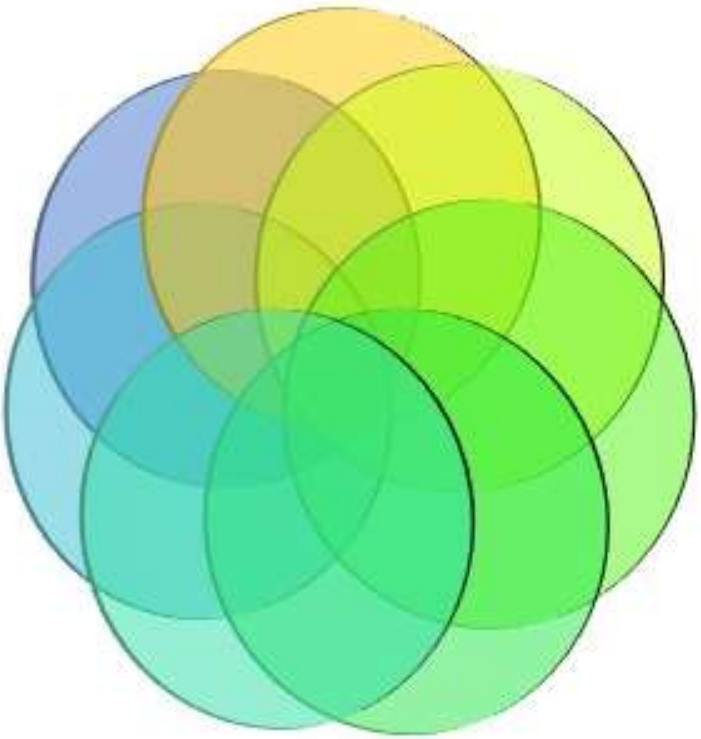
For the Clean Resource Innovation Network (CRIN)

CLEAN ENERGY RESOURCES ROADMAPS ANALYSIS



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Executive Summary

Clean resources are crucial to Canada's prosperity. While extracting value from these resources faces many challenges, innovation has been and will continue to be a powerful enabler of solutions. A collaboration alliance has emerged to foster a transformational shift in clean resources innovation and has formulated the following vision statement:

> *Canada is the global leader in producing clean hydrocarbon energy from source to end use.*

Conclusions

- Current technology roadmaps have a strong focus on environmental priorities in the near to medium term.
- Substantial challenges and transformational opportunities exist in the longer term.
- A future state roadmap and strategy should include Canadian leadership for the innovation required to undertake step change improvements in the environmental performance of the oil and gas industry.

The purpose of this document is to create a common understanding of the innovation and research efforts currently underway in regards to clean energy resources in Canada. The workflow was to gather all existing roadmaps and strategic plans relevant to the Canadian oil and gas industry and conduct a meta-analysis to articulate industry challenges, identify gaps and duplication, and provide an inventory of potential technology solutions.

The analysis paints a picture of a dominant focus in the short to medium term on improving the environmental performance of existing extraction techniques, with some pursuit of novel extraction technologies. All organizations in the Canadian oil and gas innovation system name as a key priority the reduction of GHG emissions and the mitigation of climate change. Water and land, including tailings ponds, as well as ecology and species at risk, are also frequently named environmental priorities.

Other industry needs such as improved recovery and production, cost reduction and market access are generally overshadowed by environmental priorities. Opportunities for adding value to crude oil and natural gas also receive less attention.

Oil sands is the industry segment that has a well-developed network for committing resources to improving environmental attributes. COSIA's only focus is oil sands, but the oil sands are also a top priority for Alberta Innovates and for Emissions Reduction Alberta. Organizations whose mandate covers the whole industry, such as PTAC, NRCan, SRC and the universities, cover oil sands as well as other industry segments such as tight oil, shale gas and conventional oil and gas.

A longer-term challenge is the threat to demand for liquid hydrocarbon transportation fuels. Electric vehicles are now commercially available. A transition of electric vehicles to mainstream automotive markets could cause demand and price disruption for the oil and gas industry which supplies liquid hydrocarbon fuels. This longer-term challenge is starting to be recognized but has yet to appear in the mandate or as a named priority for most organizations in the Canadian oil and gas innovation system.

Furthermore, there are some energy technologies or concepts that are associated with transformation of the current hydrocarbon fuel system that are not being pursued here. These undeveloped technologies include hydrogen production from sources other than methane and tailpipe carbon capture.

Finally, a number of major technology trends have emerged in recent years that are transforming many sectors of the economy from retail to banking, and including transportation. The oil and gas industry has not been immune and utilization of unmanned aerial vehicles (UAVs), cloud computing and trials of autonomous vehicles are being contemplated or undertaken. However, roadmaps to scout and develop these opportunities have yet to be produced.

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Disclaimer

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1. Purpose

The purpose of the roadmap analysis is to explain and help generate a common understanding of the innovation and research efforts underway in regards to clean tech and energy in Canada.

2. Scope

The scope of the work is to gather all existing roadmaps and strategic plans relevant to the Canadian oil and gas industry and conduct a meta-analysis to articulate industry challenges, identify gaps and duplication, and provide an inventory of potential technology solutions.

The workflow included:

1. Worldwide search, scan and acquisition of innovation roadmaps and strategy documents related to clean energy innovation
2. Classification the roadmaps and strategy documents into 3 tiers:
    a. Core to the vision statement
    b. Related to the vision statement
    c. Peripheral to the vision statement.
3. Development of a strategic overview of the situational context regarding:
    a. Canada's clean resources endowment
    b. The clean resources innovation system.
4. Factual summary of the core tier of roadmaps and strategic documents
5. Analysis of the assembled information with respect to:
    a. Strategic opportunities for clean resources
    b. Areas of common efforts
    c. Areas of light efforts
    d. Opportunities
    e. Inventory of potential innovation solutions

The purpose of this document is to present this review and analysis with respect clean resources innovation.

3. Strategic Context

The roadmap analysis is in the context of the Clean Resources Innovation Network (CRIN), which is composed of oil and gas industry companies (oil sands, tight oil, shale gas, and conventional production), research and learning institutions, government agencies, and other organizations who support innovation in the oil and gas industry, with a common goal of guiding clean tech and energy innovation in Canada. There are currently many innovation and research activities underway that fall into this description of clean tech and energy innovation. To help provide a common understanding of what work is underway and where, the CRIN Steering Committee struck a Road Mapping Subgroup, tasked with creating an inventory of these various initiatives and efforts, and finding a way to display how they interact and overlap.

3.1. Strategic Energy Resources in Western Canada

To be most meaningful to Canadian stakeholders, the review of existing innovation challenges and roadmaps is best placed in a Canadian context, a critical element of which is Canada's hydrocarbon resources endowment. Figure 1 provides an overview of Canadian hydrocarbon resources. The top of the infographic indicates the opportunity. Hydrocarbon resources are first categorized as to whether or not they are in commercial production currently; resources that are in production are more likely to accrue benefits to stakeholders in the near to medium term, while those which are not in production likely only offer long term potential. Then, the resources are ranked according to the size of in place volumes from left (highest) to right (lowest); larger size resources are more likely to return greater rewards for innovation investments. Current production volumes are shown for information.

The bottom section of the infographics illustrates the type and intensity of challenges faced by each resource in meeting economic and environmental expectations. It can be noted that oil sands resources face acute challenges with respect to GHG, water and global competitiveness. Light tight oil and shale gas resources on the other hand face moderate challenges with respect to recovery and production, water, and global competitiveness.

The labels for the rows in Figure 1 are further defined below

- In Production (Y/N): Indicates if the resource is currently under commercial production. Bitumen in carbonates and gas hydrates are not considered to be under commercial production, although recovery pilot projects have taken place and are under consideration.
- Resource Size: Relative assessment of in-place resource volume in oil equivalent units, based on information from the Alberta Energy Regulator, the National Energy Board, the Council of Canadian Academies, Canadian Association of Petroleum Producers and the Newfoundland and Labrador Statistics Agency.
- Current Production: Qualitative ranking based on production volume in 2015, based on information from the same organizations noted above.
- Challenges (qualitative assessments based on professional judgement and stakeholder or media interest):
    - Recovery and Production: Challenges related to the characterization, delineation, recovery technology, surface processing and transportation of the resource, including recovery rate and efficiency, costs (capital and operating) and product quality.
    - GHG – Energy Efficiency: Challenges related to emissions of greenhouse gases to atmosphere, principally CO_2, including sources such as fuel combustion, geologic CO_2, and process emissions.
    - GHG – CO_2 Storage and Utilization: Challenges related to capture and utilization of CO_2.
    - GHG – Methane: Challenges related to methane emissions (a potent greenhouse gas), including sources such as fugitives and process emissions.
    - Water: Challenges related to water sourcing, consumption, treatment, disposal and contamination risk to water, land, and ecosystem resources.
    - Land and Ecosystems: Challenges related to land use and ecosystem health, including species at risk, vegetation health, and ecosystem productivity and diversity.
    - Global Competitiveness: Challenges related to market share and growth, and economic returns, including costs versus other jurisdictions, price differential, regional refinery

capacity, and market or regulatory acceptance or penalties based on environmental attributes.

- Market Access: Challenges related to transportation capacity to markets, including pipeline capacity and Liquefied Natural Gas (LNG) export terminals.

3.2. Clean Energy Resources Innovation System

The current Canadian hydrocarbon-resources innovation system is a second crucial contextual element for guiding future innovation investments. Figure 2 provides an overview of the key organizations involved in performing or funding clean resources innovation, with a rating of their priorities for each clean resource challenge as inferred from public and private documents provided by the organizations.

Figure 2 illustrates areas of common priorities that are prospective for greater collaboration and areas where individual organizations choose to specialize or focus. It can be noted that all of the key clean resources challenges are covered at high or medium priority level by a number of organizations, particularly GHG emissions and water, and that no challenges are completely unaddressed.

