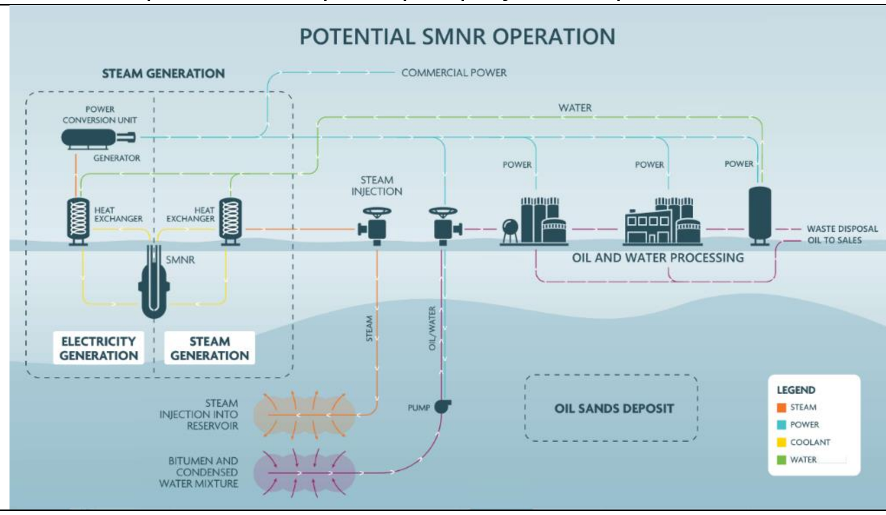
SMR FEED Study
Final Outcomes Report

This report has been prepared for public release

December 31, 2024

1. Project Information

1. **ERA Project ID #**	IT0162501
2. **Call / Round**	Industrial Transformation Challenge
3. **Project Title**	Small Modular Reactor FEED Study
4. **Company Name**	Cenovus Energy Inc.
5. **Project Type** (R&D, Development, Demonstration, Implementation)	Front-End Engineering and Design (FEED) Study
6. **Location** (primary location the project took place by address, land description, or GPS coordinates)	Cenovus Energy office 225 6 Ave SW, Calgary Alberta Canada T2P 0M5
7. **Project Start Date**	January 1, 2024
8. **Project Completion Date**	December 31, 2024
9. **Technology Readiness Level (TRL) at Project Initiation**	5
10. **TRL at Project Completion**	5
11. **Jobs Created**	4.5
12. **GHG Emissions Reduced** (Project-level: annual, cumulatively by 2030 and by 2050)	0
13. **Total ERA Funding**	$554,730.32
14. **Total Project Value**	$1,198,553.23
15. **ERA Project Advisor**	Bruce Duong
16. **Submission Date**	March 31, 2025
17. **Key Project Contact Name and Email**	Aurora Young Aurora.young@cenovus.com
18. **Quote**	"SMRs provide a unique opportunity to supply industrial heat in Alberta but they have a long timeline to deployment and many early-stage risks. With the ERA's support, this study advanced regulatory, deployment and business analysis to better understand these risks and develop potential mitigation options."
19. **Notable Communications**	Project funding announcement Sept 19/2023. https://www.eralberta.ca/media-releases/government-of-alberta-and-emissions-reduction-alberta-commit-7-million-for-cenovus-to-study-the-use-of-small-modular-nuclear-reactors-in-the-oil-sands/

	No public facing announcements during course of phase 1. Planned release of public final report upon project completion.
20. Image	

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5. Executive Summary

Small modular nuclear reactors (SMR) could potentially be a transformative energy source on a multi-industry scale by reliably delivering near zero-emissions, high-grade industrial heat, steam and electricity. SMRs have the potential to be compact and versatile with efficient onsite installation, increasing ease in placement and supporting locations and industries that need reliable energy close to where it's used. While several SMR projects in Canada and the United States are advancing from conceptual design and licensing to the construction phase, there are still considerable challenges that must be overcome before this technology can be fully commercialized.

To illustrate the potential of SMR technologies, oil sands operators could replace natural gas (NG)-fired equipment with SMRs, providing the necessary industrial heat on scale for current operations, while considerably reducing Scope 1 greenhouse gas emissions intensity. Additionally, SMRs could potentially reduce onsite NG electricity generation, further decreasing associated emissions. If onsite electricity generation displaces offsite generation, there would be Scope 2 emissions reduction for that site. The actual reduction in emissions for a conceptual project depends on the equipment replaced and SMR technology considered. Although there are trade-offs among carbon abatement technologies, SMRs are one of very few that offer nearly zero Scope 1 emissions and are an energy source as opposed to an energy draw. To illustrate, a 400-megawatt thermal (MW_{th}) SMR has the potential to abate approximately 560,000 tonnes of carbon dioxide equivalent (CO_2e) per year when replacing unabated NG-fired boilers, depending on factors such as SMR technology and energy transfer configuration and efficiencies. Oil sands companies and other industrial heat end-users that have similar process heat requirements could be users of SMR technologies.

The Cenovus SMR Front-End Engineering (FEED) Study was developed as a four-year study (the Program) of Pre-FEED and FEED activities intended to support development of a potential commercial project to deploy an SMR at a Steam-Assisted Gravity Drainage (SAGD) oil sands production site. The SMR FEED Study was structured in three phases: enabling studies, design basis memorandum (DBM), and FEED. Key objectives included developing knowledge and designing the integration facilities required to deliver energy to a SAGD facility. However, during phase 1, evaluations of costs, risks and timelines resulted in a decision not to proceed past phase 1, and therefore, not all scoped Program outcomes were progressed.

Despite the decision not to proceed, work conducted during phase 1 contributed to knowledge growth in engineering, deployment, regulatory, stakeholder, and commercial areas. Phase 1 included contributions by at least 25 internal employees and collaboration with numerous nuclear industry entities to further understand nuclear integration with SAGD technology.

The outcomes of the work conducted include key learnings on some of the risks, gaps and opportunities that may need to be addressed for any proponent in Alberta to consider next steps on deploying SMRs for SAGD. These include technology risks, such as technology development, First-of-a-kind (FOAK) challenges; project risks such as managing controlled nuclear information, long and uncertain timelines and regulatory uncertainties; and investment risks, such as high, unsure costs and nuclear liability.

6. Project Description

6.1. Introduction

Cenovus Energy Inc. is a Canadian integrated oil company and is investigating methods to deliver efficient heat, steam and electricity by use of several technologies including SMRs.

SMRs could potentially be a transformative energy source on a multi-industry scale by reliably delivering high-grade industrial heat with near zero Scope 1 emissions. SMRs provide a potential solution to reduce reliance on gas-fired steam generators (also referred to as “boilers”) on a large scale to reduce oil sands Scope 1 greenhouse gas (GHG) emissions intensity. SMRs use nuclear fission to produce heat. This heat then has several use cases such as steam production, electricity production, district heating, hydrogen generation, etc.

Although nuclear fission reactors are not new, technology developers providing a “small” modularized package is a relatively new concept and yet to be operational in any industry within Canada. Design, cost, and technology readiness levels (TRL) vary by individual reactor designs. Different designs include different coolants and heat transfer mediums that range from water, helium, molten salt, and liquid metals. The reactors also vary on the spectrums they operate on (thermal and fast) and the fuels they use. To date, primarily large-scale thermal water-cooled reactors have been used for electrical power generation facilities. In the past, Canada had a CANDU reactor supply industrial-grade heat to a heavy water production facility. Currently, the only operating nuclear reactors integrated with facilities for industrial heat are in China. SMRs are unique as they explore new methods of operation that allow them to be applicable in industries and locations that have yet to see nuclear implementation.

Commercial nuclear energy deployment within Alberta and integration into a SAGD facility has never been done before. The focus of the SMR FEED Study was to gain an understanding of front-end risks, identify, and conduct next steps towards potential commercialization, and develop the processes, workplans and resources required to accomplish this.

Cenovus is using the terminology of “Program” to refer to the SMR FEED Study work.

6.2. Background of the Project (Program)

In 2023, Cenovus Energy, TC Energy, and Alberta Innovates jointly commissioned HATCH Ltd. to prepare a feasibility study for the application of SMR technology at an Alberta oil sands SAGD facility. This was following other studies conducted by Alberta Innovates to understand the potential use of SMRs in the oil sands.

