

TECHNOLOGY ROADMAP



FOURTH EDITION, JUNE 2022

EMISSIONS
REDUCTION
ALBERTA 

CONTENTS

4 OVERVIEW OF ERA'S TECHNOLOGY ROADMAP

- 4 *PURPOSE*
- 4 *THE TECHNOLOGY IMPERATIVE*
- 6 *OBJECTIVES*
- 6 *KEY PRINCIPLES AND INSIGHTS*

19 BALANCING THE PORTFOLIO

19 BEYOND TECHNOLOGY

7 KEY INFLUENCES ON ALBERTA'S CLIMATE AND INNOVATION PRIORITIES

- 7 *INTERNATIONAL*
- 8 *NATIONAL*
- 9 *PROVINCIAL*
- 9 *INVESTOR AND INDUSTRY*

20 MEASURING PERFORMANCE

22 APPENDIX

- 22 *DESIGNING THE TECHNOLOGY ROADMAP*
- 22 *ENGAGEMENTS*

10 KEY CONSIDERATIONS

12 FOCUSING ON TECHNOLOGIES TO NET ZERO

- 13 *CARBON SEQUESTRATION*
- 14 *FUTURE FUELS*
- 15 *ENERGY EFFICIENCY*
- 16 *INDUSTRIAL TRANSFORMATION*
- 17 *CIRCULAR ECONOMY*

MESSAGE FROM THE CEO

We are living in a time of significant disruption, both internationally and locally, characterized by geopolitical unrest, economic challenges, shifting investor focus, global health pandemics, and more. These developments reinforce the reality that the transformation of global energy systems on the path to net zero will be highly uncertain, challenging, and disruptive. As the future unfolds, there will undoubtedly be different pathways to net zero.

The need for innovative technology solutions to achieve both economic prosperity and deep GHG reductions has never been greater. Emissions Reduction Alberta (ERA) has developed this Technology Roadmap (TRM) as a guiding document in our mission to reduce greenhouse gas (GHG) emissions and grow Alberta's economy. It outlines the strategic direction for our investments and ensures we are advancing the right mix of short-, medium-, and long-term technologies that will help Alberta realize its environmental and economic goals and support Canadian emissions targets. There are many emissions-reducing technologies in various stages of development right here in Alberta. Our opportunity, like other jurisdictions around the world, is to have a range of technologies deployed as quickly as possible. ERA is helping to making this happen.

ERA deliberately takes a portfolio approach to investment allowing us to consider what others are doing in each of the strategic technology areas, better manage innovation risk in a range of future scenarios, and maximize impact. Furthermore, ERA is a nimble organization with a highly scalable business model, allowing us to adjust to new information, challenges, opportunities, and uncertainties as they arise. The TRM is a living document that guides our investments and informs our portfolio mix. We are now in our fourth iteration of this document and have made changes that align with the technology disruption we are seeing. The TRM is now focused on cross-cutting technology areas that can be adopted and deployed across numerous industrial operations:

- ▶ Carbon Sequestration
- ▶ Future Fuels
- ▶ Energy Efficiency
- ▶ Industrial Transformation
- ▶ Circular Economy



These are the technology areas we consider to have the greatest potential impact on Alberta's GHG emissions and economy as well as the most relevance for other jurisdictions and sectors. Investments in each of these areas will be critical to helping achieve provincial, national, and global 2030 and 2050 climate goals.

Alberta is not alone in its efforts to seek out GHG-reducing solutions. There are significant national and international policy developments that have important implications for our economy and our approach to reducing emissions. Experts around the world are working to define the leading strategies, policies, frameworks, pathways, and guideposts for what a low-emissions future might look like. We are closely monitoring and evaluating all of this.

ERA is proud to play an important role in shaping the pathway for Alberta, and we are pleased to share our TRM as an important reference document within Alberta's innovation system.

JUSTIN RIEMER

CEO, Emissions Reduction Alberta

OVERVIEW OF ERA'S TECHNOLOGY ROADMAP

PURPOSE

Emissions Reduction Alberta (ERA)¹ has a mandate to reduce GHG emissions and grow Alberta's economy by accelerating the development and adoption of innovative technology solutions. ERA invests proceeds from Alberta's carbon pricing system to reduce GHG emissions and enable sustainability of new and incumbent industries. Our vision is for Alberta to have a diversified, net-zero economy with competitive industries that attract investment and deliver sustainable environmental outcomes. Our investments help innovators develop and demonstrate high-potential GHG-reducing technologies that build more competitive industries, enable new business opportunities, and create solutions for Alberta and the world.

ERA works with government, industry, investors, and innovators to ensure the TRM identifies technology areas that represent the greatest potential for achieving net-zero emissions and economic opportunities for Albertans. By engaging with a broad range of stakeholders and by maintaining a balanced portfolio, ERA can build a long-term strategy that accounts for uncertainty in the pace of technology development and the complexity of system transformations. The TRM also contributes to the alignment of broader innovation system priorities around environmental goals, which result in sustainable economic activities in Alberta and around the world.

THE TECHNOLOGY IMPERATIVE

The COVID-19 pandemic and recent economic downturn have added to an already difficult challenge of addressing climate change. In addition, geopolitical instability, such as the Russian invasion of Ukraine, has only further complicated the path toward net zero. This includes threats to global energy and food security through disruption to supply chains, forcing economies to turn elsewhere to meet their resource needs. European leaders are pushing for a faster switch to clean energy as part of a strategy to end dependence on Russian oil and gas. Scientific collaboration on projects, such as climate change implications on Arctic research, has also been made more challenging with increased sanctions on Russia. These significant global events have amplified the urgent need to accelerate the pace of technology change, given growing understanding of the impacts of climate change and our experience and understanding of the length of time it takes to develop and deploy technologies we need to reduce emissions. For this reason, emissions reduction targets and commitments are becoming more aggressive and technology advancements across sectors will need to keep pace. In response, there is a growing trend towards governments and companies making public commitments to achieve net-zero emissions by 2050. More specifically, the Government of Alberta is committed to taking significant action to reduce GHG emissions in the province. Alberta's GHG emissions profile (*Figure 1*) illustrates where the largest GHG reduction potential exists.

Around the world, countries, corporations, and citizens are calling for a net-zero future. This rallying cry is highlighting that we need to do more to reach a lower emissions future and we need to do it at an exponential pace. Specifically, there is an increasing sense of urgency to show significant progress towards achieving net-zero targets.

