EMISSIONS REDUCTION ALBERTA

TECHNOLOGY ROADMAP

Investing in technologies for a lower carbon future.

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

EMISSIONS REDUCTION ALBERTA - NEW DIRECTIONS

Shifting the thinking and inspiring the future

TECHNOLOGY ROADMAP PURPOSE AND OBJECTIVES

Emissions Reduction Alberta (ERA)[1] has a mandate to identify and accelerate innovative solutions that secure Alberta's success in a lower carbon economy. Its vision is for Alberta to be recognized as an innovation and technology leader in a lower carbon world. To deliver on this vision, ERA invests in transformative technologies that help build a sustainable and diversified economy that attracts investment; delivers improved environmental outcomes; and expands market access.

ERA is developing a Technology Roadmap (TRM) to guide its investment decisions and inform its portfolio mix. The TRM will also contribute to the alignment of the broader innovation system around common climate change and innovation goals that result in meaningful greenhouse gas emissions (GHG) reductions in Alberta. If successful, the TRM will assist the multiple organizations that represent ERA's 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 1 below, with the details discussed in this document.

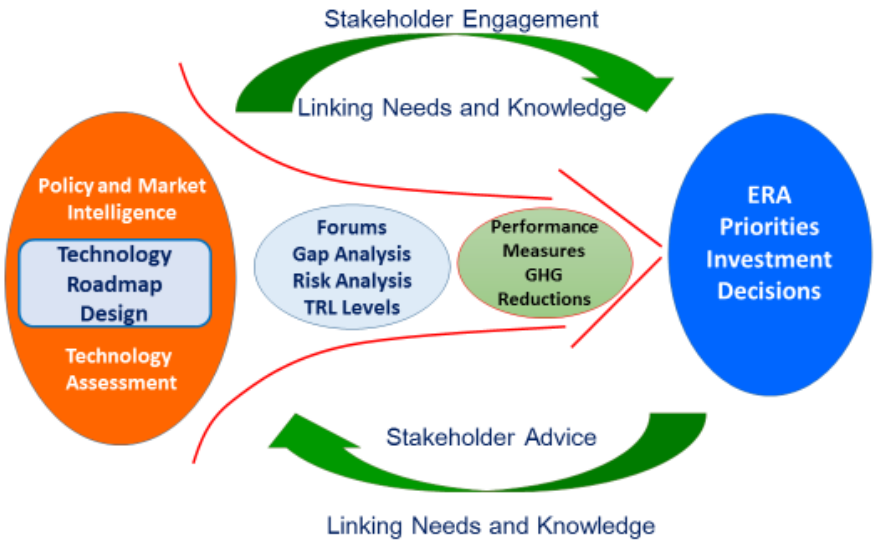


Figure 1 – ERA Technology Roadmap Design

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More specifically, the TRM will seek to deliver on the following objectives:

1. Define pathways, opportunities and barriers to achieving Alberta's climate change policy outcomes that can be achieved through investment in innovation and technology, which will allow ERA to:
   - Identify opportunities for Alberta to demonstrate climate change leadership through high potential impact investments.
   - Leverage and augment Alberta's natural strengths and build on existing capacity.
   - Demonstrate the value and potential of directing government funds towards innovation and technology solutions and provide a clearer line of sight for where funding will flow and the associated outcomes.
   - Invest exclusively in solutions that align with Alberta's needs.
   - Leverage Alberta's unique assets to attract and retain best technologies and innovators.
   - Contribute to economic prosperity and diversification of Alberta's economy through facilitating development and demonstration of successful technical innovations and associated businesses.
2. Map the potential tactical options for delivering needed solutions, providing:
   - Aligned and coordinated strategies to deliver required solutions.
   - A clearer understanding of the specific responsibilities and accountabilities of players in the innovation system.
3. Identify milestones and deliverables towards achieving our outcomes, providing:
   - Measurable benchmarks and opportunities for real emissions reductions as we work towards achieving the desired outcomes, including economic growth and job creation.
   - Actual environmental and economic performance reporting against originally identified targets.
   - An effective communications tool for understanding and demonstrating progress.

KEY INFLUENCES ON ALBERTA'S CLIMATE AND INNOVATION PRIORITIES

National Collaboration

Building on commitments and momentum from COP21 in Paris, the Federal Government, the Provinces and Territories are moving toward a Pan-Canadian framework for "clean growth and climate change". Canada has committed to achieve a 30 percent reduction in GHG emissions from 2030 levels and contributing to limiting the global temperature increase to less than 2 degrees Celsius 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.

The leadership displayed by the Government of Alberta in developing a comprehensive climate change plan places it in a strong position to work with the Federal Government to leverage investments not only in green infrastructure and the phase out of coal but also in research and innovation to support climate change goals and targets. ERA's TRM can serve as a catalyst for broadening partnerships with organizations like Sustainable Development Technology Canada (SDTC) and federal departments like Natural Resources Canada (NRCan), while bringing together diverse stakeholders to directly promote and authenticate Alberta as a global leader on mitigating greenhouse gas emissions through technology.

