Natural Gas Decarbonization Challenge: Request for Responses from Innovators

CHALLENGE SYNOPSIS
The Foresight Advanced Resource Clean Technology Innovation Centre ("ARCTIC") and Canada's Oil Sands Innovation Alliance ("COSIA") are putting forth the Natural Gas Decarbonization Challenge. This Challenge seeks solutions to decarbonize natural gas in oil sands production. Oil sands consume approximately 700,000,000 million GJ of natural gas per year, or the equivalent energy to heat 7,000,000 average sized homes. Beyond use for oil sands production, natural gas decarbonization has potential application to other natural gas combustion applications, and the hydrogen production industry.

CHALLENGE STATEMENT
Natural gas is used in oil sands operations as a fuel source for power generation, heating applications, and hydrogen source for bitumen upgrading. COSIA is seeking solutions that can reduce (or remove) carbon from natural gas to provide:

1) a carbon-lean (or depleted) combustion fuel with a lower greenhouse gas ("GHG") intensity compared to natural gas; and,
2) a valuable carbon-rich or carbon black by-product.

This by-product will provide economic and environmental value to users of the solution. Solutions must reduce overall GHG emissions reductions compared to the current natural gas combustion approach.

Funding Opportunity: up to $500,000
Response Due Date: JANUARY 15, 2018 at 11:59 PM PST

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***Only non-confidential information should be included in the response***
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The ARCTIC Program Process

This Challenge has been designed and enabled by the ARCTIC Program, which is designed to model a new approach for industry and innovator collaboration. There are four critical phases of activity designed to produce relevant field trials that will validate solutions to resource sector-defined challenges. An outline and summarized description of the phases is below, with a detailed description found in Appendix 4.

Phase 1: Challenge Definition (3 months) - Completed
Along with resource sector partners/ARCTIC participants, Foresight will define challenges in order to focus innovators on the most promising market opportunities.

Phase 2: Innovator Selection
A panel of industry, investors, and selected experts will select 2 to 5 solutions from the pool of innovators that responded to the Challenge for a six month development Sprint.

Phase 3: Challenge Sprint (6 months)
This Challenge Sprint will be sponsored by resource sector industry partners and will leverage the Foresight Accelerator and its mentorship program to advance the development of the proposed solutions through activities that further develop the solution. In this Natural Gas Decarbonization Challenge, proponents will be asked what activity or activities (e.g. testing, material validation) are needed to advance their solution towards commercialization and can be completed in the time frame for the Challenge Sprint.

Phase 4: Field Trial Preparation (12 months)
Following the Challenge Sprint, one solution could be selected for field-testing, or for the next appropriate level of development. The field trial phase will focus on advancing the technology towards commercial readiness, including equipment specification requirements.

The Size of the Opportunity (for Innovators)
The total combined project funding available, for Phases 3 and 4, for projects supported through this call for proposals is up to $500,000 Canadian Dollars (CAD), subject to the discretion of Foresight Cleantech Accelerator Centre/ARCTIC, and COSIA, and the availability of funds.

The Challenge Sprint (Phase 3) is designed to involve 2 to 5 proponents in advancing proposed solutions. The per project costs can go up or down based on the final number of projects in the sprint. The maximum contribution includes provision for
lab space and overheads, marketing, a lab manager, equipment, materials, accelerator mentoring and cash. The winner(s) of the Challenge Sprint will be invited to undertake the next step in the development of the innovation/field trial or equivalent (Phase 4). The maximum contribution from ARCTIC and COSIA to this phase includes support for a test site, test support, equipment, materials and cash.

**Oil Sands Overview**

Oil sands are a mixture of bitumen, clay, sand and water, that when combined form a solid at ambient temperature. Two types of oil sands production methods are in operation: in-situ and mining. Heat is required in both production methods to separate the bitumen from the sand. For a detailed primer on in-situ and mining oil sands production methods, please see the referenced links to Oil Sands Magazine.¹,²

Oil sands production methods combust large quantities of natural gas to produce steam in Boilers and Once Through Steam Generators (“OTSG”), and to produce electricity in Gas Turbine Generators (“GTG”). In total, Alberta’s in-situ and mining oil sands operations combust greater than 700,000,000 GJ of natural gas per year (equivalent to 7,000,000 average sized single detached homes).