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

Alberta's challenge, like most other jurisdictions, is to deliver emission reductions while growing and diversifying the province's economy—this includes keeping Albertans at the heart of transparent and cost-effective decisions. This means that we identify the critical innovation pathways, timescales to technology deployment, challenges, and opportunities to deliver on this outcome while supporting Alberta's job creation and diversification imperative. Alberta must achieve a balance between transitional and transformational technologies; scaling-up proven, commercial-ready technologies to yield quick reductions and preserve jobs, while investing in earlier-stage, game-changing opportunities that will keep the province competitive reaching 2050 and beyond.

Alberta is not alone in its efforts to seek out GHG-reducing solutions that will have the most impact. Canada is also looking for the pathways and technologies that can address the largest sources of our nation's emissions (Figure 2)¹. In March 2022, Canada released its 2030 Emissions Reduction Plan, investing over \$9 billion in new investments across sectors to reduce emissions by 40 to 45 percent below 2005 levels by 2030. Alberta has an opportunity to lead in the development of new GHG-reducing technologies that can reduce emissions locally and be exported to the world.

Regardless of the specific GHG emissions target or outcome, the scale-up and development of known technologies and the identification and acceleration of new technologies must be part of the solution to achieving significant reductions.

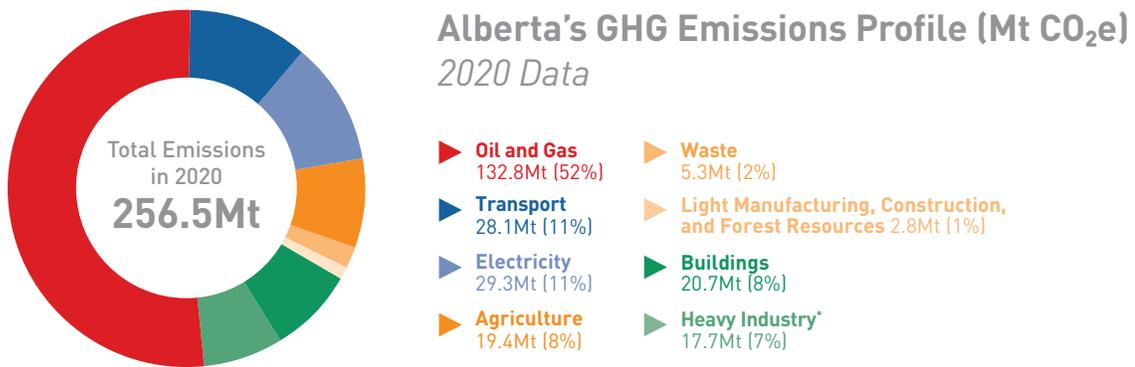


Figure 1: Alberta's GHG Emissions Profile per industry based on Canada's 2020 National GHG Inventory Data

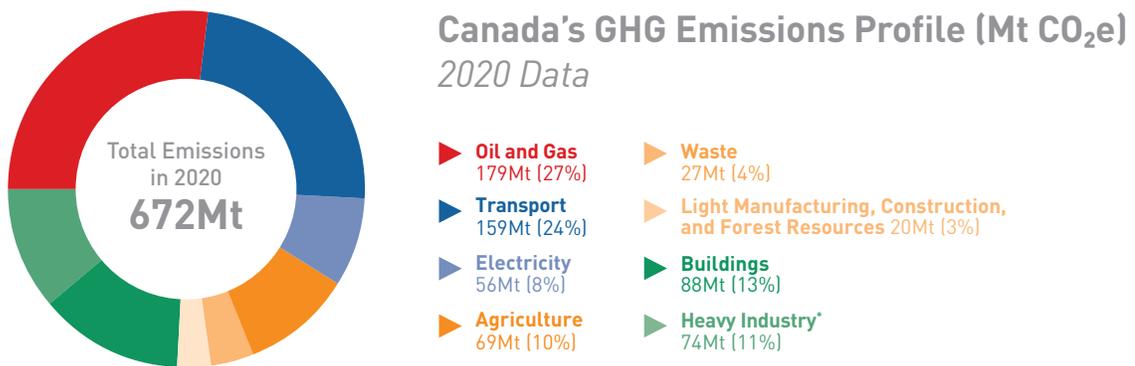


Figure 2: Canada's GHG Emissions Profile per industry based on Canada's 2020 National GHG Inventory Data

* Heavy Industry also includes coal production

¹ The provincial and national GHG emissions profile were taken from Canada's recent National Inventory Report (NIR), whose methodology is periodically updated. The 2020 NIR methodology follows that of the United Nations Framework Convention on Climate Change.

OBJECTIVES

The TRM seeks to:

1. Identify and define the guideposts, pathways, opportunities, and barriers to Alberta thriving in a net-zero future, to:

- ▶ Invest in technologies that contribute to our environmental and economic vision of the future and can be exported to the world to have a global impact
- ▶ Adapt to the uncertainty in the pace of technology development and rapidly changing global forces
- ▶ Harness the power of directing public funds toward innovation and technology and provide a clear line of sight between funding and outcomes
- ▶ Identify and accelerate solutions that align with Alberta's needs and priorities
- ▶ Leverage Alberta's assets to attract investment and world-class innovators and technologies
- ▶ Contribute to Alberta's economic prosperity and diversification by supporting clean technologies and businesses

2. Map the potential 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 GHGs 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

KEY PRINCIPLES AND INSIGHTS

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

- 1. Leveraging Alberta's unique strengths:** This includes its natural resources and highly skilled workforce.
- 2. Acting with the end in mind:** ERA will prioritize investments based on the most effective pathways toward competitive industries in a net-zero future.
- 3. Reading the guideposts:** Given the need for accelerated decarbonization, experts around the world are working to define the leading strategies, policies, frameworks, pathways, and guideposts (indicators) for what a net-zero future might look like. ERA is uniquely positioned to use and contribute to these guideposts and align its investments with the most effective near- to long-term technologies and solutions to long-term technologies and solutions.
- 4. Taking a portfolio approach:** ERA will diversify its investments across timescales, technology readiness levels (TRLs), and focus areas, allowing Alberta to better manage innovation risk and be successful in a range of future scenarios. Our highly efficient and flexible business model allows us to be responsive to these changing global scenarios.
- 5. Pursuing factors beyond technology:** A focus on technology alone is not enough given the multitude of 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. It will also continue to share lessons learned from project proponents and industry leaders—successful or not—with those who are developing technology to help accelerate adoption.
- 6. Aligning the system:** ERA can be a leader and a change agent in Alberta's energy, climate, and innovation ecosystem, collaborating with others to identify strategic pathways that maximize the returns for private and public investment, and help bridge innovation system gaps to ensure high-potential opportunities are supported and successful.

