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# IN-SITU RESOURCE UTILISATION

## A generational opportunity for Canada

Report prepared by the
**Canadian Space Mining Corporation** for
**Next Generation Manufacturing Canada**

NGen

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# Executive Summary

**From Apollo to Artemis,** space exploration has always inspired innovation and fuelled economic growth. Now, after decades of moderate advancements, a new era in space commerce is on the rise. Governments and industry worldwide are urgently advancing their scientific, military, and commercial interests in low-Earth orbit (LEO), cis-lunar space (CLS), and on the lunar surface. These efforts, backed by NASA and fortified by the multinational Artemis Accords, are enabling new economies for lunar exploration, resource extraction in-situ, and scientific research. The result is an unprecedented opportunity, with the commercial space industry expected to grow from $390 billion in 2022 to $1.4 trillion by 2040 (Bloomberg, 2022).

At the centre of this growth is the development of in-situ resource utilisation (ISRU): the practice of manufacturing products with local materials, rather than rely on materials from Earth. ISRU is necessary to sustain permanent, human and robotic operations in space. It demands collaboration across multiple strategic sectors – resource exploration, processing, and utilisation; energy generation and storage; aerospace; transportation; and advanced manufacturing and construction – and it demands innovation across next-generation technologies – artificial intelligence; autonomous vehicles; robotics; geoscience; quantum sensing; clean energy; and additive manufacturing. All of which are areas where Canada has critical expertise and strategic interest.

A national strategy for ISRU will have immediate impacts on innovation, talent and jobs across sectors that collectively represent 40% of Canada's GDP, over 2.5 million jobs, and where Canada has recently identified it is falling behind global competition.

According to the 2017 Canadian federal budget's *Innovation and Skills Plan*, there are several contributing factors to Canada's decline in its strategic industries, which is threatening our long-term national strength and global competitiveness. The plan cites a lack of investment in research and development, a shortage of skilled workers, and a lack of collaboration between businesses, academia, and government. The report notes that Canada's R&D intensity, which is measured as the percentage of GDP invested in R&D, has been consistently below the average of other countries in the OECD. In 2015, Canada's R&D intensity was just 1.7%, compared to the OECD average of 2.4%.

A notable exception is Canada's Aerospace and Space Industry which continues to demonstrate impressive innovation in the face of these challenges.

A national mission-oriented ISRU innovation strategy – a moonshot – promises to capture the energy of Canada's aerospace talent and innovation; marrying them with strategic industrial sectors in which Canada has fallen behind its international competition. Ultimately, an ISRU strategy will deliver benefits to all stakeholders and government mandates surrounding these sectors, as summarised in the following table:

| Technologies | Industries | Social impact | Government mandates |
|---|---|---|---|
| • Autonomous vehicles<br>• Artificial intelligence<br>• Robotics<br>• Quantum sensing<br>• Geoscience<br>• Materials processing<br>• Additive manufacturing<br>• Energy generation<br>• Energy storage | • Advanced manufacturing<br>• Energy<br>• Aerospace<br>• Transportation | • Climate change<br>• Just energy transition<br>• Northern land stewardship<br>• Advancement of science and exploration | • Position Canada as leading mining nation<br>• Net-zero<br>• Support R & D<br>• Critical minerals<br>• Train and create green jobs<br>• Industrial transition<br>• Pan-Canadian geoscience strategy<br>• Pan-Canadian quantum strategy<br>• Pan-Canadian AI strategy<br>• Indigenous community development national strategy |

CSMC has found that these effects are already being achieved to the benefit of Canadian universities, SME's, Indigenous communities and government mandates through isolated programs across the country. Queen's University, for example, offers a Space Mining program that attracts higher-skilled students and yields disruptive intellectual property typical of the space sector, and that are being deployed to terrestrial mining applications. It has also placed highly-skilled graduates at traditional Canadian mining companies that have otherwise struggled to attract next-generation engineering talent. Similarly, Rio Tinto's Chief Scientist reported to CSMC that novel methods for resource exploration and extraction in space align directly with new sustainable mining and critical mineral activities on Earth, and provide an opportunity to energise a new generation of the resource industry workforce. Another example is the Canadian Space Agency's Health Beyond initiative that has unified Canadian health care leaders with space innovators to develop new ways for isolated populations to access care. A national strategy for ISRU would unify and extend these effects across critical national industries and stakeholders, creating a super effect for innovation.