Alberta's industries also have a key role to play in delivering on our climate change objectives. The TRM can help align efforts to collaborate with industry partners and ensure we are investing in solutions to the problems the market is demanding. Organizations like Canada's Oil Sands Innovation Alliance (COSIA), which brings together oil sands producers to collaborate around improving environmental performance, represent strong partnership opportunities.

Alberta's Climate Leadership Plan

Alberta's Climate Leadership Plan (CLP) represents important progress for Alberta and is an example of aggressive actions by the province in support of Canada's obligation to meet GHG reduction targets. Alberta has earned a great deal of credibility not only for developing a comprehensive climate change plan to achieve substantial reductions for the period 2015 to 2030, but also for the process of bringing together diverse stakeholders to strongly support the plan, including the Alberta business community, the aboriginal and environmental community, academic institutions and the general public.

The CLP is aligned with GHG mitigation priorities for Canada and North America, as well as with international agreements, and provides a mix of policy tools with the potential to deliver significant GHG reductions. However, the extent to which the CLP will deliver on generally accepted global targets related to limiting global temperature rise to less than 2 degrees Celsius is predicated on the government's ability to "turn the dials" on those tools (e.g. increase the carbon price). Meeting such global targets will require ambitious and comprehensive programs of GHG mitigation options for Alberta and Canada for the period from 2030 to 2050. To realize the most ambitious targets the TRM must establish research and innovation priorities that not only support the CLP in the 2017 to 2030 timeframe, but also positions Alberta to achieve emissions reductions beyond 2030.

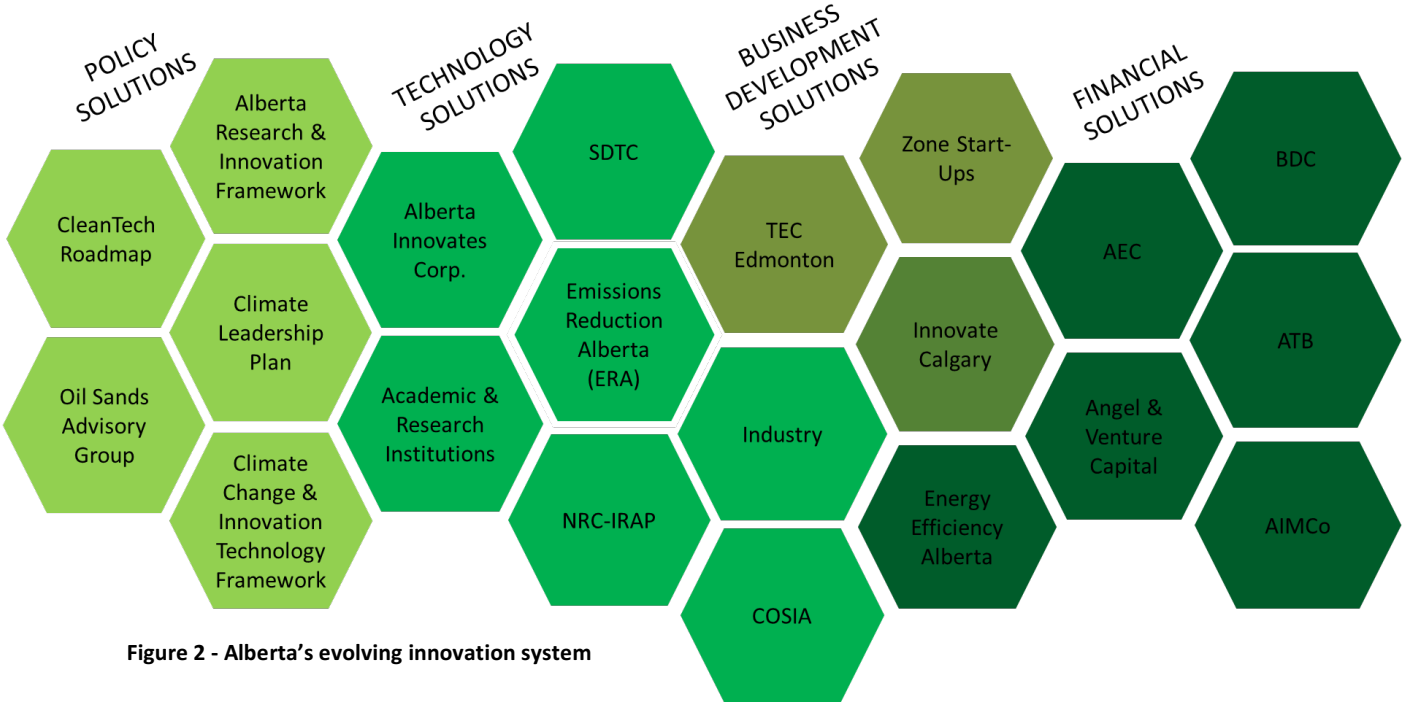


Figure 2 - Alberta's evolving innovation system

Alberta's evolving climate and innovation system

Alberta's innovation system is growing and evolving (see Figure 2), with climate change emerging as a key system priority. To support diversification, job creation, education, training and climate change action, ERA will work in close alignment with the evolving Alberta innovation system and the several complimentary strategies being developed by government departments. The implementation of the TRM can spur a rigorous engagement process and feedback loop to ensure a common and mutually supportive approach across key components of the system including:

- **The Alberta Climate Change Office (CCO)**, which is mandated to coordinate the implementation of the Climate Leadership Plan (CLP). The CCO and Alberta policy makers will be approached to ensure that there is a good understanding of their needs in implementing the CLP and shaping the next phase of mitigation options and future directions. ERA can also be a key interface point to provide advice into the CCO relating to potential opportunities for innovation to play key roles, and for policy to support rapid adoption of novel solutions.
- **The Climate Technology Task Force**, which was created by government to lead stakeholder engagement and make recommendations on a Climate Change Innovation and Technology Framework to help guide Alberta's investments in climate change innovation and technology. ERA is well positioned to be a lead agency for investing to advance Alberta's climate change innovation goals.

- **The Alberta Research and Innovation Framework**, which is being developed by Economic Development and Trade (EDT) to provide shared outcomes and aspirational targets for provincially-supported research and innovation organizations. ERA continues to benefit significantly by partnering with Alberta Innovates. With the Alberta Innovates Corporations recently consolidated into a single entity, the TRM can help delineate the roles and responsibilities for delivering on climate research and innovation priorities and timeframes.
- **The Cleantech Roadmap**, which is being developed by EDT to identify the strategic options to accelerate Alberta's Cleantech industry development. The work has identified "promising segments for Alberta" including: oilfield energy efficiency; water management particularly in oil and gas; cleaner energy including wind, solar, , biomass, geothermal energy, biochemical, biomaterials, and biofuels; municipal solid waste management; carbon capture utilization and storage and environmental products and services. The study assessed the economic and environmental impact of these segments

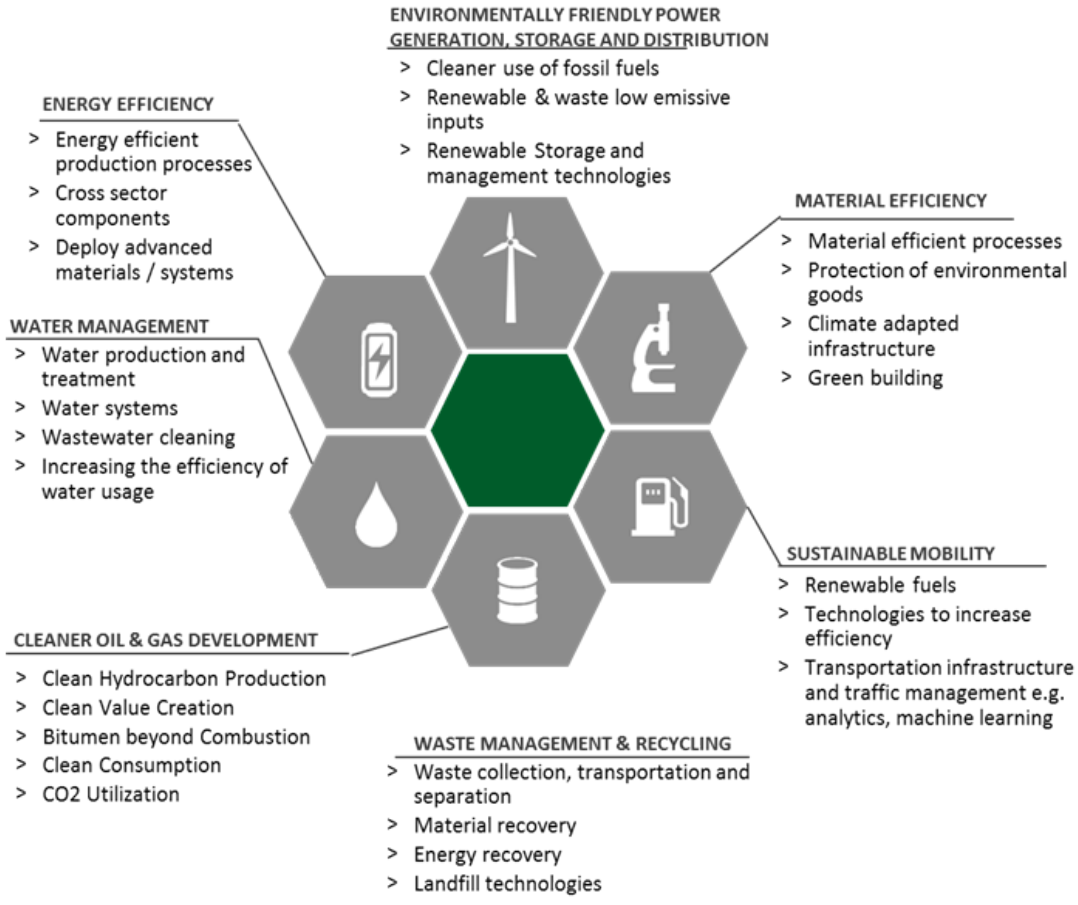


Figure 3 - Strategic Areas from Clean Technology Roadmap (draft)

which will assist in the development of the TRM. Overall, the ERA areas of focus are well aligned with the market opportunities identified by the Cleantech Roadmap (Figure 3).