	Oil Sands In SItu	Shale/ Tight Gas	Light Tight Oil and Shale Liquids	Oil Sands Mining	Conv. Oil	Conv. Gas	Cold Heavy Oil	Offshore	Coal Bed Methane	Bitumen in Carbonates	Gas Hydrates
Market Opportunities											
In Production (Y/N)											
Resource Size	Large	Large	Large	Medium	Medium	Medium	Medium	Small	Small	Large	Large
Current Production	Large	Medium	Medium	Large	Medium	Large	Medium	Small	Small	N/A	N/A
Challenges											
Recovery and Production	M	M	M	M	L	L	M	L	M	H	H
GHG - Energy Efficiency	H	L	L	H	L	L	L	L	L	H	H
GHG - CO2 Storage and Utilization	H	N/A	N/A	H	N/A	N/A	N/A	N/A	N/A	H	N/A
GHG - Methane	L	M	M	M	M	M	H	L	M	L	H
Water	H	M	M	H	L	L	L	L	M	H	L
Land	M	L	L	H	L	L	L	L	L	L	L
Global Competitiveness	H	M	M	H	M	M	M	M	M	H	H
Market Access	M	L	M	M	M	L	M	L	L	M	H
Decreased demand for hydrocarbon transportation fuels	M	L	M	M	M	L	M	M	L	M	L

Figure 1. Strategic Context for Resources

Legend

Minor Challenge (Low)	L	Substantial Challenge (High)	H
Moderate Challenge (Medium)	M	Not applicable	N/A

	COSIA	PTAC	Kinetica Ventures	Alberta Innovates	ERA	NRCan	SDTC	UCalgary	UAlberta	SAIT	NAIT	SRC	BCIC
Resource Characterization	H	H	N/A	N/A	N/A	H	N/A	H	H	L	L	H	N/A
Recovery	H	H	M	H	N/A	L	N/A	M	M	L	L	H	N/A
Production	H	H	M	H	N/A	M	N/A	L	M	L	L	H	N/A
Tailings	H	M	N/A	H	M	H	M	N/A	M	L	L	N/A	N/A
GHG - Energy Efficiency	H	H	H	H	H	H	H	H	H	H	H	H	M
GHG - CO2 Storage and Utilization	H	H	M	H	H	M	M	H	H	M	M	M	M
GHG - Methane	M	H	H	H	H	H	M	M	M	M	M	H	M
Water	H	H	H	H	N/A	H	H	H	H	H	H	H	M
Groundwater	H	H	N/A	M	N/A	M	L	M	M	L	L	M	N/A
Land	H	H	N/A	M	N/A	H	L	M	M	L	L	M	N/A
Ecology	H	H	N/A	M	N/A	H	L	M	M	L	L	M	N/A
Value Added	L	H	M	H	N/A	H	N/A	M	M	M	M	H	M
Market Access	H	H	L	M	N/A	N/A	N/A	M	M	L	L	M	N/A
Decreased demand for hydrocarbon transportation fuels	L	N/A	N/A	M	N/A	M	N/A	M	M	N/A	N/A	N/A	N/A

Figure 2. Innovation System Context

Legend

High priority/focus	H	Low priority/focus	L
Medium priority/focus	M	Outside of mandate	N/A

4. Worldwide Scan of Clean Resource Roadmaps and Strategic Documents

In order to understand the scope, priorities and level of efforts in clean energy resources, a worldwide scan of published documents, with a focus on technology roadmaps, was performed. Public sources were augmented with private documents, mostly strategy documents, from members of CRIN. The scan identified 99 roadmaps and strategy documents. They were categorized into 3 tiers:

- Tier 1 - Core documents for hydrocarbon resources in Canada
- Tier 2 - Documents relevant to the purpose and scope of CRIN
- Tier 3 - Peripheral documents, focused on other jurisdictions, sources of energy, or on end-use applications.

4.1. Tier 1 Roadmaps and Strategic Documents

Tier 1 documents are core to the mission of CRIN and provide the most relevant foundation for the development of a future state roadmap and associated innovation strategy. They are summarized in Section 5, with details provided in Appendices I and IV.

4.2. Tier 2 Roadmaps and Strategic Documents

Tier 2 documents range from the general to the specific. General scope documents include overviews of the Canadian energy sector, including forms of energy other than hydrocarbons, as well as future scenarios for the demand and the supply of energy decades into the future. Also included are strategies to address broad environmental challenges such as climate change, including life assessment studies and platform technology solutions such as Carbon Capture Storage and Utilization (CCUS).

Specific documents are focused on granular challenges and opportunities from tailings management and wellbore leakage to electricity applications.

Also included in Tier 2 are documents from other jurisdictions with broad similarities to Canada, such as the United States, the United Kingdom, Norway and Australia, with some emphasis on tight oil and shale gas.

The list of Tier 2 documents is provided in Appendix II.

4.3. Tier 3 Roadmaps and Strategic Documents

Tier 3 documents included 57 roadmaps and strategic documents from several countries and organizations addressing challenges and opportunities such as:

- Renewable energy, including wind, solar, biomass and geothermal;
- Nuclear energy, including fusion;

- No-carbon vectors for energy delivery such as electricity and hydrogen, including production technologies, infrastructure development, smart electrical grid and energy storage;
- End-use application technology innovation, particularly electric and hydrogen vehicles, but also including natural gas vehicles.

The list of Tier 3 documents is found in Appendix III.

5. Review of Tier 1 Roadmaps and Strategic Documents

This section provides short summaries of the Tier 1 roadmaps and strategic documents. Details are provided in Appendix IV.

5.1. Alberta Innovates—Clean Energy

Alberta Innovates aims to advance energy and environmental technology innovation in Alberta through the development of innovative, integrated ways to convert Alberta's natural resources into market-ready, environmentally responsible energy, and the sustainable management of Alberta's water resources.

Clean Energy Core Focus Areas

Advanced Hydrocarbons

- Recovery Technologies
  - Energy efficiency recovery
  - Low emission recovery
  - No emission recovery
- Bitumen Partial Upgrading
  - National Partial Upgrading Program
- Methane Emission Reduction
- Natural Gas Value Add
- Bitumen Beyond Combustion

Water and Land

- Water Innovation Program
  - Future water supply and watershed management
  - Healthy aquatic ecosystems
  - Water use conservation, efficiency, and productivity
  - Water quality protection
- Integrated Land Management
- Oil Sands Tailings Management
- Climate Change Adaptation

Clean Tech

- Renewable/Clean Heat and Power
- Waste to Energy
- Carbon Capture and Utilization
  - Carbon capture
  - Carbon utilization
- Energy storage
- Geothermal

5.2. Emissions Reduction Alberta

Emissions Reduction Alberta supports the deployment of promising technologies and accelerates the development of game changing innovation, in order to reduce GHG emissions and secure Alberta’s success in a lower carbon economy.

Strategic Areas of Focus

1. Reduced GHG footprint of fossil fuel supply. Transformative technologies and innovation to reduce the GHG footprint of the fossil fuel supply chain and reduce methane emissions while reducing production costs.
2. Low emitting electricity supply. Technology and innovation to reduce the GHG footprint of Alberta's electricity supply mix and add more non-emitting supply to meet overall demand.
3. Biological resource optimization. Innovation and early stage technologies for biological resource optimization in supporting energy system transformation, such as biofuels/bioproducts and carbon retention opportunities.
4. Industrial process efficiency. Industrial process efficiency technologies to deliver GHG reductions through opportunities such as energy conservation and energy efficiency.

Strategic Priorities

- Strategic Priority 1 - Accelerate GHG Reducing Technologies
- Strategic Priority 2 - Advanced Innovation System Priorities
- Strategic Priority 3 - Measure and Communicate Success
- Strategic Priority 4 - Achieved Operational Excellence

5.3. Canada's Oil Sands Innovation Alliance (COSIA)

COSIA aims to accelerate the pace of improvement in environmental performance in Canada's oil sands through collaborative action and innovation.

Environmental Priority Areas

Greenhouse Gases

To produce oil with lower greenhouse emissions than other sources of oil.

- Mining and extraction energy efficiency
- Mining and extraction mobile fleet
- Mining and extraction fugitive emissions
- Mining and extraction materials handling
- In situ energy efficiency
- In situ steam demand reduction
- Carbon capture storage and conversion
- Low carbon heat and power

Water

To be world leaders in water management, producing Canadian energy with no adverse impact on water.

- Mining chemistry and impacts of process-affected water
- Mining pit lakes
- Mining site-wide water management
- Mining water returned
- In situ sharing best practices
- In situ new technology development and implementation
- In situ residuals management
- In situ steam generation
- In situ process analysis, instrumentation and control
- In situ water treatment performance
- In situ regional water resource management
- In situ water recovery from flue gas

Land

To be world leaders in land management, restoring the land and preserving biodiversity of plants and animals.

- Optimization of planning
- Effective reclamation
- Progressive reclamation
- Effective restoration
- Management of species of concern

Tailings

To transform tailings from waste into a resource that speeds land and water reclamation.

- Tailings in pit lakes and soft deposits
- Improving deposit performance
- Collection, transportation and depositional flow
- Technology fundamentals
- Technology optimization and commercialization

5.4. Petroleum Technology Alliance Canada (PTAC)

PTAC's mission is to facilitate innovation, collaborative research and technology development, demonstration and deployment for a responsible Canadian hydrocarbon energy industry.