The near-term benefits of ISRU innovations will also have a transformative impact on federal policy objectives, including:

- 2030 E*missions Reduction Plan: Clean Air, Strong Economy* (Government of Canada, 2022b)
- *Canada's Critical Minerals Strategy* (Government of Canada, 2022a)
- *Pan-Canadian Geoscience* (National Geological Surveys Committee, 2022), *Artificial IntelligenceI* (CIFAR, 2022), and *Quantum Strategies* (Government of Canada, 2022c)
- *Indigenous Community Development National Strategy* (Government of Canada, 2021b)

Canada has a long history of delivering mission-critical **support** technologies for space exploration. ISRU, in contrast, represents a generational opportunity for Canada to ***lead***; sitting at the nexus of timing, critical technology gaps, and our national strengths. This report proceeds in three parts:

1. an introduction to the issues, concepts and market dynamics that are relevant to this opportunity;
2. the far reaching effect that a mission-oriented innovation strategy for ISRU can have across strategic industries, social goals, and governmental policy, and;
3. a summary of policy recommendations that include:
   * clear policy that signals our intent and stakes a claim on the ISRU industry;
   * a well developed regulatory framework;
   * financial support on the order of national superclusters and strategic projects;
   * leveraging our industrial strengths, inclusive of extending our mining specific tax provisions that have propelled Canada to its global leadership in resource exploration and financing; and
   * reevaluating procurement practices for space contracts to keep pace with innovation among competing nations.

Ultimately, the report signals a clear opportunity for Canada to adopt a mission-oriented innovation strategy – a "moonshot" – for ISRU. Such a strategy would unlock a new economic sector and establish the nation strategically for the next frontier in human ingenuity and exploration. It will also lift innovation across our country's strategic industries while supporting our federal mandates and fortifying Canada's global competitiveness for decades to come.