- **The Oil Sands Advisory Group (OSAG)**, which was established by Government to examine issues on implementation of the province's new 100 MT per year emissions cap on oil sands greenhouse gas emissions. The OSAG will also address land-use issues in the region and offer advice on how revenues from the carbon levy can be invested to reduce per-barrel emissions from the sector, as well as specific opportunities that can be addressed by innovation. Consultation with the OSAG will be important to respond to trends in the TRM likely affecting the oil sands sector by 2030 and beyond.
- **Energy Efficiency Alberta (EEA)** is a new provincial agency that will promote and support energy efficiency and community energy systems (including micro-generation and small-scale generation) for homes, businesses and communities. EEA will receive funding of $645 million over 5 years. The Energy Efficiency Advisory Panel was created to advise the government on the types of energy savings programs that EEA can start to deliver in the short and medium-term, as well as help set out a long-term vision. It will be important that ERA and the TRM focus on distinct energy efficiency themes that are complimentary to those of EEA.

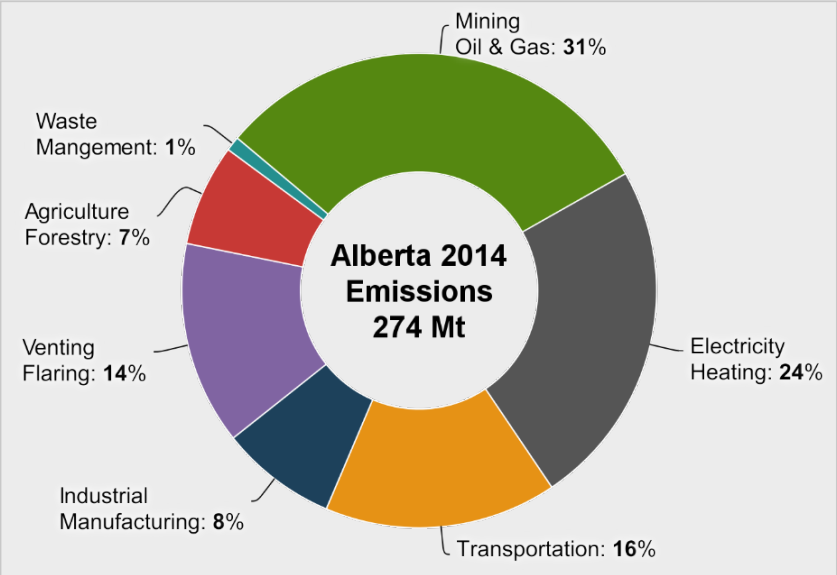


Figure 4 - Alberta's GHG Emissions Profile

THE TECHNOLOGY IMPERATIVE

Under the CLP, the Alberta government has committed to taking significant action to reduce GHG emissions in the province. Alberta's GHG emissions profile is shown in Figure 4, which

illustrates the sectors where GHG reductions will have maximum impact. The 2030 estimate of potential reductions that might be expected to be delivered under the CLP is shown in Figure 5.

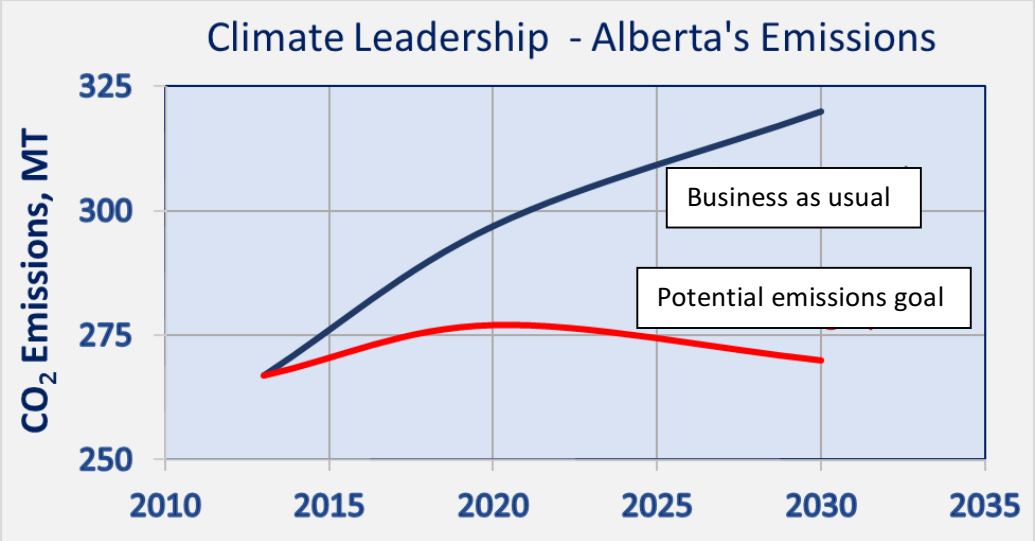


Figure 5 - Illustrating the potential emission reductions that result from the implementation of the strategic directions of Alberta's Climate Leadership Plan.

