	60	Phase 2	Pending 2019	Project start pending

https://nuclearsafety.gc.ca/eng/reactors/power-plants/pre-licensing-vendor-design-review/index.cfm

Vendor Design Reviews (applied for service agreements with CNSC)

Vendor	Name of design and cooling type	MWe	Application received	Applied for
StarCore Nuclear	StarCore Module High-temperature gas	10	2016 October	Series Phase 1 and 2
URENCO	U-Battery High-temperature gas	4	2017 February	Phase 1
Westinghouse Electric Company, LLC	eVinci Micro Reactor solid core and heat pipes	Various outputs up to 25 MWe	2018 February	Phase 2*
GE-Hitachi Nuclear Energy	BWRX-300 boiling water reactor	300	2019 March	Phase 2*

https://nuclearsafety.gc.ca/eng/reactors/power-plants/pre-licensing-vendor-design-review/index.cfm

Opportunities for Decarbonization

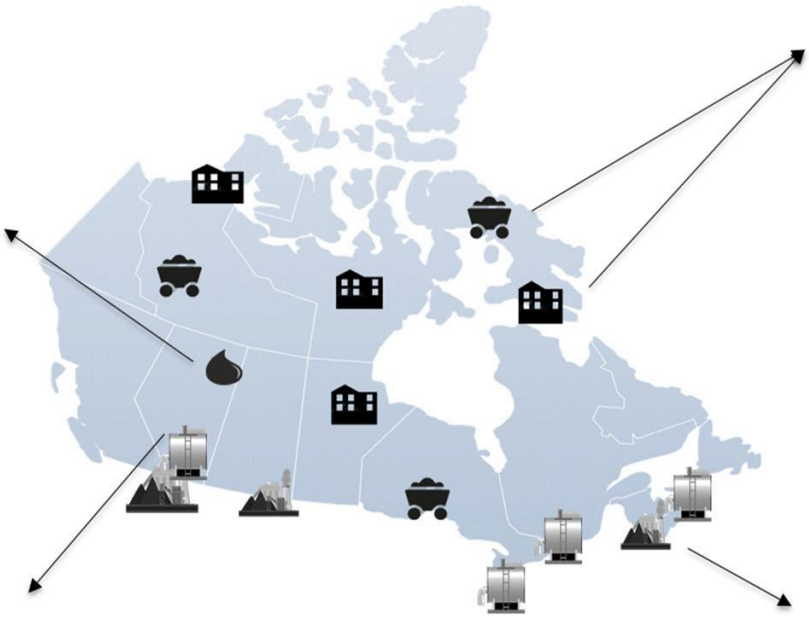
SMR Opportunities in Canada

Oil sands

- Steam for SAGD and electricity for upgrading at **96 facilities**
- 210 MWe average size for both heat and power demands
- 5% replacement by SMRs between 2030 and 2040 could **provide $350-450M in value annually**

High-temperature steam for heavy industry

- 85 heavy industry locations (e.g. chemicals, petroleum Refining)
- 25-50 MWe average size
- 5% replacement by SMRS between 2030 and 2040 could **provide $46M in value annually**



Remote communities and mines

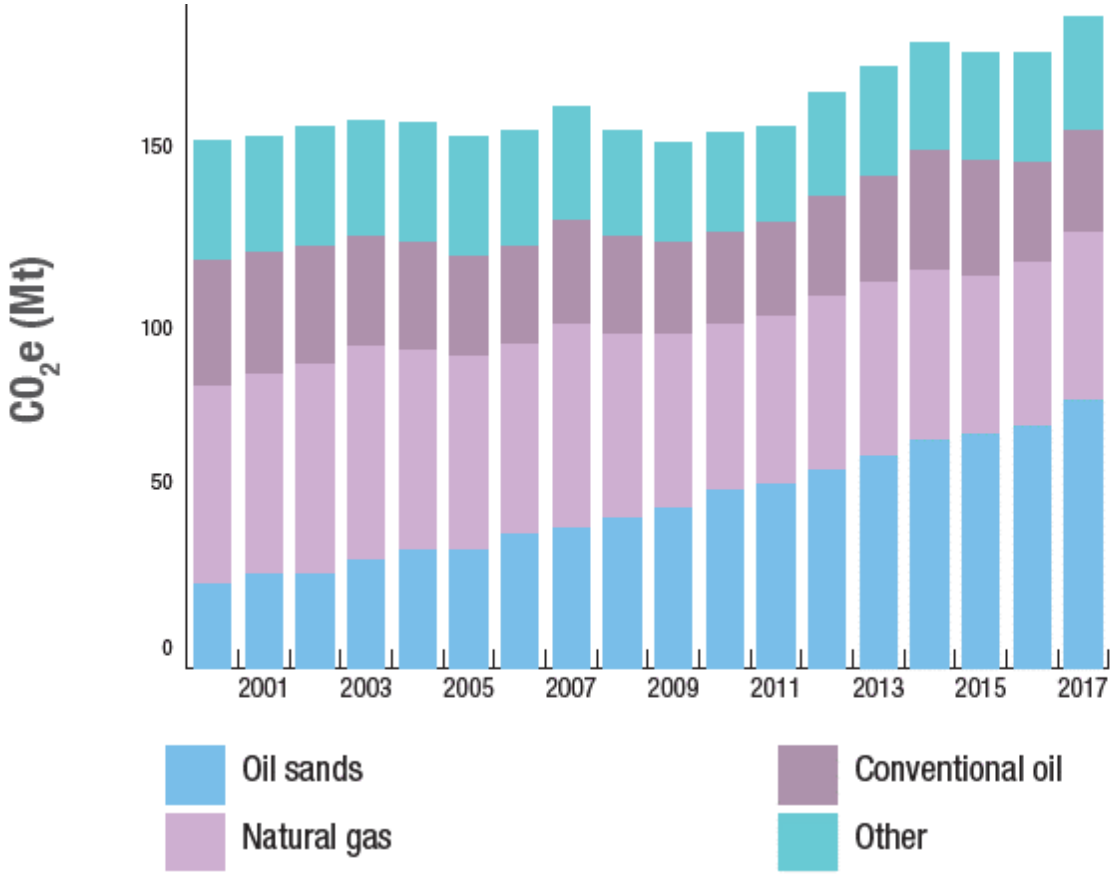
- 79 remote communities in Canada with energy needs > 1 MWe
- SMRs replacing costly diesel and heating oil could **reduce energy costs to the territorial government**
- **The high cost of energy from diesel is a barrier. SMRs could facilitate and enable new mining developments**
- 24 current and potential off-grid mines

