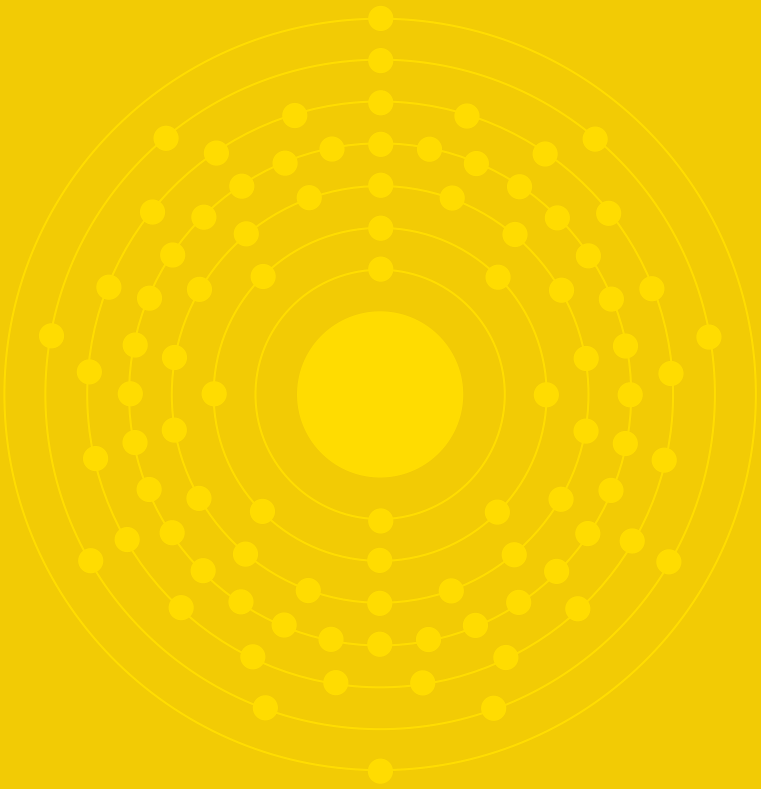
Capturing the full potential of the uranium value chain in Saskatchewan

Uranium Development Partnership

March 31, 2009



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Preface

In October 2008, the Government of Saskatchewan convened a group of representatives from business, labour, academia, urban, rural, First Nations, and environmental communities to create an expert panel – the Uranium Development Partnership (UDP). The 12 members appointed by the Government represent a broad cross-section of Saskatchewan stakeholders, as well as representatives of the uranium and nuclear industries. The group's mandate was to "identify, evaluate, and make recommendations on Saskatchewan-based value added opportunities to further develop our uranium industry."

The UDP has spent the past 5 months examining this issue – conducting its own research, interviews, and field visits, as well as commissioning independent third-party research. The result of this effort is a comprehensive view of the uranium and nuclear industries, and of Saskatchewan's role within them, both today and in the future. Our goal was to develop a vision of what is possible based on economic, technical, environmental, and social considerations. We hope this report will serve as a foundation for informed discussion and decision-making.

We believe great potential exists for the Province of Saskatchewan in the uranium and nuclear industries. We have identified where we believe these opportunities lie and what it would take to successfully realize them. We have also identified efforts that the Partnership believes should *not* be pursued in the foreseeable future. Our goal is to develop a balanced perspective on what is possible. We are excited about the potential impact for the Province in terms of job creation, GDP, economic growth, and the mitigation of carbon emissions. At the same time, we are realistic about the challenges presented by moving from leadership in uranium mining to much broader participation across the value chain.

This document is the formal submission from the Uranium Development Partnership to the Government of Saskatchewan, and it contains our specific recommendations to revitalize and capture growth opportunities across the uranium value chain. Effective public policy requires consideration of a broad range of issues and perspectives, and we believe this report is an important first step. Pursuing opportunities in the uranium and nuclear power industries must build on real engagement and open and informed discussion among governments, Northern communities, industry, researchers, and the broader public. It is our hope that this report will support and inform that dialogue on the future of the industry and its role in the prosperity and well-being of the Province of Saskatchewan.

Dr. Richard Florizone
Chair, Uranium Development Partnership
March 2009

Uranium Development Partnership members

Chair

Dr. Richard Florizone is the Vice President of Finance and Resources at the University of Saskatchewan and holds a PhD in Nuclear Physics from the Massachusetts Institute of Technology.

Members

Ray Ahenakew has served as Chief Executive Officer of the Meadow Lake Tribal Council and President of the Saskatchewan Indian Institute of Technology where he is currently serving as Business Development Advisor.

Keith Brown represents the Saskatchewan Chamber of Commerce. He is the President and founder of Trailtech Inc. in Gravelbourg and has served as Chairman of the Saskatchewan Trade and Export Development Partnership.

Neil Collins has 30 years of experience with SaskPower, is a former member of the SaskPower Board of Directors, and currently serves as Business Manager for the International Brotherhood of Electrical Workers (IBEW) Local 2067.

Allan Earle is President of the Saskatchewan Urban Municipalities Association and Mayor of the Town of Dalmeny.

Jerry Grandey is the President and CEO of Cameco Corporation, one of the world's largest uranium producers, headquartered in Saskatoon.

Jim Hallick is Vice President of the Saskatchewan Association of Rural Municipalities and a Councillor for the Rural Municipalities of Keys.

Duncan Hawthorne is the President and CEO of Bruce Power Inc. He also serves as Chair of the Canadian Nuclear Association and Director of the Energy Council of Canada, and is a member of the Board of Governors of the World Association of Nuclear Operators.

Armand Laferrere is President and CEO of AREVA Canada. With 925 employees in Canada and 75,000 employees in 43 countries, AREVA is a world leader in nuclear power and is active across the full nuclear fuel cycle.

Dr. Edward Mathie is Professor of Nuclear Physics at the University of Regina and a member of the Canadian Association of Physicists, the Canadian Institute of Particle Physics, and the Canadian Institute of Nuclear Physics.

Dr. Patrick Moore is co-founder of Greenpeace, former President of Greenpeace Canada, and a former Director of Greenpeace International. He currently serves as Chair and Chief Scientist of Greenspirit Strategies Ltd. in Vancouver, BC.

Alex Pourbaix is President – Energy, TransCanada Corporation, with responsibility for the company's power, gas storage, liquefied natural gas, and compressed gas businesses.

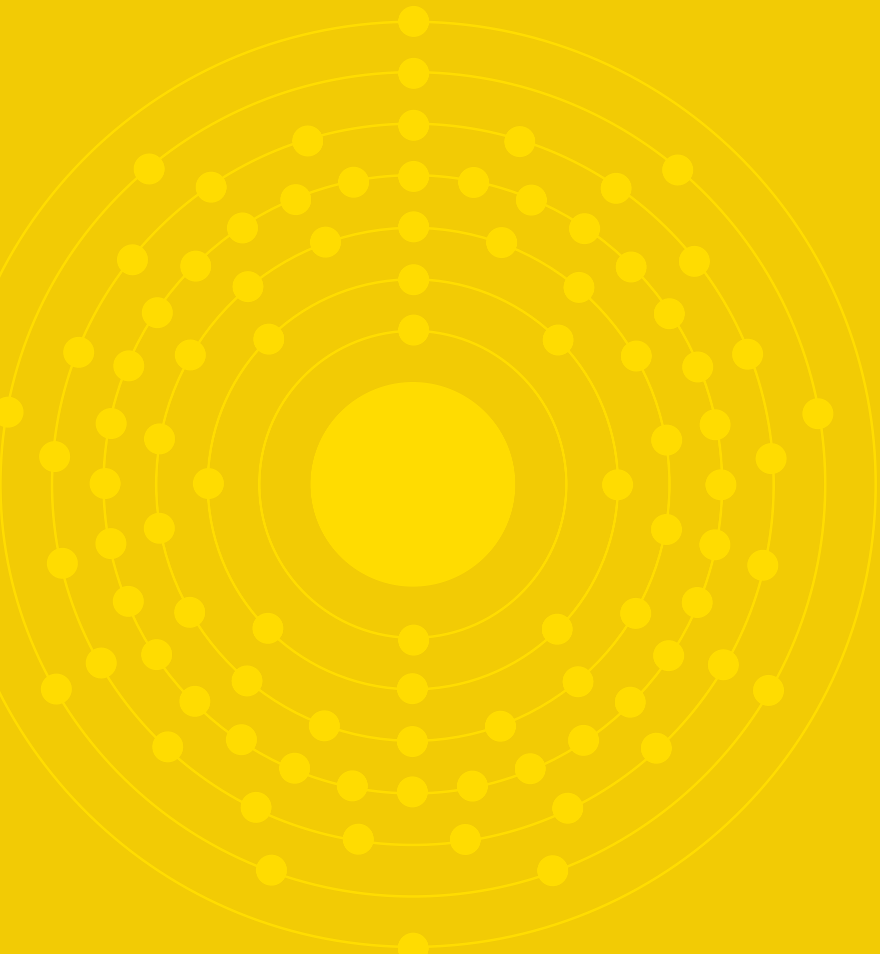
Acknowledgements

The Uranium Development Partnership would like to acknowledge the contribution of various organizations that have provided information and support during the course of its work, including AREVA Canada, Atomic Energy of Canada Limited, Bruce Power, Cameco, Golder Associates, MDS Nordion, Nuclear Waste Management Organization, SaskPower, and the University of Saskatchewan.

The Uranium Development Partnership would also like to recognize the contribution of McKinsey & Company for its research and fact-based analysis for this report.

The views and opinions expressed in this report are strictly those of the Uranium Development Partnership.

Contents



Executive summary

Context

A number of factors are combining to renew interest in nuclear energy around the world. Demand for electricity continues to grow, particularly in developing countries where urbanization and industrial growth are driving the increase in their need for power. Meanwhile, in many developed nations, the existing power generation fleet is nearing replacement age. At the same time, the options for generating power are changing dramatically. Many jurisdictions are shifting away from traditional fossil fuel sources guided by global concern over the impact of carbon dioxide emissions on climate and the long-term likelihood of a system that puts a price on carbon emissions. And emerging technologies – renewables such as wind, solar, geothermal, and biomass, as well as clean coal technology with carbon capture and storage – present new opportunities. But they also present technical and economic challenges.

As a result of these dynamics, nuclear power is emerging as an attractive potential part of the overall electricity supply mix in many parts of the world. Nuclear power generates very low carbon emissions, on par with the cleanest forms of renewable energy. And – although it has high upfront capital costs – over its full life cycle, nuclear energy has proven to be cost-competitive. The supply of uranium – the fuel source for nuclear power – is abundant and secure, with most of the world's known resources in economically and politically stable regions including Canada. Finally, over the past several decades, the industry has made significant strides in improving the reliability and safety of nuclear power.

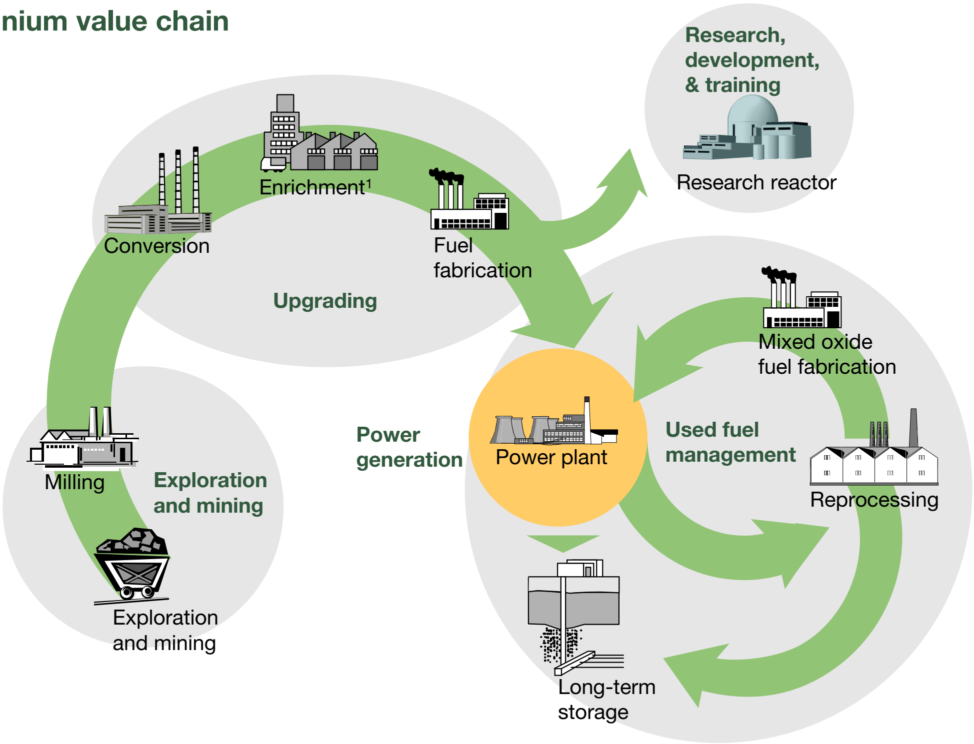
Given this combination of factors, it is not surprising that the nuclear industry is enjoying a global renaissance. And it makes particular sense for the Province of Saskatchewan to assess its options for benefitting from this nuclear resurgence. The Province has a significant, growing need for power over the next several decades, and it is already a major participant in the first step of the overall uranium value chain.

The Province of Saskatchewan occupies the enviable position of being the world's largest producer of uranium. This vibrant sector attracts investment to the Province from global-scale players and junior companies. It employs approximately 3,000 people, about 80 percent of whom work at mine sites located in Northern Saskatchewan. This established presence creates significant direct and spin-off benefits for the local and provincial economies through wages, taxes, and local investment. Supporting this activity are mining-related programs at the Province's post-secondary educational institutions and selected Saskatchewan-based research facilities, such as the Slowpoke II reactor and the Canadian Light Source synchrotron.

Despite this strong platform and robust mining activity, Saskatchewan plays virtually no role in the rest of the uranium sector – and mining and milling represent only a limited portion of the economic value added in the overall chain. Beyond mining and milling, this value chain includes processing or upgrading uranium to convert it into fuel for reactors, generating power from nuclear energy, managing the reactors' used fuel, and associated research and development, including medical applications.

EXHIBIT 1

Uranium value chain



1 Not applicable for reactors that use natural uranium, including currently operating CANDU reactors

Saskatchewan does not participate in these additional stages, except for limited involvement in advanced research into new techniques to extract and process uranium and future technical applications.

Furthermore, even in Saskatchewan's traditional areas of strength, its global position is slipping. Forecasts indicate that Kazakhstan will overtake Saskatchewan as the world's largest producer of uranium this year – and that Australia could overtake it next year. Moreover, at current rates of extraction, Saskatchewan's discovered uranium resources would only last approximately 45 more years without additional discoveries through exploration and development,[1] while Kazakhstan's and Australia's would last 110 to 160 years.

It is in this context that the Province of Saskatchewan established the Uranium Development Partnership to identify and explore opportunities for Saskatchewan to build on its current position and develop its uranium industry throughout the entire value chain.

In this report, *Capturing the full potential of the uranium value chain in Saskatchewan,* the UDP explains the approach it took, summarizes its findings, and recommends an integrated strategy to expand Saskatchewan's world-leading position in uranium exploration, mining, and milling into thriving broad-based uranium and nuclear power industries.

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[1] *Uranium 2007: Resources, Production and Demand*. Nuclear Energy Agency, 2008. Pages 16 and 39.

Approach

To evaluate Saskatchewan's opportunities across the uranium value chain, the UDP:

1. **Identified specific commercial opportunities at each step of the chain:** examining both uranium's life cycle and its end-use applications, such as power generation, taking into account the key economic, technical, and environmental trends and forces at work around the world.

2. **Evaluated the business case for each opportunity:** assessing each opportunity's commercial viability based on its market fundamentals (in terms of demand, supply, and growth) and Saskatchewan's competitive strengths and weaknesses relative to those of its global competitors. This assessment resulted in a financial evaluation of the full life cycle economics of each opportunity.

3. **Estimated the potential benefits accruing to Saskatchewan from each opportunity:** calculating the GDP impact and job creation potential based on industry standard models of both the direct and the indirect economic impact.

4. **Created a strategy for pursuing the opportunities over time and developed clear recommendations to inform discussions and decision making.**

Summary of key findings and recommendations

The UDP is making 20 specific recommendations for the Province to consider, which cover many activities: from maintaining and protecting existing strengths in the Saskatchewan market; to making strategic investments in the Province's capabilities and infrastructure; to working with other levels of government and private-sector players to achieve shared goals. These recommendations are supported by the UDP's key findings and organized into five sections according to the main components of the uranium value chain.

Exploration and mining

Key findings

a. Saskatchewan's leadership position in uranium mining is threatened by emerging players, such as Kazakhstan and Australia, that are rapidly ramping up their production.

b. World demand for primary uranium will grow substantially over the next 10 years, creating an opportunity for Saskatchewan to rapidly expand its mining sector and to maintain its position as a leader in uranium mining.

c. To achieve this goal, Saskatchewan will need to renew its discovered resource base by maintaining the level of private exploration investment reached in recent years and investing in mine development.

d. Exploration activity is cyclical. When the spot price of uranium is high, companies increase their exploration activities substantially. This trend is facilitated by the claim-staking system that creates an environment with low entry barriers.

e. The process to fulfill the duty to consult with First Nations and Métis communities is not sufficiently defined. The lack of a clear process may create an impediment to further exploration and/or development in the Province.

f. The basic royalty system in Saskatchewan appears competitive but, when the price of uranium is high, the tiered royalty structure creates a higher burden for mining operations based in Saskatchewan than for those in other jurisdictions.

g. This tiered royalty structure risks impeding the competitiveness of newer mines given that: 1) mine operating costs have increased more rapidly than the inflation index used to adjust the royalty structure; and 2) the next generation of deposits to be mined may be of lower quality and, therefore, have higher operating costs.

h. A strong and effective licensing and environmental assessment process is paramount to ensure the safety of workers and the public, as well as to protect the environment. However, the public is not well-served by lengthy delays in environmental assessment approvals.

i. The lack of basic infrastructure in the North, particularly roads and power, is likely to impede further mine developments.

j. Federal restrictions on foreign ownership may limit the ability of the Province to attract capital for exploration and mining; the Competition Policy Review Panel formed by the Federal Government recommended in June 2008 that these restrictions be selectively removed on a bilateral basis.

k. Sustaining Saskatchewan's leadership position in exploration and mining would have a significant impact on the Province's economy, contributing a total estimated GDP impact of $4.2 billion over 15 years.

Recommendations

Saskatchewan should

1. Maintain its current claim-staking system to provide a favourable environment for exploration.

2. Work with the Federal Government to establish clear parameters and accountabilities for the duty to consult with First Nations and Métis communities.

3. Examine the possibility of expanding its program incentives for exploration (e.g., flow-through shares, tax credits, and matching grants) to drive through-cycle investment decisions based on long-term uranium forecasts rather than spot prices.

4. Undertake a review of the competitiveness of the royalty system in relation to other jurisdictions, with a focus on whether:

   - The capital recovery bank correctly reflects the current cost of developing new projects in Saskatchewan.

   - The royalty rate is sufficiently competitive and reflects the costs of extracting the resource.

5. Work with the Federal Government to establish clearer timelines and guidelines for a thorough, consistent, and predictable review of license applications.

6. Work with the Federal Government to ensure the recommendations of the Competition Policy Review Panel are implemented.

7. Work with industry to prioritize and facilitate the development of key infrastructure to create an environment favourable to new mine development.

Upgrading

Key findings

l. Anticipated growth in global demand for conversion will likely be met by expansions to existing facilities, most notably in the United States and France, with additional potential capacity planned in Kazakhstan.

m. The projected supply and demand balance in the enrichment sector indicates the need for additional capacity by 2020.

n. Entering the enrichment sector would present significant challenges for Saskatchewan: 1) a new facility in Saskatchewan would require significant capital expenditure but would compete against lower-cost and more flexible expansions of existing facilities; and 2) Canada would need the consent of the Nuclear Suppliers Group to obtain a transfer of enrichment technology.

o. Over a longer time horizon, Saskatchewan may have an opportunity to enter the enrichment sector by partnering with a developer of the emerging laser enrichment technology and then, should the technology prove successful, setting up an early commercial-scale project in the Province.

p. Anticipated growth in global demand for fuel fabrication will likely be met by increasing utilization of existing plants and potential capacity addition in countries aggressive about nuclear power development.

Recommendations

Saskatchewan should

8. Work with the Federal Government to clarify the framework under which an enrichment facility could be established in the Province in accordance with all international non-proliferation agreements and obligations.

9. Target the next generation of enrichment technology (laser isotope separation) and enter into discussions with current technology developers to determine the conditions under which a commercial-scale facility could be attracted to the Province within 10 to 15 years.

10. Not proactively pursue the development of a conversion facility given current market conditions.

11. Not proactively pursue the development of a fuel fabrication facility given current market conditions.

Power generation

Key findings

q. The growing demand for electricity and the planned decommissioning of existing generation facilities indicate that Saskatchewan will require 1,200 to 1,750 MW of new power generation capacity for its domestic use by 2020, growing to 2,200 to 3,000 MW by 2030.

r. At a regional level, significant potential exists for exports – for example, Alberta could need between 4,000 and 5,000 MW of new power generation by 2020. Saskatchewan is well-positioned to provide low-carbon emission power to fill this looming supply gap.

s. Given consensus estimates of long-term CO_2e (equivalent carbon dioxide) and natural gas pricing, nuclear is a cost-competitive and low-emission power generation option.

t. Initial examination suggests that up to approximately 3,000 MW of nuclear capacity could be constructed to meet Saskatchewan's power needs and capture export opportunities.

u. Given that a nuclear power plant has not been previously built in Saskatchewan, further work needs to be done to understand the social, environmental, and grid feasibility of adding nuclear power in the Province.

v. Capital cost overruns and schedule delays are key risks in any nuclear new build project, and they would need to be carefully mitigated in the project development process. To date, the cumulative risks of nuclear new build have been too large for the private sector to bear alone and governments have played some form of facilitation in the implementation of nuclear power projects in all jurisdictions.

w. Saskatchewan could reduce licensing and first-of-a-kind risks by drawing on the recent experiences of other Canadian provinces that have developed nuclear generation capacity.

x. Transmission infrastructure, reserves, and intertie investments would be required to support larger power generation units on the Saskatchewan grid, as well as to provide the capability to export additional power to Alberta. The detailed nature and cost of this infrastructure has yet to be determined.

y. A new power plant would have a significant impact on Saskatchewan's economy, contributing approximately $12 billion in discounted GDP to the Province over its life ($1.2 billion during construction and $10.6 billion during operation), as well as employing 3,000 people during construction and providing between 400 and 700 direct jobs during operation for every unit built.

Recommendations

Saskatchewan should

12. Include nuclear as part of the Province's long-range energy mix given its cost-competitiveness as a baseload power alternative and the economic value it would generate within the Province.

13. Begin this long-range planning process by:

    - Laying out an overall process and timeline for new generation implementation.
    - Considering the development, in coordination with Alberta, of a common power generation solution for the two Provinces by pooling their power needs and building stronger interties between the two provincial grids.
    - Defining the role that the Provincial Government would play and developing a strategy to optimize the balance between expected power pricing and Saskatchewan ratepayers' exposure to cost overruns.
    - Evaluating the type of grid, reserve, and intertie upgrades required under both a domestic and an export power generation scenario to meet growing electricity demand, independent of supply mix. Consider the implications of nuclear power generation on these infrastructure upgrades.

Used fuel management

Key findings

z. Reprocessing CANDU fuel based on current technology is commercially unattractive for private investment, given the high capital and operating costs that offset potential economic benefits from recycling plutonium and reducing the volume of high-level waste for disposal.

aa. In the longer term, if reprocessing becomes viable in Canada because of a step-change in reprocessing economics or, more likely, a change in Federal policy, a Saskatchewan-based reprocessing facility may have substantial local and regional economic benefits given the magnitude of expenditure and employment associated with the facility.

bb. Federal legislation ensures that the costs of long-term used fuel management will be fully funded by the industry.

cc. The Government of Canada has approved the Nuclear Waste Management Organization's Adaptive Phased Management approach incorporating the development of a centralized deep geological repository in Canada for the long-term management of used fuel.

dd. The NWMO will be initiating a site selection process after 2009.

ee. Given its favourable geology and current participation in the nuclear fuel cycle, Saskatchewan is one of the four provinces the NWMO has identified as a potential host of the Canadian long-term repository.

ff. Past experience in other jurisdictions has shown that acceptance of a local host community is the most important factor for the successful siting of such a repository in a geologically suitable location.

gg. The potential benefits to that community and to the Province of hosting the facility would be significant, including early benefits from research and development, peak employment (4,000 to 6,000 direct and indirect jobs) during construction, sustained employment (~900 jobs) during operations and monitoring, and approximately $2.4 billion in discounted cumulative GDP impact.

Recommendations

Saskatchewan should

14. Not proactively pursue the development of PUREX (plutonium and uranium recovery extraction) and MOX (mixed oxide fuel containing plutonium) reprocessing facilities in the short term. This position should be revisited if there is a significant change in Federal policy regarding long-term fuel storage or the full cycle economics of reprocessing.

15. Support the NWMO consultation and siting process, given the potential benefits of a geological repository, while maintaining flexibility with regard to its ultimate participation.

16. Support any willing host community that comes forward through this process and, as appropriate, support the development of the deep geological repository in the context of a broader nuclear development strategy.

Research, development, and training

Key findings

hh. There is a shortage of specialists in the earth, environmental, and engineering sciences to support the activities of the uranium exploration and mining industry.

ii. If a nuclear power generation facility is built, Saskatchewan would also require that existing academic nuclear engineering and physics programs be expanded to support the training of nuclear specialists and operators.

jj. An academic centre of excellence should involve the social sciences and environmental disciplines to assist communities in assessing nuclear opportunities.

kk. Saskatchewan could play a role in a number of R&D opportunities with longer-term commercialization prospects, including small reactors and advanced fuel cycle technologies. A research reactor could serve as a catalyst for these activities.

ll. A research reactor is synergistic with existing research infrastructure and would provide Saskatchewan with significantly enhanced research capabilities, supporting innovation, competitiveness, and the Province's participation in the development of emerging technologies.

mm. A research reactor may also be used to produce medical isotopes to address the anticipated global deficit in isotope supply, providing an additional stream of revenue to partly offset the cost of developing and operating the reactor.

nn. Although medical isotope production provides an attractive source of revenue for a research reactor, the economics of a stand-alone isotope reactor are not attractive.

Recommendations

Saskatchewan should

17. Create and support a centre of excellence for nuclear research and training with a dual mission of: 1) supporting the existing nuclear industry in Saskatchewan; and 2) developing a nuclear R&D program to support emerging opportunities, with a few focused areas of research on longer-term commercialization prospects.

18. Under the first part of this mission, expand existing:

    - Mining and exploration programs at universities, colleges, and training schools to train engineers, geoscientists, and other mining specialists and to develop innovation through research in the earth, environmental, engineering, and social sciences relevant to the exploration and mining sectors.
    - Nuclear engineering and physics programs at universities and establish training facilities to help prepare students for the CNSC (Canadian Nuclear Safety Commission) nuclear operator examination.

19. Under the second part of this mission, form a group of experts to determine investment priorities in a few targeted areas of nuclear research. This group should review the most promising areas of research based on the type of skills and infrastructure required, the investment necessary to be competitive, the potential for private funding, and the prospect for commercialization. Areas to be considered by this group include, but are not limited to, small reactors and advanced fuel cycle technologies.

20. Partner with the Federal Government to pursue the construction of a research reactor in the Province as a complement to synergies with existing research infrastructure and capabilities, and to better position the Province to participate in multiple areas of study. Pursue medical isotope production as part of the reactor's mandate.

Proposed Strategy

In developing a detailed business case and economic analysis for each opportunity across the value chain, the UDP found that the opportunities fell into three broad categories (Exhibit 2):

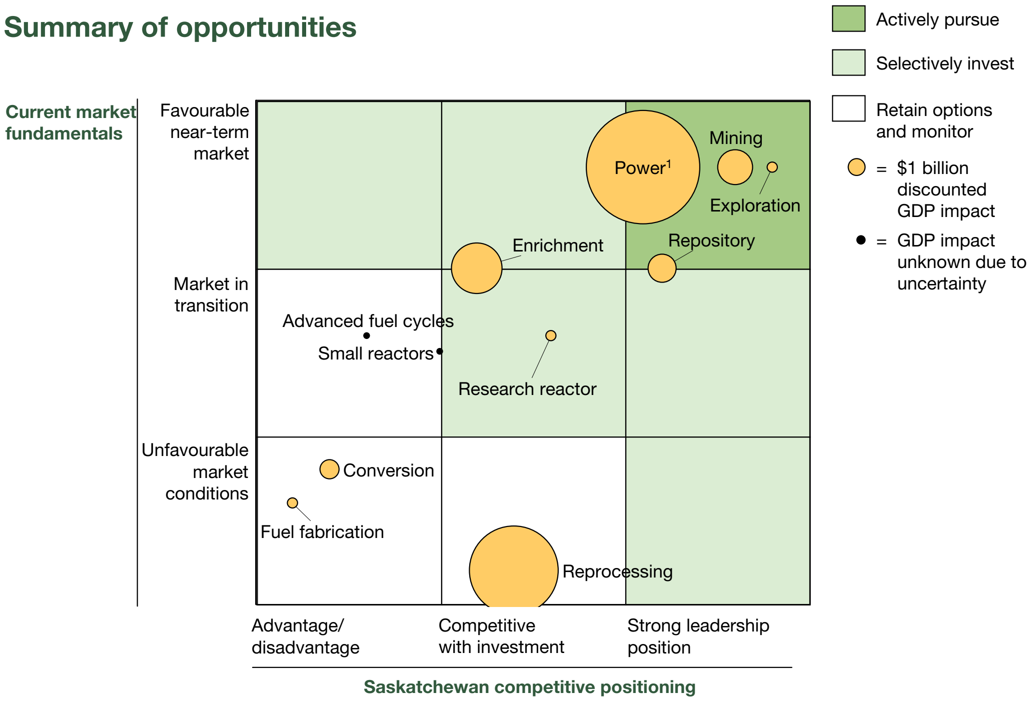
1. **Actively pursue:** Saskatchewan is well-positioned to play a leading role in the industry, and market dynamics are favourable. This applies to the segments where Saskatchewan participates today (mining and exploration) and also to power generation.
2. **Selectively invest:** the business case is slightly less clear, either because the market is uncertain or in a state of significant transition (as it is for a long-term used fuel repository) or because Saskatchewan's ultimate ability to be competitive remains unclear (in the enrichment segment, for example).
3. **Retain options and monitor:** current market conditions are unfavourable (e.g., conversion and fuel fabrication) and/or Saskatchewan is not well-positioned at this time to capitalize on those opportunities (e.g., reprocessing).

Having identified and evaluated these opportunities, the UDP developed an integrated strategy to capture the most promising opportunities. This strategy's goals are to maximize the uranium industry's contribution to Saskatchewan's economy today and lay the foundation for longer-term growth. Therefore, the UDP has integrated its recommendations into a four-pronged strategy for the Province:

1. **Grow today's core position in the value chain:** focus on ensuring that Saskatchewan remains an attractive jurisdiction for private sector investment in its areas of historical strength.
2. **Attract emerging commercial opportunities:** actively support the pursuit of new opportunities in the areas of the value chain that are commercially viable and could provide significant economic benefit to the Province.

EXHIBIT 2

Summary of opportunities



1. Based on 3,000 MW of installed nuclear capacity

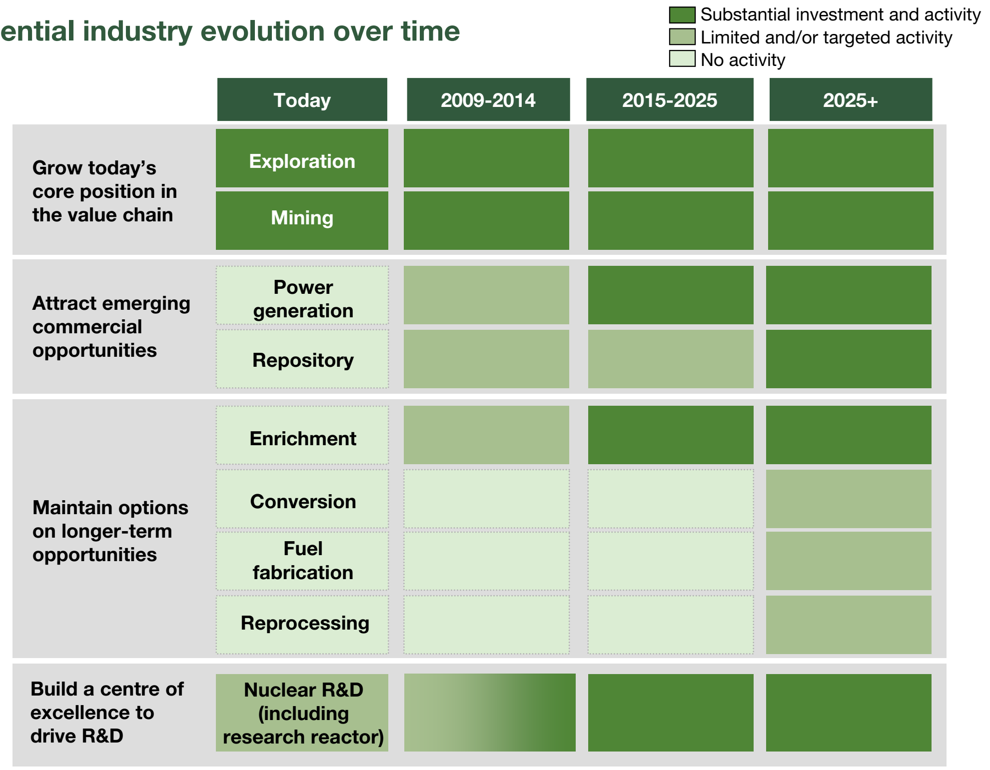
3. **Maintain options for future growth:** build the basic capabilities and infrastructure to capitalize on longer-term opportunities as they become more economically and technically feasible; avoid making major investments or commitments in the shorter term.

4. **Build a centre of excellence to drive research, development, and training:** create a concentration of skills and infrastructure within the uranium value chain to support research, development, and training.

Following this strategy would allow the Province to incrementally increase its participation in the uranium value chain, moving from its core position of mining and exploration today toward a vibrant, nearly end-to-end role by 2025. We believe this strategy allows the Province to build on its strength and develop the capability to be a global leader on a sustained basis, bringing significant economic, technological, and environmental benefits in the process.

EXHIBIT 3

Potential industry evolution over time



■ Substantial investment and activity
▨ Limited and/or targeted activity
□ No activity

	Today	2009-2014	2015-2025	2025+
Grow today's core position in the value chain	■ Exploration	■	■	■
	■ Mining	■	■	■
Attract emerging commercial opportunities	□ Power generation	▨	■	■
	□ Repository	▨	▨	■
Maintain options on longer-term opportunities	□ Enrichment	▨	■	■
	□ Conversion	□	□	▨
	□ Fuel fabrication	□	□	▨
	□ Reprocessing	□	□	▨
Build a centre of excellence to drive R&D	▨ Nuclear R&D (including research reactor)	▨→■	■	■

Report structure

The following chapters of this report examine the uranium value chain, detail the UDP's analysis and key findings, and discuss its proposed strategy and recommendations for Saskatchewan to capture the full potential of the most attractive opportunities.

Chapter 1: *Industry overview* explains the basics of the uranium value chain and provides an overview of the activities that add value at each stage; introduces the topic of the "nuclear renaissance" and its causes; and briefly describes Saskatchewan's involvement in the value chain and its supporting infrastructure.

Chapters 2-6: *Key findings and recommendations* provide an in-depth evaluation of Saskatchewan's opportunities in each of the chain's five sub-sections and present the resulting recommendations. The five sub-sections are: mining and exploration; upgrading, including conversion, enrichment and fuel fabrication; power generation; used fuel management; and research, development, and training. Each chapter includes a description of the key findings, a high-level overview of the opportunities, and a summary of the recommendations. For many opportunities, the discussion of the opportunity and key findings provides an overview of market conditions, a business case for private investment and, in the case of some more attractive opportunities, an assessment of the potential impact for Saskatchewan if an investment were to be made.

Chapter 7: *Proposed nuclear strategy for Saskatchewan* brings together the recommendations from across the uranium value chain to form a strategy for the Province that would enable it to expand the role it plays in the chain. This chapter explores the focus and timing of each opportunity, evaluating the obstacles to overcome, the necessary investment, and the educational, research, and regulatory requirements.

The report also includes several appendices:

A: *Health and safety considerations of nuclear power* draws on recent studies and operating history of modern nuclear reactors to provide an overview of the key public health and worker safety considerations of nuclear power, and it describes the technical, regulatory, and operational means employed to ensure the safe operation of nuclear facilities.

B: *Managing the risks of nuclear proliferation* outlines the mechanisms and safeguards used to ensure that nuclear technology and materials are used appropriately for peaceful, civilian uses.

C: *Introduction to medical isotopes* provides background on the medical use of radioisotopes, including information about the market for medical isotopes and how these isotopes are applied in healthcare.

D: *Small reactors* describes the current market for and development of emerging small reactor technology. It also reviews the current status of small reactor development to inform the potential role that the Province could play in this area.

The *Glossary* at the end of the report provides definitions for key technical terms and defines the acronyms that are commonly used in the nuclear industry.

The *Bibliography* lists the sources referred to in this report.

Chapter 1: Industry overview

The uranium value chain is complex, involving a broad range of large industrial processes varying from mining and upgrading uranium through to generating power and managing the used fuel. Each of these industries has substantially different characteristics and drivers that affect their evolution and attractiveness.

However, the size and attractiveness of the opportunities across the full value chain may be increasing as a result of the emerging "nuclear renaissance" around the world. This renewed interest in nuclear power is being driven by a number of factors – most notable, given growing concerns regarding climate change, is its very low carbon profile, similar to the cleanest forms of renewable energy. Other drivers of this resurgent interest in nuclear energy include: the growing global demand for electricity; nuclear power's cost competitiveness over the full life cycle; the abundant and secure supply of uranium; and the industry's greatly improved reliability and safety record.

Saskatchewan is well-positioned to expand its presence and capture significant opportunities in multiple segments of the uranium value chain. Not only is Saskatchewan the global leader in the exploration, mining, and milling of uranium but, with its core research and development capabilities and infrastructure, it also has a solid foundation on which it can build. That, together with growing regional demand for low-carbon power, places Saskatchewan in an enviable position.

This chapter:

- Examines the factors fuelling the potential nuclear renaissance.
- Describes each element in the uranium value chain.
- Provides an overview of Saskatchewan's role in the value chain.

The nuclear renaissance

Chiefly driven by the oil crises of the 1970s, nuclear power captured significant market share in the 1970s and 1980s.[2] Following that surge, a slowdown occurred because of reduced electricity demand, dissenting public opinion arising from safety incidents, and decreasing economic competitiveness resulting from cheap fossil fuels and construction delays of new nuclear builds. Since that time, nuclear power has grown much more modestly. Between 1990 and 2005, global nuclear capacity grew by 0.8 percent[3] annually while electricity demand over that same period grew by 2.9 percent[4] annually. Asia accounted for virtually all the growth in nuclear capacity, at 4 percent annually; growth in North America and Europe was flat as the only new builds were those that replaced decommissioned reactors.[5]

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[2] Power Reactor Information System (PRIS) database. International Atomic Energy Association (IAEA).

[3] PRIS database. IAEA.

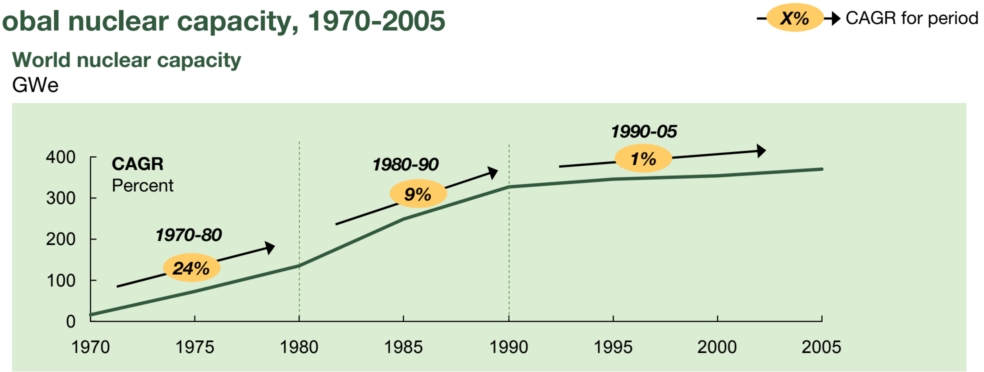
[4] *International Energy Outlook 2008*. US Department of Energy. Energy Information Administration.
Figure 52 – Growth in World Electric Power Consumption and Total Energy Consumption, 1990-2030.

[5] PRIS database. IAEA.