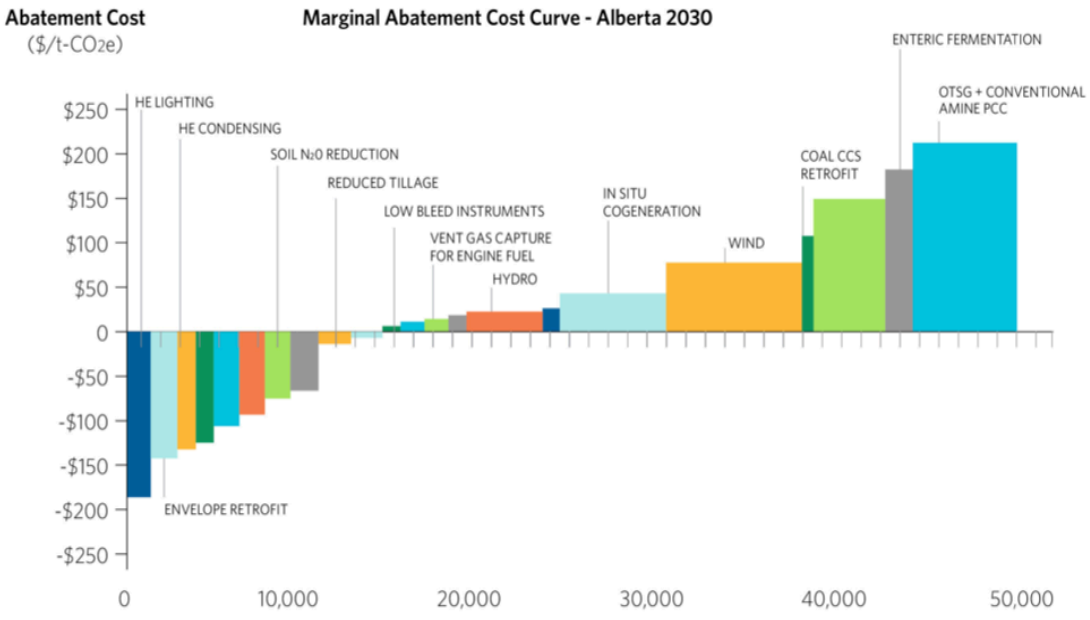


Figure 6 – Technology Options to achieve GHG reductions
(Source: Delphi Group, 2015, CAPP submission to Alberta Climate Advisory Panel)

The Federal government has committed to a 30 percent reduction in GHG emissions by 2030. A reduction of 30 percent by 2030 from business as usual in Alberta requires about 90 MT reductions. Some economically-attractive near-term GHG reductions can be achieved using existing technology, such as energy efficiency (see Figure 6).

Since a substantial share of Alberta's emissions is from oil and gas and other large industrial sources, Alberta's challenge is to drive emission reductions without damaging the province's economy. A 50 MT reduction by 2030 from business-as-usual requires that we identify the critical innovation pathways, challenges, and opportunities to achieve this target while supporting Alberta's job creation and diversification imperative. Near-term action can potentially lead to about 30 MT of annual reductions by 2030. Even with this optimistic goal, there still remains a gap of about 60+ MT.

Regardless of the specific GHG target, technology must be part of the answer to achieving significant emissions reductions. Achieving longer-term GHG targets requires new breakthrough technology options and investment in higher-risk, high-potential technology development.

TRM DESIGN AND FOCUS

The TRM is intended to inform ERA's portfolio mix and guide its investment decisions. In doing so, it should define priority areas of focus for investment that will:

- **Achieve GHG reductions in multiple timeframes (2020 and 2030+).** Investment across multiple timescales is required to be successful in addressing the climate change challenge. Nearer-term GHG reductions are typically achieved through widespread deployment of commercially available, or nearly available, technologies, at the highest readiness levels (TRL 7 through 9) (see Figure 7). Longer-term reductions require focused and sustained investment in breakthrough solutions, which involves investment in technologies lower on the TRL scale. Achieving commercialization of such technologies is substantially more risky but potentially high reward.
- **Identify Industry need or market pull.** Investment is required in GHG reduction technologies that are bold, ambitious, and demanded by the market. The concept of directed innovation involves defining key strategic GHG reduction technology development outcomes, which are unpacked into a series of smaller steps or deliverables that in sum allow attainment of the bolder outcome. Key to defining and unpacking these GHG reduction initiatives is an understanding of what solutions are being demanded by the marketplace. Directed innovation helps to define innovation challenges in the marketplace so they can be more easily understood and solved by innovation providers. While realizing the solutions required to meet the needs of industry is important, to be commercially successful these solutions must find markets first within, then beyond Alberta. It is important to acknowledge, encourage, and

measure external impacts, both economic (in terms of export-derived revenues) and environmental (tonnes CO_2 reduction from other jurisdictions).