Replacing conventional coal-fired power:

- 29 units in Canada at 17 facilities
- 343 MWe average size
- 10% replacement by SMRs between 2030 and 2040 could **provide $469M in value annually**

A Call to Action: A Canadian Roadmap for Small Modular Reactors, 2018 November
https://smrroadmap.ca/

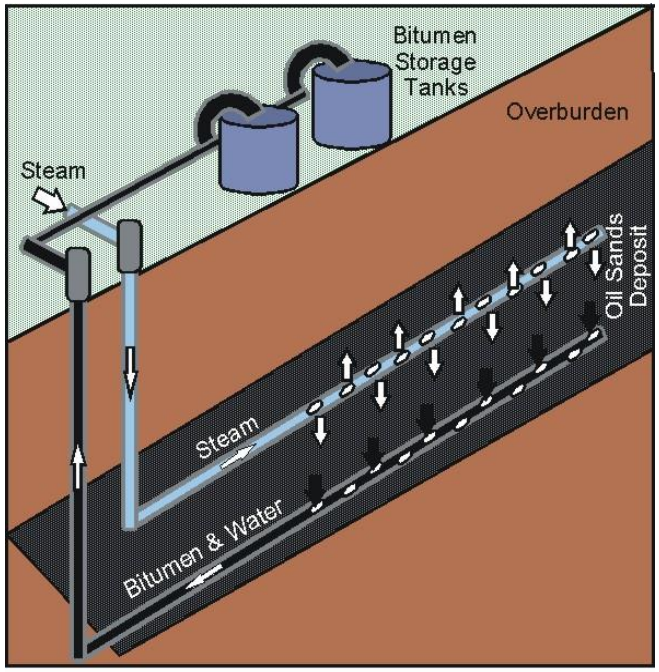
GHG Emissions by Oil & Gas Sector in Canada: 2001-2017

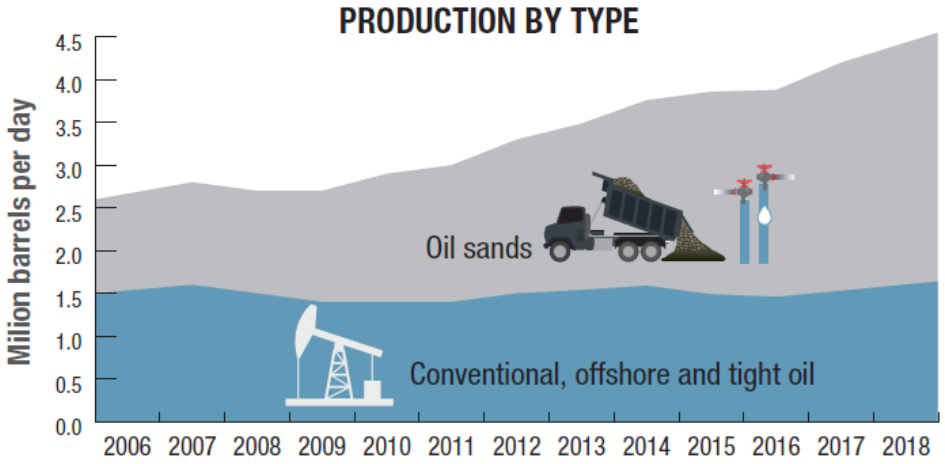


Oil sands emissions decreased by 28% per barrel

"Energy Fact Book 2019-20", Natural Resources Canada, 2019 July

Bitumen Extraction from Oil Sands





- **Increasingly, more bitumen is extracted by in-situ Steam-Assisted Gravity Drainage (SAGD) techniques**
- **About 50% of bitumen is upgraded to synthetic crude using hydrogen**

Is there potential for SMRs in the Oil Sands?

Oil sands currently rely on natural gas for:

- Steam: 1-2 MPa for surface mining, 10 MPa for in-situ extraction.
- Hydrogen Production: Canada uses ~3MT of hydrogen each year. The majority if for upgrading heavy oil.
- Electricity production.

