

TECHNOLOGY ROADMAP

Third Edition, draft, November 2019

Investing in technologies
for a lower carbon future.

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Overview of ERA's Technology Roadmap

PURPOSE

Emissions Reduction Alberta (ERA)¹ has a mandate to reduce greenhouse gas (GHG) emissions and grow Alberta's economy by accelerating the development and adoption of innovative technology solutions. ERA invests the proceeds from the price on carbon paid by Alberta's large final emitters to reduce GHGs and build the resilience of new and incumbent industries in Alberta. Our investments help innovators develop and demonstrate GHG-reducing technologies that build more competitive industries, enable new business opportunities, and create the solutions the world needs.

The goal of this Technology Roadmap (TRM) is to articulate the pathways that will enable Alberta to have a competitive economy that delivers sustainable environmental outcomes, attracts investment, and is contributing to a prosperous, lower carbon world.

The TRM is a living document that guides ERA's investment decisions and informs its portfolio mix. ERA works with government, industry, investors and innovators to develop the TRM and ensure it accounts for uncertainty in factors such as the pace of technology development and global decarbonization. The TRM is also intended to contribute to and align with the broader innovation system around common environmental and innovation goals that result in meaningful GHG reductions and economic growth in Alberta and around the world.

KEY PRINCIPLES AND INSIGHTS

The TRM builds from six key investment principles or insights that are central to its success:

- 1 Leverage Alberta's Unique Strengths** – ERA's investment strategy will position Alberta to play a key role in, and make a significant contribution to, a prosperous low carbon emissions future, including with respect to leveraging its vast hydrocarbon resources.
- 2 Think from the Future** – ERA will prioritize its investments based on the most effective pathways toward enabling a carbon and cost competitive future.
- 3 Read the Guideposts** – Given uncertainty about the pace of decarbonization, experts around the world are working to define the guideposts and indicators for what a low-carbon future might look like. ERA is uniquely positioned to use and contribute to these longer-term guideposts, in combination with near-term opportunities for cost and GHG reductions, to identify and accelerate the most impactful technologies.
- 4 Take a Portfolio Approach** – ERA will diversify its investments across timescales, technology readiness levels (TRLs) and focus areas, allowing Alberta to be successful in a range of low-carbon futures.
- 5 Pursue Factors Beyond Technology** – A focus on technology alone is not enough given the multitude of other factors that can either inhibit or enable a technology's success. ERA will be a catalyst in convening the financing, policy and business conditions for success.
- 6 Align the System** – ERA can be a leader and a change agent in Alberta's energy, climate, and innovation ecosystem, taking the "long-view" for the public interest, and collaborating with others in the system to identify strategic pathways that maximize the returns for private and public investment.

¹. Emissions Reduction Alberta (ERA) is a registered tradename of the Climate Change and Emissions Management (CCEMC) Corporation.

OBJECTIVES

The TRM seeks to:

1. Identify and define the guideposts, pathways, opportunities and barriers to allow Alberta to thrive in a low carbon future. This will allow ERA to:

- ▷ Invest in technologies that contribute to our environment and energy vision of the future; and those that can be exported to the world, having a global impact
- ▷ Account for uncertainty in the pace of technology development and global decarbonization
- ▷ Demonstrate the value of directing public funds toward innovation and technology and provide a clear line of sight between funding and outcomes
- ▷ Invest in solutions that align with Alberta's needs and priorities
- ▷ Leverage Alberta's assets to attract world-class innovators and technologies
- ▷ Contribute to Alberta's economic prosperity and diversification by accelerating successful clean technologies and businesses.

2. Map the potential tactical options for delivering solutions, providing:

- ▷ Aligned and coordinated strategies to maximize near- and long-term environmental and economic outcomes
- ▷ A clearer understanding of ERA's value proposition, responsibilities and accountabilities in the innovation system.

3. Identify milestones and deliverables, including:

- ▷ Measurable benchmarks and opportunities to reduce carbon and costs as we work toward achieving emissions reductions, economic benefits and high-quality employment opportunities
- ▷ Reporting of environmental and economic performance against identified targets
- ▷ Mechanisms to communicate and demonstrate progress.

Image: Enkern Biofuels facility in Edmonton



AREAS OF FOCUS

To achieve the TRM's objectives, we have identified four strategic investment areas of focus. The areas of focus are summarized in Figure 1 and are described in detail beginning on page 17.

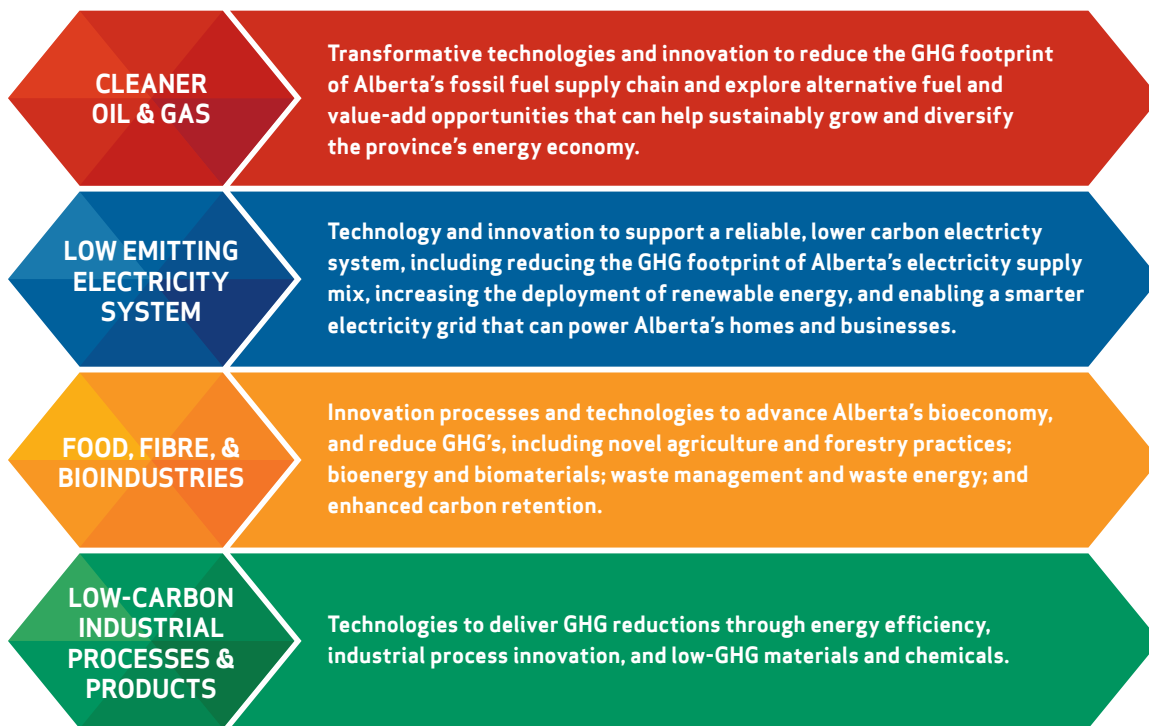


Figure 1 – TRM Areas of Focus

CONTINUOUS IMPROVEMENT

The TRM is part of a continuous process designed to support ERA as a flexible and nimble organization that can adjust to new information, challenges, opportunities and uncertainties. The first edition was released in late 2016. Now in its third edition, the TRM continues to evolve and allows ERA and its partners and stakeholders to focus on common goals, technology pathways, priorities, and defined implementation timeframes. An illustration for the design of the TRM is provided in Figure 2.