KEY INFLUENCES ON ALBERTA'S CLIMATE AND INNOVATION PRIORITIES

Significant national and international economic, social, and environmental policy developments will have important implications for Alberta's economy and ERA's approach to reducing emissions. These developments will serve as guideposts that help define a vision around what a low-emission future might look like, and shape future priorities for investment in technology and innovation. These developments include:

- ▶ Industry-wide commitments toward net-zero 2050 aspirations and more aggressive 2030 targets to demonstrate meaningful progress toward net-zero goals.
- ▶ Significant new policies and investments focused on driving emission reductions and technological change.
- ▶ Growing investor interest and action focused on the Environmental, Social and Governance (ESG) performance of industry.
- ▶ The need to expedite the pace of change through further policy, investment, and technological development.



INTERNATIONAL

The disruption of global supply chains due to the COVID-19 pandemic have been exacerbated by recent geopolitical events such as the Russian invasion of Ukraine. These events, coupled with a ramp-up in economies returning to pre-pandemic activity levels has caused energy and material supply shortages leading to inflation and rising costs for the production and consumption of goods. Countries have been focused on meeting their citizen's needs, while also navigating the increasing effects and costs of climate-related disasters.

This has spurred renewed interest and urgency around climate change leadership at the international level as the climate impacts have become more prevalent. Then start new sentence: Climate action is now increasingly seen as an important competitiveness issue. In late 2019, the European Union (EU) tabled the European Green Deal; a growth strategy for a sustainable EU economy. A central theme to this growth strategy is the commitment to becoming the first climate-neutral continent by 2050. The European Commission has also launched the first tranche of its Fit for 55% measures that will support Europe's climate policy framework and put the EU on track for a 55 per cent reduction in carbon emissions by 2030, and net-zero emissions by 2050. The interconnected legislative proposals cover areas of climate, land use, energy, transport, and taxation (including a Carbon Border Adjustment mechanism) to bring them into line with the targets agreed in the European Climate Law. Since these announcements, many other jurisdictions and industry leaders have also aligned climate commitments and rallied around the net-zero 2050 target.

At the 26th UN Climate Change Conference of the Parties (COP26) in Glasgow in Fall 2021, leaders from nearly 200 countries gathered to discuss and produce the Glasgow Climate Pact. This global agreement drives action on climate change through mitigating and reducing emissions, helping those impacted by climate change through adaptation initiatives, enabling countries to deliver on climate goals through financial mobilization, and collaboratively working together on production of international frameworks. The Paris Agreement, limiting global warming to 1.5 degrees Celsius pre-industrial levels, was adopted at COP21 in 2015. This legally binding, international treaty requires a multilateral approach to climate change, incorporating financial, technical, and social capacity elements. Since adoption of the Paris Agreement, 192 countries have declared Nationally Determined Contributions (NDCs). NDCs are central to achieving Paris Agreement goals and provide a target for jurisdictions to work towards. In addition to Paris Agreement commitments, the United Nations continues to measure global efforts against the 17 Sustainable Development Goals (SDGs), with jurisdictions using these goals as one of the many lenses to inform policy and investment decisions.

The International Energy Association released a report, *Net-zero by 2050: a Roadmap for the Global Energy Sector*¹, that report provided a comprehensive study of how to transition to a net-zero system by 2050, while ensuring stable affordable energy supplies and enabling robust economic growth. The report highlights priority actions needed today in order to ensure the opportunity to meet net zero by 2050 is achievable. In the near-term, the report describes a net-zero pathway that requires the immediate deployment of all available clean and efficient energy technologies, combined with a major push to accelerate innovation. The roadmap sets out more than 400 milestones along the path to net zero including: as of 2021, no investment in fossil fuels supply projects; by 2035, no new sales of internal combustion passenger cars; and by 2040, the global electricity sector has reached net-zero emissions. The modeling used in the development of the report indicates that global energy investment will need to surge to around \$5 trillion (USD) by 2030 on the pathway to achieving net zero by 2050. The report highlights that most of the global GHG reductions between now and 2030 will come from existing technologies readily available today. But in 2050, almost half of the reductions will need to come from technologies that are currently only at the demonstration or prototype phase.

In the United States, Canada's closest trading partner, the Biden-Harris Administration has signaled renewed US support for addressing climate change, committing to achieving a 50 to 52 per cent reduction from 2005 levels². Additionally, as part of the \$2 trillion infrastructure stimulus package, President Biden has signaled support for a green economic recovery including appealing to ESG investors and committing support for electric vehicle manufacturing and infrastructure, efficiency measures, and research and development for emission-reducing technologies.



NATIONAL

The Government of Canada is committed to a clean economic recovery following the impacts of COVID-19 and has demonstrated this through a number of commitments and investments. In March 2022, Prime Minister Justin Trudeau announced Canada's 2030 Emissions Reduction Plan (ERP), outlining a roadmap to reach emissions reductions of 40 to 45 percent below 2005 levels by 2030, and net zero by 2050. Through the *Canadian Net-Zero Emissions Accountability Act*³, the Federal Government has formalized Canada's target to achieve net zero by 2050. Beyond legislation, the Government of Canada is advancing a number of important policy and investment initiatives. The ERP commits to continuing the price on carbon pollution, which was initially set at \$20/tCO_{2e} in 2019, risen by \$10/tCO_{2e}/year to reach \$50 in 2022, and will continue rising by \$15/tCO_{2e}/year until it reaches \$170/t in 2030.

As part of the ERP, the Federal Government will continue consulting key stakeholders on the Clean Fuel Regulation, requiring suppliers to gradually reduce the carbon intensity of the fuels they produce and sell for use in Canada. In addition, the Government of Canada has created the Clean Fuels Fund, a \$1.5 billion investment designed to de-risk capital investment for building new or retrofitting or expanding existing clean fuel production facilities.

The Federal Government is also working on a CCUS strategy and has developed an ambitious Hydrogen Strategy that is intended to position hydrogen and CCUS as key pathways to achieve its net-zero emissions goal.

To meet Canada's 2030 targets, the ERP outlines the need to cap emissions in the oil and gas sector and will engage in discussions with industry, provinces, Indigenous communities, and civil society. The reduction of oil and gas and other industrial emissions will be supported by various mechanisms such as the Carbon Capture Utilization and Storage (CCUS) Investment Tax Credit and the Strategic Innovation Fund Net-Zero Accelerator (SIF-NZA). The Federal Government also committed additional funding towards the SIF-NZA, now worth \$8 billion. The development and widespread adoption of GHG reducing and removal technologies has never been more important to longer-term economic growth. Alberta will need to be a key emission reduction contributor if Canada is to meet its national and international climate commitments.