Surface Mining

200,000 bbl/d requires:

- 150-300 tonnes/h 2.1 MPa steam
- 450-900 tonnes/h 1.05 MPa steam
- 127-175 MWe power

In-Situ (SAGD) Mining

33,000 bbl/d requires:

- 655 tonnes/h 10 MPa steam
- 15 tonnes/h 1.05 MPa steam
- 18 MWe power

Deployability of Small Modular Nuclear Reactors for Alberta Applications – Phase II, PNNL-27270, 2018 March

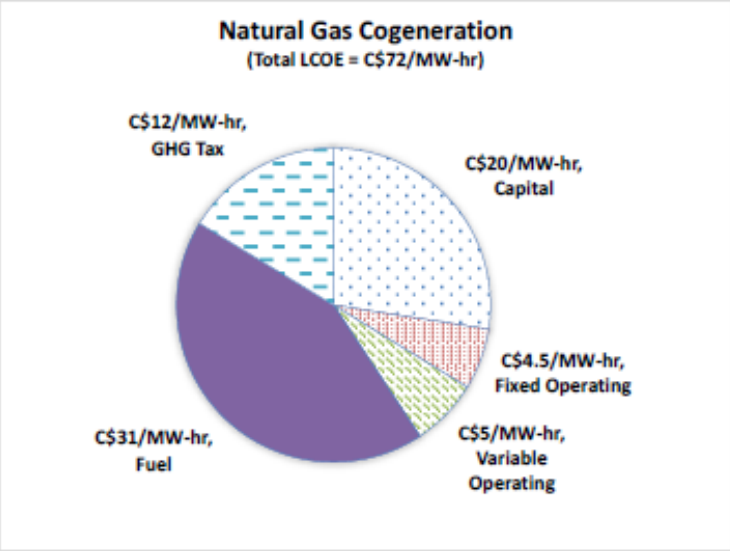
Estimates of Nuclear Energy Required to Replace Current Usage of NG

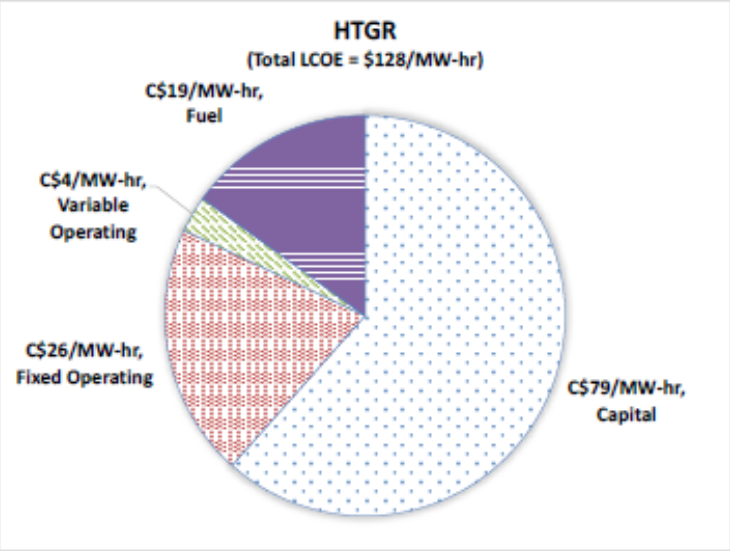
- 66 iPWRs (45 MWe) for surface mining operations
- 40 HTGRs (600 MWth) for in-situ operations
- 5 to 7.5 GWe for hydrogen production

But, What about the cost?

For in-situ SAGD

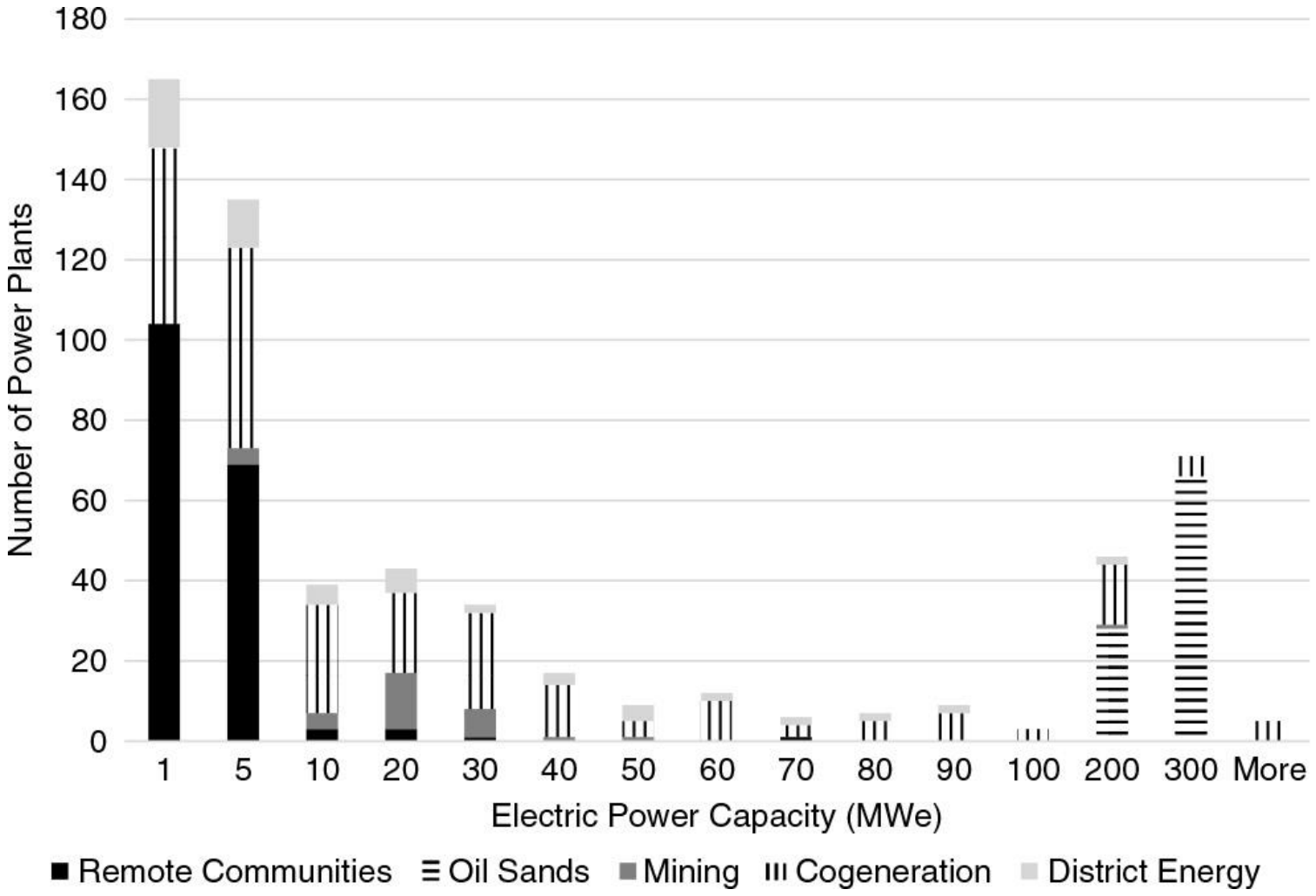
- 600 MWth single module HTGR, overnight EPC cost C$6,600/kWe (2014)
- Natural gas price C$ 3.25/GJ (would have to increase to C$10.5/GJ for iPWR to be Competitive); carbon tax C$30/tonne CO_2





