Opportunities for Critical Mineral Production and Advanced Material Innovation in Alberta

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This white paper was jointly supported by Alberta Innovates and Emissions Reduction Alberta. John Zhou, Murray Gray, Amanda Mitchell, Chris Owttrim, Grace Meikle, and Mark Donner contributed to the paper. The paper is formatted by Manuela Buretia.

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EXECUTIVE SUMMARY

Canada's natural resources (including oil, natural gas, and critical minerals) are an asset to build a strong economy and defend against external economic coercion. As a global leader, Alberta's oil and gas industry has been a major contributor to the Canadian economy and will remain so for decades to come. Alberta's critical mineral resources are yet to be developed but have the potential to become a new resource-based industry for the province.

The global transition toward sustainable energy and infrastructure development is driving an unprecedented demand for critical minerals and advanced materials. The key trends shaping these demands include electrification of transportation, infrastructure development, and energy storage solutions. Critical minerals (such as lithium, nickel, and graphite) and advanced materials (such as carbon fiber and synthetic graphite) are essential for the physical transformation during this transition.

Alberta has several critical mineral resources that have potential to be developed at commercial scale. Lithium in oil field brine may represent an important critical mineral opportunity for Alberta, potentially reaching one-billion-dollar annual revenue by 2034. Vanadium, titanium, and zirconium in oil sands bitumen and its associated byproducts may represent a modest opportunity for Alberta. The helium opportunity is likely also modest for Alberta. The potential for uranium development, while already a successful industry in Saskatchewan, is yet to be determined in Alberta. The potential for commercial production of nickel, cobalt, copper, rare earth elements (REEs), phosphate, and natural graphite in Alberta is low. However, black shales in Northeast Alberta may be an opportunity to co-produce multi-metals.

There are also opportunities in mid-stream manufacturing in Alberta. Alberta has already nickel refining. A cobalt refinery has been proposed in the Alberta Industrial Heartland region. Other opportunities include electrode and battery manufacturing, carbon fiber composite production and pressure vessel manufacturing. These mid-stream opportunities have potentials to create more value in Alberta.

The greatest opportunities for Alberta are in the advanced materials supply chain. Several advanced materials can be made from asphaltene and refinery residue of bitumen to substitute critical minerals (e.g., synthetic graphite for graphite). Carbon fiber, hard carbon, and asphalt binder each respectively represents a billion-dollar opportunity for Alberta. Synthetic graphite may also be made from bitumen derived materials although the technology is yet to be developed. Collectively, the advanced materials opportunity is at least an order of magnitude greater than all the critical minerals extraction opportunities combined and provides an alternative pathway for value extraction from Alberta bitumen other than combustion for energy. Alberta's bitumen resource should be considered as a "critical mineral" for being the ultimate source material of these highly valuable carbon-based advanced materials that will be in high demand in the decades to come.

Alberta Innovates and Emissions Reduction Alberta should continue to support critical minerals and advanced materials development in Alberta. This includes quantifying lithium, helium, and uranium resources; supporting direct lithium extraction and vanadium extraction technologies; determining the potential for multi-metal extraction from black shales in Alberta; and, most importantly, supporting innovations in and commercialization of advanced materials such as synthetic graphite, carbon fiber, hard carbon, activated carbon, and asphalt binder. Mid-stream value-add opportunities related to critical minerals and advanced materials should also be supported.

Alberta's bitumen resource is not only the third largest petroleum reserve in the world but also the most important critical mineral for Alberta.

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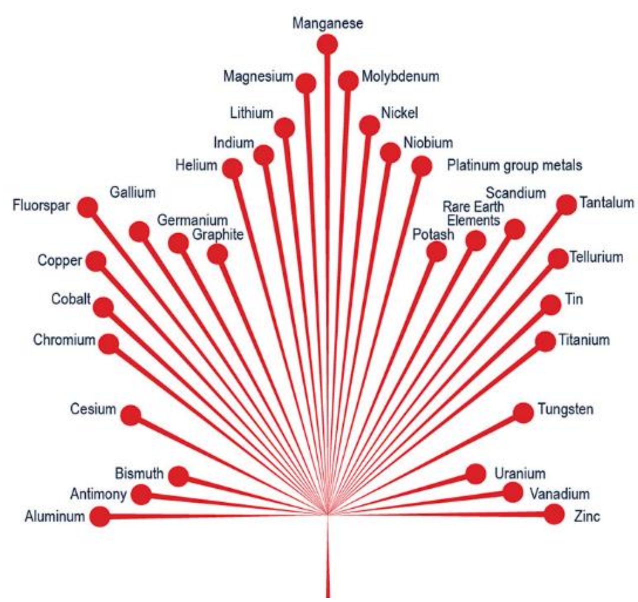
1. Introduction

This is a trying time for the free world. The world order since the end of the Cold War has been disrupted. Canada is bearing the full knock of this disruption, coerced by its neighbour, closest ally, and largest trading partner. At this crucial moment in our nation's history, Canadians have realized that our natural resources (including oil, natural gas, and critical minerals) are a strong asset to build our economy and defend against external threats. Hydrocarbon resources have been Canada's largest export for decades and will remain among the most reliable energy sources for the world in the coming decades.

However, energy transition (or diversification) is taking place around the world, driven by concerns over energy security and greenhouse gas emission. With reduced emissions footprints and increasingly competitive costs, alternative energy like solar and battery energy storage offers enhanced energy security in that they can provide energy services for decades after installation. To avoid simply trading one set of disadvantageous geopolitical dependencies for another, nations are increasingly looking to "friendshore" energy supplies, be they fossil-based or alternative energy. In this context, Canada's world class hydrocarbon resources, critical mineral resources, political stability, and reliability as a trade partner make our country a desirable strategic partner in a challenging world. Alberta's oil and gas industry is a global leader, and the industry has the potential to grow through technology innovation and market diversification. While less developed, Alberta also has resources in both critical minerals and advanced materials. Development of these resources in parallel with conventional resources can make our economy more resilient while cementing Alberta and Canada's place in the emerging new energy economy.

The global energy transition underway requires a physical transformation of our economy. The key challenges are therefore primarily physical, including the timely availability of materials embedded in infrastructures, buildings, and electric vehicles (McKinsey, 2024). Critical minerals (such as lithium, nickel, and graphite) and advanced materials (carbon fiber composites and synthetic graphite) are essential enablers for the physical transformation during this transition.

The Government of Canada (GoC) has identified 31 critical minerals that are important to Canada and the world. The Government of Alberta (GoA) has developed a Minerals Strategy and Action Plan (GoA, 2021) and identified Alberta's Critical Minerals Potential (GoA, 2023). GoA has developed the minerals strategy and action plan because it has realized that "Worldwide demand for metals and critical minerals is increasing rapidly in response to growing populations, technological advancement and the global shift towards a lower carbon economy." Alberta wants "to capitalize on our potential to become a preferred producer and supplier of metallic and industrial minerals and mineral products." With its natural resources, highly skilled and educated work force, and entrepreneurial culture, Alberta has all the ingredients to develop a new industry in critical minerals and advanced materials.



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This whitepaper identifies major global trends that are driving up demand for critical minerals and advanced materials. Alberta's critical mineral potential is discussed in a global context. We have found intricate relationships between critical minerals and advanced materials. Innovation opportunities in critical minerals and advanced materials development in Alberta will be highlighted. We also discuss how Alberta's innovation ecosystem, and in particular Alberta Innovates and Emission Reduction Alberta, can cultivate and support this new industry for the prosperity of this province.

2. Global Demands for Critical Minerals and Advanced Materials

The global transition toward sustainable energy and infrastructure development is driving an unprecedented demand for critical minerals and advanced materials. The key trends shaping these demands include electrification of transportation, infrastructure development, and energy storage solutions. The policies of the Trump administration may affect the local rate of acceleration but are unlikely to change the overarching global course of the transition, especially at global scale. For example, the key drivers of this transition in some of the world's largest economies, such as China, are less about climate change, but more about energy security and dominance in manufacturing and supply chain.

Our research has revealed significant supply chain challenges and opportunities for innovation in material sciences that are occurring within this broader transition. Three key trends impacting global demands for critical minerals and advanced materials are summarized here.

2.1 Electrification of Transportation

Electrification of transportation represents a fundamental shift in global mobility systems, creating unprecedented demand for critical minerals and advanced materials. Although there were negative headlines on electric vehicle (EV) industry throughout 2024, global EV sales grew 25% and reached17.1 million in 2024 (Rho Motion, 2025). Nowhere is this growth stronger than in China. Its new energy vehicle (NEV) sales reached 12.9 million in 2024, a 35% increase over 2023 (Electrive, 2025). EV sales in the US and Canada grew by 9% in 2024, with a total of 1.8 million units sold (Rho Motion, 2025). Statistics Canada reported EV sales in Canada were up 39% for the first nine months of 2024 compared to the same period last year.

Based on the growth trajectory of last ten years and commitments from world's top twenty automobile OEMs, IEA suggested 42%-58% of car sales in 2030 could be electric (IEA, 2024). Similarly, BloombergNEF's latest Electric Vehicle Outlook projects global EV sales to reach 50 million units (58% market share) by 2030 (BloombergNEF, 2024). As the largest automobile exporter in the world since 2023, China may achieve 100% EV sales by 2030. It is important to note that the momentum continues in China's NEV production and sales, which increased 29% and 29.4% respectively in January 2025 compared January 2024 (China Association of Automobile Manufacturers or CAAM, 2025).