Following the outcomes of the HATCH study, Cenovus began reviewing early-stage development activities for a conceptual SMR project. This led to the development of a four-year study of Pre-FEED and FEED activities (the Program) exploring a conceptual deployment of an SMR at an oil sands site for the purposes of producing heat for SAGD steam and possibly onsite electricity generation.

The scope of the Program was split into three phases.
Phase 1: enabling studies including regulatory, commercial, procurement, fleet deployment, and process studies.

Phase 2: Design Basis Memorandum (DBM) including development of engineering requirements, design criteria, technical specifications, assumptions, principles, rationale, and constrains ahead of front-end engineering and design. Preliminary schedules and cost estimating were to be based on current level of certainty.

Phase 3: Front End Engineering Design (FEED) including process design, equipment selection, material selection, cost estimation and project schedule.

6.3. Project (Program) Objectives

The objectives of the Program were designed to support early development of a conceptual commercial project. The proposed four-year Program was intended to consist of pre-FEED and FEED activities to develop knowledge, people and plans required for early-stage development. The estimated cost to conduct the Program for the three phases was $26.7 million.

The original goals of the Program included building in-house knowledge on the nuclear ecosystem, progress nuclear industry knowledge of SAGD and developing novel engineering design for the integration of SMRs in SAGD. This required evaluation of specific SMR technologies, evaluation and progression of heat transfer design configurations to SAGD operations, understanding regulatory opportunities and challenges, and assessing the commerciality of the available technologies. Due to the decision to stop progress after phase 1, some objectives were adjusted. See Section 6.5 for more details on the changes during the Program and impacts to objectives.

6.4. Performance / Success Metrics

Cenovus conducted planning and executed on scope during phase 1. Valuable knowledge was collected and developed to support the work that was completed in phase 1. Cenovus did not start work on phases 2 or 3 of the Program. Refer to Table 1 for a summary of work planned versus completed.

Activity Highlights:

- Engineering and Deployment – engagement with SMR technology developers and scope development progressed the assessment on technology readiness and improved Cenovus's understanding on the cost estimates, however, controlled nuclear information risks required implementation of protocols that would delay execution of technical enabling studies until phase 2. This controlled nuclear information risk is further described in section 8.2.
- Regulatory – regulatory reports were completed that support understanding of Alberta and federal regulatory challenges, consideration for reactor co-location with existing industrial projects in Alberta and increasing awareness on engagement requirements.
- Stakeholder and Commercial – thorough business case analysis was conducted, resulting ultimately in the decision not to proceed to phase 2. Some initial studies were progressed to frame the stakeholder and commercial work, however, further Indigenous, stakeholder and partner engagement would be required prior to development of project-based stakeholder and commercial plans.

Table 1: Phase 1 Summary of Deliverables and Activities Performance

Phase 1 Activities	Summary of Planned Work	Summary of Work Complete
ERA Reports	Complete all reports for Phase 1	• Completed all final project reports
Engineering & Deployment	Analysis on host location screening, costs, and technology screening and engineering studies	• Engineering and deployment study scopes of work (SOW), schedules & estimates for enabling multiple SMR technologies

		- SMR technology evaluation and downselect plan - Phase 2 plans: DBM SOW, Integrated workplans, technology evaluation - Assessment for application of lower temp reactors - Initial cost analysis for a potential commercial project
Regulatory	Studies on regulatory challenges and opportunities, siting requirements, engagement requirements	- Regulatory scoping and road mapping for a potential commercial project - Studies for regulatory opportunities and challenges, and siting requirements
Stakeholder	Indigenous and stakeholder communication plan	- Stakeholder considerations - Study for engagement requirements - Plan for coordination of nuclear 101 communication materials
Commercial & general	Knowledge and engineering gaps required to close, generalized study methodology and commercial analysis	- Business case, market analysis and risk assessments - Controlled Nuclear Information analysis and protocols - Isotope study

6.5. Project (Program) Changes

In the third quarter of 2024, Cenovus made the decision not to proceed with the Program beyond the end of 2024. ERA was then informed of the decision to end the Program after reaching the end of phase 1. As such, no work was executed for phases 2 and 3. A further description of the rationale for the decision follows in section 8.2.

Even with the decision to not continue, Cenovus and ERA agreed on adjusting the scope for phase 1 and Cenovus completed the updated scope in 2024. See Section 8 of this report for more information on the challenges and the practical learnings during evaluation work that supported this decision.

6.6. Technology Risk

During the Program, no new technology or intellectual property (IP) was developed. SMR vendors are actively pursuing technology development, and Cenovus may have informed some development priorities, however SMR technology development was not in scope for this Program. The two key elements for the technology that were in scope for the Program technical workplan are the intermediate facility design and the technology downselection.

The HATCH Feasibility Study found that integration of SMRs with SAGD is technically feasible and identified a comprehensive list of SMR technologies for consideration. Therefore, it was acknowledged upon Program initiation that downselecting a technology would be required as part of the anticipated scope. A reactor downselect process was developed during the first phase. It was identified that further work was required during the Program to evaluate and characterize the available technologies and develop selection criteria to choose the preferred technology for a potential commercial project. The downselection process is notably challenged as none of the available technologies have been commercially deployed.

There were several insights on technology risks framed through the discussion of technical and deployment study scopes with technology developers, engineering companies, construction companies and financing specialists. Generally, the view is that water-cooled reactors will remain as the incumbent nuclear technology for many of the near-term projects, and although some of the advanced reactors are “proven” and have operated in a demonstration capacity, the actual timeline for the first deployments of SMRs are longer than originally expected. Progression of advanced reactors on the TRL scale will take some time and will be highly dependent on technology development investment and timelines for first project deployments. The success of current planned projects, with deployments anticipated in the early 2030s, will be a key indicator.

There are several identified risks for SMRs and integration with SAGD in Canada that will extend the timeline for “commercialization”, including, but not limited to:

- novel and untested industrial heat application;
- co-location and integrated operation with an industrial facility;
- estimated capital costs on a $/kW basis that greatly exceed historical costs with no plan for reductions;
- no previous deployment or construction of SMRs anywhere in North America;
- requirement for an advanced, FOAK reactor design with limited operating time;
- requirement for enriched fuel (currently Canada cannot enrich nuclear fuel); and
- regulatory gaps for SMRs versus the incumbent traditional water-cooled reactors.

7. Project Work Completed and Outcomes

7.1. Methodology

Typically for early-stage project development work, the objectives, scope and measures of success are identified. This was the methodology used for the Program, outlining objectives and developing the scope. Next, the activities were identified based on the scope for phase 1. These activities were structured to gain an improved understanding of front-end project risks, and develop the steps towards potential commercialization, informing the processes, workplans and resources required to accomplish this.

At the start of phase 1, team members were coordinated into groups with associated workplans that provided inputs to an integrated project workplan as follows:

- Technical (Engineering and Deployment): technology characterization and evaluation, engineering and project (schedule and cost estimate) activities.
- Stakeholder and Regulatory: regulatory scoping, challenges and opportunities, siting requirements, engagement requirements, communications, and considerations for engagement and Indigenous and stakeholder planning.
- General and Commercial: business case, market analysis and risk assessments.

7.2. Technology Development

Before the start of the Program, it was identified that two areas for technology development are required to progress a commercial project: 1) the reactor technology; and 2) the intermediate facility for the integration of SMRs with SAGD.

However, it was decided that the Program scope was not intended to pursue development of the reactor technology as this is best supported by SMR vendors currently conducting reactor technology development. The Program would focus on the reactor technology evaluation and downselection for SAGD applications. It was also assumed early technology evaluation, screening and selection would reduce costs on engineering and deployment work. It was identified that further work was required during phase 1 to develop criteria to downselect to the preferred technologies to progress to the next phase.

A technical workplan was developed to outline the objectives and technology development activities relevant to the Program. See Table 2 for a summary of the technical workplan.