PTAC Networks

- Alberta Upstream Petroleum Research Fund
- Clean Bitumen Technology Action Plan
- Phoenix Network
- Tight Oil and Gas Innovation Network
- Technology for Emissions Reductions and Eco-Efficiency
- Resource Emission Management Technology Action Plan
- Pipeline Technology Action Plan
- Remote Sensing Network
- Support for Small and Medium-sized Enterprises

Technology Areas

Improve Oil and Gas Recovery

- CO_2 Enhanced Hydrocarbon Recovery
- Coalbed Methane, Shale Gas, Tight Gas, Gas Hydrates, and other Unconventional Gas
- Conventional Heavy Oil, Cold Heavy Oil Production with Sands
- Conventional Oil and Gas Recovery
- Development of Arctic Resources
- Development of Remote Resources
- Enhanced Heavy Oil Recovery
- Enhanced Oil and Gas Recovery
- Enhanced Oil Sands Recovery
- Emerging Technologies to Recover Oil Sands from Deposits with Existing Zero Recovery
- Tight Oil, Shale Oil, and other Unconventional Oil

Manage Environmental Impacts

- Air Quality
- Alternative Energy
- Ecological
- Emission Reduction / Eco-Efficiency
- Energy Efficiency
- Resource Access
- Soil and Groundwater
- Water
- Wellsite Abandonment

Reduce Capital, Operating, and General and Administrative Costs

- Automation
- Capital Cost Optimization

Improve Value-Added Products

- Gasification
- Hydrocarbon Upgrading
- Hydrogen Generation

- Cost Reduction Using Emerging Drilling and Completion Technologies
- Cost Reduction Using Surface Facilities
- Eco-Efficiency and Energy Efficiency Technologies
- Reduce Operating Costs Related to Energy and Chemical Consumption
- Technologies to Reduce Waste Energy
- Integration Petrochemicals, Refining, and Value-Added Opportunities
- Pipeline Transportation
- Transportation

5.5. University of Calgary

5.5.1. Energy Research Strategy - Energy Innovations for Today and Tomorrow

Research Themes

- Discover new sources
- Extract with minimal environmental impact
- Export to markets
- Plan for the future

Grand Challenges

- Unconventional hydrocarbon resources (heavy oil and oil sands, unconventional gas, light tight oil, and liquid rich shale).
- Hydraulic fracturing
- Toward low carbon energy (lower-carbon energy supplies, improved efficiency, and reduction in CO_2 emissions from fossil-based supply)
- Cumulative effects of energy -related processes (changes in or effects on natural, social, economic, and cultural environments caused by past, present and foreseeable future actions)

5.5.2. Global Research Initiative in Sustainable Low Carbon Unconventional Resources (Canada First Research Excellence Fund)

The purpose of the research program is to significantly reduce the carbon footprint of unconventional resource development such as heavy oil, bitumen, and tight oil and gas.

Key Research Elements

- Reduce the amount of energy and water used to decrease oil viscosity by combining novel materials, well configurations and chemical transformations
- Recover viscous oil more efficiently by combining new and nano material-enhanced geophysical imaging strategies
- Reduce the environmental impacts of hydraulic fracturing by adaptively controlling fracture growth using novel diagnostics, geophysical data, materials and fluids
- Recover more oil with the same development footprint for tight reservoirs by deploying novel combinations of fluids, materials and innovative fracturing stages
- Eliminates CO_2 emissions by extracting alternative energy carriers from reservoirs and exploiting low-temperature mixed catalysis, electrochemistry and nano materials to achieve in situ energy transformations

- Reduce the amount of energy and materials needed for CO_2 capture and conversion by greatly increasing the activity, longevity, economy and scalability of recently demonstrated catalytic, electrochemical and microbial routes.

5.6. University of Alberta

5.6.1. Helmholtz-Alberta Initiative - Energy and Environment

The purpose of the initiative is to:

- To expand fundamental knowledge, and to develop innovative technologies and system solutions, which provide for the efficient and environmentally sustainable use of energy resources of global relevance.
- To deliver world-class research and to unlock key technical limitations in order to advance the energy production processes, mitigate the environmental impacts and contribute to a sustainable development of these resources.

Research Themes (2010-2014)

To extend the knowledge base for reducing greenhouse gas emissions arising from production and consumption of fossil fuels.

- Upgrading of biogene and fossil energy sources
- Geological carbon storage
- Scale independent risk assessment and site remediation
- CO_2 separation and gas purification
- Geothermal energy
- Ecosystem and landscape development

New Research Themes (2015-2020)

- Energy systems, processes and materials
  - Energy system assessment
  - Fuels processes
  - Materials for energy and environmental technologies
- Sustainable underground management
  - Geothermal energy
  - CO_2 storage and use
  - Unconventional shale development
- Ecosystem
  - Landscape development
  - Assessment of ecological impacts of toxicant emission
  - Terrestrial ecosystem and resources informatics

5.6.2. Future Energy Systems Research Institute (Canada First Research Excellence Fund)

The purpose of the research program is to develop a path to the responsible development and use of Canada's multi-trillion-dollar energy resources, while facilitating a smooth transition to a lower-carbon energy economy.

Key Research Elements

- An integrated research program uniting University of Alberta researchers in engineering, sciences, social sciences, humanities, business and law
- Find solutions to the critical challenges of today's energy system, which is vital to Canada's current economy
- Develop technologies and practices that position Canada to thrive in a future, lower-carbon economy

- Address challenges for developing Canada's unconventional hydrocarbon resources: tailings, water use, greenhouse gas emissions, land reclamation, and safe and efficient energy transportation
- Concentrate on the University of Alberta's strengths, including advanced materials, smart electrical grids, and bioprocessing

5.7. Oil Sands Technology Roadmap – Unlocking the Potential (Alberta Chamber of Resources, 2004)

This visionary roadmap proposed the aspirational goal of achieving 5 million barrels per day of production by 2030. This topline goal was supported by the following goals:

Mining

- Continuous improvement and cost reduction in equipment and labor costs;
- Improved recovery from lower grade ores;
- Step-out technologies for improved tailings disposal and "at face" continuous mining.

Upgrading

- Significant fraction (approximately 45%) of bitumen production upgraded to Synthetic Crude Oil (SCO);
- Significant fraction (approximately 40%) of value added, green and energy products;
- Reduced costs;
- Improved SCO quality;
- Step-out technologies such as field upgrading and advanced hydroprocessing.

In Situ

- Improved rates of recovery;
- Continuous improvements in steam consumption, water usage and equipment costs;
- Significant reductions in natural gas usage;
- Step-out technologies such as in situ combustion and gasification.

Environment

- Effective management of environmental impacts in land disturbance and reclamation, tailings ponds and reduced water use.

Market Access

- Development of new markets to accept the increased production.

5.8. Tight Oil and Shale Gas Innovation Roadmap (PTAC 2017)

The purpose is to provide knowledge for industry, government and academia to address current and anticipated research and technology challenges and opportunities related to the development by multistage hydraulic fracturing of unconventional tight and shale oil and gas resources in Canada.

Sustainable Production

- Volumes of shale are larger than, for example, those of the Alberta oil sands.
- Tight oil, shale oil, shale gas and tight gas produce different products from different rocks, and use different embodiments or application methods of hydraulic fracturing.

- Technology is fast evolving and, in some plays, the application methods of a few years ago have already been adapted to new and better ones.
- Needs and opportunities can be aggregated in the following science and engineering areas:
    - Reservoir characterization
    - Optimization of completion and production processes
    - Refracturing and well re-stimulation some years after initial production
    - Enhanced Oil Recovery
- Improving the economic and environmental sustainability covers a broad front of challenges and opportunities.

Water Management and Treatment

Key environmental issues include:

- Consumption of vast quantities of water
- Risk to groundwater from potential contamination
- Risk of land contamination from potential spills of transported or stored fluids.

In addition, water chemistry is complex and compatibility issues present cost, logistics and process challenges during completion and production.

Needs and opportunities can be classified as water management and water treatment.

GHG and Air Emissions Management

Surface facilities associated with hydraulically fractured wells are generally similar to surface facilities in conventional oil and gas operations. However, key differences are that hydraulic fracturing involves significant consumption of energy and fuel during completion operations, with resulting GHG emissions (primarily CO_2 in combustion gases), and that hydraulically fractured wells exhibit a high initial production rate followed by a steep rate decline, creating operational challenges which may result in increased emissions in some circumstances (primarily flaring and venting).

Needs and opportunities are:

- Fuel consumption during production, generally for electricity generation and heat
- Venting from pneumatic equipment
- Completion venting and flaring
- Completion operations
- Flaring during production.

6. Analysis

6.1. Observations about Roadmaps and Strategy Documents

6.1.1. Areas of Common Effort

The roadmap and the strategy documents summarized in Sections 4 and 5 paint a picture of a dominant focus in the short to medium term on improving the environmental performance of existing production techniques of Canadian oil and gas, with some pursuit of novel extraction technologies.

All organizations in the oil and gas innovation system name as a key priority reduction of GHG emissions and mitigation of climate change, in the context of Canada's commitment to cut its emissions by 30% by 2030, and of the need to reach 80% emissions reduction by 2050 to avoid exceeding 2°C in global warming.

Furthermore, in the last 18 months, methane was singled out as a key GHG reduction target by governments, and this policy focus is starting to appear in recent innovation strategy documents and roadmaps.

Water and land, including tailings ponds, as well as ecology and species at risk, are also frequently named environmental priorities. Water is a priority for all organizations with the exception of Emissions Reduction Alberta whose mandate is strictly focused on GHG emissions and climate change. Groundwater, land and ecology, including species at risk, receive attention mostly from COSIA, PTAC, Alberta Innovates, SRC and the universities.

Oil sands is the industry segment that has a well-developed network for committing resources to improving environmental attributes. COSIA's only focus is oil sands, and the oil sands are also a top priority for Alberta Innovates and for Emissions Reduction Alberta. Organizations whose mandate covers the whole industry, such as PTAC, NRCan, SRC and the universities, also cover oil sands as well as other industry segments such as tight oil, shale gas and conventional oil and gas.