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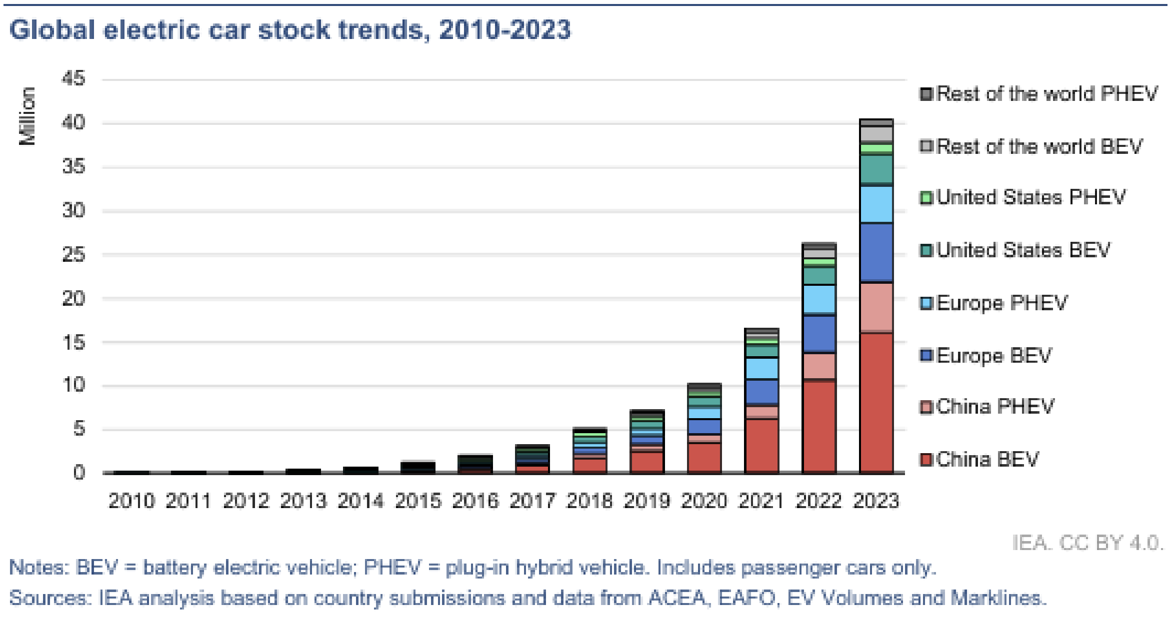

Figure 1. Global electric car stock trends, 2010-2023 (IEA, 2024).

Strong growth in global EV production has created and will continue to create demands for battery materials. Significant innovations have taken place in battery chemistry in the last fifteen years. Initially, the dominant battery technology leveraged a nickel-manganese-cobalt (NMC) chemistry. The high cost of cobalt has driven NMC batteries to increase nickel content (as high as 90%) and cobalt has been reduced significantly in the NMC battery today. Given the scrutiny on EV battery supply chains, high volatility in mineral commodity prices, and the unprecedented pace of technology advancement across battery technologies, shifts in material compositions are likely to continue, making the demand for specific minerals hard to predict even as demands for all critical minerals can be expected to grow significantly. As an example, lithium iron phosphate (LFP) batteries have now become a major battery chemistry, with about 40% of electric car battery sales by capacity in 2023. LFP contains no nickel or cobalt and has become an important asset that has helped reduced exposure to high commodity prices. Of note, graphite is used as anode in both NMC and LFP batteries.

Battery technology continues to advance. Much of current development effort in LIBs is on solid-state battery (SSB), which has higher energy density. The cathode chemistry in SSB will be largely based on NMC but anode and separator materials will be different. SSB requires even more lithium compared with NMC and LFP but does not use graphite as an anode. Lithium-silicon batteries are under active development, to provide higher storage capacity, but these cells need new designs and fabrication techniques to manage the large volume increase of silicon anode as it reacts with lithium.

Table 1: Materials in Lithium Ion Battery (LIB) and Sodium Ion Battery (SIB)

Battery Chemistry	LIB: NMC	LIB: LFP	LIB: Solid State	SIB
Cathode	Ni, Mn, Co Li-Oxides	Li, Fe, Phosphate	Ni, Mn, Co Li-Oxides	Fe, Ni, Mn, Co, Na-Oxides
Anode	Graphite	Graphite	Silicon, Li-metal	Hard Carbon, Sn-alloy

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Another emerging technology is sodium ion batteries (SIBs), which entered commercial production in China in 2023. SIBs are a low-energy density substitute for LIBs. They are poised to take a fraction of EV battery markets but expected to have greater application in grid-scale energy storage.

In summary, several critical minerals and advanced materials are essential for EV batteries. They include Li, Ni, Cu, Co, and graphite for LIBs, as well as Ni and hard carbon for SIBs. The demands for these critical minerals and advanced materials are expected to increase significantly in the next decades.

Copper and rare-earth elements are also essential for electric motors and generators. Four of seventeen rare earth elements (REEs) are commonly used to manufacture permanent magnets. Neodymium (Nd) and praseodymium (Pr) are the primary REE elements in iron-based magnet alloys, while dysprosium (Dy) and terbium (Tb) are commonly used as additives to enhance the performance of Fe-Nd-Pr-based magnets. These elements are used in automotive traction motors for EVs and wind turbine generators for greater energy efficiency. The addition of small quantities (1-2 kg) of these rare earth elements can dramatically reduce (60-80 kg of lithium, nickel, cobalt) the requirements for other critical minerals needed for an EV.

In addition to battery materials and REEs for permanent magnets, demands for components that combine carbon fibers with a polymer matrix, i.e. carbon fiber composites, will also grow as EV production and sales increase. EVs are about 20% heavier than internal combustion engine vehicles. Replacing metal parts in EVs with carbon fiber composites can lighten EVs and extend their range. A good candidate for carbon fiber composite is the battery casings in EVs, but many other parts can be replaced by carbon fiber composites. The slow penetration of carbon fiber composites is largely due to the current high cost of carbon fibers, but this may change over time.

2.2. Infrastructure Development

Global electricity consumption is expected to increase at a fast pace between 2025-2027, fuelled by growing industrial production, the rising use of air conditioning, accelerating electrification, expansion of data centres, and the use of artificial intelligence worldwide. Over the next three years, global electricity consumption is forecast to rise by an unprecedented 3500 TWh (IEA, 2025).

This rising electricity consumption will require new electricity grid infrastructure. According to IEA's "World Energy Outlook 2023", global electricity grids need to expand by 80 million kilometers by 2030. The International Renewable Energy Agency (IRENA) puts this figure at 60-70 million kilometers in its "Global Renewables Outlook 2023". Building these grids will require millions of tonnes of copper (see next section). As an alternative, carbon fibre composite core high voltage cables represent a significant advancement in the field of electrical transmission. Their lightweight, high strength, and superior electrical properties make them a great choice for many power grids. As the demand for efficient and reliable electricity transmission continues to grow, carbon fibre composite core cables will likely play a crucial role in meeting these needs and shaping the future of the power industry (SageZander, 2023).

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The second infrastructure opportunity is related to roads, bridges, and ports. The global demand for asphalt binder has exceeded 150 million tonnes per year and will continue to grow. Although global supply and demand are in balance for asphalt binder, scenarios exist that a supply gap may develop in the future. With a low wax content and high asphaltene content, Alberta's bitumen is the best feed material for making asphalt binder.

Carbon fiber composites can replace many structural components in infrastructure, such as bridge decks and beams. Carbon fibers can also be used in reinforced concretes, displacing steel fiber and reducing cement use. Development is underway to use carbon fiber-aluminum composite cable to replace steel-aluminum cable. The commercial use of carbon fiber composites is limited by their high cost. If low-cost carbon fibers can be made from bitumen, their applications can be increased significantly.

2.3. Energy Storage

Global electricity consumption increases and exponential growth in renewable energy will require significant capacity growth in grid-scale energy storage. Battery energy storage is a key solution to support reliability and grid services and is increasingly being considered by existing industrial customers (e.g., gas processing facilities) and new digital industry (data centres) to provide blackout protection, redundancy, and insulation from grid price fluctuations. The global battery industry has been gaining momentum over the last few years, and investments in battery storage and power grids surpassed 450 billion U.S. dollars in 2024 (Statista, 2025). According to BloombergNEF's latest "Energy Storage Market Outlook 2024", total installed capacity will reach 1,200 GWh by 2030. Pumped hydro, compressed air, and batteries can all be used for energy storage. Battery energy storage will contribute 680 GWh or more than half of the total. Required investment is projected to be $620 billion total ($380 billion for battery energy storage alone). The distribution of battery technologies for the grid-scale energy storage in 2030 is projected to be:

- Lithium-ion batteries: 70%
- Flow batteries (all types): 15% including 8% for vanadium flow battery, 5% for zinc flow battery, and 2% for other flow batteries
- Sodium-ion batteries: 10%
- Other battery types: 5%

Based on this significant growth trend, demand for battery-grade critical minerals as well as advanced materials and balance-of-system components (such as thermal management systems) is expected to increase dramatically. Demand is poised to approach the limits of supply consistently over the coming decades, with commodities such as lithium already demonstrating wide price swings as demand briefly overtakes supply only for excess capacity to rapidly be added in response to high prices. Forecasting long term demand for specific minerals and materials is challenging because battery technologies are changing rapidly. If SIBs and flow batteries take much greater market shares, demand for vanadium and zinc (FBs) and/or nickel and hard carbon (SIBs) will grow faster than expected while reducing demand growth for lithium and cobalt.

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2.4. Other Global Trends

In addition to three key trends summarized above, a few other trends should be noted, including the emergence and wide application of artificial intelligence, data center build-up, continued growth in renewable energy, hydrogen development, and wide deployment of drones. These trends will also impact global demands for critical minerals and advanced materials. For example, carbon fiber is used for making hydrogen storage tanks and drones.

2.5. Demands for Critical Minerals and Advanced Materials

The three physical transformations discussed above, namely electrification in transportation, infrastructure development, and energy storage, are all interconnected. Together, they will drive the growth for many critical minerals and advanced materials. Key minerals and materials required for the transformation are summarized in Table 2.

The table uses 2023 production data and demand projections for 2030. The 2023 production data is the most recently available, and the 2030 projections indicate near-term demand trends with some degree of certainty. The 2030 demand projections also highlight the immediacy of these opportunities.