Table 2: Technical 2024-2025 Workplan

#	Technical Workplan Scope Element	Objectives
1	Technology	• Engage with SMR vendors and nuclear industry entities • Define decision governance structure for technology evaluation and selection • Prepare downselection process • Begin execution of the downselection process
2	Shortlisted SMR Vendor Activities	• Prepare joint study SOWs
3	SMR Vendors Joint Studies	• Increase cost certainty with Class V cost estimates • Conduct technology due diligence • Inform the downselection process
4	Other Studies & Deliverables (Vendor Agnostic)	• Assess opportunity for isotope production • Assess SMR to SAGD energy transfer for SMR temperature outputs • Obtain industry lessons learned to optimize project planning
5	Design Basis Memorandum	• Define engineering requirements and scope • Develop inputs from and for downselect process • Prepare class IV cost estimate

Studies would need to be scoped and executed to assess the technology, develop cost and schedule, and consider the intermediate facility design. SOWs were developed with input from a select group of technology vendors with the following objectives:

- Improve cost certainty of SMR vendor technology designs as it applies to the use case at an oil sands facility for electricity and process heat.
- Conduct due diligence on SMR vendor design, status, and viability. This includes evaluating technical characteristics, design status, design to date, etc.
- Identify any potential barriers or significant cost-influencing factors associated with an oil sands facility and SMR use case that may impact operating expenses.

Incumbent Technology

Currently, SAGD producers utilize NG for onsite industrial grade heat and electricity generation. Cenovus has reviewed alternative energy technologies, such as carbon capture and storage, hydrogen blending, and efficiency improvements. SMRs produce heat and electricity in a single technology and can be assessed against NG. NG is considered a low-cost, cleaner-burning combustion fuel and is also a commodity that is produced and sold by many oil sands companies allowing synergies. NG is reliable with an almost constant supply to run once through steam generators (OTSG or “boilers”), providing nearly continuous operation. NG prices are market driven and include compliance costs and taxes with policy uncertainty.

SMR technologies were assessed within the Program, considering their potential to replace the existing NG technology. The intermediate facility design for heat and power transfer to the SAGD facility would be tailored to each SMR technology, necessitating further selection of the most suitable SMR technology.

SMR Downselect Process and Screening

As part of phase 1, Cenovus drafted an SMR downselection process and conducted initial screening of various SMR design options (see Table 3). The SMR downselection methodology developed describes a gated process where multiple SMR technologies can be evaluated independently instead of against one another until the final stage. Any near-term deployment of an SMR should not consider designs that are less than a TRL of 5, which was one of the screening criteria.

As part of the SMR downselection process development, Cenovus conducted a study on the transfer of energy from the SMR to a typical large SAGD central processing facility. This identified the most suitable SMR designs for the SAGD use case would be those technologies with a core output temperature above 385°C. Typically, water-cooled reactors are not able to achieve such temperatures. As such, this constrained the decision-making to only Generation IV high-temperature reactors given their heat output. As a conclusion of the study, water-cooled reactors were removed from the short-list of applicable reactor designs as they cannot meet the minimum temperature without additional heating mechanisms or processes.

Table 3: SMR Reactor Technologies Identified for Potential Oil Sands Heat Applications

Reactor	SMR Vendor	Country of Origin	Capacity (MWe, MWth)	Type	Considered for SAGD
AP-300	Westinghouse-Toshiba	USA	300/900	PWR	No
ARC-100	Advanced Reactor Concepts	Canada	100/286	LMFR	Yes
Aurora	Oklo	USA	1.5/4	LFR	Yes
Bandi-60s	KEPCO	South Korea	60/200	PWR	No
BWRX-300	GE-Hitachi	USA	300/870	BWR	No
CANDU-300	CANDU Energy	Canada	300/960	PHWR	No
CAREM	Various	Argentina	25/100	IPWR	No
EM2	General Atomics	USA	265/500	HTGR	Yes
eVinci	Westinghouse	USA	3.5/12	Heat-pipe	Yes
IMSR	Terrestrial Energy	Canada	195/440	MSR	Yes
KP-FHR	Kairos Power	USA	140/320	MSR	Yes
LFR-small	Newcleo	Europe/UK	200/480	LFR	Yes
MMR	Ultra-Safe Nuclear Corporation	USA	15/45	HTGR	Yes
moltexFLEX	Moltex	UK	24/60	MSR	Yes
Nuward	EDF, etc	France	170/540	MSR	Yes
PRISM	GE-Hitachi	USA	311/840	LMFR	Yes
SEALER-55	Leadcold	Canada	55/140	LFR	Yes
SMART	KAERI	South Korea	110/365	PWR	No
SMR-160	Holtec	USA	160/525	PWR	No
SSR-W	Moltex	Canada	500/1250	MSR	Yes
VOYGR	NuScale	IPWR	77/250	IPWR	No
Westinghouse LFR	Westinghouse	USA	450/950	LFR	Yes
Xe-100	X-Energy	USA	80/200	HTGR	Yes
Natrium	Terrapower	USA	345/840	LMFR	Yes
BANR	BWXT	USA	15/50	HTGR	Yes

7.3. Project Achievements, Results, and Analysis

High-level outcomes of the Program work include:

- initial screening for SMR technologies most relevant and applicable to SAGD, providing key technologies to monitor as projects progress and technologies reach milestones for commercialization;
- development of technology study scopes with technology developers that could support potential SAGD and industrial heat project proponents (See each scope area in Sections 7.3.1);
- improved understanding of risks regarding a potential deployment of an SMR in Alberta, providing initial guidelines for risk mitigation work and areas to monitor;
- improved knowledge on regulatory scope, timelines, and requirements for engagement and siting, with identified regulatory gaps and opportunities; and
- improved business perspective that guided near-term decisions for further Program work.

Achievements include the completion of activities to improve knowledge in all scope area. Accomplishments are identified in Table 1 in Section 6.4. Highlights from the analysis are below for each work area.

Engineering and Deployment

Engineering and deployment activity highlights:

- **Technology selection process**: Cenovus drafted an SMR downselection process and conducted initial screening of various SMR design options.

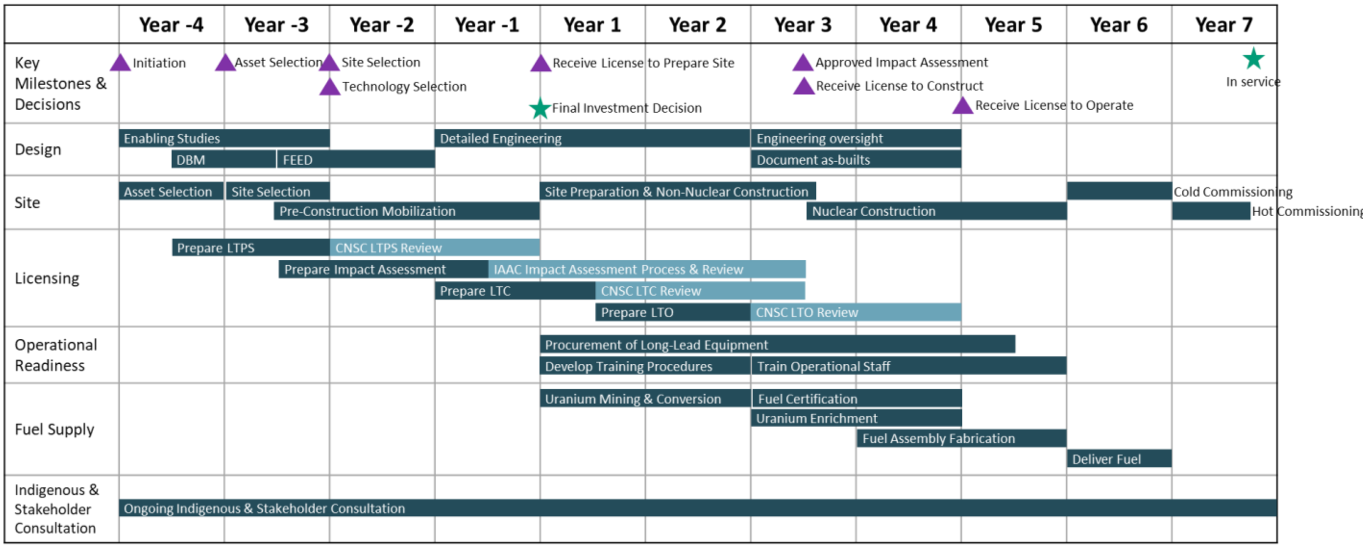
- **SMR to SAGD energy transfer analysis**: Cenovus conducted a SMR to SAGD Energy Transfer Study, where it was identified that most suitable SMR designs for the SAGD use case would be those with a core output temperature above 385°C.