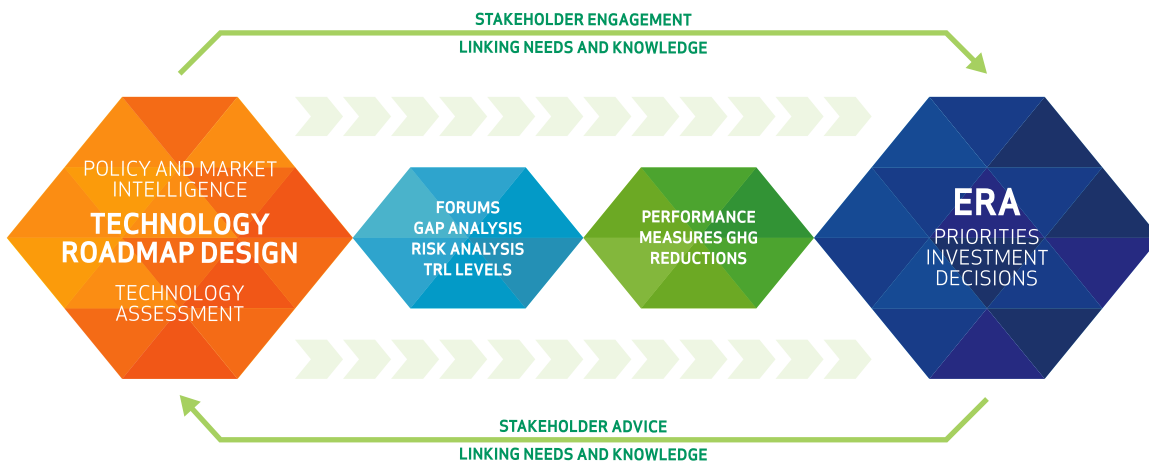


Figure 2 – TRM Design

In January 2018, ERA engaged the Energy Futures Lab (EFL) and its Fellowship to review the TRM.

Key to the EFL's review of the TRM was a "backcasting from the future" perspective. While forecasting projects past trends into the future, backcasting starts with the end in mind, seeks to outline conditions for a successful future, and then uses this vision for the future as the starting point for planning.

The second edition of the TRM, released in May 2018, incorporated valuable input provided by the EFL Fellowship. Central to their advice was that the TRM help better clarify the question, "A Road Map to What?" by providing a more specific and compelling vision of Alberta's lower carbon future. This vision can help paint a picture of the unique contributions Alberta can make in a low-carbon emissions future and illuminate options for technological pathways to get there.



1. Begin with the end in mind.
2. Look back from the future to the present.
3. Move step-by-step toward the future.

Figure 3 - Backcasting — What and Why

In May 2019, ERA worked with The Natural Step (TNS) to consider the tension between the global need for carbon-based energy we see today and the drive toward a global low-carbon economy of the future. This exercise uncovered important implications for the TRM including:

- ▶ The potential pace of long-term global technological change, energy transition and decarbonization is characterized by a high degree of uncertainty and divergence of opinion
- ▶ "Guideposts" provided by organizations like the International Energy Agency (IEA) and the Intergovernmental Panel on Climate Change (IPCC) can help define the boundary conditions for what a global low-carbon future might look like
- ▶ ERA is uniquely positioned to use these longer-term guideposts in combination with near-term opportunities for cost and GHG reductions to identify and accelerate the most impactful portfolio of technologies.

The third edition of the TRM accounts for these findings. It emphasizes that the portfolio approach ERA embraces will continue to be the key to success. This portfolio approach acknowledges the importance of investing in technologies for near-term cost and GHG reductions that will maintain the competitiveness of Alberta's natural-resource and hydrocarbon-based industries and commodities – commodities that the world demands today to maintain and improve global quality of life.

It also takes into account the opportunity for Alberta to prepare for and prosper in a diversity of futures where the degree to which the world relies on carbon-based energy and fossil-fuel based commodities is less clear.

Finally, it identifies key guideposts to watch, provides greater clarity on what is meant by timeframes such as "near-term", "long-term", and narrows in on the time horizon on which ERA will focus to maximize the impact of its investments.

Key Influences on Alberta's Climate and Innovation Priorities

A PROVINCIAL PLAN OF ACTION

The world is grappling with the tension between the need for carbon-based energy sources and a consensus that their emissions are directly contributing to climate change. The Government of Alberta is committed to responsible energy development, including action to mitigate GHG emissions and reduce their contribution to climate change.

In 2007, Alberta became the first jurisdiction in North America to put a price on carbon with the Specified Gas Emitters Regulations (SGER). Today, the Alberta Government is building on this foundation with implementation of its Technology Innovation and Emission Reduction (TIER) system. The centerpiece of Alberta's climate change strategy, the TIER system prices carbon for large industrial emitters in the province. Revenues are invested in the implementation and development of innovative technology that will reduce GHG emissions, such as new and improved technologies for oil sands extraction, research and investment in carbon capture, utilization and storage, or other areas of opportunity for industrial emissions reductions.

The TIER system will encourage energy-intensive industries such as oil and gas to find innovative ways to reduce emissions and invest in clean technology to stay competitive; addressing climate change and strengthening investor confidence. These technologies can then be commercialized and exported to the world.

The TIER system is grounded in three principles:

- ▶ **Increase Competitiveness** through decreases in economic costs and emissions
- ▶ **Encourage Innovation** through a strong regulatory incentive and investment in technology
- ▶ **Continuous Improvement** through ongoing efficiency advancements.

The Alberta Government is also committed to making Alberta a magnet for investment in new technologies such as artificial intelligence, geothermal energy, and information technology. It will ensure public funding for start-up and growth companies is coordinated and streamlined across the province's programs and agencies and ensure public investments in innovation can demonstrate a clear return on investment.

Since the establishment of SGER, ERA has been the mechanism for investing the revenues from the carbon price paid by large final emitters directly into clean technology solutions, helping to reduce GHGs and attract investment in Alberta. ERA's TRM aligns with and supports the principles of TIER. It defines technology pathways and areas of focus for ERA's funding that will deliver the most impactful environmental and economic outcomes for Alberta.

NATIONAL COMMITMENTS

The Government of Canada has committed to achieve a 30 per cent reduction in GHG emissions from 2030 levels and contribute to limiting the global temperature increase to less than 2°C above pre-industrial levels. Its proposed approach to combat climate change includes putting a price on carbon, working with international partners, and using evidence-based knowledge in decision making.

In 2015, the Federal Government signed on to “Mission Innovation,” committing to double its clean energy research and development investment over five years. As a result, Canada will invest more than \$750 million per year in cleantech research and development.

Canada’s support for clean growth and innovation is focused on early-stage technology development, establishing international partnerships, and encouraging “mission-oriented” initiatives to help generate innovative new ideas and create economic opportunities. The Government has committed to ensuring natural resource industries are key players in the clean growth economy, and to developing and adopting clean technologies that improve competitiveness and environmental performance. It is committed to improving access to capital for clean technology businesses to bring their products and services to market.

ERA’s TRM can serve as a catalyst for broadening partnerships with federal organizations and departments like Sustainable Development Technology Canada (SDTC), Natural Resources Canada (NRCan) and Business Development Bank of Canada (BDC), while bringing together diverse stakeholders to directly promote and authenticate Alberta as a global leader on mitigating GHG emissions through technology innovation.