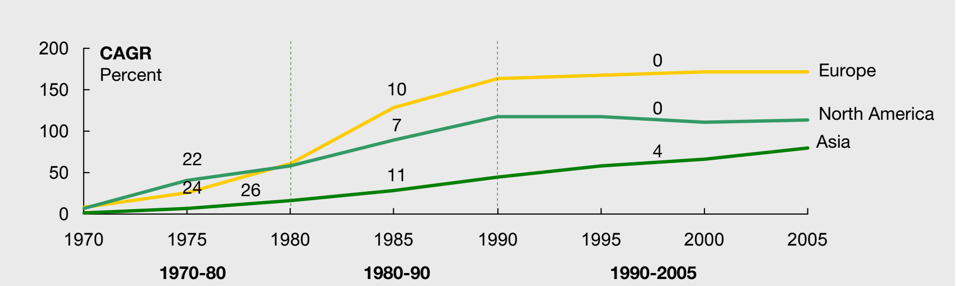
EXHIBIT 1-1

Global nuclear capacity, 1970-2005

World nuclear capacity
GWe



Regional nuclear capacity
GWe



Source: Power Reactor Information System (PRIS)

Base projections for nuclear capacity growth remain modest. This base case is similar to that of the preceding 15 years, with moderate additions in capacity, concentrated in Asia, and a slight decline in nuclear's market share relative to other power sources. In this scenario, a total of 147 GW of new nuclear capacity is expected by 2020, with 27 GW anticipated in North America and only 6 GW in Europe.[6]

However, a revival of nuclear energy may push growth well beyond this base level. Several factors may enable nuclear to capture more than its proportionate share of overall global electricity demand growth. First and foremost, nuclear growth will be supported by a continued global consensus and responsiveness to the potential issues arising from carbon emissions and climate change. Nuclear power represents the only currently feasible low-carbon, large-scale baseload alternative. At the same time, concern over secure sources of conventional fossil fuel supply and a significantly improved safety record of nuclear power also strengthen a renewed emphasis on nuclear power. Many governments and stakeholder groups worldwide are reconsidering their historical anti-nuclear stance.

Still, the future remains uncertain, and nuclear new builds in North American and Europe are progressing more slowly than the industry had hoped; however, momentum is increasing in favour of nuclear technology in several major markets.

If this renaissance scenario comes to pass, nuclear new builds could be significantly higher than the base case. Total growth in global nuclear capacity could average 2.1 percent annually, translating to an additional 226 GW of capacity by 2020– a 60 percent increase over current installed capacity.[7] The majority of the growth would still be in Asia, but North America and Europe would also see big increases.

The following is a description of the four factors influencing nuclear growth.

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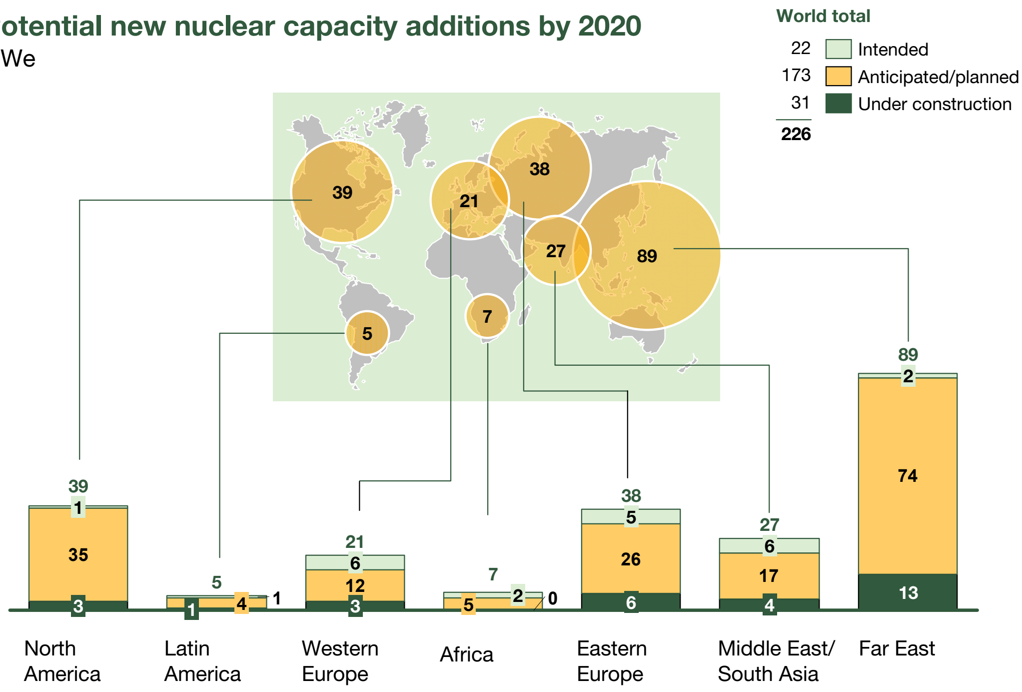
[6] PRIS database. IAEA.

[7] PRIS database. IAEA.

EXHIBIT 1-2

Potential new nuclear capacity additions by 2020

GWe



Source: Power Reactor Information System (PRIS) database; press releases; industry publications

Increasing need for electricity

The industrial development of emerging economies, such as China and India, and global population growth are fuelling an unprecedented demand for electricity, which is expected to double by 2030.[8] Recent projections continue to support this growth forecast, as the global economic crisis is not expected to significantly alter long-term global macroeconomic factors, such as rapidly increasing industrialization and urbanization in the developing world.

The exhaustion of conventional power sources like hydroelectricity and the continued energy intensity of developed economies are also driving growth. Meeting this global demand will require growth across all generation technologies – renewables like wind, solar, and biomass; fossil fuels like natural gas and cleaner coal; and nuclear power.

Climate change

Nuclear is the lowest emission source of baseload power generation available today (Exhibit 1 - 3). On a full life cycle basis, a nuclear power plant will produce 9 to 21 grams of CO$_2$-equivalent greenhouse gas emissions per kilowatt hour of electricity produced – in the same range as a wind turbine (10 to 48 grams of CO$_2$ per kWh) and many times less than fossil fuel baseload power sources.[9] The process of power generation in a nuclear reactor produces almost no greenhouse gas emissions. As with all power generation options, however, processes such as producing the raw materials (uranium, steel, and concrete, for example) and constructing the plant do contribute some emissions.

In comparison, a coal power plant has 100 times the emissions of a nuclear plant at 970

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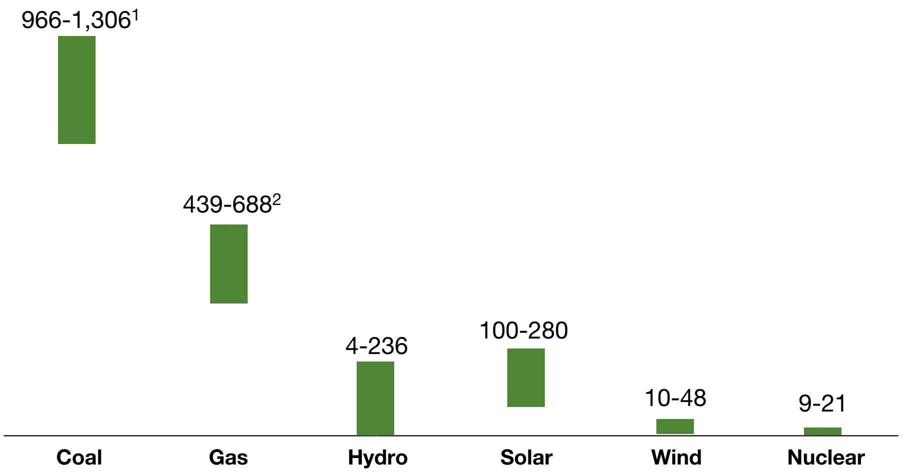
[8] *The Nuclear Renaissance*. World Nuclear Association, 2007.

[9] Spadaro, J.V., L. Langlois, and B. Hamilton, *Greenhouse Gas Emissions of Electricity Generation Chains: Assessing the Difference*. IAEA Bulletin, 42/2/2000, Vienna, Austria, 2000.

EXHIBIT 1-3

Greenhouse gas emissions

Grams of CO_2 equivalent per kWh generated



1 Consists of 790-1,017 gCO_2e/kWh direct and 176-289 gCO_2e/kWh indirect

2 Consists of 362-575 gCO_2e/kWh direct and 77-113 gCO_2e/kWh indirect

Note: Life cycle GHG emissions include mining, transportation, and processing of fuel, construction and manufacturing of components, and removal and transportation of wastes and byproducts

Source: IAEA, Greenhouse Gas Emissions of Electricity Generation Chains, 2000

to 1,300 grams of CO_2 equivalent for every kWh of electricity. A typical 1,000 MW coal power plant will emit 5.4 million tonnes of CO_2 annually during its operation. An equivalent natural gas plant will emit 2.5 million tonnes. An operating nuclear plant's CO_2 emissions are negligible.

Security of supply

Fossil fuels are mostly found in regions of the world with perceived geopolitical risks and are becoming ever scarcer, whereas the vast majority of the world's uranium is found in Canada, Kazakhstan, and Australia.[10] Additionally, the relatively small volume of uranium required in a reactor and its infrequent refuelling enable utilities to stockpile inventories of fuel, thereby hedging short-term fluctuations in the spot price of uranium in favour of longer-term prices driven by supply-demand fundamentals.

Safety and maturation of technology

Nuclear power is a safe and well-understood technology. Technological advancements over the past few decades, including significant improvements to the inherent and passive safety mechanisms[11] of reactors, have resulted in a greatly improved safety record, as indicated by a 71 percent reduction in the incident rate at plants since 1983. Additionally, the abundance of nuclear new build activity and well-established design specifications will likely contribute to a reduction in the size and frequency of capital overruns on new facility construction.

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[10] *World Uranium Mining*. World Nuclear Association (WNA), 2008. http://www.world-nuclear.org/info/inf23.html.

[11] Traditional reactor safety systems are active in the sense that they involve electrical or mechanical operation on command. Some engineered systems operate passively – e.g., pressure relief valves. Both require parallel redundant systems. Inherent or full passive safety depends only on physical phenomena such as convection, gravity, or resistance to high temperatures, not on functioning of engineered components. *Small Nuclear Power Reactors*. WNA, 2009. http://www.world-nuclear.org/info/inf33.html.

The uranium value chain's elements

The uranium value chain extends from the mining of natural uranium through to the management of used fuel from nuclear reactors, and it includes research and medical applications of nuclear technology.

Mining and milling

The value chain begins with the mining and milling of uranium. Uranium is found naturally in trace amounts across the earth's surface in soil, water, rocks, and living organisms. Typically, uranium constitutes no more than a few parts per million of these items. In some parts of the planet, however, uranium can be found in high enough concentrations (0.1 to 20 percent)[12] that extracting it from the ground is economically viable.

Saskatchewan is one of those places. It is the leading uranium producer in the world, with the McArthur River mine accounting for three-quarters of Canada's production.

Uranium mining operations consist of three types.

- In open pit mining, the uranium is sufficiently close to the ground's surface to be removed and transported via loaders and trucks.
- In underground mining, the uranium is deeper and is accessed via tunnels and shafts.
- In situ recovery, not currently employed in Canada, is used when the uranium deposits are too deep or too low grade for conventional underground mining. In this process, a weak acid or alkaline liquid is pumped into the mineral deposit and recovery wells pump the leached uranium bearing solution up to the surface.

To produce pure uranium, the extracted rock is ground into a fine powder and leached in a chemical solution. This solution is then subjected to several stages of purification and precipitation, out of which uranium oxide powder (U_3O_8), or yellowcake, is collected.

Conversion

Before it can be used as nuclear fuel, yellowcake needs to be refined and converted. These processes use standard industrial chemical reactions, based on a mature technology unchanged for decades.

The first step at a conversion or refinery facility is to remove the yellowcake's impurities. Then, if the purified uranium is to be used in a pressurized heavy water reactor, it will be converted into uranium dioxide (UO_2) before being shipped to a fuel fabrication facility.

If the uranium is to be used in a light water reactor, the process is different. Through a series of steps, the uranium is infused with hydrogen fluoride to form UF_4 (uranium tetrafluoride), a green salt. This UF_4 is then treated at high temperatures with fluorine gas to form UF_6 (uranium hexafluoride), which is a compound of uranium that is a gas at elevated temperatures. Volatile impurities and light fraction gases are also removed before the UF_6 is pressurized and cooled for transport to an enrichment facility.

What are isotopes?

Isotopes are variants of chemical elements

- Each isotope of an element has the same atomic number (number of protons in its nucleus) but a different atomic mass (the number of neutrons and protons in its nucleus).
- Uranium has six isotopes: U-232, U-233, U-234, U-235, U-236, and U-238. All of them are radioactive to some extent.
- An isotope is considered fissile if it is capable of sustaining a chain reaction of nuclear fission.

Cameco is Canada's only conversion supplier and controls approximately 30 percent of the Western world's capacity. Through its Blind River refining facility in Ontario, and a conversion facility in Port Hope, Ontario, Cameco produces both natural UO_2 used to

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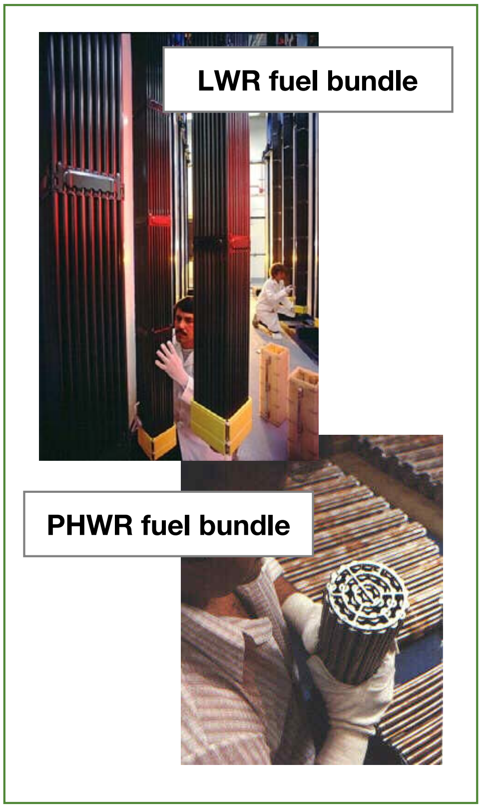
[12] *Uranium Supplier Annual 2008*. The Ux Consulting Company LLC (UxC). 2008 ore grades for all major mines listed.

fuel Canada's CANDU reactors and UF_6 that is shipped to enrichment facilities around the world. The Blind River refinery processes yellowcake from mines around the world and ships three-quarters of its production to Port Hope for conversion. Port Hope converts UO_3 to UO_2 as well as to UF_6. It then ships the UO_2 in steel drums to fuel manufacturers who prepare the reactor-ready fuel bundles. The UF_6 is shipped in special transport cylinders to enrichment plants in the United States and Europe.

LWR and PHWR fuel bundles

Two types of fuel fabrication plants are currently in operation: one manufactures fuel for use in light water reactors (LWRs) and the other for pressurized heavy water reactors (PHWRs). Because LWR fuel is more enriched in U-235 and therefore more likely to undergo fission at close proximity with other fuel, LWRs use longer, thinner fuel rods.

Completed fuel bundles



Enrichment

Approximately 99.3 percent of the world's uranium exists as uranium 238 – also known as U-238 (see the sidebar, "What are isotopes?") – while most of the remaining exists as U-235.[13] Both isotopes are capable of fission – the process that generates heat and thus power in nuclear reactors – but U-235 has a much higher probability of undergoing fission in a given amount of time. Enrichment is the process used to increase the U-235 content of the uranium and thus increase the fuel's fissile potential. The byproduct of this process is uranium with very low U-235 content and is referred to as depleted uranium.

The two current commercial enrichment technologies are gaseous diffusion and gas centrifuge. Although the underlying technologies differ in approach, they both exploit the difference in mass between the two isotopes to separate the lighter U-235 from the heavier U-238, creating enriched and depleted uranium. A third enrichment technology, employing lasers to separate these isotopes, is under development.

The enriched UF_6 is shipped to a fuel fabrication facility where it undergoes deconversion back into solid UO_2 before it is manufactured into fuel rods.

Canada has no enrichment facilities.

Fuel fabrication

Whether or not UO_2 has gone through the enrichment process, it needs to be formed into fuel bundles for use in a reactor. This fuel fabrication process involves three steps: 1) pressing the fuel into ceramic pellets; 2) encasing the pellets in zircaloy or stainless steel tubes; and 3) assembling fuel tubes into bundles, with bundle design configurations determined by reactor type – light water or pressurized heavy water.

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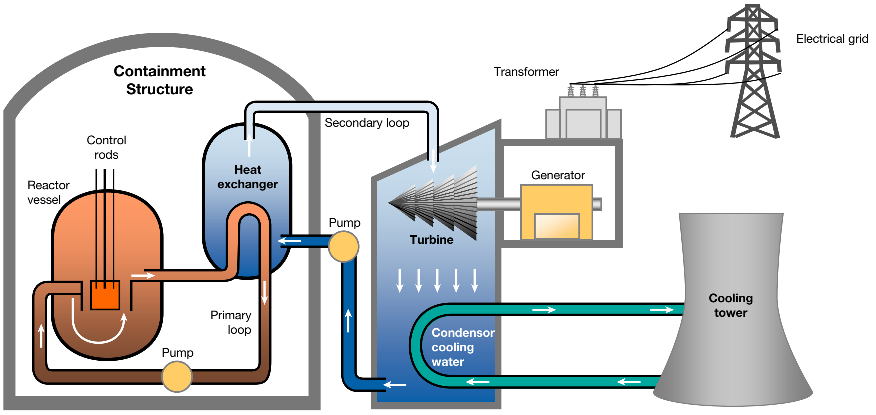
[13] *Nuclear Data Evaluation Table*. Korea Atomic Energy Research Institute, 2000. Searchable database accessible at atom.kaeri.re.kr/ton/.

EXHIBIT 1-4

Nuclear power plant schematic (LWR example)



1. Fission of nuclear fuel generates heat in the reactor vessel. Control rods are raised or lowered to control the rate of fission
2. The reaction heats pressurized water in the primary loop
3. Heat from the primary loop generates steam in the secondary loop via a heat exchanger
4. Steam in the secondary loop is used to spin turbines to produce electricity at the generator
5. Steam exiting the turbine is cooled down through heat exchange with cooling water at the condenser, where it becomes a liquid again
6. Cooling water is collected from a large water reservoir (e.g., lake or river). A cooling tower is sometimes used to convert excess heat into steam

Two fuel fabrication facilities in Ontario, Canada, combined account for 67 percent of the world's fuel fabrication capacity for pressurized heavy water reactors such as CANDU reactors.

Cameco manufactures fuel bundles for CANDU reactors at its fuel fabrication plant in Port Hope. Uranium from the Port Hope conversion facility is pressed into pellets, sintered, ground, and fitted into zirconium tubes, which are supplied by Cameco's nearby Cobourg plant.

GE-Hitachi (GEH) runs a similar CANDU nuclear fuel fabrication facility in Peterborough. UO_2 pellets are manufactured in a plant in Toronto.

Nuclear power generation

Nuclear power plants use controlled fission to harness the power of uranium or alternative nuclear fuels to generate electricity. Several reactor designs exist, but all operate on similar principles of using fission to heat water in a reactor core, which produces steam to drive a turbine and generate electricity. Light water reactors (LWRs) account for 88 percent of the world's nuclear capacity, while pressurized heavy water reactors (PHWRs) account for 6 percent.[14] The newest generation of power reactors (Generation 3+) produce between approximately 1,000 MW and 1,600 MW, which is enough electricity to power approximately 1 to 1.6 million homes.[15]

About 16 percent of Canada's electricity comes from nuclear power – a total of 18 operating reactors, or 12,652 MW of generation capacity.[16] All 18 of these reactors (16 in Ontario, 1 in New

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[14] *Nuclear Power Reactors*. WNA, 2008. http://www.world-nuclear.org/info/inf32.html. The remaining installed capacity is composed of a combination of boiling water reactors, gas-cooled reactors, light water graphite reactors, and fast neutron reactors.

[15] *U.S. Household Electricity Report*. Energy Information Administration, US Department of Energy, 2005. Based on average US household consumption of 10,656 kWh per year, and 90 percent utilization factor of the power plant.

[16] *Canada's Uranium Production & Nuclear Power*. WNA, 2008. http://www.world-nuclear.org/info/inf49.html.

Brunswick, and 1 in Québec) use domestically designed CANDU technology.

Most reactors use a “once through” fuel cycle, where a fuel bundle is burned in a reactor for 1 to 3 years until it becomes used fuel. These bundles are then removed and stored in pools of water for a number of years. During this time, the radioactivity of used fuel declines substantially – 10 years after being removed from the reactor, the radioactivity is approximately 1,000 times lower than it was initially. Sometimes bundles are transferred to dry storage after their temperatures and radioactivity have declined.

Reprocessing

Reprocessing separates the individual components of used fuel and, where appropriate, recycles the valuable elements back into nuclear fuel. This achieves two immediate benefits. It enables a greater amount of energy to be captured from the same amount of fuel and it reduces the total volume of high-level waste that requires long-term storage.

The components of used fuel that are separated during reprocessing include uranium (which makes up over 95 percent of the LWR’s used fuel),[17] as well as a range of products (e.g., plutonium, minor actinides, and fission products)[18] that have built up through the nuclear reaction in the generator.

The reprocessed uranium may be recycled by sending it back to an enrichment facility. More typically, though, this uranium is stockpiled and managed as low-level waste given its relatively low radioactivity. The plutonium recovered through reprocessing is mixed with either natural or depleted uranium to form mixed oxide (MOX) fuel. This fuel can then be used in a nuclear reactor to capture the fission energy of the plutonium. The minor actinides and fission products, which comprise 4 percent of the LWR’s used fuel,[19] are the only remaining high-level waste and are encased in glass (vitrified) and prepared for long-term storage.

Reprocessing used fuel has several advantages. It increases a country’s ability to control the security of its uranium supply, and it reduces the volume of high-level wastes for long-term storage. But it also raises substantial concerns – primarily the high capital and operating costs of reprocessing facilities and the potential risk that plutonium may be diverted and used to manufacture weapons. These concerns have limited the global adoption of reprocessing. Only a few nations – including France, the United Kingdom, Japan, India, and Russia – have operating commercial reprocessing facilities. Canada does not have any. Nor do Canadian nuclear utilities reprocess their used fuel at facilities outside Canada.

Deep geological repository

Fuel that has been used in a nuclear reactor contains a number of extremely long-lived radioactive components. The presence of these components means that used fuel has elevated levels of radioactivity for hundreds of thousands of years, requiring that it be managed safely in a secure and environmentally friendly manner throughout this time.

A number of countries are planning – or in the process of developing – deep geological repositories, in which the used fuel and any other high-level waste (e.g., minor actinides and fission products separated through reprocessing) are placed in a facility located deep within a stable rock formation. These facilities are designed to isolate and contain the used fuel in a way that indefinitely mitigates the potential for this radioactivity to affect human health or the environment. Among the countries pursuing this approach, Finland has already initiated development of a repository at Olkiluoto. Other countries, including the Czech Republic, Slovakia, and Sweden are conducting site selection activities

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[17] Bunn, Matthew, et al. *The Economics of Reprocessing vs. Direct Disposal of Spent Fuel*, 2003. Page 3.

[18] See Chapter 5 for a more detailed description of these used fuel components.

[19] Bunn, Matthew, et al. *The Economics of Reprocessing vs. Direct Disposal of Spent Fuel*, 2003. Page 3.

for a deep geological repository.[20] The United States has undertaken significant studies at the Yucca Mountain site in Nevada, although the current administration is re-examining additional alternatives for long-term used fuel management.

In Canada, the Federal Government's preferred solution is an approach incorporating a deep geological repository with the capability to retrieve the used fuel.[21] This approach is being advanced by the Nuclear Waste Management Organization (NWMO), which was established and is funded by the Canadian owners of used fuel.

Saskatchewan's role in the uranium value chain

Saskatchewan is well-positioned to expand its participation in the uranium value chain. It is the world's leading producer of uranium; the demand for low-carbon electrical power is growing in Saskatchewan and in adjacent power markets in Canada and the United States; and the Province has an existing base of nuclear R&D infrastructure and activity.

World's leading producer of uranium

Slightly less than one-quarter of the world's annual supply of uranium – some 25 million pounds of yellowcake – comes from Saskatchewan, making it the largest producer of uranium in the world.[22] The Province has a vibrant uranium exploration and mining community of world-scale competitors, such as Cameco and AREVA, and active junior players. This community and their operations contribute substantially to the economy and employment in Saskatchewan, and they provide a solid economic foundation for the future.

Moreover, the Province is a leading miner of other materials including potash, coal, and a variety of precious metals. This rich mineral endowment has driven the development of a world-class commercial mining industry. As the demand for nuclear power rises, and existing stockpiles are depleted, the Province's uranium industry is poised for continued growth.

Growing demand for electricity

As a result of the growing need for power and the decommissioning of generation plants, Saskatchewan is expected to experience a baseload power deficit of 1,200 to 1,750 MW by 2020, expanding to 2,200 to 3,000 MW by 2030. Regional demand could intensify this requirement. For example, Alberta will likely require an additional 4,000 to 4,900 MW of power by 2020.

Supporting infrastructure

Activities from the academic and research community have helped support mining activity, as well as contributing nuclear and non-nuclear R&D. In partnership with industry players like Cameco, the University of Saskatchewan and the University of Regina have established research initiatives to train workers in the uranium industry and to support the sustainable development of Saskatchewan's uranium resource. For example, current research topics include the design of new exploration and mining techniques.

Saskatchewan's nuclear research infrastructure helps support these academic programs and niche research topics, and it could play a foundational role in the expansion of R&D. The Canadian Light Source is one of Canada's largest scientific projects and one of the most advanced synchrotrons in the world.[23] Actively hosting both the academic and commercial community, it plays an important role in environmental, natural resource, and health research. Among its many uses are probing the impact of mine water, improving ore processes, and helping design and understand the next generation of drugs. Saskatchewan is host

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[20] Hogselius, Per. "Spent nuclear fuel policies in historical perspective: an international comparison," *Energy Policy 37*, 2009. Page 255.

[21] *Canada's Nuclear Future: Clean, safe, responsible.* Natural Resources Canada press release, June 2007.

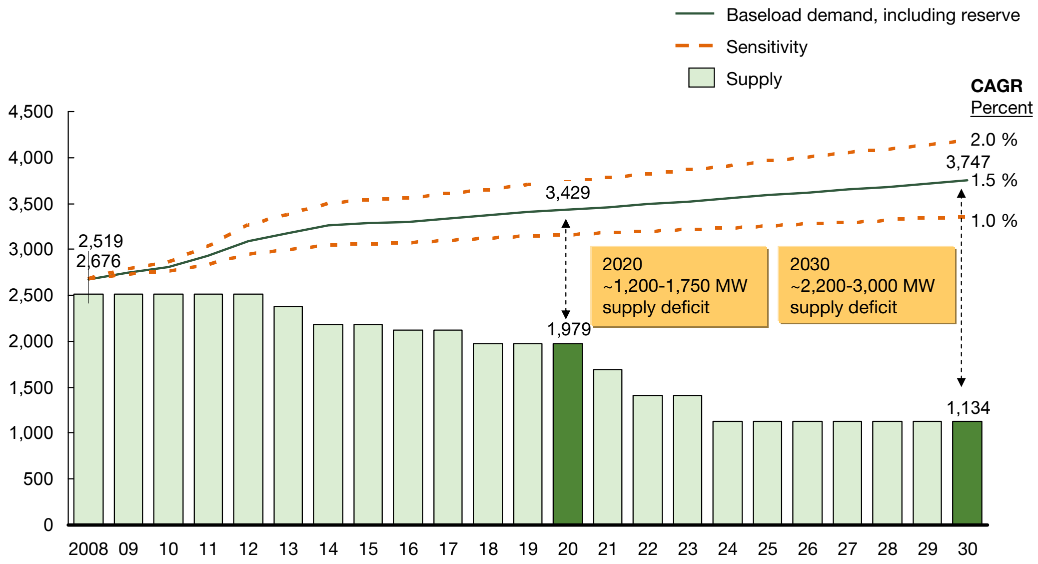
[22] *World Uranium Mining.* WNA, July 2008.

[23] *Annual Report.* Canadian Light Source, 2008. Page 6.

EXHIBIT 1-5

Saskatchewan 2020-2030 baseload electricity profile

MW



Note: Assumes phased shutdown of Boundary Dam complete by 2016: assumed 74% load factor for baseload; reserve margin based on largest coal unit at Poplar River

Source: SaskPower

to additional research resources, including a Slowpoke II research reactor that can be used for training purposes and a Tokamak plasma research facility.

In addition, Saskatchewan's universities provide research-focused training opportunities for nuclear and particle physicists that contribute significantly to our academic and research capabilities in selected areas. For example, the University of Regina has active research programs at the Vancouver-located TRIUMF, which has the world's largest cyclotron, as well as in Japan, the United States, and Switzerland.

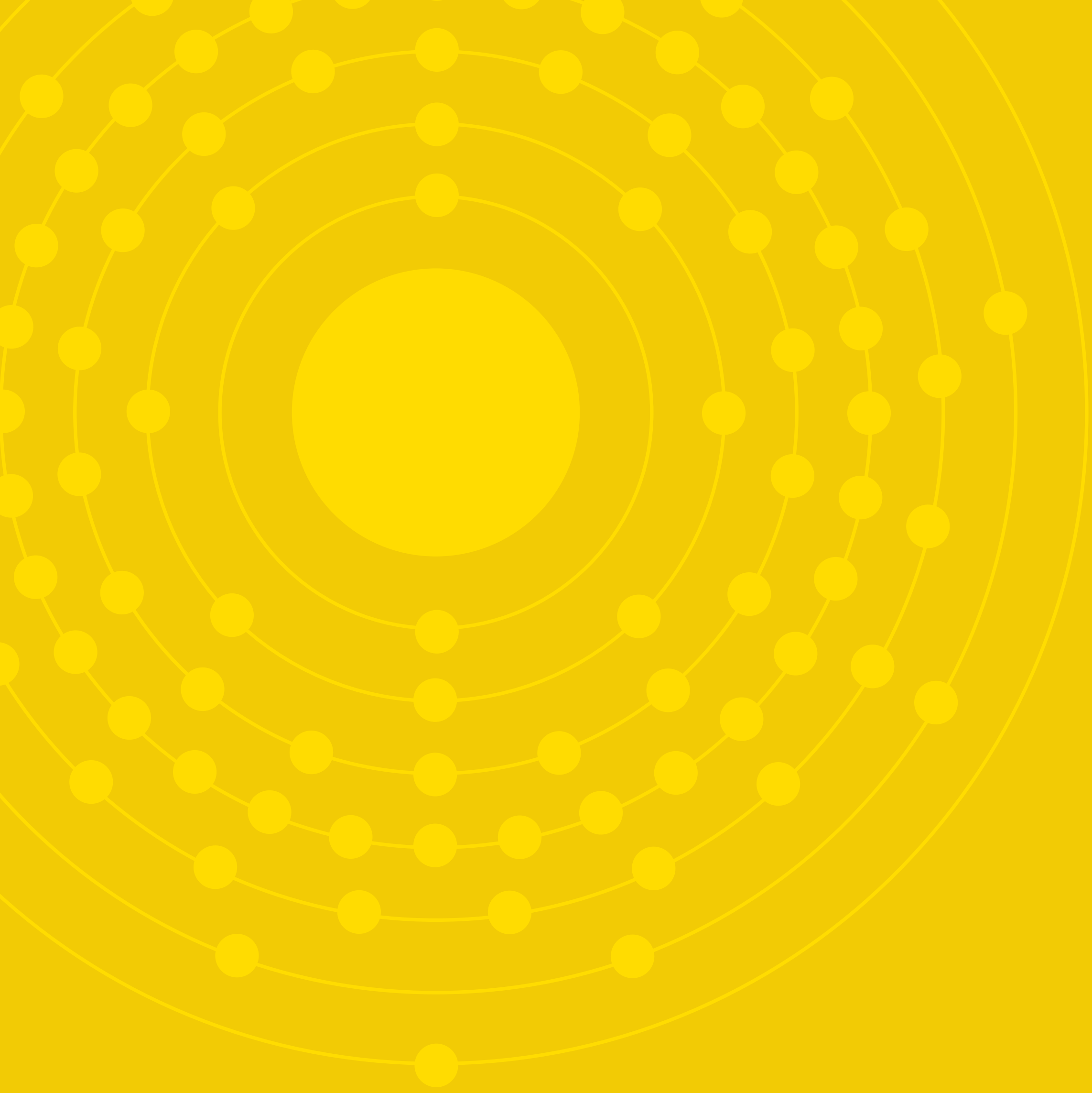
Together, the Province's researchers, industry partners, and infrastructure have established a solid foundation that Saskatchewan can build on in nurturing further research and innovation.

Key findings and recommendations

The following Chapters 2 through 6 provide a comprehensive view of the UDP's key findings of where the opportunities lie in each of the five elements of the uranium value chain and what it would take to successfully realize them. Accordingly, each of these chapters focuses on a specific element of the chain: mining and exploration; upgrading, including conversion enrichment and fuel fabrication; generating power; managing used fuel; and research, development, and training.

Each chapter describes the UDP's findings, provides a high-level overview of the opportunities, and summarizes the recommendations.

The UDP also provides an overview of market conditions and a business case for private investment for many of the opportunities. In addition, for some of the more attractive opportunities, the UDP assesses their potential impact on the Province if an investment were to be made.



Chapter 2: Exploration and mining

Key findings

a. Saskatchewan's leadership position in uranium mining is threatened by emerging players, such as Kazakhstan and Australia, that are rapidly ramping up their production.

b. World demand for primary uranium will grow substantially over the next 10 years, creating an opportunity for Saskatchewan to rapidly expand its mining sector and to maintain its position as a leader in uranium mining.

c. To achieve this goal, Saskatchewan will need to renew its discovered resource base by maintaining the level of private exploration investment reached in recent years and investing in mine development.

d. Exploration activity is cyclical. When the spot price of uranium is high, companies increase their exploration activities substantially. This trend is facilitated by the claim-staking system that creates an environment with low entry barriers.

e. The process to fulfill the duty to consult with First Nations and Métis communities is not sufficiently defined. The lack of a clear process may create an impediment to further exploration and/or development in the Province.

f. The basic royalty system in Saskatchewan appears competitive but, when the price of uranium is high, the tiered royalty structure creates a higher burden for mining operations based in Saskatchewan than for those in other jurisdictions.

g. This tiered royalty structure risks impeding the competitiveness of newer mines given that: 1) mine operating costs have increased more rapidly than the inflation index used to adjust the royalty structure; and 2) the next generation of deposits to be mined may be of lower quality and, therefore, have higher operating costs.

h. A strong and effective licensing and environmental assessment process is paramount to ensure the safety of workers and the public, as well as to protect the environment. However, the public is not well-served by lengthy delays in environmental assessment approvals.

i. The lack of basic infrastructure in the North, particularly roads and power, is likely to impede further mine developments.

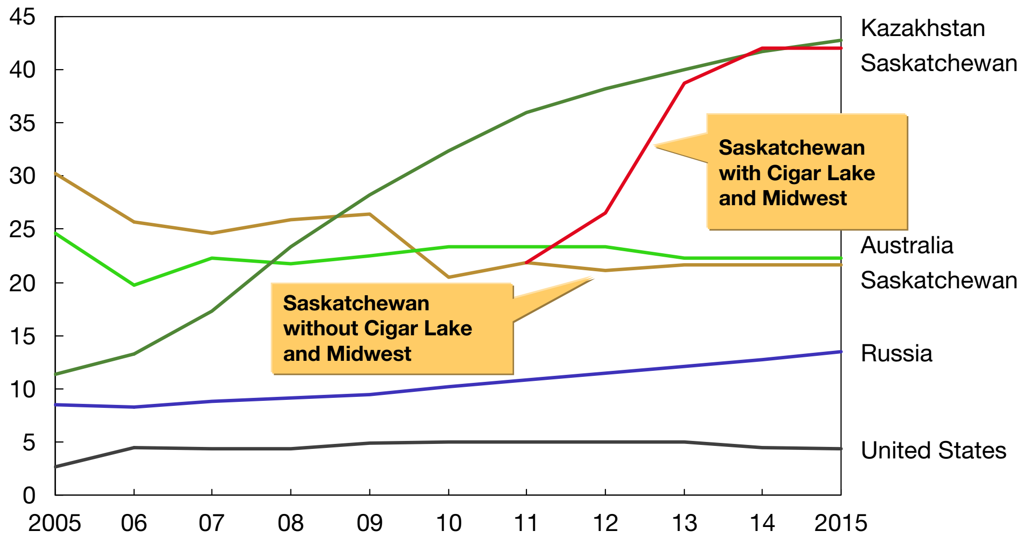
j. Federal restrictions on foreign ownership may limit the ability of the Province to attract capital for exploration and mining; the Competition Policy Review Panel formed by the Federal Government recommended in June 2008 that these restrictions be selectively removed on a bilateral basis.

k. Sustaining Saskatchewan's leadership position in exploration and mining would have a significant impact on the Province's economy, contributing a total estimated GDP impact of $4.2 billion over 15 years.

EXHIBIT 2-1

Expected production of U_3O_8 by country

Millions of pounds of U_3O_8



Source: UxC, August 2008

Primary versus secondary uranium supply

The nuclear power industry draws uranium from two main sources, referred to as primary and secondary supplies. Primary supply is the extraction of natural uranium from the ground through the mining process. Secondary supply is the reutilization of uranium from various sources, including the decommissioning of weapons, reprocessing of used fuel from nuclear reactors, and depleting of existing inventories.

The main secondary supply of uranium is currently the “Megatons to Megawatts” agreement between the United States and Russia. Under this program, Russia is dismantling some of its nuclear warheads and downblending the highly enriched uranium into low- enriched uranium for use in nuclear power reactors. This program is expected to end in 2013.

a. Saskatchewan’s leadership position in uranium mining is threatened by emerging players, such as Kazakhstan and Australia, that are rapidly ramping up their production

While smaller in size than the potash or petroleum industries, uranium mining and exploration is an important source of economic activity in Saskatchewan. According to the Saskatchewan Mining Association, the industry employs approximately 3,000 people, almost 80 percent of whom are working directly at mine sites in Northern Saskatchewan. More than a third of these employees are from First Nations and Métis communities.

As of 2008, Saskatchewan was the largest producer of uranium in the world, representing about 22 percent of total global production.[24] However, a number of countries are increasingly threatening Saskatchewan’s leading position. Chief among them is Kazakhstan, which

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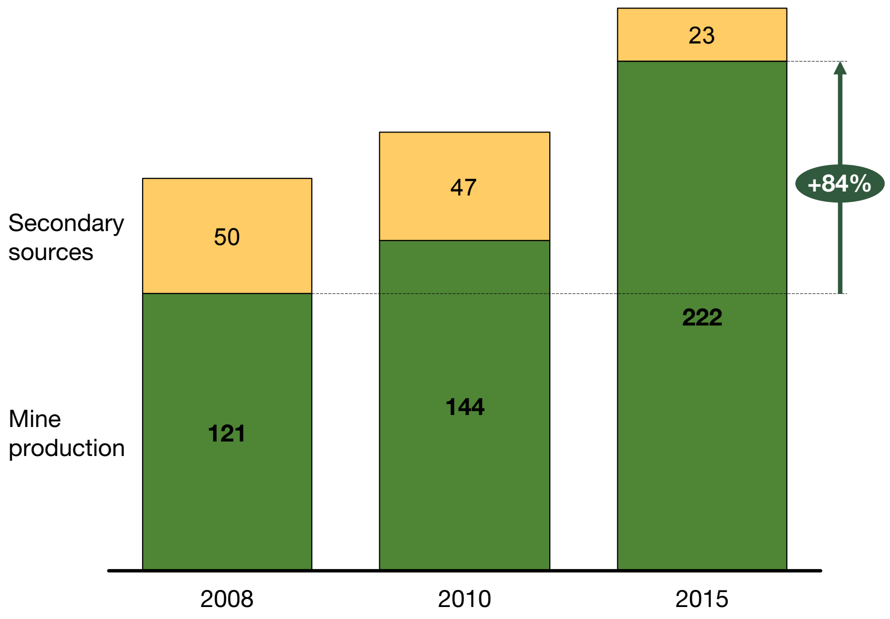
[24] *Uranium Suppliers Annual*. The UX Consulting Company LLC (UxC), August 2008. Page 25.

EXHIBIT 2-2

Expected U_3O_8 supply growth between 2008-2015

Millions of pounds of U_3O_8



Source: UxC, *Uranium Suppliers Annual* – 2008

is expected to increase its current production by more than 80 percent by 2015.[25] In fact, Kazakhstan could overtake Saskatchewan's position as the world's largest producer as early as this year.

In Australia, BHP Billiton has begun the environmental impact assessment for a significant expansion of the Olympic Dam mine, home to the largest uranium deposit in the world.[26] BHP Billiton recently announced that it was slowing the project down because of the prevailing economic conditions.[27] Should the planned expansion happen, it could more than triple the mine's production and make Olympic Dam the world's largest uranium producing mine.

In the short term, Saskatchewan's position as a world-leading uranium producer will depend on the timing of two key projects. The most important is Cigar Lake, a very large and high-grade underground mine with an estimated reserve of 226 million pounds of U_3O_8.[28] Cigar Lake's production has been delayed because of the various technical challenges that have resulted from the unexpected flooding of the underground areas.[29] The second is the Midwest mine, an open-pit project with an estimated reserve of 37 million pounds;[30] this project has been postponed indefinitely because of a significant increase in the cost and timing of regulatory approvals.[31]

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[25] *Uranium Suppliers Annual*. UxC, August 2008. Page 25.

[26] *Uranium Suppliers Annual*. UxC, August 2008. Page 51.

[27] *BHP Billiton Quarterly Report on Exploration and Development Activities* news release. BHP Billiton, January 29, 2009.

[28] *Saskatchewan Exploration and Development Highlights 2008*. Government of Saskatchewan.