- **Technical studies scope development with technology developers:** Cenovus developed study scopes with a few technology developers to support the understanding of potential project scope, cost, schedule and risk. This included engineering and deployment activities that would lead into DBM studies. The outcomes of the studies would support the assessment of the status of the technology and make informed decisions on the potential deployment of the technology in the oil sands. This included scope for the technology developer as well as a project coordinator with expertise in development of nuclear projects. The outcomes of the studies could be utilized for the technology evaluation process and provide additional inputs to an asset and site screening process.

- **Asset (host location) screening**: Cenovus developed an internal process to support selection of an oil sands facility to co-locate an SMR. This process is crucial for the early stages of the project. The asset screening process, supported by relevant business stakeholders, ensures proper project governance, stakeholder engagement (both internal and external), and the availability of necessary resources. It also addresses scope and risk management. Additionally, our process considers proactive and meaningful engagement with neighbouring Indigenous nations. This screening is essential for the pre-work required for site selection, which is a separate process within the asset, while also considering requirements for provincial approvals and the federal License to Prepare Site.

- **Potential commercial project deployment schedule:** Information from various sources during phase 1 of the Program was integrated into a high-level illustrative commercial project timeline. See Figure 1.

Figure 1: Commercial Project Illustrative Timeline



- **Costs (potential FOAK cost estimate at an oil sands facility):** Numerous sources of information were aggregated and evaluated to develop estimates on capital costs for an SMR. It was determined that the cost estimate as identified in the HATCH Feasibility Study was the most representative for the analysis. The estimated cost range from that study was \$1.5 billion to \$4.5 billion, however, it is estimated that the capital costs will be at least \$3.5 billion, pushing the updated expected range to be on the high end of the range determined in the Feasibility Study. This projection is based on several factors: the project would likely be the first nuclear reactor in Alberta, it involves FOAK and advanced reactor technology, it likely has higher owner's costs and cost escalations compared to vendor estimates, and it faces significant regulatory and stakeholder risks.

Regulatory

Phase 1 regulatory activities included the scoping and execution of studies were designed to better understand regulatory gaps and inform subsequent workplans.

Regulatory activity highlights:

- **Regulatory Scoping:** As a first step in phase 1, Cenovus's team developed the following information:
  - potential SMR project scenarios and subsequent decisions required;
  - currently known regulatory requirements that would be applicable;
  - areas where regulation, guidance, or policy is not available or unclear;
  - assumptions and clarifications required for a potential SMR project;
  - regulatory risks and potential mitigations; and
  - engagement and resources required to progress a potential SMR project.

- **Regulatory workplans:** A high-level roadmap was developed (based on current information) that included estimated timing for the Canadian Nuclear Safety Commission (CNSC) and Impact Assessment Act (IAA) Initial Project Description (IPD) and license applications and reviews, and Environmental Impact Assessment (EIA).

- **Report on regulatory challenges and opportunities:** This report includes illustrative regulatory timelines and can supplement the regulatory roadmap generated previously in phase 1. See the summary of the report below.

- **Report on siting requirements:** This report was conducted as a first step to understand the siting process for a nuclear project. As a starting point, no site has been selected for a potential commercial project. It has been identified that site selection requires a comprehensive understanding of regulations and an in-depth engagement process to support the selection process.

  This report provides information to support initial site screening and allows for the identification of major barriers to siting an SMR at an oil sands site to reduce the number of potential sites. It was identified that the siting process would require more detailed screening at each potential site and included evaluation of site characteristics and siting criteria. Technology selection and safety analysis should also be considered for siting.

  In conclusion, federal nuclear siting requirements will inform the site selection process. The exclusion zones are an important factor in the siting analysis. There are also Alberta Acts and regulations that will inform the siting process. Specifically, there are constraints for highly sensitive or high value sites.

- **Report on engagement requirements**: This report includes approximate timelines for CNSC, IAA, Alberta Energy Regulator (AER) pre-licensing engagement and can supplement the regulatory roadmap generated earlier. See the summary of the report below.

Summary: Regulatory Opportunities and Challenges Report

As part of phase 1, Torys LLP developed a report for Cenovus entitled: *Report on Key Regulatory Challenges and Opportunities for Small Modular Reactors In Support Of An Oil Sands Facility.* This report outlines the regulatory requirements, challenges, and opportunities for deploying an SMR in Alberta. It serves as a guide for navigating the regulatory landscape for SMR deployment in Alberta, highlighting the importance of understanding federal and provincial regulations and the unique aspects of the nuclear industry.

The report examines three scenarios for an SMR producing over 200 MW_{th} to support a hypothetical oil sands facility:

Scenario 1: Provision of industrial heat to one oil sands facility.

Scenario 2: Provision of industrial heat and electricity to one oil sands facility.

Scenario 3: Provision of industrial heat and electricity to one oil sands facility with an option to supply electricity to the provincial grid.

The report covers the following topics:

1. Federal and provincial regulatory approval requirements: Overview of the integrated assessment process, including federal impact assessment under the IAA and licensing under the Nuclear Safety and Control Act (NSCA).
2. Regulatory uncertainties and overlap: Identification of current regulatory uncertainties and overlap between federal and provincial requirements.

3. Practical impacts and risks: Analysis of the practical impacts and risks associated with key policies and processes.
4. Opportunities for improved processes: Exploration of opportunities for improved regulatory approval processes, potential benefits, and risks.
5. Potential timeline: Outline of a potential timeline for regulatory approval requirements.

Key federal regulatory requirements include, in summary:

- IAA: Projects exceeding 200 MW_{th} capacity require an impact assessment. The process includes pre-planning, planning, impact statement, assessment, decision-making, and post-decision phases.
- NSCA: Licenses required at each stage of the nuclear facility lifecycle, including site preparation, construction, operation, and decommissioning.
- Other Federal Approvals: May include authorizations under the Fisheries Act and exemptions under the Canada Labour Code.

Key Alberta regulatory requirements include, in summary:

- AER: Regulates energy development, including scheme amendments under the Oil Sands Conservation Act (OSCA) and facility and pipeline licenses under the Oil and Gas Conservation Act (OGCA) and Pipeline Act.
- Alberta Environment and Protected Areas (AEPA): Assesses EIAs and issues environmental approvals under the Environmental Protection and Enhancement Act (EPEA), Water Act, and Public Lands Act (PLA).
- Alberta Utilities Commission (AUC): Regulates power plant approvals and grid connections under the Hydro and Electric Energy Act (HEEA) and Electric Utilities Act (EUA).
- Alberta Electric System Operator (AESO): Manages grid connections and transmission capacity.
- Ministry of Arts, Culture and Status of Women (ACSW): Issues approvals under the Historical Resources Act (HRA).

The additional approvals for grid connection are, in summary:

- AESO – Needs Identification Document (NID); AUC – NID approval, permit, and licenses: If new or enhanced transmission facilities are required, AESO prepares a NID for AUC approval. The designated transmission facility owner then applies for permits and licenses to construct and operate the facilities.
- AESO – Connection Process or Behind-the-Fence (BTF) Process: Grants generating assets access to the grid through a System Access Service Agreement (SASA). The Connection Process or BTF Process applies depending on whether new transmission facilities are needed.
- AUC – Connection Order: Issued prior to connecting the SMR to the grid.

The key regulatory gaps, uncertainties, and overlap are, in summary:

1. Federal and provincial roles in SMR regulation: Need for alignment to avoid regulatory gaps and duplication.

2. Alberta EIA: Potential requirement for an EIA for the nuclear power plant and water intake structure, and multiple assessment processes are not likely to result in the most efficient outcomes.
3. Necessary agreements: Agreements between federal and provincial governments to facilitate SMRs.
4. Duty to consult and accommodate: Potentially conflicting requirements for consultation with Indigenous communities.

The key practical impacts and risks of the current policy and processes as well as opportunities are, in summary:

1. Potential for overly broad scoping of the impact assessment.
2. Inefficiencies in consultation related to the project.
3. Uncertainty regarding Alberta approvals required for the project.
4. The intersection of emergency responsibilities.
5. Uncertainty with respect to the “incidental aspect” of impact assessments.