6.1.2. Areas of Light Effort

Other industry needs such as improved recovery and production, cost reduction and market access are generally overshadowed by environmental priorities. However, PTAC and COSIA list improved recovery and production, and cost reduction as priorities. Market access, mostly in respect to pipelines, appears in some programs of the University of Calgary, PTAC and COSIA. Liquefied natural gas is less frequently mentioned.

Opportunities for adding value to crude oil and natural gas are areas of focus for only a few organizations, generally taking the form of partial upgrading programs by Alberta Innovates, NRCan, the University of Calgary, PTAC and SDTC. Other opportunities for adding value, such as gas to liquids and petrochemicals are less frequently mentioned.

A longer-term challenge is the threat to demand for liquid hydrocarbon transportation fuels. Electric vehicles are now commercially available, although they are still a niche product. An uptake of electric vehicles by the mainstream automotive markets could cause demand and price disruption for the oil and gas industry which supplies liquid hydrocarbon fuels. This longer-term challenge is starting to be recognized but has yet to appear in the mandate or as a named priority for most organizations in the Canadian oil and gas innovation system. While there are a number of roadmaps for electric and hydrogen fuel cell vehicles, as well as for developing an electric or hydrogen infrastructure for transportation needs, these roadmaps generally describe the strategic intent of organizations outside the existing oil and gas industry.

6.1.3. Opportunities

A number of major technology trends have emerged in recent years and they are transforming many sectors of the economy from retail to banking, and including transportation. The oil and gas industry has not been immune and utilization of unmanned aerial vehicles (UAVs), cloud computing and trials of autonomous vehicles are being contemplated or undertaken. However, roadmaps to scout and develop these opportunities have yet to be produced.

Technology Opportunities

Major broad based technology innovation trends include the following:

Innovation	Applications and Benefits
• Digitization and connectivity	• Digital data capture • Operational efficiency • Remote operations • Cost reduction
• Cloud computing (ubiquitous database access and step change in parallelized computing power)	• Geological modelling • Reservoir simulation • Facilities description, planning and optimization
• Sensor and utilization (Internet of things, micro-electrical mechanical systems and nanotechnology)	• Environmental monitoring • Leak detection and repair • Process monitoring
• Unmanned sensing platforms (UAVs, airborne and satellites)	• Wide area environmental monitoring • Cost reduction
• Autonomous/driverless vehicles	• Cost reduction • Process efficiency
• Robotics and process automation	• Operational efficiency • Cost reduction • Improved safety
• Artificial intelligence (including “big data” and analytics)	• Identification of unobvious knowledge and opportunities • Process Improvements • Cost reduction
• 3D printing and “maker economy"	• Reductions in cost, inventory and working capital

Energy Systems Opportunities

While it is difficult to articulate actions that are not happening, there are some energy technologies or concepts that are associated with transformation of the current hydrocarbon fuel system that are not being pursued by the groups identified in Tier 1 of the technology roadmaps. These undeveloped technologies include hydrogen production from sources other than methane and tailpipe carbon capture.

6.2. Analysis of Strategic Opportunities for Clean Resources

6.2.1. Short to Medium Term

The Canadian hydrocarbon industry is facing two separate but related challenges: 1) short-term pressures around cost and environmental footprint, and 2) long-term position in the energy market, with the current general preference of oil and gas for energy being gradually supplanted by alternative energy sources.

The Strategic Context table (Figure 1) illustrates the areas of current hydrocarbon production that face cost and environmental performance challenges (resources currently in production with large amounts of current production, while facing substantial challenges.)

In the short to medium term, the oil and gas industry is actively working to improve its use of resources to reduce costs and to reduce the environmental footprint of the industry. If the cost and environmental performance of current production improves sufficiently to allow Canadian hydrocarbons to compete in the oil and gas markets, and for hydrocarbons to be seen as source of energy compatible with climate change and environmental performance expectations, then the opportunity will be unlocked for the hydrocarbon resources not currently in commercial production (bitumen in carbonates and gas hydrates).

Another challenge, recent but significant, is that for decades, the U.S. had relied on oil and gas imports from Canada and in turn was considered our country's largest customer. However, with disruptive horizontal drilling and multi-stage hydraulic fracturing technologies, the U.S. is now a major competitor to Canada. Both oil and gas production from the U.S. has increased significantly in recent years, with tight oil plays from the U.S. standing as a formidable competitor to Canadian oil sands. Tight oil development from the U.S. requires significantly less capital costs, has a much shorter pay out period, can be shut-in with little economic impact in a low commodity price environment, and can be produced at lower overall cost Canada's oil sands. Canadian conventional oil and gas, tight oil, and shale gas plays are economically better positioned than oil sands. However, these Canadian plays are also facing severe competition from the U.S. due to their higher cost structure, and Canada's more stringent climate change regulations and policies.

The short-term government target to reduce methane emission by 45% by 2025, and the long-term target to reduce net GHG emissions by 80% from 1990 levels by the year 2050, or in other words - the transitioning to a clean, low carbon economy - is undoubtedly the biggest challenge facing the Canadian oil and gas industry today.

6.2.2. Medium to Long Term

CRIN's vision is that *Canada is the global leader in producing clean hydrocarbon energy from source to end use*.

A critical strategic challenge is the impact of hydrocarbon production and utilization on climate change. In this respect, the hydrocarbon industry is focused in the short to medium term on reducing the GHG emissions associated with hydrocarbon production which is the part of the value chain directly under its purview. However, GHG emissions associated with hydrocarbon production represent only approximately 20% of lifecycle hydrocarbon emissions. 80% of emissions take place during utilization of hydrocarbons by sectors of the economy that are customers and consumers of the hydrocarbons produced by the oil

and gas industry. Thus, to meet the long-term policy goals of 80% reduction in GHG emissions by 2050, the hydrocarbon end-use part of the value chain will need to be addressed.

In order to maintain a market position in a clean energy future (i.e. transportation fuels with zero carbon emissions), research is required to develop technology to manufacture and distribute alternative fuels such as hydrocarbon-derived hydrogen or hydrocarbon-derived electricity, linked with carbon capture and utilization or sequestration (CCUS).

Canadian hydrocarbon resources are used in applications other than liquid transportation fuels. Natural gas is converted to electricity. A number of hydrocarbon-based petrochemicals and plastics are produced in Canada, mostly from natural gas liquids. However, research opportunities exist, as proposed in the Alberta Innovates' Bitumen Beyond Combustion project, to convert the asphaltenes fraction in bitumen to high-value products such as carbon fibers, graphene, carbon nanotubes, high quality asphalts and controlled release fertilizers, as well as recovering non-hydrocarbon materials such as valuable metals. This research would leverage the high carbon and high aromatic contents of bitumen, as well as complement Alberta industries such as forestry and agriculture.

In the absence of completing a proper Future State Map, there are some aspects of the future that can be readily forecast at a high-level. Until that complete Future State Map is completed, it is worth noting that the general direction of current technology roadmaps and strategic plans are toward improved resource efficiency. By reducing the needs for resources such as fuel, water, and land footprint, hydrocarbon production can become more cost effective and deliver improved environmental performance. As noted above, a gap in the current technology roadmaps is research into GHG reduction opportunities associated with the combustion of hydrocarbon fuels. It is anticipated that future roadmaps and technology strategies will increasingly focus on this issue. In addition to pursuing clean energy from hydrocarbons, there is increasing interest in researching and developing non-combustion products from hydrocarbon, such as Bitumen Beyond Combustion.

6.2.3. Potential Technology Pathways

Achieving CRIN's vision will require two steps – that technology is developed to enable hydrocarbons to be seen as a clean resource in the global energy market, and that Canada is positioned as a leader in this area. Neither of these steps are trivial. Achieving the label of a clean resource in the energy market requires aggressive changes to the current environmental performance of the oil and gas industry, and may involve some of the following pathways:

1. Production of clean hydrocarbons through improved technologies, potentially with tailpipe carbon capture, storage and utilization
2. Carbon capture storage and utilization, to address utilization emissions
3. Production from hydrocarbon resources of alternative energy carriers such as hydrogen and electricity
4. Production of products from hydrocarbon resources such as those envisioned in Bitumen Beyond Combustion

Maintaining a position as a global leader in marketing a clean resource requires both the right technology to ensure that the resource is clean, and the economic efficiency to hold a position as a commercial leader.

7. Conclusion

This analysis of technology roadmaps highlighted a strong focus on environmental priorities in the near to medium term. However, substantial challenges and transformational opportunities exist in the longer term.

CRIN has formulated a vision that will motivate the creation of a future state roadmap and strategy that would include Canadian leadership for the innovation required to undertake step change improvements in the environmental performance of the oil and gas industry.