[29] Cameco press releases. October 23, 2006, and August 12, 2008.

[30] *Saskatchewan Exploration and Development Highlights 2008*. Government of Saskatchewan.

[31] AREVA press release. November 25, 2008.

Until these two projects, or other mines of similar magnitude, come online, Saskatchewan will likely drop to third place globally.

b. World demand for primary uranium will grow substantially over the next 10 years, creating an opportunity for Saskatchewan to rapidly expand its mining sector and to maintain its position as a leader in uranium mining

The demand for primary uranium is expected to grow by more than 80 percent between now and 2015.[32] This growth exceeds the growth in the overall demand for uranium because of a decline in the secondary supply of uranium – that is, from sources other than mining. The secondary supply is expected to fall from 33 percent to 10 percent of the total global supply, largely because Russia will significantly curtail its program of downblending highly enriched uranium stocks for civilian use by 2013[33] (See sidebar "Primary versus secondary uranium supply").

This increase in the demand for primary uranium creates tremendous opportunity and challenges for mining companies. They will need to increase their output significantly by bringing new mines into operation over the next 6 years – equivalent to almost one new mine the size of the McArthur River mine each year – to ensure sufficient supply.

Reserves and resources

Reserves and resources are specific industry terms with legal definitions for regulatory reporting and accounting purposes. The following descriptions provide an overview of the concepts:

- *Reserves* are identified and significantly delineated ore deposits that are both technically and economically feasible to extract under current conditions.
- *Discovered resources* include ore deposits that have been identified or may be inferred from other known deposits, but they have not yet been fully delineated nor has a detailed plan yet been designed for their extraction.

c. To achieve this goal, Saskatchewan will need to renew its discovered resource base by maintaining the level of private exploration investment reached in recent years and investing in mine development

The expected increase in demand for primary uranium creates a particular challenge for Saskatchewan, which relies heavily on a few existing larger mines. Saskatchewan's two largest discovered reserves, McArthur River and Cigar Lake, will likely be exhausted by 2030 based on their current rate of production and without the discovery of additional reserves.[34]

To maintain its global leadership position, Saskatchewan would have to increase its annual production to 48 million pounds per year by 2015 (compared to 25 million pounds per year today). Currently, Saskatchewan has the equivalent of about 30 years of production in discovered resources. Maintaining this ratio of production to reserve would require Saskatchewan to grow its resource base to 1,430 million pounds of U_3O_8. This is equivalent to adding 65 million pounds of U_3O_8 to the resource base every year until 2015.[35]

Estimating the level of exploration activity required to meet this target resource base is difficult – exploration dollars are often spent for many years before a significant discovery is made. Nonetheless, using a 10-year average during the last surge of uranium exploration expenditures in the late 1970s, about $1.35

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[32] *Uranium Suppliers Annual*. UxC, August 2008. Page 26.

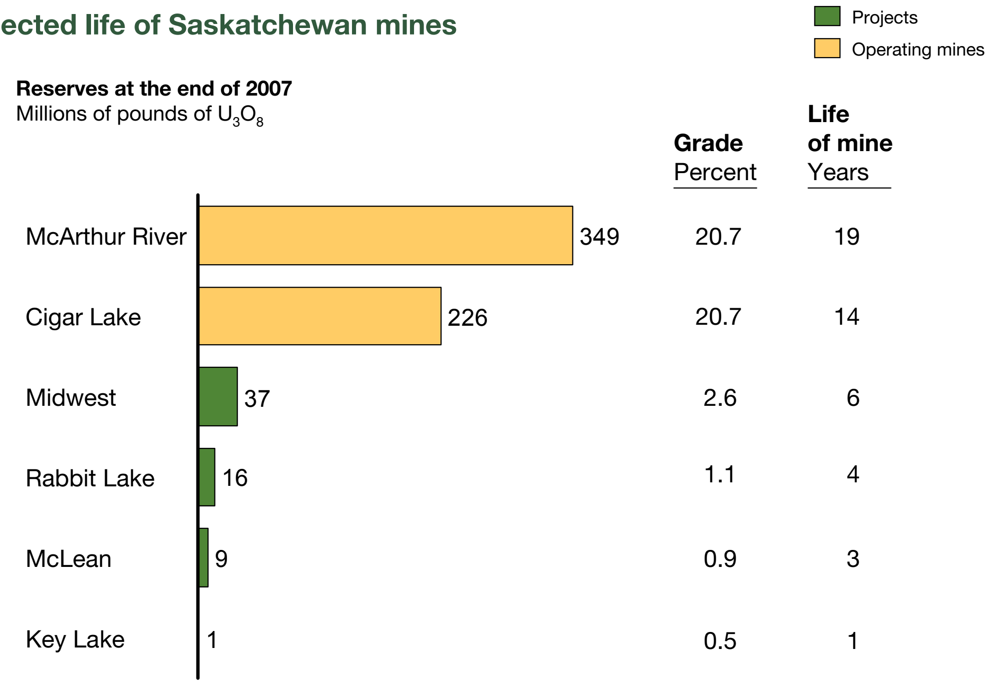
[33] *Uranium Suppliers Annual*. UxC, August 2008. Page 26.

[34] *Saskatchewan Exploration and Development Highlights 2008*. Government of Saskatchewan.

[35] Assumes that the surge in exploration activities in 2007-2008 will translate into 258 million pounds of additional resource base, in addition to the approximately 1,000 million pounds of U_3O_8 currently existing. See *Saskatchewan Exploration and Development Highlights 2008*. Government of Saskatchewan.

EXHIBIT 2-3

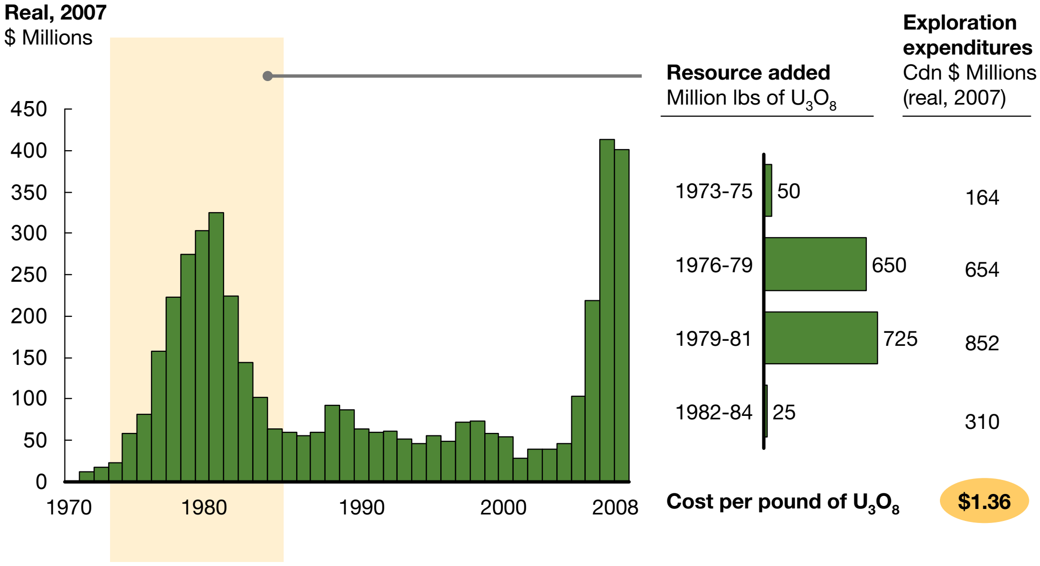
Expected life of Saskatchewan mines



Source: *Saskatchewan Exploration and Development Highlights 2008,* Government of Saskatchewan

EXHIBIT 2-4

Cost of uranium discoveries in Canada between 1973 and 1984



Uranium exploration expenditures in Canada

Uranium discovered in Canada

Source: Cranstone, Donald A. *A History of Mining and Mineral Exploration in Canada*; *Canadian Mineral Yearbook*, Natural Resources Canada, 2002 (in real 2007 dollars) has been spent on exploration for every pound of U_3O_8 discovered in Canada during this period.[36]

A similar analysis using more recent uranium discoveries in Saskatchewan suggests a comparable cost of about $1.25 per pound of U_3O_8 discovered between 2004 and 2007.[37] Accordingly, to achieve a target of 65 million pounds of U_3O_8 annual addition to the resource base between now and 2015, Saskatchewan would have to maintain total yearly exploration expenditures of approximately $80 million.

d. Exploration activity is cyclical. When the spot price of uranium is high, companies increase their exploration activities substantially. This trend is facilitated by the claim-staking system that creates an environment with low entry barriers

A strong correlation exists between the price of uranium and exploration expenditures in Saskatchewan, as illustrated in Exhibit 2 - 5.[38] Exploration expenditures have exceeded $80 million only in years when the price of U_3O_8 exceeded US $55 per pound. This happened in both price surges since 1970 – from 1977 to 1981 and from 2005 to 2007.

Therefore, a positive price outlook will be a primary driver of exploration in Saskatchewan. Most price forecasts currently predict a long-term price of uranium in the US $45 to $75 per

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[36] Cranstone, Donald A. *A History of Mining Exploration in Canada. Canadian Mineral Yearbook*. Natural Resources Canada, 2002.

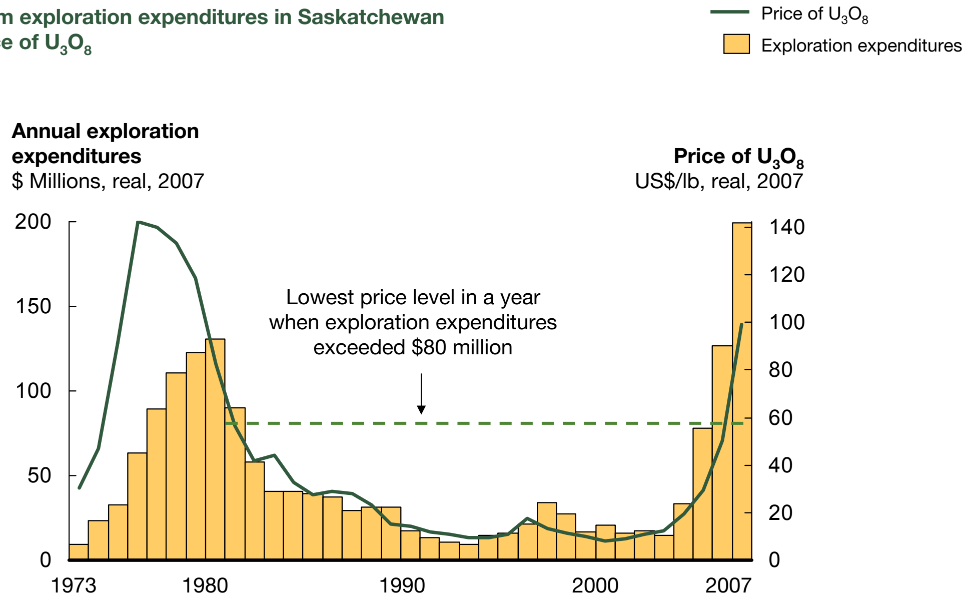
[37] Additional resources reported between 2004 and 2007 totalled 112 million pounds of U_3O_8. Assuming a 2-year lag between the timing of discoveries and their reporting, the total expenditure between 2002 and 2005 equalled $140 million (in real 2007 dollars) leading to a cost per pound of $1.25 ($140 million for 112 million pounds). *Saskatchewan Exploration and Development Highlights 2008*. Government of Saskatchewan.

[38] *Canada Mining Exploration Yearbook*. Natural Resources Canada, 1994 & 2000. Consensus Economics Inc.

EXHIBIT 2-5

Exploration expenditures in Saskatchewan and price of U_3O_8

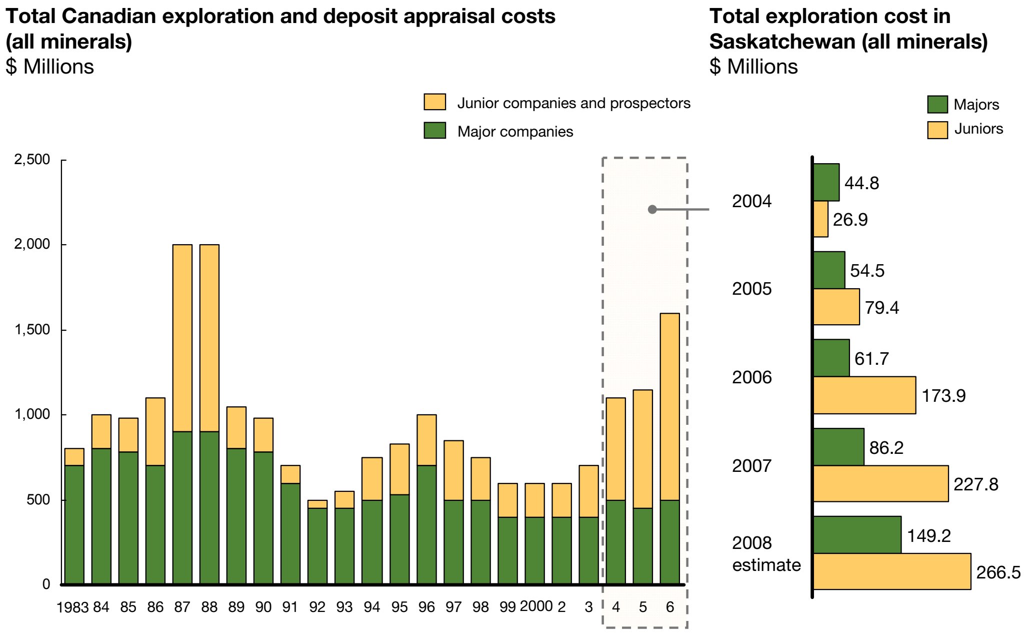
Uranium exploration expenditures in Saskatchewan vs. price of U_3O_8



Note: Saskatchewan's expenditures for 1973-1987 are estimated as 40% of total Canadian expenditures (its historical average)
Source: *Canadian Mining Exploration Yearbook*, Natural Resources Canada; RWE NUKEM; NUEXCO

EXHIBIT 2-6

Exploration expenditures by junior and major companies in Canada



Total Canadian exploration and deposit appraisal costs (all minerals)
$ Millions

Total exploration cost in Saskatchewan (all minerals)
$ Millions

Source: Cranstone, Donald A. *A History of Mining and Mineral Exploration in Canada*

pound price range, with an average estimate of US $53 per pound.[39]

The role of junior exploration companies in driving Canada's mining industries should not be overlooked as spikes in exploration are generally driven by these players. Exhibit 2 - 6 presents the split of exploration expenditures for juniors and majors for all Canadian mining sectors combined between 1983 and 2006.[40] The two main spikes in exploration – from 1987 to 1988 and from 2004 to 2008 – were driven by sharp increases in exploration expenditures by juniors, whereas the profile of exploration expenditures for majors has been more stable over time.

The underlying economic drivers of exploration differ somewhat for junior and major exploration companies.[41] Juniors typically do not develop the resources themselves and will seek to sell a large stake or the entirety of the resources to a major in the short term. As such, they will typically be more influenced by uranium spot prices since it is easier for them to raise capital or sell discovered resources at a higher price. While price considerations are important for majors, they will also be heavily influenced by the expected cost and schedule for mine development, as well as the operating cost of extraction, including royalties.

Juniors will be more heavily influenced by the ease with which they can access Crown land for exploration purposes. The mineral disposition system in Saskatchewan creates a level playing field by making it relatively easy and inexpensive for companies to stake a claim and maintain it. Under the current system, anyone

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[39] Based on the price forecasts reported by Consensus Economics, January 26, 2009.

[40] Cranstone, Donald A. *A History of Mining and Mineral Exploration in Canada*. Natural Resources Canada, 2002.

[41] Junior exploration companies are small companies engaged in mineral exploration but, as of yet, without a mineral discovery in production, and they therefore rely largely on capital markets to finance exploration activities. Major companies have significant mining operations that provide their major source of revenue.

EXHIBIT 2-7

Summary of three-stage disposition system for Crown land in Saskatchewan

	Permit	Claim	Lease
Eligibility	- **Anyone can apply for a permit**, but it is subject to the Province's discretion to grant it	- **Anyone can stake a claim** in an area not subject to a permit or **any holder of a permit** can convert it into a claim	- **Any holder of a claim** can convert it into a lease
Rights provided	- Exclusive rights to prospect for the minerals and to convert into a claim	- Exclusive rights to explore and prospect for the minerals and to convert into a lease	- Exclusive rights to explore for and to mine the minerals subject to payment of royalties
Duration	- 2 years, non-renewable	- 2 years, then renewable every year	- 10 years, then renewable for further terms of 10 years
Minimum expenditure on assessment work (per hectare)	- Year 1: $1.25 - Year 2: $4.00	- Year 1: nil - Years 2-10: $12 - After 10 years: $25	- Years 1-10: $25 Years 11-20: $50 After 20 years: $75

Source: Crown Minerals Act; The Mineral Disposition Regulations, 1986

can stake a claim in an area and acquire an exclusive right to explore and prospect the minerals, provided that a minimum of assessment work is conducted every year.

Juniors will also be more dependent on their ability to raise capital to sustain their exploration programs, whereas majors will be able to finance their exploration programs with cash flow generated by their operating mines. The recent collapse in equity share prices of junior companies suggests that the financial crisis could affect the juniors' ability to pursue their exploration programs in the short term.

e. The process to fulfill the duty to consult with First Nations and Métis communities is not sufficiently defined. The lack of a clear process may create an impediment to further exploration and/or development in the Province

The duty to consult with First Nations and Métis communities on any activity that could affect Treaty or Aboriginal rights has been reaffirmed a number of times by the Supreme Court of Canada. In early 2008, the Government of Saskatchewan announced that it was developing a new consultation policy with First Nations and Métis communities for decisions that may impact Treaty or Aboriginal rights. A roundtable conference was held in May 2008 with industry and key stakeholders, but no formal policy has yet been announced as part of this process.

Defining clear parameters and accountability to ensure a thorough but efficient process to consult First Nations and Métis people is a key success factor for the development of exploration activities in Saskatchewan, since these activities often take place on traditional lands.

f. The basic royalty system in Saskatchewan appears competitive but, when the price of uranium is high, the tiered royalty structure creates a higher burden for mining operations based in Saskatchewan than for those in other jurisdictions

The Saskatchewan royalty system is described in Exhibit 2 - 8. It has three separate

EXHIBIT 2-8

Summary of the Saskatchewan uranium royalty system

1	**Basic royalty**	• 4% of the gross value of sales (net of the Saskatchewan Resource Credit)
2	**Tiered royalty***	• Percentage applied on each tranche of the average price per pound of U_3O_8 – 0%: Up to $17 per pound of U_3O_8 – 6%: Between $17-26 per pound of U_3O_8 – 10%: Between $27-34 per pound of U_3O_8 – 15%: More than $34 per pound of U_3O_8
3	**Capital recovery bank[1]**	• Amount used to offset the tiered royalty – Open pit mine: $26 per pound of annual capacity – Underground mine: $34 per pound of annual capacity – Mill construction: $46 per pound of annual capacity – Mill expansion: $29 per pound of expanded capacity

[1] These amounts are indexed every year; the numbers shown are for 2008

Source: Saskatchewan Energy and Resources

components: the basic royalty, the tiered royalty, and the capital recovery bank. The effective rate of the **basic royalty** is 4 percent, while the **tiered royalty** can vary from 0 to 15 percent, depending on the price of uranium. The system also provides for a **capital recovery bank,** which allows mine developers to recoup some of their capital before paying any tiered royalty to the Government.

Exhibit 2 - 9 presents a comparison of the effective rate of Saskatchewan's royalty with those of Australia and Kazakhstan at the current price of approximately US $45 per pound of U_3O_8. The basic royalty of 4 percent is comparable to the two main uranium-producing jurisdictions in Australia, which levy royalties of 5.5 percent (Northern Territory) and 3.5 percent (South Australia) respectively. This basic rate is higher than the base royalty in Kazakhstan, but meaningful comparisons with Kazakhstan are difficult, given that all its resources are State-controlled and that contributions to the State can take many different forms, including lump sum payments to acquire rights to the resources, resource discovery bonuses, and excess profit taxes.[42]

In higher price environments, however, the tiered royalty can significantly impact the total value levied for uranium mining in Saskatchewan. At current uranium prices of approximately US $45 per pound of U_3O_8, the effective rate of the tiered royalty is in excess of 8 percent, once a company has exhausted its capital recovery bank.

Although the capital recovery bank was designed to allow mining companies to recoup the cost of their investment in a new mine before being affected by the higher burden of the tiered royalty structure, the cost of recent project developments in Saskatchewan suggests that it is falling short of this objective. For example, the estimated capital cost of developing the Cigar Lake project is about 65 percent higher than the amount available

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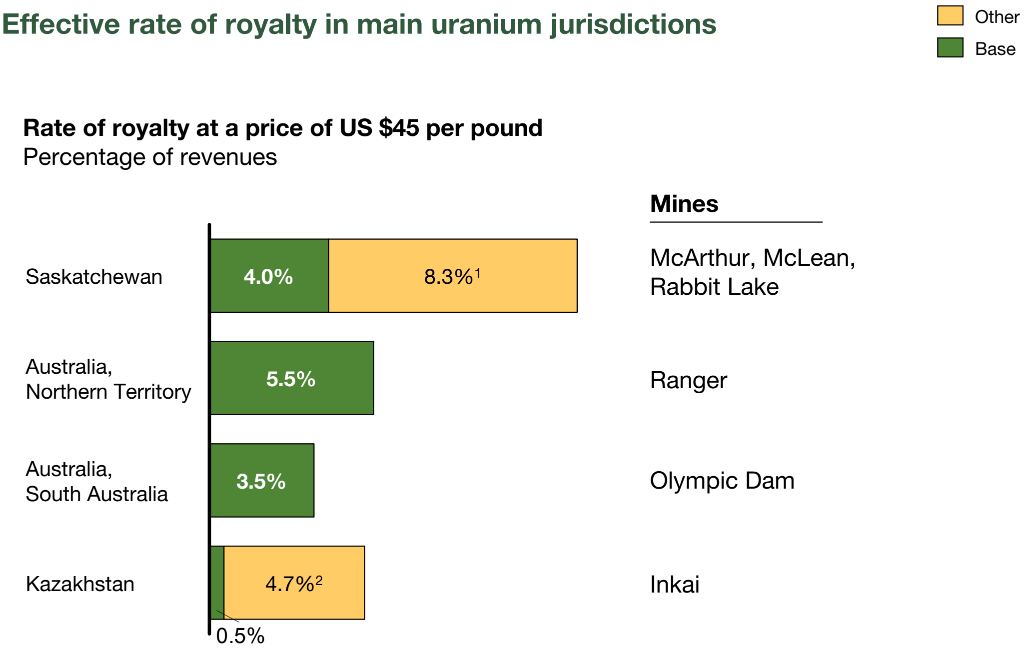
42 *Technical Report on the South Inkai Uranium Project, Kazakhstan*. UrAsia Energy, March 20, 2006. Page 4-2.

EXHIBIT 2-9

Effective rate of royalty in main uranium jurisdictions



[1] Tiered royalty
[2] Discovery bonus tax on new resources found; Kazakhstan also has an excess profit tax when the ratio of accumulated income to accumulated expenses exceeds 1.2 (not included above)

Source: Saskatchewan Energy and Resources; *Australia Bills Digest No. 79*, 2008-09; Government of South Australia Website; *Technical Report on the South Inkai Uranium Project, Kazakhstan*, UrAsia Energy, March 20, 2006, p 4-2

from the capital recovery bank.[43] Similarly, the estimated development cost of Midwest is almost five times higher. This is a reflection of two factors: 1) recent cost inflation in the mining sector in Canada and globally; and 2) greater technical complexity resulting in higher costs for today's projects.

g. This tiered royalty structure risks impeding the competitiveness of newer mines given that: 1) mine operating costs have increased more rapidly than the inflation index used to adjust the royalty structure; and 2) the next generation of deposits to be mined may be of lower quality and, therefore, have higher operating costs

The current tiered royalty structure was introduced in 2001 to replace the profit-based system in place between 1989 and 2001. The tiered royalty structure was designed to reduce the administrative complexity of the previous system, while being revenue neutral for the Government. A stated objective of the system was to minimize the distributional impacts of the new tiered royalty across a range of price scenarios.[44] In effect, the tiered royalty was meant to replicate, as much as possible, the previous system by allowing the Government to capture a comparable share of the profits generated by operators.

In the past decade, two developments have likely increased the burden of the tiered royalty in comparison to a profit-based royalty. First, the royalty system is taking an increasing share of the mine operating profits, as operating costs are increasing faster than the rate of indexation of the royalty system. Exhibit 2 - 11 shows the percentage increase of mine and mill operating costs between 1998 and 2008, as well as the rate of indexation of the royalty system. The operating cost of surface mines

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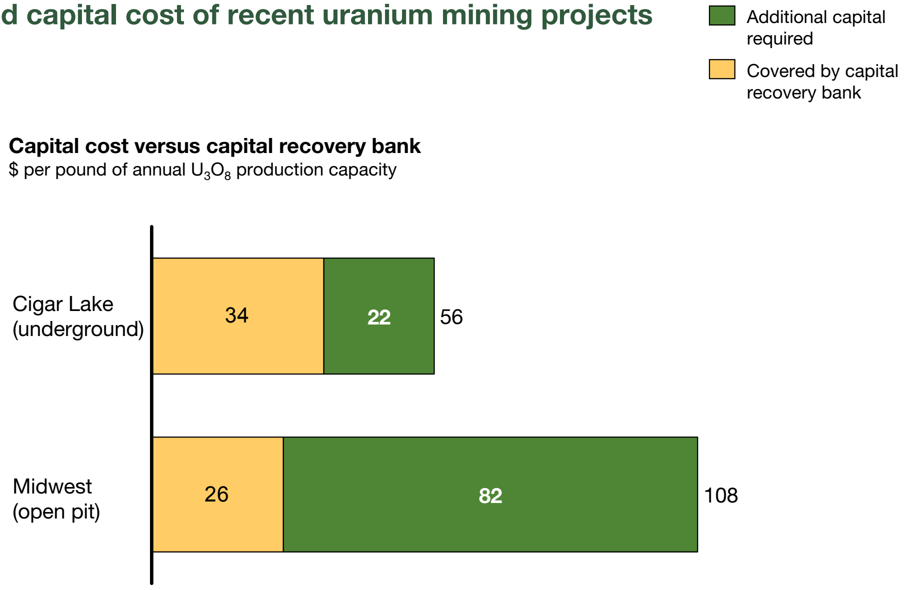
[43] *Cigar Lake Technical Study (2007)*. Page 16. "Denison Mines postpone the development of Midwest uranium project in Saskatchewan." *Daily Commercial News*, November 27, 2008.

[44] Background on the royalty system provided by Saskatchewan Resources.

EXHIBIT 2-10

Estimated capital cost of recent uranium mining projects



Source: Saskatchewan Energy and Resources

has increased at a rate of 52 percent, which is double the royalty index factor.

Second, the overall mix of mining assets in Saskatchewan is likely to evolve toward mines that are more expensive to operate. In recent years, most of Saskatchewan's production has come from the McArthur River mine, which is a low-cost mine because of its high-grade ore and large size. However, if Saskatchewan wants to grow its mining sector substantially in the coming years, it may have to rely increasingly on mines that have higher operating costs because of technical complexity or lower ore grades. For example, the next likely developments in Saskatchewan are the Cigar Lake, Midwest, and Millennium mines. Cigar Lake will have higher costs because of its technical complexity, while Midwest and Millenium will have less than 50 million pounds of resources and have a grade of less than 5 percent.[45] Such smaller and lower-grade deposits are estimated to have operating costs up to three times higher than those of the McArthur River mine.[46]

h. A strong and effective licensing and environmental assessment process is paramount to ensure the safety of workers and the public, as well as to protect the environment. However, the public is not well-served by lengthy delays in environmental assessment approvals

The Canadian Nuclear Safety Commission (CNSC) has primary responsibility for ensuring that the public, the workers, and the environment are protected from the potential risks of nuclear activities. One aspect of the CNSC's mandate is to review all license applications for the construction and operation of

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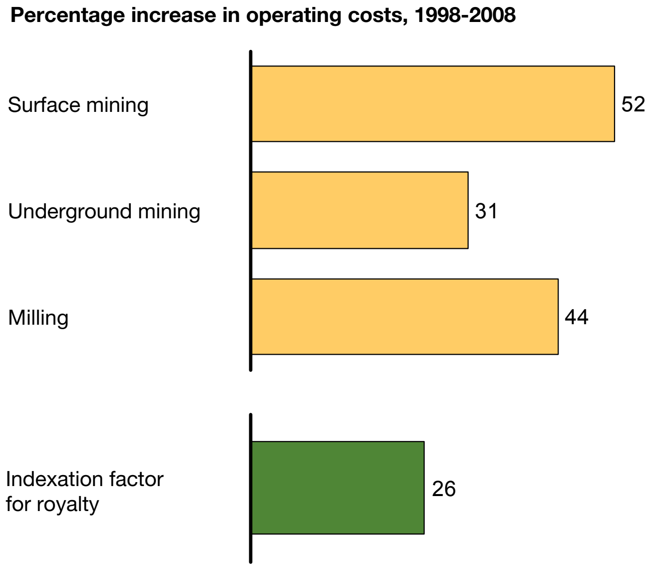
[45] *Saskatchewan Exploration and Development Highlights 2008*. Government of Saskatchewan. Page 6.

[46] *Uranium Suppliers Annual*. UxC, August 2008. Pages 38 and 60. Reported cash costs for McArthur River are US $8 to $10 per lb compared to $20 to $30 per lb for McClean River, Midwest, Dawn Lake, and Eagle Point Rabbit Lake, all of which have reported reserves of less than 40 million pounds and 1 to 3 percent grades.

EXHIBIT 2-11

Increase in operating costs



Source: Mining Cost Service Indices Canada

uranium mines and milling plants in Canada. If the proposed activities entail a potential risk to people or the environment, the applicant has the burden to demonstrate that proper mitigation measures will be implemented to reduce this risk below an acceptable threshold.

The Environmental Assessment (EA) is an integral part of the licensing process, but the unpredictability of the length of the EA process has been a cause for concern in the industry. EAs can take anywhere from 1 to 7 years to complete, with nearly half of recent projects taking more than 5 years. Although some of these delays are unavoidable, the cost of delaying a mine development for several years is substantial. For example, for a mine with 50 million pounds of reserves that cost $100 million dollars to bring from exploration to development, every year of delay will cost approximately $10 million, plus the cost of postponing any future profit on mine production.[47]

i. The lack of basic infrastructure in the North, particularly roads and power, is likely to impede further mine developments

The development of mines is dependent on basic infrastructure provided by the Government. Industry players have cited several examples of necessary infrastructure upgrades, two of which are the need for additional roads and electric power transmission and distribution.

The McArthur River mine produces three-quarters of Saskatchewan's uranium. Uranium ore at McArthur River is currently trucked to the Key Lake milling facility, 70 kilometres away. Additional capacity, with the ability

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[47] Based on a cost of exploration of $1.3 per pound of U_3O_8, a cost of capital of 10 percent, and 5 years of carrying charge between exploration expenditures and the beginning of the regulatory process.

to process higher grades, is available at the McClean Lake milling facility, 100 kilometres away. However, given the current road system, the shortest route between McClean Lake and McArthur River is over 700 kilometres. Building a direct road between the two facilities is an example of the kind of public infrastructure that could facilitate existing and future operations.

There is also a limited supply of power to Northern communities and mines. The industries' demand for power is already creating stress on the system. With plans to open Cigar Lake pending and ambitious plans to expand the mining industry in the North, improving the availability of power will be an essential precondition to growth. While current power generation capacity exceeds demand, transmission capacity is limiting the availability of power. Additional access to electricity will be required for substantial new mining production to come online. For example, Cigar Lake could require approximately 15 to 20 MW.[48]

j. Federal restrictions on foreign ownership may limit the ability of the Province to attract capital for exploration and mining; the Competition Policy Review Panel formed by the Federal Government recommended in June 2008 that these restrictions be selectively removed on a bilateral basis

Under the Non-Resident Ownership Policy in the Uranium Mining Sector, the Federal Government formulated certain rules limiting foreign ownership of Canadian uranium mining assets.[49] In particular, the current policy stipulates that:

- A minimum level of resident ownership in individual uranium-mining properties of 51 percent must be maintained at the mining and milling stages of production.
- Resident ownership levels of less that 51 percent may be allowed only when the project is Canadian-controlled.
- Exemptions to the policy may be granted in cases where it can be demonstrated that no Canadian partners could be found.

While the purpose of the policy was to ensure Canadian control of a strategic asset, recent trends in Canada and abroad have been moving toward the liberalization of foreign ownership rules. In 2008, the Competition Policy Review Panel formed by the Federal Government recommended selectively removing the restrictions on foreign ownership for uranium mining for specific countries offering reciprocity. The Federal Government has not officially responded to the Panel's

Methodology for calculating GDP impact

1. Operating and capital costs were estimated for each opportunity along the value chain and broken down into major categories of spending (e.g., labour, equipment, and materials).
2. Analysis from Statistics Canada was used to determine what portion of the total spend in each major category would be expected to remain in Saskatchewan.[1]
3. This was used to calculate the direct and indirect GDP impact per year, then discounted using a 3 percent real social discount rate to estimate the cumulative GDP impact in Saskatchewan.

This approach employed three major assumptions:

- All economic activity associated with an opportunity is incremental.
- The opportunity does not impact the price of key inputs (e.g., steel).
- External factors (e.g., cost of debt and inflation) are constant.

[1] *2005 Open Interprovincial Input-Output Model*. Statistics Canada System of National Accounts.

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[48] Based on an assumption of 350 mine employees and 50 kW requirement per employee.

[49] Letter from the Minister of Natural Resources of Canada dated December 23, 1987.

recommendation, but the Prime Minister has publicly endorsed the liberalization of these foreign ownership rules.[50]

At a time when Saskatchewan will be seeking to attract capital and commercial partners to strengthen its position in uranium mining and to participate in other areas in the value chain, barriers to investment such as this one appear counterproductive. The argument of security of supply does not seem to apply in the present context, given that Canada holds the third largest known reserves of uranium and has vastly more resources than it requires for its local needs. Furthermore, as pointed out by the Competition Policy Review Panel, foreign access to Saskatchewan uranium resources could be negotiated as part of reciprocity agreements that include greater access by Canadian companies to other markets or to restricted technologies, such as enrichment.[51]

It should also be noted that foreign-owned companies, such as AREVA Resources Canada, have a long history of investing and developing uranium mining assets in Saskatchewan and may be able to extend their contribution to the Province without this limitation on foreign ownership. Similarly, Canadian-owned Cameco is increasingly diversifying its portfolio of assets and investing in mining assets abroad.

k. Sustaining Saskatchewan's leadership position in exploration and mining would have a significant impact on the Province's economy, contributing a total estimated GDP impact of $4.2 billion over 15 years

Increasing exploration expenditures from its historical average of $20 million to $80 million per annum would have significant potential benefit in the Province. The additional GDP from this increase in exploration activity that would be retained in the Province is estimated to be approximately $500 million over 15 years.

For the mining industry, growing production from its current level of 25 million pounds per annum to 48 million pounds per annum would have an even more significant impact, translating into an additional $3.7 billion of GDP for the Province over 15 years, and adding substantially to employment at mine sites in the Northern parts of the Province.

Recommendations

The UDP has developed its recommendations, supported by these findings, to materially improve the Province's competitiveness and increase its economic activity in mining and exploration.

Saskatchewan should:

1. Maintain its current claim-staking system to provide a favourable environment for exploration.

2. Work with the Federal Government to establish clear parameters and accountabilities for the duty to consult with First Nations and Métis communities.

3. Examine the possibility of expanding its program incentives for exploration (e.g., flow-through shares, tax credits, and matching grants) to drive through-cycle investment decisions based on long-term uranium forecasts rather than spot prices.

4. Undertake a review of the competitiveness of the royalty system in relation to other jurisdictions, with a focus on whether:

    - The capital recovery bank correctly reflects the current cost of developing new projects in Saskatchewan.

    - The royalty rate is sufficiently competitive and reflects the costs of extracting the resource.

5. Work with the Federal Government to establish clearer timelines and guidelines for a thorough, consistent, and predictable review of license applications.

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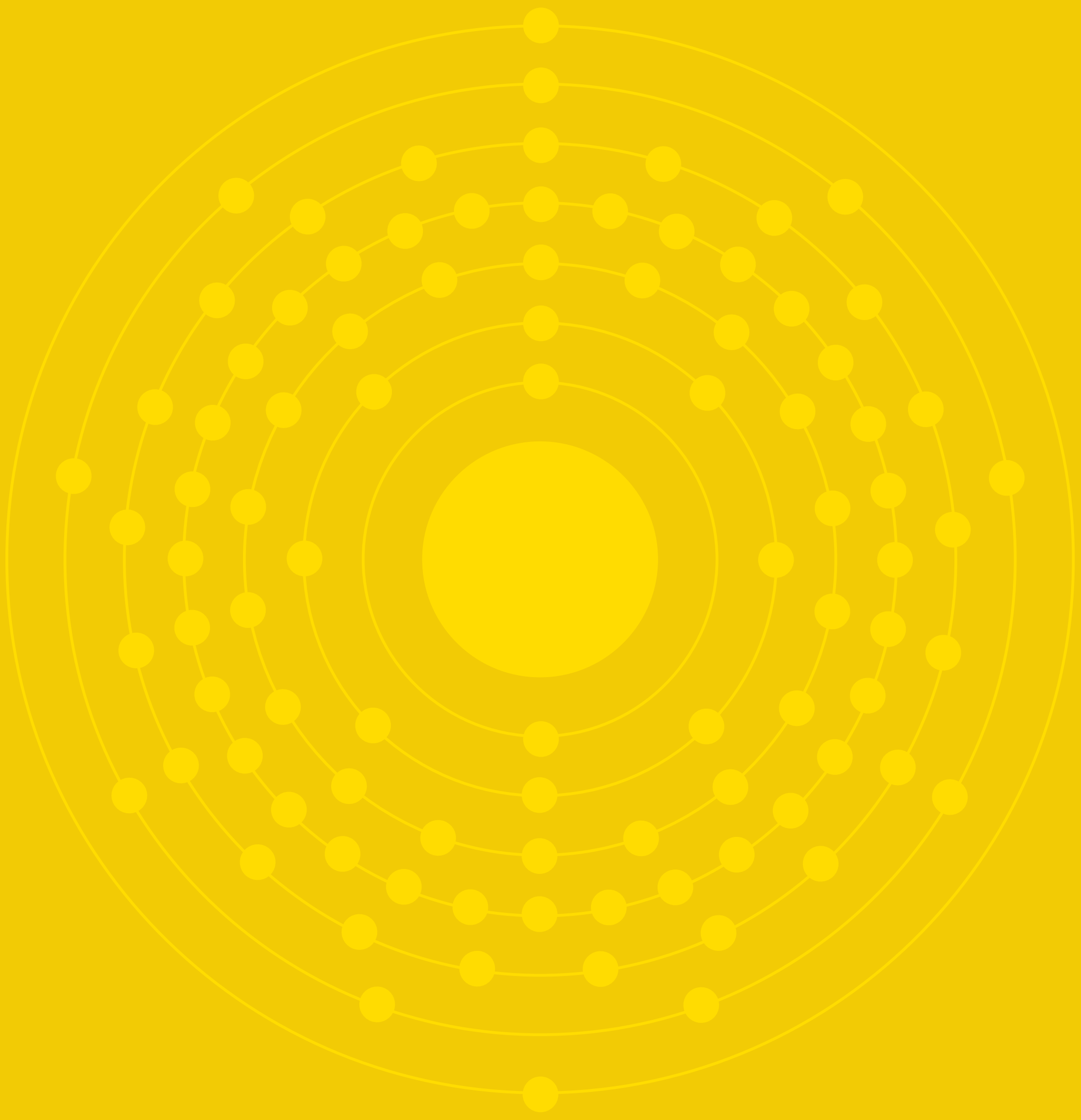
[50] *Tories would ease foreign ownership restrictions: Harper.* CBC News, September 12, 2008.

[51] *Compete to Win.* Competition Policy Review Panel, Final Report, June 2008. Page 45.

6. Work with the Federal Government to ensure the recommendations of the Competition Policy Review Panel are implemented.

7. Work with industry to prioritize and facilitate the development of key infrastructure to create an environment favourable to new mine development.



Chapter 3: Upgrading

Key findings

l. Anticipated growth in global demand for **conversion** will likely be met by expansions to existing facilities, most notably in the United States and France, with additional potential capacity planned in Kazakhstan.

m. The projected supply and demand balance in the **enrichment** sector indicates the need for additional capacity by 2020.

n. Entering the **enrichment** sector would present significant challenges for Saskatchewan:

   - A new facility in Saskatchewan would require significant capital expenditure but would compete against lower-cost and more flexible expansions of existing facilities.
   - Canada would need the consent of the Nuclear Suppliers Group to obtain a transfer of enrichment technology.

o. Over a longer time horizon, Saskatchewan may have an opportunity to enter the **enrichment** sector by partnering with a developer of the emerging laser enrichment technology and then, should the technology prove successful, setting up an early commercial-scale project in the Province.

p. Anticipated growth in global demand for **fuel fabrication** will likely be met by increasing utilization of existing plants and potential capacity addition in countries aggressive about nuclear power development.