¹ <https://www.iea.org/reports/net-zero-by-2050>

² <https://www.whitehouse.gov/briefing-room/statements-releases/2021/04/22/fact-sheet-president-biden-sets-2030-greenhouse-gas-pollution-reduction-target-aimed-at-creating-good-paying-union-jobs-and-securing-u-s-leadership-on-clean-energy-technologies/#:~:text=Today%2C%20President%20Biden%20will%20announce,to%20tackle%20the%20climate%20crisis>

³ <https://www.canada.ca/en/services/environment/weather/climatechange/climate-plan/net-zero-emissions-2050/canadian-net-zero-emissions-accountability-act.html>

ERA's TRM can serve as a catalyst for broadening partnerships with federal organizations and departments like Environment and Climate Change Canada (ECCC), 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 demonstrate Alberta's leadership in mitigating GHG emissions through technology innovation.

Equally important, the TRM helps to facilitate 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.



PROVINCIAL

As ERA developed this TRM, geopolitical volatility was impacting global commodities markets. Canada was also moving through the COVID-19 pandemic. This, layered with more ambitious national and global climate emission reduction commitments, underscores the magnitude of the challenge of meeting rising energy demand and strengthening economic outcomes while lowering emissions. In Alberta, we've seen greater public interest in taking action on climate change and increased demand for energy efficiency measures. Net-zero is now seen as the minimum requirement internationally—in Alberta we've seen an increasing number of domestic corporate commitments to net-zero and significant interest in the development of technology pathways and energy systems (e.g., CCUS; hydrogen; small modular nuclear reactors) that can help industry and Alberta get there. The Government of Alberta remains committed to responsible energy development, including action to mitigate GHG emissions and reduce their contribution to climate change. Alberta's core industries are the backbone of the economy and are playing a vital role in reducing provincial emissions. They are also supporting the development of new and emerging technologies that will play a critical role in our economic recovery, as well as create sustainable, diversified economic opportunities and jobs in the future.

Alberta is responding to the global challenge to reduce GHG emissions and turning to its highly-skilled and educated workforce to advance the new ideas, technologies, and solutions the world needs. Diversification across industries promotes a sustainable economic recovery, leading to a stronger, more competitive Alberta. The provincial government supports advancing development of new products and markets as well as expanded and circular pathways that capture the value of resources not only downstream through recycling and recovery, but in the upstream stages of the product lifecycle as well. Innovations to upstream activities such as harvesting raw materials, product design, manufacturing, and transportation can help accomplish this. For example, the Government of Alberta's Natural Gas Strategy identified hydrogen deployment in areas such as transportation, home-heating, and fuel blending as important pathways for helping Canada meet its climate goals.

While hydrogen has tremendous potential to become part of the decarbonization solution, production from hydrocarbon feedstocks will require parallel development and deployment of CCUS technologies to achieve the environmental benefit (i.e., reduced emissions) that make the fuel an attractive and viable solution. CCUS technologies are also an important technology, overall, for decarbonizing existing industries and energy systems. Investment in energy efficiency and methane emission reductions remains among the most cost-effective emission reduction opportunities for Alberta businesses and industry.

INVESTOR AND INDUSTRY

Around the world, investors and industry are recognizing the challenge climate change could pose for the global economy, as well as the opportunity that investment in low- and zero-carbon solutions and clean technologies represents. Industry leaders across sectors have started committing to net-zero emissions by 2050, diversifying their portfolios, and increasing their efficiency measures, while finding ways to decrease operating costs.



In parallel, ESG standards are becoming a more heavily weighted criteria for investors looking to help drive the transition to a lower emission future. Supporting these efforts is an increased emphasis on climate-related financial disclosures. In 2021, the Task Force on Climate-Related Financial Disclosures, an investor-led initiative created in 2015 by the Financial Stability Board, detailed sector-specific risk drivers that have potential economic and financial impacts such as supply chain disruptions, changes in resources/input prices, and changes in demand for products and services. Climate-related risks are being assessed as the world transitions to a clean economy.

Despite the inherent tensions and competing opinions about resource development and outlook for traditional emissions-intensive, trade-exposed industries, the immediate conversation must continue to focus on addressing the emissions, regardless of the sector. A balance must be achieved that promotes a sustainable, prosperous, low-carbon future, recognizing the importance of traditional industries as pillars and the potential for them to act as catalysts in spearheading new opportunities and creating new markets. The transition to a low-emissions future will be an enormous challenge, but also presents huge opportunities for our economies. A transition of the scale and speed needed to reach net-zero emissions by 2050 cannot be achieved without sustained support and participation from citizens, whose lives will be affected in multiple ways. Canada's ambition to half emissions by 2030 will be an important milestone along the pathway to 2050 and highlights the need to significantly increase the pace of investment in innovation and reductions. It will be important that the transition is fair and inclusive, leaving nobody behind.

The TRM is utilizing these guideposts to help mark a pathway, define success, and outline the boundary conditions and critical technologies needed to reduce GHG emissions, allow Alberta industries to remain competitive, attract investment, and create new business opportunities. ERA's commitment to supporting innovative GHG-reducing technologies that have potential to contribute to the public good will help accelerate the overall pace of transition to a competitive and successful low-carbon economy in Alberta and beyond.

KEY CONSIDERATIONS



The TRM defines priority areas of focus for investment for ERA that will help prepare Alberta for success in a low-emissions future. At time of writing, there remains uncertainty around climate targets and shifting global dynamics. The TRM remains a fluid document, allowing ERA to adapt as new knowledge comes to light. ERA continues to take a portfolio approach to support technologies and solutions that enable Alberta's long-term competitiveness. Key to ERA's success is a portfolio approach that will:

TAKE INTO ACCOUNT IMPACT: To position Alberta for success in a low-emissions future, ERA must invest in technologies that will reduce emissions, lower operating costs, attract investment, and create jobs in Alberta. We need to:

- ▶ **Invest in process improvements:** 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-emissions technologies:** Address near- to-medium-term GHG reductions by minimizing the carbon footprint of energy production and use through renewable energy, low-emissions fuels, and implementation of energy efficiency technologies and measures.
- ▶ **Invest in zero emissions technologies:** Address long-term GHG reductions through disruptive technologies and solutions that have the potential to reshape our economy.



TAKE INTO ACCOUNT INDUSTRY NEED AND MARKET OPPORTUNITY: For new technology to become commercialized, it must provide a solution that the market needs. We need to:

- ▶ **Build on Alberta's existing strengths:** Reducing emissions in existing industries that represent historical areas of economic strength will ensure a sustainable transition. Some of these sectors are among the largest sources of emissions and can help reach provincial and national reduction goals while continuing to provide jobs and leverage Alberta's talent pool.
- ▶ **Create new business opportunities:** Investing in opportunities to create new industries and markets

such as precious minerals for battery materials and feedstocks for value-added products, while leveraging digital technologies and solutions to provide a platform for future growth and global competitiveness.