In-situ bitumen production using the steam assisted gravity drainage (“SAGD”) process uses large natural gas volumes to produce the necessary steam volumes to heat and mobilize the oil in the subsurface. A representative 33,000 barrel/day production facility will combust approximately 37,000 GJ/day (higher heating value [“HHV”]) of natural gas to produce high-pressure steam that is sent into the reservoir to mobilize and produce bitumen.³ Approximately 16,000 tonnes of steam are sent downhole daily.

Surface mining bitumen production similarly uses large daily volumes of natural gas. A representative 200,000 barrel/day mine, will use approximately 70,000-150,000 GJ/day of natural gas for processes to separate bitumen from the ore.⁴

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The focus of this ARCTIC Natural Gas Decarbonization ("NGD") Challenge involves removing carbon, all or in part, from natural gas prior to combustion, therefore, avoiding the need for pre- or post-combustion gas phase carbon dioxide ("CO₂") capture from a flue gas stack. While pre- and post-combustion carbon capture technologies offer a means to reduce CO₂ emissions associated with combustion of natural gas, they are beyond the scope of this Challenge.

This challenge presents not only the opportunity to decarbonize natural gas, but if successful would have a positive impact on the largest source of GHG emissions in oil sands production. Beyond use in the oil sands, natural gas decarbonization that produces hydrogen can be utilized in other natural gas combustion applications and for hydrogen production and use.

Additional information for innovators is provided within this document to help understand the market opportunities, available resources, and leveraged funding opportunities, and to help proponents appreciate the magnitude of the opportunity and get access to additional support.

**Challenge Overview**

This Challenge will focus on advancing solutions/technologies at all Technology Readiness Levels ("TRL"). Partial solution submissions are encouraged and welcome. Through the ARCTIC program and its multiple stages the technology will be de-risked as it advances in maturity. Details on the stages are provided in section below entitled The ARCTIC Program Process.

Natural gas decarbonization for the purpose of this challenge means the conversion of methane into a carbon-lean fuel (e.g., hydrogen), and a carbon-rich by-product (e.g., diesel, diluent, flocculants, alkanes, cycloalkanes, aromatics, solvents, carbon black, etc.). Figure 1 shows how the NGD Challenge integrates into existing oil sands operations.
Figure 1. A) simplified process diagram for natural gas use in oil sands facilities, and; B) simplified process diagram for Natural Gas Decarbonization Technology for the Challenge.

The carbon-lean fuel generated from the NGD technology could either be blended with natural gas, or combusted on its own, to provide the required thermal energy for bitumen production. Combustion of the carbon-lean fuel must lower the GHG emissions when compared to natural gas to be considered an effective alternative. Any carbon dioxide generated from the NGD process will need to be considered as part of the total carbon dioxide emissions for the process.

NGD solutions for this Challenge do not need to replace 100% of the natural gas usage for oil sands operations. The natural gas usage information provided above is meant only to help respondents understand the potential scope for oil sands application. In practice, a hydrogen fuel source could only comprise 10-15% of the fuel stream for a boiler before significant modifications to the equipment would be required.

Figure 2 below depicts the NGD conversion scheme with different possible decarbonization solutions, and carbon-rich by-products. Selectivity for by-products will be dependent on the implemented decarbonization solution.
Figure 2 - Natural Gas Decarbonization scheme with possible decarbonization methods, and potential carbon-rich by-products listed. Items in figure do not represent an exhaustive list of potential solutions, and by-products.

A recently completed technology evaluation\(^5\) entitled “Scan and Evaluation of Natural Gas Decarbonization Technologies” produced by the Gas Technology Institute (“GTI”) and commissioned by COSIA describes in further detail a selection of the different methods, products, and chemistries that can be used for NGD. Table 1 from the report is reproduced in Appendix 2 for illustrative purposes. Methods described in Table 1 of the GTI report are not exhaustive and other approaches or methods are welcome for submission.

While there are numerous potential end-uses for the carbon by-product, for this Challenge the carbon-rich by-product will provide economic and environmental benefit to users of the NGD solution.