High-level overview

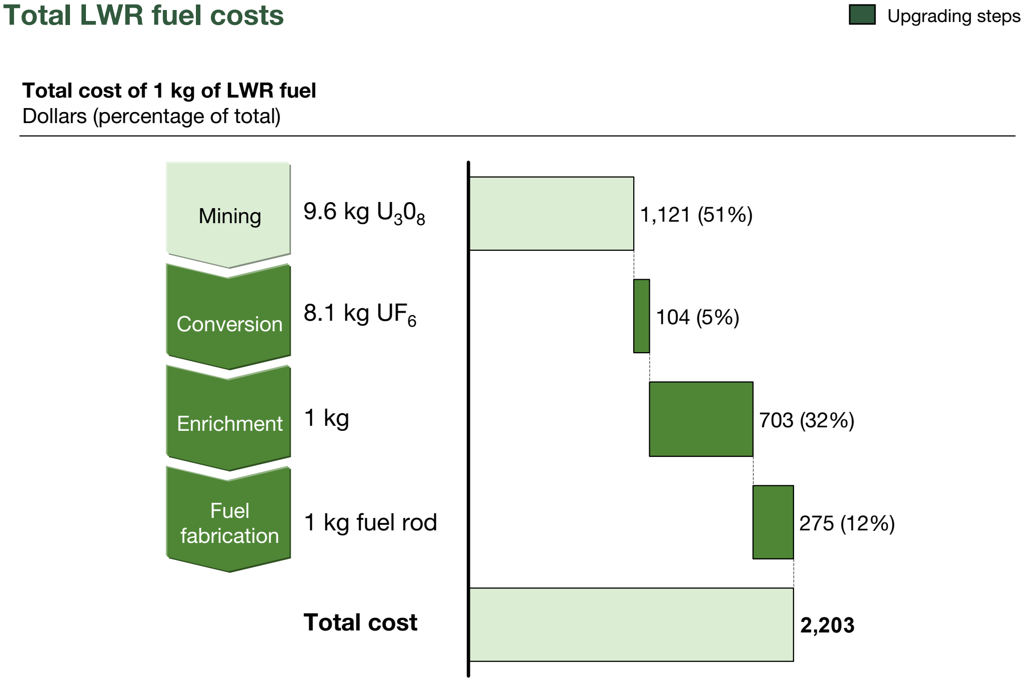
Three main steps are required to turn natural uranium, in the form of yellowcake (U_3O_8), into a useable energy source for nuclear power generation:

- **Conversion:** Transforms natural uranium (U_3O_8) into uranium oxide (UO_2) and then into a gas (UF_6).
- **Enrichment:** Increases the U-235 content from a natural level (approximately 0.7 percent) to a reactor-grade level (3 to 5 percent) through diffusion or centrifugal separation. This step is not required for CANDU reactors.
- **Fuel fabrication:** Construct fuel bundles for use in reactors by pressing and baking powdered fuel into pellets and encasing the pellets in fuel tubes that are then assembled together into bundles.

The total value added at each of the stages of upgrading varies significantly. Enrichment accounts for approximately 32 percent of total LWR fuel costs, almost double that of fuel fabrication (12 percent) and conversion (5 percent) combined (Exhibit 3 -1).

EXHIBIT 3-1

Total LWR fuel costs



Note: Based on costs of $116.8/kg for uranium ore, $12.83/kg UF_6 conversion, $153.73/SWU enrichment costs (4.576 SWU/kg @ 0.3% tails assay), $275/kg fuel rod fabrication, $600/kg spent fuel; all costs YTD average as of October, 2008
Source: World Nuclear Association; WISE

I. Anticipated growth in global demand for **conversion** will likely be met by expansions to existing facilities, most notably in the United States and France, with additional potential capacity planned in Kazakhstan

Today, five major conversion facilities worldwide process a combined total of more than 65,000 tonnes of uranium (tU) annually.[52] The main operators of the largest plants, Comurhex (AREVA), Cameco, Rosatom, and ConverDyn, each run facilities with capacities of over 10,000 tU per year (Exhibit 3 - 2).

With existing producers benefiting from economies of scale, and with competition limited to a few operators in the market, the conversion landscape has remained unchanged for a number of years. There have been no new entrants and no greenfield (new facility construction) capacity has been built since Cameco completed the construction of its Port Hope conversion facility in 1984 to replace the previous plant on that site.[53]

Looking forward, current producers have the capacity to meet anticipated future demands either by upgrading or by expanding existing facility capacity. Specifically, two main plants are likely to meet the changes to market demand:

- **Comurhex II:** a new conversion facility being built by AREVA.[54] This plant will replace conversion facilities at Malvési and Pierrelatte. Comurhex II will reach production of 15,000 tU per year by 2012 and has the capacity for up to 21,000 tU per year.

- **Metropolis:** an expansion of the ConverDyn facility in the United States.[55] This was recently completed and produc-

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[52] *The Global Nuclear Fuel Market*. WNA, 2007. Page 137.

[53] *Country Nuclear Profiles: 2005*. IAEA. Page 17.

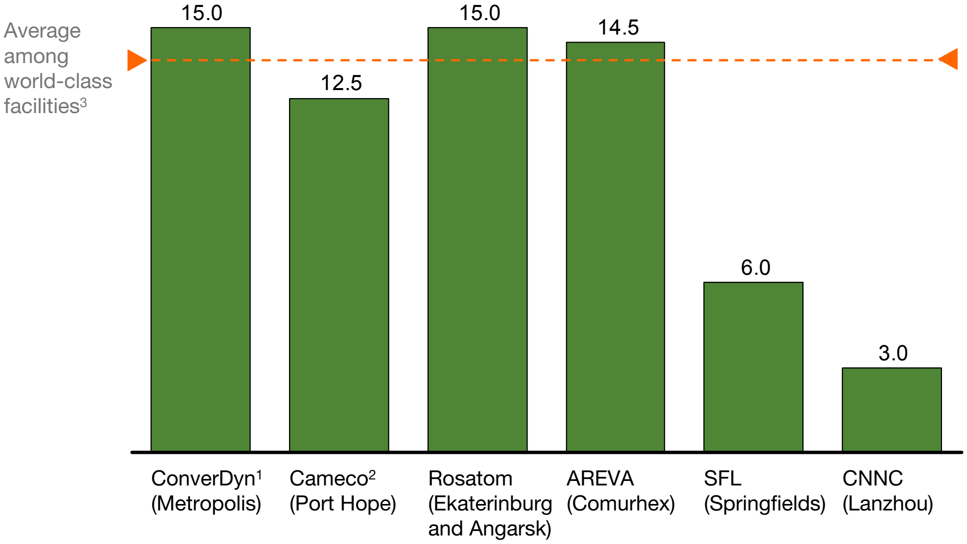
[54] *Euratom 2007 Annual Report*. Page 13.

[55] WNA, 2007. Page 139.

EXHIBIT 3-2

Current global conversion capacity by operator

Thousands tU per year



1 Future operating capacity can be increased to 23,000 tU per year
2 Port Hope capacity is UF_6: 12.5 million kilograms uranium and UO_2: 2.8 million kilograms uranium
3 Average of Metropolis, Port Hope, and Comurhex facilities
Source: *The Global Nuclear Fuel Market, Supply and Demand 2007-2030*, World Nuclear Association; *Country Nuclear Profiles: 2005,* IAEA

tion at this facility can now be expanded to 23,000 tU per year.

Should the nuclear renaissance trigger higher demand for nuclear fuel, additional conversion capacity would likely come online from two sources:

- **Ulba:** Kazatomprom signed an agreement with Cameco in 2006 to build a conversion plant with a capacity of 12,000 tU in Kazakhstan. Construction has not yet started and it is uncertain if or when the project will go ahead.
- **Ekaterinburg and Angarsk:** Russia, through its State-controlled nuclear operator Rosatom, has the potential to add conversion capacity to its two main facilities.[56]

The supply of UF_6 is expected to meet or exceed demand for the foreseeable future. As shown in Exhibit 3 - 3, the existing and projected supply should be enough to meet demand if the predicted nuclear renaissance occurs.

This oversupply is reflected in conversion prices. Prices have been well below the breakeven point of a greenfield conversion facility for nearly 15 years (Exhibit 3 - 4). Based on estimated capital costs of approximately $1 billion and operating costs of approximately $75 million per year, a long-term price for conversion of $13 to $17 per kilogram would be required to justify investment.[57] North American spot prices have never surpassed $13 per kilogram and are currently below $10 per kilogram.[58]

Saskatchewan's current uranium production capabilities do not give it an ability to disrupt the supply curve and enter as a low-cost

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[56] WNA, 2007. Page 139.

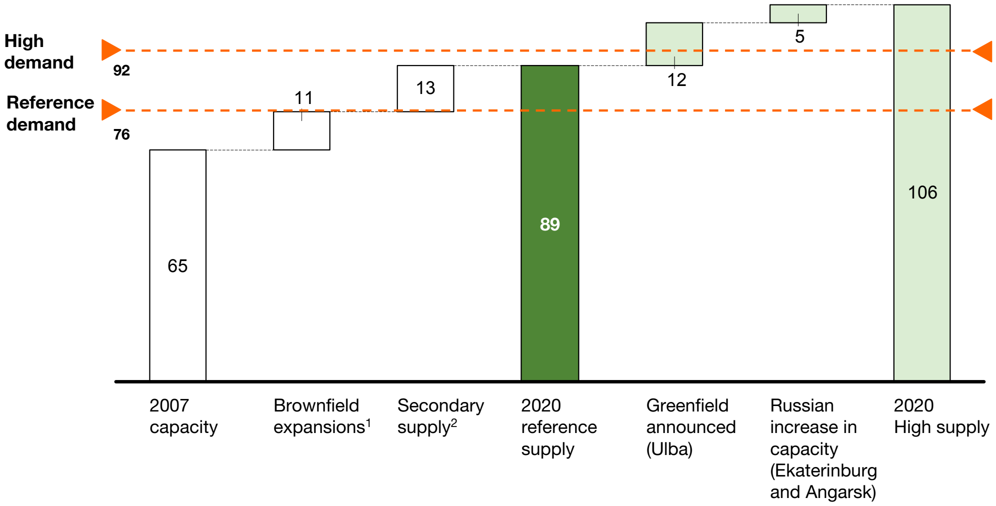
[57] Due to limited publicly available information on conversion costs, capital costs of €610 million were based on AREVA's press release from May 21, 2007. Operating costs were estimated using Cameco's *2005 Annual Report* and ERI consulting estimates from 2007.

[58] UxC, March 2009.

EXHIBIT 3-3

Conversion supply and demand forecasts

Thousands tU per year



1 Includes AREVA's Comurhex II and ConverDyn's Metropolis potential expansions to meet production capacity of facilities
2 Includes inventory, highly enriched uranium (HEU)
Source: *Euratom 2007 Annual Report.* World Nuclear Association, 2007

producer. Synergies with mining are limited: transportation costs are insignificant relative to total nuclear fuel costs; the regulatory requirements for transporting UF_6 are more stringent than those for yellowcake; and few operational efficiencies can be gained across mining, milling, and conversion.[59] [60]

With supply and demand expected to be balanced under most scenarios and with no clear competitive advantage, there is unlikely to be an opportunity in the conversion market for Saskatchewan for at least 5 to 10 years.

m. The projected supply and demand balance in the **enrichment** sector indicates the need for additional capacity by 2020

In contrast to conversion, the uranium enrichment market is undergoing significant transition. In the next 10 years, capacity is expected to grow from 56 million to 65 million SWUs (see sidebar). A total of 30 million SWUs of new capacity will be brought online in this timeframe – 22 million of which will be replacement capacity (Exhibit 3 - 5).[61]

These changes are largely driven by lower operating costs of a centrifuge plant versus gas diffusion (Exhibit 3 - 6).[62] A centrifuge offers 98 percent electricity savings over gas diffusion. This significantly lowers electricity costs for centrifuge enrichment, more than

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[59] Estimated synergies of approximately $3 million are insignificant relative to other costs for a combined facility (in excess of $250 million): transportation costs assumed to be $0.09 per kilometre per kilogram for shipping U_3O_8 from a milling station to the conversion facility. Labour is the largest component of operating costs for both mining and conversion (35 percent and 40 percent, respectively), and it is unlikely to be a source of synergies given that mining and conversion activities are separate.

[60] Interviews with AREVA and Cameco, February 2009.

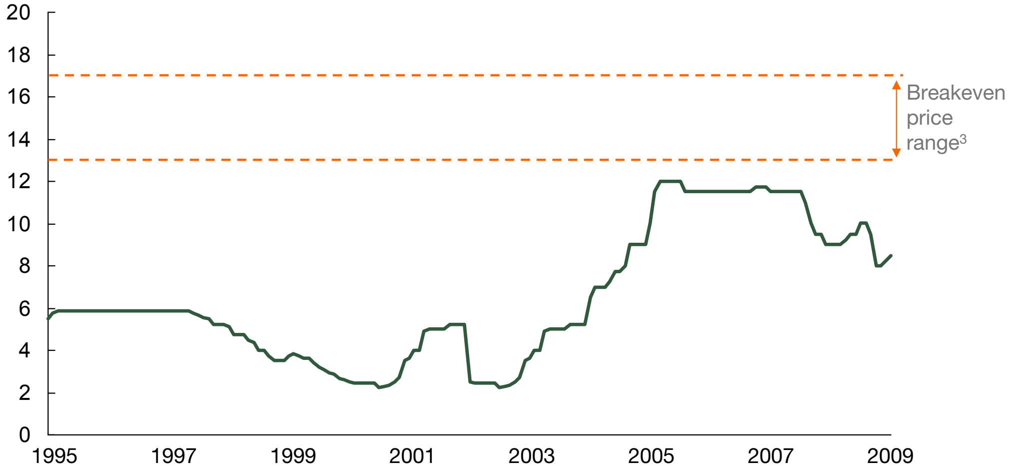
[61] WNA, 2007. Page 143.

[62] Rothwell, Geoffrey, and Chaim Braun. "The cost structure of international enrichment service supply." *Science & Global Security*, 2008. Page 19.

EXHIBIT 3-4

Historical UF_6 prices[1]

US $ per kg[2]



1 Conversion to UF_6 sold as a **service** to utilities that provide U_3O_8 (purchased via spot market or long-term contracts)
2 Not adjusted for inflation; data for years 2007 to 2009 estimated
3 Based on sensitivity analysis of capital costs ($800 million to $1.6 billion), operating costs ($4 to $8/kg), cost of capital (6-8%), and life of facility (20-60 years)

Source: AREVA; Energy Resources International; UxC

offsetting the labour cost advantage of gas diffusion.

This step-change in technology has resulted in a number of investments in greenfield centrifuge facilities. Three projects are either under construction or planned and are likely to come online between now and 2015:

- **GB II:** AREVA centrifuge facility that started construction in 2006. The plant will use Urenco technology, which AREVA acquired as a result of a joint venture with Urenco. It is expected to reach full capacity of 7.5 million SWUs by 2016 and will replace gaseous diffusion capacity of approximately 11 million SWUs. Capacity can be extended to 11 million SWUs.[63]
- **Eagle Rock:** AREVA's planned 3 million SWUs centrifuge facility in Idaho. It is projected for initial production in 2013 and will likely reach targeted production in 2016.[64]
- **The National Enrichment Facility:** Louisiana Energy Services (LES), a Urenco facility being built in New Mexico. Company press releases suggest nominal capacity will begin in 2009 (with saleable SWUs in 2010); the facility will have a total capacity of 5.9 million SWUs by 2016.[65]

What is a SWU?

SWU stands for Separative Work Unit. It is a measure of the amount of work applied to enrich uranium (i.e., to increase the concentration of U-235 in the uranium).

It is a function of the amount of uranium processed, the composition of the starting material, and the degree of enrichment desired.

About 100,000 to 120,000 SWUs are required to support a typical 1,000 MW light water reactor.

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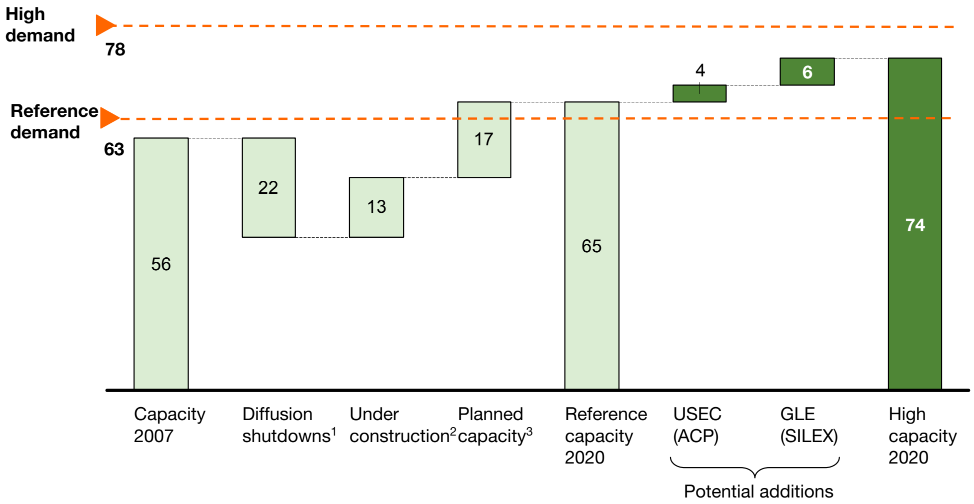
[63] WNA, 2007. Page 143.
[64] WNA, 2007. Page 144.
[65] WNA, 2007. Page 144.

EXHIBIT 3-5

Enrichment supply and demand forecasts

Millions of SWU per year



1 GB facility 2010-2013 approximate shutdown of 10.8 M SWUs, USEC Paducah GDP approximate shutdown May 2012, 11.3 M SWUs
2 Georges Besse II ground breaking 08/06: Phase 1 operational 2013, 4.0 M SWUs/year; Phase 2 completion by 2016, total capacity 7.5 M SWUs/year; LES NEF ground breaking 07/06, initial capacity of 3.0 M SWUs/yr by 2013, 5.9 M SWUs by 2016
3 Eagle Rock site selection decision 05/08, construction finished 2019 with 3.3 M SWUs/year capacity; USEC ACP construction 3.8 M SWUs/yr by 2012; GB II licensed to increase capacity up to 11M SWUs/year; Russian enrichment facility upgrade (Gen 5) potential +8 M SWUs

Source: *The Global Nuclear Fuel Market, 2007*. World Nuclear Association; *Urenco Annual Report*, 2007; *Advanced Fuel Cycle Cost Basis,* INL; DoE

In addition, several facility expansions are planned:

- **Urenco:** by 2012, the firm intends to increase its total production capacity at three European sites to about 15 million SWUs, an increase of about 30 percent over the current SWUs capacity.[66]

- **Rosatom:** expected to replace Generation 5 centrifuge machines with Generation 7 machines, which could increase capacity by 25 percent by 2010.

Longer-term projects that are still in development but are likely to come online between now and 2020 include:

- **American Centrifuge Program (ACP):** USEC's replacement facility for the current Paducah gas diffusion plant. The ACP centrifuges represent an upgrade from other centrifuges and could increase SWUs output per machine eight-fold.[67] USEC aims to have a commercial plant in operation by 2012, with a total capacity of 3.8 million SWUs per year. A number of key milestones remain for USEC; financing issues may delay construction; and, in addition, the ACP technology remains unproven on a commercial scale.[68]

- **Global Laser Enrichment:** the enrichment market entry by GE-Hitachi (GEH) and Cameco with SILEX, a technology originally developed in Australia that uses laser excitation to separate uranium isotopes. Uncertainties still exist over how long it will take GLE to prove SILEX on a commercial scale, but GLE is aiming to be operational by as early as 2012.[69]

In addition to these enrichment capacity additions, a significant development in the second-

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[66] WNA, 2007. Page 145.

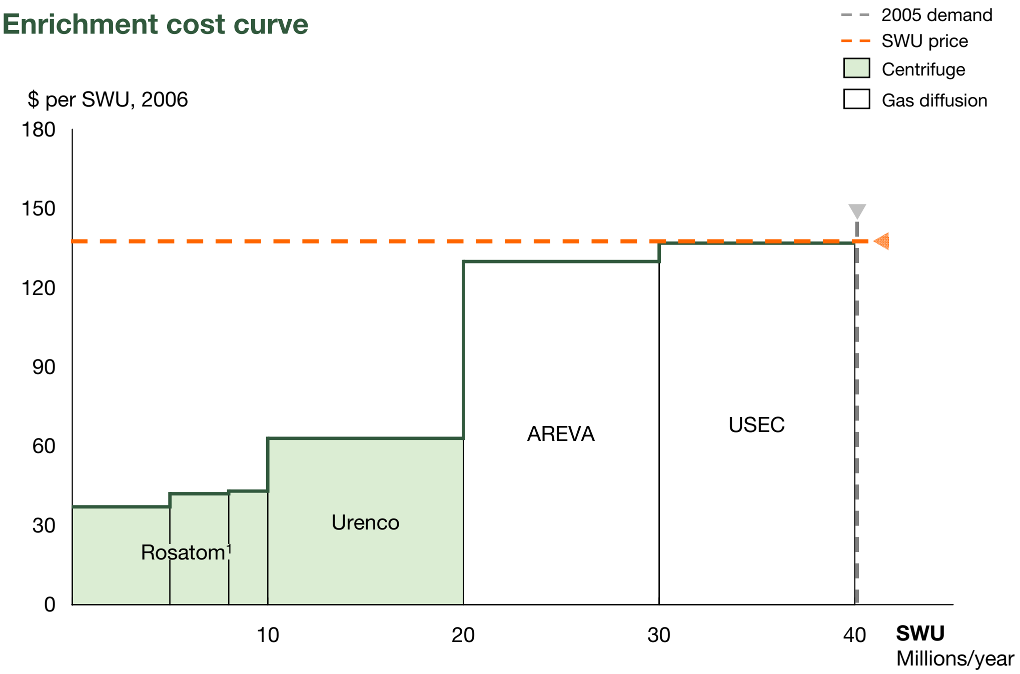
[67] Expert interviews with UxC consultant Ruthanne G. Neely, February 2009.

[68] USEC company press release, February 5, 2009.

[69] *Euratom 2007 Annual Report*. Page 14.

EXHIBIT 3-6

Enrichment cost curve



1 Assume that Russian capacity from the Novouralsk facility is not competing on the international market because of domestic commitments and blending agreements

Source: Rothwell, Geoffrey, and Chaim Braun, *The Cost Structure of International Enrichment Service Supply,* 2008

ary supply of enriched uranium is expected. By 2013, the HEU agreement between Russia and the United States will expire, which will likely increase commercial SWU demand by approximately 3 million.[70]

Almost all of the new capacity now being built will replace diffusion plants being shut down. Given the uncertainty and incremental capacity additions (ACP and GLE), there is likely to be a need for additional enrichment capacity, particularly in the nuclear renaissance scenario.

n. Entering the **enrichment** sector would present significant challenges for Saskatchewan

With a minimum scale requirement of approximately 3 million SWUs, building a new greenfield centrifuge enrichment plant in Saskatchewan would be expected to require a capital investment of approximately $3 billion. This facility would need to compete against lower-cost centrifuge brownfield expansion opportunities, which would take advantage of the modular design of centrifuges and benefit from avoiding the lengthy site selection or licensing processes of a new facility.[71]

To build an enrichment facility, Canada would also need to receive approval from the Nuclear Suppliers Group (NSG). The NSG is a group of 45 supplier countries established to limit the proliferation of nuclear weapons through the implementation of nuclear exports

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[70] The HEU deal was signed between the United States and Russia in 1993; the United States agreed to purchase 500 tons of Russian HEU. The HEU comes from the dismantling of nuclear warheads. It is then converted and diluted into LEU with LEU shipped to USEC in the United States. USEC pays Russia for the SWU component of the LEU and sells the enrichment services direct to enrichment customers.

[71] Rothwell, Geoffrey, and Chaim Braun. "The cost structure of international enrichment service supply." *Science & Global Securities*, 2008. Page 17.

controls (see sidebar).[72] Consensus as to how enrichment technology can be transferred to a non-enriching state has not been reached by the NSG, but it is likely that it would only occur in a black box form (i.e., no access to or knowledge about the enrichment technology) and would be limited to NPT states and states agreeing to the safeguards imposed by the International Atomic Energy Agency (IAEA).

The Non-Proliferation Treaty and the Nuclear Suppliers Group

- The Non-Proliferation Treaty (NPT) opened for signature on July 1, 1968, and was designed to limit the spread of nuclear weapons, and "to promote co-operation in the peaceful uses of nuclear energy."[1] There are 189 signatories, including Canada and the United States, with only 4 sovereign states not signatories (India, Israel, Pakistan, and North Korea). Under Article IV of the NPT, all countries are entitled to "participate in the fullest possible exchange of equipment, materials and scientific and technological information for the peaceful uses of nuclear energy."[2]
- The Nuclear Suppliers Group (NSG) is a group of nuclear supplier countries with the goal of preventing proliferation of nuclear weapons through export controls. The guidelines are "implemented by each Participating Government in accordance with its national laws and practices."[3] Decisions on export applications are taken at the national level in accordance with national export licensing requirements.[4] The NSG initially had 7 members (including Canada) and there are now 45 member countries.

1,2 United Nations.

3,4 Nuclear Suppliers Group.

o. Over a longer time horizon, Saskatchewan may have an opportunity to enter the **enrichment** sector by partnering with a developer of the emerging laser enrichment technology and then, should the technology prove successful, setting up an early commercial-scale project in the Province

GE-Hitachi (GEH) and Cameco are part owners of the new Separation of Isotopes by Laser Excitation (SILEX) technology and aim to expand the Global Laser Enrichment (GLE) production plant to achieve capacity of 3.5 to 6.0 million SWUs by as early as 2016. GLE intends to make decisions on the construction of the facility as early as this year and has already submitted the first part of its licence application for the enrichment plant in Wilmington to the US NRC.

If and when this new enrichment technology comes to the market, it will likely cause another dramatic shift in enrichment production because of the very attractive economics of SILEX. This could provide Saskatchewan with an opportunity to enter the industry as GLE looks to expand the penetration of SILEX beyond the initial facility at Wilmington. A new SILEX facility would leapfrog current centrifuge technology.[73] This competitive advantage would likely last for a number of years given the large amount of capital that has already been invested to build new centrifuge plants in the United States.

p. Anticipated growth in global demand for **fuel fabrication** will likely be met by increasing utilization of existing plants and potential capacity addition in countries aggressive about nuclear power development

Two types of fuel fabrication plants are currently in operation: one manufactures fuel for use in a Light Water Reactor (LWR) and the other for use in a Pressurized Heavy Water Reactor (PHWR). The processes at both plants are relatively similar. However, LWR uses

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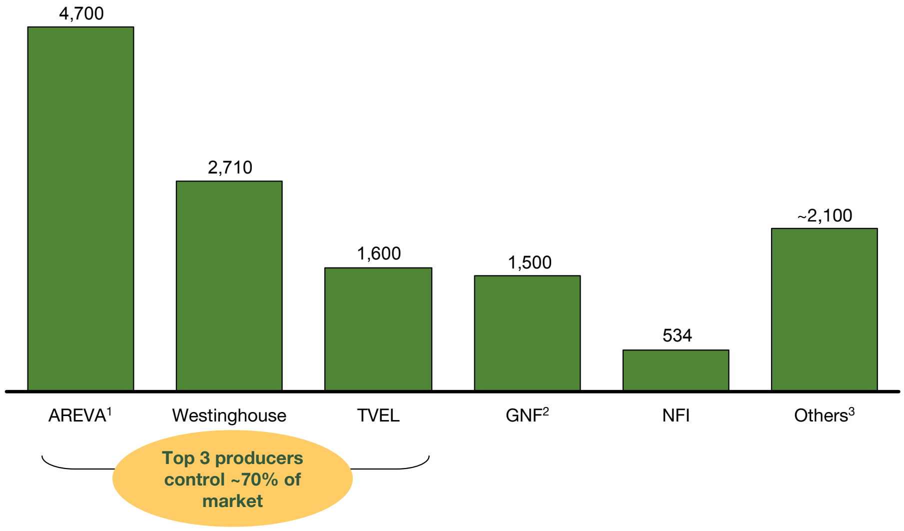
[72] Nuclear Suppliers Group website, February 2009

[73] Reed, J. Jensen, P. Judd, O'Dean, and J. Man Sullivan. "Separating isotopes with lasers." *Los Alamos Science*. Page 7.

EXHIBIT 3-7

LWR fuel fabrication capacity of major producers

Tonnes of heavy metal (tHM) per year



1 Includes announced 1,200 tHM Kazakhstan facility
2 Global Nuclear Fuel is a partnership between GE, Hitachi, and Toshiba
3 Includes CNNC, NFI, KNFC, ENUSA

Source: *World Nuclear Organization 2007 Annual Report*, Page 148; *Environmental Aspects Based on Operational Performance of Nuclear Fuel Fabrication Facilities*. IAEA, 2002, Page 4.

longer, thinner fuel bundles based on enriched uranium, while PHWR bundles are shorter and based on natural UO_2. To fully understand the dynamics of the fuel fabrication market, it is important to separate LWR and PHWR supply and demand.

LWR fuel fabrication is by far the bigger market, with approximately 370 operating reactors of 1,000 MW each requiring approximately 25 tonnes of fuel per year.[74] Despite being a large market, the LWR fuel fabricators have recently consolidated significantly and only three main players remain: AREVA, Westinghouse, and GNF (Exhibit 3 - 7). The most significant of these mergers took place between 1998 and 2001, when the price for fuel fabrication services collapsed (Exhibit 3 - 8).

In spite of these mergers, significant overcapacity of approximately 6,000 tonnes of heavy metal (tHM) per year of LWR fuel exists. With one new fuel fabrication plant announced in Kazakhstan, even under an optimistic nuclear renaissance scenario, there is unlikely to be a need for new LWR fuel fabrication capacity between now and 2020.[75] This is reflected in fuel fabrication prices, which have been steadily declining over the past 15 years (Exhibit 3 - 8).

Overcapacity also exists in the PHWR market. Each CANDU reactor requires approximately 100 tonnes of fuel per year, with Canada's fleet of reactors consuming a total of approximately 1,700 tonnes of fuel per year.[76] There are currently two fuel fabrication facilities in Canada with a combined capacity of 2,700 tHM per year. The 1,000 tonnes of excess capacity would be sufficient to serve an additional 16 Canadian CANDU reactors. Given this overcapacity, no additional PHWR fuel fabrication facilities would be required in the foreseeable future. (Exhibit 3 - 9).

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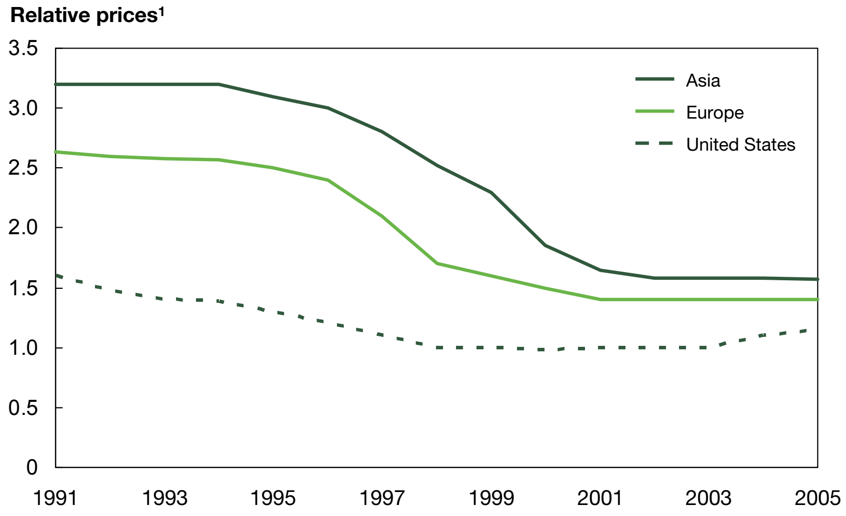
[74] Nuclear Power Reactors Information Papers. WNA.

[75] WNA, 2007. Page 148.

[76] Charpin, Jean-Michel, Benjamin Dessus, and René Pellat. *Economic Forecast Study of the Nuclear Power Option for Atomic Energy.* Report to the Prime Minister, 2001.

EXHIBIT 3-8

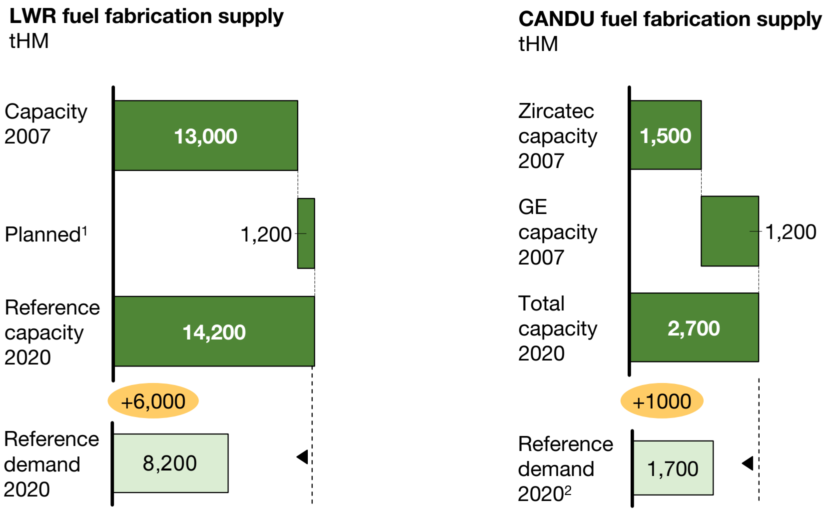
LWR fuel fabrication relative historic prices



1 Estimates
Source: CKA Associates; 2005 World Nuclear Symposium

EXHIBIT 3-9

Fuel fabrication supply and demand forecasts



1 In June 2008 AREVA signed a memorandum of understanding to provide engineering expertise to build a 1,200 tonne/yr fuel fabrication plant as part of the Ulba complex
2 Based on intended, operating, and planned nuclear reactors
3 Assumes that number of CANDU reactors in Canada remains constant
Source: *Country Nuclear Fuel Cycle Profiles*, second edition, IAEA 2005, Page 19; *The Global Nuclear Fuel Market, 2007*, World Nuclear Association, Page 148

Recommendations

The UDP has developed its recommendations, supported by these findings, for the Province to establish a sustainable competitive position in a targeted segment of upgrading.

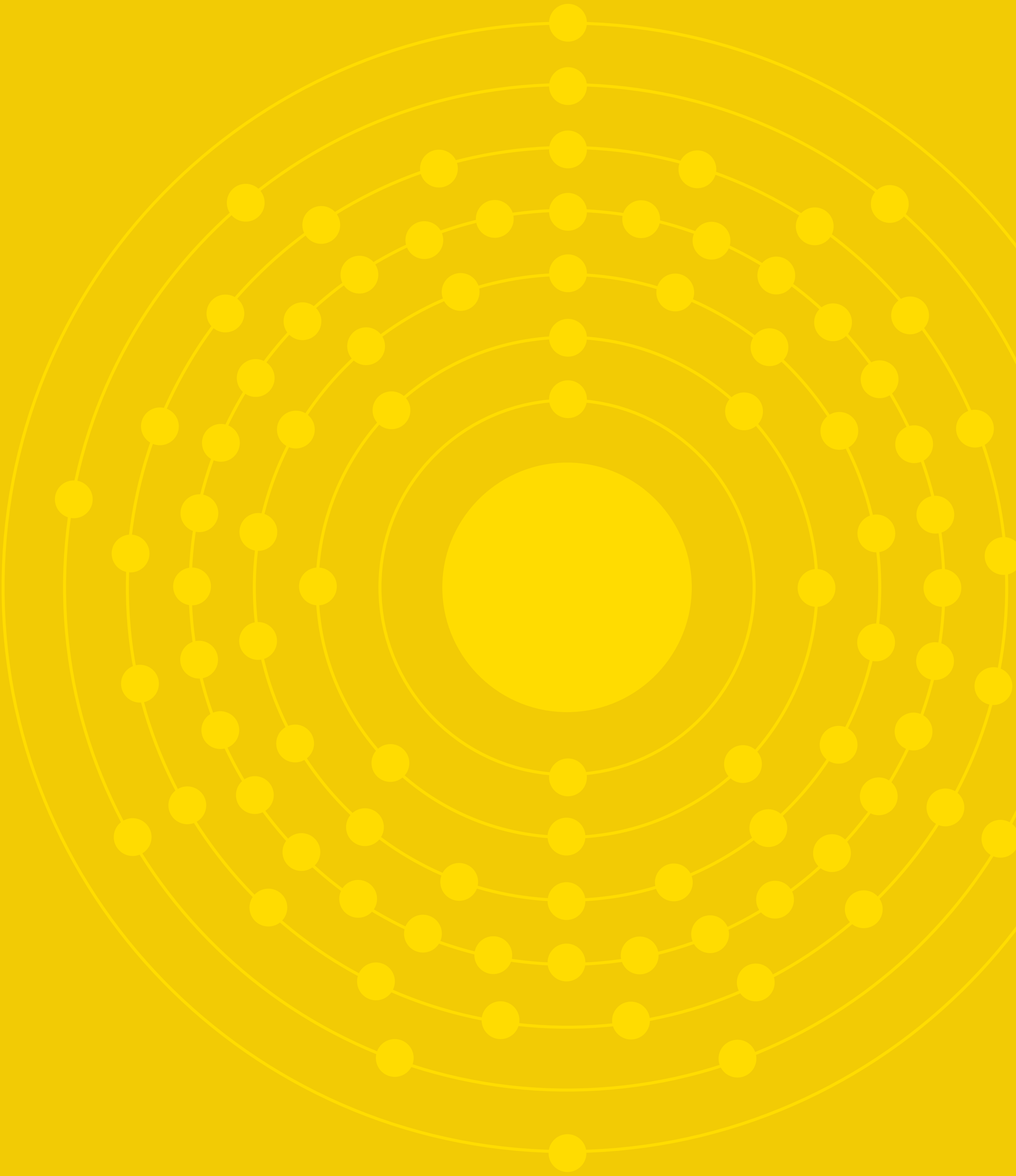
Saskatchewan should:

8. Work with the Federal government to clarify the framework under which an enrichment facility could be established in the Province in accordance with all international non-proliferation agreements and obligations.

9. Target the next generation of enrichment technology (laser isotope separation) and enter into discussions with current technology developers to determine the conditions under which a commercial-scale facility could be attracted to the Province within 10 to 15 years.

10. Not proactively pursue the development of a conversion facility given current market conditions.

11. Not proactively pursue the development of a fuel fabrication facility given current market conditions.



Chapter 4: Power generation

Key findings

q. The growing demand for electricity and the planned decommissioning of existing generation facilities indicates that Saskatchewan will require 1,200 to 1,750 MW of new power generation capacity for its domestic use by 2020, growing to 2,200 to 3,000 MW by 2030.

r. At a regional level, significant potential exists for exports – for example, Alberta could need between 4,000 and 5,000 MW of new power generation by 2020. Saskatchewan is well-positioned to provide low-carbon emission power to fill this looming supply gap.

s. Given consensus estimates of long-term CO_2e (equivalent carbon dioxide) and natural gas pricing, nuclear is a cost-competitive and low-emission power generation option.

t. Initial examination suggests that up to approximately 3,000 MW of nuclear capacity could be constructed to meet Saskatchewan's power needs and capture export opportunities.

u. Given that a nuclear power plant has not been previously built in Saskatchewan, further work needs to be done to understand the social, environmental, and grid feasibility of adding nuclear power in the Province.

v. Capital cost overruns and schedule delays are key risks in any nuclear new build project, and they would need to be carefully mitigated in the project development process. To date, the cumulative risks of nuclear new build have been too large for the private sector to bear alone and governments have played some form of facilitation in the implementation of nuclear power projects in all jurisdictions.

w. Saskatchewan could reduce licensing and first-of-a-kind risks by drawing on the recent experiences of other Canadian provinces that have developed nuclear generation capacity.

x. Transmission infrastructure, reserves, and intertie investments would be required to support larger power generation units on the Saskatchewan grid, as well as to provide the capability to export additional power to Alberta. The detailed nature and cost of this infrastructure has yet to be determined.

y. A new power plant would have a significant impact on Saskatchewan's economy, contributing approximately $12 billion in discounted GDP to the Province over its life ($1.2 billion during construction and $10.6 billion during operation), as well as employing 3,000 people during construction and providing between 400 and 700 direct jobs during operation for every unit built.

High-level overview

Saskatchewan's electricity supply mix predominantly consists of coal, gas, hydro, and wind. Along with neighbouring Alberta, Saskatchewan is among the most coal-dependent provinces in Canada: 45 percent of the Province's installed capacity is generated by coal (Exhibit 4 - 1) – the most CO_2-intensive power source available.[77]

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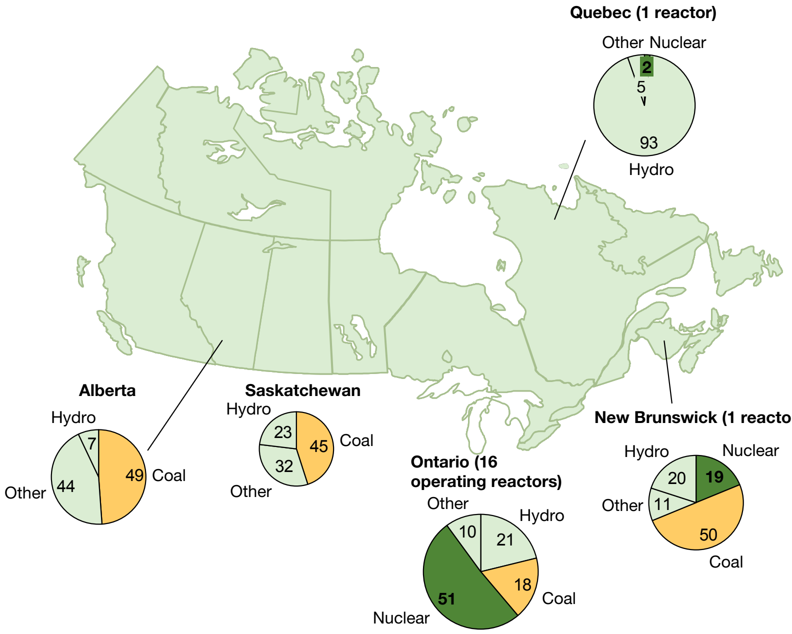
[77] All current and forecasted electricity capacity and demand data for Saskatchewan acquired from SaskPower.