Appendix I. List of Tier 1 Clean Energy Roadmaps and Strategic Documents

List of Tier 1 Clean Resources Roadmaps			
Title	**Author**	**Date**	**Source**
Alberta Innovates Business Plan	Alberta Innovates - Clean Energy	2017	http://www.ai-ees.ca/wp-content/uploads/2016/12/2016-Business-Plan_final.pdf
Energy Production Alberta 2017-2020 Business Plan	Emissions Reduction Alberta	2017	Draft document
COSIA Projects Portfolio	Canada's Oil Sands Innovation Alliance (COSIA)	2017	www.cosia.com
PTAC vision, mission, strategy and priority areas	PTAC Petroleum Technology Alliance Canada	2017	www.ptac.org
Energy Research Strategy - Energy Innovations for Today and Tomorrow	University of Calgary	2013	http://www.ucalgary.ca/energy/
Global Research Initiative in Sustainable Low Carbon Unconventional Resources	University of Calgary	2017	http://www.cfref-apogee.gc.ca/results-resultats/abstracts-resumes/competition_2/university_of_calgary-eng.aspx
Helmholtz-Alberta Initiative - Energy and Environment	University of Alberta	2010-2017	http://www.helmholtz-alberta.org/
Future Energy Systems Research Institute	University of Alberta	2017	http://www.cfref-apogee.gc.ca/results-resultats/abstracts-resumes/competition_2/university_of_Alberta-eng.aspx
Oil Sands Technology Roadmap - Unlocking the Potential	Alberta Chamber of Resources	2004	http://www.acr-alberta.com/OSTR_report.pdf
Tight Oil and Shale Gas Innovation Roadmap	PTAC Petroleum Technology Alliance Canada	2017	To be published in May 2017

Appendix II. List of Tier 2 Clean Energy Roadmaps and Strategic Documents

List of Tier 2 Clean Resources Roadmaps			
Title	**Author**	**Date**	**Source**
Canada: Becoming a Sustainable Energy Powerhouse	Canadian Academy of Engineering	2014	http://www.ai-ees.ca/wp-content/uploads/2016/04/canada-july9.pdf
North American Shale Revolution and Potential and Prospects of Shale/Tight Oil and Shale Gas Production in Alberta	CanZealand Geoscience	2013	http://www.ai-ees.ca/wp-content/uploads/2016/03/north_american_shale_revolution_and_potential_and_prospects_of_shale_tight_oil_and_shale_gas_production_in_alberta_1_-1.pdf
Assessment of Innovative Applications of Electricity for Oil Sands Development	Jacobs Consultancy	2012	AIEES download
Greenhouse Gas Reduction Roadmap for Oil Sands	Suncor	2012	http://sustainability.suncor.com/2014/pdf/CCEMC-Suncor_GHG_Reduction_Roadmap-Final_Jacobs_Report.pdf
Oil Sands Tailings Technology Deployment Roadmaps	Thurber Engineering	2012	http://www.ai-ees.ca/wp-content/uploads/2016/04/1906-project_summary_report.pdf
Federal Multiagency Collaboration on Unconventional Oil and Gas Research	U.S. Department of Energy	2014	https://unconventional.energy.gov/pdf/Multiagency_UOG_Research_Strategy.pdf
Life Cycle Assessment Comparison of North American and Imported Crudes	Jacobs Consultancy	2009	AIEES download
Life Cycle Assessment Comparison of North American and Imported Crudes	Tiax LLC	2009	AIEES download

Innovation Roadmap for Transmission Pipeline Transportation of Petroleum Products	PTAC Petroleum Technology Alliance Canada	2014	http://www.ptac.org/projects/186
Industrial Decarbonisation & Energy Efficiency Roadmaps to 2050 Oil Refining	U.K Department of Energy and Climate Change and the Department for Business, Innovation and Skills	2015	https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/416671/Oil_Refining_Report.pdf
Technology Opportunities to Improve the Competitiveness of Alberta's Oil Sands for U.S. Refineries	Jacobs Consultancy	2012	http://www.ai-ees.ca/wp-content/uploads/2016/04/final_report_technology_opportunities_to_improve_the_competitiveness_of_albertas_oil_sands_for_u_s__refineries_ver_1.pdf
Unconventional Gas Technology Roadmap	PTAC Petroleum Technology Alliance Canada	2006	http://www.ptac.org/projects/406
World Energy Outlook 2016	International Energy Agency	2016	https://www.iea.org/publications/freepublications/publication/WorldEnergyOutlook2016ExecutiveSummaryEnglish.pdf
BP Statistical Review of World Energy June 2016	BP	2016	http://www.bp.com/content/dam/bp/pdf/energy-economics/statistical-review-2016/bp-statistical-review-of-world-energy-2016-full-report.pdf
A Better Life with a Healthy Planet - Pathways to Net-Zero emissions	Shell	2016	http://www.shell.com/energy-and-innovation/the-energy-future/scenarios/a-better-life-with-a-healthy-planet/_jcr_content/par/textimage.stream/1475857466913/a1aa5660d50ab79942f7e4a629fcb37ab93d021afb308b92c1b77696ce6b2ba6/scenarios-nze-brochure-interactive-afwv9-interactive.pdf

New Lenses on Future Cities	Shell	2014	http://www.shell.com/energy-and-innovation/the-energy-future/scenarios/new-lenses-on-future-cities/_jcr_content/par/tabbedcontent/tab/textimage.stream/1447854282580/c391a74670d29b3e8f4f64a70a6d5653fb1f9fbeef0ede22dd2daccdb5cdab2c/newlensesonfuturecities-june-2014.pdf
New Lenses Scenarios - Mountains and Oceans	Shell	2013	http://www.shell.com/promos/english/_jcr_content.stream/1448477051486/08032d761ef7d81a4d3b1b6df8620c1e9a64e564a9548e1f2db02e575b00b765/scenarios-newdoc-english.pdf
World Energy Scenarios: Composing energy futures to 2050	World Energy Council	2013	http://www.worldenergy.org/publications/2013/world-energy-scenarios-composing-energy-futures-to-2050/
Wellbore Leakage Technology Roadmap	Canadian Society for Gas Migration	2016	https://csgm.ca/wp-content/uploads/2016/06/Wellbore-Leakage-TRM-presentation-slides.pdf
Renewable energy opportunities in the oil and gas sector	Pembina Institute	2013	http://www.ai-ees.ca/wp-content/uploads/2016/04/renewable_energy_opportunities_in_the_oil_and_gas_sector.pdf
Roadmap for the Norwegian Continental Shelf (NCS) Value creation on and reduced greenhouse gas emissions from the NCS up to 2030 and 2050	Norwegian Oil and Gas Association and the Federation of Norwegian Industries through KonKraft	2016	http://gcenode.no/news/a-new-road-map-for-reduced-emissions/
Climate and the Norwegian Continental Shelf - Introduction, Recommendations and Roadmap for the NCS	KonKraft	2016	https://www.norskoljeoggass.no/Global/2016%20dokumenter/Klimarapport_engelsk_komprimert_web.pdf
Oil and Gas Resources in China: A Roadmap to 2050	Chinese Academy of Sciences	2010	Book in print

The capture, transport, geological storage and re-use of CO2 (CCUS)	French Environment and Energy Management Agency (ADEME)	2011	http://www.ademe.fr/sites/default/files/assets/documents/capture-transport-geological-storage-re-use-co2-strategic-roadmap-2011-7319.pdf
Technology Roadmap Carbon Capture and Storage	International Energy Agency	2013	https://www.iea.org/publications/freepublications/publication/technologyroadmapcarboncaptureandstorage.pdf
Technology Roadmap Carbon Capture and Storage in Industrial Applications	International Energy Agency	2011	https://www.iea.org/publications/freepublications/publication/ccs_industry.pdf
DOE/NETL Carbon Dioxide Capture and Storage RD&D Roadmap	U.S. Department of Energy	2010	http://www.netl.doe.gov/File%20Library/Research/Carbon%20Seq/Reference%20Shelf/CCSRoadmap.pdf
Carbon Dioxide Capture and Storage Technology Roadmap	Natural Resources Canada	2006	http://publications.gc.ca/collections/collection_2014/rncan-nrcan/M154-16-2008-eng.pdf
Quadrennial Technology Review 2015: An Assessment of Energy Technologies and Research Opportunities	U.S. Department of Energy	2015	https://energy.gov/sites/prod/files/2015/09/f26/Quadrennial-Technology-Review-2015_0.pdf
Global Gaps in Clean Energy RD&D --- Update and Recommendations for International Collaboration	International Energy Agency	2010	https://www.iea.org/publications/freepublications/publication/global_gaps.pdf
Global Gaps in Clean Energy Research, Development, and Demonstration	International Energy Agency	2009	http://www.iea.org/publications/freepublications/publication/Global_gaps_in_Clean_Energy.pdf
Strategic Technology Roadmap in Energy Field - Energy Technology Vision 2100	Japan Institute of Applied Energy (IAE)	2006	http://www.iae.or.jp/wp/wp-content/uploads/2014/09/ene_vision_2100/overview.pdf

Energi21 - national strategy for research, development, demonstration and commercialisation of new energy technology	Norway Energi21	2014	http://www.energi21.no/prognett-energi21/Artikkel/NATIONAL_STRATEGY/1254009659799

Appendix III. List of Tier 3 Clean Energy Roadmaps and Strategic Documents

List of Tier 3 Clean Resources Roadmaps			
Title	**Author**	**Date**	**Source**
Roadmap 2020: Powering Canada's Future with Solar Electricity	Canadian Solar Industries Association	2014	http://www.cansia.ca/uploads/7/2/5/1/72513707/cansia_roadmap_2020_final.pdf
Technology Roadmap: Solar Photovoltaic Energy - 2014 edition	International Energy Agency	2014	https://www.iea.org/publications/freepublications/publication/TechnologyRoadmapSolarPhotovoltaicEnergy_2014edition.pdf
Technology Roadmap: Solar Thermal Electricity - 2014 edition	International Energy Agency	2014	https://www.iea.org/publications/freepublications/publication/TechnologyRoadmapSolarThermalElectricity_2014edition.pdf
Photovoltaic Technology Status and Prospects: Canadian Annual Report 2014	Natural Resources Canada	2014	http://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/canmetenergy/files/pubs/pv-technology-status-prospects-canadian-annual-report-2014.pdf
Technology Roadmap: Solar Heating and Cooling	International Energy Agency	2012	https://www.iea.org/publications/freepublications/publication/Solar_Heating_Cooling_Roadmap_2012_WEB.pdf
SunShot Vision Study	U.S. Department of Energy	2012	https://energy.gov/eere/sunshot/sunshot-vision-study
Technology Roadmap Solar Photovoltaic Energy	International Energy Agency	2010	http://www.iea.org/publications/freepublications/publication/pv_roadmap.pdf
Wind Vision: A New Era for Wind Power in the United States	U.S. Department of Energy	2015	https://www.energy.gov/sites/prod/files/WindVision_Report_final.pdf
WindVision 2025 Powering Canada's Future	Canadian Wind Energy Association	2013	http://canwea.ca/pdf/windvision/Windvision_summary_e.pdf