The NGD solution for this challenge must produce a carbon-lean fuel that can be combusted in existing burners (e.g., drum boilers, once through steam generators, etc.). Any new vessels or associated equipment that must be additionally designed in order to burn the carbon-lean fuel generated from NGD is out of scope for this challenge.

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\(^5\) Scan and Evaluation of Natural Gas Decarbonization Technologies  
The Challenge Statement

Natural gas is used in oil sands operations as a fuel source for power generation, heating applications, and hydrogen source for bitumen upgrading. COSIA is seeking solutions that can reduce (or remove) carbon from natural gas to provide:

1) a carbon-lean (or depleted) combustion fuel with a lower greenhouse gas ("GHG") intensity compared to natural gas; and,
2) a valuable carbon-rich or carbon black by-product.

This by-product will provide economic and environmental value to users of the solution. Solutions must reduce overall GHG emissions reductions compared to the current natural gas combustion approach.

Solutions, complete or partial, at all stages of technical maturity are of interest. The objective of this Challenge is to accelerate the development of short listed solutions.

The successful solution will:

- Produce a combustible carbon-lean fuel, and
- Produce a carbon-rich by product:
  - Preference will be given for by-products that can be used/sequestered on site (e.g., diesel, diluent, flocculants, alkanes, cycloalkanes, aromatics, solvents, carbon black, etc.), and
- Reduce overall GHG emissions compared to natural gas combustion, and
- Describe a path to commercial viability

The following opportunities will not be considered:
- Solar technologies for hydrogen production
- Geothermal technologies
- Other renewable/bio energy sources
- Pre- and post-combustion gas phase carbon capture
- Biofuels, biogas and biomass utilization
- Direct oxidation of natural gas with oxygen to produce water
The Challenge - Key Performance Indicators

The evaluation of proposed solutions for Phase 3 (Challenge Sprint) of this Challenge will be based on the KPIs presented below are listed in Appendix 1. COSIA is interested in information regarding how each proposed solution relates to the following key performance indicators, where possible. Detailed questions for proponents to respond to are included in the Response Template, Appendix 1:

1. Technology and business readiness.
2. GHG emissions reductions compared to the reference case
3. Solution process requirements
4. Carbon by-product benefit value
5. Material and energy balance
6. Supplementary Indicators
   a. Technology development plan
   b. Project team

1. Technology and Business Readiness

COSIA uses a D4 scale to describe technological maturity. Table 1 describes the D4 scale relationship to the Technology Readiness Scale. Technologies from all D stages and TRL levels are of interest. Please indicate in the submission the current D stage and TRL level of the proposed solution. If the proposed technology solution is currently operating in another sector, please note which sector and considerations in adapting it to oil sands facilities. Please refer to question 2.8 in Appendix 1 for submission details.

Table 1. 4D TECHNOLOGY DEVELOPMENTAL STAGES AND COMMON LANGUAGE COMPARISON TO TECHNOLOGY READINESS LEVELS (IN BRACKETS) –

<table>
<thead>
<tr>
<th>Stage</th>
<th>Basic Description (TRL #)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Discover 1</td>
<td>Basic principles observed and reported (TRL 1)</td>
<td>Lowest level of technology maturation. At this level, scientific research begins to be translated into applied research and development.</td>
</tr>
<tr>
<td></td>
<td>Technology concept and/or application formulated (TRL 2)</td>
<td>Once basic physical principles are observed, practical applications of those characteristics can be “invented” or identified. Application is still speculative. Experimental proof or detailed analysis to support is conjecture</td>
</tr>
<tr>
<td>Design 2</td>
<td>Analytical and experimental critical function and/or characteristic proof of concept (TRL 3)</td>
<td>Research and development is initiated including studies to set the technology into an appropriate context and to physically validate that the analytical predictions are correct. This includes &quot;proof of concept&quot; validation of the applications of the discovery phase.</td>
</tr>
</tbody>
</table>
Component validation (TRL 4)  
Following successful “proof of concept”, basic technological elements are integrated to establish that the “pieces” will work together to achieve concept-enabling levels of performance. Validation to support the concept that was formulated earlier.

System validation in relevant environment (TRL 5)  
Increased effort to validate the components. The basic technological elements must be integrated with reasonably realistic supporting elements so that the total applications (component-level, sub-system level, or system-level) can be tested in a somewhat realistic environment.