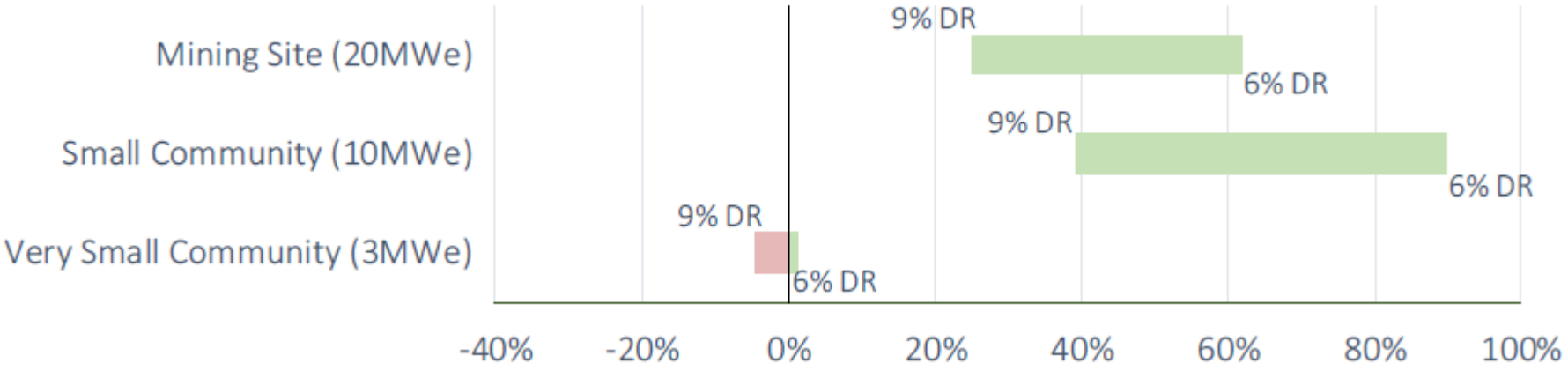
Deployability of Small Modular Nuclear Reactors for Alberta Applications – Phase II, PNNL-27270, 2018 March

Off-Grid Market Potential for SMRs



Potential Off-Gris Markets for SMRs in Canada, D.T. Wojtaszek, CNL Nuclear Review, 2017 September

Economics – Off-grid Applications



Cost advantage of SMRs over diesel: The difference in levelized cost of electricity for diesel and SMR options, expressed as a percentage of the levelized cost of electricity for diesel generators.

- 79 remote communities
- 24 off-grid mines

A Call to Action: A Canadian Roadmap for Small Modular Reactors, 2018 November
https://smrroadmap.ca/