# 1
# Introduction

Pixabay

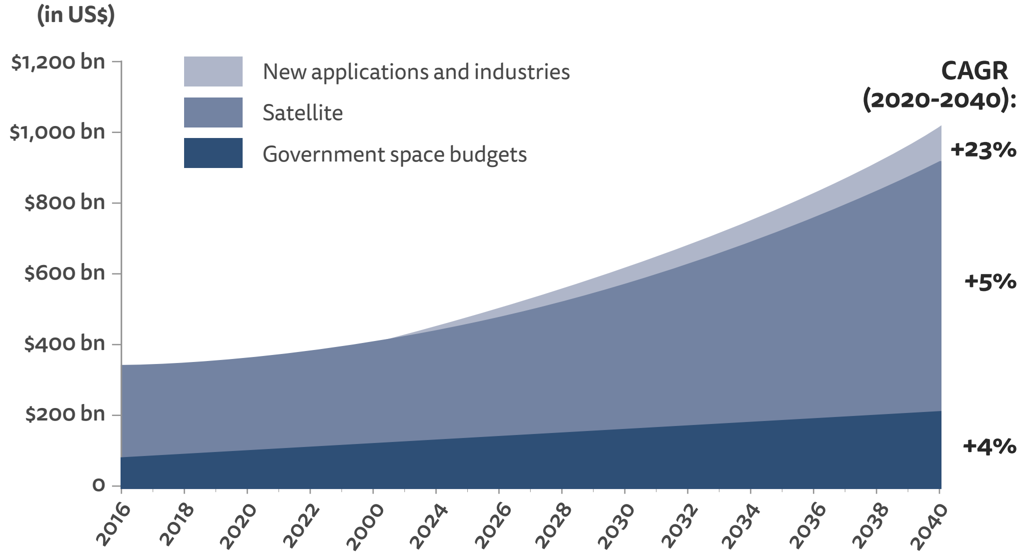
# 1
# Introduction

**Space has always inspired innovation** and fuelled economic growth. After decades of cooperation and incremental advancement, a new era of space exploration has commenced with an unprecedented volume of competition, agility, and commercial opportunity. Where past space activity has been dominated by large enterprise prime contractors, smaller, more agile Newspace[1] companies are now identifying and often leading strategic space objectives that are not only helping governments execute on their strategic objectives, but are adding previously unseen economic growth to both the terrestrial and space industries. The results are staggering, with the commercial space industry expected to grow from $390 billion in 2022 to $1.4 trillion by 2040 (Bloomberg, 2022) and yielding innovations with untold potential for life on Earth.

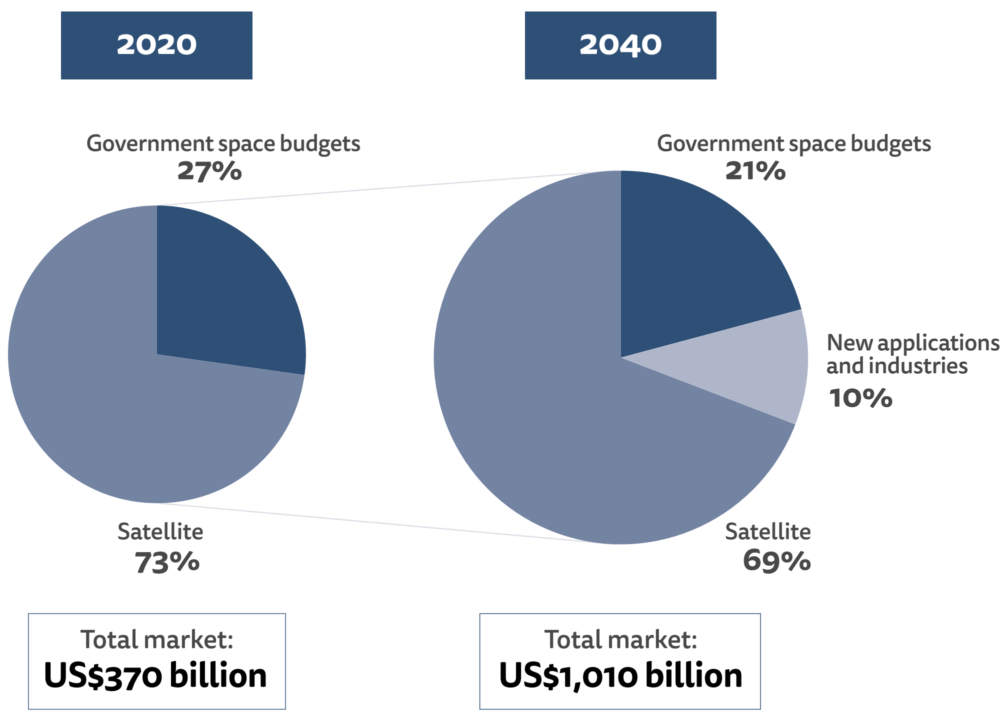
Innovation for space has a long history of supporting life on Earth. The most obvious example is GPS, which is used by more than 23 million Canadians to do everything from getting through traffic to autonomously guiding mining and agricultural vehicles. Carbon fibre and Velcro were also originally designed for space. Mobile phones depend on complementary metal oxide semiconductor (CMOS) technology developed to take pictures of the Earth from orbital satellites. Smoke detectors, scratch resistant lenses, dust busters; the list is endless. NASA's Technology Transfer Program has transferred thousands of innovations developed for space exploration and discovery to academic and commercial

1 The idea of New Space refers to the emergence of a private industry for space flight and an aerospace industry with a clearly commercial outlook that is free from government policy, political motivations and traditional contractors (Santamaria, 2021).