Technology Roadmap: Wind Energy - 2013 edition	International Energy Agency	2013	https://www.iea.org/publications/freepublications/publication/Wind_2013_Roadmap.pdf
Industrial Wind Strategic Roadmap	French Environment and Energy Management Agency (ADEME)	2012	http://www.ademe.fr/sites/default/files/assets/documents/88721_roadmap-industrial-wind.pdf
Technology Roadmap China Wind Energy Development Roadmap 2050	International Energy Agency	2011	https://www.iea.org/publications/freepublications/publication/china_wind.pdf
Wind Technology Road Map	Natural Resources Canada	2009	http://canmetenergy-canmetenergie.nrcan.gc.ca/fichier/81768/windtrm_summary_e.pdf
Moving Forward: Alberta Biogas Industry 2016	Iresco Solutions	2016	http://www.ai-ees.ca/wp-content/uploads/2017/02/Alberta-Biogas-White-Paper-2017-02-05_web.pdf
Renewable Natural Gas Technology Roadmap for Canada	Canadian Gas Association	2014	http://www.cga.ca/wp-content/uploads/2015/04/The-Renewable-Natural-Gas-Technology-Roadmap.pdf
Technology Roadmap Bioenergy for Heat and Power	International Energy Agency	2012	https://www.iea.org/publications/freepublications/publication/2012_Bioenergy_Roadmap_2nd_Edition_WEB.pdf
Technology Roadmap Biofuels for Transport	International Energy Agency	2011	https://www.iea.org/publications/freepublications/publication/Biofuels_Roadmap_WEB.pdf
Strategy on R&D activities for Thermo-chemical conversion and promotion of biomass	Indian Institute of Science/Ministry of New and Renewable Energy	2011	http://mnre.gov.in/file-manager/UserFiles/national_rdbiomass.pdf

Advanced Biofuels Roadmap	French Environment and Energy Management Agency (ADEME)	2011	http://www.ademe.fr/sites/default/files/assets/documents/advanced-biofuels-strategic-roadmap-2011-6922.pdf
U.S. BILLION-TON UPDATE - Biomass Supply for a Bioenergy and Bioproducts Industry	U.S. Department of Energy	2011	https://www1.eere.energy.gov/bioenergy/pdfs/billion_ton_update.pdf
Charting the Course - Canada's Marine Renewable Energy Technology Roadmap	Natural Resources Canada	2011	http://publications.gc.ca/collections/collection_2012/rncan-nrcan/M154-56-2011-eng.pdf
National Algal Biofuels Technology Roadmap	U.S. Department of Energy	2010	https://www1.eere.energy.gov/bioenergy/pdfs/algal_biofuels_roadmap.pdf
Geothermal Technology Roadmap: Global Best Practices Summary	Canadian Geothermal Energy Association	2013	Available for purchase at: http://www.cangea.ca/reports--resource-material.html
Technology Roadmap for Strategic Development of Enhanced Geothermal Systems	U.S. Department of Energy	2013	https://energy.gov/sites/prod/files/2014/02/f7/stanford_egs_technical_roadmap2013.pdf
Technology Roadmap: Geothermal Heat and Power	International Energy Agency	2011	https://www.iea.org/publications/freepublications/publication/Geothermal_Roadmap.pdf
Geothermal Energy Strategic Roadmap	French Environment and Energy Management Agency (ADEME)	2011	http://www.ademe.fr/sites/default/files/assets/documents/88741_roadmap-geothermal-energy.pdf
Low Temperature Co-produced Geothermal Strategic Action Plan	U.S. Department of Energy	2010	https://energy.gov/sites/prod/files/2014/02/f7/ltcg_strategic_action_plan.pdf
Hydropower Vision: A New Chapter for America's 1st Renewable Electricity Source	U.S. Department of Energy	2016	https://energy.gov/sites/prod/files/2016/10/f33/Hydropower-Vision-10262016_0.pdf
Technology Roadmap: Hydropower	International Energy Agency	2012	https://www.iea.org/publications/freepublications/publication/2012_Hydropower_Roadmap.pdf

Technology Roadmap: High-Efficiency, Low-Emissions Coal-Fired Power Generation	International Energy Agency	2012	https://www.iea.org/publications/freepublications/publication/TechnologyRoadmapHighEfficiencyLowEmissionsCoalFiredPowerGeneration_WEB_Updated_March2013.pdf
Canada's Clean Coal Technology Roadmap	Natural Resources Canada	2008	http://publications.gc.ca/collections/collection_2014/rncan-nrcan/M154-17-2008-eng.pdf
Fusion 2030 - Roadmap for Canada	Alberta/Canada Fusion Technology Alliance	2016	http://www.fedorukcentre.ca/docs/Fusion_2030_roadmap_20160930.pdf
Technology Roadmap: Nuclear Energy	International Energy Agency	2015	https://www.iea.org/publications/freepublications/publication/Nuclear_RM_2015_FINAL_WEB_Sept_2015_V3.pdf
Nuclear Energy Research and Development Roadmap: Report to Congress	U.S. Department of Energy	2010	https://energy.gov/sites/prod/files/NuclearEnergy_Roadmap_Final.pdf
Australian Energy Storage Roadmap	Clean Energy Council	2015	https://www.cleanenergycouncil.org.au/dam/cec/policy-and-advocacy/reports/2015/150429-Australia-storage-industry-roadmap-FINAL/150429%20Australia%20energy%20storage%20roadmap%20FINAL.pdf
Energy Storage: State of the Industry	Energy Information Administration	2015	https://www.eia.gov/conference/2015/pdf/presentations/hamilton.pdf
Technology Roadmap: Energy Storage	International Energy Agency	2014	https://www.iea.org/publications/freepublications/publication/TechnologyRoadmapEnergystorage.pdf
Energy Storage Safety Strategic Plan	U.S. Department of Energy	2014	https://energy.gov/sites/prod/files/2014/12/f19/OE%20Safety%20Strategic%20Plan%20December%202014.pdf

Energy Storage Systems Strategic Roadmap	French Environment and Energy Management Agency (ADEME)	2012	http://www.ademe.fr/sites/default/files/assets/documents/88768_6920-roadmap-energy-storage-systems.pdf
Smart Grid R&D Multi-Year Program Plan	U.S. Department of Energy	2012	https://energy.gov/sites/prod/files/SG_MYPP_2012%20Update.pdf
Technology Roadmap: Smart Grids	International Energy Agency	2011	https://www.iea.org/publications/freepublications/publication/smartgrids_roadmap.pdf
Strategic Road Map for Hydrogen and Fuel Cells	Japan Ministry of Economy, Trade and Industry	2016	http://www.meti.go.jp/english/press/2014/pdf/0624_04a.pdf
Examining Future Global Transportation Energy Demand	Energy Information Administration	2016	https://www.eia.gov/conference/2016/pdf/presentations/maples.pdf
Natural Gas Vehicles Research Roadmap	California Energy Commission	2015	http://www.energy.ca.gov/2015publications/CEC-500-2015-091/CEC-500-2015-091-D.pdf
Technology Roadmap: Hydrogen and Fuel Cells	International Energy Agency	2015	https://www.iea.org/publications/freepublications/publication/TechnologyRoadmapHydrogenandFuelCells.pdf
Transportation Energy Futures Study	U.S. Department of Energy	2013	http://www.nrel.gov/docs/fy13osti/56270.pdf
Technology Roadmap: Fuel Economy of Road Vehicles	International Energy Agency	2012	https://www.iea.org/publications/freepublications/publication/Fuel_Economy_2012_WEB.pdf
Roadmap for Low GHG-emitting Vehicles	French Environment and Energy Management Agency (ADEME)	2011	http://www.ademe.fr/en/roadmap-for-low-ghg-emitting-road-vehicles
Technology Roadmap Fuel Economy of Road Vehicles	International Energy Agency	2012	https://www.iea.org/publications/freepublications/publication/Fuel_Economy_2012_WEB.pdf

Strategic roadmap for plug-in electric and hybrid vehicle charging infrastructure	French Environment and Energy Management Agency (ADEME)	2011	http://www.ademe.fr/sites/default/files/assets/documents/88761_roadmap-plug-in-electric-and-hybrid-vehicle-charging-infra.pdf
Hydrogen energy and fuel cells strategic roadmap	French Environment and Energy Management Agency (ADEME)	2011	http://www.ademe.fr/sites/default/files/assets/documents/hydrogen-energy-fuel-cells-strategic-roadmap-2011-6924.pdf
Technology Roadmap: Electric and Plug-in Hybrid Electric Vehicles (EV/PHEV)	International Energy Agency	2009	https://www.iea.org/publications/freepublications/publication/EV_PHEV_Roadmap.pdf
Electric Vehicle Technology Roadmap for Canada	Natural Resources Canada	2009	http://www.publications.gc.ca/site/eng/357226/publication.html
Review of some renewable energy technologies and their applicability to Alberta	Solas Energy Consulting	2015	http://www.ai-ees.ca/wp-content/uploads/2016/04/solas_re_primer_-_aiees_02apr2015.pdf
REmap: Roadmap for A Renewable Energy Future	International Renewable Energy Agency	2016	http://www.irena.org/DocumentDownloads/Publications/IRENA_REmap_2016_edition_report.pdf
Saudi Arabia's Renewable Energy Strategy and Solar Energy Deployment Roadmap	King Abdullah City for Atomic and Renewable Energy	2011	https://www.irena.org/DocumentDownloads/masdar/Abdulrahman%20Al%20Ghabban%20Presentation.pdf
Roadmap for IP protection strategies for oil and gas technologies	Norton Rose Fullbright	2013	http://www.nortonrosefulbright.com/files/a-roadmap-for-ip-protection-strategies-for-oil-and-gas-technologies-pdf-53kb-109540.pdf

Appendix IV. Description of Tier 1 Roadmaps and Strategic Documents

A4.01 Alberta Innovates—Clean Energy

To advance energy and environmental technology innovation in Alberta through the development of innovative, integrated ways to convert Alberta's natural resources into market-ready, environmentally responsible energy, and the sustainable management of Alberta's water resources.