EXHIBIT 4-1

Power generation capacity mix by province

Percent



Source: Statistics Canada Electric Power Capability and Load; SaskPower

In contrast, water-rich provinces like British Columbia, Manitoba, and Québec rely mostly on hydroelectric power.[78] Ontario and New Brunswick have installed bases of nuclear power of 46 percent and 19 percent respectively[79] and both are evaluating further investment in new nuclear capacity.

q. The growing demand for electricity and the planned decommissioning of existing generation facilities indicates that Saskatchewan will require 1,200 to 1,750 MW of new power generation capacity for its domestic use by 2020, growing to 2,200 to 3,000 MW by 2030

Between 2009 and 2020, demand for electricity in Saskatchewan is expected to grow by over 1.5 percent annually, from roughly 2,500 MW of baseload demand to 3,750 MW.[80-81] Additionally, the planned decommissioning of the aging Boundary Dam generation facility could result in an additional 540 MW of supply deficit. This modest growth in demand coupled with the planned decommissioning of existing capacity is expected to result in a baseload supply-demand deficit of approximately 1,500 MW by 2020. This deficit is expected to expand to approximately 2,600 MW by 2030. Ultimately, electricity need will be determined by population and industrial growth, but even under a conservative 1 percent growth scenario, 1,200 MW of additional baseload power will be required by 2020.

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[78] *Electric Power Statistics*. Statistics Canada, 2003. Pages 10, 12, and 16.

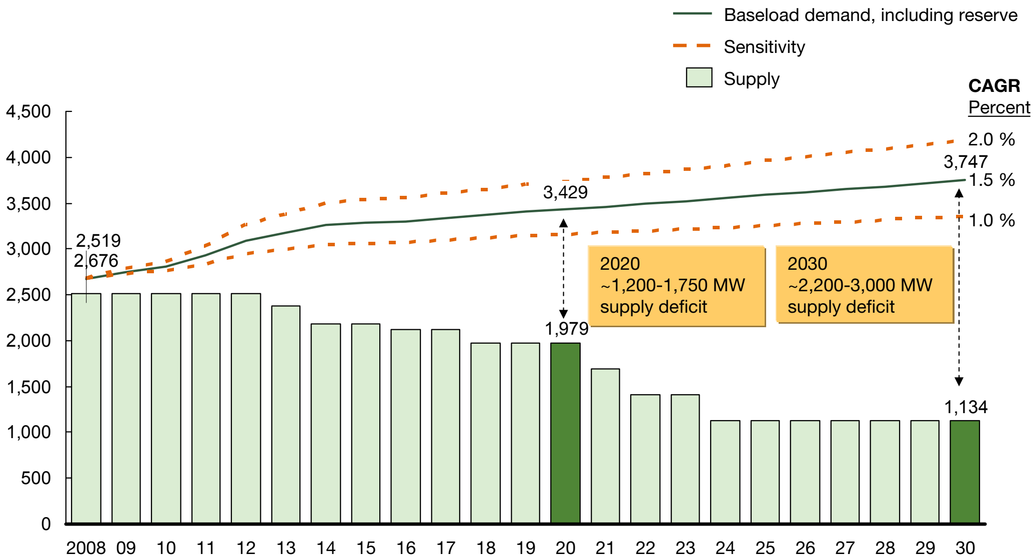
[79] New Brunswick Power and Ontario Ministry of Energy and Infrastructure websites.

[80] Based on 74 percent capacity factor and peak demand growth of 3,227 MW in 2008 to 4,244 MW in 2020.

[81] Baseload demand refers to the minimum level of electricity required by a grid at any one time, whereas peak demand refers to the maximum electricity need occurring in a year. See Exhibit 4-5 for more details.

EXHIBIT 4-2

Saskatchewan 2020-2030 baseload electricity profile
MW



Note: Assumes phased shutdown of Boundary Dam complete by 2016: assumed 74% load factor for baseload; reserve margin based on largest coal unit at Poplar River
Source: SaskPower

r. At a regional level, significant potential exists for exports – for example, Alberta could need between 4,000 and 5,000 MW of new power generation by 2020. Saskatchewan is well-positioned to provide low-carbon emission power to fill this looming supply gap

In addition to serving its domestic power needs, Saskatchewan currently exports some power to neighbours like Alberta, and potential exists to significantly increase this activity. Two unique power market opportunities exist in Alberta: the oil sands of the northeast, and the large economies of the south. As shown in Exhibit 4 - 3, taken together, these opportunities could represent up to 5,000 MW in additional demand.

In the oil sands, power-intense industrial processes like upgrading bitumen or steam assisted gravity drainage (SAGD) could expand the need for electricity by approximately 3,000 MW by 2020.[82] However, much of the energy need in the oil sands is in the form of steam, making cogeneration power stations (that produce both steam and electricity) the most attractive source of power. Over 2,100 MW of cogeneration capacity is already planned,[83] leaving the remaining 940 MW of unmet demand as a potentially viable market for shared power from Saskatchewan. In the longer term, this unmet demand may further increase as a result of emerging, more power-intensive oil sands extraction technologies.

The southern Alberta market is also expected to experience a significant power deficit by 2020, up to 4,000 MW, largely driven by demand growth of approximately 2,000 MW and decommissioning of 4,000 MW of existing coal units. Altogether, the Alberta market

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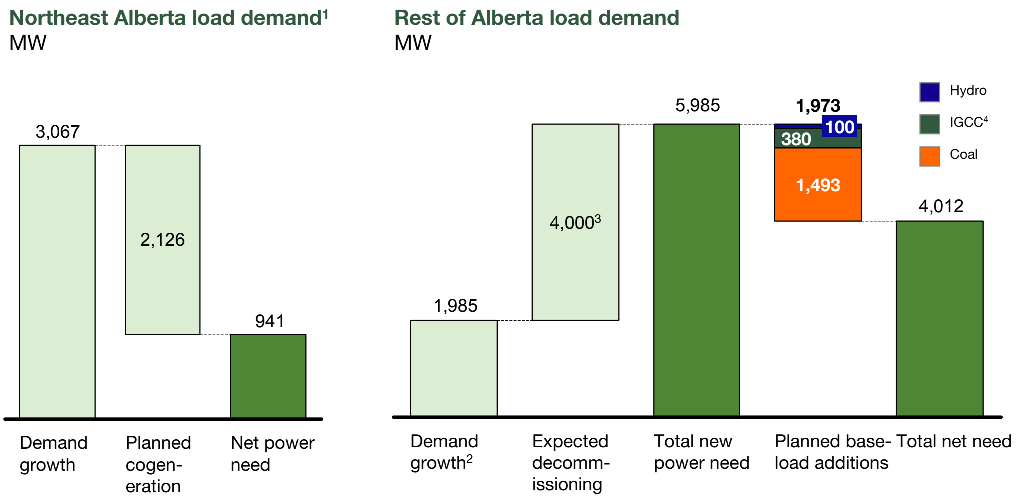
[82] *Future Demand and Energy Outlook*. Alberta Electric System Operator (AESO), 2007. Page 7. AESO assumptions made prior to the economic downturn – long-term estimates assumed unaffected.

[83] *Proposed Generation*. Alberta Ministry of Energy. http://www.energy.alberta.ca/Electricity/682.asp.

EXHIBIT 4-3

Potential 2020 Alberta energy deficit



1 Does not reflect potential changes resulting from recent economic downturn
2 Net of capacity under construction – assumes 2008 81% load factor
3 Golder Associates estimate; based on actual commissioning dates and industry plant life benchmarks
4 Integrated Gasificatiion Combined Cycle

Source: *AESO Future Demand and Energy Outlook* (2007-2027); Canadian Association of Petroleum Producers; Alberta Energy Resources Conservation Board; National Energy Board; Canadian Energy Resource Institute; Alberta Chamber of Commerce; NEB Project Level Estimates

could require up to 5,000 MW of generation capacity.

In Alberta's deregulated power market, nuclear will consistently compete against other power sources, accepting a price that varies with the constantly changing market supply/demand dynamics. The market price for power in a deregulated market is set by the marginal electricity producer, which is typically natural gas. Nuclear's low operating costs will ensure it remains a competitive source once it is built, but the average expected market price of power in Alberta will determine whether a shared power agreement is attractive.

s. Given consensus estimates of long-term CO$_2$e (equivalent carbon dioxide) and natural gas pricing, nuclear is a cost-competitive and low-emission power generation option

Given the need to establish a balanced supply portfolio to effectively meet baseload demand, the nuclear options should be weighed against other power-generation alternatives. Seven major sources of power are available for use in Saskatchewan: nuclear, coal (and coal with potential for carbon capture), gas, hydro, solar, and wind. Not all of these are appropriate as independent baseload solutions. As shown in Exhibit 4 - 4, each comes with its own advantages and challenges.

Wind and solar are renewable energy sources with very low life cycle greenhouse gas emissions resulting from their manufacture and installation. Both options could be used as clean sources of renewable energy for Saskatchewan, but their high cost and low reliability require that they be used in the context of a balanced baseload supply portfolio. For example, without tax incentives, the life cycle cost of solar is estimated at $350 to $400 per MWh[84] – three times the cost of nuclear. Additionally, because the power sources of wind and solar vary with natural conditions, they cannot act as independent sources of baseload power. Consequently, they require sources that can quickly be turned on and off to offset changes in solar or wind output. Exhibit 4 - 5 outlines

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[84] *Levelized Cost of Energy Analysis*. Lazard. 2008. Page 5.

EXHIBIT 4-4

Power generation alternatives

	Nuclear 	**Coal** 	**Gas** 	**Hydro** 	**Solar** 	**Wind** 
Advantages	• Baseload source • High availability • Low cost over life • Very low carbon emissions	• Very low cost without carbon regulation	• Easy maintenance • Low capital cost	• Renewable energy • Mature technology • Usable for baseload and short-term peak	• Renewable energy • Easy maintenance	• Renewable energy • Very low carbon emissions
Disadvantages	• Nuclear waste • Public acceptance • High capital cost • Lack of public support in some jurisdictions due to proliferation and safety concerns	• Expected carbon costs make it economically unattractive • Lower-carbon coal solutions (IGCC and CCS*) are currently 2-3 times more expensive than traditional plants	• Highly variable gas prices • Multiple units required to meet large baseload requirements	• **Limited opportunity for additional large-scale baseload facilities** • Environmental damage • Potential dam failures	• **Not a large-scale baseload solution** – production cannot be controlled • Grid stability • **Very high full costs** • Low load factor in some countries	• **Not a large-scale baseload solution –** production cannot be controlled • High full costs • Low load factor in some countries
Comparison	• **1 nuclear unit** of 1 GW capacity at 90% availability	• **1 coal-fired power plant unit** at 90% availability	• **2-3 gas CCGT** (combined cycle gas turbine)	• **~1 large-scale dam** (e.g., MB Limestone station)	• Not a large-scale baseload **– not comparable**	• Not a large-scale baseload **– not comparable**

* Carbon Capture and Storage

Source: UDI

the key differences between peak and baseload power options.

Hydroelectric power is arguably among the most attractive power generation options when feasible; it is highly economical, uses a renewable resource, and has the potential to store energy to act as both a base and a peak source of power. However, as a result of its attractiveness, many of the economical large-scale sources of hydroelectric power in Saskatchewan have already been captured, limiting the potential for additional large-scale baseload hydro. Of the remaining options – nuclear, coal, and natural gas – several factors make nuclear a competitive power choice for Saskatchewan.

Environment

Nuclear power is a low-carbon generation option,[85] whereas even a newly designed 1,000 MW coal or gas plant will respectively emit 5.4 million and 2.5 million tonnes of CO_2 annually. Using a 1,000 MW nuclear power plant instead of a coal plant has the equivalent effect of removing 700,000 cars from the road.

Research and development

Nuclear power is highly technology intensive and is supported by billions of dollars of R&D spend globally.[86] The continuous need for further innovation could create a significant opportunity for Saskatchewan to expand its role in nuclear research and development and potentially attract second-tier suppliers of the nuclear industry.

Safety

Nuclear power is a safe and well-understood technology. As a result of newer generations of technology, significant improvements to the

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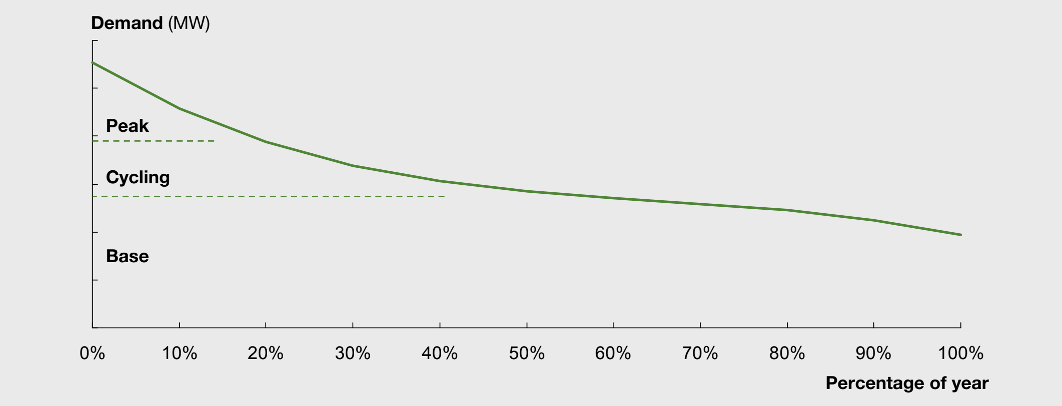
[85] The mining of uranium and construction of nuclear power plants results in CO_2 emissions, but these are low relative to other baseload options (Exhibit 1 - 3).

[86] R&D Statistics Database. International Atomic Energy Association. 2007.

EXHIBIT 4-5

Demand load types



Load type	**Key factors**	**Typically**
Peak	• Low fixed costs • Quick start capability	• Combustion turbines
Cycling	• Lower variable costs relative to peak capacity • Lower fixed costs relative to base capacity • Load following capability (i.e., ability to move quickly between varying levels of demand)	• Oil/gas steam and plants (CCS eventually here as well)
Baseload	• Low variable costs • Reliability	• Coal, nuclear, and hydro plants • CCS

Baseload power

An electricity supply system cannot use baseload power alone. Variations in demand between seasons and within a day require that the supply of power be dynamic. Conventional baseload power sources like nuclear and coal can require days to fully ramp up and their output cannot be changed quickly enough to handle rapid peaks or troughs in demand. Even what is conventionally thought of as baseload demand can vary significantly with the seasons, making "cycling" sources like gas, with lower fixed costs relative to baseload, more economical.

inherent and passive safety mechanisms[87] of reactors have resulted in a greatly improved safety record, as indicated by a 71 percent reduction in the incident rate of plants since 1983. (See Appendix A for an in-depth discussion of the safety of nuclear energy.)

On a pure cost basis and with realistic assumptions on future carbon pricing, nuclear power is a competitive baseload power alternative. Exhibit 4 - 6 depicts the relative competitiveness of the three alternatives under varying CO_2 and natural gas prices. The competitive analysis suggests that above a carbon price of roughly $30 and a natural gas price greater

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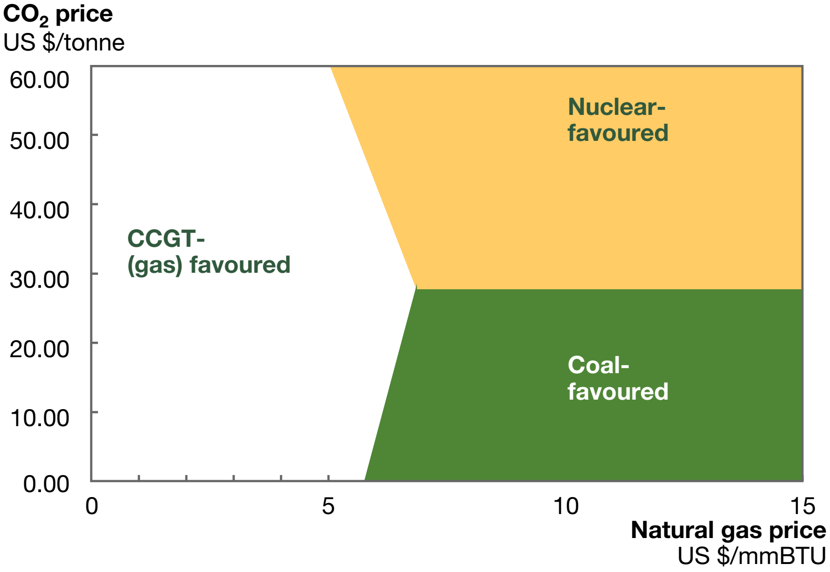
[87] Traditional reactor safety systems are active in the sense that they involve electrical or mechanical operation on command. Some engineered systems operate passively, e.g., pressure relief valves. Both require parallel redundant systems. Inherent or full passive safety depends only on physical phenomena such as convection, gravity, or resistance to high temperatures, not on the functioning of engineered components. *Small Nuclear Power Reactors*. World Nuclear Association, 2009. http://www.world-nuclear.org/info/inf33.html.

EXHIBIT 4-6

Relative cost competitiveness of power generation options



Note: Based on $3,850/kW, $2,500/kW, and $1,300/kW overnight cost for nuclear, coal, and natural gas CCGT (combined cycle gas turbine) respectively

Source: McKinsey Electric Power and Natural Gas Practice levelized unit electricity cost model

than roughly $6.00/mmBTU,[88] nuclear emerges as the most competitive option.

Current estimates suggest that carbon prices will drop to the $18 to $50 range and natural gas prices to the $8 to $15 range. (See sidebar)

Clean coal is another low-carbon baseload option that has received considerable political attention recently. However, clean coal technology is still in its early stages of development, and its economic viability still needs to be demonstrated. There are two types of clean coal technologies: integrated gasification combined cycle (IGCC) and IGCC with carbon capture and storage. An IGCC plant gasifies coal into synthetic gas, which is then used to power a combined cycle gas turbine – similar technology to that of a gas-fired power plant. IGCC emits less carbon dioxide than a conventional coal-fired plant but does not fully eliminate emissions. Carbon capture and storage technology is required to eliminate

Natural gas and carbon price estimates

Natural gas typically trades between the prices of residual fuel oil and distillates. Residual fuel oil and distillates are refined petroleum products. Residual fuel oil is a heavier and lower-value hydrocarbon, whereas distillates are lighter, higher-value products (e.g., gasoline and naphtha). At high natural gas prices, gas-powered combined cycle gas turbine (CCGT) plants can displace natural gas with distillate. At low natural gas prices, residual-fuel-oil-fired steam units switch to natural gas, raising the price of natural gas. Supply-demand expectations place this long-term price band between $8 and $15 per mmBTU.

Carbon price forecasts are typically built on consensus expectations under different “what if” scenarios of global carbon cap-and-trade systems. Even under conservative assumptions, where developed countries are reluctant to impose stringent CO_2 targets without similar efforts from the developing world, a carbon price of roughly $18 is expected. Under more optimistic assumptions of a “global deal,” where national representatives agree on a global carbon-abatement framework, a $40 to $50 per tCO_2 carbon price is possible.

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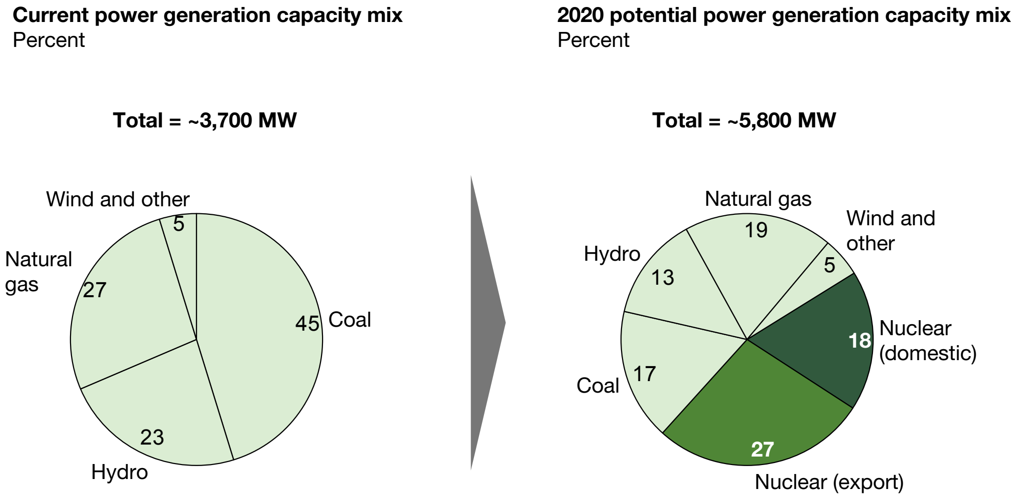
[88] Million British Thermal Units – industry standard unit of measure for natural gas.

EXHIBIT 4-7

Saskatchewan power generation capacity mix

3,000 MW EXAMPLE



Source: Saskpower

CO_2 emissions at an IGCC facility. Currently, capital costs for an IGCC plant are almost 50 percent higher than conventional coal plants,[89] while capital costs for a coal plant with carbon capture and storage technology are estimated to be 60 to 80 percent higher than a typical plant.[90] Advancements are being made in clean coal technology, but nuclear is likely to remain the more economical option for the foreseeable future.

t. Initial examination suggests that up to approximately 3,000 MW of nuclear capacity could be constructed to meet Saskatchewan's power needs and capture export opportunities

Subject to a number of key potential constraints, up to 3,000 MW of nuclear power generation capacity could reasonably be constructed in Saskatchewan. These potential constraints follow.

Nuclear's share of supply

With approximately 3,000 MW of added capacity in place, for example, nuclear power would represent only 45 percent of Saskatchewan's full production capacity, with a little under half available for domestic use and the remaining for export. This nuclear market share is in line with that of other nuclear jurisdictions.

By 2020, at most 1,800 MW of capacity would need to be exported to justify building 3,000 MW of nuclear capacity, with less export required as domestic demand grows beyond 2020. Negotiated electricity trade agreements would be necessary but, given 1,800 MW would represent only 12 percent of Alberta's

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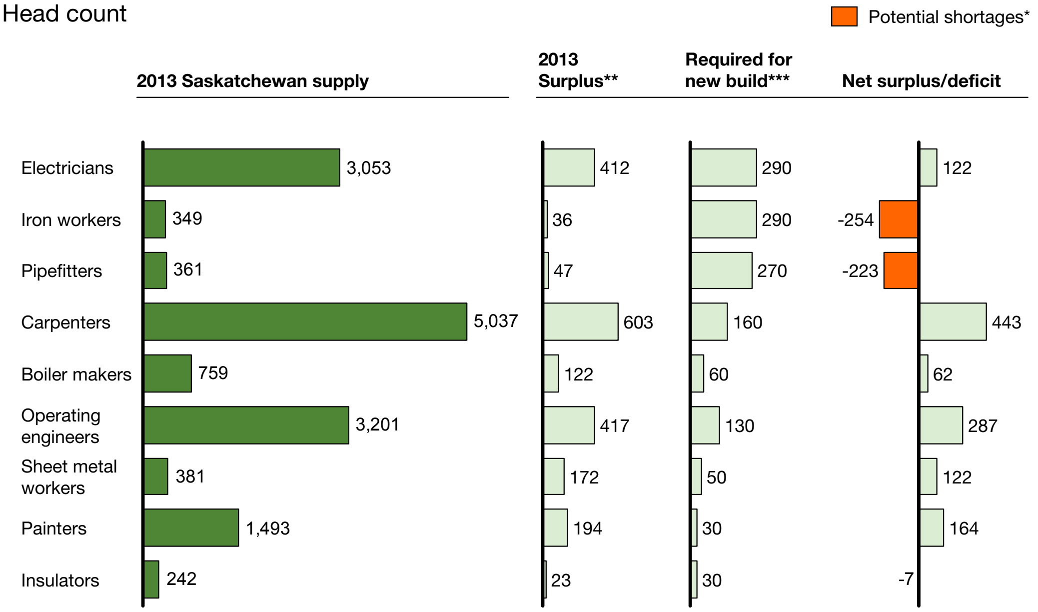
[89] *Levelized Cost of Energy Analysis – Version 2.0*. Lazard, 2008. Page 12.

[90] Schlissel et al. *Coal Fired Power Plant Construction Costs*. Synapse Energy Economics Inc., 2008. Page 7. http://www.synapse-energy.com/Downloads/SynapsePaper.2008-07.0.Coal-Plant-Construction-Costs.A0021.pdf.

EXHIBIT 4-8

Availability of Saskatchewan tradespeople for nuclear new builds

Head count



* Shortage will require diversion of tradespeople from other industries and provinces

** Expected number of tradespeople available before they need to be diverted from existing employers

*** Labour demand by trade assumed based on US new build average of ABWR, ESBWR, and AP1000 designs; does not include other on-site labour (e.g., craft supervision, warehouse personnel, clerical and payroll staff, and security)

Source: Construction Sector Council; US Department of Energy 2010 Nuclear Construction Infrastructure Assessment

generation capacity,[91] this export scenario is probable and greater levels of export may be possible.

Labour availability

The physical process of building a very large capital project like a nuclear reactor requires a great number of skilled tradespeople and labourers, which can limit the number of plants built in parallel. As Exhibit 4 - 8 depicts, the Province will likely have the available surplus of labour to build one or two nuclear power plants with minimal need to import skilled labour.[92]

Cooling water

The heat generated from a nuclear reactor requires cooling. The most economical coolant is water from a source such as a lake or river. Bruce Power's initial feasibility report suggests that 10 percent of the flow from the North or the South Saskatchewan rivers could be used to cool 2,200 MW of capacity. Additional power generation capacity would likely require additional investment for cooling towers.

Willing host community

According to a poll by Sigma Analytics conducted for the Regina *Leader-Post* in 2008, resident support for a nuclear reactor in Saskatchewan significantly exceeded opposition. When asked how they felt about the construction of a nuclear reactor to produce

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[91] *Future Demand and Energy Outlook*. Alberta Electric System Operator (AESO), 2007. Page 7. Based on 2020 demand forecast.

[92] Two units would likely be built out of sequence to minimize the need for additional resources.

electricity, 49 percent of residents were supportive, while 29 percent were opposed.[93]

Meeting interim power demand during construction

Whereas the supply-demand gap is expected to slowly expand between 2009 and 2020, additional capacity from a nuclear new build would come online all at once when construction is complete. During construction, other supply alternatives would need to be leveraged, including additional electricity imports and the use of peaking capacity for supply (e.g., peaking gas-fired plants).

u. Given that a nuclear power plant has not been previously built in Saskatchewan, further work needs to be done to understand the social, environmental, and grid feasibility of adding nuclear power in the Province

A nuclear new build would be a first for Saskatchewan and, more broadly, for Western Canada. However, the high-level economic and technical analysis described above has shown that nuclear could be a competitive power generation option for Saskatchewan, with the potential to build up to 3,000 MW of new capacity. This opportunity justifies a more in-depth analysis to confirm the feasibility of building a nuclear power plant in Saskatchewan. This focused economic, environmental, technical, and social analysis would need to address a range of topics at a much more detailed level, including site selection, environmental impacts, domestic and interprovincial grid impacts, reserve solutions, long-term export potential, and financing and cost recovery.

v. Capital cost overruns and schedule delays are key risks in any nuclear new build project, and they would need to be carefully mitigated in the project development process. To date, the cumulative risks of nuclear new build have been too large for the private sector to bear alone and governments have played some form of facilitation in the implementation of nuclear power projects in all jurisdictions.

All very large capital projects face several significant financial risks: cost overruns during construction, schedule delays, and lower than expected performance of the asset. As the nuclear industry begins the slow and steady process of renewing the global fleet of nuclear power plants with a new generation of reactors, the first wave of new plants in Canada will face some unique risks.

- **Licensing delays.** The Canadian Nuclear Safety Commission (CNSC) has not reviewed a construction license application for a nuclear power plant since Ontario's Darlington project in the 1980s and has limited experience in reviewing the Generation III(+) designs. Most of the potential reactor vendors for Saskatchewan have little or no experience working within the Canadian nuclear regulatory system.

- **Supply chain bottlenecks.** Building a nuclear power plant requires a very extensive network of nuclear-certified equipment suppliers and subcontractors. Given the stagnation that affected the nuclear industry in the 1980s and 1990s, the current supply chain is fragmented and lacks recent experience.

- **Labour availability and productivity.** Hundreds of nuclear-certified skilled tradespeople are required for a nuclear new build project, including many that are already in short supply, such as welders, pipefitters, and boilermakers. In addition, there is a significant shortage of project managers with the skills and experience

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[93] Sigma Analytics is a Saskatchewan firm providing data mining and modelling, attitudinal polling, and market research. The telephone survey was conducted in May with 626 respondents aged 18 or older, stratified by 10 regions across the Province. This sample produces a general margin of error of plus or minus 4 percent, 19 times out of 20. Regina *Leader-Post*. http://www.canada.com/reginaleaderpost/story.html?id=5ddb57e4-70a9-4986-be2d-00bacbc02544.

TABLE 4-1

Country	Number of units under construction	Government role
China	12	Nuclear industry is largely State-owned.
Finland	1	Finnish government holds equity stake in project.
France	1	French government holds equity stake in utility and technology vendor.
India	6	Nuclear industry is largely State-owned.
Japan	2	Strong national pro-nuclear policy, including national R&D funding that supports private investment in nuclear generation.
Korea	5	Nuclear industry is largely State-owned.
Russia	8	Nuclear industry is largely State-owned.
US	0 (24 license applications filed)	Federal government provides loan guarantees, risk insurance, and production tax credits. State governments provide early cost recovery.

required to lead a nuclear new build project.

- **First-of-a-kind technology risks.** As of today, most of Saskatchewan's likely reactor design choices have not been constructed and commissioned, resulting in some uncertainty about their ultimate constructability and operating cost and performance.

Historically, the requirement for significant upfront capital investment, the long development timelines, and the uncertainties of licensing and cost overruns have resulted in the need for cooperation between public and private sector players to ensure nuclear new build projects are successfully executed. The most important roles of government are to provide strong and effective regulation of the nuclear power industry to ensure public safety and to provide policy stability to allow efficient licensing, construction, and operation. Table 4 - 1 outlines various roles that governments around the world are playing in the nuclear new build projects underway.

w. Saskatchewan could reduce licensing and first-of-a-kind risks by drawing on the recent experiences of other Canadian provinces that have developed nuclear generation capacity

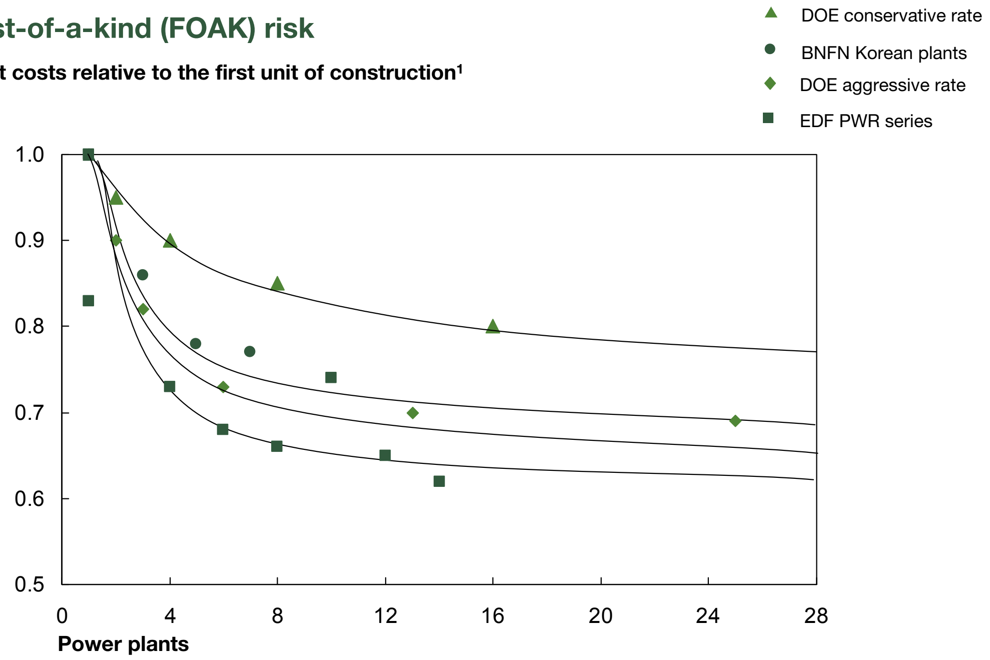
Ontario is in the process of procuring new nuclear capacity at the Darlington site, which is targeted to bring power online in 2018. The Province is choosing between three Generation III(+) designs – AECL's Advanced CANDU Reactor, AREVA's US-EPR, and the APR-1000 from Westinghouse – none of which is in operation anywhere in the world nor licensed or built in Canada (this is true of all Generation III(+) designs).

Given that Saskatchewan's nuclear power plans would lag Ontario's by at least a year or more, a straightforward way to mitigate licensing and first-of-a-kind technology

EXHIBIT 4-9

First-of-a-kind (FOAK) risk

Plant costs relative to the first unit of construction[1]



1 Exclusive of interest and include EPC costs, owner's costs, and contingencies

Note: FOAK costs can add several hundred million dollars to the overnight cost to complete engineering design specifications; price charged for electricity includes overnight costs as well as yearly recurring fuel cost, interest accrued during and following construction, and O&M costs

Source: University of Chicago; TVA Bellfonte

risks would be to "follow Ontario's lead" in selecting a reactor vendor and contractor for the new build project. This would provide several risk-mitigating benefits: the CNSC would have familiarity with licensing the design; the vendor/contractor would have significant experience working with Canadian suppliers and labour forces; and Saskatchewan could build mutually beneficial relationships with Ontario Power Generation to share learnings and experience with the technology. As Exhibit 4 – 9 shows, nuclear power plant projects follow a steep learning curve, with each subsequent project incurring lower costs and risks than the previous.

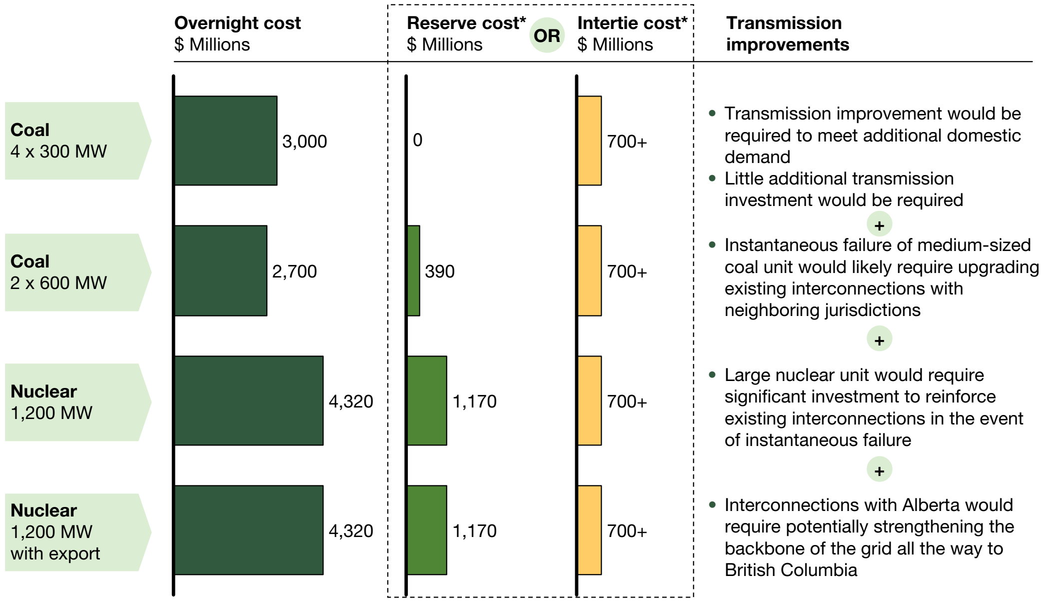
x. Transmission infrastructure reserves and intertie investments would be required to support larger power generation units on the Saskatchewan grid, as well as to provide the capability to export additional power to Alberta. The detailed nature and cost of this infrastructure has yet to be determined

Regardless of whether power is exported, some investments would need to be made to strengthen the grid in Saskatchewan and potentially those in neighbouring regions.

If a new power generation plant is built, additional investments would need to be made in the Province's electricity infrastructure. Saskatchewan's transmission system cannot currently handle very much additional generation capacity: its intraprovincial grid system requires capacity upgrades, and its interties with its neighbours are limited. Additionally, its reserve capacity is currently only 288 MW, the size of its single largest single power generation unit, the Poplar River coal plant. Building a larger single unit (e.g., 1,000 to

EXHIBIT 4-10

Non-core investment requirements of power generation alternatives



* Based on $1,300 per kW overnight capital cost of gas CCGT, and existing reserves of approximately 300 MW

** An intertie with Alberta could eliminate the need for domestic reserves through a reserve-sharing agreement; the cost of reserve sharing would need to be investigated

Source: Can-NW-Cal Study Group; *IEEE Power & Energy Magazine*

1,600 MW) requires additional reserve to supplement power supply in the event of failure.

Under a purely domestic (i.e., no export) scenario, a nuclear plant could require an investment of over $1 billion in additional reserve capacity. These reserve requirements are a function of unit size. Although coal plants can be built in smaller units, significant economies of scale would offset the investment in additional reserve capacity and would likely mean that any coal units built would be larger than any currently operating units. As a result, regardless of whether nuclear or coal is chosen, additional reserves would likely be required.

Under an export scenario, an intertie would be required to physically transmit power as well as convert AC power in Alberta in step with its export market. With the intertie infrastructure in place, a reserve-sharing agreement with the importing jurisdiction could make it possible to forego considerable investment in domestic reserve infrastructure.

Although the degree of investment required would depend in part on the size and scale of the units added and the decision to export, some investment would still need to be made. Exhibit 4 - 10 provides preliminary, high-level estimates of the potential investment requirements. Further feasibility analysis needs to be undertaken to fully understand the necessary infrastructure improvements.

y. A new power plant would have a significant impact on Saskatchewan's economy, contributing approximately $12 billion in discounted GDP to the Province over its life ($1.2 billion during construction and $10.6 billion during operation), as well as employing 3,000 people during construction and providing between 400 and 700 direct jobs during operation for every unit built

A nuclear power plant would contribute significantly to the Saskatchewan's economy, both during its construction and its 60-year operating life.

Licensing, construction, and commissioning of an approximately 1,000 MW nuclear power plant is expected to contribute $2.1 billion to Saskatchewan's GDP over the project's 10-year duration. Construction labour would have the greatest economic impact during construction, employing approximately 3,000 employees onsite over the 5-year construction period. Most of the economic activity in the production of bulk construction materials and the manufacturing of power plant equipment occurs outside of the Province, resulting in relatively little added value for Saskatchewan.

In addition to providing affordable low-carbon electricity for the Province's residential, commercial, and industrial users, a nuclear power plant would create 700 to 800 long-term jobs. In total, the plant would contribute $600 million to the Province's GDP annually, representing a cumulative discounted value of nearly $11 billion in GDP impact.

A full build-out of approximately 3,000 MW could create up to 3,000 construction jobs over an equivalent of 15 years of total construction time, 2,100 to 2,400 long-term jobs in nuclear operations, and $38 billion dollars in total GDP benefit.

Recommendations

The UDP has developed its recommendations, supported by these findings, for the Province to develop a competitive position in nuclear power generation that would contribute significant benefits to the Province.

Saskatchewan should:

12. Include nuclear as part of the Province's long-range energy mix, given its cost-competitiveness as a baseload power alternative and the economic value it would generate within the Province.

13. Begin this long-range planning process by:

    - Laying out an overall process and timeline for new generation implementation.

    - Considering the development, in coordination with Alberta, of a common power generation solution for the two Provinces by pooling their power needs and building stronger interties between the two provincial grids.

    - Defining the role that the Provincial government would play and developing a strategy to optimize the balance between expected power pricing and Saskatchewan ratepayers' exposure to cost overruns.

    - Evaluating the type of grid, reserve, and intertie upgrades required under both a domestic and an export power generation scenario to meet growing electricity demand, independent of supply mix. Consider the implications of nuclear power generation on these infrastructure upgrades.