On-grid SMRs to Replace Fossil – Best Case

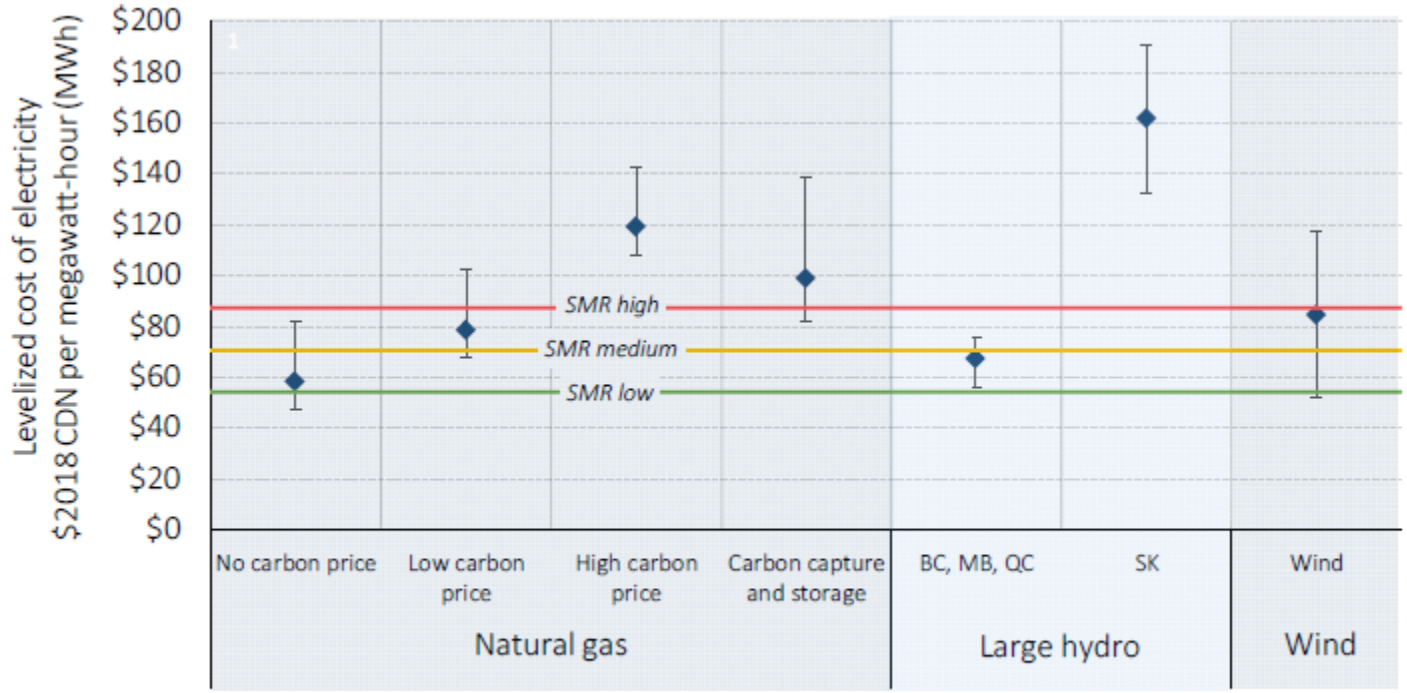


Figure 1. Comparison of levelized cost of electricity from on-grid SMRs with other options: Best case (6% discount rate, more innovative technology)

A Call to Action: A Canadian Roadmap for Small Modular Reactors, 2018 November
https://smrroadmap.ca/

On-grid SMRs to Replace Fossil – Worst Case

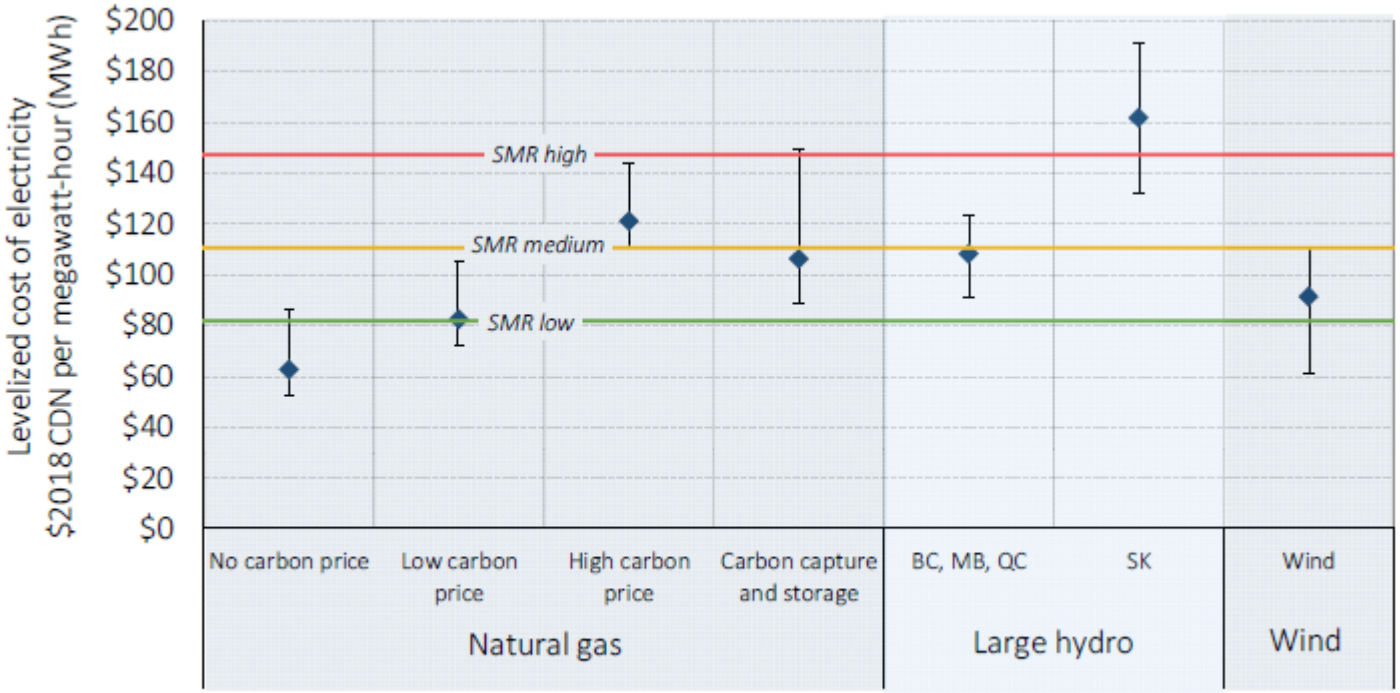


Figure 2. Comparison of levelized cost of electricity from on-grid SMRs with other options: Worst case (9% discount rate, less innovative technology)