- ▶ **Mitigate future risk and uncertainty:** Investing in technologies that put Alberta on a pathway to net zero, supporting the creation of a prosperous, low-emission economy across all sectors.

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 create more diversified economic opportunities. 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. As a result, ERA must also consider the relative capital intensity of the solutions being demanded by Alberta's industries and markets.



CONSIDER TIMESCALES AND TECHNOLOGY READINESS: Most of ERA funding is directed to technology scale-up, field pilots, and first-of-kind demonstrations and deployments. However, ERA's portfolio should consider and balance not only its areas of focus, but also the timescale and development risks. Later stage solutions may offer lower technology risk and nearer term reward; however, the emission reductions achieved are typically more incremental. Whereas earlier stage or more disruptive technologies by nature often represent higher technology and investment risk, they potentially offer a long-term, game-changing reward.

As the deployment of new technology can often take ten years or more to scale up, Alberta must be prepared to invest across multiple timescales and TRLs to be successful in addressing the climate change challenge.

There are currently two main climate milestones that policymakers are working towards: 2030 and 2050. The technologies and solutions needed to meet these targets are likely to be very different. Investment into a suite of technologies at different readiness levels are needed to reach these milestones. ERA will:

- ▶ **Invest in leading solutions that can deliver GHG reductions by 2030:** Nearer-term GHG emissions reductions are 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 three to five years.
- ▶ **Invest in longer-term solutions to accelerate GHG reductions beyond 2030:** 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 transformative GHG reductions to meet 2050 goals:** Longer-term reductions require focused and sustained investment in breakthrough solutions beginning at earlier stages. Investment may involve higher technology risk but potentially higher reward, delivering game-changing GHG reduction impacts if commercially proven and deployed. ERA will work closely with early-stage partners, including post-secondary institutions and Alberta Innovates, to develop longer-term solutions.

Delivery agents in Alberta's innovation system such as post-secondary educational institutes and Alberta Innovates have historically focused their investment in earlier stage technologies, while ERA has had success in accelerating technologies in the later stages of development. ERA's investments have, and will continue to focus largely 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 (three to 10 years). ERA continues to work with partners in the innovation ecosystem to not only ensure a seamless hand-off process as technologies progress through various stages of development towards commercialization, but also to reduce administrative burden on applicants, avoid program duplication, and leverage funding within the system.

FOCUSING ON TECHNOLOGIES TO NET ZERO

Considering Alberta's industry emissions profile, the opportunity for reduction, and timescales to technology deployment, ERA has identified technology areas of focus summarized on the following pages. We have chosen this portfolio mix based on our planning considerations, stakeholder engagement, and research into technology needs of the future. These focus areas consider the most potential for GHG reductions and economic benefits for Alberta and will ensure we are investing in the optimal short-, mid-, and long-term technologies that realize our environmental and economic objectives on the journey towards a net-zero future. It is important to consider that these focus areas have been designed to be complementary to one another to enable synergies.



Technologies and solutions that provide the means to capture and permanently sequester and store carbon dioxide, including capture from industrial or diffuse sources and sequestration through biological processes and natural systems.



Technologies that minimize emissions at the point of energy end-use through production of renewable electricity, clean heat, low-GHG fuels and energy carriers. This includes hydrogen and novel next-generation biofuels to increase the supply of clean energies coupled with fuel switching and electrification solutions to create and expand markets for low-carbon energy.



Scaling and deploying near-commercial technologies to optimize processes, enhance energy management, and improve building energy performance for a wide range of residential, commercial, institutional, agricultural, and industrial energy consumers.



Emerging solutions to accelerate Alberta's transformation to a low-carbon economy by implementing new products and processes within existing industries, mitigating fugitive emissions, and developing new high-value opportunities such as bitumen beyond combustion, advanced materials, and energy minerals.



Technology solutions to improve the value of products in Alberta and keep resources circulating for longer, helping Alberta to become a leader in new low-carbon materials, critical energy minerals, and waste-to-value-added products.

FOCUS AREA 1
CARBON SEQUESTRATION
 ESTIMATED ERA INVESTMENT: 15-25%

<p>In Brief</p>	<p>Technologies and solutions that provide the means to capture and permanently sequester and store carbon dioxide, including capture from industrial or diffuse sources and sequestration through biological processes and natural systems.</p>
<p>Alberta's Opportunity</p>	<ul style="list-style-type: none"> ▶ Lead in the development of technologies to "decarbonize hydrocarbons" such as carbon capture and storage. ▶ Address some of Alberta's largest sources of emissions. ▶ Build on Alberta's historical strengths in agriculture, forestry, and land-use. ▶ Leverage existing strengths in drilling, completions, infrastructure, and Alberta's abundant geological pore space resource. ▶ Capitalize on nature-based solutions to sequester, retain, and remove emissions from the atmosphere.
<p>A Roadmap to What?</p>	<ul style="list-style-type: none"> ▶ Hydrocarbons remain cost- and emissions-competitive nationally and globally, resulting in ongoing commercial opportunities, job creation, and royalty income for the province. ▶ Utilize and build on current CCUS infrastructure such as the Alberta Carbon Trunk Line and Shell Quest. ▶ Remain leaders in development of exportable technology solutions for CO₂ sequestration. ▶ Pioneer CO₂ transformation and utilization opportunities across industries. ▶ Lead in the development of innovative solutions to identify, measure, and quantify nature-based emissions sources and sinks. ▶ Alberta's natural resource sectors benefit economically and reputationally by becoming leaders in nature-based CO₂ sequestration.
<p>Timeline to Market Adoption</p>	
<p>Economic Opportunity Potential</p>	
<p>Example Technologies and Solutions</p>	<ul style="list-style-type: none"> ▶ Carbon capture (post-combustion or pre-combustion) ▶ Carbon transportation, hubs, and permanent sequestration solutions ▶ Nature-based solutions (e.g., land use, soil carbon, ecosystems, forestry) ▶ Carbon dioxide removal (e.g., direct air capture)