Chapter 5: Used fuel management

Key findings

z. Reprocessing CANDU fuel based on current technology is commercially unattractive for private investment, given the high capital and operating costs that offset potential economic benefits from recycling plutonium and reducing the volume of high-level waste for disposal.

aa. In the longer term, if reprocessing becomes viable in Canada because of a step-change in reprocessing economics or, more likely, a change in Federal policy, a Saskatchewan-based reprocessing facility may have substantial local and regional economic benefits given the magnitude of expenditure and employment associated with the facility.

bb. Federal legislation ensures that the costs of long-term used fuel management will be fully funded by the industry.

cc. The Government of Canada has approved the Nuclear Waste Management Organization's Adaptive Phased Management approach incorporating the development of a centralized deep geological repository in Canada for long-term management of used fuel.

dd. The NWMO will be initiating a site selection process after 2009.

ee. Given its favourable geology and current participation in the nuclear fuel cycle, Saskatchewan is one of the four provinces the NWMO has identified as a potential host of the Canadian long-term repository.

ff. Past experience in other jurisdictions has shown that acceptance of a local host community is the most important factor for the successful siting of such a repository in a geologically suitable location.

gg. The potential benefits to that community and to the Province of hosting the facility would be significant, including early benefits from research and development, peak employment (4,000 to 6,000 direct and indirect jobs) during construction, sustained employment (~900 jobs) during operations and monitoring, and approximately $2.4 billion in discounted cumulative GDP impact.

High-level overview – Reprocessing

Reprocessing is the physical and chemical process by which nuclear fuel that has been used in a nuclear reactor is separated into its individual components. It has two primary purposes: to increase the energy captured from the original uranium resource through recycling; and to reduce long-term storage requirements for high-level waste.

Used nuclear fuel contains a mix of products generated through the nuclear reaction that occurs in a power generator's reactor. These products include:

- **Recyclable products:** Plutonium, a fissionable byproduct that has significant value as a fuel for nuclear reactors when refabricated into mixed oxide (MOX) fuel bundles, and residual uranium-235.

- **Remaining uranium:** Uranium-238 continues to comprise over 95 percent of the fuel bundle and, if sufficiently isolated and purified, may be treated as low-level waste along with the other isotopes of uranium.[94]

- **High-level waste:** Minor actinides, long-lived radioisotopes that contribute significantly to the long-term radiotoxicity of used fuel (i.e., after several hundred years), and fission products, which are typically shorter-lived radioisotopes (such as strontium and cesium) that are the primary contributors of the initial heat output and radiotoxicity of used fuel bundles.

Reprocessing encompasses a number of steps. Used nuclear fuel bundles are first disassembled to release the fuel pellets they contain. The fuel pellets then undergo a range of processes that result in the separation of plutonium, uranium, and high-level waste.

The separated plutonium is the primary recycled product and is transferred to a facility for fabricating MOX fuel. This fuel may be used in nuclear reactors with the appropriate design and licensing. Approximately 30 reactors in Europe regularly accept MOX fuel.[95]

While it is technically feasible to re-enrich and recycle the separated uranium as nuclear fuel, it is typically stockpiled because of the presence of undesirable uranium isotopes within the separated material. It is expected that future generations of nuclear reactors, including Generation IV fast neutron reactors, will be able to capture the remaining energy content of this product. In the meantime, the characteristics of this separated uranium allow it to be handled as low-level waste.

The high-level waste streams from reprocessing undergo vitrification, a process by which they are encased in glass, in preparation for placement in a long-term storage facility.

Beyond pure economics, current reprocessing activity is driven by a number of factors,[96] including:

- Concern over potential future availability of uranium, particularly for nations such as France and Japan with little or no natural uranium resources and a high reliance on nuclear power.
- Mitigation of the environmental and safety risks of used nuclear fuel, especially in the absence of long-term storage or repository facilities.
- Preparation for fast neutron (Generation IV) power generation technology, which will require a plutonium feedstock and will be able to leverage the energy value of the reprocessed uranium.

Despite these considerations, relatively few countries reprocess used fuel.[97] There are several reasons for this limited reprocessing activity. Most notable among these are the high costs associated with the construction and operation of reprocessing and MOX fuel fabrication facilities, and potential proliferation risks arising out of the separation of pure plutonium from used fuel that could be diverted to manufacture nuclear weapons.

Canadian utilities do not reprocess their used fuel. Instead, Canada operates a “single pass” nuclear fuel cycle, where used fuel is destined for long-term storage rather than reprocessing. This is similar to the approach taken by many nuclear countries, including the United States and many European nations.

There are only a small number of industrial scale commercial reprocessing facilities in world. The most significant of these are located in the United Kingdom, France, and Japan,

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[94] Reprocessed uranium will contain a mixture of all uranium isotopes, including both U-238 and U-235.

[95] *NDA Plutonium Options*. UK Nuclear Decommissioning Authority, 2008. Page 13.

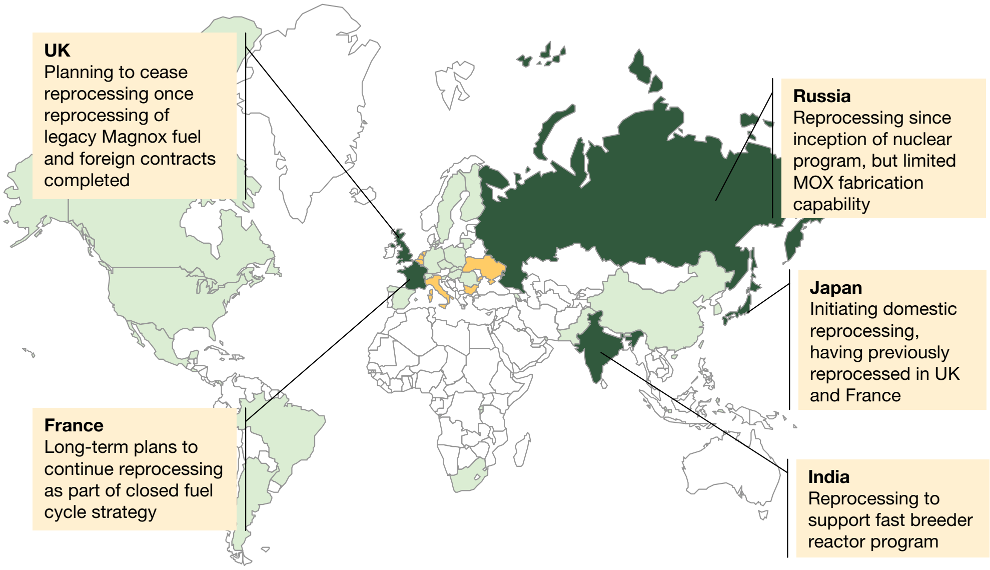
[96] For a detailed discussion on used nuclear fuel policies across all nations with nuclear generation facilities, see Hogselius, Per. “Spent nuclear fuel policies in historical perspective: an international comparison,” *Energy Policy 37,* 2009. Pages 254-263.

[97] Hogselius, Per. “Spent nuclear fuel policies in historical perspective: an international comparison,” *Energy Policy 37,* 2009. Page 255.

EXHIBIT 5-1

Countries reprocessing spent fuel

🟩 Not currently reprocessing
■ Have reprocessing facilities
🟨 Sending fuel to another country for reprocessing



UK
Planning to cease reprocessing once reprocessing of legacy Magnox fuel and foreign contracts completed

France
Long-term plans to continue reprocessing as part of closed fuel cycle strategy

Russia
Reprocessing since inception of nuclear program, but limited MOX fabrication capability

Japan
Initiating domestic reprocessing, having previously reprocessed in UK and France

India
Reprocessing to support fast breeder reactor program

Source: “Spent nuclear fuel policies in historical perspective: an international comparison,” *Energy Policy 37,* 2009

with smaller-scale facilities located in Russia and India.[98] All of these operating facilities use the highly mature PUREX technology for reprocessing.

z. Reprocessing CANDU fuel based on current technology is commercially unattractive for private investment, given the high capital and operating costs that offset potential economic benefits from recycling plutonium and reducing the volume of high-level waste for disposal

Reprocessing involves a number of complexities, driven by the highly radioactive nature of the materials being handled, the corrosiveness of the chemicals involved, and proliferation concerns that result from the separation of plutonium from the used fuel. International experience has shown that reprocessing facilities capable of managing these complexities are highly capital intensive and have substantial operating costs.

As shown in Exhibit 5 - 3, several recent studies[99] into reprocessing economics suggest that, for light water reactors, the high costs for reprocessing offset the economic benefits that may be realized from recycling plutonium and uranium[100] into fresh fuel for nuclear generators and from the reduction in volume of high-level waste for long-term management.

The overall economics of reprocessing Canada’s used fuel are even less favourable

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[98] *Management of Reprocessed Uranium: Current Status and Future Prospects.* IAEA, 2007. Pages 20-27. *Separating Indian Military and Civilian Nuclear Facilities.* ISIS, 2005. Page 4.

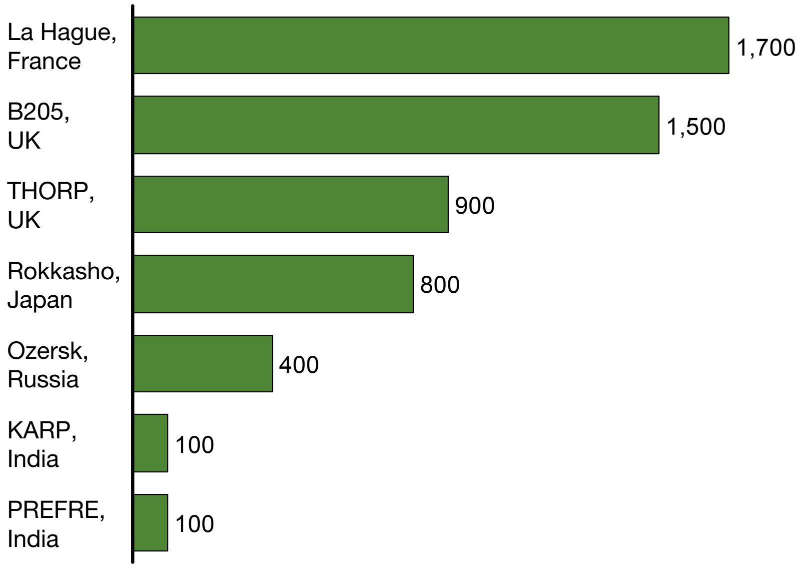
[99] Bunn, Matthew, et al. *The Future of Nuclear Power.* MIT, 2003. Appendix to Chapter 5. *The Economics of Reprocessing vs. Direct Disposal of Spent Nuclear Fuel.* 2003. *Economic Assessment of Used Nuclear Fuel Management in the United States.* AREVA and The Boston Consulting Group, 2006.

[100] These studies assumed a credit for recycling uranium into the fuel cycle, despite the fact that reprocessed uranium is being stockpiled at reprocessing facilities and represents a storage cost rather than a fuel credit.

EXHIBIT 5-2

Reprocessing capacity by facility

Tonnes per year

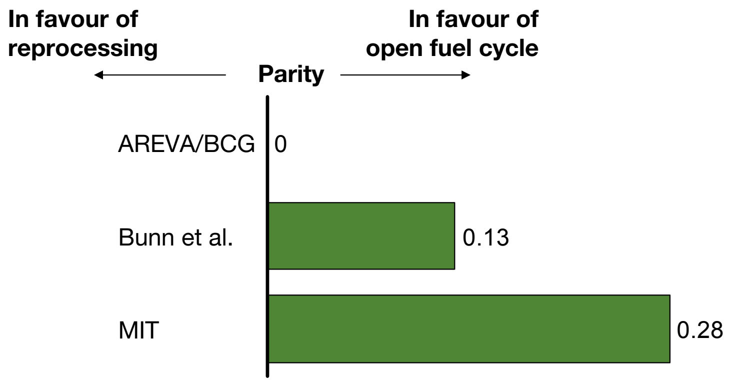


Source: *Management of Reprocessed Uranium: Current Status and Future Prospects*, IAEA, 2007

EXHIBIT 5-3

Additional costs of LWR reprocessing across studies

Cents per kWh



Source: AREVA and The Boston Consulting Group, *Economic Assessment of Used Nuclear Fuel Management in the United States*, 2006; Bunn, Matthew et al., John F. Kennedy School of Government; *The Economics of Reprocessing vs. Direct Disposal of Spent Nuclear Fuel*, 2003; MIT, *The Future of Nuclear* Power, 2003;

given three characteristics of the CANDU fuel cycle. First, the cost for new CANDU fuel bundles made from natural uranium are lower than those of light water reactors, which are made from more costly enriched uranium, reducing the potential credit that would be realized for recycled plutonium. Second, the lack of enrichment also means that the uranium separated through reprocessing would have less potential recycle value than reprocessed uranium from light water reactor fuels. Third, the benefit that would accrue from reducing the volume of used fuel destined for long-term management would also be reduced relative to light water reactors, given the lower repository costs[101] for CANDU fuel.

Given these factors, the economics of CANDU reprocessing would not generate sufficient returns to support private investment, particularly given the significant capital and operating costs of industrial scale reprocessing.[102]

aa. In the longer term, if reprocessing becomes viable in Canada because of a step-change in reprocessing economics or, more likely, a change in Federal policy, a Saskatchewan-based reprocessing facility may have substantial local and regional economic benefits given the magnitude of expenditure and employment associated with the facility

While the economics of CANDU fuel reprocessing do not currently justify private investment, there are two circumstances in which reprocessing CANDU fuel may emerge as a commercially viable opportunity.

Construction costs of existing reprocessing facilities

Publicly available estimates for the construction costs of recent reprocessing facilities range from US $7 billion for the 900 tonnes per year at the UK THORP facility; to US $18 billion for the French facilities at La Hague, with a combined capacity of 1,700 tonnes per year; to US $20 billion or more for the new 800 tonnes per year for the Japanese Rokkasho reprocessing plant.

Source: Bunn, Matthew, et al. John F. Kennedy School of Government. *The Economics of Reprocessing vs. Direct Disposal of Spent Nuclear Fuel."* 2003. Pages 26 and 29. Costs reported in real 2003 US dollars have been escalated to 2007 using US GDP deflators.

Over the long term, the economics of reprocessing may shift significantly to the point where returns would justify private investment. This could be driven by substantial sustained increases in either natural uranium prices or the costs of used fuel management in a deep geological repository. Alternatively, it may result from step-changes in reprocessing technology that significantly reduce its capital and/or operating costs.

A shift in Federal policy could also drive the industry to a multi-pass fuel cycle. This shift could be the result of a number of considerations that have driven decisions in countries such as France and Japan. These include potential challenges that may arise during the siting and construction of a repository, perceived environmental and safety benefits of reprocessing, or the desire to establish feedstock inventories for the potential emergence of Generation IV reactor technology. At this time, the Federal Government has given no indication that it is considering such a shift.

If either of these scenarios occurred, Saskatchewan should reconsider its participation in this segment of the value chain. A Saskatchewan-based reprocessing facility would generate substantial economic activity and benefits to the host community. The capital investment of a large-scale industrial

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101 The costs of a long-term repository are largely a function of the heat output and radiotoxicity of the used fuel. Used CANDU fuels have lower heat output and radiotoxicity than the same volume of light water fuel and thus have lower management costs.

102 Estimates drawn from the studies of reprocessing economics suggest that the upfront capital cost of a full industrial scale facility, sized to process all the used fuel generated by Canada's nuclear reactors currently in operation, could be between $15 billion and $20 billion, with ongoing annual operating costs of up to $1 billion.

reprocessing facility sufficient to handle all of Canada's used fuel production would be in the range of $15 billion and $20 billion and could employ more than 6,000 people during operation.[103]

High-level overview – Deep geological repository

Managing nuclear fuel once it has been used in a nuclear reactor is a critical step in the overall uranium value chain. Public confidence in the approach to long-term management of used fuel should contribute significantly to public acceptance of the overall nuclear industry. Given its radioactivity, used fuel and other high-level wastes remain hazardous to humans and the environment and need to be safely and securely contained and isolated for periods of up to hundreds of thousands of years. It is recognized, however, that this used nuclear fuel may have future value as an energy resource.

The amount of used fuel produced to generate large amounts of electricity is relatively small – Canada's total inventory of used fuel from all operating and decommissioned reactors would fill five hockey rinks to approximately the top of the boards – and is managed to extremely high standards.

Used fuel storage typically happens in three phases:

1. Used fuel bundles are initially placed in cooling pools to dissipate their high initial heat output and provide shielding from their radioactivity.

2. Over time, the fuel bundles are transferred to aboveground dry casks, with specifically designed shielding and containment that typically have a design life of approximately 50 years, although it is anticipated that their actual useful life will likely exceed 100 years.[104]

3. Over the longer term, some form of management facility is required for used fuel and other high-level waste.

In Canada, all used fuel is currently stored in licensed pools or dry storage facilities at the nuclear generation sites. At this time, a little more than 2 million used fuel bundles are being stored in this manner; currently operating nuclear generators are anticipated to produce between 0.7 million and 3.5 million more bundles by the end of their operating lives.[105]

In 2002, the Federal Government passed the Nuclear Fuel Waste Act, which recognized the need for a permanent solution for used nuclear fuel and required the Canadian nuclear energy corporations (i.e., Ontario Power Generation, Hydro-Québec, and New Brunswick Power) to establish an organization with the mandate to develop and implement a long-term management solution. This organization, the Nuclear Waste Management Organization, was established shortly after the passage of the Act and undertook extensive public consultations across Canada. Concurrently, the NWMO developed a detailed study of the options for long-term used fuel management in Canada.

bb. Federal legislation ensures that the costs of long-term used fuel management will be fully funded by the industry

In addition to requiring the creation of the NWMO, The Nuclear Fuel Waste Act 2002 put in place the means to fund this organization. The Federal Government's goal was to ensure that any solution for long-term used fuel management is fully funded by the owners of the used fuel. No third-party funding of any sort, public or private, will be required to support the implementation of the solution.

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[103] Employment estimate based on employment at the French reprocessing facility at La Hague of 6,000 to 8,000 people as per Christian Bataille and Robert Galley, *L'Aval du Cycle Nucléaire (The Back End of the Nuclear Fuel Cycle*) Part 1, General Study, Report to the Parliamentary Office for the Evaluation of Scientific and Technological Choices," June 1998. Introduction to Chapter 1. Available at http://www.senat.fr/rap/097-612/097-6123.html.

[104] *Status of Reactor Site Storage Systems for Used Nuclear Fuel*. SENES Consultants Ltd., 2003. Pages 4, 20, and 21.

[105] *Nuclear Fuel Waste Projections in Canada – 2008 Update*. NWMO, 2008. Pages 2 and 3.

Each of the owners is required to put a mandated amount of funds into a Trust account each year. These funds may only be accessed by the NWMO and may only be used to fund the implementation of a long-term management solution once a construction or operation license is received by the NWMO from the Canadian Nuclear Safety Commission (CNSC).[106] The NWMO is also required to make recommendations to the Federal Government regarding the sufficiency of the Trust funds and funding formula to fully cover the costs of the used nuclear fuel management solution.

cc. The Government of Canada has approved the Nuclear Waste Management Organization's Adaptive Phased Management approach incorporating the development of a centralized deep geological repository in Canada for long-term management of used fuel

In its comprehensive report published in 2005,[107] the NWMO studied a range of options and recommended a solution based on the ultimate placement of used fuel in a deep geological repository.

In this recommendation, all used fuel is to be transported to a single, centralized facility in certified transportation containers that meet comprehensive safety standards. At the site, the fuel will be received, removed from the transportation containers, and repackaged for underground storage. The fuel will then be placed in the repository constructed approximately 500 metres underground in a stable geological formation. This facility will be designed to accept used nuclear fuel from the existing nuclear fleet (and, potentially, future nuclear plants), support retrievability of that fuel at some point in the future, and incorporate a variety of engineered elements to ensure the fuel is appropriately contained and managed for the entire period it is anticipated to be radiotoxic.

Overview of the Adaptive Phased Management (APM) approach

This approach's ultimate objective is the safe and secure management of used nuclear fuel in a deep geological repository.

To achieve this goal, the APM model incorporates several key elements, including: phased implementation tied to clear decision points; flexibility and responsiveness to evolving knowledge and societal values; and sustained effective stakeholder engagement based on openness and inclusiveness.

The NWMO also recommended an Adaptive Phased Management approach as the preferred means to implement this solution. The Federal Government agreed, and the NWMO is now moving forward with implementation.[108]

dd. The NWMO will be initiating a site selection process after 2009

The NWMO is designing a process to identify a willing and informed host community for the deep geological repository.[109] The NWMO plans to release a *Proposed Site Selection Process* in spring 2009 for public review and comment. This will be revised based on the comments received from stakeholders, and a finalized process for site selection will be released sometime after 2009, at which time the NWMO will formally initiate the site selection process.

ee. Given its favourable geology and current participation in the nuclear fuel cycle, Saskatchewan is one of the four provinces the NWMO has identified as a potential host of the Canadian long-term repository

The NWMO is focusing the site selection process on the four provinces that are currently

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[106] The Nuclear Fuel Waste Act 2002

[107] *Choosing a Way Forward – The Future Management of Canada's Used Nuclear Fuel*. NWMO, 2005.

[108] *Implementing Adaptive Phased Management – 2009 to 2013*. NWMO, 2009. Pages 3 and 6.

[109] *Implementing Adaptive Phased Management – 2009 to 2013*. NWMO, 2009; *Moving Forward Together: Designing the Process for Selecting a Site*. NWMO, 2008.

involved in and benefit from the uranium value chain – Saskatchewan, Ontario, Québec, and New Brunswick.

The potential site must have specific geology that is appropriate for long-term management of used fuel. The NWMO's recent technical studies have confirmed that a range of geological formations may be appropriate for the siting of the repository, including the crystalline rock of the Canadian Shield and selected sedimentary formations. Based on these studies, most of Saskatchewan may have the appropriate type of geology, although location-specific analysis will be required to validate any potential site.

Recent experiences in siting deep geological repositories

Yucca Mountain, US

The US Congress drove the selection of the Yucca Mountain site in Nevada through an act of legislation. However, local opposition to the repository's development has been strong at both the State and the local levels. Through numerous court challenges, this opposition has contributed significantly to more than a decade of project delays.

Nevada Senator Harry Reid, as Senate majority leader, has worked with the new Obama administration to scale back the budget of the Yucca Mountain project to where only the license review process will proceed. The administration has also indicated that Yucca Mountain is not an option for used fuel management in the United States.

Olkiluoto, Finland

In contrast to the US experience, the Finnish siting effort identified four candidate sites and provided local community councils with veto rights throughout the process. A comprehensive stakeholder engagement process was incorporated into the Environmental Impact Assessment effort.

Public support was cultivated through a recognition of the need for a solution for used fuel, an open dialogue regarding public safety concerns, and a focus on strengthening public confidence in regulatory and operating authorities.

The local council ultimately voted 20-7 in favour of the facility, and the development of the full-scale facility continues to target commissioning in 2020.

ff. Past experience in other jurisdictions has shown that acceptance of a local host community is the most important factor for the successful siting of such a repository in a geologically suitable location

As has been shown in other countries, the support of the local host community is paramount to the success of the siting process and the eventual implementation of the repository. Drawing on learnings from these examples, the NWMO will be basing its site selection process on expressions of interest from willing and informed host communities (rather than prior identification of high-potential sites, followed by a process of elimination).

In addition to local community support and the geological considerations, a number of other important factors will define an appropriate site, including:

- **Economic impacts.** The repository needs to be located in a region without known economic resources under or above the ground.

- **Land use.** The land surrounding the repository may not be available for other uses, including other commercial uses, during its construction, operation, and monitoring phases. Depending upon the location, this may have an impact on traditional First Nations and Métis activities in the region.

- **Labour availability.** Both the construction and the operation phases of the repository will employ a significant number of personnel, including engineers, skilled tradespeople, and operators. The facility's location will need to be able to attract and accommodate these staffing requirements.

Given the complexity and sensitivity of the site selection process and the siting experiences of other countries, it may take 10 years or more to finalize the site's selection.

gg. The potential benefits to that community and to the Province of hosting the facility would be significant, including early benefits from research and development, peak employment (4,000 to 6,000 direct and indirect jobs) during construction, sustained employment (~900 jobs) during operations and monitoring, and approximately $2.4 billion in discounted cumulative GDP impact

The development of a deep geological repository will have a significant economic impact on potential host communities and, ultimately, on the community where it is built.

Potential host communities will benefit from the initial research conducted to characterize and validate the appropriateness of local geology, and from the front-end engineering and design efforts.

With a site's selection, total costs through construction could be up to $9 billion (undiscounted 2007 real dollars).[110] The NWMO estimates that the total cost of the facility over its full life, excluding transportation and any interim storage costs at reactor sites, will be between $18 billion and $27 billion (undiscounted 2007 real dollars).[111]

Roughly 40 percent of these costs are personnel costs. At the peak of the main construction phase, the facility could generate 4,000 to 6,000 jobs.[112] Through operations and monitoring, the facility could sustain approximately 900 direct employees for as much as 200 years. The economic benefit of this employment would predominantly flow to the local community in the form of wages and benefits. Further benefit to the host province would likely accrue from the sales of equipment, materials, and professional services (e.g., engineering and design and chemical analysis) over the course of the facility's life.[113]

Should a willing host community come forward in Saskatchewan, there is the potential for these benefits to be realized within that community and within the Province. On a discounted basis, the total GDP impact to the Province could be approximately $2.4 billion.

Developing this facility will be a complex, four-phased undertaking:

1. Siting, engineering and design, and technical demonstration.
2. Construction of full repository including supporting infrastructure.
3. Operation (placement of all used fuel in the repository).
4. Long-term maintenance and monitoring.

Over one-third of the economic impact will be realized in the first two phases.

Even under an accelerated timeline, the first phase will likely take 15 years or more. Construction therefore is not likely to start until approximately 2025 and operations will extend through to approximately 2070.[114] A smaller staffing contingent, responsible for the extended monitoring of the facility, would remain in place for up to a further 2 centuries before the facility is finally sealed, decommissioned, and closed.

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[110] *Adaptive Phased Management Approach Cost Estimate Summary Report*. 2005. Appendix A.

[111] The cost estimate range of $16 billion to $24 billion in undiscounted 2002 real dollars was obtained through conversations with NWMO personnel, based on work conducted by Golder & Associates and Gartner Lee Ltd. These amounts were inflated to 2007 dollars using CPI data from Statistics Canada.

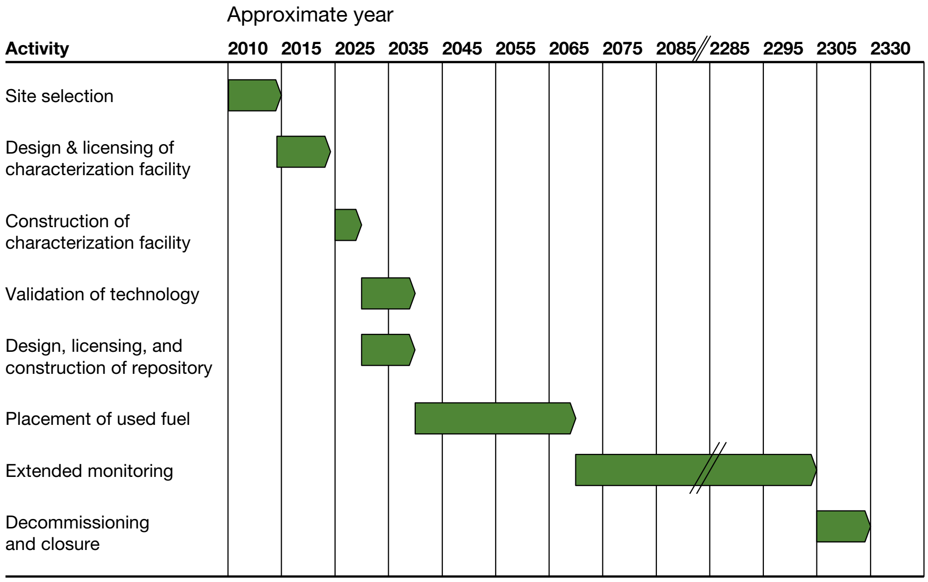
[112] *Assessment of benefits, risks and costs of a proposed adaptive phased management approach by illustrative economic region*. Golder & Associates and Gartner Lee Ltd., 2005. Pages 63 to 65.

[113] *Adaptive Phased Management Approach Cost Estimate Summary Report*. 2005. Appendix A.

[114] *Choosing a Way Forward – The Future Management of Canada's Used Nuclear Fuel*. NWMO. 2005. Pages 315 to 323.

EXHIBIT 5-4

Accelerated timeline of repository



Source: Nuclear Waste Management Organization

Recommendations

The UDP has developed its recommendations, supported by these findings, for the Province to position itself to participate in and, as appropriate, benefit from used fuel management.

Saskatchewan should:

14. Not proactively pursue the development of PUREX (plutonium and uranium recovery extraction) and MOX (mixed oxide fuel containing plutonium) reprocessing facilities in the short term. This position should be revisited if there is a significant change in Federal policy regarding long-term fuel storage or the full cycle economics of reprocessing.

15. Support the NWMO consultation and siting process, given the potential benefits of a geological repository, while maintaining flexibility with regard to its ultimate participation.

16. Support any willing host community that comes forward through this process and, as appropriate, support the development of the deep geological repository in the context of a broader nuclear development strategy.

Chapter 6: Research, development, and training

Key findings

hh. There is a shortage of specialists in the earth, environmental, and engineering sciences to support the activities of the uranium exploration and mining industry.

ii. If a nuclear power generation facility is built, Saskatchewan would also require that existing academic nuclear engineering and physics programs be expanded to support the training of nuclear specialists and operators.

jj. An academic centre of excellence should involve the social sciences and environmental disciplines to assist communities in assessing nuclear opportunities.

kk. Saskatchewan could play a role in a number of R&D opportunities with longer-term commercialization prospects, including small reactors and advanced fuel cycle technologies. A research reactor could serve as a catalyst for these activities.

ll. A research reactor is synergistic with existing research infrastructure and would provide Saskatchewan with significantly enhanced research capabilities, supporting innovation, competitiveness, and the Province's participation in the development of emerging technologies.

mm. A research reactor may also be used to produce medical isotopes to address the anticipated global deficit in isotope supply, providing an additional stream of revenue to partly offset the cost of developing and operating the reactor.

nn. Although medical isotope production provides an attractive source of revenue for a research reactor, the economics of a stand-alone isotope reactor are not attractive.

High-level overview

Expanding Saskatchewan's R&D program by developing a centre of excellence in research, development, and training would serve two complementary purposes. First, training skilled labour and coordinating research with industry would help support Saskatchewan's competitive position in its existing industries. Second, targeted investments would contribute to the development, demonstration, and/or commercialization of emerging technologies with high potential. The nuclear industry is young, and as next generation technologies along the value chain are continuously evolving, research and development is necessary to stay competitive. Being part of the development of these ideas would naturally position Saskatchewan to eventually participate in commercialization.

hh. There is a shortage of specialists in the earth, environmental, and engineering sciences to support the activities of the uranium exploration and mining industry

Uranium mining requires equipment operators and technicians to physically extract uranium ore from the ground. Behind the scenes, mining and exploration require the support of many specialists to understand geological formations, engineer and plan mining activities, and assess environmental impact. Additionally, there is a need for innovation in exploration and mining, such as new techniques to pinpoint resources, model and assess potential mines, and review mining activities in real time. These innovations could help drive Saskatchewan's leadership in the industry. There is currently a domestic shortage of the skills and innovations necessary in the mining industry.

An estimated 15 to 25 incremental specialists (e.g., hydrogeologists and toxicologists) are needed in the uranium mining industry annually.[115] Most of these experts are being imported from other provinces, as there are not enough graduates from Saskatchewan universities. Saskatchewan's major uranium mining players spend an estimated $30 million to $45 million annually on engineering and construction consulting services. Expanding existing higher education programs and establishing R&D and training capabilities would help capture some of this spend domestically. Additionally, coordinating research programs with industry could create innovative solutions to discovering new resources and mining them more effectively.

ii. If a nuclear power generation facility is built, Saskatchewan would also require that existing academic nuclear engineering and physics programs be expanded to support the training of nuclear specialists and operators

A typical nuclear power plant requires 700 to 800 staff, roughly 5 percent of whom are nuclear operators that require licensing from the CNSC.[116] It takes 3 to 5 years (depending on the amount of plant experience) to train senior reactor engineers before they can take the required CNSC examination. Although a nuclear engineering degree is not necessary, someone with an understanding of nuclear power and some experience can take the exam earlier and is typically more successful. Experience with a Slowpoke reactor (which Saskatchewan already has) can give students the basic understanding of nuclear energy they need to prepare for specific qualification training leading up to the CNSC examination. Desktop simulators are also very effective training tools.

Graduates from a training program, similar to the one at the University of Ontario Institute of Technology (UOIT) with training tools like desktop simulators, would have a higher chance of passing the CNSC examination. A significant program expansion along those lines and coordination between universities, facilitated by the University Network of Excellence in Nuclear Engineering (UNENE) and the Saskatchewan Research Council (SRC)-operated Slowpoke reactor, would help prepare students to become part of the workforce required for a nuclear reactor.

There are on average 10 subatomic physics graduate students and 5 undergraduate students at the University of Saskatchewan and a similar number at the University of Regina. There are 6 subatomic physics professors at the University of Saskatchewan and 7 at the University of Regina. An expansion in these numbers would likely be necessary to support research activities, as well as operate nuclear facilities.

jj. An academic centre of excellence should involve the social sciences and environmental disciplines to assist communities in assessing nuclear opportunities

A social sciences and environmental component of a larger research program would facilitate the sustainable expansion of Saskatchewan's nuclear program by supporting initiatives in Northern development, establishing complementary nuclear public policy and governance research, and enabling the creation and management of applications for new nuclear facilities.

A close working relationship exists between Saskatchewan's universities and industry; expanding this activity to include interactions with the Northern communities could have additional benefits. Several opportunities exist to strengthen particular areas of a nuclear research program by including leadership from First Nations and Métis communities.

Partnering with the Johnson-Shoyama Graduate School of Public Policy, which is part of both the University of Saskatchewan and the University of Regina, would help

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[115] Correspondence with industry experts.

[116] Correspondence with industry experts.

create relevant policy research and promote public discussion of nuclear-related issues. The school prepares graduates for work in policy research, policy drafting, and advocacy groups, as well as organizing thought-provoking events and timely policy publications in an effort to continually engage the public and stimulate public policy debate. This is an important part of the nuclear debate, serving as a forum for exchanging information with the community.

Research programs could also partner with the International Centre for Governance and Development (ICGD) to work with urban and rural municipalities to develop techniques for stakeholder involvement. The ICGD was formed as a hub of excellence in 2000 and seeks to address aspects of governance and development in three key areas: capacity building for legal and judicial reform; knowledge development on market economy and social development interrelationships; and policy analysis for good governance. With respect to nuclear development, the ICGD can play an objective role for municipalities assessing the applications, building permits, and the social and environmental impacts of a new facility.

kk. Saskatchewan could play a role in a number of R&D opportunities with longer-term commercialization prospects, including small reactors and advanced fuel cycle technologies. A research reactor could serve as a catalyst for these activities

Commercial nuclear fuel and generation technologies have a number of limitations, the most notable of which are: generation facilities must be built to a large scale to be economically competitive; only a fraction of the total energy potential of the uranium is captured to generate electricity; and used fuels and high-level wastes generated through the fuel cycle require specialized storage over very long time frames.

Research into solutions for these challenges is still in a very early phase and extensive effort and investment of both time and money would be required to address them. However, the jurisdictions at the forefront of this research would have the most to gain from the eventual commercialization of technologies.

Several global research and development projects are underway that seek to address these challenges. Efforts to develop economically competitive small reactors (i.e., with capacities under 100 MW) and advanced fuel cycle technologies with improved fuel utilization and safety and environmental characteristics could be of particular interest to Saskatchewan.

Small reactors

Commercially marketed nuclear reactors are of significant scale, with capacities greater than 1,000 MW. At these unit sizes, the costs of these reactors are competitive with alternative baseload options, including large hydro, coal, and natural gas generators.

Small nuclear reactors would not be designed to compete in the baseload power market. However, the benefits of small reactors would make them attractive in targeted applications, including: providing power and heat to remote communities (replacing diesel or propane generation); providing power to remote industrial sites (e.g., desalination plants); and cogeneration applications (e.g., oil sands production). The total global potential market for such applications is approximately 36,000 MW,[117] based on current off-grid oil and diesel-fired generation capacity.

Given this market potential, 10 to 50 MW small reactor technology is under active development by a number of commercial players. The most advanced solution relevant to North American applications is being led by Toshiba who, with its 4S (Super Safe, Small and Simple) reactor, has a proposal in place for a demonstration facility in Alaska. Toshiba plans to apply for NRC approval in 2009 with hopes of approval as early as 2013.[118] Other technologies are in the design stage and approximately 10 years from commercialization.

The biggest barriers to commercialization of small-scale reactors in North America today

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[117] UDI power generation database query: off-grid diesel power plants of 5 to 100 MW.

[118] "Nukes Get Small." *Energy Tribune*, 2008.

are the infancy of the technology and designs, the CNSC's and NRC's stringent safety and licensing requirements, and the fact that a proven demonstration project has not yet been built. Saskatchewan's greatest opportunity to participate in this market could be partnering with one or more commercial developers to host a demonstration small reactor. This would give Saskatchewan access to the technology and position it to participate in the small reactor supply chain and the development of relevant R&D activities.

Advanced fuel cycle technologies

A number of significant global research efforts are underway to address the constraints of the existing fuel cycle by developing advanced technologies, including:

- Improvements to the recycling of used fuel to make greater use of the energy potential of the raw resource.
- Reductions in the immediate and long-term safety and environmental impacts of used fuel.
- Development of the next generation of reactors, including fast neutron reactors.

These global research efforts encompass a range of different technologies. While each of these technologies is at varying levels of development, the majority are decades away from industrial-scale commercial implementation and require substantial investment.

Saskatchewan has existing capabilities and infrastructure, including the research facilities at the Universities, the Canadian Light Source, and the existing Slowpoke reactor at the SRC, that may enable the Province to develop a leading contribution in targeted areas of this technological development.

In the longer term, full participation in the research efforts may require new infrastructure construction, which could include building a research reactor or developing targeted technology demonstration facilities.

Given the significant investment required for each of these efforts, Saskatchewan would likely need to focus its efforts in a few key areas. A process to engage key technology, research, and industry stakeholders to determine the appropriate areas of focus may need to be established.

II. A research reactor is synergistic with existing research infrastructure and would provide Saskatchewan with significantly enhanced research capabilities, supporting innovation, competitiveness, and the Province's participation in the development of emerging technologies

Research reactors may be used for a variety of purposes. While much smaller and operating at lower temperatures than power reactors, they are a critical means of testing fuels, reactor components, and reactor operating systems to support advancement in generation technologies. As a source of neutrons, these facilities also enable detailed materials analysis. Neutron beams in a research reactor can be used across a number of industries and disciplines (e.g., design of superconductors, pharmaceutical agents, batteries, and hydrogen storage). Many countries have recently invested in new neutron beam facilities for this purpose: Japan ($2.4 billion), Australia ($300 million), the United States ($2.2 billion), and Germany ($750 million).[119] In addition, they provide training facilities for nuclear physicists and reactor operators.

These capabilities would provide significant benefits to the Province, enabling it to develop new competencies in training, research, and nuclear sciences. In the longer term, full participation in advanced fuel and reactor research efforts would likely require the construction of a research reactor.

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[119] Root, John. "The Importance of Neutron Beams for Materials Research and Development." *Nuclear Canada Yearbook*. National Research Council 2009. Page 15.

mm. A research reactor may also be used to produce medical isotopes to address the anticipated global deficit in isotope supply, providing an additional stream of revenue to partly offset the cost of developing and operating the reactor

Appendix C provides a detailed introduction to medical isotopes.

The production of medical isotopes is concentrated among a few major research reactors. Estimates indicate that Canada's National Research Universal (NRU) reactor and the Dutch Petten reactor produce 70 percent of the world's supply of medical isotopes today.[120] Both reactors are very old: the NRU has been in use since 1957 and Petten since 1961. The remaining major reactors, Belgium's BR-2, France's OSIRIS, and South Africa's SAFARI, were also built in the 1960s and are aging rapidly. Together, these five reactors account for 90 percent of the world's molybdenum-99 supply.[121]

Recent failures at the NRU and Petten are adding to the growing insecurity of supply. The shortages resulting from these shutdowns and the upcoming decommissioning of these two reactors have prompted major consumers of medical isotopes like the United States to launch initiatives to secure a long-term domestic supply. This is leading to alternative sources of supply being considered. For example, Exelon and GE-Hitachi announced in March 2009 that they are considering producing cobalt-60, an isotope with applications in therapeutic drugs, at an existing Exelon-owned, 1,000 MW nuclear power plant in Illinois.

Meanwhile, the market for the most in-demand medical isotope, molybdenum-99m (Mo-99),[122] has been growing steadily in recent years. In the United States, growth averaged 3.6 percent between 2002 and 2008.[123] The global demand for Mo-99 is 12,000 6-day curies per week,[124] and median estimates of future global demand range between 1 and 5 percent.[125] When coupled with the expiring licenses of the NRU, HFR (Petten), and OSIRIS reactors, a supply deficit of roughly 13,000 6-day curies per week is expected by 2020. Even under optimistic assumptions, new isotope production expected at research reactors in the United States (MURR), Argentina (CNEA), Australia (OPAL), and France (JHR[126]) will fail to fully close this gap. If all four reactors begin maximum isotope production before 2020, roughly 4,000 6-day curies per week of unmet demand would still exist (Exhibit 6 - 1). Four additional reactors producing isotopes would be required to meet the demand.

In addition to the global supply-demand gap, a second more strategic reason for Canada to maintain a role in medical isotope production exists. Should Canada become reliant on a US supplier of medical isotopes, it may be difficult to ensure a secure and continuous supply in terms of global shortage. This would make a Canadian solution vital for the long-term health interests of the country.