Opportunities for improved regulatory processes are, in summary:

1. Streamline the impact assessment: Achieving the federal government's three-year target for SMR assessments.
2. Remove Alberta environmental approvals or streamline approvals: Collaborating with CNSC to streamline or eliminate redundant approvals.
3. Joint impact assessment process: Addressing both Alberta and federal requirements.
4. Clarity on Alberta approvals: Ensuring clear and efficient regulatory pathways.
5. Benefits of an Alberta nuclear coordinator: Coordinating regulatory processes and facilitating cooperation among agencies.

Report key messages and take-aways:

- **Regulatory approvals:** An SMR in Alberta will require both federal and provincial regulatory approvals. Currently, there are gaps, uncertainties, and overlap in these regulations, which add risk to future projects. The estimated regulatory timelines are long and uncertain.
- **Challenges for proponents:** Some identified challenges may deter potential proponents from considering an SMR project. Notably, the "incidental aspects" analysis for the impact assessment may include the co-located oil sands facility as part of the integrated assessment.
- **Streamlining impact assessment:** It is recommended that the federal government streamline the impact assessment process and address the overly broad scoping. The agency has significant discretion in determining the information to be provided and assessed, particularly for the "incidental aspects" analysis, and this must exclude the oil sands facility from the integrated assessment.
- **Alignment of regulations:** Federal and provincial governments and regulators should align their processes and consider agreements to avoid regulatory gaps and duplication. This is particularly important for areas expected to have repeated, overlapping requirements at both levels, such as:
    - EIA
    - Indigenous consultation
    - Emergency responsibilities

- **Appointment of a nuclear coordinator:** It is recommended the Government of Alberta consider appointing a nuclear coordinator with extensive knowledge of the nuclear sector. This coordinator would determine the necessity for a provincial EIA, provide clarity on applicable Alberta approvals, coordinate across relevant provincial departments and regulators, and engage with federal entities.

Summary: Engagement Requirements Report

During phase 1, Torys LLP developed a report for Cenovus: *"Engagement Requirements for Key Regulatory Approvals for Small Modular Reactors In Support of an Oil Sands Facility".* The report includes a list of provincial and federal legislation that have required engagement activities, and a potential timeline based on the required regulatory stakeholder engagement for a SMR that produces more than 200 MW_{th} in support of a hypothetical existing oil sands facility in Alberta based on three operating scenarios. For this report, the term "project" refers to a SMR project in any operating scenario and project "proponent" to include any potential person or entity involved.

Key Recommendation #1: Develop a proponent-specific engagement plan. The potential proponent will need to develop an engagement plan that considers proponent needs and operating scenario as opposed to relying on a checklist of established requirements. A project of this nature (regardless of which operating scenario is selected) would currently be FOAK and raise many novel issues, as well as potential opportunities to chart a more efficient and effective course.

Key Recommendation #2: Develop the engagement timeline. Incorporate the engagement timeline with the proponent-specific engagement plan (based on operating scenario) to ensure the regulatory engagement requirements are fulfilled. Key Conclusion: The engagement timeline is at least nine years, impacting overall project planning.

Key Recommendation #3: Develop plans for each of the listed elements in the engagement timeline. While most of the public engagement and Indigenous consultation requirements would be the same or similar based on the operating scenarios, some of the requirements may differ based on the operating scenario selected, as well as proximity and interest from neighbouring Indigenous nations. For example, an operating scenario with supply of electricity to the provincial grid would be subject to more engagement requirements due to the transmission facilities.

Specific elements that require distinct engagement planning include:

- Integrated Assessment: Includes federal impact assessment and site preparation license under the NSCA.
- Other NSCA Licenses.
- Alberta's EIA.
- AER Approvals: Scheme amendment under the OSCA and facility/pipeline licenses under the OGCA and Pipeline Act.
- Alberta's EPEA, Water Act, and PLA Approvals.
- AUC and AESO Approvals: Under the HEEA and EUA.
- ACSW Approval: Under the HRA.

Key Recommendation #4: Review the Indigenous communities consultation considerations.

Assess how to integrate this process into the proponent-specific engagement plan. These considerations include: 1) the duty to consult and accommodate, and 2) consultation process and interests of Indigenous nations to be consulted.

Key Recommendation #5: Include an advocacy step at the front end of the engagement timeline. Reduce schedule uncertainties by first including advocacy and engagement activities for the practical impacts and risks of current policy or processes.

These advocacy opportunities include:

- addressing the overly broad integrated assessment and inefficient consultation; and
- clarifying applicable Alberta approvals such as providing suggestions regarding how uncertainties and overlaps could be addressed, including through a proposed "made in Alberta" strategy to clearly define the regulatory path for SMRs in Alberta.

Stakeholder Considerations

For phase 1 stakeholder activities, Cenovus identified engagement considerations and evaluated potential organizations to coordinate for Nuclear 101 communication materials.

Engaging early with Indigenous and non-Indigenous communities is an essential part of a commercial project's broad planning process – particularly when discussing new technology associated with nuclear energy, which is tantamount to introducing a new industry in the Alberta region.

In Alberta, there are several ongoing activities led by both government organizations and private companies to progress the use of nuclear technology in the province. See Table 4.

Table 4: Government and Non-Government Organizations' Activities in Alberta to Build Public Knowledge

Date	Description	Source
April 14, 2021	The Government of Alberta joined an interprovincial Memorandum of Understanding (MOU) with the governments of Saskatchewan, Ontario, and New Brunswick	Canadian provinces partner on SMR development and release feasibility study | Canadian Nuclear Association (cna.ca)
March 28, 2022	The above MOU signatories jointly released *A Strategic Plan for the Development of Small Modular Reactors*	A strategic plan for the deployment of small modular reactors - Open Government (alberta.ca)
July 2022	The Government of Alberta, through Invest Alberta Corporation, signed MOU with Terrestrial Energy	Terrestrial Energy Opens Nuclear Tech Office in Alberta - Invest Alberta
January 30, 2023	The Government of Alberta, through Invest Alberta Corporation, signed MOU with X-Energy Canada	X-energy Canada and Invest Alberta Collaborate to Develop Economic Opportunities in Support of Potential Xe-100 SMR Projects — X-energy
March 23, 2023	The Government of Alberta, through Invest Alberta Corporation, signed MOU with ARC Clean Technology Canada	ARC Clean Technology and Invest Alberta sign agreement to support the deployment of advanced Small Modular Reactors in Alberta | ARC
April 19, 2023	The Government of Alberta, through Invest Alberta Corporation, signed MOU with KAERI	MoU sees KAERI, Alberta cooperation on SMRs - World Nuclear News (world-nuclear-news.org)

April 2, 2024	Emissions Reduction Alberta provided funding for X-Energy Canada to conduct a Research and Development (R&D) project assessing Site and Distribution Infrastructure from Transitioning a Thermal Power Plant to an SMR in collaboration with TransAlta	X-energy, TransAlta Partner to Study Deployment of Advanced Small Modular Nuclear Reactors in Alberta through Emissions Reduction Alberta Award — X-energy
January 15, 2024	Capital Power and Ontario Power Generation announced a partnership to advance new nuclear and the feasibility of deploying SMRs in Alberta	Capital Power and Ontario Power Generation partner to advance new nuclear in Alberta - Capital Power
May 2, 2024	Saskatchewan and Alberta Partner to Advance Nuclear Power Generation	Saskatchewan and Alberta Partner to Advance Nuclear Power Generation | News and Media | Government of Saskatchewan

Considering the forward momentum to deploy nuclear technology in Alberta from both public and private entities, it is recognized that government, industry organizations and project developers should develop and/or support extensive public education and engagement programs, in addition to development of a provincial regulatory framework. It should be recognized that government and/or crown corporations in Canadian nuclear provinces play a large role in such education and engagement programs. However, Alberta does not have a Crown Corporation for electricity generation that would play such a role.

Cenovus already engages with Indigenous groups and local communities within the proximity of operating sites. Since 2023, Cenovus' Indigenous Affairs team has informed neighbouring Indigenous nations of Cenovus' role in SMR research. It should be noted that this was conducted prior to the Program work. Engagement requirements were scoped as part of a regulatory study conducted in phase 1 and is discussed under regulatory activity highlights in this report.