Table 2. Current (2023) Production and Projected 2030 Demands for Selected Critical Minerals and Advanced Materials

	2023 Production (t)	**2030 Demand Projection (t)**	**World Reserve + Indicated Resource (t)**
Lithium	165,000	503,000	105,000,000
Helium	170 million m3	240 million m3	39.8 billion m3
Nickel	3,104,000	4,754,000	130,000,000
Cobalt	215,000	344,000	11,000,000
Copper	25,800,000	31,128,000	1,000,000,000
Vanadium (in V2O5)	120,000	175,000	63,000,000
Titanium Mineral Concentrate **Zirconium Mineral Concentrate**	9,200,000 1,600,000	N/A N/A	750,000,000 74,000,000
Rare Erath Elements (REEs)	82,000	151,000	478,000,000 (REOs)
Uranium	65,650	83,840	6,000,000
Phosphate (in P2O5)	250,000,000	300,000,000	300,000,000,000 in phosphate rock
Graphite	4,630,000	10,400,000	280,000,000
Hard Carbon		722,000	
Cabon Fiber	150,000	575,000	
Asphalt Binder	150,000,000	160,000,000	
Activated Carbon*	3,100,000	5,800,000	

*Market numbers for activated carbon are total market. The size of addressable market is unknown at this point.

Effort is made to include all critical minerals and other minerals relevant to Alberta. Although helium, titanium, zirconium, and phosphate are either not critical minerals or not related to energy transition, there has been interest for their economic development in Alberta. Advanced materials related to critical minerals are also included. The sources of the numbers listed in the table will be discussed in the next section. The demand for most critical minerals and advanced materials will increase very significantly in the next five years. We will examine if and how Alberta may be able to take on these opportunities.

When assessing future demand for critical minerals and advanced materials, recyclability and circularity are key concepts to consider. Unlike the current energy supply chain, where fuels are extracted, processed, and irreversibly consumed, a future energy system founded on critical minerals may exhibit significantly more circularity and therefore lower net demand for inputs. Analysts have pointed to nascent but credible work in mineral recovery and recycling, particularly for lithium. The potential for circularity to reduce mineral demand is underlined by the simple calculation that if batteries last 15 years and 90% of materials are recyclable, a relatively small annual improvement in material efficiency would enable the same unit of lithium to provide the same energy service for over a century. Certain carbon products and construction materials also exhibit near-complete potential for recyclability. Thus, when considering the potential for Alberta and Canada to become a supplier of choice for critical minerals and advanced materials, it is imperative to also include the potential for recycling and re-processing of such materials.

3. Opportunities for Alberta

Electrification in transportation, infrastructure development, and energy storage are key drivers for demand increase for critical minerals and advanced materials in the next decade and beyond. Geological formations in Alberta contain critical mineral resources that will be valuable for this transition (AGS, 2021; GoA, 2025), but the extent of the occurrence is not well defined, and the critical technology for economic production is not yet established. Consequently, critical mineral resources have not been produced at commercial scale in Alberta. Lithium production from oil field brine is at pilot stage.

The unique composition of bituminous sand and by-products of its processing has also been a focus for economic opportunities related to critical minerals. Significant effort has been made by CVW CleanTech (and its predecessor Titanium Corporation) to recover titanium and zircon from bitumen froth treatment tailings. In close collaboration with industry operators, the process completed pilot-phase testing and front-end engineering design (Class 3) but has not proceeded to full commercial deployment. In addition to the economic opportunity, the environmental benefits associated with removing reactive minerals and residual solvent is an appreciable opportunity to improve environmental sustainability of oil sands mining and reduce major financial liabilities for the province. Vanadium and nickel recovery from petroleum coke has yet to show commercial potential, and the quantity of gasification ash is limited. The concentrations of REEs in oilsands tailings are generally below the threshold of available extraction technologies and are not competitive with established mineral resources. CVW CleanTech is trying to isolate a mineral concentrate stream of REE-rich monazitefrom bitumen froth treatment tailings, commercial viability is yet to be demonstrated. Further details about the status of these opportunities are provided in the following sections.

On the other hand, Alberta's vast bitumen resource could be made into advanced materials such carbon fiber composites and energy carbons for battery and supercapacitor applications (AI-BBC-WHITE-PAPER-Nov-2023.pdf).

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In this section, we will examine critical mineral development opportunity in Alberta within a global context. Like our hydrocarbon resources, Alberta's critical minerals must compete with the resources from other jurisdictions. Only with competitive advantages (either in quality of resources or more advanced recovery technologies) along with capital access and clear regulatory process, a critical mineral resource can be commercially developed. Similarly, new advanced materials industry can be created in Alberta only if we have competitive advantages such as stable feedstock supply, low production cost, and high product quality. The opportunities of key critical mineral resources and advanced materials in Alberta will be reviewed and analyzed below.

3.1 Lithium

The largest global use of lithium, accounting for 87% of total demand, is the manufacturing of rechargeable batteries for electronics, electric vehicles, and grid storage (NRCan, 2025). The average EV requires 6-8 kg of lithium for current lithium-ion battery technologies. Lithium production in 2023 was 180 kilotonne (Kt) (USGS, 2024). About 503 Kt of lithium will be required by 2030 (IEA, 2024b). Lithium production, demand, and price are often reported or cited as lithium carbonate equivalent (LCE). Lithium demand by 2030 is estimated to be 2.68 Mt in LCE based on current lithium dependant technologies and applications.

World lithium reserves were 28 Mt and measured and indicated lithium resources in the world were 105 Mt and as of 2023 (USGS, 2024). Sources of lithium include hard rock ores (about 25% known reserve), and brines (about 75% of known reserve), and sedimentary-volcanic (USGS, 2023).

Hard rock lithium resources are largely found in spodumene ores in Australia, Africa, and China with smaller deposits in the US, Canada, and Brazil.

Continental brine lithium is mostly concentrated in South America (Boliva, Argentina and Chile) is reported to make up approximately 66% of global lithium reserves (Bogossian, 2021), with some reserve in China, North America, Europe, Indonesia, and the Himalayas (Munk et al., 2025). Lithium in continental brines is extracted from salt lakes of Latin America (Chile and Argentina), but also from high plateaux in western China.

Oilfield brines (formation waters) containing lithium found in the US, Canada, Saudi Arabia and United Arab Emirates (UAE) are considered emerging resources containing approximately 3% of known resources (Bogossian, 2021).

The amount of brine reserve required relative to ore reserve to produce one tonne of lithium varies greatly between these two sources, with 750 tonnes of brine relative to 250 tonnes of lithium ore required to yield a single tonne of battery grade lithium (USDOE, 2021).

Lithium production has more than doubled in the past three years (2021-2023). Annual production of lithium raw materials (from hard rock, brines and clays) amounted to around 180 kt lithium in 2023 (USGS, 2024). Most of today's lithium production are from spodumene-bearing hard rock, with Australia being the dominant producer. Another type of hard rock ore, lepidolite, was developed in China in 2023. As of 2022, Australia, China, Chile and Argentina are responsible for 97% of the world's lithium production (USGS).

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There are significant geopolitical risks in both raw materials supply and refining capacity. China currently dominates refining of hard rock ore from domestic resources and African countries and Australia. IEA (2023) suggested that there might be a risk of a 25-30% supply deficit by 2030. As of 2023, Canada had 900 Kt lithium (4.8 Mt LCE) reserve (USGS, 2024). NRCan (2025) put this number at 930 Kt lithium (5 Mt LCE). Measured and indicated lithium resources in Canada are 3 Mt lithium (16 Mt LCE) or approximately 3% of the world's known lithium resources (USGS, 2024). Canada has a limited lithium production in Manitoba and Quebec. NRCan (2024) reported 520 t lithium production in Canada in 2023.

As of 2022, Alberta did not have any probable or proven lithium reserves. Concentration of lithium in Alberta's brine reserves vary from 0 ppm upwards of 140 ppm based on various Alberta Geological Survey (AGS) data collected (Eccles, D.R. & Jean G.M. 2013 and AGS, 2021). The most encouraging sampling data was collected by the AGS indicated lithium concentration between 50 and 140 ppm (AGS, 2021), Since that time, additional sampling by independent companies report lithium concentrations measured from Alberta Oilfield brines to be between 25 to 80 ppm, with an average of about 40 ppm (Enverus, 2023 and Recion, 2023).

Table 3. Summary of water samples with lithium concentrations above 50 mg/L in Alberta (AGS, 2021a). Abbreviations: P25, 25^{th} percentile; P50, 50^{th} percentile; P75, 75^{th} percentile.

Geological Interval (as specified in source data)	**Sample Count**	**Mean (mg/L)**	**Minimum (mg/L)**	**P25 (mg/L)**	**P50 (mg/L)**	**P75 (mg/L)**	**Maximum (mg/L)**
Cretaceous System[1]	1	130.0					
Mannville Group	1	53.0					
Jurassic System	5	61.8	53.0	60.0	62.0	66.0	68.0
Triassic System	5	57.8	55.0	57.0	58.0	59.0	60.0
Mississippian System	9	54.9	51.0	52.0	54.0	58.0	60.0
Wabamun Group	13	81.0	51.0	72.0	82.0	89.0	115.0
Winterburn Group	40	77.2	51.0	66.7	74.3	84.8	140.0
Woodbend Group[2]	64	74.7	50.0	64.8	67.9	74.0	140.0
Leduc Formation	74	72.0	50.0	65.3	72.4	76.2	103.5
Beaverhill Lake Group[2]	27	80.0	60.0	75.0	77.2	80.9	130.0
Swan Hills / Slave Point Formation	16	84.6	58.3	78.9	86.6	87.4	112.0
Elk Point Group[2]	7	62.0	51.0	51.5	53.7	74.5	77.0
Gilwood Member	1	98.0					
Keg River Formation	3	69.0	54.0	56.0	58.0	76.5	95.0
Granite Wash	2	83.0	71.0	77.0	83.0	89.0	95.0
Cambrian System	1	81.0					

[1] may or may not be from the Mannville Group
[2] may or may not include additional samples of the formation/member below

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A summary of water samples with lithium concentrations above 50 mg/L in Alberta are shown in Table 3. The greatest prospectivity areas for lithium based on current data are in Devonian strata in the Peace River Arch area (northwestern Alberta) and in central Alberta near Red Deer.