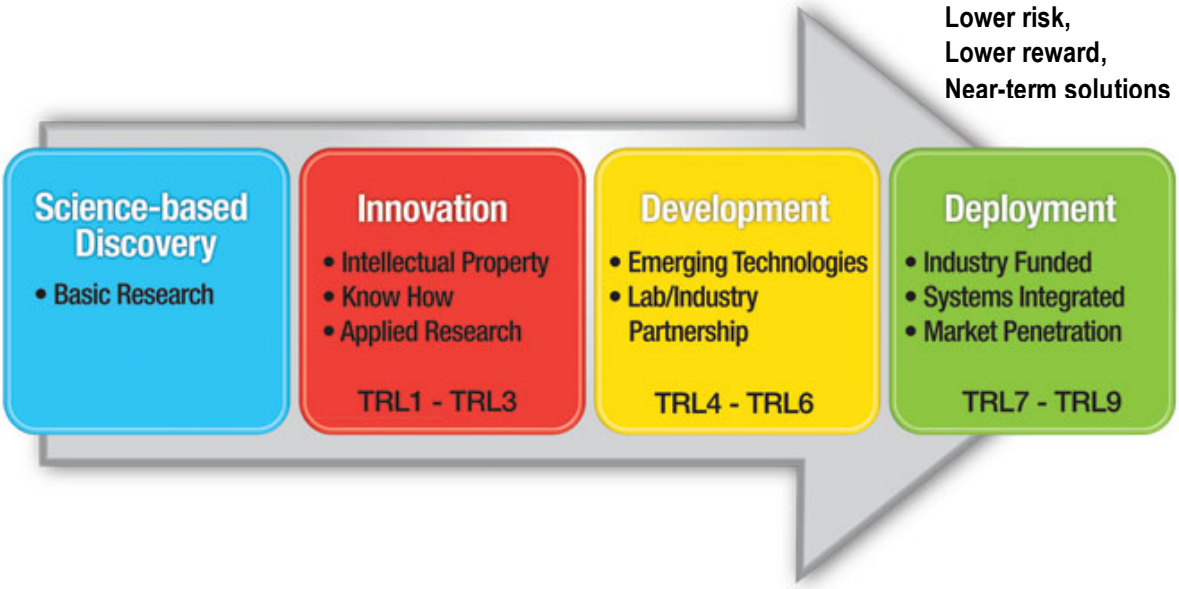


Figure 7 - Technology Readiness Levels, Risk and Reward

- **Build on Alberta's existing strengths and create new opportunities.** There is an opportunity to invest in GHG reduction technologies in support of greening Alberta's existing industries and historical areas of strength, such as our oil and gas sectors, as well as help identify and support technologies in new industries in support of economic diversification, such as our growing renewable and bioenergy industries. In doing so we can create a more sustainable economy, create new markets, and encourage job and economic growth. This requires alignment of the innovations with the purchasing intent of prospective industrial buyers, not simply with abstract concepts of potential impact.

  Breakthroughs may originate in other jurisdictions then come to Alberta at a later stage. In part this can be due to systemic barriers and lack of access to early capital for innovative/entrepreneurial companies. It is important to explore mechanisms to reduce barriers to early development of innovative technologies, and to increase adoption of technologies that may initially emerge in other markets.

- **Guidance from Alberta's climate and innovation system.** The Alberta Forum of the Trottier Transformation Project was held in July 2016 and brought together technical experts from government, academia, the environmental community and industry representing the oil and gas, renewables and power sectors around goals. This included

analyzing decarbonization pathways to guide decision makers on evidence based options for mitigating climate change impacts and assessing the most important short term and long term GHG mitigation transformation options for Alberta. ERA priority areas of focus (see below) were guided in part by the Forum's pathways.

ERA TRM Emergent Areas of Focus

It is recommended that ERA's emergent areas of focus include the four strategic areas summarized below, with emphasis on the TRL indicated in order to deliver maximum GHG reductions in the 2020 and 2030+ timeframes:

1. Transformative technologies and innovation to **reduce GHG footprint of fossil fuel supply** and **reduce methane emissions** while reducing production costs *(TRL 4 - 8)*;
2. Technology and innovation to **reduce the GHG footprint of Alberta's electricity supply mix** and add more **non-emitting supply** to meet overall demand *(TRL 5 - 8)*;
3. Innovation and early stage technologies for **biological resource optimization** in supporting energy system transformation, such as **biofuels/bioproducts** and **carbon retention** opportunities *(TRL 3 – 7)*;
4. **Industrial process efficiency** technologies to deliver GHG reductions and cost competitiveness through opportunities such as process improvement and energy efficiency *(TRL 8 - 9)*.

Figure 8 shows examples of potential technology initiatives within each focus area.