Equally as important, the TRM helps to demonstrate alignment with federal government environmental, economic and innovation outcomes, allowing ERA to partner and leverage federal funds. This leverage maximizes the value of ERA’s investments, creating larger pools of capital for innovation and technology in Alberta than would otherwise be available.

GLOBAL IMPERATIVE

The world is seeking solutions that can address the climate change challenge, support ongoing economic growth, and enable improved quality of life.

At the 21st meeting of the Conference of the Parties (COP 21) of the United Nations Framework Convention on Climate Change (UNFCCC) in Paris, a commitment to what is now known as the Paris Agreement was made.

Signatories committed to “holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5 °C”.² To date, 185 parties have ratified the Paris Agreement,³ and there is general global agreement that in the long-term, driving net CO₂ emitted into the atmosphere to zero is an imperative.

However, there is inherent uncertainty and often debate around the role that hydrocarbon-based industries will continue to play in such a future and the potential impact of technologies like carbon capture, utilization and storage. Additional uncertainty surrounds the pace of clean technology development and adoption, as well as the overall pace and trajectory that global emissions reductions will take.

The Sustainable Development Scenario (SDS) in the International Energy Agency’s (IEA) World Energy Outlook (WEO) 2018 envisions a future in which accelerated clean energy transitions put the world on track to achieve the objectives of the Paris Agreement.^{4,5}

2. <https://unfccc.int/process-and-meetings/the-paris-agreement/what-is-the-paris-agreement>

3. <https://unfccc.int/process/the-paris-agreement/status-of-ratification>

4. World Energy Outlook 2018 Executive Summary

5. <https://www.iea.org/weo/weomodel/sds/>

The SDS recognizes that energy production and use is the largest source of global GHG emissions. Under the SDS, energy-related GHG emissions peak around 2020 and then decline rapidly. By 2040, they are at around half of today's level and on course toward net-zero emissions by 2070.

The SDS provides an integrated strategy to achieve energy access, air quality and climate goals, with all sectors and low-carbon technologies – including CCUS – contributing to a broad transformation of global energy. Highlights of this scenario include:

- ▶ The number of people without access to modern energy is zero by 2030
- ▶ All economically viable avenues to improve efficiency are pursued, keeping overall demand in 2040 at today's level
- ▶ Renewable energy technologies provide the main pathway to the provision of universal energy access
- ▶ The share of renewables in the power mix rises from one-quarter today to two-thirds in 2040
- ▶ Natural gas and oil continue to meet a major share of global energy demand in 2040.

The SDS highlights that maintaining or accelerating the reduction of energy and process-related emissions up to and beyond 2040 will require robust technological innovation. Sectors where emissions reductions are more challenging to achieve, such as industry and freight transport, will be critical. Other important innovations will include CCUS and so-called “negative emissions” technologies that could allow CO₂ to be withdrawn from the atmosphere at scale.

The SDS notes that indirect emissions from producing, processing and transporting oil and gas represent a significant opportunity for reductions. Reducing methane emissions and eliminating flaring are two of the most cost-effective approaches, while more “game-changing” options include use of CO₂ to support enhanced oil recovery, greater use of low-carbon electricity, and the conversion of hydrocarbons to hydrogen (with carbon capture).

The Intergovernmental Panel on Climate Change's (IPCC) Special Report “Global Warming of 1.5°C” discusses the impacts of global warming of 1.5°C above pre-industrial levels and related global GHG emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty.^{6,7}

The IPCC Special Report notes that limiting warming to 1.5°C implies that global net anthropogenic CO₂ emissions decline by about 45 per cent from 2010 levels by 2030 and reach net zero by around 2050. Mitigation pathways to achieve this outcome are characterized by:

- ▶ Energy-demand reductions through enhanced energy efficiency
- ▶ Decarbonization of electricity and other fuels
- ▶ Electrification of energy end use
- ▶ Deep reductions in agricultural emissions
- ▶ Some form of carbon dioxide removal (CDR) with carbon storage on land or sequestration in geological reservoirs
- ▶ Low energy demand and low demand for land- and GHG-intensive consumption goods.

6. IPCC, 2018: Summary for Policymakers

7. IPCC, 2018: Chapter 2

The IPCC Special Report indicates that mitigation pathways that limit warming to 1.5°C rely on lower energy use, including through enhanced energy efficiency measures, and show faster electrification. Increases in renewable, nuclear and fossil fuels with carbon capture and storage (CCS) for electricity generation are required, and significant reductions in industrial emissions are achieved through combinations of new and existing technologies and practices, including electrification, hydrogen, sustainable bio-based feedstocks, product substitution, and CCUS.

Mitigation pathways that limit warming to 1.5°C show renewable energy (including bioenergy, hydro, wind, and solar) supply a share of half to two-thirds of primary energy, while coal and oil decline significantly. In some pathways natural gas use increases with widespread deployment of CCS.

Changes in land and urban planning practices, as well as deeper emissions reductions in transport and buildings are critical. Significant land-use changes will be required, and could include reductions in pasture lands, increases in agricultural land for energy crops and increases in forests.

The viability of more resource- and energy-intensive pathways depends on emissions reductions being mainly achieved through technological means, making strong use of CDR and the deployment of bioenergy with CCS. The Special Report notes that CDR deployed at scale is unproven, and reliance on such technology is a major risk in the ability to limit warming to 1.5°C.

The TRM can use resources such as the IEA and IPCC to help define success and outline the boundary conditions, pathways and critical technologies that can help Alberta remain competitive, attract investment, create new business opportunities, and reduce GHG emissions.

The two scenarios differ fundamentally in terms of the pace of decarbonization, with emissions reaching net-zero by 2050 in the IPCC scenario and by 2070 in the IEA scenario, respectively. However, the TRM should draw upon important commonalities between the two analyses, including the importance of energy demand reductions through energy efficiency improvements, electrification, a transition away from high-emitting coal-fired generation, and significant increases in renewable energy. Both scenarios are explicit about the need for technologies that can capture, utilize, store and remove CO₂ from the atmosphere.

Implicit in both scenarios is the need for a transition period of up to three decades where hydrocarbons, and in particular natural gas, remain a critical, albeit potentially declining, component of meeting global energy demand.

The importance of technology development and adoption in both scenarios underpins the importance of organizations like ERA, and the role ERA can play in supporting the *acceleration* of technology development and deployment. This in turn could help accelerate the overall pace of transition to a competitive and successful low-carbon economy in Alberta and beyond.

INVESTOR AND INDUSTRY PRIORITIES

Around the world, investors and industry alike are recognizing the challenge climate change could pose for the global economy, as well as the opportunity that investment in low-carbon solutions and clean technologies represents.

Global initiatives like the “We Mean Business Coalition”⁸, which has seen 87 major companies with a combined market capitalization of over \$2.3 trillion (USD) commit to set climate targets across their operations aligned with limiting global temperature rise to 1.5°C, suggest the growing business imperative. Investor-led initiatives such as the Task Force on Climate-related Financial Disclosures⁹, which is committed to developing guidance on climate change related financial disclosure for companies in

8. <https://www.wemeanbusinesscoalition.org/>

9. <https://www.fsb-tcfd.org/>

alignment with investor's needs, indicates the increasing demand from investors to understand the impact businesses will have on climate change, and the impacts climate change could potentially have on them.