Several startups including E3 Lithium, Lithium Bank, and Neolithica are piloting direct lithium extraction (DLE) from formation waters in Alberta. E3 is targeting over 32 Kt lithium hydroxide (LHM) production in 2027 with 16.2 Mt lithium-carbonate equivalents (LCE) measured and indicated, and 0.9 Mt of LCE inferred mineral resource (E3, 2025). E3 has lithium resource rights in Saskatchewan of approximately 1.13 Mt LCE of proven and probable mineral reserve. Lithium Bank indicates their Boardwalk project has 5.2 Mt LCE (976 Kt lithium) measured and 2.8 Mt LCE inferred resource and will target a 34 Kt LCE/year operation (Lithium Bank, 2025). Their Park Place project has an inferred 27.7 Mt of LCE (Lithium Bank, 2025). Neolithica's Peace River project has an inferred mineral resource of 10 Mt LCE, Peace River project which is currently operating a pilot DLE (Global Energy Metals, 2025) and holds mineral interests in the Red Water area (Neolithica, n.d.). Other companies with lithium interests reported to have at least 1.9Mt LCE of inferred resources in central and Northeast Alberta (Empire Metals Corp. 2017).

The commercial viability of DLE from formation waters brines in Alberta has not been proven. Compared with lithium resource in continental brines in South America, lithium concentration in Alberta's formation waters is much lower, and the brine chemistry is more complex including materials such as hydrogen sulphide, trace organics, and high levels of suspended solids. This means many of the DLE technologies available will require pre-processing of formation brines prior to extraction, and a larger volume of formation brines need to be processed to produce a tonne of battery grade lithium. For example, to recover one tonne LCE from formation brine with 75ppm lithium, 2,505 m3 of formation water will have to be processed assuming 100% lithium in brine can be recovered. Therefore, extraction process will have to be very efficient.

However, DLE from formation waters may have competitive advantages in land use, short processing time, and the ability to have a continuous process in comparison to the brine evaporation process. Lithium production from hard rock involves mining, beneficiation (to obtain a lithium concentrate), and Li-extraction. In Li-extraction process, the spodumene ore concentrate is calcined to transform it into a more reactive state. The calcined ore can then be subjected to roasting, leaching and purification processes to produce battery grade lithium compounds based on convention methods. Lithium production from continental brines involves pumping the Li-bearing brine out from salt lakes, leaving the brine to evaporate for between 12-18 months in large pools, removing the water, and leaving behind lithium along with other elements. Table 4 compares DLE with hard rock mining and evaporation process.

As indicated above, lithium demand will be 2.68 Mt in LCE by 2030. Lithium price has been fluctuating greatly since COVID-19. If the price for LCE is assumed US$20,000 by 2030, lithium market will be US$54 billion. Based on AER (2025) projection of 14,800 t lithium annual production in Alberta by 2034 and depending on price assumption, the total value from lithium production can reach one billion dollar per year. Taking resource quality, the cost and effectiveness of extraction methods, and tax/royalty burden into consideration, CERI (2022) concluded that select formation waters in Alberta have the potential for commercial development.

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Table 4. Comparison of Alberta's Lithium Resource with Known Global Li-Resources

	Australia Spodumene Ore	**Argentina Salt Lake Brine**	**Alberta Formation Waters**
Li concentration	Li in spodumene: 3.73%	200-1,800 ppm	50-150 ppm
Measured and Indicated Resources[1]	8.7Mt	22 Mt	>6.8 MT
Land use (ha per Mt LCE)[2]	High, open pit 4,700	High, evaporation pond 26,000	Minimal Est <5[4]
Water use (Mm3 per Mt LCE)[2, 3]	High, used in leaching with some recovered/recycled 1,500-3,000 [3]	High, through evaporation with most water lost 500-2000[3]	High through-put and with most re-injected 10-70[4]
GHG Production Intensity (CO2e per Mt LCE)	~14[5]-15 Mt[3]	~2.45[5]-15 Mt[5]	1.9Mt[1]
Production process	Continuous	Seasonal	Continuous
Production time[2]	3-6 months	2-3 years	2 Hours
TRL	10	10	~7

[1] Measured and indicated resources for Australia and Argentina are from USGS (2024), for Alberta formation waters, the numbers are aggregated from E3 Lithium, Lithium Bank, NeoLithica, and others.
[2]Lithium Harvest, 2025 (International Energy Agency, International Council on Mining and Metals, Center on Global Energy Policy)
[3]Benchmark Global Lithum, 2023
[4]Stower. 2024
[5]SKARN Associates, 2024

The economics associated with existing piloted technology for DLE in Alberta is not yet commercially competitive relative to the current price of lithium. Additional measures to improve efficiency, concentrate lithium materials, and reduce overall processing costs associated with DLE technology are being explored to improve the current economics. Other opportunities to develop other extraction technologies or combining non-DLE technologies is being explored to help improve the economics associated with extracting and processing.

3.2 Helium

Liquid helium is used in cryogenics and in the cooling of superconducting magnets, with its main commercial applications in MRI scanners and semiconductor manufacturing. Helium's other industrial uses—as a pressurizing and purge gas, as a protective atmosphere for arc welding, and in processes such as growing crystals to make silicon wafers—account for half of the gas produced.

Helium is considered a critical mineral because it is rare on Earth but the demand for it is increasing. Commercially, helium is extracted from natural gas. Global helium production was 170 million cubic meters in 2023. The US and Qatar are the largest helium producers and dominate global helium supply. Global demand is projected to reach 240 million cubic meters in 2030 (Industry ARC, 2024). The United States has world's largest helium reserve, estimated 8.5 billion cubic meters (306 billion cubic feet). The U.S. also has 51.5 million cubic meters (1.86 billion cubic feet) in Federal helium reserve. Helium resources of the

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world, exclusive of the United States, were estimated to be about 31.3 billion cubic meters (1.13 trillion cubic feet).

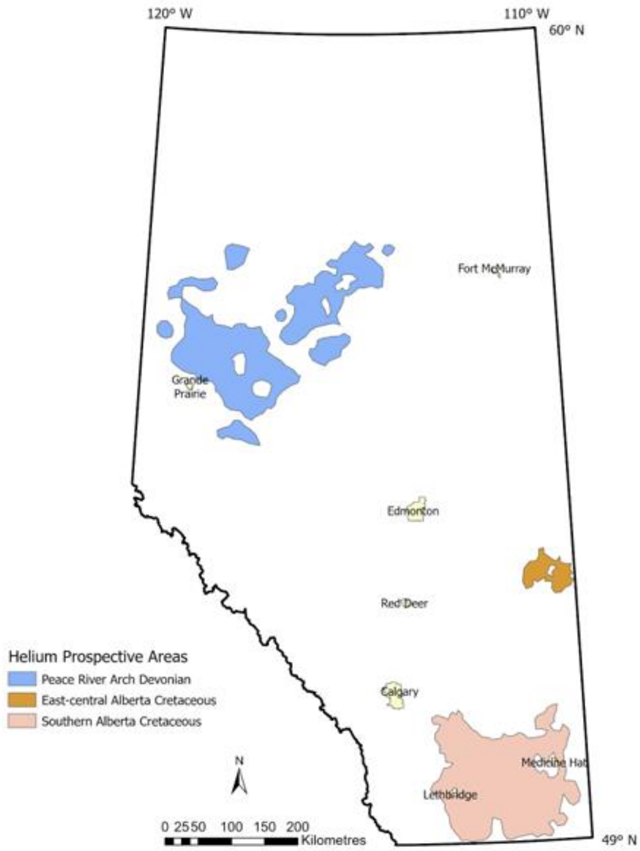

Figure 2. Helium prospective areas in Alberta (AGS, 2021).

There are two intervals of unusually high helium partial pressures in Alberta. The first interval is in Devonian reservoirs within 500 m above the Precambrian crystalline basement in central and northern Alberta. The second interval of high helium partial pressures was found to be within Lower Cretaceous Mannville Group reservoirs approximately 1000 m above the basement, predominantly in southern Alberta (AGS, 2021). AGS reported the locations of 1,580 gas samples with a helium concentration >0.3% taken from Devonian strata, with average concentrations of helium in Alberta wells varying between 0.5% to 14% (CER, 2022, AGS 2021). Most of the samples are from the Peace River Arch area and to the northeast of that area. In Cretaceous strata, 1848 gas samples with a helium concentration > 0.3% are mostly from southern Alberta, in the Lethbridge to Medicine Hat area.

Although prospective areas are outlined, no estimate is available for helium reserve in Alberta. Four companies have developed helium resource in Alberta to date with a total of 6 wells in production which generate over 2,200 m3/day of helium. Current projections for helium development in Alberta aim to have 17 production wells established by 2034 for a forecasted 10,400 m3/day of helium production (AER, 2025).

On Saskatchewan side, North American Helium commenced first helium production in July 2020. The Company has 9 production facilities on-stream with a total production capacity of approximately 210 MMcf/year of purified helium and expects to grow that capacity further in 2025.

Global shortage in helium supply is an opportunity. However, the commercial opportunity for helium production in Alberta may be modest. Based on AER's projection of 10,400 m3/day by 2034, the total revenue will be about USD$50M annually. A more detailed understanding of the quality and size of resources will help helium industry development in Alberta.

3.3 Nickel

Nickel is a versatile metal valued for its strength, corrosion resistance, and ability to withstand extreme temperatures. Primarily used in stainless steel production, it supports a wide range of industries and everyday products. More recently, nickel's role has expanded into advanced technologies, particularly in batteries for electric vehicles (EVs), as the market for EVs and renewable energy accelerates. Its growing importance in sustainable technologies has made nickel a cornerstone of the green transition, positioning it at the forefront of innovation and the shift toward a low-carbon economy.

Average NMC/NCA battery requires 30-40 kg of nickel. Current (2023) demand for nickel is 3.1 Mt including 478 Kt in battery (IEA, 2024b). Nickel use in clean energy technologies (including battery) will drive overall growth in nickel demand. About 4.75 Mt nickel will be required by 2030 including 1.95 Mt nickel (annually) for clean energy technologies (IEA, 2024b). The demand for nickel in other applications will increase slightly

In 2023, global nickel reserves were estimated at over 130 Mt. The largest reserves are in Indonesia (42%), Australia (18%), and Brazil (12%). Canada holds an estimated 2.2 Mt, representing 2% of global reserves, and ranks eighth globally. Global nickel mine production in 2023 was estimated at 3.6 Mt, an 8% increase from 2022. Indonesia was the largest producer, accounting for 1.8 Mt or 51% of global output. Canada ranked sixth, contributing 5% of the global total (NRCan, 2025a).