## *FIGURE 1:* Space Economy Forecast (Citi, 2022)




*Source: Citi Research, Satellite Industry Association (2016-20)*




*Source: Citi Research (2040), Satellite Industry Association (2020)* sectors to maximise their benefits for all of us on Earth. This innovation has taken not only the form of purposeful invention, but also of accidental invention, where the need to solve complex problems in space led to disruptive technologies with dual use applications for other purposes. A key example of this is the creation of Magnetic Resonance Imagining (MRI) technology, which relies heavily on image processing developed as part of NASA's work in satellites and telescopes (Heraeus, n.d.).

As space exploration becomes more ambitious, so too do the related technologies and the corresponding benefits. In the coming 20 years, astronauts will require the ability to transform space-based resources on the Moon into breathable air; clean water for drinking and plant growth; and resources to manufacture rocket propellants and building materials in space. For example, advances in planetary observation, science and imagery are ever growing. Northern Sky Research, a global market research and consulting firm, projects global revenue from Earth observation satellite data and services to grow from over $3 billion today to $7.2 billion by 2028. These projections, however, do not properly account for innovation in quantum sensing, artificial intelligence, and other advancements that are being driven by both resource exploration and situational awareness in space that are likely to transform remote sensing, exploration, and science. Satellite-enabled internet (SEI) is another example. The SEI industry added C$2.2 billion of value to Canada's GDP in the decade prior to 2017, with the potential to add another C$2.7 billion to the Canadian economy over the next 10 years just by solving several problems in rural and remote regions for the Canadian economy regarding productivity, access to essential government services and healthcare. As new technologies are developed to compensate for unconventional bandwidth and communication needs to support industrial operations between the Earth, the Moon and beyond, the capabilities and terrestrial value associated with satellite internet will increase at unimaginable rates.

At the centre of the new era of space activity is the development of in-situ resource utilisation (ISRU): the practice of manufacturing products with local materials, rather than rely on materials from Earth. Earth's gravity is too strong to perpetually fly resources into space. The ratio of fuel consumption to excess cargo capacity to leave Earth's atmosphere is 10:1. This means that it would require 10 ships to refuel one that's been launched to low-Earth orbit. Even as launching costs become more affordable, the current estimates are still prohibitive, costing up to USD $100,000 per kg to reach low-Earth orbit. Supplying resources from Earth to sustain long-term space exploration is not viable. Solar power is one of the longest-standing and simplest examples of addressing these challenges through ISRU: collecting and processing solar energy to generate power in-situ. The new era of space operations is extending ISRU to finding and processing critical elements in-situ, such as oxygen and water for life support, or minerals and metals to supply in-situ advanced manufacturing techniques in austere environments.

> ISRU is intrinsically driven by sustainable, clean technologies for natural resource management, energy generation, and energy storage.

ISRU is intrinsically driven by sustainable, clean technologies for natural resource management, energy generation, and energy storage. It in-turn gives rise to transformative technologies with the potential to help reach global climate goals and clean energy transition within the next ten years. These have far-reaching impacts, but might be most profound in the Canadian Arctic where ISRU technologies can directly impact Canada's capabilities to provide effective land stewardship and demonstrate a strong presence, in service of balancing our responsibilities to northern Indigenous communities with our responsibilities to maintain control over the Northwest Passage and stewardship over the region as a whole. The corresponding technologies represent an opportunity to modernise infrastructure, increase equitable access to heat and power in the North, and improve Canada's defensive capabilities, all while substantially reducing emissions.

Canada's space innovation strategy has come a long way since Canada became the third space faring nation by placing a satellite, Alouette 1, in orbit in 1962. Canada now has a celebrated history of delivering mission-critical *support* technologies for space exploration – most notably the iconic Canadarms for the US space shuttle program and International Space Station (ISS), respectively – and will continue in that tradition by supplying the Canadarm3 for the new Lunar Gateway Space Station before the end of the decade. ISRU represents a generational opportunity for Canada to **lead**, sitting at the nexus of timing, critical technology gaps, and our national strengths.