In the Bank of Canada's 2019 Financial System Review¹⁰, climate change was listed as one of the main vulnerabilities facing Canada's economy.

In its 2019 Review, the Bank notes that "economic activity and the environment are intertwined," that the changing of the climate has "growing implications for the economy," and that "the range of possible outcomes is large."

The Bank of Canada Review suggests that the transition to a low-carbon economy will result in both transition risk and new opportunities. It notes that transition costs will likely be felt most in carbon-intensive sectors, such as the oil and gas sector, while sectors such as green technology and alternative energy will likely benefit.

The Expert Panel on Sustainable Finance, appointed in April 2018 to explore opportunities and challenges facing Canada in this field, found in its Final Report¹¹ that the innovation solutions that will come with a low-carbon transition represent a global market opportunity for wealth and job creation:

"The world is seeing shifts in consumer preferences, innovation, economic activity, competitive advantage and wealth creation. Consumers are increasingly looking for services and products with a smaller environmental footprint. Climate-smart innovations are no longer marginal alternatives-- they are becoming a massive global market opportunity yielding quality jobs. With these shifts, sound environmental stewardship is increasingly intersecting with market access and becoming a critical source of sustained competitive advantage."

The IEA's 2019 World Energy Investment Report¹² signals that industry is also recognizing the economic opportunity for innovation.

The Report found that corporate annual energy research and development (R&D) spending reached nearly \$94 billion (USD) in 2018, up four per cent from the previous year¹³. Excluding transport, two-thirds of total corporate energy R&D was in low-carbon sectors.

According to the IEA, automakers were the biggest contributors to corporate R&D growth, driven by government policies and competitive pressures for spending on energy efficiency and electric vehicles. Investment by electricity generation and supply companies continued to rise, with Siemens and General Electric occupying the top spots in the list of the highest global energy R&D spenders. Corporate R&D spending by companies in the oil and gas and other fossil fuel extraction sectors showed one per cent growth in real terms in 2018, the first increase in R&D spending in this sector since 2014.

The Smart Prosperity Institute's June 2019 Report, *Growing Clean: Investment Flows In Low-Carbon Technology to 2030*¹⁴, suggests that the clean-technology investment opportunity is growing.

The report finds that Canadian demand for low-carbon technologies could double through 2030, compared to today's levels, with the size of the clean technology investment opportunity reaching a cumulative \$184 billion from 2020 to 2030. The report predicts that investment in low-carbon technologies could climb from a historical annual average of \$11 billion in the pre-2020 era, to an average of \$22 billion annually through 2030.

10. <https://www.bankofcanada.ca/2019/05/financial-system-review-2019/>

11. http://publications.gc.ca/collections/collection_2019/eccc/En4-350-2-2019-eng.pdf

12. <https://www.iea.org/wei2019/rdd/>

13. Based on a sample of companies active in energy technology sectors for which 2018 data is currently available.

14. <https://institute.smartprosperity.ca/sites/default/files/report-growingclean.pdf>

The TRM can help ERA collaborate with industry and financial partners, including large final emitters, technology developers, and organizations such as Canada's Oil Sands Innovation Alliance (COSIA) and the Clean Resources Innovation Network (CRIN), to ensure we are investing in solutions the market is demanding. Through the TRM, we can work with other funders and financial institutions, including venture capital and private equity funds, banks, pension and sovereign wealth funds – organizations like BDC, ATB and AIMCo – to understand their investment priorities and make certain they view Alberta's clean technology sectors as a source of deal-flow.

ALBERTA'S EVOLVING INNOVATION SYSTEM

The innovation system in Alberta is complex, yet rich in resources and capacity. Combatting climate change, reducing costs, and increasing competitiveness are all key system priorities. To support diversification, education, training, climate change action, and job creation, ERA works in close alignment with the ever-evolving innovation system and the guiding policies and strategies being developed by government departments. The TRM is part of an ongoing dialogue and feedback loop to ensure a common and mutually supportive approach across key components of the system.

ERA partners with other organizations in Alberta and Canada who are working to advance GHG-reducing solutions. This is creating a continuum of support that spans the innovation development spectrum, and includes like-minded organizations here in Alberta, such as Alberta Innovates and ATB. Partnerships with organizations such as SDTC and BDC allow us to leverage federal funds and maximize the impact of ERA's investments (Figure 4).

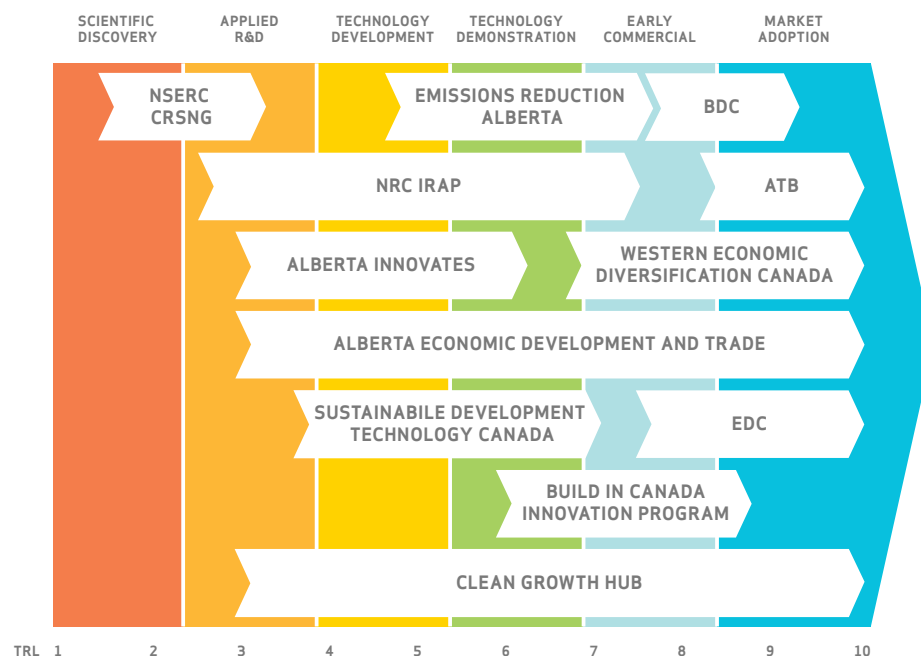


Figure 4 - Illustrates organizational focus areas on the technology readiness continuum

THE TECHNOLOGY IMPERATIVE

The Government of Alberta is committed to taking significant action to reduce GHG emissions in the province. Alberta's GHG emissions profile (Figure 5) illustrates the sectors where GHG reductions will have maximum impact.

Alberta's challenge is to deliver emission reductions while growing and diversifying the province's economy. This requires that we identify the critical innovation pathways, challenges, and opportunities to deliver on this outcome while supporting Alberta's job creation and diversification imperative.

Alberta is not alone in its efforts to seek out those GHG-reducing solutions that will have the most impact. Around the world, jurisdictions are looking for the pathways and technologies that can address the largest sources of emissions globally (Figure 6). Alberta has an opportunity to lead in the development of new GHG-reducing technologies that can reduce emissions at home, and be exported to the world.

Regardless of the specific GHG emissions target or outcome, new technology must be part of the solution to achieving significant reductions, as illustrated by both the IEA and IPCC.