Alberta's bitumen resource contains 70 - 80 ppm of nickel, giving total production of circa 20 kt/y in a total bitumen production of 231 Mt/y. Only 5% of this nickel is currently recovered using commercially available technology, from spent catalysts from bitumen upgraders. Nickel recovery from ash residues after combustion is feasible, but combustion of Ni-bearing fuels in Alberta has been almost completely phased out. Small volumes of solid residue with lower carbon content are produced from gasification, but the potential Ni production is very small.
Alberta also has nickel resources in its sedimentary rocks. Black shales in SBH Property in NE Alberta contains about half million tonnes of nickel (Critical Minerals America, 2023). But nickel concentration in the black shales is low and it is not economic to produce nickel from the sedimentary rock in SBH Property.

In Canadian and global context, Alberta's nickel resources are small in quantity. The nickel concentration in black shales is too low to be produced economically. The case for producing nickel from bitumen byproducts like petroleum coke is even weaker. It should be mentioned that Alberta has a nickel refinery in Fort Saskatchewan, using imported laterite

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ore from Cuba, and Fortune Minerals plans to refine nickel in their future Alberta-based refinery using multi-metal ores from their NICO mine in the NWT.

3.4 Cobalt

Cobalt is a hard, lustrous, silver-grey metal that is used mainly as a cathode material in lithium ion and other types of batteries. It is also used in powerful magnets, cutting tools and high-strength alloys in the aerospace, energy and defense sectors. Average NMC battery is 10-10% cobalt (Cobalt Institute, 2023), with a standard EV battery containing about 8 kgs of cobalt (IGreenpow, 2024). Current (2023) demand for cobalt is 215 Kt including 64 Kt in batteries (IEA, 2024b). About 344 Kt of cobalt will be required by 2030 including 177 Kt for cleantech applications (including battery) by 2030 (IEA, 2024b). Most of the demand increase for cobalt is from battery applications.

World reserves of cobalt were estimated to be approximately 11 million tonnes (USGS, 2024). The Democratic Republic of Congo has the largest known reserves of cobalt, making up more than 50% of the world total. Canada ranks seventh in the world with 230 Kt. Global production of cobalt was 230 Kt in 2023 (USGS, 2024). The Democratic Republic of Congo is the largest global producer of cobalt, accounting for 73% of world production. Canada produced 3 Kt of cobalt in 2022 (NRCan, 2023) and ranked seventh in the world for cobalt production, contributing 2% of the global total. All Canadian cobalt production is from primary nickel mines. Canada also produced 5.5 Kt of refined cobalt at four refineries across the country including Sherritt International in Fort Saskatchewan.

There are no cobalt reserves in Alberta. Black shales in SBH Property in NE Alberta are estimated to contain 120 Kt of cobalt (Critical Minerals America, 2023). However, these concentrations are too low for the resource to be produced economically. Fortune Minerals is developing a multi-metal (including Co) mine in NWT and refined in the proposed Fortune Minerals Lamont County refinery (Resource World, 2024).

3.5 Copper

Copper is used in clean energy, EV, energy storage, and electricity grids. It also has many other uses. Current (2023) demand for copper is 6.3 Mt for clean energy applications and 19.5 Mt for other uses (IEA, 2024b). About 12 Mt of copper (annually) will be required for clean energy applications by 2030 and but the demand for copper for other applications will have little change during this period (IEA, 2024b). Electrical grid wires (80 million kilometers required) and EVs (20 kg per EV) account for much of the demand increase for copper. Supply risk and geopolitical risks related to copper are low.

Worldwide copper reserves were estimated at 1,000 Mt (USGS, 2024). Chile held the largest share of global copper reserves, totaling 190 Mt or 19% of the total reserves. Canada holds about 7.6 Mt, making up less than 1% of the global total (NRCan, 2025a). Refined copper production worldwide reached 26.6 Mt in 2023. Chile led global copper production with 5 Mt of copper, representing 22.7% of the world's total. Canada ranked 12th, contributing 2.2% of global mined copper.

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There is currently no recoverable copper reserve in Alberta. Black shales associated with the SBH Property in NE Alberta are reported to contain about 150 Kt of copper (Critical Minerals America, 2023). This is a small quantity in Canadian and global context. The concentration is also too low for the resource to be produced economically.

3.6 Vanadium

Traditional use for vanadium is in steel, aerospace, and catalyst. Its new use is in vanadium flow batteries. Current global vanadium demand is about 67 Kt vanadium metal basis annually (The Vanadium International Technical Committee or Vanitec, 2025). Traditional steel sector accounts for 90% of demand, energy storage accounts for 2-3% and other applications 7-8%. Vanadium for flow battery will increase from 5 Kt in 2025 to 30 Kt in 2030. Total demand for vanadium is expected to increase to 96 Kt vanadium metal basis by 2030 (Wood Mackenzie, 2024).

World resources of vanadium exceed 35 million tons (V metal) with the majority located in Australia, Russia, China, and South Africa. Vanadium occurs in deposits of phosphate rock, titaniferous magnetite, and uraniferous sandstone and siltstone. Significant quantities are also present in bauxite and carboniferous materials, such as coal, crude oil, oil shale, and oil sands (USGS, 2024). Because vanadium is typically recovered as a byproduct or coproduct, demonstrated world resources of the element are not fully indicative of available supplies. Global vanadium production was 71 Kt (V metal) in 2023 (Vanitec, 2025). USGS (2024)'s estimate China continued to be the world's top vanadium producer, producing the majority of its vanadium from vanadiferous iron ore processed for steel production.

Alberta's ironstones and black shales contain a potential vanadium resource. The Clear Hills iron-vanadium deposit, situated on the eastern slopes of the Clear Hills northwest of the town of Peace River is Alberta's largest (AGS, 2023). The indicated resource totalled 558 Mt at 33.3% Fe and 0.1% V, which translates to 182 Mt of Fe and 0.6 Mt of V (AGS, 2023). Black shales in SBH Property in NE Alberta contains over half million tonnes of V2O5 (Critical Minerals America, 2023). But the concentration is lower. Commercial primary vanadium mines contain 0.1-0.7% V in magnetite deposits and 0.15-0.8% V in titaniferous magnetite. Therefore, Clear Hills ironstone is marginal compared with commercial grade vanadium.

Oil sands is another potential source of vanadium. Bitumen contains 210-240 ppm of V, giving 50 kt vanadium in the 3.98 million barrels produced in 2024. No technology is available to recover this type of vanadium from bitumen, therefore, only by products from upgrading process that concentrate the vanadium currently represent an opportunity. Vanadium is concentrated in petcoke when bitumen is upgraded or refined with a concentration of 945 to 1,600 ppm. Annual production of vanadium in petcoke is circa 20 kt, and existing petcoke stockpiles contain over 135 Kt of V (AGS, 2023), twice 2023 global production. The vanadium in this petcoke is distributed in a carbon-rich matrix as isolated atoms, therefore, recovery is only possible after complete combustion of the entire carbon matrix to give a vanadium-rich fly ash. The fly ash from Suncor's coke contains 0.4-2.6 % vanadium on a metal basis (total sample basis, including combustible material (Holloway et al., 2004); and a stockpile of accumulated fly ash is available from years of operation. Combustion of petcoke will be completely phased out within the next year at

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Suncor, therefore, such fly ash will no longer be produced. In 2023, Suncor proposed a $36 million project to recover vanadium from the accessible stockpile of fly ash material, but the project did not go ahead. A plant operated north of Fort McMurray in the early 1990s to recover this type of vanadium, but it closed after only one year of operation.

Much higher concentrations of vanadium accumulate in catalysts during catalytic processing of heavy bitumen fractions, giving an ore with over 10 wt% vanadium, present as vanadium sulfide. The spent catalysts from upgraders in Alberta are processed to recover vanadium, nickel and molybdenum. Vanadium from this source is over 2,400 tonnes/y of V. Most of this processing of spent catalyst is carried out in the United States, mainly producing ferro-vanadium for high-quality steels.

Gasification of refinery residues in Alberta produces a vanadium-rich ash, containing circa 140 t/y of vanadium metal, but the residual carbon content and water content of over 80% make this waste very difficult to process, and too expensive to ship to US and European metals processors that handle such waste streams. Still, Taiyo Oil of Japan has been pursuing this opportunity for a few years. Local entrepreneurs are investigating this opportunity. Alberta Innovates is helping these entrepreneurs.

The highest quality vanadium sources in Alberta, the spent upgrader catalysts, are already commercially exploited. Lower grade sources, such as gasification ash, petroleum coke and unrecovered bitumen fractions in tailings from oilsands mining lack available technology for recovery except after complete combustion. Vanadium is recoverable from fly ash, and an available stockpile is available at the Suncor mine site.

3.7 Titanium and Zirconium

Titanium is a silver metal that is strong, resistant to corrosion, and inert. Titanium combines with iron, aluminum, vanadium, nickel, molybdenum and other metals to produce high-performance alloys. Jet engines, spacecraft, military equipment, bearings, body armor, and other high-tech products need parts made with these alloys. Global titanium sponge production was 330 Kt in 2023, and the production capacity was 410 Kt in the same year (USGS, 2024).

Over 90% of titanium in Earth's crust occurs in ilmenite (FeTiO3). Global titanium mineral concentrate production was 9.2 Mt in 2023, and the reserve was 750 Mt in the same year (USGS, 2024). A very small fraction of titanium minerals is used to make titanium metal. The majority of titanium mineral concentrates are used to make titanium oxide which is mainly used as pigment. There is no shortage of titanium mineral concentrates in the world. China is the leading producer and consumer of titanium mineral concentrates, accounting for approximately one-third of global production of ilmenite. Canada exported 500 Kt titaniferous slag to the U.S. in 2023.

Zirconium is a transition metal element primarily known for its high resistance to corrosion. It is commonly used in various high-performance materials and applications, such as nuclear reactors and surgical instruments. zircon is employed in the manufacturing of refractory materials, ceramics, foundry casting, and nuclear technology, making it a key mineral in modern industrial processes. In nature, zirconium is mostly found in zircon

($ZrSiO_4$), a mineral with a remarkable resistance to heat, corrosion, and chemical alteration.