System/subsystem model or prototype demonstration in a relevant environment (TRL 6)  
A representative model or prototype system would be tested in a relevant environment. At this level, if the only “relevant environment” is the environment of space, then the model/prototype must be demonstrated in space.

System prototype demonstration in an actual environment (TRL 7)  
System prototype demonstration in a relevant environment. The prototype should be near or at the scale of the planned operational system with an actual and realistic (e.g. field) system demonstration.

Final system test and demonstration (TRL 8)  
In almost all cases, this level is the end of true “system development” for most technology elements. This might include integration of new technology into an existing system.

True system demonstration (TRL 9)  
In almost all cases, the end of last “bug fixing” aspects of true “system development”. This might include integration of new technology into an existing system. This TRL does not include planned product improvement of ongoing or reusable systems.

2. GHG emissions reductions compared to the reference case.  
Total GHG emissions arising from the proponent solution are to be reported and calculated in terms of tonnes of CO₂e. The complete GHG emission total from the proponent’s process will need to be subtracted from the GHG emissions (tCO₂e) generated from the baseline (i.e. combustion of natural gas) to determine the overall GHG reduction.

A simplified calculation of GHG reductions should be included with the submission. The GHG boundary for this calculation is activity that occurs onsite at an oil sands facility. Upstream and downstream emissions do not need to be calculated. Emissions from the NGD process, and any natural gas and electricity consumption should be clearly stated. An estimate of the embodied GHG of the carbon-rich by-product should also be provided (i.e. how much CO₂ would be produced if the by-product was combusted). All assumptions should be explicitly stated. Appendix 3 provides the natural gas consumption and GHG emission metrics for reference SAGD...
and mining oil sands facilities. Please use the following emissions factors in the calculations: natural gas (1.939 kgCO$_2$e/m$^3$); and Alberta grid electricity provided (0.65 tCO$_2$e/MWh). Please refer to question 2.7 in Appendix 1 for submission details.

3. **Solution Process Requirements**
   To evaluate the proposed solution, the following process requirements will need to be provided.

4. **Carbon by-product benefit value**
   Carbon emissions should not increase or be shifted downstream as a result of transferring carbon from natural gas to the carbon by-product. The carbon by-product should also provide economic and environmental value to the end users of the technology. As part of the submission, please provide a statement that describes the positive benefits of the carbon by-product generated as part of the solution. Please include in the statement benefits to the environment, economic benefits, and any ancillary benefits that may arise from the generation and use of the carbon by-product. Please refer to question 2.7 in Appendix 1 for submission details.

5. **Material and Energy Balance**
   A simplified process flow diagram should be included with known (or estimated) energy and mass balances. Please include equipment in the process flow diagram. Please refer to question 2.3 in Appendix 1 for submission details.

6. **Supplementary Information**
   a. **Technology Development Plan**
      Applicants should describe their technology development plan with milestones, capital requirements and other information that will help reviewers understand the time to commercialization. Please refer to question 2.8 in Appendix 1 for submission details.

   b. **Project Team**
      Applicants should provide project team members, project role, experience and background. If there are existing partners, their names and roles should be stated.
The Challenge Sponsors

**COSIA**
Canada’s Oil Sands Innovation Alliance is an alliance of oil sands producers focused on accelerating the pace of improvement in environmental performance in Canada’s oil sands through collaborative action and innovation. COSIA brings together leading thinkers from industry, government, academia and the wider public to improve measurement, accountability and environmental performance in the oil sands in four priority areas. These four Environmental Priority Areas (“EPAs”) are tailings, water, land, and greenhouse gases (“GHG”).

COSIA’s GHG EPA is looking for innovative and sustainable solutions to significantly reduce GHGs at oil sands mining and in situ (in place) operations without environmental burden shifting (causing negative environmental impacts in other areas). Its aspiration is to “Produce our oil with lower GHG emissions than other sources of oil.”

**Foresight ARCTIC**
Foresight is a catalyst and connector, providing Canadian and international innovators with access to resources, expertise, talent and partners to mature and implement innovative solutions quickly. Advanced Resource Clean Technology Innovation Centre is a Foresight program designed to fulfill the need for a demand-pull approach while identifying both specific environmental, operational and environmental challenges in the resource sector and potential sources of innovation from across Canada, and connecting them to drive performance improvements and accelerate the commercialization of new technologies. The ARCTIC program is funded with support from the British Columbia Innovation Council (“BCIC”) and Western Economic Diversification (“WD”). In this Challenge, the ARCTIC program is working with COSIA to search for alternative hot water production methods with lower GHG emissions.