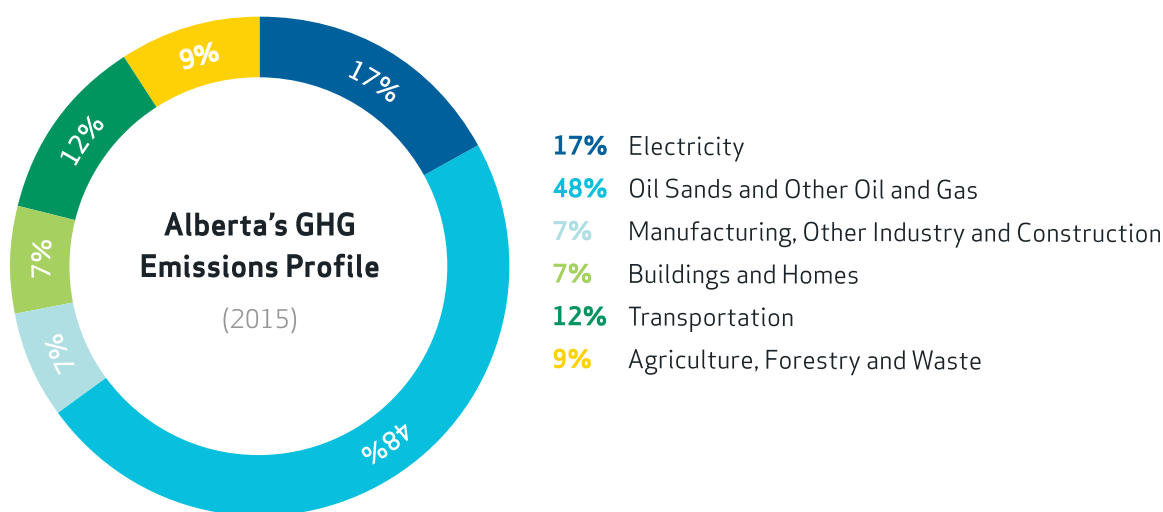


Figure 5 - Alberta's GHG Emissions Profile (2015)

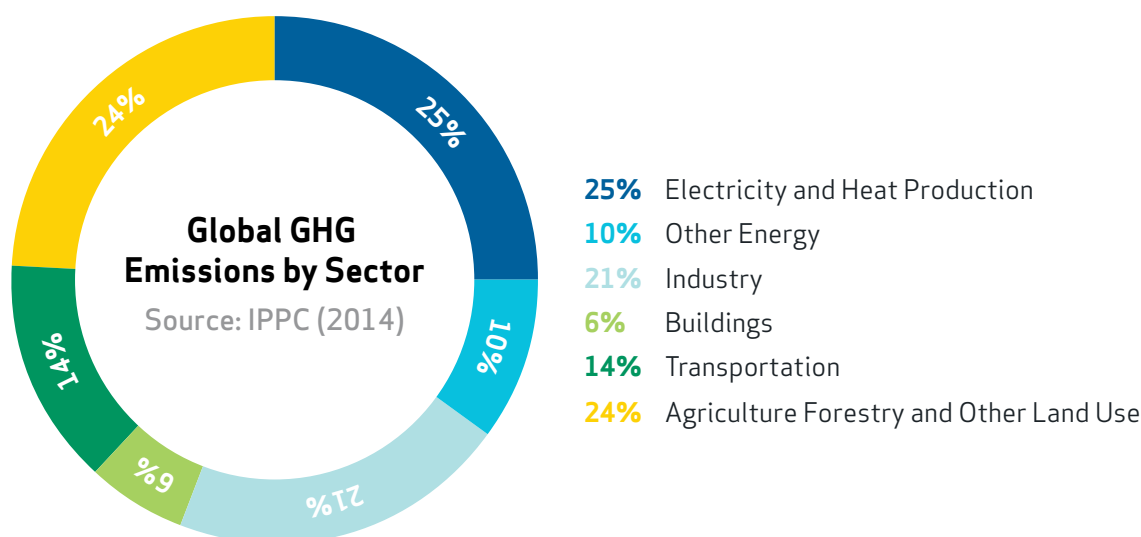


Figure 6 - Global GHG Emissions by Sector (2014)

Design and Focus

The TRM defines priority areas of focus for investment for ERA that will help prepare Alberta for success in a low-carbon future, considering the range of possible outcomes that this could entail. Key to ERA's success is a portfolio approach that takes into account the uncertainty of the pace at which the world will transition towards decarbonization. We need to consider the following factors:

1. Industry need and market opportunity
2. Timescale and technology readiness
3. Carbon impact
4. Opportunities beyond technology.

1) The TRM will take into account industry need and market opportunity:

For new technology to become commercialized, it must provide a solution that the market needs. ERA invests in solutions that address Alberta's largest GHG challenges, seeks out technologies that will help build new business opportunities and accelerates the development and deployment of technologies that can be exported to the world. We need to:

- ▶ **Build on Alberta's existing strengths.** There is an opportunity to invest in technologies that will reduce the GHG impact and increase the costs competitiveness of existing industries that represent historical areas of economic strength for Alberta. These sectors can deliver meaningful reductions since they are among the largest sources of emissions, such as oil and gas, or they hold potential to act as significant carbon sinks, such as in our agriculture and forestry sectors. By investing in these areas, ERA can create a more sustainable economy, address Alberta's largest sources of emissions, and encourage job and economic growth.
- ▶ **Create new business opportunities.** There is also an opportunity to invest in technologies and industries that support new business development, such as our growing renewable and bioenergy industries. Furthermore, emerging technologies in artificial intelligence (AI), digital and data-driven solutions, as well as game-changing technologies like CCUS and "bitumen beyond combustion" (BBC) represent opportunities for economic diversification, growth and export.
- ▶ **Mitigate future risk and uncertainty.** By all accounts, the pace of global decarbonization and extent to which the world will continue to rely on fossil fuels is uncertain. Alberta should be the world's supplier of the cleanest and most cost competitive hydrocarbons – whether that be for primary energy use, or as inputs for creating even more valuable and low-carbon processes and products "beyond combustion". Investing in technologies that can reduce emissions in Alberta's oil and gas industry ensures the world has access to low-carbon and low-cost sources of hydrocarbons.

Going forward, ERA's portfolio approach will continue to include investment in technologies to address Alberta's largest sources of emissions, innovations that will improve the cost and carbon competitiveness in sectors of historical economic strength, and opportunities to create new businesses and new technologies that can be exported to the world. In many cases, costs to develop and deploy technologies to reduce emissions in capital-intensive industries like oil and gas, cement, and chemicals are orders of magnitude higher than costs to develop and deploy emerging technologies like digital and data driven solutions. ERA must also take into account the relative capital intensity of the solutions being demanded by Alberta's industries and markets.

2) The TRM will take into account timescales and technology readiness:

In order to curb the most serious impacts of climate change, both the IEA and IPCC note that significant emissions reductions are required in the near-term, and these efforts must be sustained and accelerated in the medium and long-term. This means Alberta must be prepared to invest across multiple timescales and technology readiness levels (TRLs) to be successful in addressing the climate change challenge.