Global mine production of zirconium mineral concentrates increased to about 1.6 Mt in 2023. Global zirconium reserves were 74 Mt (ZrO_2 content) in 2023 (USGS, 2024). The leading global exporters of zirconium mineral concentrates were Australia and South Africa. China was the leading importer of zirconium mineral concentrates. Zircon imports into China included zircon in mixed heavy-mineral concentrates. Global producers of zirconium sponge included China, France, India, Russia, and the United States. The United States was a net exporter of zirconium metal.

Oil sands tailings contain both zircon and ilmenite. CVW Cleantech (previously known as Titanium Corporation) has developed a technology to recover zircon and titanium minerals (ilmenite, rutile, etc.). In its most recent presentation, CVW indicates the mineral recovery operation has the potential to generate $200 million sale annually (CVW Cleantech, 2024a). A pilot to extract zirconium and vanadium from tailings material was proposed with partner Canadian Natural Resources in 2018 with no updates to the project status since that time. CVW's priority is now shifted to recover solvent from froth treatment tails. Mineral recovery becomes a secondary objective, and no additional projects have been announced for the application of the technology by other resource developers in the region.

3.8 Rare Earth Elements (REEs)

Rare earth elements (REEs) are a group of 17 elements, including the 15 elements of the lanthanide series on the periodic table of elements together with the transition metals scandium and yttrium. The latter two elements exhibit similar properties to the lanthanides and are found in the same ore bodies. REEs are key components in many electronic devices that we use in our daily lives, as well as in a variety of industrial applications. Four REEs are commonly used to manufacture modern permanent magnets: neodymium (Nd) and praseodymium (Pr) are the primary elements, while dysprosium (Dy) and terbium (Tb) are commonly used as additives to enhance the performance of Nd-Pr-based magnets. Current (2023) demand for these REEs is 16 Kt for clean energy applications and 76 Kt for other uses (IEA, 2024b). Sixty-four kilotonnes (64 Kt) of REEs will be required for clean energy application and 87 Kt for other uses by 2030 (IEA, 2024b).

Known global REE resource is estimated at 478 Mt in rare earth oxide (REO), mainly located in China (164 Mt), Brazil (55 Mt), Australia (49 Mt), Russia (48 Mt), and Greenland (43 Mt), with the remaining 119 Mt spread in Canada, Sweden, USA, Vietnam, and others (Zhou et al., 2017). China is the world's largest producer of REEs, accounting for 70% of global annual mine production, estimated at 210 Kt for 2022. The United States, Australia, Burma (Myanmar) and Thailand accounted for much of the remaining production (NRCan, 2025b).

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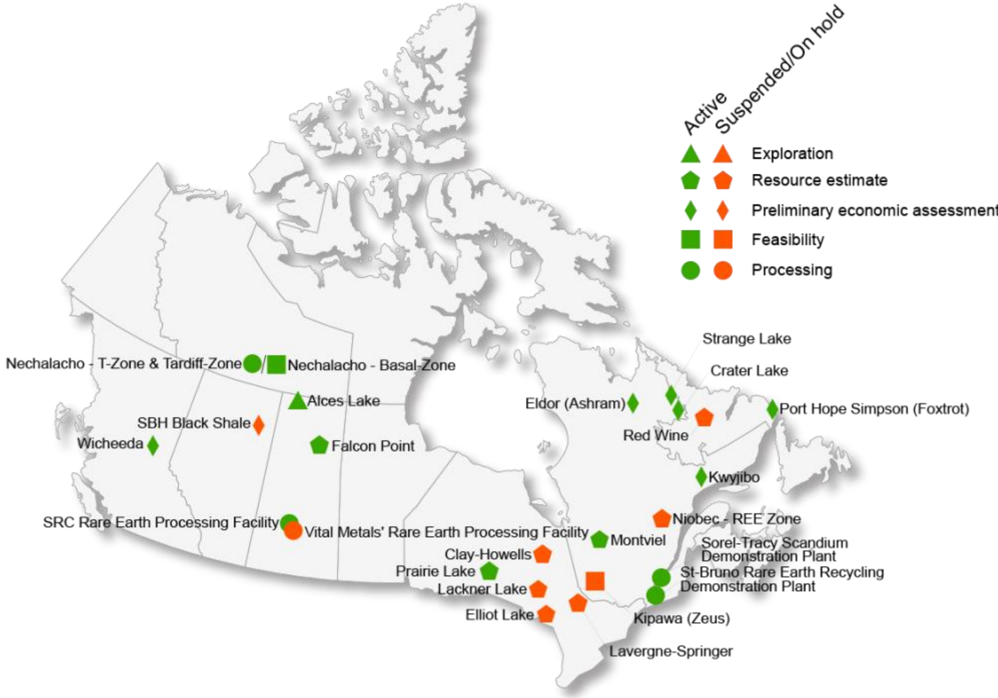

Although not a current commercial producer of REEs, Canada is host to several advanced exploration projects and some of the largest reserves and resources (measured and indicated) of REEs worldwide. Canadian reserves and resources are estimated to be 15.2 Mt of rare earth oxide (NRCan, 2025b).

A dozen projects are active in Canada at various stage of REEs development, but none of them are in Alberta. The SBH Black Shale project in NE Alberta is on hold at the preliminary economic assessment stage (Critical Minerals America, 2023). Three mineralization zone combined in the black shales contains one million tonnes REEOs. The Alberta black shales are typical metals enriched polymetallic black shales known worldwide to carry low concentrations of a long list of metals, of which no single metal occurs in sufficient concentration to support mining operations by itself. If collectively recovered in a single circuit, they may offer enticing low-cost bulk mining opportunities.

REEs in oil sands tailings are not included in the measured or indicated REE resources in the Canadian context (NRCan, 2025b). REE concentrations in oil sands tailings are generally low, with concentrations in the parts per million. For example, it was reported that the highest concentration found in tailings from solvent recovery units was 0.11%wt (if converted to oxide, it will be 0.7-0.,8%wt; Roth et al., 2017). In comparison, commercial REE ores are 1-12%wt in REO. REE concentrations in a few projects in assessment or evaluation in Canada are also at a few percent REO level.

To be economically viable, REEs in oil sands tailings would need to be pursued as an additional opportunity to mineral processing for titanium and zircon (CVW CleanTech, 2024). One such opportunity being explored is the capture of monazite, a rare phosphate mineral that contains a concentrated amount of REEs, in particular cerium. CVW CleanTech is advancing research that would add additional mineral extraction capabilities to their existing process to capture monazite. However, this process has not yet been fully

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proven and would provide a smaller portion of revenue compared to titanium and zircon concentrates.

Overall, REEs in oil sands may not have competitive advantages over REE projects under development in Canda and are not competitive with commercial projects around the world.

3.9 Uranium

Uranium is used primarily to produce fuel for nuclear power plants (more than 99% of the total use). Other uses (less than 1%) include producing fuel for research reactors and medical isotopes. After raw uranium is mined and milled, it is processed to make fuel for nuclear reactors to generate electricity. Global uranium production was 48.9 Kt in 2022, with Kazakhstan being the largest producer at 43%. Canada was the second largest producer and exporter of uranium in the world, with 15% of global production in 2022 (NRCan 2023). Demand for uranium is expected to climb to 83,840 tonnes by 2030 and 130,000 tonnes by 2040, from 65,650 this year (World Nuclear Association, 2023).

In 2022, 80% of Canada's uranium production was exported for use in nuclear power generation throughout the world. All production is from high-grade deposits in Saskatchewan, where the uranium concentrations are up to 100 times larger than the world average. Canada’s 7.4 kt of uranium produced in 2022 was valued at approximately $1.1 billion (NRCan, 2023). However, both production and price have increased significantly since then.

The world’s currently recoverable uranium reserve is about six million tonnes (World Nuclear Association, 2023). Canada has the third largest uranium reserve in the world at 588 Kt or 10% (World Nuclear Association, 2025). Both global and Canadian reserves were estimated assuming US$50/lb U_3O_8. Canadian uranium reserve can sustain current production for more than 50 years (NRCan, 2023). If price increases, the recoverable reserves will increase too.

Uranium is found in three deposit types in Alberta: unconformity related, pegmatite hosted, and sandstone hosted (AGS, 2025). Of these three deposit types, the unconformity-related uranium deposits, particularly in the Athabasca Basin in northeastern Alberta, show the most potential for future development (AGS, 2009, 2024). This potential is exemplified by the world-class uranium mines in the Athabasca Basin in neighbouring northwestern Saskatchewan, increasing the probability of finding similar deposits in Alberta. No quantitative information is available for the uranium resources in Alberta in relation to the same resources in Saskatchewan. Saskatchewan’s uranium deposits are of world class. Uranium development in Alberta will need to be competitive with our neighbouring province.

3.10 Phosphate

Phosphate is mainly used for agriculture fertilizer (85%-90%) and industrial applications (10-15% for food additives, animal feed, and batteries) (USGS, 2024). The demand for phosphate is 270 Mt for 2025 and 300 Mt for 2030. The success of LFP battery chemistries is creating a market for a new input, iron phosphate, and its precursor – purified phosphoric

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acid. Further demand growth for high phosphoric acid comes from next-generation lithium-iron phosphate manganese (LMFP) chemistries, whose higher performance is likely to further popularise EV batteries containing phosphate.

Global phosphate rock production was 220 Mt (63.6 Mt in terms of P2O5 content) in 2023. Global production is dominated by China (90 Mt), Morocco (35 Mt), and USA (20 Mt) (USGS, 2024). World resources of phosphate rock are more than 74 billion tonnes (Bt). There are no imminent shortages of phosphate rock.

Canada does not currently have active commercial phosphate mining operations. The Kapuskasing phosphate mine in Ontario, operated by Agrium, ceased production in 2013. However, several projects are in development in the country, including:

- Lac à Paul Project (Quebec): Developed by Arianne Phosphate, this project is situated in the Saguenay–Lac-Saint-Jean region. It boasts proven and probable reserves of 472.1 million tonnes grading 6.88% P_2O_5 and is projected to produce 3 million tonnes of phosphate concentrate annually over a 26-year mine life.
- Wapiti Project (British Columbia): Managed by Fertoz, the Wapiti project has an inferred and indicated resource totaling 1.54 Mt at 21.6% P_2O_5. Fertoz has conducted bulk sampling and is working towards securing necessary permits for further development.