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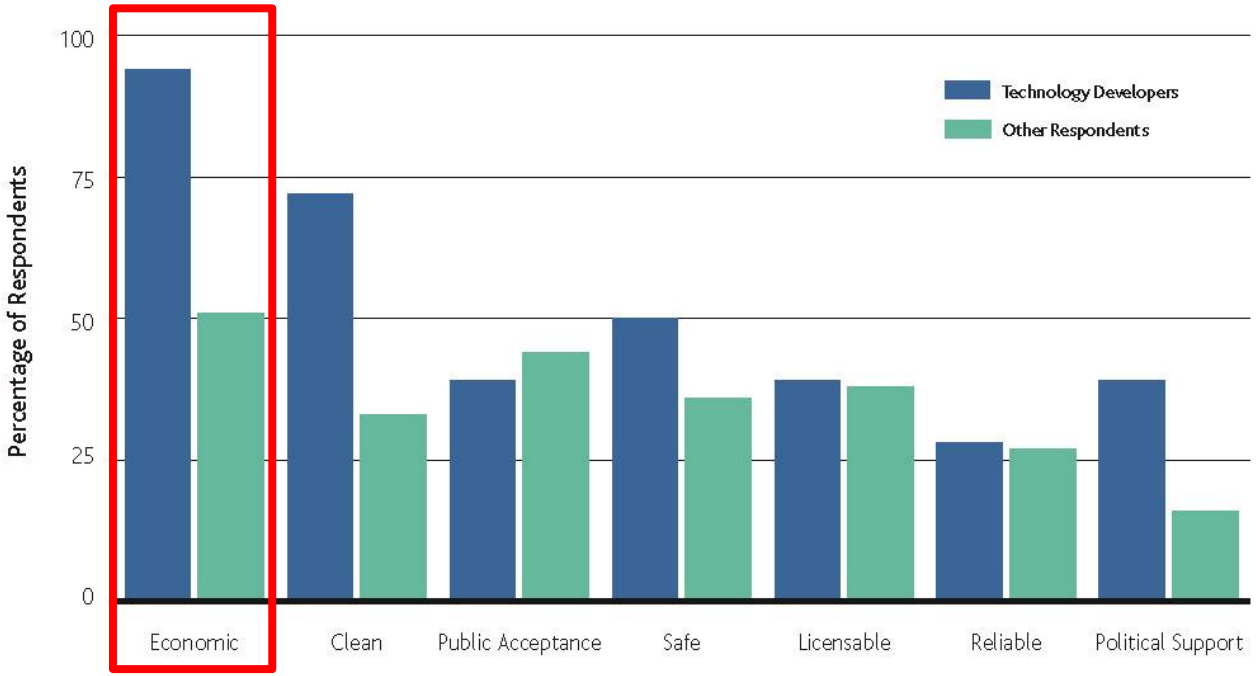
https://smrroadmap.ca/

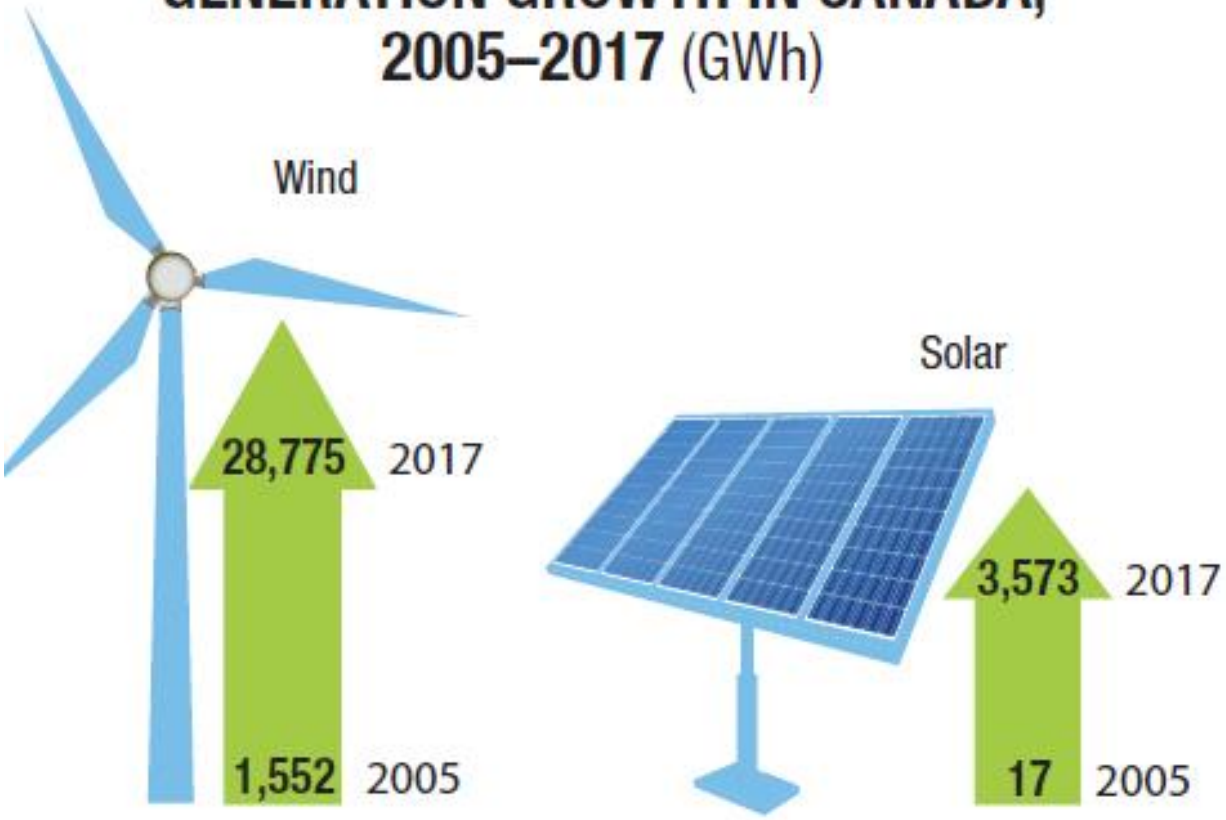
Economic Competitiveness- the Most Requirement for SMR Deployment