FOCUS AREA 2 FUTURE FUELS

ESTIMATED ERA INVESTMENT: 25-30%

<p>In Brief</p>	<p>Technologies that minimize emissions at the point of energy end-use through production of renewable electricity, clean heat, low-GHG fuels and energy carriers. This includes hydrogen and novel next-generation biofuels to increase the supply of clean energies coupled with fuel switching and electrification solutions to create and expand markets for low-carbon energy.</p>
<p>Alberta's Opportunity</p>	<ul style="list-style-type: none"> ▶ Accelerate novel solutions to enable increased electrification (e.g., end-use sectors, transportation) and demand-side management. ▶ Enable a cleaner and more resilient and reliable power grid by investing in technologies that facilitate optimizations such as energy storage. ▶ Existing industrial clusters and large hydrogen demand provide a strong initial market for low-emissions hydrogen. ▶ Combine energy and agricultural/forestry expertise to develop a world-class bioenergy industry. ▶ Capitalize on significant local wind and solar resources to build on existing momentum in the renewables market.
<p>A Roadmap to What?</p>	<ul style="list-style-type: none"> ▶ Alberta continues to grow its world-class market for clean electricity and becomes a significant producer/exporter of low-emissions power and other clean energy carriers such as hydrogen. ▶ Build on the existing hydrogen market to catalyze a robust clean hydrogen economy, particularly in the context of industrial clusters. ▶ Alberta's light-, medium-, and heavy-duty transportation systems benefit from global trends towards zero-emissions and improved efficiency. ▶ Alberta becomes the jurisdiction of choice for demonstration of advanced energy technologies such as deep geothermal and novel energy storage solutions. ▶ A wide range of reliable, cost-effective, low-emissions energy sources are made available to residential, commercial, institutional, and industrial customers across Alberta. ▶ Provincial energy system will achieve net-zero emissions, enabled by a mix of low-emitting energy sources, efficient energy carriers, and demand-side measures to enable an increasingly electrified economy.
<p>Timeline to Market Adoption</p>	
<p>Economic Opportunity Potential</p>	
<p>Example Technologies and Solutions</p>	<ul style="list-style-type: none"> ▶ Clean electricity ▶ Energy storage, distributed energy resources, and smart grid ▶ Hydrogen, synfuels, and fuel cells ▶ Small Modular Reactors (SMRs) ▶ Novel/next-generation bioenergy and bioelectricity ▶ Low- to zero-emission transportation ▶ Electric vehicle charging infrastructure



FOCUS AREA 3

ENERGY EFFICIENCY

ESTIMATED ERA INVESTMENT: 5-15%

In Brief	Scaling and deploying near-commercial technologies to optimize processes, enhance energy management, and improve building energy performance for a wide range of residential, commercial, institutional, agricultural, and industrial energy consumers.
Alberta's Opportunity	<ul style="list-style-type: none"> ▶ Develop and apply leading edge digital tool that incorporate artificial intelligence and data-driven solutions to increase energy efficiency and productivity. ▶ Secure quick wins by addressing low-hanging fruit emissions sources (e.g., waste heat recovery and utilization, low-carbon fuels). ▶ Build on existing initiatives and recent successes to accelerate growth in Alberta's artificial intelligence and digital solutions sectors. ▶ Support improvements across the large population of existing industrial, commercial, and institutional energy users across the province.
A Roadmap to What?	<ul style="list-style-type: none"> ▶ Alberta benefits from rapid growth in digital/automation/artificial intelligence sectors as both a regional centre of excellence and through application of digital technologies to reduce costs and enhance performance. ▶ Consumers and businesses are able to optimize operations and manage energy use, enhancing Alberta's competitiveness by reducing energy costs and increasing productivity. ▶ The profitability and performance of existing assets are improved while greenfield developments benefit from the full suite of best-available technologies and practices.
Timeline to Market Adoption	
Economic Opportunity Potential	
Example Technologies and Solutions	<ul style="list-style-type: none"> ▶ Green buildings including improved HVAC, lighting, and envelope technologies ▶ Digital solutions for automation and optimization including machine learning and artificial intelligence ▶ Energy management and conservation via process optimization and equipment upgrades for commercial, institutional, agriculture, and manufacturing facilities

FOCUS AREA 4 INDUSTRIAL TRANSFORMATION

ESTIMATED ERA INVESTMENT: 20-30%

<p>In Brief</p>	<p>Emerging solutions to accelerate Alberta's transformation to a low-carbon economy by implementing new products and processes within existing industries, mitigating fugitive emissions, and developing new high-value opportunities such as bitumen beyond combustion, advanced materials, and energy minerals.</p>
<p>Alberta's Opportunity</p>	<ul style="list-style-type: none"> ▶ Apply transformative net-zero GHG technologies to enable Alberta's existing emissions-intensive industries to continue to provide products and services critical to the global economy. ▶ Increase industry competitiveness and attract investment by delivering low-carbon products and aligning industry operations with ESG targets including net-zero GHG emissions. ▶ Accelerate oil and gas emissions reduction efforts to bring Alberta's production into alignment with global lifecycle carbon intensities. ▶ Build on existing set of industry hubs/clusters across the province. ▶ Support economic diversification and continued economic growth by adopting emerging industrial technologies. ▶ Accelerate technologies the world needs to monitor, detect, and reduce methane emissions.
<p>A Roadmap to What?</p>	<ul style="list-style-type: none"> ▶ Alberta's industries are recognized for developing innovative solutions to reduce emissions and meet climate goals. ▶ Alberta is known for providing the lowest-emitting hydrocarbons the world has to offer on a life-cycle basis. ▶ Alberta becomes a leader in industrial ecology; industrial processes will be designed to maximize positive feedbacks from systems integration opportunities. ▶ Increase competitiveness in critical industries such as cement, chemicals, and fertilizers through investment in new product lines and transformative processes. ▶ Natural sectors including agriculture, agrifood, and forestry adopt world-leading solutions and develop technologies for export.
<p>Timeline to Market Adoption</p>	
<p>Economic Opportunity Potential</p>	
<p>Example Technologies and Solutions</p>	<ul style="list-style-type: none"> ▶ Hydrocarbons beyond combustion ▶ Advanced bitumen extraction techniques including solvent-based recovery ▶ Next-generation industrial processes and advanced manufacturing ▶ Advanced solutions and new products in the agriculture, agrifood, and forestry sectors ▶ Cementitious material substitution ▶ Low to zero-emission heat production ▶ Management and mitigation of fugitive, vented, and diffuse emissions ▶ Emissions detection, monitoring, and quantification