Phosphate is found in for major geological units in the Cordillera of Alberta and southeastern British Columbia: the Devonian-Mississippian Exshaw Formation, the Permo-Pennsylvanian Rocky Mountain Supergroup, the Jurassic Fernie Formation and the Triassic Spray River Group (AGS, 1986). The Exshaw Formation has its best phosphate potential in the Crowsnest Pass region of Alberta. Grades of phosphate are up to 25 percent P2O5. However, none of the seams are thicker than 50 cm, and mining would be very difficult because the deposits are not easily accessible and are under thick overburden (AGS, 1986).

Considering the availability of rich phosphate resources around the world and active projects under development in other parts of Canada, Alberta's phosphate resources are unlikely to be commercially competitive.

3.11 Graphite

Natural and synthetic graphite are used in various applications, including electrodes, refractories, batteries, lubricants and foundry products. Coated spherical graphite is used to manufacture the anode in lithium-ion batteries. High-grade graphite is also used in fuel cells, semiconductors, LEDs and nuclear reactors. A LIB EV requires between 44 and 66 kg of graphite. Current (2023) demand for graphite is 1.29 Mt for batteries and 3,34 Mt for other uses (IEA, 2024b). More than 6 Mt of graphite will be required for EV and energy storage batteries and 4.4 Mt for other uses by 2030 (IEA, 2024b).

Global natural graphite production in 2023 was 1.6 Mt (NRCan, 2025a) and synthetic graphite production is about 3.0 Mt annually (USGS, 2024). Major natural graphite producers in 2023 are China at 1,230 Kt (77.4%), Madagascar at 100 Kt (6.3%), Mozambique at 96 Kt (6.0%), Brazil at 73Kt (4.6%), etc. (NRcan, 2025a). China dominates synthetic graphite production with >80% of global capacity (USGS, 2024).

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In 2023, global graphite reserves were estimated at 280 Mt (NRCan, 2025). However, USGS (2024) indicates that the world's resources exceed 800 Mt of recoverable graphite. China holds the largest reserves, followed by Brazil and Mozambique, with these three countries collectively accounting for 63% of the world's graphite reserves (NRCan, 2025a). Canada produced 16.2 Kt of graphite in 2020 but only 4.3 Kt of graphite in 2023 (NRcan, 2025).

Alberta doesn't have natural graphite mines or resources or synthetic graphite production. Alberta's petcoke cannot be used to produce synthetic graphite using available technology due to its high concentration of sulfur and metals and its lack of the required crystalline structure. Current production of synthetic graphite is from premium-quality needle coke with sulfur below 0.5 wt% and total ash content below 0.1 wt%. The feedstock to produce such a coke must be below 0.2-0.3% sulfur and be rich in aromatic compounds boiling in the range 350-524°C. Asphaltene content is undesirable because the coke product is not crystalline and is a poor feedstock for making graphite. After calcining at 1300–1500ºC, the needle coke is converted to graphite by adding a binder derived from coal tar and slowly heating it in high temperature furnaces at over 2800°C.

A Canadian company, NOVONIX is a leading producer of synthetic graphite anode materials used in the making of lithium-ion batteries that power electric vehicles, personal electronics, medical devices and energy storage units. NOVONIX's anode materials business is based in Chattanooga, Tennessee, where it is increasing capacity to produce 10 Kt per year of synthetic graphite beginning in 2025, with plans to expand to 150 Kt/year by 2030 (Phillips 66, 2022; Novonix ESG report, 2024). The feedstock needle coke for Novonix is produced at the Lake Charles refinery of Phillips 66 in a specialized coking unit running on low-sulfur vacuum distillate.

As indicated in the last section, the demand for battery-grade graphite is expected to increase to 6 Mt by 2030, almost five times from 2023. Over the longer term, the successful development of solid-state batteries and Li-silicon batteries with faster charging and higher capacity could reduce demand because these batteries do not use graphite anodes. Current price for battery-grade graphite is US$6,000 - US$8,000 per tonne. The battery-grade graphite itself represents a US$40 billion market in 2030. Considering the geopolitical risk in the supply chain and the size of the opportunity, interest in developing North American supplies is intense as evidenced from the rapid development of Novonix production capacity in Tennessee over the past several years.

The opportunity of using asphaltene and refinery residue to make synthetic graphite should be explored. The composition and structure of asphaltene and refinery residue may pose some challenges in this conversion. However, significant knowledge and expertise have been developed in pre-treatment in converting asphaltene and refinery residue to carbon fiber. Thes knowledge and expertise can be applied to synthetic graphite conversion.

3.12 Hard Carbon

Hard carbon is a solid form of carbon that cannot be converted to graphite by heat-treatment, even at high temperatures. Examples of hard carbon include charcoal from biomass, pyrolysis carbons from a range of resins and precursors, and coke materials from petroleum and coal. Hard carbon is used as anodes in sodium ion batteries (SIB) for

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stationary storage and small vehicle transport applications. Although current production is very low, the world market for carbon anodes for sodium ion batteries could reach 722,000 t/y by 2030 (Gray and Liu, 2025).

The rapid growth of production of lithium-ion batteries has spurred considerable effort on sodium-ion batteries to alleviate concerns about scarcity and cost of key components. Sodium ion batteries are now entering commercial production in China and are forecast to rapidly expand adoption for stationary storage and small vehicle transport applications. The carbon anodes for sodium-ion batteries could potentially be produced from oilsands bitumen, based on the current knowledge of hard carbon materials and the experience of bitumen-derived products through the Bitumen Beyond Combustion (BBC) program. The world market for carbon anodes for sodium ion batteries could reach 722,000 t/y by 2030, comparable to forecasts for carbon fibres and much larger than the other high-value carbon materials currently in development. Alberta Innovates has developed projects and partnerships with researchers to provide data on the performance of bitumen-derived hard carbon within the next 12-18 months. These studies should be used to assess the Alberta bitumen opportunity for hard carbon, and to identify key knowledge gaps on production and performance. In parallel, Alberta Innovates should expand partnerships with research experts and producers of hard carbon and sodium-ion batteries.

The majority of current production of hard carbon is from biomass wastes such as coconut shell, followed by coal and petroleum sources. Bitumen-based production offers higher yield and consistency of product, but higher GHG emissions than biomass conversion.

Assuming 722 Kt per year demand and US$15/kg, hard carbon market can be over US$10 billion by 2030. Because incumbent products cost more and asphaltene appears to have advantages in making hard carbon, this should be a major priority for Alberta.

3.13 Carbon Fiber

Carbon fibers are used in aerospace, wind turbine blades, automotive, pressure vessels, sports/recreation, etc. Current global market size is about 150 Kt annually. The market size is anticipated to increase 300% between 2022 and 2032 (Walk, 2023, private communication). In China, carbon fiber demand has been increasing at 19% CAGR between 2008 and 2025. China's domestic capacity was ~45 Kt in 2024 and is projected to reach 90 Kt in 2026. Globally, wind turbine blades have been a major growth driver for carbon fiber in the last decade. The new growth drivers will be electrical grid, energy storage, and automotive applications.

Until very recently, global carbon fiber production was dominated by Toray (Japan), Hexcel (USA), Mitsubishi Chemical (Japan), SGL Carbon (Germany), and Formosa Plastics (Taiwan). However, China is quickly becoming the largest carbon fiber producers in the world and is expected to dominate low-cost carbon fiber market (e.g., wind turbine) in the near future.

The market potential of carbon fiber is much greater than current market size. In auto sector alone, carbon fiber market can be 10 times today's total market for replacement of steel to reduce weight. The wind market will continue to grow for carbon fiber. There has also been suggestion that carbon fiber core cables (like ACCC – Aluminum Conductor

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Composite Core) may be used to replace traditional ACSR (Aluminum Conductor Steel-Reinforced) for high voltage power lines (SageZander, 2023). Indeed, an industry expert once considered this as the largest opportunity for carbon fiber (Walk, 2023). Other new applications for carbon fiber include marine, civil engineering, oil and gas, etc. Carbon fiber may also be functionalized for some speciality applications. Alberta Innovates (2023) estimates the total carbon fiber market can be $11B by 2030.

The key impediment for greater deployment of carbon fiber is the cost. In many applications, carbon fiber cost is higher than incumbent materials (often metals and glass fibers). It is commonly accepted that the cost needs to be reduced by half for mass deployment of carbon fiber (Alberta Innovates, 2023). Secondary barriers include the high GHG intensity in making carbon fiber, and the difficult of recycling carbon-fibre composites.

With a vast quantity, asphaltene from Albert's bitumen has the potential to be a feed stock to make carbon fiber. Bitumen-derived carbon fibers have the potential to be 50% lower cost and more than 50% lower in GHG intensity (Alberta Innovates, 2023). Alberta Innovates and Emission Reduction Alberta's Carbon Fiber Grand Challenge Phase III (CFGC III) is supporting four projects aiming to scale up their technologies. One or two commercial production facilities may be built in Alberta within this decade.

3.14 Asphalt Binder

Asphalt binder is made from distillation of crude oil, mostly medium and heavy crude oils. It is mainly used for road paving, roofing, and water proofing. Although not considered as a critical mineral or an advanced material, asphalt binder is an essential material for road infrastructure around the world and has relevance to Alberta. Market numbers and projections for asphalt vary considerably. The global demand for asphalt was estimated at ~143 Mt in 2020 and was expected to grow at 3.6% annually to reach ~174 Mt by 2025 (ADI Analytics, 2021). More recently, Research and Markets (2025) estimates that the global market for Asphalt was sized at 158 Mt in 2024 and is projected to reach 226 Mt by 2030.

Although global asphalt supply and demand is in balance, there could be a supply gap in the future as demand increases and supply decreases (Alberta Innovates, 2023). More than 50% of bitumen can be made into asphalt while most conventional crude oils can yield less than 5%. No asphalt can be made from shale oils. The heavy fraction in bitumen has a naturally lower wax content than other global crude oils. Because of this, asphalt binder derived from bitumen has high durability and resistance to cracking, placing its property among the best in the world when compared to other asphalt binders from global crudes (Hesp, 2021). Asphalt derived from bitumen will also have lower GHG intensity compared with those from conventional refineries.