Survey Results (2017)



Perspectives on Canada`s SMR Opportunity, Summary Report: Request for Expressions of Interest – CNL`s Small Modular Reactor Strategy, Canadian Nuclear Laboratories, 2017 October

WIND AND SOLAR NET ELECTRICITY GENERATION GROWTH IN CANADA, 2005–2017 (GWh)



- **Nuclear needs to be flexible for integration with renewables**
- **Hybrid systems**

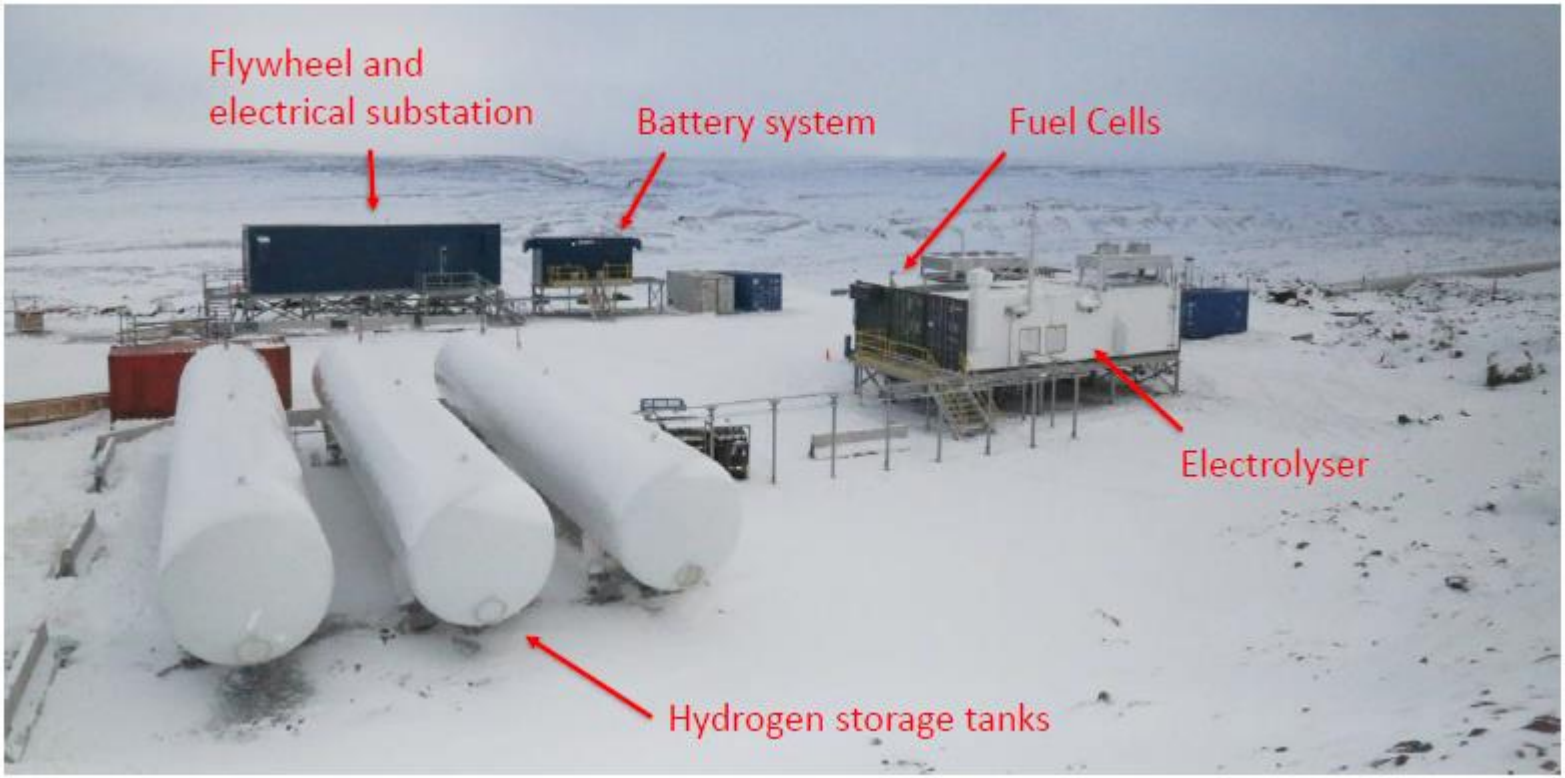
"Energy Fact Book 2019-20", Natural Resources Canada, 2019 July