If Saskatchewan decides to pursue a research reactor, medical isotope production could be an attractive secondary source of research funding and a future secure source of medical isotopes for the Canadian market. The specifications of an isotope production facility in Saskatchewan would depend largely on the degree of investment and research reactor design choice, but the Australian OPAL reactor, which opened in 2007, could serve as a useful example. The OPAL reactor, although not yet fully operational, is intended to satisfy and potentially exceed Australia's demand for isotopes, producing up to 1,800 6-day curies

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[120] *Medical Isotope Production Without Highly Enriched Uranium*. National Research Council. Page 58.

[121] *Making Medical Isotopes*. TRIUMF, 2009. Page 7.

[122] As measured by technetium-99m medical procedures.

[123] *Medical Isotope Production Without Highly Enriched Uranium*. National Research Council. Page 88.

[124] *Medical Isotope Production Without Highly Enriched Uranium*. National Research Council. Page 78.

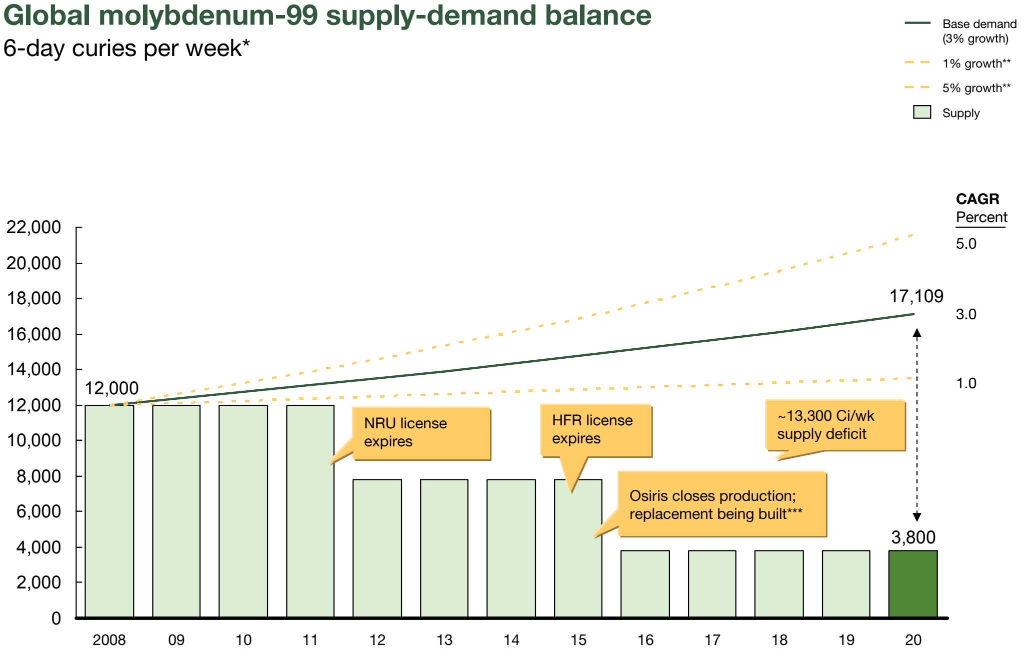
[125] *Medical Isotope Production Without Highly Enriched Uranium*. National Research Council. Page 86.

[126] Expected to replace the OSIRIS facility.

EXHIBIT 6-1

Global molybdenum-99 supply-demand balance

6-day curies per week*



* Production quantity calibrated to adjust for loss of Mo-99 curies during 6 days between shipment to average use

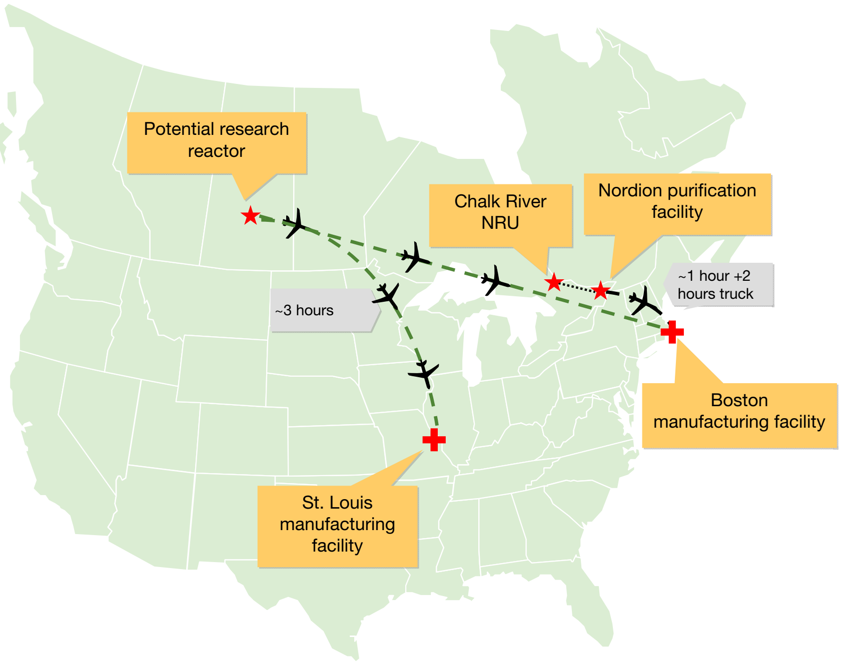
** Range based on US estimate

*** Replacement could have same capacity as Osiris, approximately 1,000 6-day Ci per week, but no investors have yet expressed interest

Source: National Research Council

EXHIBIT 6-2

North American isotope production and manufacturing facilities



Source: National Research Council

per week. A similar reactor in Saskatchewan, not including the revenue from a purification facility, could contribute a roughly $9 million profit annually at today's unprocessed Mo-99 prices (Exhibit 6 – 3). The cash flow from this isotope production would be equal to $75 million in net present value (NPV), and the relatively modest supply could easily meet Canadian demand.[127] The public benefit of an alternative to the NRU for isotope supply could justify further funding from Federal authorities.

nn. Although medical isotope production provides an attractive source of revenue for a research reactor, the economics of a stand-alone isotope reactor are not attractive.

All major operating medical-isotope production facilities currently rely on existing research reactors. Most of these reactors sacrifice research time in exchange for isotope production, with the exception of the NRU, which is designed to accommodate constant isotope production and a limited number of research activities (Exhibit 6 - 4). As a result, the price of isotopes is driven by research reactors, and therefore does not cover the full cost of a stand-alone facility. Today, molybdenum prices per 6-day curie can range from $250[128] to $470,[129] and the price of marginally produced isotopes sometimes fluctuates considerably outside this range. Within a reasonable range of higher margins or molybdenum-99 prices, a stand-alone reactor would still have a negative NPV. Several significant capital investments are required to produce isotopes (the cost of a reactor, the hot-cell facility for Mo-99 separation, the processing facility, waste storage, and numerous safety and security investments) that weaken the economics of a dedicated isotope-producing facility.

To date, the only attempt at a dedicated isotope production facility, the MAPLE reactors at Chalk River, has experienced 300 percent capital cost overruns despite being located at an existing nuclear research facility and has been abandoned by AECL due to technical safety failures. This further supports the conclusion that isotope production can currently only be justified in the context of a research reactor where the revenue from isotopes offsets costs and complements the research and training mandate of the reactor.

Siting an isotope reactor

The biggest issue to consider with respect to siting an isotope-producing reactor is the logistics involved in marketing the isotopes. Given molybdenum-99's short half-life, processed isotopes need to be packed and shipped to generator manufacturers in a matter of hours.

Saskatchewan could viably host an isotope manufacturing reactor and facility despite being geographically distant from major technetium-99 markets or generator manufacturers. Once a Mo-99 is removed from a reactor, it can take up to 28 hours to process and ship the Mo-99 to a generator facility and several days before its ultimate clinical application. The NRU currently ships its Mo-99 to MDS Nordion's processing facility in Kanata (2 hours by truck). Most of it is then flown to Lantheus' generator-manufacturing facility in Massachusetts (1 hour) for a total of 3 hours travel time. A co-located reactor and processing facility in Saskatchewan would need roughly equal time to charter purified molybdenum-99 to the nearest generator-manufacturing facilities in Massachusetts or Missouri.

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[127] The sales and the reactor uptime of isotope production are highly coordinated between suppliers to deal with variations in available supply. Even a Canadian-only solution would require working with other global suppliers to provide a truly secure supply.

[128] Kidd, Lawrence. *Curies for Patients*. World Nuclear Association. 2008. Page 9.

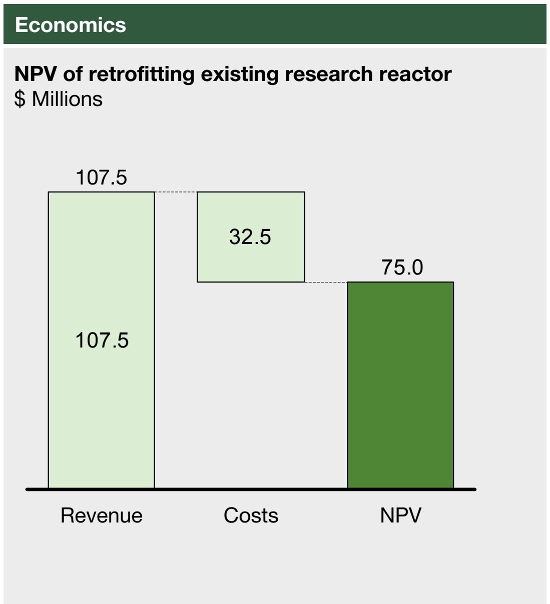
[129] *Medical Isotope Production Without Highly Enriched Uranium*. National Research Council. Page 94.

EXHIBIT 6-3

Economics of retrofitting research reactor for isotope production

Assumptions

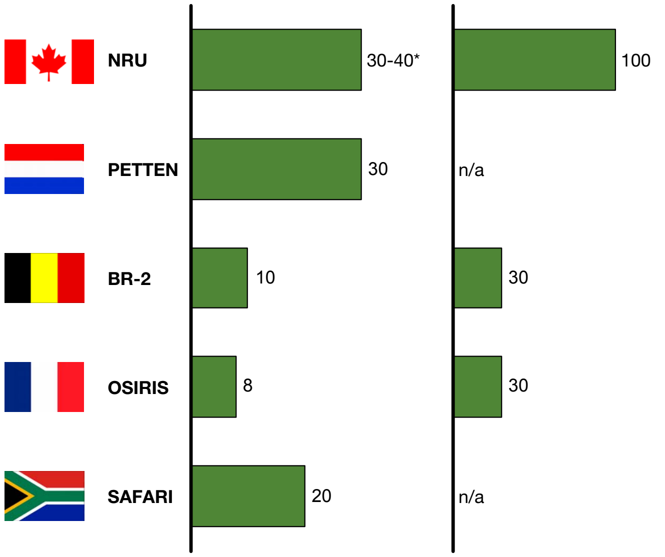
Raw Mo-99 price	$100/Ci
Curies produced	1,800/wk
Mo-99 revenue	~$10 million
Total revenue	~$13 million
Variable cost	$4/Ci
Fixed cost	$0



Source: World Nuclear Association; press releases

EXHIBIT 6-4

Major isotope-producing research reactors



	Molybdenum-99 market share Percentage of world production	Time allocated to isotope production Percentage of total run time	Comments
NRU	30-40*	100	• Reactor has physical space for both research and isotope production • Research mission has become secondary to isotope production
PETTEN	30	n/a	• Supplies 60% of European demand for medical isotopes • License expires in 2015
BR-2	10	30	• Nuclear materials science, nuclear reactor design, health and safety, training
OSIRIS	8	30	• Supports array of research for CEA • Legislated to close by 2015, expected to be replaced by JHR reactor
SAFARI	20	n/a	• Expected to be converted from HEU (high-enriched uranium) to LEU (low-enriched uranium) • Used for high-level nuclear research

* Range based on actual versus typical downtime in 2008

Source: Press search

Recommendations

The UDP has developed its recommendations, supported by these findings, for the Province to enhance and sustain its competitiveness across the value chain through research, development, and training.

Saskatchewan should:

17. Create and support a centre of excellence for nuclear research and training with a dual mission of: 1) supporting the existing nuclear industry in Saskatchewan; and 2) developing a nuclear R&D program to support emerging opportunities, with a few focused areas of research on longer-term commercialization prospects.

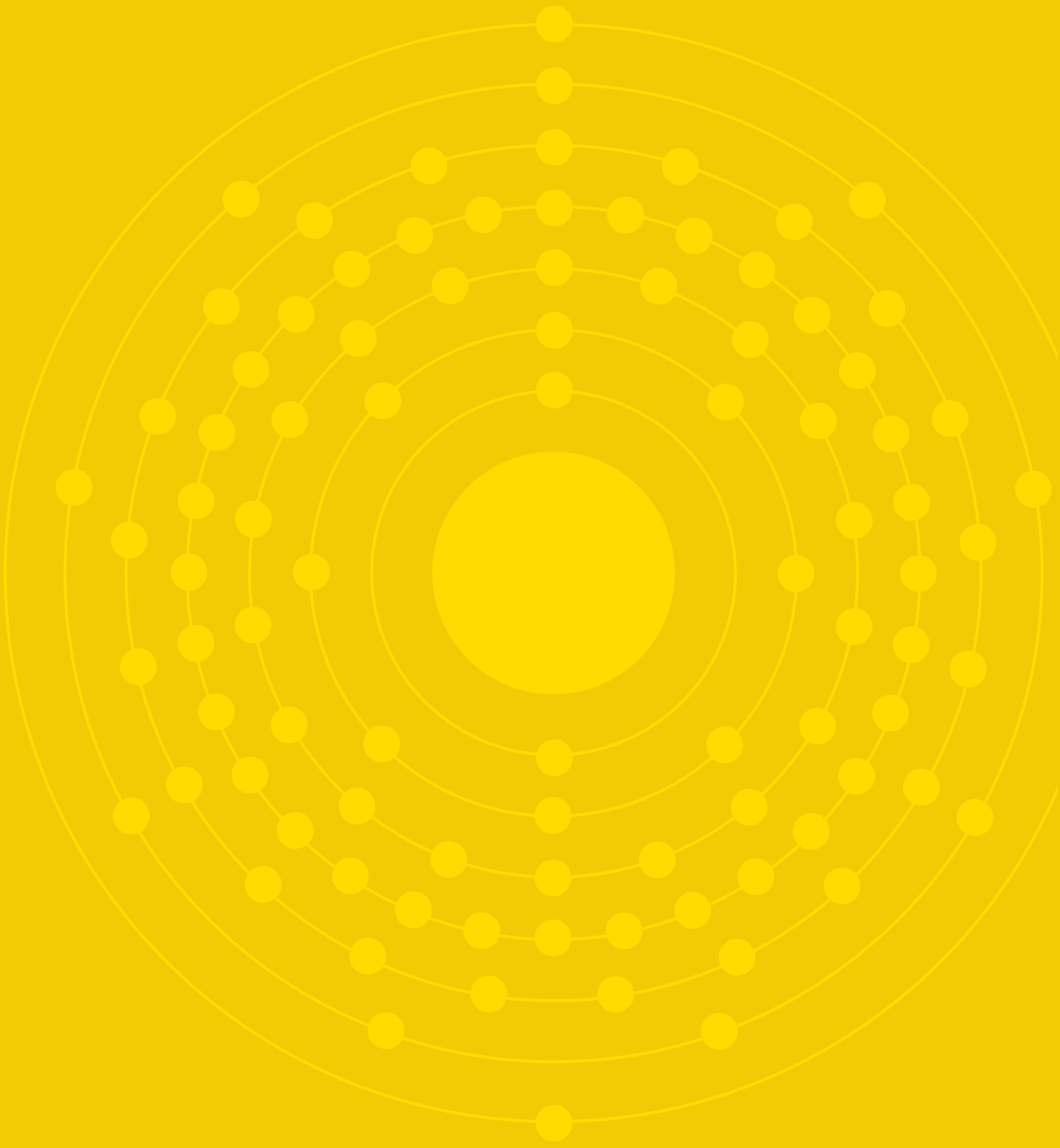
18. Under the first part of this mission, expand existing:

    - Mining and exploration programs at universities, colleges, and training schools to train engineers, geoscientists, and other mining specialists and to develop innovation through research in the earth, environmental, engineering, and social sciences relevant to the exploration and mining sectors.

    - Nuclear engineering and physics programs at universities and establish training facilities to help prepare students for the CNSC (Canadian Nuclear Safety Commission) nuclear operator examination.

19. Under the second part of this mission, form a group of experts to determine investment priorities in a few targeted areas of nuclear research. This group should review the most promising areas of research based on the type of skills and infrastructure required, the investment necessary to be competitive, the potential for private funding, and the prospect for commercialization. Areas to be considered by this group include, but are not limited to, small reactors and advanced fuel cycle technologies.

20. Partner with the Federal Government to pursue the construction of a research reactor in the Province as a complement to synergies with existing research infrastructure and capabilities and to better position the Province to participate in multiple areas of study. Pursue medical isotope production as part of the reactor's mandate.



Chapter 7: Proposed nuclear strategy for Saskatchewan

The previous chapters explored the key facts and findings, identified growth opportunities across the uranium value chain, and presented the specific recommendations to capture them.

This chapter:

- Outlines the steps taken to determine and prioritize the opportunities and to develop an integrated approach to capture the most promising ones over time.

- Recommends a four-pronged strategy that would maximize the uranium industry's contribution to Saskatchewan's economy today and lay the foundation for the Province's longer-term growth. This strategy details the evolution of the skills, knowledge, and focus that would guide how and when Saskatchewan could pursue each opportunity to realize its goal of greater participation in the value-added components of the uranium value chain. It also describes how the Province's existing capabilities and infrastructure would provide leverage to achieve this goal.

Determining priorities and time sensitivities

The first step in creating an integrated strategy was to prioritize the individual opportunities and the actions necessary to realize them by assessing each one from two perspectives.

- **Current market fundamentals.** Is the market *favourable* (unmet market demand exists, returns are attractive), *in transition* (supply-demand uncertainties likely to be resolved in the near to medium term), or *unfavourable* (no significant or economically attractive market opening exists)?

- **Saskatchewan's competitive position.** Does Saskatchewan already have a *leadership position*, with all the necessary assets and capabilities to be successful? Can the Province position itself to be *competitive with investment*? Or is Saskatchewan clearly *disadvantaged?*

Priority assessment

The **exploration and mining** market is characterized by a growing global demand for uranium, a declining secondary uranium supply, and a positive outlook for prices. Saskatchewan, as a global leader in uranium production, has world-leading expertise, high-grade ore reserves, and potentially large untapped resources.

The **conversion** and **fuel fabrication** markets share many similarities. Both represent markets that are well-served and any growth in demand would be adequately addressed through plans already announced or brownfield expansions of existing facilities. These operations have no major synergies with Saskatchewan's existing mining and milling activities.

By contrast, the growth in the **enrichment** market – combined with attractive margins – is likely to create opportunities for new entrants. The emerging laser enrichment technology, while more than 5 years from being commercially proven, may offer a significant cost advantage over existing technologies and may be a viable technology choice for new entrants.

Baseload electricity demand is growing steadily in both Saskatchewan and Alberta. At the same time, decommissioning of existing facilities will reduce installed capacity. These factors may result in a potential gap of 2,000 to 6,000 MW and create favourable conditions for new **power generation** investments. Nuclear power is attractive as part of the supply mix in the Province, particularly with its low-carbon emissions, the excellent safety record of modern reactors, and the economic attractiveness given anticipated natural gas and carbon prices. Broad-based public support for nuclear generation and an opportunity to leverage lessons from other nuclear provinces strengthen Saskatchewan's ability to successfully incorporate nuclear power into the Province.

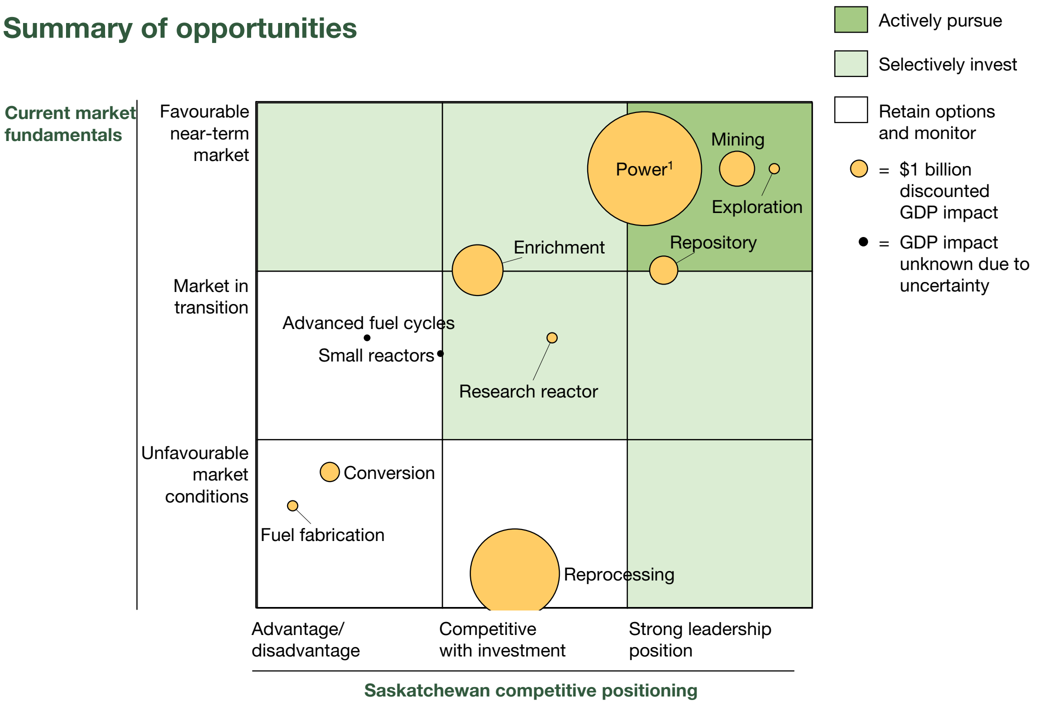
Without a change in Federal policy, **reprocessing** Canada's nuclear used fuel is unattractive to private investment. Saskatchewan lacks the used fuel inventory to make it a natural location for reprocessing should it proceed. However, this positioning may evolve, particularly as the siting process for the **deep geological repository** moves forward, as there is evidence that location-based synergies may exist between these two operations. Canada's current "once through" fuel cycle has a clear need for a repository – and Saskatchewan is under consideration as a potential host, given its position in the uranium value chain and its appropriate geology.

Nuclear **research, development, and training** will be necessary for long-term success in the uranium industry. Saskatchewan has a solid foundation, with existing research and post-secondary education programs relevant to the value chain. The Province also has an opportunity to participate in the industry's technological evolution in selected areas, such as small reactors or advanced fuel cycle technologies. Saskatchewan could enhance its position by constructing a research reactor, the economics of which could be strengthened by integrating medical isotope production into the reactor's design and operation.

This assessment found the opportunities fall into three broad categories: actively pursue; selectively invest; and retain options and monitor. The high-priority opportunities for Saskatchewan appear to be exploration, mining, nuclear power generation, and hosting a used fuel repository (Exhibit 7 - 1). In each of these, the markets have strong fundamentals

EXHIBIT 7-1

Summary of opportunities



1. Based on 3,000 MW of installed nuclear capacity

and Saskatchewan may have an inherent advantage (Exhibit 7 - 1).

Tiime sensitivities

The next step was to develop an approach for capturing these opportunities over time. Some opportunities may be immediate and have a limited time in which they may be successfully pursued, others may have an extended window, and some may not be viable until key market changes occur. Many of these opportunities may also be affected by long development time frames and changing market dynamics.

Although **mining and exploration** are among the high-priority opportunities identified, Saskatchewan is at risk of losing its global leadership position in these areas unless it acts now to renew its resource base given the expected depletion of existing mines, growing competitive pressures from Kazakhstan and Australia, and the long lead times associated with exploration and mine development.

The technology employed for **conversion** and **fuel fabrication** is mature and no significant technological change is anticipated that might upset market dynamics. As a result, there is no clear time sensitivity to these markets.

By contrast, the current development of laser **enrichment** technology creates a window of opportunity for Saskatchewan that, as the technology matures, will begin to close.

The long development cycles of all large baseload **power generation** facilities require Saskatchewan to begin selecting and advancing generation solutions in the near term to address the anticipated supply gap that will be created through the growth in demand and the potential closure of aging generation assets. An early move into nuclear technology, particularly as a regional solution, offers Saskatchewan the potential to serve anticipated regional power demand growth while also positioning the Province to be the lead in Western Canada's nuclear supply chain.

With no supporting Federal policy and unfavourable economics, **reprocessing** is not a strong opportunity at this time. However, Federal policy has been defined for long-term used fuel management, and the NWMO is about to launch a process to site a **deep geological repository**. This process will take time. And the construction, operation, and monitoring of the repository is an extremely long-term endeavour.

Research and development, by its nature, tends to be a long-term investment. However, given the long time frames involved in nuclear research, near-term action is required to position Saskatchewan for long-term success. For example, a research reactor may take upwards of 10 years to be licensed, constructed, and commissioned.

Overall proposed strategy

To emerge as a global player across the entire uranium value chain, Saskatchewan should pursue a four-pronged strategy (see Exhibit 3 - 2):

Grow today's core position in the value chain in uranium exploration and mining to keep pace with the rapidly growing global demand for uranium and to sustain Saskatchewan's position as a global leader.

Attract emerging commercially viable opportunities to the Province, where an unmet market need exists and appropriate technology is available. These new commercial ventures would create a platform of broad value chain participation that will enable the Province to take advantage of new opportunities.

Maintain options for future growth, particularly through developing the infrastructure and capabilities to support new technologies that have substantial future market potential.

Build a centre of excellence in research, development, and training to support innovation and competitiveness in existing commercial operations while laying the groundwork of skills and infrastructure to take a leadership role and capture value-adding opportunities associated with new and emerging technologies.

Initial efforts in the first two prongs would likely draw upon proven commercial technologies. However, as the fourth prong indicates, Saskatchewan's long-term sustainable competitiveness would require a commitment to research, development, and training. This would help ensure the Province could maximize the value captured in each opportunity, as well as create a foundation for participating in emerging technologies. The proposed centre of excellence would leverage and build upon existing infrastructure and capabilities in the Province to provide the necessary leadership in developing the intellectual and human capital for sustained success in the industry.

Given the typically long development cycles in the uranium value chain, the evolution of Saskatchewan's increasing participation in the chain is anticipated to occur over the course of more than a decade. Near-term actions would be required across the strategy's four prongs to lay the groundwork for current and future success. Over time, these actions will need to adapt to reflect the industry's evolution, both within the Province and globally.

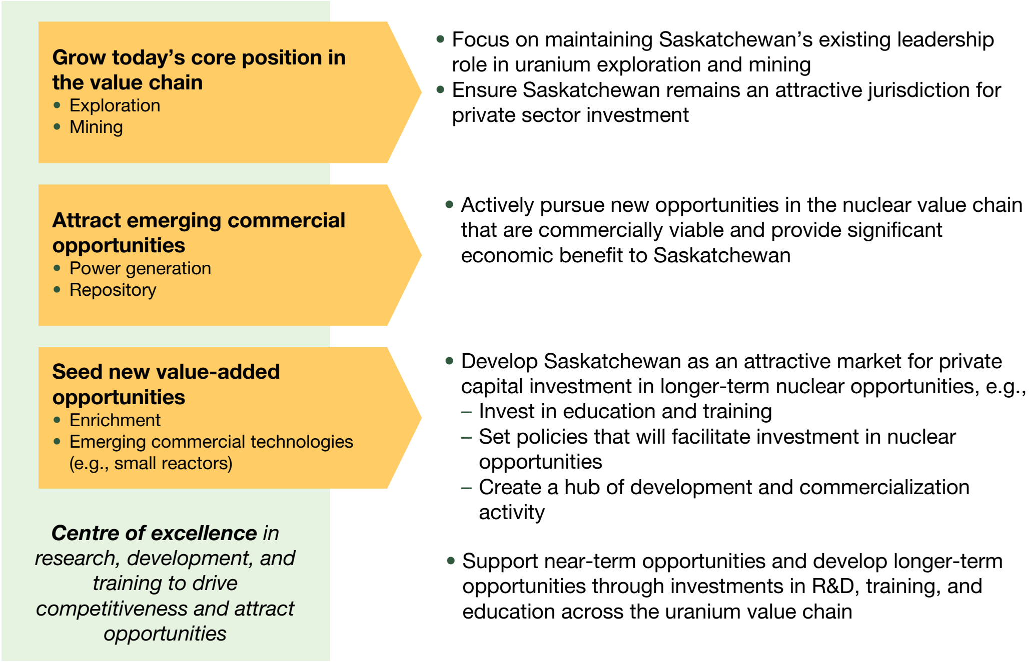
This is illustrated in Exhibit 7 - 3, which shows this potential industry evolution in three time horizons – spanning from today through 2025.

In the **first time horizon**, from 2009-2014, the Province has the opportunity to take bold steps to promote the competitiveness and leadership of current industry positions, create an attractive environment for new commercial ventures to enter Saskatchewan, and begin to develop the necessary technological and human capabilities to capitalize on longer-term opportunities. These initial steps would be crucial to Saskatchewan's ability to retain its leadership position in its core activities and establish itself as a successful player across multiple segments of the value chain.

By 2015, these first steps would have produced results. This may be demonstrated by an exploration and mining sector that remains the world leader, the initiation of a nuclear generation new build process in Saskatchewan, participation through partnerships in the commercialization of key emerging technologies (e.g., enrichment), or the development of

EXHIBIT 7-2

Proposed strategy for Saskatchewan's nuclear industry



Grow today's core position in the value chain
- Exploration
- Mining

- Focus on maintaining Saskatchewan's existing leadership role in uranium exploration and mining
- Ensure Saskatchewan remains an attractive jurisdiction for private sector investment

Attract emerging commercial opportunities
- Power generation
- Repository

- Actively pursue new opportunities in the nuclear value chain that are commercially viable and provide significant economic benefit to Saskatchewan

Seed new value-added opportunities
- Enrichment
- Emerging commercial technologies (e.g., small reactors)

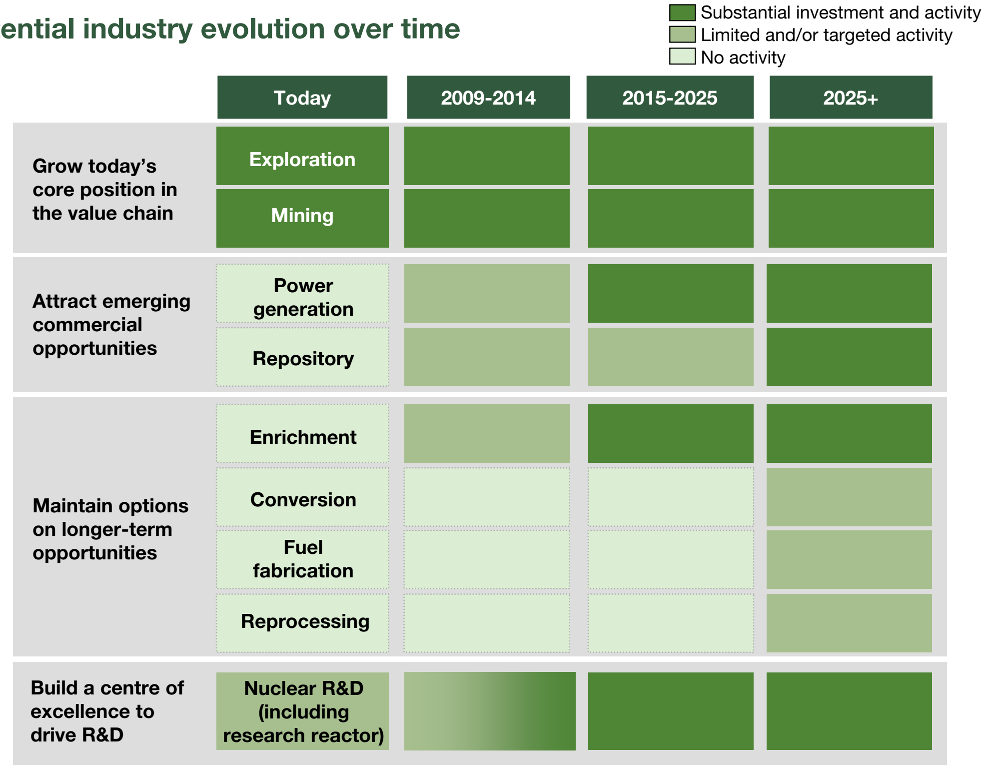
- Develop Saskatchewan as an attractive market for private capital investment in longer-term nuclear opportunities, e.g.,
  - Invest in education and training
  - Set policies that will facilitate investment in nuclear opportunities
  - Create a hub of development and commercialization activity

***Centre of excellence** in research, development, and training to drive competitiveness and attract opportunities*

- Support near-term opportunities and develop longer-term opportunities through investments in R&D, training, and education across the uranium value chain

EXHIBIT 7-3

Potential industry evolution over time



■ Substantial investment and activity
▨ Limited and/or targeted activity
□ No activity

	Today	2009-2014	2015-2025	2025+
Grow today's core position in the value chain	■ Exploration	■	■	■
	■ Mining	■	■	■
Attract emerging commercial opportunities	□ Power generation	▨	■	■
	□ Repository	▨	▨	■
Maintain options on longer-term opportunities	□ Enrichment	▨	■	■
	□ Conversion	□	□	▨
	□ Fuel fabrication	□	□	▨
	□ Reprocessing	□	□	▨
Build a centre of excellence to drive R&D	▨ Nuclear R&D (including research reactor)	▨ → ■	■	■

focused research and development capabilities. Willing host communities of a geological repository may also have come forward.

In the **second time horizon**, from 2015 through 2025, Saskatchewan would be in a position to establish itself as a nuclear Province participating across the value chain. To do so, it would need to deliver on the potential created by its efforts in the first horizon. This may include developing the next generation of globally competitive uranium mines, commissioning the first nuclear generation units in the Province, potentially constructing Canada's first enrichment facility leveraging new laser enrichment technology and, if a willing local host community comes forward, taking the initial steps to develop a deep geological repository in the Province.

By 2025, success may be reflected in Saskatchewan's continued global leadership in its core mining and exploration efforts, coupled with meaningful investment and participation in multiple additional segments of the value chain and a larger and more diverse corporate office presence. A new research reactor may also come online within this time frame.

In the **third time horizon**, extending beyond 2025, Saskatchewan would have established core investments across the value chain that would create a range of new options and opportunities. Earlier moves would have strengthened exploration and mining, established a presence in nuclear generation and potentially repository and enrichment, and expanded targeted research and development capabilities.

When integrated, these in-Province activities would provide Saskatchewan with a world-leading presence throughout the value chain. New opportunities may then emerge as a result of these comprehensive capabilities or through external changes to market conditions that Saskatchewan would be well-prepared to evaluate and, if appropriate, successfully pursue.

Appendix A: Health and safety considerations of nuclear power

Key findings

a. Modern nuclear power plants are widely regarded as an extremely safe means of generating electricity.

   - In terms of operational safety, nuclear is 10 times safer than natural gas, the next safest form of electricity generation.
   - Under normal operations, worker radiation exposure is near naturally occurring levels and presents no known health risks.
   - Public exposure levels from nuclear power are significantly below naturally occurring levels and come with no known health risks.
   - Mitigating the threat of accident in the reactor core has been the primary focus for the industry since Generation I reactors were first introduced in 1950. Today's Generation III(+) reactors are designed to be even safer than those in operation.

b. The Canadian Nuclear Safety Commission (CNSC) is an independent governing body that provides a regulatory framework to manage all nuclear activity in the country. The CNSC also co-operates closely with the International Atomic Energy Agency (IAEA) to ensure that international standards are followed.

c. There are some occupational hazards associated with all underground mining, but significant strides in technology have been made to help reduce these risks in Canada's uranium mining industry.

High-level overview

The current and potential risks associated with the nuclear industry have been the subject of detailed reports by a range of international agencies. The focus of many of these reports has been on the accidents at both Chernobyl and Three Mile Island – two events that have come to dominate the public perception of the key risks of nuclear power. As these reports show, however, improvements in reactor design, regulation, and culture have fundamentally changed the nuclear safety landscape.

The purpose of this section is to review the findings from major studies on nuclear safety, as well as to briefly describe the regulatory environment that is in place to ensure continued safe operations across the nuclear value chain in Canada.

a. Modern nuclear power plants are widely regarded as an extremely safe means of generating electricity

Safe nuclear power requires protecting plant workers and the general public from undue radiation exposure during normal plant operations and ensuring the probability of radiation exposure due to a reactor core accident is held to vanishingly small levels.

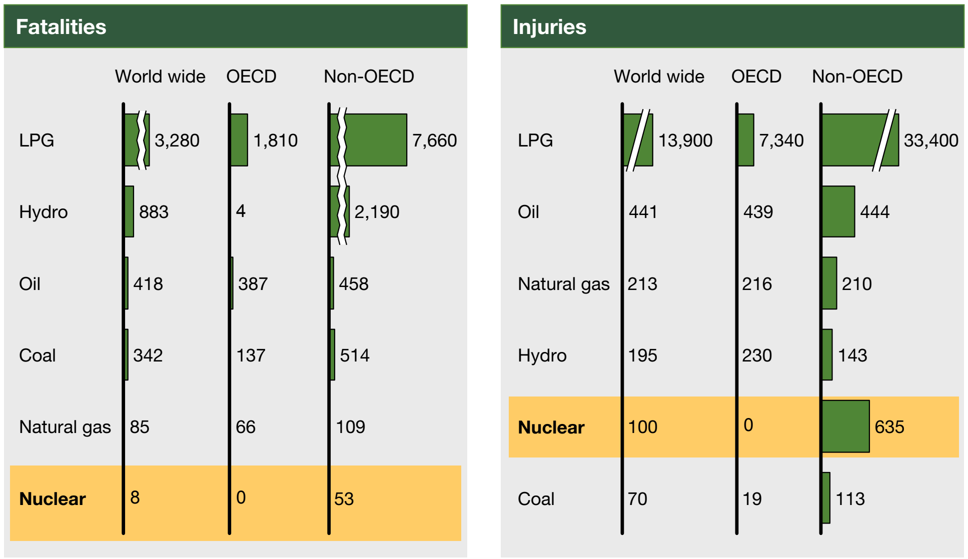
Worker safety

The nuclear power industry has the lowest direct fatality rates among power generation technologies (e.g., hydro, coal, and natural gas). One of the most comprehensive recent studies on the comparative operational safety of energy systems was done by the Paul Scherrer Institut in Switzerland in 1998. The Institut has a database of 13,914 severe accidents across all industries – 4,290 of which are energy system related. Commissioned by

EXHIBIT A-1

Severe accidents at power generation facilities in OECD and non-OECD countries

Per TWa



Source: *Severe accident analysis for large energy systems*. Paul Scherrer Institut, 1998

the Swiss Federal Office of Energy, the study examined severe accidents for major power generating facilities, including coal, oil, natural gas, hydro, and nuclear.

The study's findings reveal that nuclear is the safest form of energy generation in terms of loss of human life and is 10 times safer than natural gas, the next safest form.[130] In Canada, there have been no fatal accidents from the operation of nuclear facilities.

Exposure to ionizing radiation is a risk facing nuclear power workers; however, thanks to strict worker health and safety protocols, numerous studies have shown that radiation exposure for workers in nuclear power is near naturally occurring levels and presents no health risks. The globally observed radiation exposure for workers in the uranium value chain is no more than 6 mSv[131] per year.[132]

These levels are significantly below the CNSC threshold for nuclear workers set at 100 mSv in a 5-year dosimetry period, with no more than 50 mSv in any single year.[133] No health effects from radiation have been observed in humans below about 100 mSv of exposure.

To comply with these limits, radiation protection regimes have been put in place throughout the nuclear value chain based upon the "as low as reasonably achievable" (ALARA) principle.[134] In practice, this means weighing the incremental economic cost of adding another layer of protection against the radiation risk.

Scientific bodies including the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) and the National Academy of Science (NAS) have studied the effect of radiation on workers extensively,

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[130] *Severe accident analysis for large energy systems*. Paul Scherrer Institut, 1998.

[131] A millisievert is one one-thousandth of a sievert, which is a unit for expressing dosages of radiation.

[132] *Appendix E*. UNSCEAR. Page 512.

[133] *Canadian National Report for the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management, Annex 5*. Government of Canada. Page 98.

[134] *Nuclear Electricity Generation: What are the external costs?* OECD, NEA.

with a particular focus on stochastic rather than deterministic effects because of generally low-level exposures of radiation.[135]

In June 2005, the NAS released its report, *Health risks from exposure to low levels of ionizing radiation*.[136] The study confirms that the risk of health effects from exposure to low levels of radiation is small and concludes that current radiation protection standards for workers and the public remain appropriate. This report forms the updated scientific basis for radiation safety standards in the United States for the next decade.[137]

Several reports have been written that focus on specific areas of the nuclear value chain, with a large number evaluating power generation given that radiation levels for nuclear power workers are higher than those for workers in other parts of the value chain.