**Strategic Partners**

**Alberta Innovates**
Alberta Innovates is a provincially-funded Corporation with a mandate to deliver 21st century solutions for the most compelling challenges facing Albertans. We do this by building on our province’s research and technology development strengths in the core sectors of health, environment, energy, food and fibre and platforms such as artificial intelligence, nanotechnology, and omics. We are working with our partners to diversify Alberta’s economy, improve our environmental performance and enhance our well-being through research and innovation.
For more information on this program, please visit www.albertainnovates.ca.

**Additional Challenge Context**

**Market Applications**
In 2016, bitumen production from in-situ oil sands operations was 1,372,000 barrels per day. Production is forecast to nearly double by 2030 with an estimated 2.2 million barrels per day. The oil sands market demand for carbon-lean fuels is even greater when considering the thermal requirements for upgrading and refining of oil sands bitumen.

COSIA is taking a leadership position on supporting innovators to develop technologies that have global applications in other high natural gas usage industries such as power plants, cement, manufacturing, refining, hydrogen fueled transportation, etc.

**SME Resources**
In kind resources, such as time for a technical person, as well as potentially senior management, are a necessary contribution to participation in ARCTIC.

**Leveraging Other Opportunities**
The ARCTIC program and COSIA do not have restrictions on leveraging other sources of external funding, provided this works with the timelines of the Challenge Sprint. Other financing opportunities could include Alberta Innovates, Export Development Canada, Sustainable Development Technology Canada, or others. The ARCTIC program evaluation process could be leveraged to support accessing other investment.

**ARCTIC/COSIA Non-Financial Support**
COSIA technical experts will be involved in the evaluation process and will be available to the Sprint winners for technical support. Foresight will also provide access to executives in residence and executive business advisors, respectively, on business and commercial support, and exposure to financing experts. Alberta Innovates will provide subject-matter expertise and guidance during the challenge.

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7. Western Economic Development, a funder of the ARCTIC program, might have conditions with regards to other federal funding applied to this program. It is the responsibility of the applicant to understand and abide by those restrictions. Of prime concern is the application of stacking limits with federal funding not accounting for more than 75% of the project budget.
Schedule
The following table outlines the anticipated timeline for the Innovator Selection phase. Please refer to the ARCTIC website for updated information.

Table 2 – Innovator Selection Schedule

<table>
<thead>
<tr>
<th>Action</th>
<th>By Whom</th>
<th>Dates</th>
</tr>
</thead>
<tbody>
<tr>
<td>Potential applicants and innovation ecosystem partner program briefing webinar</td>
<td>ARCTIC/COSIA</td>
<td>December 6, 2017</td>
</tr>
<tr>
<td>Proposal Submitted</td>
<td>Proponents</td>
<td>January 15, 2018</td>
</tr>
<tr>
<td>Shortlisted proponents contacted for presentations</td>
<td>ARCTIC Review Team</td>
<td>January 30, 2018</td>
</tr>
<tr>
<td>Final Sprint Decisions and Start Sprint (prototype or test, or equivalent)</td>
<td>Proponents and ARCTIC/COSIA</td>
<td>March 7, 2018</td>
</tr>
<tr>
<td>Wrap up Sprint, choose Field trial winner</td>
<td>Proponents and ARCTIC/ COSIA</td>
<td>September 7, 2018</td>
</tr>
</tbody>
</table>
Appendix 1: Response Template

ONLY NON-CONFIDENTIAL INFORMATION SHOULD BE INCLUDED IN THIS RESPONSE

The evaluation criteria used for selecting innovators for Phase 3 (Challenge Sprint) of this Challenge are:

- **Performance**
  - GHG emission reductions
  - Solution process requirements
  - Carbon by-product benefit
  - Other environmental impacts and benefits.