FOCUS AREA 5 CIRCULAR ECONOMY

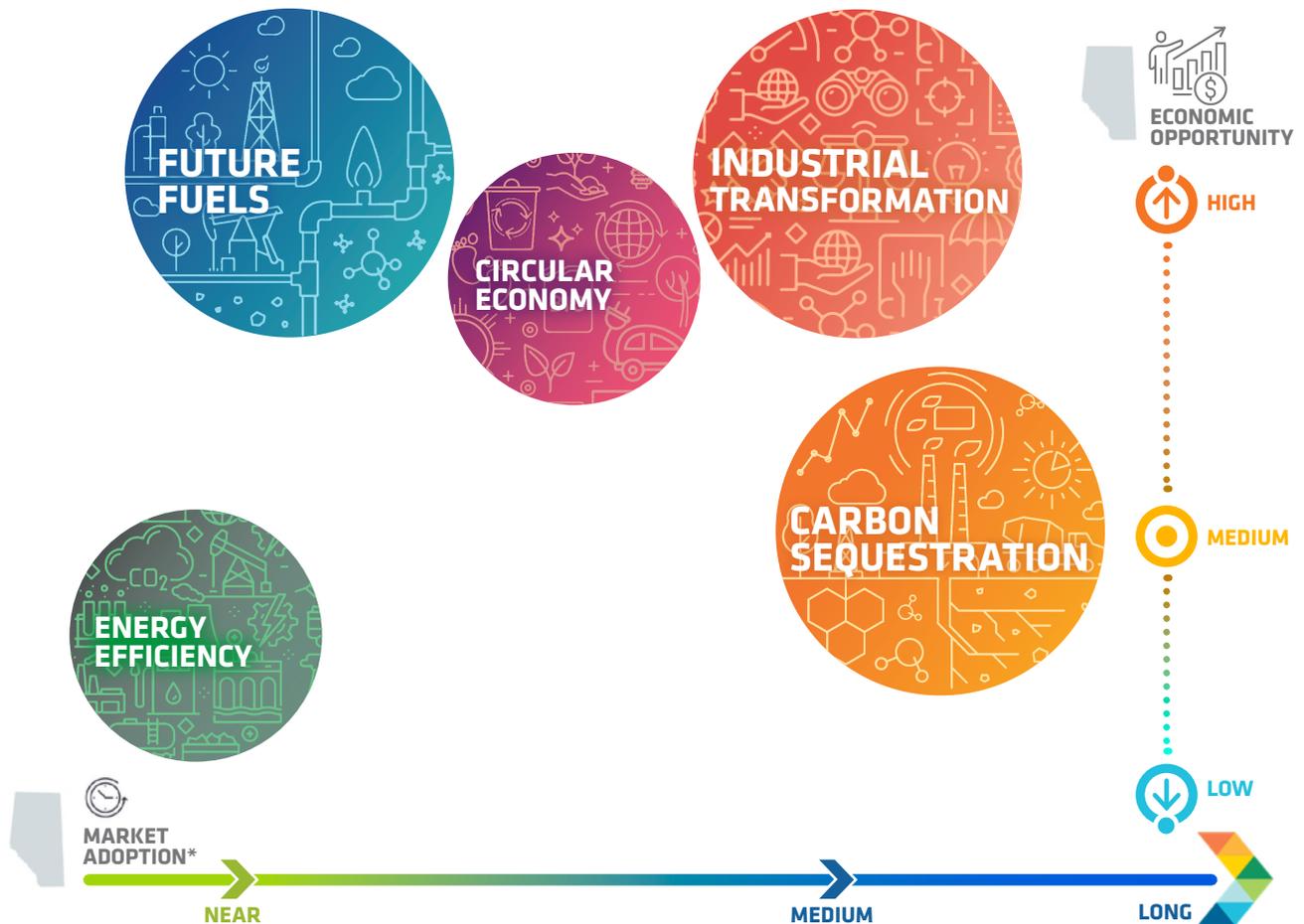
ESTIMATED ERA INVESTMENT: 10-20%

<p>In Brief</p>	<p>Technology solutions to improve the value of products in Alberta and keep resources circulating for longer, helping Alberta to become a leader in new low-carbon materials, critical energy minerals, and waste-to-value-added products.</p>
<p>Alberta's Opportunity</p>	<ul style="list-style-type: none"> ▶ Lead in the development of technologies that contribute to a circular economy, enhancing the resilience of the supply chain while reducing environmental footprint and costs. ▶ Accelerate adoption of technologies that reduce waste and/or upcycle various waste streams (e.g., food, construction, municipal, industrial) to value-added products and minimize its production and impacts. ▶ Ensure Alberta has a seat at the table in the growing global markets for production, processing, and recycling of critical energy minerals such as those required for renewable energy and energy storage. ▶ Build on petroleum industry expertise (e.g., geosciences, drilling, processing) to develop abundant resources of energy minerals such as lithium, vanadium, and carbonates from waste sources. ▶ Build on the foundation of strong existing agriculture, forestry, and waste management sectors to spearhead new product lines and value-added investments.
<p>A Roadmap to What?</p>	<ul style="list-style-type: none"> ▶ Pioneer CO₂ utilization opportunities across industries. ▶ Forests, agricultural, and natural lands will be optimized to provide food and fibre while reducing water consumption and land use impacts. ▶ Wastes from food, agriculture, forestry, industry, and other sources will be converted from a cost to an additional source of value. ▶ Alberta will become a leading supplier of green materials critical to a net-zero economy such as novel construction materials, zero-emissions chemicals and plastics, and carbon fibre. ▶ Alberta capitalizes on market trends to become a major producer of lithium, vanadium, rare-earths, and other 'technology metals' from waste and recycled resources required for manufacturing of low-carbon technologies such as solar panels and fuel cells. ▶ Alberta attracts new investments into battery recycling, biomaterials, sustainable chemicals, and other emerging markets.
<p>Timeline to Market Adoption</p>	
<p>Economic Opportunity Potential</p>	
<p>Example Technologies and Solutions</p>	<ul style="list-style-type: none"> ▶ Circular value chains ▶ Tailings treatments and reduction ▶ Metals and minerals extraction and recycling from waste streams ▶ Green materials ▶ Water and wastewater management ▶ Agriculture and forestry waste to value-added products ▶ Reduced food waste ▶ Improved forest management and recovery

FOCUSING ON TECHNOLOGIES TO NET ZERO

Each technology area has unique investment and deployment needs. In the image below, we present ERA's high-level perspective of the technologies and their market adoption timelines, as well as their GHG reduction and economic opportunity potential. The GHG reduction potential is reflected in the size of technology circles as they apply to Alberta's industries. ERA's investments in each of these areas remains critical to achieving provincial, national, and global 2030 and 2050 climate goals.

MIX OF OPPORTUNITIES, PRIORITIES + CHALLENGES ACROSS INDUSTRIES



The size of the technology circles reflects the amount of potential they have in reducing GHG emissions

Depending on where you sit in the ecosystem, you may see the placement of these focus areas differently. Also, it's important to point out that although the focus areas are plotted once on this scale, there are technology solutions across different timescales in each area.

BALANCING THE PORTFOLIO

The TRM embraces a portfolio approach to ERA investments that allows us to consider technology development opportunities across sectors as well as timescales. The approach acknowledges the importance of investing in technologies for near-term cost and GHG reductions that will maintain the competitiveness of Alberta's existing industries. It also takes into account the need to lay the foundation for long-term transformational technologies that may initially be more expensive or pose higher investment risk, but are essential to unlocking longer-term mitigation opportunities and to achieving Alberta's economic and environmental goals.