> ISRU represents a generational opportunity for Canada to **lead**, sitting at the nexus of timing, critical technology gaps, and our national strengths.

Advanced manufacturing is one such example; where Canada's depth of capabilities, capacity, and diversified sectors offers a springboard for ISRU innovation and leadership. Advanced manufacturing serves to augment traditional manufacturing practices with new technology, leading to innovative production models that have the capacity to significantly alter business operations. While the size of the Canadian manufacturing sector is smaller than that of the US (with 270 manufacturing operators large enough to employ 500 people compared to 33,000), Canadian manufacturers are more profitable on average than American manufacturers, are more flexible, and are highly specialised when compared to their large-volume American counterparts (TheFutureEconomy.ca, 2019). As a result, Canadian manufacturers are better positioned to take advantage of transformative and agile technologies. The evolution of advanced manufacturing practices have the capacity to create high quality jobs related to the development, management, and maintenance of a diverse portfolio of supporting technologies. The government of Canada estimates that the sector will result in a $13.5 billion GDP increase and the creation of 13,500 jobs over the next 10 years (Government of Canada, 2023b).

Canada is also recognized as a global leader in natural resource exploration, development, and finance, and through its Critical Minerals Strategy has a clear mandate to continue that into the future (Government of Canada, 2022a). Between its reputation and proficiency in responsible resource development, unrivalled space robotics technology, and expertise across every requisite domain and technology, Canada is uniquely positioned to establish itself as the trusted, global leader in space resources. This represents an unparalleled potential for economic development, creating opportunities for the next generation of STEM workers as well as positioning Canada strategically for economic success in the 21st century and beyond.

The time to invest is now. According to the European Space Agency at least 250 lunar missions will take place before 2031, which is driving market demand for resources, advanced manufacturing, data and infrastructure solutions. Economic estimates indicate that hundreds of billions of dollars in spending are on the horizon for those corporations, industries and governments daring enough to take their shot in the near- and mid-term space economy. Businesses and entire industries with still-nascent connections to space stand to reap significant rewards. Citi suggests that those industries can become a financial driving force for the economy, as they benefit from spillover effects created by space-related innovations (Citi, 2022). PWC goes on to highlight that solutions to some of the biggest challenges associated with establishing ex-terran human habitation – from energy, mining and processing to robotics and autonomous vehicles – will also be used to solve some of the biggest challenges facing industries on Earth (PWC, 2021). The automotive industry is already developing lunar rovers and lunar autonomous vehicles, while the construction industry explores additive manufacturing to establish sustainable infrastructures and facilities on the lunar surface.

Canada has the national strength to lead ISRU. What's needed is daring leadership and the bold investments to realise this generational opportunity for our strategic industries and citizens.

## 1.1 ISRU: Driving innovation for Canada's strategic industries

The innovations being developed for ISRU underlie some of Canada's most important industrial sectors: Natural resources prospecting, extraction and processing; manufacturing and construction; aerospace; and energy production. Together these sectors represent over 40% of Canada's GDP and employ 2,626,000 Canadians.

According to Canada's I*nnovation and Skills Plan* (Government of Canada, 2017), however, there are several threats to our long-term national strength and global competitiveness that require intervention. The plan cites a lack of investment in research and development, a shortage of skilled workers, and a lack of collaboration between businesses, academia, and government. Canada's R&D intensity ratio of 1.8 is well below the OECD average of 2.7, and it ranks only 17th in that group of advanced economies (Statistics Canada, 2023). Driving innovation across any one of these sectors would create significant opportunities for economic growth and job creation. A mission-oriented innovation strategy across all of them can fortify Canada's global competitiveness for decades.