- **Technology and Business Readiness**
  - Demonstration, proof-of-concept, experience, sector fit
  - Technology Readiness Level (TRL)/D level
  - Modularity/scalability
  - Candidate experience, projects, clients, understanding of the challenge

This response template has two main sections: one that focuses on your technology and the other on your business.

1. **Candidate Info**

<table>
<thead>
<tr>
<th>Company Contact Information: Fill out all applicable fields.</th>
<th>Company Representative Contact Information: Fill out all applicable fields if different from Applicant.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Legal Name:</td>
<td>First Name:</td>
</tr>
<tr>
<td>Trade Name:</td>
<td>Last Name:</td>
</tr>
<tr>
<td>Department/Division:</td>
<td>Position:</td>
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<tr>
<td>Street Address:</td>
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<td>Postal/Zip Code:</td>
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<tr>
<td>Email:</td>
<td>Email:</td>
</tr>
<tr>
<td>Website (if applicable):</td>
<td></td>
</tr>
</tbody>
</table>

If there are other partners other than the lead proponent, please list their name(s) and describe their role(s).
2. Solution and Technology Requirements:

In submitting responses to this Request For Proposals, please respond to the questions in the order they are presented below. Where multiple sub-questions exist within a question, please respond to those subquestions in the order they appear. Cross-references to relevant information within the body of the Challenge Statement document are included where applicable. Please refer to the cross-references for additional information that may help to prepare a response for that particular question.

1. Technology is... (Check all that apply)
   - Strategic
   - Scalable
   - Ability to create jobs
   - Generate revenue through sales
   - Attract investment
   - Benefit society
   - Make a profit

2.1. Overview of solution including where applicable the tool(s), technology(ies) and innovations to processes, practices or technologies involved.

2.2. If proposing only a component of an entire solution, indicate remaining requirements in order to fully address the challenge.

2.3. Please provide a simplified process flow diagram (KPI #5) with known (or estimated) energy and mass balances. Please include equipment on the process flow diagram.

2.4. Please describe the activity or activities (e.g. testing, validation) that are proposed for the Challenge Sprint that will help to advance the proposed solution forward towards commercialization. What needs or challenges do the activity or activities help to overcome? Note: the activity/activities must be completed in the Challenge Sprint timeframe (i.e. 6 months).

2.5. Please provide information on the following attributes of the proposed solution for the Challenge Sprint activity/activities (KPI #3):
   a) List of equipment needed, or projected equipment required
2.6. Please provide information on following attributes of the proposed solution for a commercial application (KPI #3). Please provide a best estimate if attributes for a commercial application are unknown.

a) List of equipment needed, or projected equipment required
b) List of consumables, or expected consumables
c) Anticipated energy use (electricity, natural gas, heat, etc.)
d) Is the process continuous? What is the anticipated downtime?
e) Expected maintenance issues that may arise, or maintenance requirements
f) Expected lifetime of equipment. Which units of equipment are expected to need replacement?
g) Projected technology life span

2.7. Clear articulation of benefits as they relate to the target outcomes and benefits for this Challenge including:

- GHG emissions reductions compared to the reference case (KPI #2).

  **Reference case:** combustion of 37,000 GJ/day HHV natural gas to produce heat and carbon dioxide

  - GHG calculations for the reference case and proponent proposal should assume the same energy content is present in the fuel(s) prior to combustion (i.e. energy content of natural gas in reference case prior to combustion = energy content of the carbon lean fuel in proponent proposal prior to combustion)
  - Please use HHV to perform the calculations
  - GHG emissions are to be represented as metric tonnes of CO2e.
  - Emissions from the NGD process, natural gas and electricity consumption should be clearly stated.
- An estimate of the embodied GHG of the carbon-rich by-product should be provided (i.e. how much CO₂ would be produced if the by-product was combusted).
- Please describe any additional GHG emissions arising from the proponent NGD process.
- Please use the following emissions factors for the calculations: natural gas (1.939 kgCO₂e/m³); and Alberta grid electricity provided (0.65 tCO₂e/MWh). 
  Please use the reference data in the table below to calculate GHG reductions.