As part of the Stakeholder scoping, several key topics for engagement were identified which include:

- Nuclear 101
- Site selection
- SMR technology selection
- SMR and SAGD site integration scenario (heat and electricity production and uses)
- Ownership model
- Operating model
- Construction timeline and stakeholders
- Construction and operations employment opportunities
- Waste management planning

General and Commercial

Phase 1 Risk Assessment

The risk assessment for progressing the Program beyond phase 1 to phase 2 identified several key risks. High risks included managing sensitive nuclear information, and the level of government fiscal and risk mitigation support. Medium and low risks involved contract terms, partner alignment, internal alignment, external factors, regulatory approval, land use restrictions, and impacts on other carbon abatement initiatives. High risks required prioritized mitigation efforts, while standard processes were in place for medium and low risks, except for external factors, which required monitoring and reactive communication.

Isotope Study

As part of the commercial activities for the Program, analysis of isotopes was identified as a potential revenue generating stream and benefit to stakeholders. It was also identified that isotope production depends on reactor technology selection and should be analyzed early as a criterion in the technology selection process. Nuclear reactors can be used to produce isotopes by bombarding neutrons, which are a product of the fission chain reaction, at a target material in a process known as irradiation. The study provides an overview on the history of isotopes, the current isotope production landscape, uses of isotopes, current available information on isotope production economics, isotope supply chains, and compatibility with SMRs.

Key take-aways:

- isotope revenue is significantly less than revenue for power generation, with an estimation of less than 2% of total revenues;
- production of isotopes provides critical medical and industrial products as additional benefits of nuclear power; and
- isotope production will only be feasible with certain SMR designs, due to physics and chemistry properties of the reactor core design, as well as physical access limitations, and it is important to consider whether isotope production is a priority during the SMR technology evaluation and selection planning phase.

Supply Chain Studies – Identified SOWs

To further evaluate the current state and future requirements for the nuclear supply chain, several studies were identified (as outlined in Table 5 below). These studies would be recommended to ensure early understanding of the availability of new and long-lead items as well as labour and training requirements.

These studies require collaboration and consultation with partners that have expertise in the study areas.

Table 5: Supply Chain Studies - Identified SOWs

Identified Study	Description
SMR Equipment Supply Chain	• **Existing and future fabricators, manufacturers, suppliers (Canada and International):** Identify and evaluate the current and potential fabricators, manufacturers, and suppliers of SMR equipment in Canada and internationally and their ability to meet potential future demand. Exploration of utilizing Alberta and Canadian based supply chains and manufacturers. • **Associated costs:** Analyze the costs of SMR equipment, including manufacturing, transportation, and installation based on the material takeoffs for specific reactor designs. • **Transportation logistics and costs:** Examine transportation logistics for SMR equipment and assess associated costs. • **Reactor coolant supply:** Supply chain readiness, and supply chain robustness. • **Compliance**: Evaluation of equipment supply chain compliance to Canadian Standards Association (CSA) N286, N299, import/export controls requirements and other governing regulations for supply chain locations.
SMR Fuel Supply Chain	• **Fuel qualification:** Validation of the status and plans for fuel qualification. • **Evaluate the fuel cycle:** Assess the complete lifecycle of the fuel, from fabrication to disposal, and identify any gaps in the process for the suppliers. • **Existing and future fabricators, manufacturers, suppliers:** Identify and evaluate the current and prospective fuel fabricators, equipment and module manufacturers, and suppliers in Canada and internationally.

Identified Study	Description
	• **Associated costs:** Analyze the costs associated with the production, transportation, and storage of SMR fuel. • **Scale of demand and subsequent supply:** Estimate the scale of demand for SMR fuel in the oil sands and determine its impact on the supply chain and pricing. • **Security:** Security of fuel supply chains. • **Transportation logistics:** Examine transportation logistics for SMR fuel, including safety, regulations, and potential challenges. • **Compliance**: Evaluation of fuel supply chain compliance to CSA N286, N299, import/export controls requirements and other governing regulations for fuel supply chain locations.

Labour and Training Plans	• **Labour Plan**
	  • Identify the resources, quantities, and skills/trades required for each of the following phases:
	    o Construction
	    o Operations and Maintenance
	    o Outages, Turnarounds, and Refueling
	    o Decommissioning
	• **Labour Gap Assessment**
	  • Assessment of available resources within project proponent or partner workforce.
	  • Assessment of Alberta workforce skills and trades.
	  • Identify gaps between current state and the labour plan.
	• **Training Plan**
	  • Document trainings for specific labour resources to upskill in the appropriate areas.
	  • Identify who has the expertise to facilitate this training (such as project proponent, existing nuclear operator, equipment OEM, or other appropriate third party).
	  • Prepare training schedule.
	• **Post-Secondary Plan**
	  • Consider collaborations with universities and colleges to identify methods to close gaps identified in the labour gap assessment through post-secondary classes and degrees or diplomas.
	  • Prepare long-term plan to build local talent through post-secondary programs.

Nuclear Waste Supply Chain	• **Consultation with Canadian Nuclear Waste Management Organization (NWMO):** Overview of current activities. • **Alberta waste regulation mapping:** Map the existing waste regulations in Alberta related to nuclear waste. • **Gap identification:** Identify any gaps in waste management practices and regulations concerning SMR deployment in Alberta. • **Waste strategy and structure:** Propose a waste management strategy and structure for SMR-related nuclear waste in the region. • **Waste management partnerships:** Explore potential partnerships and collaborations for effective nuclear waste management. • **Storage and transportation costs:** Analyze the costs associated with nuclear waste storage and transportation. • **Security**: Security of waste supply chains. • **Overall liabilities and cost impact:** Assess the overall liabilities and cost implications related to nuclear waste management for SMRs in the oil sands facility. • **Vendor-specific:** Develop understanding of vendor waste streams, volumes, radiological activity, and storage methods. • **Compliance**: Evaluation of waste supply chain compliance to CSA N286, N299, import/export controls requirements and other governing regulations for waste supply chain locations.

Economic Evaluation

At this time, SMRs are not economically competitive for SAGD steam generation due to high capital costs and associated risks. The Hatch Feasibility Study concluded that while SMRs are technically feasible for providing steam to SAGD, they are not viable under current market conditions. While existing government support programs are beneficial, they do not currently provide sufficient financial and risk management support to appropriately improve SMR feasibility.

8. Lessons Learned

8.1. Challenges

The first challenge encountered was a difficulty in finding knowledge resources to support SMR study work in Alberta. Section 8.3 provides further detail regarding on-boarding resources with nuclear knowledge. A second challenge was assessing the ability to manage sensitive and confidential information with nuclear technology developers. Section 8.2 provides more detail on learnings about Controlled Nuclear Information and U.S. Export Controlled Information.

A nuclear project is inherently complex and demands extensive legal work. Please note that none of the information provided should be construed as legal advice.

8.2. Practical Learnings

Impact on Project Decision

Cenovus decided in 2024 (during the execution of phase 1 work) not to continue with the Program beyond the end of 2024. The phase 1 evaluation of nuclear from a business perspective showed SMRs are not economic or commercially feasible at present or in the near future. The capital costs are high, the timelines are long and uncertain, and technology and supply chains lack maturity. While there is a potential application for industrial heat needs, significant progress in these areas is required, which may not happen for several years.

Cenovus continues to actively work with the Pathways Alliance to advance opportunities such as SMRs. Cenovus will look to sharing knowledge and lessons learned with the Pathways Alliance as they progress risk-mitigation work for the potential deployment of nuclear in the oil sands.

IP Considerations

Oil sands companies have not historically brought resources inhouse required for nuclear technology development. Cenovus engaged with nuclear technology developers that are progressing their own research and design. See Section 7.2 Technology Development. A technology was not selected, nor was selection in scope, during the work conducted in phase 1. It was identified that once a technology is selected, appropriate agreements would be required for the use of that technology.

Even before a technology is selected, all involved parties should consider the potential generation of new IP. SMR technology developers are expected to own their reactor designs and have existing IP. The SMR developer may generate new IP not related to the oil sands SMR project design. There may be multiples parties participating in an oil sands SMR project, including but not limited to, the nuclear project proponent, the oil sands company (if not the project proponent), and nuclear technology developer. There may be new IP that is not clearly within the nuclear developers existing IP.

Controlled Nuclear Information and US Export Controlled Information (ECI)

Early in the Program work, it was identified that exposure to controlled nuclear information has legal implications and is a risk to team members and the business.