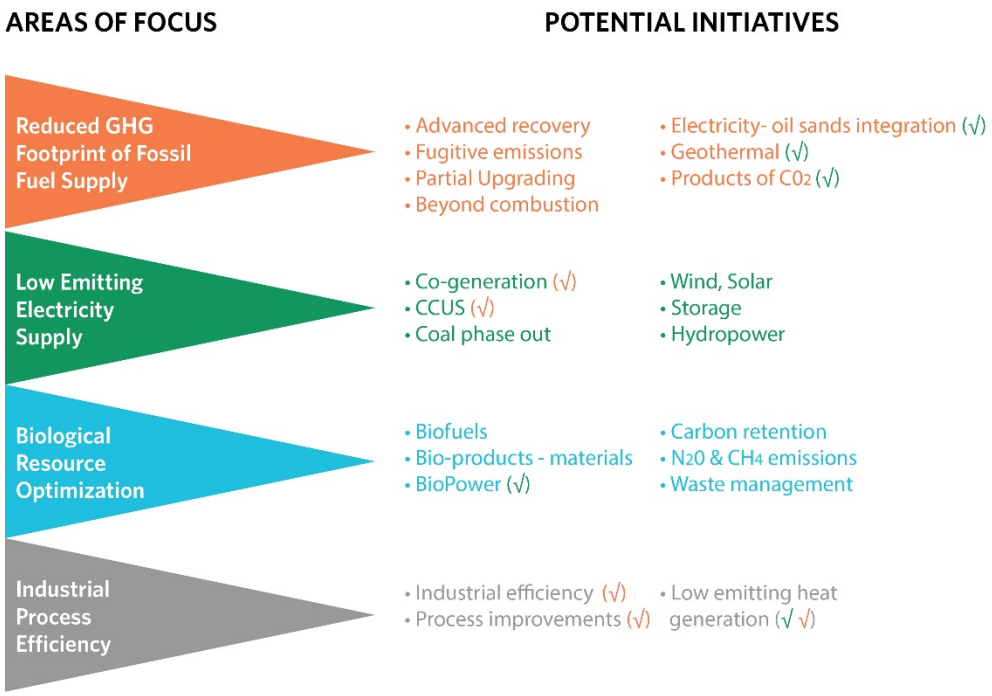


Figure 8 - Strategic Focus Areas and Potential Initiatives

Note: Check marks indicate initiatives that apply to more than one Strategic Area

Balancing the Portfolio

Given the prevalence of fossil fuels in the Alberta energy mix it is not surprising that emissions from the combustion of fossil fuels account for some 90% of Alberta's GHG emissions. The four strategic areas are, therefore, planned to focus primarily on innovation that will:

- Significantly reduce the emissions from fossil fuel use in the electricity sector, in oil and gas production and refining and in heating (thermal energy load).
- Displace high emitting fossil fuels with renewables and other low emitting sources from the major sectors of Alberta's economy.
- Enable technologies that will likely be commercialized in the medium- to long-term including low-cost, efficient electrical storage, carbon capture and utilization, and non-combustion products of fossil fuels.

Considering Alberta's CLP and the amount of emissions emitted by various sectors, a possible breakdown of ERA's investment portfolio is provided in Table 1. ERA's portfolio should give consideration to balance not only with respect to areas of focus, but also in terms of time scale and development risks. Timescale and relative risk can be correlated roughly to the TRL levels. Investment in solutions of TRL 1-3 are typically high risk but potentially offer higher long-term reward; solutions of TRL 3-6 represent more moderate risk and a correspondingly more moderate reward; and finally investment in solutions of TRL 6-9 are lower risk and offer near term, but usually more modest, results.

As such, ERA should consider attributing small a portion of its investments across its portfolio (e.g. 10-15 percent) to low TRL, disruptive and emergent technologies. This would include early stage technologies with potential to be highly transformative, or low-cost pre-demonstration and feasibility studies. ERA should work closely with the post-secondary system and Alberta Innovates to align and coordinate such efforts.

ERA may also consider dedicating a small portion of its investments to piloting or demonstration of prospective system-level innovations that may shift the cost curve for broader penetration of key technologies. Such investments would enable proving out of alternative approaches to infrastructure or system configuration, such as next-generation smart grid/ microgrid demonstrations.

Opportunities should be sought to identify alignment with other provincial and federal government initiatives to coordinate reporting of those areas currently aligned and adjust from time to time to maximize synergies. Examples include work of the Energy Diversification Advisory Committee and Clean Technology Roadmap.

Strategic Area	Possible ERA Investment, %	Description
1. Reducing the GHG Footprint of Fossil Fuel Supply (TRL 4 – 8)	30 – 50%	▪ Vast majority of GHG emitted and growing emissions ▪ 100 Mt cap on oil sands emissions ▪ Costly to pilot novel technologies ▪ Focus on monetizing vented and flared natural gas from oil and natural gas production, gas processing, pipeline compressor stations
2. Low Emitting Electricity Supply (TRL 5 – 8)	20 – 30%	▪ Focus on novel technologies that are not already commercial such as pumped hydro, electrical storage, geothermal ▪ CCS (CCUS) and co-gen (also captured in 3)
3. Biological Resource Optimization (TRL 3 – 7)	10-15%	▪ Earlier stage technologies exploring the best uses for the land (reforestation, forest and agricultural management) and biological resources ▪ Later stage bioenergy and biocleantech opportunities ▪ Need for technologies to support improved measurement and quantification
4. Industrial Process Efficiency for Industry (TRL 8 – 9)	15-20%	▪ Focus on demonstration at the facility level of novel process and energy efficiency technologies ▪ Technologies to address fugitive leaks from pumps, valves, pipes, pneumatic devices