Clean Energy Core Focus

- Recovery technologies
- Partial upgrading
- Landscape restoration
- Water resources
- Water use/treatment
- Bioenergy
- Clean heat and power

Advanced Hydrocarbon

- Bitumen beyond combustion
- Value added natural gas
- Partial upgrading
- Advance recovery
- Methane reduction

Bitumen Partial Upgrading

- National Partial Upgrading Program

Clean Tech

- Geothermal
- Energy storage
- carbon capture and utilization
- Waste to energy

Water and Land

- Integrated land management
- Water innovation program
- Tailings management
- Climate change adaptation

A4.02 Emissions Reduction Alberta

Emissions Reduction Alberta supports the deployment of promising technologies and accelerates the development of game changing innovation, in order to reduce GHG emissions and secure Alberta’s success in a lower carbon economy.

Strategic Areas of Focus

5. Reduced GHG footprint of fossil fuel supply. Transformative technologies and innovation to reduce the GHG footprint of the fossil fuel supply chain and reduce methane emissions while reducing production costs.

   Potential Initiatives

   - Advanced recovery
   - Fugitive emissions
   - Partial upgrading
   - Beyond combustion
   - Electricity - oil sands integration
   - Small nuclear
   - Products of CO_2

6. Low emitting electricity supply. Technology and innovation to reduce the GHG footprint of Alberta's electricity supply mix and add more non-emitting supply to meet overall demand.

   Potential Initiatives

   - Cogeneration
   - Carbon Capture Utilization and Storage (CCUS)
   - Coal phase out
   - Wind, solar
   - Storage
   - Hydropower

7. Biological resource optimization. Innovation and early stage technologies for biological resource optimization in supporting energy system transformation, such as biofuels/bioproducts and carbon retention opportunities.

   Potential Initiatives

   - Biofuels
   - Bioproducts, biomaterials
   - Biopower
   - Carbon retention
   - N2O and methane emissions
   - Waste management

8. Industrial process efficiency. Industrial process efficiency technologies to deliver GHG reductions through opportunities such as energy conservation and energy efficiency.

   Potential Initiatives

   - Industrial efficiency
   - Process improvements
   - Low emitting heat generation

Strategic Priorities

Strategic Priority 1 - Accelerate GHG Reducing Technologies. Fund innovative solutions that result in meaningful GHG emissions reductions in Alberta and contribute to a lower carbon world.

Strategic Priority 2 - Advanced Innovation System Priorities. Leverage our strengths to contribute to critical climate change innovation priorities in Alberta.

Strategic Priority 3 - Measure and Communicate Success .Define and report on metrics to demonstrate results.

Strategic Priority 4 - Achieved Operational Excellence. Strive for excellence in operations and efficiency while maintaining responsiveness to stakeholders and funders.

A4.03 Canada's Oil Sands Innovation Alliance (COSIA)

To accelerate the pace of improvement in environmental performance in Canada's oil sands through collaborative action and innovation.

Greenhouse Gases

To produce oil with lower greenhouse emissions than other sources of oil.

- Mining and extraction energy efficiency
- Mining and extraction mobile fleet
- Mining and extraction fugitive emissions
- Mining and extraction materials handling
- In situ energy efficiency
- In situ steam demand reduction
- Carbon capture storage and conversion
- Low carbon heat and power

Land

To be world leaders in land management, restoring the land and preserving biodiversity of plants and animals.

- Optimization of planning
- Effective reclamation
- Progressive reclamation
- Effective restoration
- Management of species of concern

Water

To be world leaders in water management, producing Canadian energy with no adverse impact on water.

- Mining chemistry and impacts of process-affected water
- Mining pit lakes
- Mining site-wide water management
- Mining water returned
- In situ sharing best practices
- In situ new technology development and implementation
- In situ residuals management
- In situ steam generation
- In situ process analysis, instrumentation and control
- In situ water treatment performance
- In situ regional water resource management
- In situ water recovery from flue gas

Tailings

To transform tailings from waste into a resource that speeds land and water reclamation.

- Tailings in pit lakes and soft deposits
- Improving deposit performance
- Collection, transportation and depositional flow
- Technology fundamentals
- Technology optimization and commercialization

A4.04 Petroleum Technology Alliance Canada (PTAC)

To facilitate innovation, collaborative research and technology development, demonstration and deployment for a responsible Canadian hydrocarbon energy industry.

PTAC Networks

- Alberta Upstream Petroleum Research Fund
- Clean Bitumen Technology Action Plan
- Phoenix Network
- Tight Oil and Gas Innovation Network
- Technology for Emissions Reductions and Eco-Efficiency
- Resource Emission Management Technology Action Plan
- Pipeline Technology Action Plan
- Remote Sensing Network
- Support for Small and Medium-sized Enterprises

Improve Oil and Gas Recovery

- CO_2 Enhanced Hydrocarbon Recovery
- Coalbed Methane, Shale Gas, Tight Gas, Gas Hydrates, and other Unconventional Gas
- Conventional Heavy Oil, Cold Heavy Oil Production with Sands
- Conventional Oil and Gas Recovery
- Development of Arctic Resources
- Development of Remote Resources
- Enhanced Heavy Oil Recovery
- Enhanced Oil and Gas Recovery
- Enhanced Oil Sands Recovery
- Emerging Technologies to Recover Oil Sands from Deposits with Existing Zero Recovery
- Tight Oil, Shale Oil, and other Unconventional Oil

Reduce Capital, Operating, and General and Administrative Costs

- Automation
- Capital Cost Optimization
- Cost Reduction Using Emerging Drilling and Completion Technologies
- Cost Reduction Using Surface Facilities
- Eco-Efficiency and Energy Efficiency Technologies
- Reduce Operating Costs Related to Energy and Chemical Consumption
- Technologies to Reduce Waste Energy

Improve Value-Added Products

- Gasification
- Hydrocarbon Upgrading
- Hydrogen Generation
- Integration Petrochemicals, Refining, and Value-Added Opportunities
- Pipeline Transportation
- Transportation

Manage Environmental Impacts

- Air Quality
- Alternative Energy
- Ecological
- Emission Reduction / Eco-Efficiency
- Energy Efficiency
- Resource Access
- Soil and Groundwater
- Water
- Wellsite Abandonment

Additional PTAC Technical Areas

- e-Business
- Genomics
- Geomatics
- Geosciences
- Health and Safety
- Instrumentation/Measurement
- Nano Technology
- Operations
- Photonics
- Production Engineering

- Remote Sensing
- Reservoir Engineering
- Security
- Telecommunications

A4.05 University of Calgary

(a) Energy Research Strategy - Energy Innovations for Today and Tomorrow

Research Themes

- Discover new sources: new or efficient development of existing fossil resources, or development of novel ways to produce green or alternative energy.
- Extract with minimal environmental impact: improved and game-changing extraction technologies to increase efficiency and reduce environmental footprint, in the oil sands, in situ heavy oil, hydraulic fracturing, upgrading, shale gas and tight oil.
- Export to markets: safe and reliable transportation of oil and gas to markets with minimal impact on the environment and local populations.
- Plan for the future: the complete "cradle to grave" energy system with full accounting of economic, social and environmental impacts.

Grand Challenges

- Unconventional hydrocarbon resources (heavy oil and oil sands, unconventional gas, light tight oil, and liquid rich shale).

  Key areas of investigation:

  - Fundamentals of fluid flow and storage
  - Characterization of the subsurface petroleum and groundwater system
  - Characterization of the surface impacts on ecosystems and communities
  - Development of the production analysis and reservoir simulation methods
  - Improvement of existing recovery technologies
  - Development of next-generation in situ technologies
  - Development of new play and prospect techniques
  - New sources of unconventional gas and novel gas to liquid conversion strategies
  - Evaluation of markets for unconventional gas, including transportation and power generation
  - Reduction of environmental footprint and enhancement of safety
  - Improvement in efficiency of production, cost reduction, and analysis of cost overruns on major projects
  - Regulatory framework, policy development and engagement
- Hydraulic fracturing

Key areas of investigation:

- Hydraulic fracture monitoring and characterization
- hydraulic fracture design and optimization
- Effects on water, atmosphere and terrestrial environments
- Use of hydraulic fracturing to simultaneously enhanced oil recovery and sequester CO_2
- Comparison of Canadian play lifecycles to those in the U.S.
- Development of new methods to forecast long-term production
- Water usage and recycling of water
- Wellbore integrity pre-and post-hydraulic fracture
- Health risks to society and wildlife
- Legal and regulatory framework
- Policy development and stakeholder relations
- Development of new social science models to quantify the benefits and costs of hydraulic fracturing
- Business plan to export technology to U.S. and other nations
- Communication strategies to explain scientific results to the public and education of the public in understanding technical risk.

- Toward low carbon energy (lower-carbon energy supplies, improved efficiency, and reduction in CO_2 emissions from fossil-based supply)

  Key areas of investigation:

  - Solar energy
  - Wind energy
  - Storage of renewable energy
  - Biofuels
  - Geothermal energy
  - Technologies to enable low-carbon communities, including building design and transportation
  - Reducing CO_2 emissions from transitional hydrocarbon-based supply with carbon capture and storage technologies
  - New CO_2 utilization
  - Geological storage of CO_2
  - Novel carbon-capture and storage techniques
  - CO_2 pipeline monitoring
  - Energy efficiency and demand-side management
  - System design, analysis in control
  - Public policy and regulatory frameworks and public engagement

- Cumulative effects of energy -related processes (changes in or effects on natural, social, economic, and cultural environments caused by past, present and foreseeable future actions)

  Key areas of investigation:

  - Risks of energy production and cumulative pollutant effects to human and ecosystem health, society and economy
  - Economic and social costs of risk in the energy industry
  - Effective communication of risk to aboriginal and other affected populations
  - Ways to improve government and private decision-making
  - Life-cycle analysis
  - Sensors for use in populated and remote areas for air, land and water measurements
  - Electrical-based and biological-based sensors
  - Data collection software and integration databases for optimal assessment
  - Advances in toxicity assessment
  - Corporate responsibility, legislation and engagement of affected populations
  - New technologies to mitigate risk/cumulative effects
  - Novel and innovative contaminant-remediation technologies
  - Novel pollution-prevention technologies
  - Translation into legislation, regulation and social license to operate of new remediation and pollution prevention technologies

(b) Global Research Initiative in Sustainable Low Carbon Unconventional Resources (Canada First Research Excellence Fund)

To significantly reduce the carbon footprint of unconventional resource development such as heavy oil, bitumen, and tight oil and gas.