Smart Grid Demonstration in Canada's North

Location of Tugliq Energy Co's Wind Mill Smart-Grid

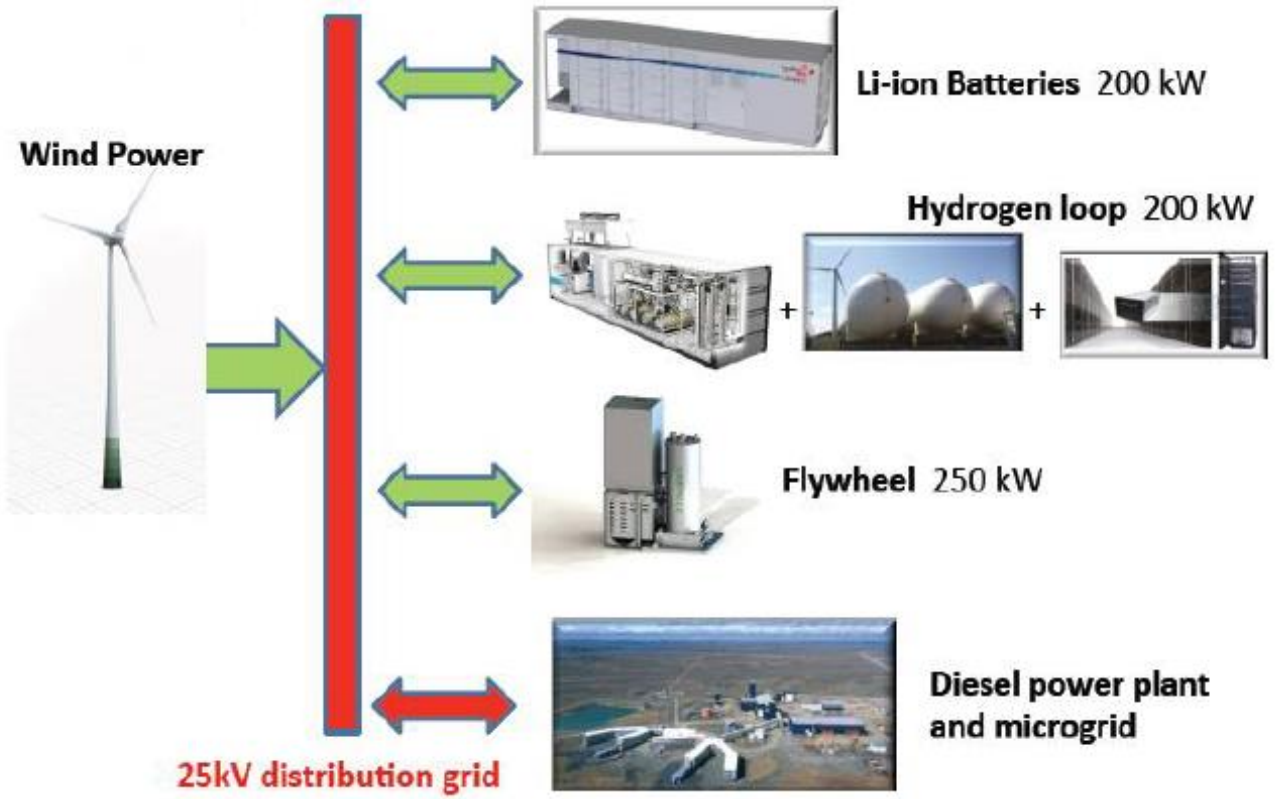
Canadian Nuclear Laboratories | Laboratoires Nucléaires Canadiens

Does it Look Like a Hybrid Energy System?



"Update on Quebec's Renewable Hydrogen Energy Activities" Tugliq Energy Co., presented to Osaka Chamber of Commerce and Industry, 2016 January

Hybrid Energy System



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Past Experience with Nuclear Co-generation

Largest Co-generation Application Operated in Canada - Bruce Bulk Steam System

- **Largest bulk nuclear steam system in the world – capacity 5,350 MW medium-pressure steam, 6 km of piping**

- **Operated until early 2000s, demolished in 2006**

- **Major users**
  - Heavy water Plant – 750 MW thermal
  - Building heating – 15 MWth
  - Bruce Energy Centre (BEC) – 72 MWth

- **Three barriers between steam user and nuclear plant**

Bruce Bulk Steam System

- **Heat source: 4 x 848 MWe Bruce A reactors**
  - Each of four reactors capable of supplying high pressure steam to a bank of 6 heat exchangers (24 in total)
  - Heat exchangers provided medium pressure steam
- **Emergency back-up provided by 3 oil-fired boilers**
- **Nominal capacity 1680 kg/s medium pressure steam, Emergency back-up 320 kg/s**
- **~ 6km line; steam supply 36” diameter (0.91 m); return condensate line 18” diameter (0.46 m)**

Largest Nuclear Co-generation Application in Canada - Heavy Water Production

Bruce Heavy Water Plant

Bruce Nuclear Generating Station

Bruce Heavy Water Plant

- Four heavy water (Girdler-Sulphite type) plants were planned, two actually operated (800MT/y/plant)
- Plant A was in production from 1973 to 1984
- Plant B was in production from 1979, partially shutdown in 1993 and completely closed in 1997
- Total production of heavy water (>99.75% D2O) = 16,000 MT
- Feed water/product ratio = 340,000
- Average medium pressure steam requirement -750 MWth

HWP – Steam Supply

- **Steam (750 MW Th) supplied from Bruce A station ~ 30% of the output of a single 800 MWe unit.**

- **Reliability criteria for steam supply**
  - Maximum interruption in summer – 4 hours
  - Maximum interruption in winter – few minutes

- **Back-up supply:**
  - Condensate pumps supplied by uninterruptible power from gas turbine stand-by generator
  - 3 oil fired boilers; one on hot stand-by

- **No loss of emergency steam during 17 years of operation**

Bruce Energy Centre

Bruce Energy Centre

- **Located on ~390 acres land near Bruce nuclear power plants**
- **Steam system originally designed for 75 MWth**
- **Types of industries**
  - Plastic film production
  - Alcohol plant
  - Food processing
- **Nuclear steam supply shutdown in 1990s; replaced by natural gas fired system**

Concluding Remarks

- **Significant potential for AR/SMR for decarbonisation**
- **Unique opportunities – for oil sands, remote mines, off-grid applications**
- **Current lower natural prices are hurdle to deployment of AR/SMR**
- **Canada's SMR roadmap makes specific recommendations to the governments, utilities, vendors, industry associations and research institutions to make SMR happen**
- **CNL's SMR initiative is on target for demonstration by 2026**

Thank you / Merci

Questions?

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