Table 1 – Potential ERA portfolio mix

PERFORMANCE MEASUREMENT

ERA will define success as a TRM that 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 should consider varying its performance metrics depending on the TRL focus. Figure 9 below is the "opportunity radar" for the Fossil Fuel Supply Decarbonization Strategic Area as an example of the evaluation process for new technologies that is represented by the TRM. At the higher TRL levels (typically 6-9) ERA's performance measures will be based on absolute GHG reductions (tonnes delivered) or GHG benefits. At the lower TRL levels (typically 2-5) the success factors will be based on indicators such TRL level advancement, success rate, estimates of potential impact, partner's interest and investments (leverage). It should be noted that each of these points represent a basket of specific technologies, individual examples of which may deviate significantly in risk and development time from the notional distribution illustrated in Figure 9.

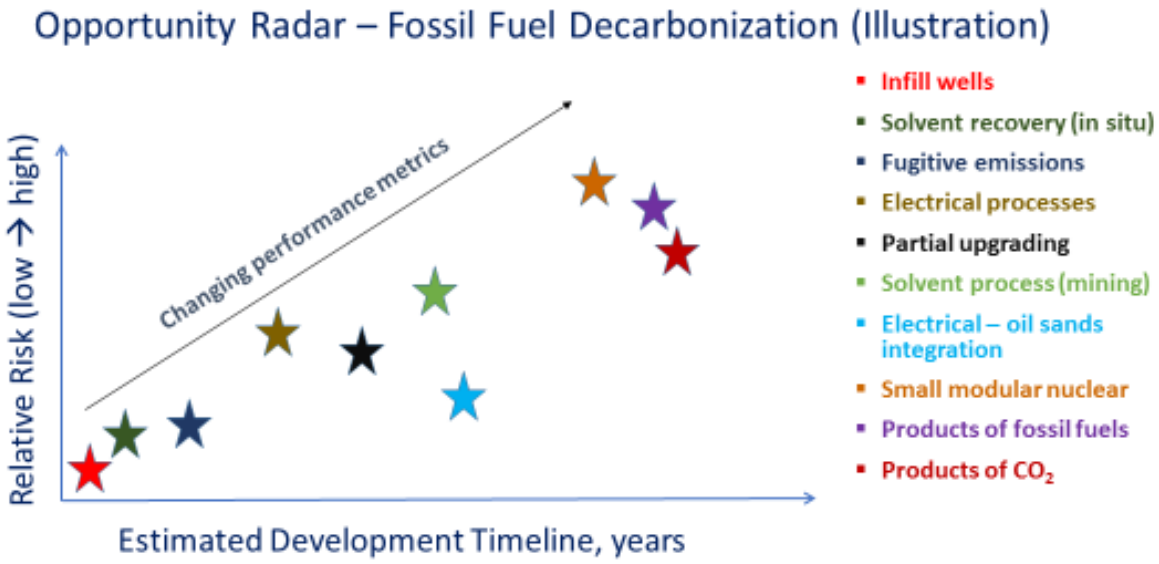


Figure 9 - Opportunity Radar – Fossil Fuel Decarbonization

While committed to delivering against a strong vision for the future, ERA is transparent and accountable to Albertans. For this reason, in addition to forward-looking performance measures used in selection of investment decisions, a program of ongoing retrospective performance measures, including how closely actual investment performance tracks 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. In addition, 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 (example, fracking) represent major uncertainties for the direction of innovation. At the same time, global and Canadian climate policies remain uncertain and could evolve rapidly and would likely become greater drivers for technological innovation and change.

In view of the above, ERA's TRM should be viewed as a continuous process designed to position ERA as a flexible and nimble organization that can adjust to new information, new challenges and new opportunities. 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** (e.g. Alberta Innovates), **market intelligence** (e.g. MaRS in the Cleantech sector), **policy leadership** (e.g. Alberta's Climate Change Office) and rigorous **process modeling** to assess technology pathways (e.g. University of Calgary; University of Alberta; Deep Decarbonization Pathways Project).

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 will be important to engage broadly 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 to demonstrate that ERA is driven by a compelling vision acting on principles of innovation, integration and collaboration. It is also important to stress that ERA's TRM and innovation pathways will help chart a course towards investment in innovative solutions that reduce GHG emissions while growing a diversified economy in a low carbon world. This, along with other roadmaps that have been or are currently under development may help to increase the coherence across the innovation ecosystem.

It is recommended that an engagement plan be developed leading to the convening of a series of dialogue sessions with the ERA Board members, government & its agencies, industry, environmental groups and technology experts to:

- Better 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.
- Confer on the emerging business model, portfolio approach and the sequencing of calls for proposals in the delivery of GHG emission reductions.
- Seek advice on what success for ERA would like to assist in developing 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. For example seeking to ensure that regulatory and/or procurement policies are responsive to positive results from ERA projects.