Key research elements:

- Reduce the amount of energy and water used to decrease oil viscosity by combining novel materials, well configurations and chemical transformations
- Recover viscous oil more efficiently by combining new and nano material-enhanced geophysical imaging strategies
- Reduce the environmental impacts of hydraulic fracturing by adaptively controlling fracture growth using novel diagnostics, geophysical data, materials and fluids
- Recover more oil with the same development footprint for tight reservoirs by deploying novel combinations of fluids, materials and innovative fracturing stages
- Eliminates CO_2 emissions by extracting alternative energy carriers from reservoirs and exploiting low-temperature mixed catalysis, electrochemistry and nano materials to achieve in situ energy transformations

- Reduce the amount of energy and materials needed for CO_2 capture and conversion by greatly increasing the activity, longevity, economy and scalability of recently demonstrated catalytic, electrochemical and microbial routes.

A4.06 University of Alberta

(a) Helmholtz-Alberta Initiative - Energy and Environment

To expand fundamental knowledge, and to develop innovative technologies and system solutions, which provide for the efficient and environmentally sustainable use of energy resources of global relevance.

To deliver world-class research and to unlock key technical limitations in order to advance the energy production processes, mitigate the environmental impacts and contribute to a sustainable development of these resources.

Research Themes (2010-2014)

To extend the knowledge base for reducing greenhouse gas emissions arising from production and consumption of fossil fuels.

- Upgrading of biogene and fossil energy sources
- Geological carbon storage
- Scale independent risk assessment and site remediation
- CO_2 separation and gas purification
- Geothermal energy
- Ecosystem and landscape development

New Research Themes (2015-2020)

- Energy systems, processes and materials
  - Energy system assessment
  - Fuels processes
  - Materials for energy and environmental technologies
- Sustainable underground management
  - Geothermal energy
  - CO_2 storage and use
  - Unconventional shale development
- Ecosystem
  - Landscape development
  - Assessment of ecological impacts of toxicant emission
  - Terrestrial ecosystem and resources informatics

(b) Future Energy Systems Research Institute (Canada First Research Excellence Fund)

To develop a path to the responsible development and use of Canada's multi-trillion-dollar energy resources, while facilitating a smooth transition to a lower-carbon energy economy.

Key research elements:

- An integrated research program uniting University of Alberta researchers in engineering, sciences, social sciences, humanities, business and law
- Find solutions to the critical challenges of today's energy system, which is vital to Canada's current economy
- Develop technologies and practices that position Canada to thrive in a future, lower-carbon economy
- Address challenges for developing Canada's unconventional hydrocarbon resources: tailings, water use, greenhouse gas emissions, land reclamation, and safe and efficient energy transportation
- Concentrate on the University of Alberta's strengths, including advanced materials, smart electrical grids, and bioprocessing

A4.07 Oil Sands Technology Roadmap – Unlocking the Potential (Alberta Chamber of Resources, 2004)

A visionary roadmap that proposed the aspirational goal of achieving 5 million barrels per day of production by 2030. This topline goal was supported by the following goals:

Mining

- Continuous improvement and cost reduction in equipment and labor costs;
- Improved recovery from lower grade ores;
- Step-out technologies for improved tailings disposal and "at face" continuous mining.

In Situ

- Improved rates of recovery;
- Continuous improvements in steam consumption, water usage and equipment costs;
- Significant reductions in natural gas usage;
- Step-out technologies such as in situ combustion and gasification.

Upgrading

- Significant fraction (approximately 45%) of bitumen production upgraded to Synthetic Crude Oil (SCO);
- Significant fraction (approximately 40%) of value added, green and energy products;
- Reduced costs;
- Improved SCO quality;
- Step-out technologies such as field upgrading and advanced hydroprocessing.

Environment

- Effective management of environmental impacts in land disturbance and reclamation, tailings ponds and reduced water use.

Market Access

- Development of new markets to accept the increased production.

A4.08 Tight Oil and Shale Gas Innovation Roadmap (PTAC, 2017)

To provide knowledge for industry, government and academia to address current and anticipated research and technology challenges and opportunities related to the development by multistage hydraulic fracturing of unconventional tight and shale oil and gas resources in Canada.

Sustainable Production

- Volumes of petroleum resources found in shale formations are larger than, for example, those of the Alberta oil sands.
- Tight oil, shale oil, shale gas and tight gas produce different products from different rocks, and use different embodiments or application methods of hydraulic fracturing.
- Technology is fast evolving and, in some plays, the application methods of a few years ago have already been adapted to new and better ones. Therefore, the identification of dominant trends and of long term needs is difficult.
- Needs and opportunities can be aggregated in the following science and engineering areas:
    - Reservoir characterization, including rock and fluid geochemistry and thermodynamic properties.
    - Optimization of completion and production processes, including various completions and production variables such as well spacing, stage spacing, length of laterals, number of stages, multilateral schemes, proppant type and quantity, fracturing fluid type and chemical formulation, and production rate control schemes.
    - Refracturing and well re-stimulation some years after initial production to re-energize production and to access bypassed resources.
    - Enhanced Oil Recovery, as an alternative to refracturing individual wells, to coax more production from an existing field.
- Improving the economic and environmental sustainability of tight and shale oil and gas recovery and production covers a broad front of challenges and opportunities from new knowledge from rock characterization and data analytics, to novel equipment design and innovative processes.

Water Management and Treatment

The environmental challenges with water management and treatment are a dominating concern associated with hydraulic fracturing. Key environmental issues include:

- Consumption of vast quantities of water which may deplete scarce surface sources of fresh water and/or compete with population needs, agriculture and other economic activities in the region;
- Risk to groundwater from potential contamination from injected or produced fluids; and
- Risk of land contamination from potential spills of transported or stored fluids.

In addition, water chemistry is complex and compatibility issues present cost, logistics and process challenges during completion and production.

Needs and opportunities can be classified as water management and water treatment:

- Water Management
    - The interactions between surface and ground waters within and between watershed basins as well as the supply-demand for water on a watershed basis are not well understood in all cases. Additional studies are required to increase the knowledge base of groundwater resources in Western Canada, particularly saline aquifers.
    - Thorough characterization of source waters is key for determining compatibility impacts. Improved water characterizations through standardized methodologies would allow for water chemistry data that is comparable between different laboratories, which is crucial for supporting operations.
    - Flowback and produced water may contain trace amounts of additives (e.g. residual crosslinkers), Naturally Occurring Radioactive Material (NORMs), and are often nutrient rich. Detailed flowback and produced water characterizations are crucial for assessing the reusability and compatibility of these waters with fracture fluid chemicals, make-up sources and the producing formation.
    - When reuse is not possible, these wastewaters are typically injected into deep wells for disposal. Detailed wastewater characterizations together with best practices and guidelines for preventing the comingling of incompatible waters could help prevent injectivity losses and the potential for permanent formation damage within disposal wells.
    - Logistical challenges of storage and transport of water are determined by the supply-demand relationship for water at one or multiple locations. The storage capacities, transport distances, available transfer equipment, means of transport, completions schedules make for complex logistics, which must be safely and economically addressed.
- Water Treatment
    - Overall treatment intensity is anticipated to be the lowest with non-saline water management processes with progressively more treatment intensity required for saline and reuse applications. The current technology gaps lie in the treatment for key water quality parameters that influence reuse challenges. The parameters most likely to create reuse challenges include sulphates, residual crosslinkers and polymer, bacteria, and NORMs. The treatment gaps related to these issues include sulfate removal to avoid hardness and NORM-based scale precipitation, developing

best practices for bacteria management during treatment and storage, and determining the maximum allowable concentrations of residual crosslinkers and polymer without impacting the compatibility with fracturing fluids.

GHG and Air Emissions Management

Surface facilities associated with hydraulically fractured wells are generally similar to surface facilities in conventional oil and gas operations. However, key differences are that hydraulic fracturing involves significant consumption of energy and fuel during completion operations, with resulting GHG emissions (primarily CO_2 in combustion gases), and that hydraulically fractured wells exhibit a high initial production rate followed by a steep rate decline, creating operational challenges which may result in increased emissions in some circumstances (primarily flaring and venting).

Needs and opportunities are:

- Fuel consumption during production, generally for electricity generation and heat.
- Venting from pneumatic equipment, particularly related to chemical injection pump emissions.
- Completion venting and flaring of flow-back gases prior to production, which can last 3 to 7 days.
- Completion operations, which mostly involves fuel consumption for pumping the fracturing fluid and can last one to several days.
- Flaring during production, related to the disposal of solution gas after the well has come on stream; may be a significant emission source when pipeline infrastructure is lacking.

Gap Analysis

24 specific gaps were identified, documented and aggregated in the areas of sustainable production (13 gaps), water management and treatment (6 gaps) and GHG and air emissions management (5 gaps).

Technology Directions

49 potential areas for research studies and technology development that were assembled into three portfolios: sustainable production (21 opportunities), water management and treatment (13 opportunities), and GHG and air emissions management (15 opportunities.