Figure 7 - Technology Readiness Levels

Delivery agents in Alberta's innovation system such as post-secondaries and Alberta Innovates have historically focused their investment in earlier stage clean technologies, while ERA has had success in accelerating technologies in the later stages of development. ERA will:

- ▶ **Invest in leading solutions that can deliver GHG reductions in the near-term (2025).**
Nearer-term GHG emissions reductions are typically achieved through deployment of technologies at the highest readiness levels that are commercially available, or nearly available and can have a significant GHG impact in the next two to five years.
- ▶ **Invest in technology solutions that can deliver GHG reductions in the medium-term (2025-2040).**
Technologies that are being piloted in the field or demonstrated at scale but are not yet ready for commercial deployment are typically five to 10 years or more from commercial deployment, when they can have a significant GHG impact.
- ▶ **Develop a pipeline of early-stage technologies that can deliver significant GHG reductions in the long-term (2040+).** Longer-term reductions require focused and sustained investment in breakthrough solutions beginning at earlier stages. Investment may involve higher technology risk but is potentially higher reward, delivering game-changing GHG impact if commercially proven and deployed.

Going forward, we expect ERA's investments will largely focus on field-pilots, demonstration and first of kind deployment projects (e.g., TRL 6 to 9) that can deliver significant GHG reduction impacts in the near- and medium term (2 to 10 years). However, we will work with our partners in the system to ensure seamless hand-offs as technologies progress through the various stages of development towards commercialization.

3) The TRM will take into account relative carbon impact:

Some technologies, like energy efficiency investments, represent an opportunity to do something we already do – but do it better. Other technology investments represent opportunities to create new businesses and industries with potential to reshape the global economy. To position Alberta for success in a low-carbon future, ERA must invest in technologies that will have a range of relative carbon and economic impacts. We need to:

- ▶ **Invest in operational excellence.** Technologies that improve energy efficiency and reduce the costs and carbon associated with existing industrial processes will be critical to delivering near-term GHG reductions and impacts.
- ▶ **Invest in low-carbon emissions technologies.** Opportunities to significantly reduce the carbon footprint of energy production and use, such as renewable energy and low-carbon fuels, or opportunities to significantly change and decarbonize industrial processes or manufacturing, such as artificial intelligence and data-driven solutions, will be critical to delivering near and medium term GHG reductions and impacts.
- ▶ **Invest in no-carbon emissions technologies.** Disruptive solutions that can reshape whole aspects of our economy, like hydrogen-based technologies, including “blue hydrogen” from natural gas, and those that can remove carbon from the atmosphere and reimagine carbon as a value-add input, such as carbon sinks, CCUS, and BBC could have game-changing impacts on GHG reductions in the long-term.

In order to achieve its economic and environmental goals, Alberta must leverage all opportunities to maintain the competitiveness of its existing industries and create new businesses - all while reducing emissions. Going forward, ERA will invest in projects representing a range of relative carbon impacts; from energy efficiency technologies to deliver cost and carbon competitiveness today, to disruptive innovation that has the potential to transform our energy and economic future.

4) The TRM will take into account factors and opportunities beyond the technology:

Although ERA's core business is seeking out and investing in technology solutions, funding the right technologies alone will not deliver the ambitious environmental and innovation goals Alberta has established. Clean technologies face significant challenges on the path to commercialization, including high capital costs; public awareness and acceptance; market and customer identification; and policy and regulatory uncertainty. Addressing these challenges requires a complete solutions approach that goes beyond the technology, including smart financing and strong business models, building awareness and understanding of the role of technology in addressing our climate change challenges, and creating an effective and efficient environment where good policies and strong regulatory frameworks enable us to deliver results.

To advance technologies toward commercialization, ERA will play a role not just as a funder, but also in engaging in complementary strategies being developed by government, providing mentorship, and convening organizations that promote innovation in Alberta and across Canada. ERA will:

- ▶ **Play a convening/catalyzing role.** In addition to funding, we will do our part to convene the resources required for success, including informing the suite of policy, regulatory, program and business innovation tools required to address system gaps and deploy new technologies. By helping to put these conditions for success in place, we will make it clear to investors and inventors and all the players in between, that Alberta is a place to commercialize clean technology solutions.
- ▶ **Broker opportunities for policies and regulatory innovation to stimulate adoption of clean technology solutions.** ERA will engage and collaborate with regulators and policy makers to ensure we are aligned with the government's policy direction, and to provide pro-active and evidence-based policy advice. We will work with key stakeholders on an ongoing basis to help ensure policy and regulation are enablers of innovation and technology deployment, rather than barriers.

- ▶ **Engage in effective communications and storytelling.** Effective communications help us make certain our trusted partners, key stakeholders and funded projects understand our processes, and benefit from lessons learned as a result of our investments. Working with Government, industry and other key stakeholders to share and amplify our technology success stories helps build public awareness and acceptance of innovation. This also helps us develop and retain strong advocates in the system who recommend ERA as a partner to advance technologies to reduce GHGs and improve Alberta's competitiveness.
- ▶ **Generate and evaluate performance data.** Performance management is critical to demonstrating that ERA is delivering on its mandate and living its core values. Tracking and reporting performance demonstrates the impact of ERA's investments and leads to new opportunities that further capitalize on our available data.

Going forward, ERA will continue to build on its strengths as a convener to not only fund successful clean technology projects, but to make Alberta home to successful clean technology companies that are commercializing the solutions the world needs.

BALANCING THE PORTFOLIO

A breakdown of ERA's investments by pathway or focus area are represented in Figure 8 and are summarized in the tables on the pages that follow. The summaries reflect the 2018 input provided by the EFL Fellowship, and its advice on how to better clarify a "A Road Map to What?" by providing a clearer vision of Alberta's lower carbon future, both overall and for each of the four investment focus areas the TRM identifies. The summaries also reflect the four influencing factors that help shape ERA's investment portfolio described on pages 12 to 15. The resulting pathways paint a picture of the unique contributions our province can make in a low-carbon emissions future in a way that inspires confidence in Alberta's prosperity and helps illuminate options for technological pathways to get there. These four pathways or strategic areas of focus are influenced by the guideposts, indicators, and factors described in the earlier sections of the TRM. Through this balanced portfolio approach, ERA's investments enable Alberta to:

- ▶ Respond to uncertainty in the pace of global decarbonization and technology development, and the likelihood that low-emitting hydrocarbons will remain a component of meeting global energy demand for up to three decades.
- ▶ Lead in the development of clean technology solutions the world needs and where Alberta has a unique advantage to reduce GHGs, grow its businesses and attract investment.
- ▶ Target the largest sources of GHG emissions in Alberta and globally, including oil and gas production and refining, electricity, heating applications and industrial processes.
- ▶ Build on Alberta's historical strengths in natural resource-based and industrial sectors and account for the relative capital intensity of investment in technologies to increase cost and carbon competitiveness in these sectors.
- ▶ Increase the use of energy demand reduction, energy efficiency, renewable energy and other low emitting sources of energy in major sectors of Alberta's economy.
- ▶ Enable solutions that can capture and store CO₂ from the atmosphere and from industrial practices, including agricultural and nature-based solutions and direct air capture.
- ▶ Develop and deploy innovation to "decarbonize hydrocarbons", including use and conversion of CO₂ into valuable products and processes and non-combustion products of fossil fuels.
- ▶ Accelerate field-pilots, demonstration and first-of-kind deployment projects that can deliver GHG reduction impacts in the near- and medium-term, while working with our partners to identify a pipeline of technologies that can deliver significant GHG reductions in the long-term.
- ▶ Leverage all opportunities to maintain and improve Alberta's economic and environmental competitiveness by investing in technologies representing a range of relative carbon impacts, from improving the operations of existing facilities to transformation of our energy economy.
- ▶ Consider the conditions for success that are required to grow companies and successfully commercialize technologies that can be addressed through ERA's role as a convener of complete solutions.