The Treaty on the Non-Proliferation of Nuclear Weapons (NPT), for which Canada is a signatory, established foundational requirements to limit the transfer of nuclear information. Each signatory has legislation that implement such controls to limit proliferation. The United States, as a signatory of the NPT and a nuclear weapons nation, has strong controls to manage the export of nuclear information.

Since most SMR designs under consideration include some design in the United States, a project proponent must consider whether either or both the American and Canadian legislation must be adhered to or addressed. The scope of legal requirements associated with controlled nuclear information, including ECI, may be significant and introduce risk and potentially high costs to address legal requirements.

At the beginning of the work, Cenovus considered the following, at minimum:

- Canadian and international laws and regulations.
- National security and non-proliferation obligations.
- Requirement to obtain NSCA licenses prior to obtaining controlled information.
- Procedures for handling sensitive information, including security controls for compliance on management of controlled information.
- Most advanced nuclear technology that is of interest for oil sands applications is developed in the United States and therefore all nuclear technology information should be assumed to contain ECI, until proven otherwise.
- Technology developers with United States ECI are required to comply with the laws of the United States.
- Any request by Canadian employers for employees to provide citizenship may violate one or more Canadian laws, and employee clearing and screening should be assumed to violate Canadian laws, until proven otherwise.

In summary, there are regulations in place to manage the distribution of nuclear information, substances, and equipment as part of international nuclear non-proliferation requirements. Information such as design details for the nuclear reactor core, fuel and spent fuel is considered controlled. As such, this limits the type of information a company without nuclear controls in place may legally receive.

Government Support

There are government funding opportunities currently available for nuclear projects, however, these are generally time-limited, and do not align to the timelines required for an SMR in the Alberta oil sands. See Table 6.

Table 6: Currently Available Federal Government Funding for Nuclear in Canada

Government Funding Opportunities		Description
Supplementary tax incentives for nuclear	Extended reduced tax rates	• In the 2023 budget, Canada extended reduced corporate tax rates (4.5% for small business and 6.5% for other businesses) to the nuclear power sector, including fuel reprocessing and heavy water treatment. • These tax rates will have a gradual phase-out starting in 2032 (previously beginning phase out in 2029) and will

		be fully phased-out after 2034 (previously phased out after 2031).
	Investment Tax Credits (ITC)	• Clean Electricity ITC: 15% refundable Electricity Credit for investments in non-emitting electricity generation systems, including SMRs. • Clean Technology ITC: 30% refundable Technology Credit available to businesses investing in technology including non-emitting generating technologies and SMRs. • Clean Technology Manufacturing ITC: Credit equal to 30% of the capital cost of eligible property associated with clean technology manufacturing, including manufacturing of nuclear equipment and processing or recycling of nuclear fuels.
Additional funding for nuclear advancement in Canada	Canada Infrastructure Bank (CIB) funding	• $20 billion being granted to CIB for accelerating the energy transition, including up to $10 billion in clean power, and a further $10 billion in green infrastructure.
	Funding to fast-track regulatory processes	• Increased budget of $1.3 billion to increase efficiencies with regulatory reviews and approvals, including for the CNSC, IAA, and others.
	Funding to support clean technologies and developments	• $500 million over 10 years to the Strategic Innovation Fund (SIF), which has previously supported SMR projects. • Natural Resources Canada (NRCan)'s Electricity Predevelopment Program (April 2022) - $250 million allocated over 4 years to fund predevelopment work for clean infrastructure projects (national and regional).

Historically, traditional nuclear projects benefited from significant government support due to the complex risk profile. There are several additional and novel risks for present day SMR projects that could benefit from additional government support, including, but not limited to:

- novel and untested industrial heat application;
- co-location and integrated operation with an industrial facility;
- no previous construction of SMRs anywhere in North America;
- requirements for an advanced, FOAK reactor design with limited operating time;
- anticipated requirements for enriched fuel;
- deployment in a province with no existing nuclear regulatory framework;
- deployment in a province with no framework for nuclear liability;
- deployment in a province with no history, framework or infrastructure for nuclear spent fuel and waste management; and
- deployment in a jurisdiction with an unregulated electricity market.

Regulatory Key Learnings

See Section 7.3.2 for key messages and take-aways from the Regulatory Opportunities and Challenges Report.

Engagement Key Learnings

See Section 7.3.2 for Key Recommendations from the report on Engagement.

Other key learnings and considerations include:

- Long and uncertain project timeline increase risk to project development and capital costs.
- This concept would likely be the first nuclear reactor in Alberta, where there remains regulatory gaps and uncertainties, therefore adding to the schedule and cost uncertainties.
- SMRs for heat/steam production in the oil sands are a fundamentally different use case, meriting different designs and size than power generation.
- Reactors capable of meeting SAGD temperatures would be advanced, generation IV designs, which have minimal commercial operations experience, including limited deployment learnings.
- FOAK, referring to the first deployment of a reactor technology, comes with additional cost inflation risk by its very nature; this is compounded by an immature supply chain.
- Engineering design of most SMRs is still in progress, with immature and highly uncertain commercialization estimates.
- Existing nuclear owners have indicated that owners' costs are significant and much higher than indicated on technology developers estimates; the owners' costs portion of the estimates generally have no basis, are factored, are very immature, and/or lack site-specificity.

8.3. Organizational Learnings

Difficulty Onboarding Local Nuclear-skilled Resources

There are few resources in Alberta that have knowledge and experience in nuclear technology development and deployment. This creates a significant challenge for an Alberta-based company to access nuclear expertise. Externally, service providers across Canada can be engaged, however this is typically centralized to Ontario. These Ontario resources are strong and effective but lack oil sands specific experience and nuances of the Alberta market.

Alignment on Asset (Host Facility) Selection

While the predominant use case for an SMR in the oil sands is generally agreed to be for heat production to replace OTSGs, specific details about the integration scenario were identified but not decided. It was identified that the selection of an asset (the host facility) requires significant internal organizational engagement because there is an existing and operating host facility that is not a nuclear facility. This is quite different from the traditional nuclear projects for on-grid scale power. The potential target facilities should be considered based on the facility requirements and parameters. These include (but are not limited to):

- Electricity production and amount of electricity production:
  - Will the SMR(s) be used for any electricity production? If so, how much?
- End use of the electricity:
  - Will the electricity produced by the SMR(s) be used to accommodate the SMR plant house load?
  - Will the electricity produced by the SMR(s) be used to accommodate SAGD facility house load?
  - Will any electricity be sold to the grid?
- Integration facility configuration:
  - Will the SMR working fluid run through an electricity generating turbine before going to the intermediate facility heat exchanger to the SAGD facility?
  - Will the SMR working fluid run directly to the intermediate facility?
  - Will only some SMR units have power generating capability, or all?

9. GHG Benefits

The objective of the Program was to develop the knowledge to support a potential project which could result in future GHG emissions reductions intensity. Despite the decision not to continue with the SMR FEED Study, the work conducted during phase 1 contributed to knowledge growth in engineering, deployment, regulatory, stakeholder, and commercial areas. SMR commercialization still holds the potential for significant GHG benefits.

To illustrate the potential of SMR technologies, oil sands operators could substitute NG-fired equipment, such as boilers and gas turbines, with SMRs and supply the required industrial heat and electricity at scale for current operations. A first illustrative project could be a 400 MW_{th} SMR with the potential to abate approximately 560,000 tCO_2e per year, depending on factors such as SMR technology and energy transfer configuration and efficiencies. Considering the thousands of MW_{th} of energy demand across SAGD sites, SMRs could abate millions of tons of Scope 1 and possibly Scope 2 CO_2e per year.

Due to the long regulatory and deployment timelines, there are no expected annual GHG reductions in Alberta from the commercial roll out of SMR technology in Alberta until at least the 2040 to 2050 timeframe. Without significant progress on technology commercialization and capital cost reduction by technology developers, it is expected that market adoption will be slow.

10. Environmental, Economic, and Social Impacts

Conducting the work for the Program did not result in direct environmental impacts. However, potential environmental impacts, such as those discussed in Section 9, are approximated for a conceptual future project. The work resulted in the generation of approximately 4.5 full-time equivalent jobs for the duration of the scope.