Table 4 – Key Reference Data

<table>
<thead>
<tr>
<th>Metric</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bitumen production (bbl/day)</td>
<td>33,000</td>
</tr>
<tr>
<td>NG input (GJ/day)</td>
<td>37,000 (HHV)</td>
</tr>
<tr>
<td>Natural gas energy content (GJ/m³)</td>
<td>0.0377</td>
</tr>
</tbody>
</table>

- Carbon by-product benefits (KPI #4) should be described in a short narrative. Please describe the environmental, economic, and any ancillary benefits and value that are generated through the production of the carbon by-product.

2.8. All Technology Readiness Levels and D stages are of interest in this Challenge. Please indicate the following information in the submission:
  o current Technology Readiness Level (TRL)/D stage (KPI #1)
  o technology development plan (KPI #6a) including milestones, capital requirements, and timelines
  o if the proposed technology is currently operating in another sector, please note which sector and considerations in adapting it to oil sands facilities

2.9. Please provide the following information, if available:
  o safety of technology
  o robust and reliable in extreme weather conditions

2.10. Any other necessary assumptions
2.11. Any information on independent technical reviews

2.12. IP status (list any relevant patents or patent applications by number and jurisdiction)

**Business Description**

Please answer the following questions, for your business in general, as applicable:

1. Experience and background of management and project team

2. Technology Offering (if there are non-technical aspects of your technology offering not covered in the above technical questions that you would like to share)

3. Market Description: (who is your target market, how big is it, etc.)

4. Do you have current customers?
   - Yes, paying
   - Yes, no revenue
   - Commitments to purchase
   - None

5. How many T4 salaried employees do you currently have and in which provinces?

6. Will your business create new jobs? How many and how?
   - Unknown
   - Low Paying (<$80,000)
   - High Paying ($>80,000)

7. Please provide a Business Plan executive summary. Please be prepared to provide financial statements upon request.

8. Is your business incorporated?
   - Yes
     - Incorporation Date:
     - Jurisdiction of incorporation:
   - No
9. List 2 or 3 specific technical and business goals for the next 12 months:

10. Current annual revenue

11. Has your company ever applied for funding through IRAP or Alberta Innovates?
   o Yes
   o No

12. If you answered yes to 11, which funding programs and what were the decisions?

<table>
<thead>
<tr>
<th>Funding Organization</th>
<th>Program</th>
<th>Result</th>
<th>$ Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

13. How much money is invested in your company currently?

14. Who has invested in your company?
### Appendix 2: Table of Natural Gas Decarbonization Routes

The Natural Gas Decarbonization routes in the following table are not an exhaustive list of conversion pathways.

<table>
<thead>
<tr>
<th>Direct Routes</th>
<th>Non-extractive coupling</th>
<th>Route</th>
<th>Chemical Reaction</th>
<th>Brief Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Remove H₂ Electrochemically</td>
<td></td>
<td>Remove H₂ with Selective membrane</td>
<td></td>
<td>An electrochemical cell is used to remove hydrogen from the reaction as it is formed, driving equilibrium to higher conversion.</td>
</tr>
<tr>
<td>Catalysts</td>
<td></td>
<td></td>
<td>2CH₄ → C₂H₆ + H₂</td>
<td>A hydrogen-selective membrane is used to remove hydrogen from the reaction as it is formed, driving equilibrium to higher conversion.</td>
</tr>
<tr>
<td>Aromatization Catalysts</td>
<td></td>
<td>Partial Oxidation with rapid quenching</td>
<td></td>
<td>Catalysts used to lower reaction temperature, increase conversion and selectivity.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>C₆H₆ → Coupled Aromatics + H₂</td>
<td>Catalysts with high selectivity towards aromatic compounds are utilized.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Coupled Aromatics → Carbon + H₂</td>
<td>A small fraction of the feed is combusted with oxygen, this provides heat for the coupling reaction of the remaining feed, which is accelerated to supersonic speeds and then rapidly quenched with a fluid to prevent further coupling beyond ethylene and acetylene.</td>
</tr>
<tr>
<td>Non-thermal Plasma</td>
<td></td>
<td>Non-thermal plasma is used as the energy source to drive the reaction.</td>
<td>Electron beams are used as the energy source to drive the reaction.</td>
<td></td>
</tr>
<tr>
<td>Electron Beam</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Microwaves</td>
<td></td>
<td>Microwaves are used as the energy source to drive the reaction.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ultraviolet light</td>
<td></td>
<td>UV light is used as the energy source to drive the reaction.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| Electrochemical | | | | An electrochemical cell very similar to a nickel metal hydride battery in charging mode is used to generate a NiOOH, which is known in the literature as a catalyst for the methane to methanol reaction. |