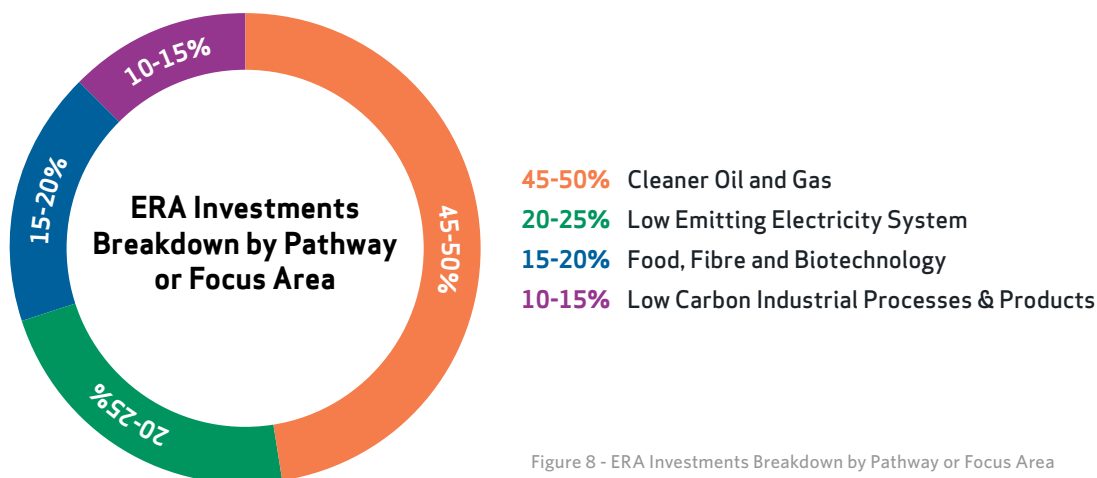


Figure 8 - ERA Investments Breakdown by Pathway or Focus Area

FOCUS AREA 1 – CLEANER OIL AND GAS

Possible ERA Investment: 45 – 50%

In Brief	Transformative technologies and innovation to reduce the GHG footprint of Alberta's fossil fuel supply chain and explore value-add opportunities that can help sustainably grow and diversify the province's energy economy.	
Alberta's Opportunity	<ul style="list-style-type: none"> ▶ Address the largest sources of GHG emissions in Alberta. ▶ Accelerate technologies the world needs to monitor, detect and reduce methane emissions. ▶ Provide the lowest-emitting hydrocarbons the world has to offer. ▶ Lead in the development of technologies to "decarbonize hydrocarbons", such as CCUS, BBC and blue hydrogen. 	
A Roadmap to What?	<ul style="list-style-type: none"> ▶ Alberta's hydrocarbons will remain in demand and competitive as a source of primary energy nationally and globally, resulting in ongoing commercial opportunities (e.g., the development of new exportable clean technologies), job creation, and royalty income for the province. ▶ Alberta will be a leading user and provider of cost-effective Carbon Capture, Utilization, and/or Sequestration (CCUS). ▶ Alberta's hydrocarbon production will be the lowest GHG-intensity in the world (e.g., no methane emissions, energy efficient, utilizes renewable energy inputs and / or coupling hydrocarbon use with CCUS). ▶ Alberta will offer a range of energy products derived from hydrocarbons, including non-GHG emitting energy products such as hydrogen and electricity, as well as non-energy and value-added products (e.g. bitumen beyond combustion). ▶ Alberta and its business community will be leaders in technology and expertise that have helped the oil and gas sector reduce GHGs. 	
Potential Technology Initiatives	<ul style="list-style-type: none"> ▶ Advanced recovery ▶ Monitoring, detection and reduction of fugitive emissions ▶ Partial upgrading ▶ Blue hydrogen and other hydrogen-based technologies 	<ul style="list-style-type: none"> ▶ Production of oil and gas using renewable and zero-CO₂ energy ▶ Beyond combustion ▶ Carbon capture, utilization and storage
Beyond Technology	<ul style="list-style-type: none"> ▶ Requires a strong focus on capacity building, training and social/cultural innovation. ▶ Requires continued effort to reduce polarization of energy and environment issues, specifically for oil and gas. ▶ Capital intensity of development and deployment of clean technologies in the oil and gas sectors is relatively higher than other sectors. 	

FOCUS AREA 2 – LOW EMITTING ELECTRICITY SYSTEM

Possible ERA Investment: 20 – 25%

In Brief	Technology and innovation to support a reliable, lower carbon electricity system, including reducing the GHG footprint of Alberta's electricity supply mix, increasing the deployment of renewable energy, and enabling a smarter electricity grid that can efficiently power Alberta's homes, businesses and transportation.	
Alberta's Opportunity	<ul style="list-style-type: none"> ▶ Address a large portion of Alberta's GHG emissions. ▶ Lead in the development of technologies to decarbonize electricity generation. ▶ Accelerate novel solutions to enable increased electrification, demand-side management and grid optimization. ▶ Lead in the sustainable production of lithium and rare earth metals required for advanced battery technology. 	
A Roadmap to What?	<ul style="list-style-type: none"> ▶ Alberta's energy system will achieve net-zero emissions, enabled by low emitting baseload (e.g. hydrocarbons with CCUS, renewable energy, cogeneration) and flexible capacity solutions (e.g., storage, demand response, grid management). ▶ Alberta's no/low emitting baseload generators will use hydrogen from Alberta's oil and gas sector and/or oil and gas directly with CCUS. ▶ Alberta will make major advancements in deployment of geothermal energy, particularly connected to existing oil and gas infrastructure. ▶ Alberta leverages its sustainable mining and extraction expertise to be a leading producer of lithium, rare earth and other "technology metals" required for manufacture of low-carbon technologies such as solar panels, batteries and cells. ▶ Alberta's low-emitting electricity system will provide electricity for an increasingly electrified and highly efficient energy system (e.g., industrial processes, transportation). 	
Potential Technology Initiatives	<ul style="list-style-type: none"> ▶ Co-generation ▶ Technologies to support advanced grid management (e.g. microgrids, decentralized energy) ▶ Geothermal ▶ Non-conventional wind, solar, hydropower 	<ul style="list-style-type: none"> ▶ Batteries and other energy storage technologies (including production of lithium and rare earth metals) ▶ Low-carbon electrification (e.g., transportation, industrial processes, buildings, etc.)
Beyond Technology	<ul style="list-style-type: none"> ▶ Requires a strong focus on the potential for digitization, other enabling technologies (e.g., artificial intelligence), and policies to match demand and supply. 	