- In the United States, one of the larger reports focused on a group of about 36,000 workers at the Hanford, Oak Ridge, and Rocky Flats facilities; the results showed no increasing trend of risk of any cancer or leukemia with dose.[138]

- In the United Kingdom, the National Registry for Radiation Workers (NRRW) looked at approximately 125,000 workers. Overall, their study found that socio-economic status (as indicated by employment status) had a greater influence on mortality than did radiation exposure.[139]

Public safety

The variation of doses over time and by geography make it difficult to summarize the average dose to the public. The UN Scientific Committee, however, suggests that the average annual dose from natural sources is 2.4 mSv.[140] Less than 0.1 percent of radiation to the public comes from the nuclear industry.[141]

Despite low levels of exposure, the effects on civilians living near nuclear facilities have been the subject of extensive research. These studies, conducted in Canada and other countries, have focused on the stochastic or long-term effects of low levels of radiation. Thus far, no adverse health effects have been observed. Two important North American studies are often cited:

- A 1990 study by the US National Cancer Institute examining 62 communities with major nuclear facilities whose overall results showed no evidence of any increase in cancer.[142]

- In Canada, an ecologic study was conducted to determine whether the health of residents in the vicinity of Ontario-based nuclear facilities differed from the provincial average. Overall there was no evidence of excess health effects.[143]

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[135] Stochastic effects include cancers and inheritable defects, which result from damage to the genetic material (DNA) in cells; deterministic effects result from a relatively high dose experienced over a short time period.
Radiation Emergencies. World Health Organization. Page 1.

[136] *Biological Effects of Ionizing Radiation* BEIR VII Committee.

[137] *Radiation safety at nuclear power plants fact sheet*. Nuclear Energy Institute, Feburary 2008. Page 1.

[138] *Health and Safety Background Paper*. Nuclear Waste Management Organization.

[139] McGeoghegan, Dave, Keith Binks, Michael Gillies, Steve Jones, and Steve Whaley. *The non-cancer mortality experience of male workers at British Nuclear Fuels plc, 1946-2005*.

[140] *Report on the effects of atomic radiation*. United Nations Scientific Committee. Page 29.

[141] *Radiation Emergencies*. World Health Organization. Page 1.

[142] *Cancer in Populations Living Near Nuclear Facilities* looked at the health of populations in areas near 62 major nuclear facilities. Health and Safety Background Paper. Nuclear Waste Management Organization.

[143] The report considered leukemia cases and deaths at ages 0-4, and a second report considered deaths at ages 0-14. These facilities comprised the AECL Laboratories at Chalk River (which started operations in 1944), a uranium processing plant at Port Hope (1935), a uranium mining and milling plant at Elliot Lake (1954), and six power reactors. McLaughlin, John R., E. Aileen Clarke, E. Diane Nishri, and Terence W. Anderson. *Childhood Leukemia in the Vicinity of Canadian Nuclear Facilities*.

Protection from nuclear accidents

The single most important issue facing nuclear power is the threat of an accident occurring in the reactor core. As a result, finding ways to improve reactor designs has been a focus for the industry since Generation I reactors were first introduced in 1950.

The first major safety changes came in the early 1960s when early Generation I reactors were being replaced with, or upgraded to, Generation II reactors. During this time, a wide range of technology prototypes were discontinued.

Improvements also occurred during the 1970s and the early 1980s, when computerization of control systems and faster acting controls were widely introduced.[144] These changes allowed workers to monitor reactor systems for normal operations, as well as for anticipated operational occurrences (AOO). This helped to decrease the likelihood of reactor core damage and, as a result, the likelihood of an accident.

Two nuclear safety incidents have been widely cited as examples of nuclear power's inherent danger. In 1979, the Three Mile Island Nuclear Generating Station suffered a partial core meltdown, initially caused by a faulty valve and exacerbated by operator failure to stem the resulting loss of coolant.

This accident caused no injuries, and the amount of radiation released into the atmosphere was negligible. The *Kemeny Commission Report* concluded that "there will either be no case of cancer or the number of cases will be so small that it will never be possible to detect them. The same conclusion applies to the other possible health effects." Several epidemiological studies in the years since the accident have supported the conclusion that radiation released from the accident had no perceptible effect on cancer incidence in residents near the plant.

In 1986, operators at the Chernobyl power plant in the Ukraine intentionally deactivated parts of the reactor's safety system. This caused a chain of events that ultimately resulted in a reactor core meltdown with release of radioactive elements into the air – unmitigated due to the lack of a proper containment structure in this particular reactor's design. The Chernobyl Forum, a joint effort of eight United Nations organizations, estimated in 2005 that the radioactivity released will eventually cause up to 4,000 premature deaths among the approximately 600,000 individuals who received significant excess exposure as a result of the accident.

In response to these unfortunate incidents, nuclear regulations have been tightened globally, and the nuclear industry has focused on increasing the safety of their reactors. Generation III reactors continued to build on existing safety features and by the late 1980s the major safety advancements included:

- A greater degree of redundant safety systems to further minimize the impact of a component failure on overall plant safety.
- Detailed analysis and large-scale testing of reactor components based on design basis accidents (DBA) and beyond design basis accidents (BDBA),[145] leading to improvements in construction material and system design.
- Additional physical barriers between the atmosphere and reactor core to contain the release of radioactive material in the unlikely event of reactor core damage; this follows the "defense in-depth" philosophy of nuclear design.[146]
- Passive safety systems that do not rely on human intervention to provide plant protection (i.e., eliminating the need for emergency pumps and diesel generators).

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[144] Canada was the first to use digital control in its Pickering reactors built in the late 1960s.

[145] DBA are accidents that a nuclear facility must bedesigned to withstand, whereas BDBA are accidents that are deemed so unlikely that they do not need to be incorporated into the facility design. US Nuclear Regulatory Commission.

[146] A design and operational philosophy with regard to nuclear facilities that calls for multiple layers of protection to prevent and mitigate accidents. US Nuclear Regulatory Commission.

- Re-enforced reactor building containment walls to protect the plant in the unlikely event of an aircraft strike.
- Seismic qualification of critical safety equipment.

In Canada, CANDU reactor design closely followed these developments. Today, some of the specific features that are in place to protect Canadians against a nuclear accident include:

- **Non-combustible moderator:** Heavy water is used as the moderator in CANDU reactors.
- **Reactivity control:** Cadmium shutoff rods are gravity fed vertically into the reactor to absorb neutrons and stop the nuclear chain reaction. A second system involves injecting gadolinium nitrate dissolved in heavy water – this absorbs neutrons and terminates the chain reaction.[147]
- **Emergency Core Cooling System:** To ensure the reactor does not overheat, this system can inject a large quantity of pressurized water in emergency situations.[148]
- **Several layers protecting the reactor core:** These include massive steel reactor vaults that are capable of handling the release of high pressure steam.[149]

b. The Canadian Nuclear Safety Commission (CNSC) is an independent governing body that provides a regulatory framework to manage all nuclear activity in the country. The CNSC also co-operates closely with the International Atomic Energy Agency (IAEA) to ensure that international standards are followed

In Canada, the Canadian Nuclear Safety Commission (CNSC) is responsible for ensuring the public, the environment, and workers are protected from any potential effects of nuclear energy and that all international industry guidelines are followed.

The CNSC operates as an independent agency of the Federal Government that reports to Parliament (via the Minister of Natural Resources). The agency has no role in promoting nuclear power and is split into a decision-making Commission Tribunal and a staff organization including technical experts in nuclear safety and controls.[150]

One of the main responsibilities of the Commission Tribunal is to run the nuclear licensing process. Before being granted a license or renewal, licensees are required to prove to the CNSC that their facility or activity is acceptably safe. The CNSC approach to safety assumes that nothing is 100 percent risk free, but that risk can be minimized through multiple layers of verifiable protection.[151] When a facility is licensed, the staff organization supports the compliance activities (among other things) and ensures that domestic nuclear operators provide quarterly reports highlighting radioactive discharges.

The CNSC has responsibilities outside Canada and is charged with implementing the Canada/IAEA safeguards. The IAEA, using CNSC-supplied reports, inspects and monitors nuclear activities, verifying material flows and inventories as required under Canada's safeguards agreement.[152] The CNSC also cooperates with the IAEA to develop new safeguards approaches for Canadian facilities.

c. There are some occupational hazards associated with all underground mining, but significant strides in technology have been made to help reduce these risks in Canada's uranium mining industry

Mine worker exposure to radon decay products (RDP) has been more difficult to control than other forms of low-level radiation. Radon is a colourless, odourless, tasteless radioactive gas

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[147] *Safety in the nuclear industry*. Canadian Nuclear Association.
[148] *Safety in the nuclear industry*. Canadian Nuclear Association.
[149] *Safety in the nuclear industry*. Canadian Nuclear Association.
[150] Canadian Nuclear Safety Commission.
[151] *How is nuclear technology regulated in Canada*? Canadian Nuclear FAQ. http://nuclearfaq.ca.
[152] *International Responsibilities*. Canadian Nuclear Safety Commission.

that comes from the natural decay of radium found in nearly all rock and soils and poses a risk for many types of mining, including uranium, coal, and iron ore.[153]

Various cohorts of uranium mine workers have been examined to determine the relationship between RDP exposure and the risk of lung cancer. At least 11 such studies have shown a linear relationship between radon exposure and risk of lung cancer.[154]

One of the more significant studies was conducted in Canada for uranium miners who worked for Eldorado Nuclear Limited. The report, updated in 2006, presents the results of statistical analysis of a cohort of 17,660 workers known to have worked for Eldorado for some period of time between 1930 and 1999.[155]

The findings from the report, which are consistent with other studies, have indicated that underground miners have a higher incidence of lung cancer than the public. Several other occupational exposures have shown similar results.

As a result, modern mining safety technologies such as remote-controlled mining have been developed to reduce workers' direct exposure to radon. Today, uranium miners in Saskatchewan have radon exposures that are between 100 and 1,000 times lower than the exposures of past uranium miners.[156]

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[153] *Radiation risks and realities*. United States Environmental Protection Agency. May 2007. Page 5.

[154] Lubin, Boice, et al., 1994.

[155] Howe, Dr. Geoffrey R. *Updated analysis of the Eldorado Uranium Miners' cohort: Part I of the Saskatchewan Uranium Miners' cohort study*.

[156] Statistics Canada.

Appendix B: Managing the risks of nuclear proliferation

Key findings

a. Political safeguards have largely succeeded in preventing additional nations from acquiring nuclear weapons and ensuring global cooperation regarding the peaceful uses of nuclear energy. These safeguards consist mostly of multilateral agreements and organizations including the Treaty on the Non-Proliferation of Nuclear Weapons, the International Atomic Energy Agency, and the Nuclear Suppliers Group.

b. Several technical safeguards exist in the design of nuclear power plants, reprocessing facilities, and enrichment facilities to minimize the availability of fissile material for diversion.

c. Canada's proliferation risk is currently limited to its power generation program, which has several effective technical and regulatory safeguards in place to prevent the diversion of fissile material.

High-level overview

Nuclear proliferation is a term used to describe the development of nuclear weapons programs, including the spread of fissile material and weapons-development technology to non-nuclear-weapon States.[157] Though the term has traditionally referred to sovereign nations acquiring nuclear weapons, it has been extended to refer to the diversion of fissile or radioactive materials (highly enriched uranium or plutonium-239) to any groups with the intention of developing a weapon.[158] [159]

Three phases in the nuclear value chain may be susceptible to proliferation risk: nuclear power generation, uranium enrichment, and used fuel reprocessing. As a result, several preventative technical, regulatory, and physical safeguards have been put in place to mitigate this risk.

a. Political safeguards have largely succeeeded in preventing additional nations from acquiring nuclear weapons and ensuring global cooperation regarding the peaceful uses of nuclear energy. These safeguards consist mostly of multilateral agreements and organizations including the Treaty on the Non-Proliferation of Nuclear Weapons, the International Atomic Energy Agency, and the Nuclear Suppliers Group

Although technological safeguards will continue to be applied to ensure the peaceful use of nuclear technology, proliferation is also a matter of political will[160] and therefore requires a political solution. Accordingly, several international agreements and institutions have been established over the past century – chief among them, the Treaty on the Non-Proliferation of Nuclear Weapons (NPT), the International Atomic Energy Agency (IAEA), and the Nuclear Suppliers Group.

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[157] As defined by the Treaty on the Non-Proliferation of Nuclear Weapons.

[158] *All about nuclear energy*. AREVA, 2008. Page 134.

[159] Can include dirty bombs, which are designed to widely disperse radioactive material, as opposed to the use of fissile material to generate an explosion.

[160] *All about nuclear energy*. AREVA, 2008. Page 139.

The NPT, established in 1970, is an agreement that denounces the development of nuclear weapons outside of the five original nuclear-weapon States (NWS) – China, France, Russia, the United Kingdom, and the United States – and pledges cooperation and trade between signatories with respect to the peaceful use of nuclear energy. At present, 187 countries are signatories of the NPT.[161] Notable exceptions include India, Pakistan, North Korea, and Israel, all of which have nuclear weapons.[162]

The IAEA is responsible for verifying nations' compliance with NPT guidelines on peaceful fuel cycle activities. Its inspections include document auditing, inventory checks, and materials analysis, all of which are designed to prevent the diversion of fissile material or the development of sensitive technologies. Nations that do not comply with IAEA inspections or NPT guidelines are met with sanctions.

In addition to the NPT, several multilateral agreements, such as the Nuclear Suppliers Group (NSG), have been established to monitor and control the export of materials and technology along the nuclear value chain.

Although political efforts and treaties have failed to completely restrain the spread of nuclear weapons, the safeguards have contributed greatly to non-proliferation. In 1960, it was expected that there would be 30 to 35 weaponized States by the turn of the century[163] – that there are now only nine highlights the NPT's effectiveness. For example, the NPT has largely succeeded in preventing the development of weapons from civilian energy programs: of the four weaponized non-NWS nations (India, Pakistan, Israel, and North Korea), three had no energy program at the time of their weapons development.

b. Several technical safeguards exist in the design of nuclear power plants, reprocessing facilities, and enrichment facilities to minimize the availability of fissile material for diversion

Nuclear power's greatest safeguard is in the design of its plants. A nuclear power plant uses uranium enriched to levels of 0.7 to 5.0 percent, whereas weapons require at least 90 percent enrichment.[164] Any fuel redirected from a plant requires further enrichment before it can be used in a weapon. These safeguards are also in place with used fuel. Fuel must undergo short periods in a reactor to produce significant amounts of plutonium-239 (a fissile material). With additional time in the reactor, as in the normal fueling cycle, plutonium has time to become Pu-240, which cannot be used in a weapon. Peaceful energy programs fully burn their fuel for non-proliferation and economic reasons, which leaves a large proportion of Pu-240 remaining in the used fuel. Additionally, the short fuel cycles required to produce Pu-239 are nearly impossible to camouflage in most reactor designs, given that the required plant shutdowns can be spotted by regulators or satellites. In the unlikely event that plutonium is redirected to a weapons program, it requires further chemical separation at a reprocessing facility before it can be used.

As a result of advancements in centrifugal technology, isotopic enrichment is arguably the greatest source of proliferation risk, as it can be used to enrich uranium to highly fissile levels. To address this risk, tight international controls on enrichment technology and the movement and supply of enriched uranium are required. With these controls in place, enriched uranium cannot easily be diverted from a large-scale civilian enrichment facility.

A reprocessing facility that separates pure plutonium from used fuel could be prone to diversion risk. However, new methods for producing MOX fuel, which cannot be used in a bomb, involve immediately mixing separated plutonium with depleted or raw uranium, thereby eliminating the presence of pure plutonium in the reprocessing phase.

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[161] *Safeguards to Prevent Nuclear Proliferation*. World Nuclear Association. 2009.

[162] *Safeguards to Prevent Nuclear Proliferation*. World Nuclear Association. 2009.

[163] *Safeguards to Prevent Nuclear Proliferation*. World Nuclear Association. 2009.

[164] *Uranium Enrichment*. World Nuclear Association, 2009.

c. Canada's proliferation risk is currently limited to its power generation program, which has several effective technical and regulatory safeguards in place to prevent the diversion of fissile material

Canada is a signatory of the NPT and has expressed no interest in developing nuclear weapons. Accordingly, Canada's proliferation risk is limited to the unauthorized diversion of nuclear materials. Of the three phases of the nuclear value chain susceptible to this (power generation, reprocessing, and enrichment), Canada currently only plays a role in power generation.

All of Canada's nuclear fleet currently consists of CANDU reactors.[165] [166] These reactors use natural uranium, which cannot be used in a nuclear weapon. This leaves the plutonium-239 contained in the used fuel coming out of reactors as the sole source of potential diversion. Not only does Canada's nuclear fleet abide by the guidelines outlined by the NPT, but it is also governed by the authority of the Canadian Nuclear Safety Commission (CNSC). As Class I nuclear facilities, power plants must have measures in place to facilitate Canada's compliance with applicable safeguards,[167] including the requirement for armed security personnel. In its 50 years as a nuclear-capable nation, Canada has experienced no diversion of material from its facilities for malicious intent.

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165 The National Research Universal Reactor at Chalk River is an exception that uses enriched uranium.

166 *Canada's Uranium Production & Nuclear Power*. World Nuclear Association, 2009.

167 *Class I Nuclear Facilities Regulations*. Canadian Nuclear Safety Commission, 2000. http://laws.justice.gc.ca/en/ShowFullDoc/cr/sor-2000-204///en.

Appendix C: Introduction to medical isotopes

Key findings

a. Medical isotopes are trace amounts of radioactive materials produced in a reactor that are combined with pharmaceutical agents for medical applications, including diagnostic imaging, radiation therapy, and therapeutic drugs.

b. Molybdenum-99 is the world's most important medical isotope, accounting for 80 to 85 percent of nuclear medicine procedures. Its short half-life requires constant production and a highly co-ordinated supply chain.

a. Medical isotopes are trace amounts of radioactive materials produced in a reactor that are combined with pharmaceutical agents for medical applications, including diagnostic imaging, radiation therapy, and therapeutic drugs

Isotopes are variants of chemical elements; each specific isotope is characterized by a different atomic mass and radioactivity. A radioisotope is a measurably radioactive isotope of an element and is characterized as having excess energy in its nucleus, which may be released as radiation, the emission of gamma rays, or subatomic particles. Many radioisotopes exist, often occurring naturally in nature – but only a certain variety, with very specific characteristics, are applicable in medical applications.

To be useful, isotopes must have a particular radioactivity profile, defined by both the energy released during decay and the rate of decay or half-life (the time required for half of the nuclei in a sample to decay). The radioactive content in isotopes is typically measured in curies, one of which is equal to the decay of 37 billion atoms per second.[168] Because isotopes are often injected into patients, they must exhibit a short enough half-life (on the scale of hours or days) to prevent long-term tissue damage. Additionally, to prevent unnecessary overexposure to the body, they typically are designed to target specific tissues, either through the body's natural absorption of

Medical applications of radioisotopes

Several isotopes with unique medical applications can be created as a result of the radioactivity within a nuclear reactor. These medical isotopes serve three different functions: medical imaging, radiation therapy, and therapeutic drugs.

- **Diagnostic imaging –** isotopes are injected into a patient along with a pharmaceutical companion agent that targets the isotopes to specific issues, which can then be detected by specialized imaging machines. Technetium-99m is the most commonly used imaging isotope, and its parent, molybdenum-99 (Mo-99), is the world's most in-demand medical isotope.
- **Radiation therapy –** radiation emitted from an isotope source is directed onto a tumour to destroy cancerous cells. Iodine-125, for example, is used as a therapy treatment for prostatic carcinoma.
- **Therapeutic drugs –** isotopes are manufactured into injectable/insertable drugs for cancer treatment (e.g., Brachytherapy, a type of cancer treatment where the radioactive source is placed inside the body). Cobalt-60 is the most commonly used isotope in therapeutic drugs.

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[168] *Encyclopedia Britannica*, 2009.

particular elements (e.g., the thyroid's absorption of iodine) or through combination with a pharmaceutical agent.

b. Molybdenum-99 is the world's most important medical isotope, accounting for 80 to 85 percent of nuclear medicine procedures. Its short half-life requires constant production and a highly coordinated supply chain

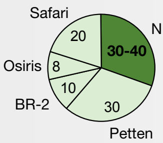
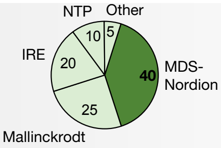
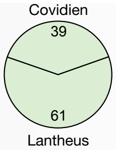
The most common means of producing medical isotopes is through irradiation in a nuclear reactor. Currently, the production of major medical isotopes is highly concentrated, with a small number of research reactors accounting for a significant majority of global production. Given the relatively short half-life of these medical isotopes, they must be manufactured on a regular basis or shortages will occur. This requires specifically tailored facility design and operation, conditions that are best met by research reactors rather than large electricity generating reactors.

About 40 million nuclear medicine procedures are performed annually worldwide, with 20 million in North America and 1.5 million in Canada. Presently, 80 to 85 percent of these procedures use molybdenum-99, making it the most important medical isotope.[169] The final isotope used in these medical procedures is technetium-99m because of its short, 6-hour half-life. When administered, it emits radiation for long enough to collect imaging data, but it decays quickly enough to eliminate the danger of long-term exposure.

Technetium-99m is collected from the decay of Mo-99, which has a longer half-life of 66 hours.[170] Mo-99 is typically produced and extracted at a research reactor, shipped to a processing facility for purification, then sent to a manufacturing facility where small

EXHIBIT C-1

Molybdenum-99 value chain

	Reactor	Purification and processing	Tc-99 generator manufacturing	Hospital/patient
Time at stage	**5-7 days**	**1-2 days**	**1-2 days**	**Up to 1 week**
Global market share[1] Percent				
Description	• Molybdenum/uranium alloy targets are entered into reactor • Molybdenum-99 is a fission product of high enriched uranium (HEU) in a reactor • Targets are removed and separated by hand within hot cell	• Molybdenum-99 is further processed and purified into a solution • Solution is shipped to generator manufacturing facilities • Molybdenum's 66-hour half-life allows for enough time for significant material to reach patient	• Generators are manufactured that are capable of recovering Technetium-99m (Tc-99m) from the decay of molybdenum-99	• Technetium-99m, gradually produced from the generator, is combined with companion agent (targets specific tissues) for injection into patient • Technetium-99m decays into technetium-99 and releases radiation
Normalized sale price	$100-200	$225-450	$550-900	$900-1,150

[1] Generator market share based only on US sales

Source: National Research Council

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169 *Making Medical Isotopes*. TRIUMF, 2000. Page 7.

170 *Medical Isotope Production Without Highly Enriched Uranium*. National Research Council, 2009. Page 8.

quantities are assembled in technetium-99m generators that slowly release Tc-99m, before it is finally sent to hospitals, where it is mixed with pharmaceuticals and administered to patients. Because of Mo-99's short half-life, this process needs to be done quickly; it typically takes from 2 to 10 days. As a result, Mo-99 sold on the market is conventionally quoted in 6-day curies, which adjusts for the loss of radioactivity in the 6 days between shipment and average use.

Appendix D: Small reactors

Key findings

a. Because they require little or no refueling and produce both heat and electricity, small reactors could eventually compete with small-scale diesel, oil, and gas generation as a power alternative in remote sites.

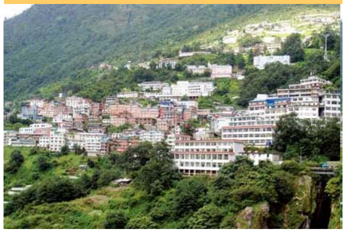
b. Although several companies are pursuing small reactor designs, no licensed solution exists. Saskatchewan has the opportunity to participate in this market by partnering with a commercial technology developer on a demonstration project.

a. Because they require little or no refueling and produce both heat and electricity, small reactors could eventually compete with small-scale diesel, oil, and gas generation as a power alternative in remote sites

As the world's demand for power grows, so too does its need for niche power generation alternatives to meet the increasingly complex requirements of communities and industry. Large-scale nuclear power reactors are expected to grow in popularity over the coming decades to power the world's major urban and industrial centres. The need for much smaller-scale applications has prompted entrepreneurs to begin pursuing the development of very

EXHIBIT D-1

Power remote communities



- Remote towns with **no access to transmission grids must import power via diesel or propane**
- Excess **thermal output can efficiently be used as a heating solution** (medium-sized reactors are already being utilized for this purpose in Siberia)

Industrial applications

- Remote industrial operations with power-intensive processes (e.g., mining, desalination) could utilize small reactors and **save on transmission or diesel costs**
- **Unused heat can be used for distillation desalination** with minimal (~3.5 MW) electrical loss
  - Russian KLT-40s (150 MWt, 35 MWe), currently used for mega-scale nuclear ships, are proposed for use in remote desalination

Cogeneration

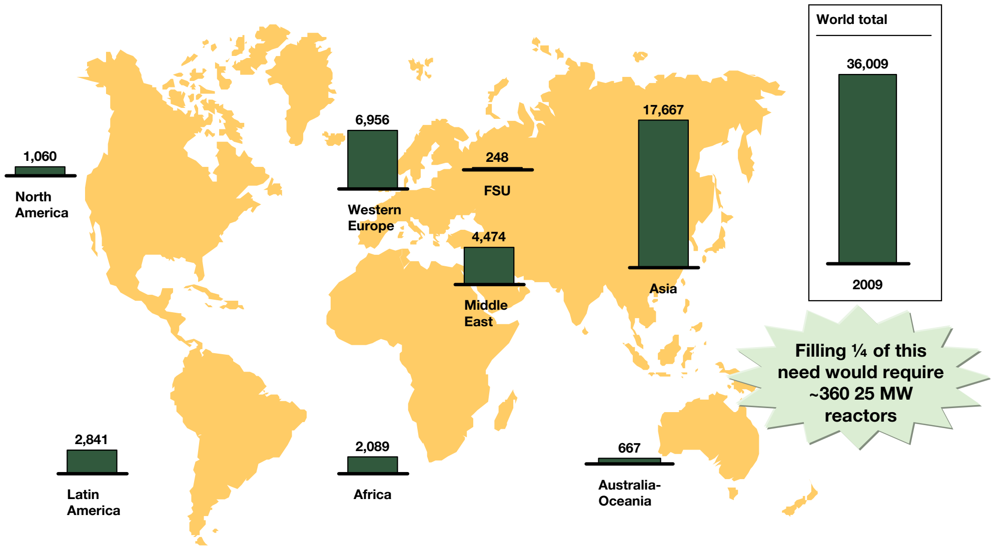
- The unutilized steam output of a nuclear plant can be used in industrial applications, particularly at the oil sands
- 2,100 MW of cogeneration capacity, **the equivalent of ~50 small reactors, is already planned for the Alberta oil sands** by 2020

Source: WNA; press

EXHIBIT D-2

Small-scale[1] off-grid oil/diesel generation capacity

MW



Filling ¼ of this need would require ~360 25 MW reactors

1 Defined as 5 MWe-100 MWe

Source: UDI Power Generation Database

EXHIBIT D-3

Illustrative small reactor technologies

🟩 Thermal

🟧 Electricity

Technology	Description	Power output MW	Commercialization	Benefits/issues
TOSHIBA	• Toshiba 4S (super safe, small and simple) reactor • Small reactor buried 30 metres underground with room-sized station on ground • Joint development between Toshiba and Central Research Institute of Electric Power Industry of Japan	n/a 10 or 50	• Will apply for NRC approval in 2009 with expectations of approval as early as 2013 • Currently in pre-application review for its proposed plant in Galena, Alaska	• Liquid metal coolant allows lower pressure, preventing excess pipe corrosion • Operates for 30 years without refuelling • Targeted to produce power between $0.05-$0.13/kWh (operating cost)
NUSCALE POWER	• Oregon-based company with VC funding • Reactor designed largely by Oregon State University • Small-scale and simple LWR • Goal to displace gas turbines	150 45	• Light water design might speed up certification process	• Light water design relies on existing research and development • Passive safety (natural cooling circulation) avoids potential pump or valve failure
HYPERION	• Based on technology developed at Los Alamos National Laboratory • Hydrogen moderated and potassium cooled • Received VC funding in 2008 • Goal to build prototype for under $100 million with cost target of $25 million to $32 million	75 25	• Plan to submit US design certification application to NRC by 2009, approval possible as early 2012-2015 • "NRC skill set and tools are lacking for LMR and hydride reactor" – NRC	• Inherent safety (reactivity lowers at greater temperatures) • Buried in ground and requires refuelling every 5-7 years • Small size: 1.5 x 1.5 x 2.0 metres • Fewer non-proliferation risks with uranium hydride fuel that would likely require enrichment
Other	• 3 other major reactor designs below 100 MWe – CAREM (CNEA), KLT-40 (Russia), MRX (Japan), IRIS-100 (Westinghouse), SMART (Korea), • Larger, 100-300 MWe reactors include NP-300 (Areva), Fuji (Japan/Russia/US)	90-300 27-100	• Each design's commercialization potential varies with origin country • Some existing demonstrations exist but are not viable for North American application (e.g., KLT-40 icebreaker reactor) • South Korea's SMART is in demo phase	• Designs vary, with benefits balancing commercial viability, safety features, and energy efficiency

Source: WNA; Company literature

small (10 to 50 MW of electrical generation capacity) nuclear reactors.

Small reactors would potentially have three primary advantages over alternative diesel or oil generators. First, they would require very infrequent refueling. Proposed technologies require refueling as little as once every 5 to 30 years.[171] Second, their high thermal output could be captured and used for heat or steam supply. Third, depending on the difficulty of fuel delivery of diesel or oil alternatives, they could be considerably more cost effective. These benefits lend themselves to powering and heating remote off-grid communities and supporting remote industrial applications like water desalinization plants or refineries. As this technology matures, it may also become increasingly competitive in other applications, such as cogeneration targeted at the Alberta oil sands.

The total global potential power generation market for such applications is approximately 36,000 MW,[172] based on current small-scale, off-grid oil and diesel-fired generation capacity. Asia accounts for almost half of this capacity and could likely drive the majority of future growth. Displacing just one-quarter of this diesel/oil capacity would require roughly 360 small reactors with 25 MW generation capacity.

b. Although several companies are pursuing small reactor designs, no licensed solution exists. Saskatchewan has the opportunity to participate in this market by partnering with a commercial technology developer on a demonstration project

Several companies are pursuing the commercialization of small reactor technologies. Each major technology is designed to operate with little ongoing maintenance and, therefore, requires several safety features and specialized components to ensure a long operating life.

The most advanced solution relevant to North American applications is being led by Toshiba, who, with its 4S (Super Safe, Small and Simple) reactor, has a proposal in place for a demonstration facility in Galena, Alaska. In exchange for Toshiba covering all construction costs, the community of Galena has agreed to host the facility. Toshiba plans to apply for NRC approval in 2009, with hopes for approval as early as 2013. Despite being furthest down the path of commercialization, the 4S reactor design will likely require relatively long NRC approval because of its novel technologies and use of liquid metal coolant to prevent corrosion and eliminate refueling over its operating life.

Competitors vary in their approach to commercialization; some favour speedier regulatory approval over more advanced technologies. NuScale's reactor, for example, is a light water design with specifications that already exist within the NRC regulatory framework.

Saskatchewan could participate in this market by partnering with one or more commercial technology developers to host a demonstration small reactor. This would enable Saskatchewan to establish access to the technology and position it to participate in the small reactor supply chain and the development of the relevant R&D activities necessary for a commercial small reactor program, such as materials analysis or fuel design.

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[171] The smaller fuel volumes and infrequent refuelling also enable strong effective controls and processes for used fuel management.

[172] UDI power generation database

Glossary

ABWR	Advanced Boiling Water Reactor. Generation III boiling water reactor design by GE-Hitachi Nuclear.
ACR	Advanced CANDU Reactor, Generation III+ pressurized heavy water reactor design by AECL.
Actinides	A series of 15 elements whose atomic number (i.e., number of protons in their nucleus) is between 89 and 103. Uranium (92) and plutonium (94) are often referred to as major actinides, while neptunium (93) and americium (95) are commonly referred to as minor actinides.
AECB	Atomic Energy Control Board, the former Canadian Federal nuclear regulator (now replaced by the CNSC).
AECL	Atomic Energy of Canada Limited, the Crown Corporation that designs and sells CANDU reactors.
AP1000	Generation III+ pressurized water reactor design by Westinghouse.
APR-1400	Generation III+ pressurized water reactor design by KHNP.
APWR	Advanced Pressurized Water Reactor. Generation III+ pressurized water reactor design by Mitsubishi.
Becquerel (Bq)	The SI (metric) unit of intrinsic radioactivity of a material, equal to one radioactive disintegration per second.
Brownfield	Former industrial lands, now vacant or underused, but with potential for redevelopment.
CAGR	Compound Annual Growth Rate.
CANDU	Canadian Deuterium Uranium Reactor. This reactor design is based on natural uranium fuel with heavy water as a moderator.
CCGT	Combined Cycle Gas Turbine.
CCS	Carbon capture and storage.
Capacity factor	The percentage of time that a generating unit is available to produce energy.
Carbon price	The cost – in the form of tax, levy, emissions credit or other mechanism – of emitting carbon (typically as carbon dioxide) into the atmosphere.

Centrifuge enrichment	A method for enriching uranium that uses a rapidly rotating tube. The heavier U-238 isotope tends to be pushed to the walls of the centrifuge as it spins and can be separated from the lighter U-235.
CEAA	Canadian Environmental Assessment Agency.
CERI	Canadian Energy Research Institute.
CNS	Canadian Nuclear Society.
CNNC	China National Nuclear Corporation.
CNSC	Canadian Nuclear Safety Commission, the Federal nuclear regulator.
CNSCA	Canada's Nuclear Safety and Control Act.
CO_2	Carbon dioxide.
CO_2-e	Carbon dioxide equivalent. A standardized measure of the global warming impact of various greenhouse gases.
Decommissioning	The shutdown, dismantling, and eventual removal of a nuclear facility, making the site available for unrestricted use.
Depleted uranium (DU)	Uranium from which U-235 has been removed, usually as part of the process of making nuclear fuel.
DoE	Department of Energy (United States).
Dose limits	The maximum radiation dose, as defined through regulation, that a person may receive over a stated period of time. It excludes doses from background radiation and medical exposures.
EA	Environmental assessment
Enriched uranium	Uranium has to be enriched to be used as fuel for light water reactors – the fraction of fissile isotope U-235 (~0.71 percent) in the uranium has to be increased to approximately 3 percent. Material with 20 percent or greater enrichment is called high-enriched uranium (HEU); below 20 per cent is low-enriched uranium (LEU).
EPR	European Pressurized Reactor; also Evolutionary Pressurized Reactor. Generation III+ pressurized water reactor design by AREVA NP.
Fissile material	Any material capable of undergoing fission by thermal (or slow) neutrons. For example, U-233, U-235, and Pu-239 are fissile nuclides.
Fission	The splitting of a heavy atom into smaller fragments when it is hit by a neutron. While fission may occur spontaneously in fissile material, in a reactor it is triggered by a uranium nucleus absorbing or interacting with a neutron and becoming unstable.
Fission products	Unstable isotopes of lighter elements created through the fission of uranium and other fissile elements.

FOAK	First of a kind.
Fuel rod	A single tube comprising fissionable material encased in cladding. Fuel rods are assembled into fuel bundles.
Gamma radiation	Electromagnetic radiation similar to X-rays.
GDP	Gross Domestic Product, a measure of total economic activity in a region or country.
Gen IV	Industry term for nuclear power plant designs that represent a significant advance in nuclear technology, particularly in efficiency, fuel use, and waste management. These designs are not yet commercially available.
Greenfield	A term used to describe previously undeveloped land.
GW	Gigawatt – a unit of power equal to one billion (10^9) watts.
GWd	Gigawatt day. The energy equal to one gigawatt of generating capacity operating over one full day.
GWh	Gigawatt hour. The energy equal to one gigawatt of generating capacity operating over one hour.
Half-life	The period required for half of the atoms of a particular radioactive isotope to decay. Half-lives vary, according to the isotope, from less than a millionth of a second to more than a billion years.
Heavy water	Water containing significantly more than the natural proportion of deuterium (heavy hydrogen) atoms to normal hydrogen atoms. Heavy water is used as a moderator in CANDU reactors.
High-enriched uranium (HEU)	Uranium enriched to at least 20 percent U-235.
HLW	High-level waste that contains large concentrations of short- and long-lived radioactive nuclides and requires both shielding and cooling. It generates more than $2kW/m^3$ of heat.
HM	Heavy metal, commonly used in units such as kg of HM and refers to the weight of nuclear fuel.
IAEA	International Atomic Energy Agency.
IEA	International Energy Agency.
IGCC	Integrated Gasification Combined Cycle, a technology for creating synthetic gas from coal or other sources and burning it to produce energy.
ILW	Intermediate level waste material that contains quantities of radioactive material above clearance levels and requires shielding and has a thermal power below $2kW/m^3$.
Intertie	An interconnection permitting passage of current between two or more electric utility systems.

Ionizing radiation	Radiation capable of causing the matter that it passes through to become electrically charged.
Isotopes	Nuclides that have the same atomic number (same number of protons) but different mass numbers (different number of neutrons). Different isotopes of the same element have the same chemical properties, but different physical properties.
Light water reactor (LWR)	Reactors that are cooled and usually moderated by normal water. They account for most of the world's installed nuclear power generating capacity.
Low-enriched uranium (LEU)	Uranium enriched above the natural level of 0.71 per cent U-235 but to less than 20 percent U-235. LEU in modern power reactors is usually 3.5–5 per cent U-235.
LLW	Low-level waste material that contains quantities of radioactive material above the clearance level that requires minimum standards of protection for personnel when the waste is handled, transported, and stored.
LUEC	Levelized unit electricity cost.
Megawatt (MW)	Unit of power equal to one million (10^6) watts. Typically used to refer to the electrical power output of a reactor.
Microsievert (µSv)	Unit of radiation dose, one millionth of a sievert.
Millisievert (mSv)	Unit of radiation dose, one thousandth of a sievert.
Mixed oxide fuel (MOX)	Reactor fuel that consists of both uranium and plutonium oxides.
Moderator	A material used in a reactor to slow down neutrons to increase the likelihood of those neutrons being captured by heavy atoms in the reactor, leading to further fission.
MWe	Megawatts electrical.
MWt	Megawatt of thermal power. The total heat output of fuel in a reactor, not accounting for the losses that occur in converting thermal energy into electrical power.
Nuclear power plant (NPP)	A nuclear reactor that converts nuclear energy into electrical power.
NPV	Net present value.
Nuclear reactor	A structure in which a fission chain reaction can be maintained and controlled. It usually contains fuel, coolant, moderator, control absorbers, and safety devices and is most often surrounded by a concrete shield to absorb radioactive emission.
Nuclear Suppliers Group (NSG)	A group of 45 states that agree to certain conditions on the export of nuclear materials and nuclear-related dual use materials, items, and technologies, as defined in annexes to IAEA document INFCIRC/254 rev 4.

NWMO	Nuclear Waste Management Organization, an organization created by the owners of used nuclear fuel to manage Canada's nuclear waste.
O&M	Operations & Maintenance.
Overnight cost	The hypothetical cost of a power plant if it were built overnight. In practice, overnight cost excludes escalation – the increase in unit costs that typically occurs during the period of construction of a facility – and financing costs, but includes contingency.
Plutonium (Pu)	A heavy radioactive, human-made metallic element. Its most important isotope is fissionable Pu-239, produced by neutron irradiation of U-238. It is the main isotope of value recovered from reprocessing spent fuel.
PUREX	Plutonium and Uranium Recovery by Extraction. The only reprocessing technology in large-scale commercial use.
PHWR	Pressurized heavy water reactor.
PWR	Pressurized water reactor.
Radioactivity	The ability of certain nuclides to emit particles, gamma rays, or x-rays during their spontaneous decay into other nuclei.
Radioisotope	An isotope that is radioactive.
Radiotoxicity	Of, relating to, or being a radioactive substance that is toxic to living cells or tissues.
Repository	A permanent storage space for radioactive waste.
Reprocessing	The physical and chemical dissolution of spent fuel to separate unused uranium and plutonium from fission products and other actinides. The recovered uranium and plutonium may then be recycled into new fuel elements.
Sievert (Sv)	A unit for expressing dosages of radiation, reflecting the biological effects of radiation received. A milli-Sievert is one one-thousandth of a Sievert.
Sintering	A method for making objects from powder by heating the material below its melting point until its particles adhere to each other.
Spinning reserve	Spinning reserve is any back-up energy production capacity that can be made available to a transmission system with 10 minutes' notice and can operate continuously for at least 2 hours once it is brought online.
Stable isotope	An isotope incapable of spontaneous radioactive decay.
SWU	Separative work unit, a unit that measures the quantity of separative work required to increase the concentration of U-235 in an amount of uranium feedstock. Approximately 100,000 to 120,000 SWUs are required to enrich the annual fuel loading for a typical 1,000 MW light water reactor.

Tailings	Ground rock remaining after particular ore minerals (e.g., uranium oxides) are extracted.
Thermal reactor	A reactor in which the fission chain reaction is sustained primarily by thermal (slow) neutrons.
Uranium (U)	A radioactive element with two isotopes that are fissile (U-233 and U-235) and two that are fertile (U-234 and U-238). Uranium is the heaviest element normally found in nature and the basic fuel for nuclear power.
Uranium dioxide (UO_2)	The uranium compound that is formed into pellets and assembled into fuel rods as fuel for modern nuclear reactors.
Uranium hexafluoride (UF_6)	A compound of uranium that is a gas above 56°C and is a suitable form for processing uranium for enrichment.
Uranium oxide (U_3O_8)	The mixture of uranium oxides produced after milling uranium ore from a mine.
Used fuel	Nuclear fuel that has spent time in an operating nuclear reactor and, as result, in which fission products have built up and the fissile material depleted to a point where a chain reaction does not operate efficiently.
Vitrification	The incorporation of intermediate and high-level radioactive waste into glass for long-term storage.
WNA	World Nuclear Association.
Yellowcake	A solid form of uranium that is the final product of the milling process. Contains mainly U_3O_8 along with other uranium components.

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