Commercialized SMR technology has the potential for significant environmental, economic, and social benefits. As described in the economic impact assessment of the HATCH feasibility study, it is estimated that the construction of a 400 MW_{th} (technology-generic) SMR for use in the oil sands will generate $ 3.0 Billion (+/- 50%) of total capital expenditures. This includes project management and direct construction labour, spending on materials, such as concrete and structural steel, and spending on specialty equipment, such as the reactor vessel and core, pumps, and turbines, indirect construction support and inspections and commissioning.

Alberta has a very strong industrial economy, particularly in manufacturing, construction, oil and gas, and mining. These industries have a proven track record of delivering complex mega projects in related sectors. Given the synergies and adjacencies with the conventional island aspects, Alberta's industries are well-positioned to support various components of a new SMR build, including site infrastructure, buildings, structures, and balance of plant equipment. Although Alberta currently lacks a comprehensive supply chain with multiple certified manufacturers, recent developments by Alberta constructors to support nuclear projects outside the province highlight Alberta's potential for economic growth through nuclear development.

From the illustrative project in the HATCH feasibility study, it is estimated that $1,561 million (51% of total) from the construction period will occur within the province. This spending will generate a significant ripple effect through the Alberta economy. An additional $973 million (31%) will occur at other Canadian firms located outside of Alberta. This spending will result in an increase to federal tax revenues. The remaining spending will be with international suppliers. This would generate over $3.4 billion in total GDP for the Alberta economy, including over $2.1 billion of direct, nearly $700 million of indirect, and nearly $642 million of induced GDP within the province. In addition to the 7,336 direct job-years at the site, the project will support 4,885 indirect job-years and 5,650 induced job-years for a total employment impact of nearly 17,870 total job-years within the province. A project of this nature would also support nearly $1.5 billion in total wages and salaries within the province.

Similar to the GHG benefits outlined in Section 9, SMR commercialization still holds the potential for significant economic and social benefits when considering the potential market size, however, due to the long regulatory and deployment timelines, the expected economic and social benefits in Alberta and Canada will be limited from the commercial roll out of SMR technology until at least the 2040 to 2050 timeframe.

11. Scientific Achievements

There were no applied for or obtained patents, published books, journal articles, conference presentations, student theses, etc., based on work conducted during the Program.

12. Post-Project Steps

Cenovus continues to actively work with the Pathways Alliance to advance opportunities such as SMRs. Cenovus will look to sharing knowledge and lessons learned with the Pathways Alliance as they progress risk-mitigation work for the potential deployment of nuclear in the oil sands.

13. Overall Conclusions

Cenovus established the Program to begin investigating SMRs as a method to reliably deliver efficient, high-grade industrial heat to a SAGD facility. The Program was conceived in phases to align to an internal stage gate process. Ultimately, the first phase of enabling studies was the only portion of the Program that was progressed.

The analysis, memos, reports and studies generated supported knowledge growth in areas of engineering, deployment, regulatory, stakeholder, and commercial. Potential commercial project proponents, including government, will have to consider how to address the following items as next steps to deploying SMRs for SAGD:

- addressing Controlled Nuclear Information and ECI;
- limited resources with nuclear knowledge;
- long and uncertain timelines including engagement timelines;
- regulatory gaps, uncertainties and opportunities;
- high early-stage costs and pre-Final Investment Decision (FID) investment;
- high and uncertain total project costs;
- nuclear liability uncertainty;
- engineering design, cost estimates, fuel requirements and commercial operation of generation IV SMRs (the identified SMRs for heat and steam production for SAGD); and
- FOAK challenges.

See Section 8 Lessons Learned for further details on these items.

14. Commercialization and Technology Transfer Plan

Nuclear technologies typically take a significant amount of time to develop to commercialization. This is generally true in any case; whether it is using an existing reactor technology for the same use case at a new site, or if it is a new reactor design for a new use case at a new site, there is significant front-end effort required to successfully see the project through to commercial operations. As such, this Program was undertaken to begin to address some of these activities, identify hurdles, potential risks, and gain knowledge to support the eventual FID of a potential commercial project.

The work conducted for the Program contributed to SMR evaluation for SAGD application and enhanced the knowledge SMR SAGD integration, however, it did not directly advance the SMR technology towards commercialization. This Program identified some of the early-stage requirements to facilitate potentially building a nuclear reactor at a SAGD site. This includes identifying regulatory activities, identifying gaps and opportunities in the regulatory structure through the report developed on regulatory challenges and opportunities. Technical activities largely inform the regulatory and commercial activities that ultimately lead to FID. As such, technical activities were orchestrated in consultation with commercial consideration and feedback to ensure that the best technical decisions are being made. For example, this includes certain cost requirements in the *SMR Technology Down-Selection Plan*, as well as the consideration of alternative revenue sources through the *Isotope Study*, among other examples. Inputs from all workstreams were used to continuously refine investment and commercial models.

Ultimately, this project identified several significant barriers to the commercial operations of an SMR in the oil sands in the early 2030s. Prior to progression commercialization, there is a requirement to take on the FOAK risks.

15. Communications Plan

Cenovus has and will conduct knowledge sharing as described in the post-project steps.

Notable Communications:

- Project funding announcement Sept 19, 2023.

https://www.eralberta.ca/media-releases/government-of-alberta-and-emissions-reduction-alberta-commit-7-million-for-cenovus-to-study-the-use-of-small-modular-nuclear-reactors-in-the-oil-sands/

- Planned release of the SMR FEED Study public final report in 2025.

16. Literature Review

Hatch, Small Modular Reactors Feasibility Study for Oil Sands Applications (SAGD Facility) (2023).

17. Acronyms

ACSW	Arts, Culture and Status of Women (Alberta Ministry)
AEPA	Alberta Environment and Protected Areas
AER	Alberta Energy Regulator
AESO	Alberta Electric System Operator
ARC	Advanced Reactor Concepts, LLC
AUC	Alberta Utilities Commission
BFW	Boiler Feed Water
BTF	Behind-the-Fence

BWR	Boiling Water Reactor
BWXT	BWX Technologies Inc
CNA	Canadian Nuclear Association
CIB	Canada Infrastructure Bank
CNL	Canadian Nuclear Laboratory
CNSC	Canadian Nuclear Safety Commission
CO_2e	carbon dioxide equivalent
CSA	Canadian Standards Association
DBM	Design Basis Memorandum
ECI	Export Controlled Information
EIA	Environmental Impact Assessment
EPEA	Environmental Protection and Enhancement Act
EUA	Electric Utilities Act (Alberta)
FEED	Front End Engineering Design
FID	Final Investment Decision
FOAK	First of a kind
GE	General Electric
GEH	General Electric - Hitachi
GHG	Green House Gases
GoA	Government of Alberta
HEEA	Hydro and Electric Energy Act (Alberta)
HRA	Historical Resources Act (Alberta)
HTGR	High Temperature Gas Reactor
IAA	Impact Assessment Act
IMSR	Integral Molten Salt Reactor
IPD	Initial Project Description
IPWR	Integral Pressurized Water Reactor
ITC	Investment Tax Credits
KAERI	Korea Atomic Energy Research Institute
KEPCO	Korea Electric Power Corporation
KP-FHR	Kairos Power Fluoride salt-cooled high-temperature reactor
LEU	Low Enriched Uranium
LFR	Lead Fast Reactor
LMFR	Liquid Metal Fast Reactors
LOCA	Large Loss of Coolant Accidents
MMR	Micro Modular Reactor
MOU	Memorandum of Understanding
MSR	Molten Salt Reactor
MW_{th}	megawatt thermal
NG	Natural Gas
NID	Needs Identification Document (AESO)
NPT	Treaty on the Non-Proliferation of Nuclear Weapons
NRCan	Natural Resources Canada
NSCA	Nuclear Safety and Control Act
NWMO	Nuclear Waste Management Organization
OGCA	Oil and Gas Conservation Act
OSCA	Oil Sands Conservation Act
OTSG	Once Through Steam Generator

PHWR	Pressurized Heavy Water Reactor
PLA	Public Lands Act
PWR	Pressurized Water Reactor
SAGD	Steam-Assisted Gravity Drainage
SASA	System Access Service Agreement
SIF	Strategic Innovation Fund
SMART	System-integrated Modular Advanced ReacTor
SMR	Small Modular Reactors
SOW	Scope of Work
TRL	Technology Readiness Level