Several asphalt binder projects in Alberta Innovates' Bitumen Advanced Materials program are entering commercialization stage. Alberta Innovates (2023) has suggested that bitumen-derive asphalt may reach $2 billion sales in 2030 and $85 billion in a net zero emission global economy.

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3.15 Activated Carbon

Activated carbon is carbon produced from carbonaceous source materials such as bamboo, coconut husk, willow peat, wood, coir, lignite, coal, and petroleum pitch. It has micro pores and high surface area available for adsorption or chemical reactions. Activated carbon is used in water treatment, sewage treatment, air purification, solvent recovery, methane and hydrogen storage, supercapacitors, and many other applications. The current (2023) global production is 3.1 Mt, and the market is projected to grow to 5.8 Mt by 2030 (Industry Expert, 2025).

Alberta Innovates has been supporting research and development projects to make activated carbon from asphaltene in its Bitumen Advanced Materials (formerly known as Bitumen Beyond Combustion) program. Bitumen-derived activated carbon may be most suitable for supercapacitor applications for very quick energy storage and release in specialized applications.

3.16 Midstream Opportunities

In addition to the critical mineral production and advanced materials manufacturing opportunities summarized above, there are also opportunities in mid-stream manufacturing in Alberta. Alberta already has nickel refinery at Sherritt International. If Fortune Minerals' project goes forward, cobalt ore from NWT can be refined in Fort Saskatchewan. There are also efforts to make cathode and anode electrodes. There can be even speciality battery pack manufacturing opportunity related to CPKC's hydrogen locomotives. Vanadium flow battery manufacturing could be another opportunity. Carbon fiber composites and pressure vessels are already at pilot production. These mid-stream opportunities have potentials to create more value in Alberta.

3.17 Summary

In summary, there is minimal critical minerals production at commercial scale in Alberta at present. However, Alberta has several critical mineral resources that have potential to be developed at commercial scale. There is also a strong opportunity to develop advanced carbon-based materials as substitutes for many currently more common critical minerals for the same applications.

Lithium in oil field brine may represent a strong critical mineral development potential for Alberta. Although lithium concentrations in Alberta's formation waters are low compared with other lithium resources around the world, direct lithium extraction method may have some advantages in terms of extraction rate and environmental impacts compared to hard rock mining and brine evaporation methods. If successfully commercialized, lithium production could grow into a billion-dollar industry in Alberta.

Titanium and zirconium in oil sands and vanadium in bitumen gasification ash or accumulated coke combustion ash may represent a modest opportunity for Alberta. If properly developed, these minerals may be able to generate a modest business for Alberta. Helium opportunity is likely much smaller for the province. There might be an opportunity

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for uranium development in Alberta, but the quality and size of the resource in Alberta are yet to be quantified.

The potential to produce nickel, cobalt, copper, rare earth elements (REEs), phosphate, and natural graphite in Alberta is low. Although there are occurrences of mineralization of these metals in Alberta, either the grade or size of the resources is not competitive. However, there might be an opportunity to co-produce multiple critical metals from black shales in Northeast Alberta.

There are opportunities in mid-stream manufacturing in Alberta. Alberta has already nickel refining. A cobalt refinery has been proposed in the Alberta Industrial Heartland Region. Other opportunities include electrode and battery manufacturing, carbon fiber composite production and pressure vessel manufacturing. These mid-stream opportunities have potentials to create more value in Alberta.

The greatest opportunities for Alberta are in advanced carbon-based materials derived primarily from bitumen. Advanced materials can substitute for critical minerals (e.g., synthetic graphite for graphite) and/or conventional materials (cement, steel, etc.). Carbon fiber, hard carbon, and asphalt binder each represent a billion-dollar opportunity for Alberta. Synthetic graphite market is larger than other advanced carbon materials, although making synthetic graphite from asphaltene and bitumen refinery residue will require significant effort to overcome technical barriers. Collectively, the advanced materials opportunity is at least an order of magnitude greater than all the critical minerals opportunities combined. Alberta's bitumen resource should be considered as a critical mineral for making these advanced materials that will be in high demands in the decades to come.

4. The Role for Alberta Innovates and Emissions Reduction Alberta

Based on the opportunities identified above, Alberta Innovates and Emissions Reduction Alberta should consider the following initiatives:

- Collaborate with or support (if necessary) Alberta Geological Survey (AGS) and other partners to quantify lithium, helium, and uranium resources. AGS has reported the occurrences for these resources. However, the indicated resources are not quantified. Quantification of these resources will encourage the development of theses resources.
- Continue to support direct lithium extraction (DLE) process development; initiate a comparative analysis on environmental impacts between DLE from oil field brine, hard rock mining, and continental brine evaporation processes.
- Engage Critical Minerals America to revisit its Alberta Critical Metals Projects and determine if there is a business case for multi-metal extraction in its SBH Property and if so, what support will be required to move the project forward.
- Support innovations to recover vanadium from bitumen gasification ash and petcoke combustion ash. Vanadium concentrations in these ashes are comparable with those in commercial sources. Support should be provided to SMEs to overcome technical challenges in vanadium recovery from bitumen gasification and coke combustion ashes.

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- Continue to support innovations in and commercialization of advanced materials including, carbon fiber, hard carbon, activated carbon, and asphalt binder in Bitumen Advanced Materials (BAM) program.
- Determine the potential of making synthetic graphite from asphaltene and refining residues in Alberta. Alberta Industrial Heartland Association also has interest in this. If the potential is confirmed, initiate a competition to pursue the opportunity as part of BAM. The synthetic graphite opportunity could be as large or even greater than carbon fiber and hard carbon opportunity.
- Identify and support mid-stream value-add opportunities related to critical minerals and advanced materials. They include nickel and cobalt refining, electrode and battery manufacturing, carbon fiber composite production and pressure vessel manufacturing.
- Develop a narrative that Alberta's bitumen resource is not only the third largest petroleum reserve in the world but also the most important critical mineral for Alberta. Communicate this narrative to the Governments of Alberta and Canada and other stakeholders.
- Continue supporting knowledge generation that improve our understanding of the natural environment and changes (e.g., future water supply) that could impact the future success and viability of economic opportunities.

5. Summary

At this crucial moment in our national's history, Canadians have realized that Canada's natural resources (including oil, natural gas, and critical minerals) are a strong asset to build our economy and defend against external threats via establishment of secure local supply chains. Hydrocarbon resources have been Canada's largest export for decades and have created a strong technical, regulatory, and financial foundation for development of new resource industries like critical minerals. Development of Canada's world class critical mineral resources can make our economy more resilient and make our country a desirable strategic partner in a challenging world.

The global transition toward sustainable energy and infrastructure development is driving an unprecedented demand for critical minerals and advanced materials. The key trends shaping these demands include electrification of transportation, infrastructure development, and energy storage solutions. Critical minerals (such as lithium, nickel, and graphite) and advanced materials (such as carbon fiber composites, and synthetic graphite) are essential for the physical transformation during this transition. Our research has revealed significant supply chain challenges and opportunities for innovation in material sciences.

No critical minerals are produced at commercial scale in Alberta at present. However, Alberta has several critical mineral resources that have potential to be developed at commercial scale. Lithium in oil field brine may represent the greatest critical mineral potential for Alberta. Although lithium concentrations in Alberta's formation waters are low compared with other lithium resources around the world. The direct lithium extraction may have some advantages in extraction process and environmental impacts compared to hard rock mining and continental brine evaporation methods. If successful, lithium production can grow into a billion-dollar industry in Alberta.

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Vanadium, titanium, and zirconium may represent in oil sands and bitumen may represent a modest opportunity for Alberta. If properly developed, these minerals may be able to generate hundreds of million-dollars business for Alberta. Helium opportunity is also modest for Alberta. There might be an opportunity for uranium development in Alberta.

The potential for commercial production of nickel, cobalt, copper, rare earth elements (REEs), phosphate, and natural graphite in Alberta is low. Although there are occurrences of mineralization of some of these metals in Alberta, either the grade or size of the resources is not competitive. However, there might be an opportunity to co-produce multiple critical metals from black shales in Northeast Alberta.

There are also opportunities in mid-stream manufacturing in Alberta. Alberta has already nickel refining. A cobalt refinery has been proposed in the Alberta Industrial Heartland Region. Other opportunities include electrode and battery manufacturing, carbon fiber composite production and pressure vessel manufacturing. These mid-stream opportunities have potentials to create more value in Alberta.

The greatest opportunities for Alberta are in advanced materials. Advanced materials can substitute critical minerals (e.g., synthetic graphite for graphite). Synthetic graphite, carbon fiber, hard carbon, and asphalt binder each represents a billion-dollar opportunity for Alberta. Collectively, the advanced materials opportunity is at least an order of magnitude greater than all the critical minerals opportunities combined. Alberta's bitumen resource should be considered as a critical mineral for making these advanced materials that will be in high demands in the decades to come.

Alberta Innovates and Emissions Reduction Alberta should consider following initiatives:

- Continue to support innovations in and commercialization of advanced materials including, carbon fiber, hard carbon, activated carbon, and asphalt binder in Bitumen Advanced Materials (BAM) program.
- Determine the potential of and initiate a competition in making synthetic graphite from asphaltene and refining residues in Alberta.
- Continue to support direct lithium extraction (DLE) process development; initiate a comparative analysis on environmental impacts between DLE from oil field brine, hard rock mining, and continental brine evaporation processes.
- Collaborate with or affect Alberta Geological Survey (AGS) to quantify lithium, helium, and uranium resources in Alberta.
- Engage Critical Minerals America to revisit its Alberta Critical Metals Projects and determine the potential of multi-metal extraction from black shales in Alberta.
- Support innovations to recover vanadium from bitumen gasification ash and petcoke combustion ash.
- Identify and support mid-stream value-add opportunities related to critical minerals and advanced materials.

Critical minerals such as lithium and vanadium can become a new industry in Alberta. However, bitumen is Alberta's most valuable critical mineral. Bitumen can be used to make advanced materials that will be in high demands in the decades to come. The economic

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potential of bitumen-derived advanced materials will be at least an order of magnitude greater than that of all other critical minerals combined.

Alberta's bitumen resource is not only the third largest petroleum reserve in the world but also the most important critical mineral for Alberta.

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