| Indirect Routes | Reform to Syngas | Fischer-Tropsch | | Methane is first reformed to syngas, the hydrogen in the syngas is under-utilized in the F-T reactor, resulting in product stream of liquid hydrocarbons plus hydrogen. |
| | | | CH₄ + H₂O → CO + 3H₂ | |
| | | | Fischer-Tropsch | |
| | | | 2(n=1)H₂ + nCO → C₆H₆ + nH₂O | |
| | | | Bio-Reactors | Methane is first reformed to syngas, the hydrogen in the syngas is under-utilized in the bio-reactor, resulting in product stream of ethanol plus hydrogen. |
| | | | 6 CO + 3H₂O → C₆H₆OH + 4CO₂ | |
| | | | 5 H₂ + 2 CO₂ → C₆H₆OH + 3H₂O | |

| H₂S / CS₂ | Soft Oxidation | Reactor 1 | CH₄ + 2H₂S → 4H₂ + CS₂ | Methane is endothermically reacted with H₂S to produce H₂ and a CS₂ intermediate which is then exothermically oligomerized and hydrogenated. There is leftover hydrogen. H₂S is produced and then recycled to the first reactor. |
| | | Reactor 2 | CS₂ + 3H₂ → [CH₂]₄ + 2H₂S | |

Source: Table 1 from “Scan and Evaluation of Natural Gas Decarbonization Technologies” – COSIA
Appendix 3: SAGD and Mining Reference Facility - Material and Energy Flow

Reference documentation for SAGD and mining facilities can be found at the following links:

*COSIA SAGD Reference Facilities*

*Development of a Static Oil Sands Mine and Extraction Reference Facility*
Appendix 4: ARCTIC Program Process (Detailed Description)

This Challenge has been designed and enabled by the ARCTIC Program, which is designed to model a new approach for industry and innovator collaboration. There are four critical phases of activity designed to produce relevant field trials that will validate solutions to resource sector-defined challenges.

Phase 1: Challenge Definition (3 months) - Completed
In conjunction with resource sector partners/ARCTIC participants, Foresight will define challenges in order to focus innovators on the most promising market opportunities.

Outcomes:

- Resource sector consultation events delivered in conjunction with communications or industry partners.
- Definition of resource sector challenges to focus innovators.
- Development of a broad community of industry and cleantech innovators.

Phase 2: Innovator Selection
Foresight and COSIA are launching this Natural Gas Decarbonization Challenge and inviting potential solution providers to respond by filling out the attached Response Template (Appendix 1). A panel of industry, investors, and selected experts will select 2 to 5 solutions from the pool of innovators that responded to the Challenge for a six to nine-month development Sprint.

Phase 3: Challenge Sprint (6 months)
This Challenge Sprint will be sponsored by resource sector industry partners and will leverage the Foresight Accelerator and its mentorship program to:

- Further advance the development of the proposed solutions through activities that advance the solution – such as developing a prototype or performing a feasibility study of the technology; (and)/or
- Further advance the development of proposed solutions through testing in a laboratory or other environment.
- Move the companies to a point where they can seek first funding
- Deliver a focused stream of companies to operate within Foresight/ARCTIC’s facilities. The ARCTIC program has access to specialized facilities in Alberta, BC and Saskatchewan that can respond to the needs of the selected innovators and solutions, if required. Alternatively, selected solution providers can use their own facilities for the Sprint.
Expected Outcomes:
- 2 to 5 promising solutions identified and evaluated.
- 1 technology/solution selected for field trial.
- 1 industry showcase event delivered with a marketing partner.

Phase 4: Field Trial Preparation (12 months)
Following the Challenge Sprint, one solution could be selected for field-testing, or for the next appropriate level of development.

The field trial phase will focus on advancing the technology towards commercial readiness, including equipment specification requirements. Foresight will coordinate with the industrial partner(s) existing stage-gating process to determine the test parameters the technology must meet to achieve field trial readiness. The process will include quarterly progress reviews with the industry partner to ensure the development remains on track.