FOCUS AREA 3 – FOOD, FIBRE AND BIOINDUSTRIES

Possible ERA Investment: 15 – 20%

In Brief	Innovative processes and technologies to advance Alberta's bioeconomy, and reduce GHG's, including novel agricultural, livestock, land use, and forestry practices; bioenergy and biomaterials; waste management and waste to energy; and enhanced carbon retention.	
Alberta's Opportunity	<ul style="list-style-type: none"> ▶ Build on Alberta's historical strengths in agriculture, forestry and land use. ▶ Lead in the development of nature-based solutions to sequester, retain and remove emissions from the atmosphere. ▶ Accelerate technologies that minimize and derive value from food waste. ▶ Enable the export of sustainable food sources and technology to the world. ▶ Lead in the development of bioenergy and biofuel technologies. 	
A Roadmap to What?	<ul style="list-style-type: none"> ▶ Forestry, agriculture, and natural lands will be managed as energy systems such that they sequester carbon, optimize food and wood production, recycle and clean water. ▶ Alberta will leverage and build on traditional agricultural and land management practices through integration of advances in digital technologies. ▶ Alberta will leverage its energy and agricultural expertise to develop a world-class bioenergy industry. ▶ Food, agriculture, forestry and other sources of waste will be aggregated and allocated for use (no waste left on field or in forest). ▶ Alberta is a leader in the development of innovative solutions to detect, measure and quantify nature-based emissions sources and sinks. 	
Potential Technology Initiatives	<ul style="list-style-type: none"> ▶ Innovation that builds on traditional practices (e.g. crop rotation, soil management, tillage, mixed animal foraging, and fertilization) ▶ Precision and data-enabled agricultural practices ▶ Nature-based solutions for carbon sequestration, retention and capture 	<ul style="list-style-type: none"> ▶ Technologies and practices to minimize, manage and create value from waste ▶ Detection, monitoring, quantification and reduction of nitrous oxide and methane emissions ▶ Biofuels and bioenergy for electricity, transportation and industrial applications ▶ Bioproducts and materials ▶ "Omic" Technologies (e.g. genomics, transcriptomics, proteomics, and metabolomics)
Beyond Technology	<ul style="list-style-type: none"> ▶ Requires a stronger focus on aggregation and prioritized use of biomass to determine which use cases will provide the biggest emissions reduction and economic potential (e.g., biojet to reduce aviation emissions). ▶ Requires that innovative solutions and practices to reduce emissions through agriculture, forestry and other nature-based solutions are recognized and valued in global carbon markets. ▶ Development of innovative GHG-reducing solutions in biological sectors is relatively less capital intensive than other sectors but often requires longer lead times to demonstrate environmental return on investment. 	

FOCUS AREA 4 – LOW-CARBON INDUSTRIAL PROCESSES AND PRODUCTS

Possible ERA Investment: 10 – 15%

In Brief	Technologies to deliver GHG reductions through energy efficiency, industrial process innovation, and low-GHG materials and chemicals.	
Alberta's Opportunity	<ul style="list-style-type: none"> ▶ Decarbonize emissions-intensive products and processes that are critical to the global economy while maintaining or increasing industry competitiveness. ▶ Demonstrate and deploy technologies to address fugitive leaks from pumps, valves, pipes and pneumatic devices. ▶ Lead in the development of technologies that contribute to the circular economy, including using waste CO₂ as a feedstock for new industrial processes and products. ▶ Accelerate the demonstration and deployment of leading edge digital and machine learning technologies to improve the efficiency of industrial processes. 	
A Roadmap to What?	<ul style="list-style-type: none"> ▶ Alberta will be a leader in industrial ecology; industrial processes will be designed to maximize positive feedbacks from systems integration opportunities. ▶ Alberta will be a world leader in developing and applying leading edge digital tools for process optimization (e.g., artificial intelligence and machine learning). ▶ Alberta will lead in pioneering CO₂ transformation and utilization opportunities. ▶ Alberta will maintain and increase its competitiveness in critical industries such as cement, chemicals, and fertilizers, through investments in efficiency improvements. 	
Potential Technology Initiatives	<ul style="list-style-type: none"> ▶ Industrial efficiency ▶ Process improvements ▶ Digitization and machine learning 	<ul style="list-style-type: none"> ▶ Low grade heat utilization ▶ Carbon utilization and conversion
Beyond Technology	<ul style="list-style-type: none"> ▶ Benefits from a stronger focus on capacity building for “industrial symbiosis” and circular economy, where one’s waste is another’s input, as a way to reduce emissions. ▶ Requires clarity between accelerating novel solutions for industrial processes and financing commercially available energy efficiency measures. 	

Performance Measurement

The TRM will be deemed successful if it delivers on the purpose and objectives described in the first section of the document.

Due to the varying magnitudes of risk and reward associated with investment across timescales and TRLs, ERA will adapt its performance metrics across the TRL categories.

At the higher TRL levels, ERA's performance measures will be based on absolute GHG reductions (tonnes delivered), near-term GHG potential, and economic benefits such as jobs created, investment into the province, and GDP growth. At the lower TRL levels, the success factors will be based on indicators such as TRL level advancement, success rate, estimates of potential impact, and partner's interest and investments (leverage).

While committed to delivering against a strong vision for the future, ERA is transparent and accountable to Albertans. In addition to forward-looking performance measures used in selection of investment decisions, ERA relies upon a program of ongoing retrospective performance measures. This includes monitoring how closely actual investment performance tracks against projections used during project selection. This reporting will be done in the context that investment in innovation carries an intrinsic level of risk, and the role of this fund is to support de-risking prospective future contributors to the Alberta economy.

As such, impacts on emissions and economic activity, including leveraged investment, will be monitored during the course of the projects. Longer-term impacts following completion of the funded project will also be tracked. These include environmental impacts (domestic and international) as well as economic impacts, such as employment, attracted investment, domestic and export sales. Outcomes will then be compared and reported against forward-looking projections made at the time of investment.

COURSE CORRECTION

The unprecedented pace of technological change, as well as the breadth and the depth of many radical changes unleashed by both the new digital age and energy production technologies (e.g., fracking) represent major uncertainties for the direction of innovation. At the same time, global and Canadian climate policies will continue to evolve rapidly and will likely become greater drivers for technological innovation and change.

To ensure that ERA has the best available information for investment decisions, the TRM process will explore opportunities to work with other organizations on technology scouting and partnerships (e.g., Alberta Innovates, SDTC, etc.), market intelligence (e.g., COSIA), policy leadership (e.g., Alberta Environment and Parks and Economic Development, Trade and Tourism) and process modeling to assess technology pathways (e.g., University of Calgary; University of Alberta; Energy Futures Lab).

Recommendation and Next Steps

The process for decision making on the GHG mitigation options and the understanding of how such mitigation programs can be implemented is complex. While the TRM ultimately belongs to ERA and will be used first and foremost to guide its investment decisions, it is important to continuously engage with others within the innovation ecosystem in Alberta and Canada to seek advice on and validate the priorities and directions of the TRM, to ensure that key stakeholders are familiar with ERA's renewed mandate, and demonstrate that ERA is driven by a compelling vision based upon the principles of innovation, integration and collaboration. It is also important to stress that ERA's TRM and innovation pathways will help chart a course toward investment in innovative solutions that reduce GHG emissions while growing a diversified economy in a low carbon world.

To address these needs and ensure the TRM remains current, ERA will regularly engage with ERA Board members, government and its agencies, industry, environmental groups and technology experts to:

- ▶ Define the specific technologies supporting low GHG pathways and their timeframes, assess the trade-offs associated with alternative pathways and identify/validate the gaps and barriers that need to be addressed and, in general, the directions of the TRM.
- ▶ Continually consider the evolving business model, portfolio approach and the sequencing of calls for proposals to maximize delivery of GHG emission reductions.
- ▶ Seek advice on how ERA defines success in order to assist in developing and refining performance measures for ERA direction and investments.
- ▶ Identify ways in which greater impact might be achieved through bi-directional influence and synergies between/among organizations.

THANK YOU

To our dedicated stakeholders for input and insights that supported the creation of the Technology Roadmap.