Going forward, the availability and scale-up of transformational technologies will ultimately shape the timeline and pathways, and influence the cost of achieving our longer-term climate change goals. ERA recognizes that periodically, our portfolio of investments will need to be adjusted as the global economic and policy context evolves, new technologies and emission reduction opportunities emerge, and government and market priorities change.

ERA's funding model allows it to scale up or down its activities in response to these changing contexts. This creates a flexible mechanism to respond to immediate needs while investing in long-term solutions to build a sustainable future.

BEYOND 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.** Leverage 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.
- ▶ **Broker opportunities for policy and regulatory innovation to stimulate adoption of clean technology solutions.** Work with governments and other key stakeholders to help ensure policy and regulation are enablers of innovation and technology deployment, rather than barriers.
- ▶ **Engage in effective communications and storytelling.** Work with governments, industry and other key stakeholders to share and amplify our technology success stories to build public awareness and acceptance of innovation in Alberta and worldwide.
- ▶ **Generate and evaluate performance data.** Track and report performance to demonstrate the impact of ERA's investments and ensure the organization continues to deliver on its mandate.

Advancing innovation requires understanding the challenges that come with scaling and adopting a technology. To that end, ERA disseminates this knowledge and celebrates project success by hosting events such as lessons learned, participating in panel discussions, and working with our Trusted Partners to help leverage innovation system funding. Bringing stakeholders together will continue to accelerate Alberta's transition to a low-emissions economy and advance key technologies and solutions.

Sharing insights and knowledge from projects shows Alberta continues to lead in developing the technology solutions the world needs.

This work also provides a clear line of sight from the carbon price paid by industry, under the TIER to Technology Innovation and Emissions Reduction regulation, to investment in the solutions needed to achieve GHG reductions.

MEASURING PERFORMANCE

The TRM's success is measured against how it delivers on the purpose and objectives described in the first sections of the document.

Due to the varying magnitudes of risk and reward associated with investment across timescales and TRLs, ERA has continued to update and track its suite of performance metrics, reporting on performance indicators across environmental, economic, technology, and community areas. 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 and GDP growth. At the lower TRL levels, the success factors will be based on indicators such as TRL level advancement, project success rate, estimates of potential impact (e.g., social, other environmental), and partner involvement and investments (i.e., 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 the 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.

Performance is reported through various public documents such as ERA's Annual Report, rolling three-year Business Plan, and quarterly Stewardship Report. Qualitative metrics and project learnings and knowledge-transfer are reported through ERA's Lessons Learned series, as final reports on ERA's website once projects are completed, and through ERA's media communications including Twitter, and ERA's podcast series, Carbon Copy.

CONTINUOUS IMPROVEMENT

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, continuous engagement with others in the innovation ecosystem helps validate the priority areas of investment of the TRM and ensures ERA's investments are driven by broad 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. This course includes pathways to reach 2030 and 2050, both of which require a different set of technologies and have different environmental, economic, and social implications. ERA will continue working with others in the innovation ecosystem to accelerate scale-up of transitional technologies needed to reach 2030 targets, while investing in transformational opportunities needed for net-zero 2050 and beyond.

To address these needs and ensure the TRM remains current, ERA will regularly engage with 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 assess 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.
- ▶ Identify ways in which greater impact might be achieved through bi-directional influence and synergies between/among organizations.

APPENDIX

DESIGNING THE TECHNOLOGY ROADMAP

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 fourth 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 3*.

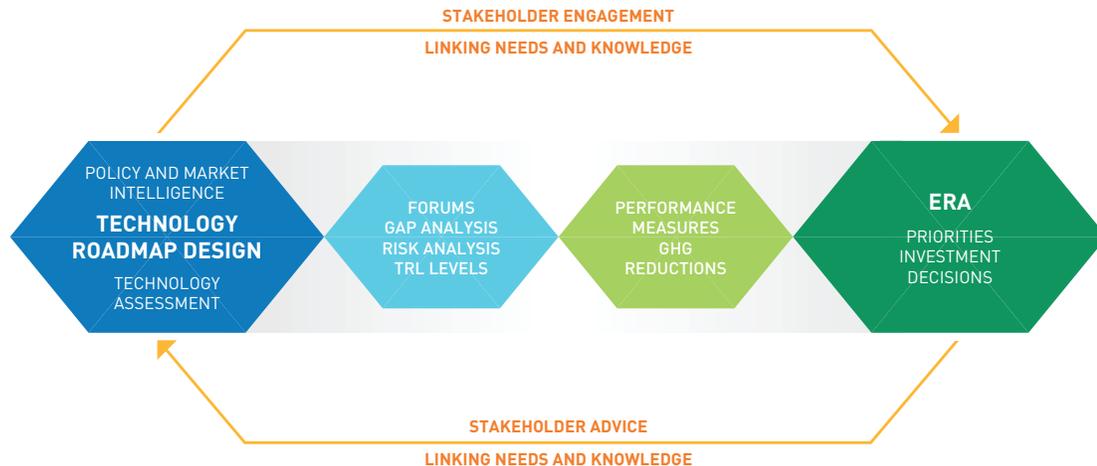


Figure 3: TRM Design

2021/2022 ENGAGEMENT

When ERA last reviewed the TRM in 2018, we were given the guidance by stakeholders to begin with the “end in mind.” Since that time, there have been significant national and international economic, social, and policy developments that provide important guideposts that help define a vision around what a low-emission future might look like.

Increasingly, governments, industry, and investors in Canada and around the world are committing to achieving net zero emissions by 2050. These commitments help clarify an “end” that will require significant transformation, bringing unprecedented opportunities—as well as risks—and requiring strong action and a commitment to accelerate the pace of investment and innovation. The pathway to achieving net zero, as well as how to balance ERA’s investments over time to support reaching that goal, were key themes of the engagement for the TRM in 2021.

In two rounds of engagement, we heard that the TRM needs to include the deployment of existing technologies that help Alberta’s industry achieve immediate reductions, as well as investments in emerging or game-changing technologies that open the door to significant transformation or new business opportunities that are sustainable in a low-emissions future.

In the first round of multi-stakeholder engagement sessions, we asked key thought leaders in industry, the innovation ecosystem, academics, and government to help us define the guideposts that should shape our investment decisions. We then asked them what opportunities, risks, and considerations are important to the short-, medium-, and long-term when it comes to reducing Alberta’s emissions contributions.

Following initial conversations and the incorporation of feedback, the TRM was circulated with a second round of key thought leaders to validate that we had captured where ERA’s contributions to reducing emissions could best be realized.

This version of the TRM reflects the thoughtful insights of these key thought leaders from across the country. We are grateful for their contribution.

EMISSIONS
REDUCTION
ALBERTA