Canada's aerospace sector – which includes the space industry – is a notable exception, continuing to demonstrate impressive innovation in the face of these challenges. As reported on ISED's website:

> "The aerospace industry is the top R&D stakeholder among all Canadian manufacturing industries, with investments totalling $710 million in 2021, three times higher than the national manufacturing average. The Canadian aerospace industry's share of science, technology, engineering, and mathematics (STEM) employment was also over two times higher than the national manufacturing average (ISED, 2022).

***TABLE 1:*** Key Canadian Sectors

| Industry | Canadian GDP | | Directly employed |
|---|---|---|---|
| | % | $ | |
| Natural Resources (Statistics Canada, 2022) | 14.4% | $350 billion | >650,000 |
| Manufacturing (Government of Canada, 2021a) | 10% | $174 billion | >1,700,000 |
| Energy (Government of Canada, 2023d) | 9.2% | $175 billion | >276,000 |
| Aerospace (Government of Canada, 2022d) | 1.0% | $24 billion | >200,000 |

A national ISRU moonshot promises to capture the strongest parts of Canada's talent and innovation, and marry them with critical industrial sectors in which Canada has fallen behind. This effect has already been observed across universities and industry in isolation – which will be explored later in the report – and it is clear that a unified strategy can amplify it exponentially. Ultimately, an ISRU strategy will deliver benefits to strategic national industries, while simultaneously fostering interdisciplinary collaborations, advancing social objectives, and helping to realise government mandates.

## 1.2 The basics of ISRU

NASA's Artemis program is sending astronauts to the lunar surface for the first time in over half a century. Over time, they will establish a lunar base and a permanent human presence on the Moon. Resources will initially be sent to establish the base and the Gateway space station in the Moon's orbit, but ultimately it will be essential to generate products manufactured with local materials.

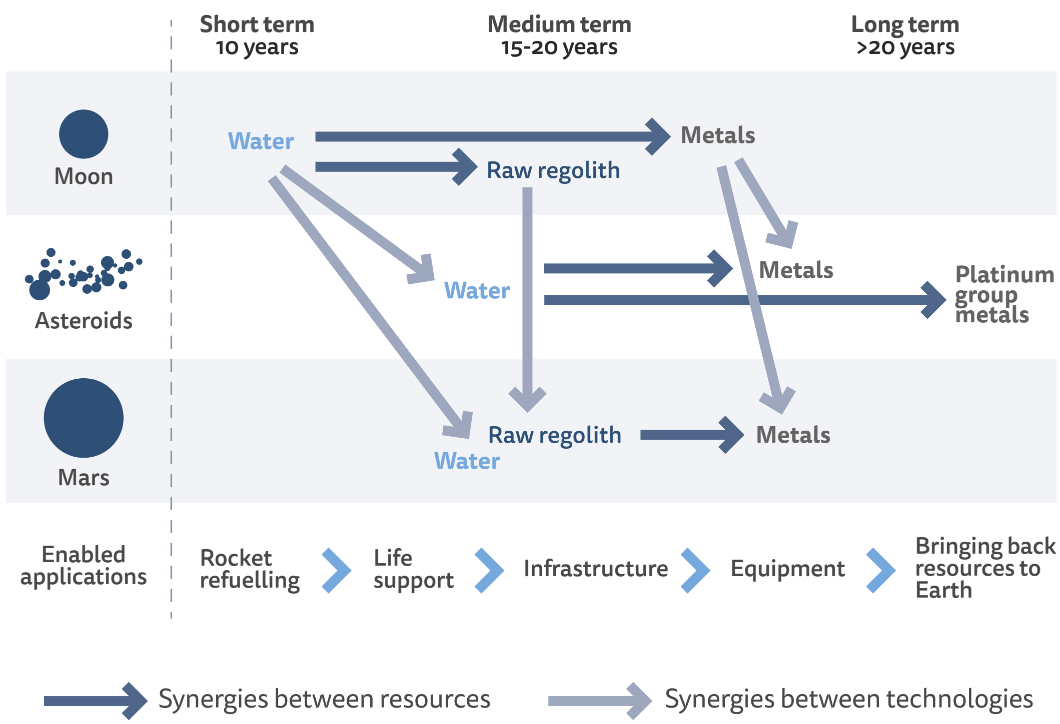
The European Space Agency says the mastering of space resource utilisation transcends domains to advance technologies and transfer expertise across sectors. Technologies are required across the value chain, some of which are being developed today. The Luxembourg Space Agency (2018) classifies the requisite technologies into the following groups:

- prospecting technologies to explore and identify resources;
- mining technologies to enable the extraction, local transportation, processing and handling;
- transport and supply technologies to enable the transportation of the resources through space to the point of storage or utilisation, such as a staging station in lunar or Earth orbit, or a fueling station to get to Mars;
- refinement technologies to allow the processing of material to obtain final products like structural materials in intermediate or final shape;
- manufacturing technologies to provide for in-situ creation of structural elements and fabrication of tools, possibly via the use of 3D printing; and
- support technologies applicable across the whole value chain, including software, robotics, communications and energy technologies.

ISRU is seen as a gating factor to future space activity. It provides for the extraction of volatiles – like oxygen, nitrogen and hydrogen – in addition to critical minerals and metals, many of which are abundant on the lunar surface. After being processed on-site, these essential resources could be used to sustain life support systems, create water for lunar and space-based colonies, and will lead to a supply chain for in-situ manufacturing and construction. The production of rocket propellant from lunar resources is also essential to powering deep-space missions involving humans, or for safely returning them to Earth.

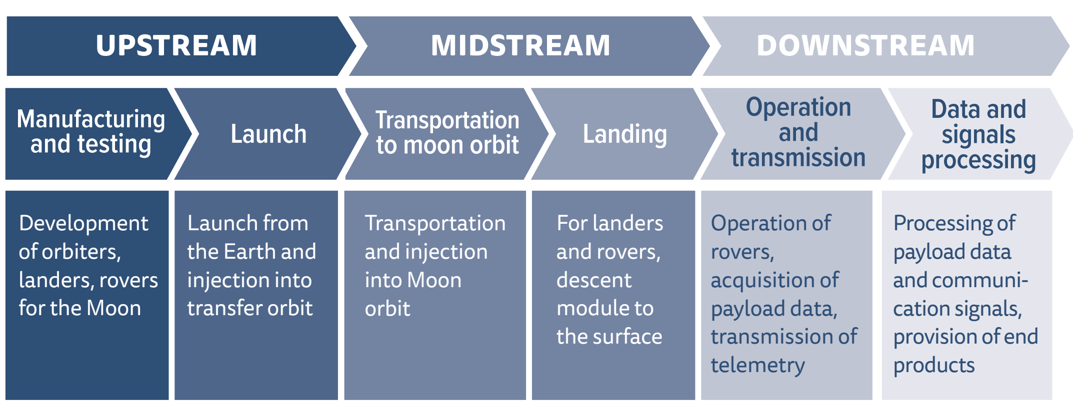
An immediate example of ISRU's potential for a sustained human presence in space is the International Space Station (ISS). The majority of resources needed to sustain the ISS still largely originate on and are transported from Earth, which makes the structure very expensive to maintain. But not everything is transported to the ISS and utilising local resources is thought to be significantly less expensive than transporting them from Earth to space. Solar power is still the most common example of ISRU being employed by the ISS.

## *FIGURE 2:* The space resources utilisation value chain over time




*Source: Luxembourg Space Agency, 2018.*

## *FIGURE 3:* Breakdown of SRU value chain




*Source: PWC, 2021.*

The ISS's solar arrays have harnessed sunlight to generate the power to sustain a continuous human presence for over 20 years. Another example is the ISS's capabilities for recycling water, ensuring that the heavy, life-sustaining resource is efficiently and sustainably processed in-situ to remove the need for replenishment from Earth.

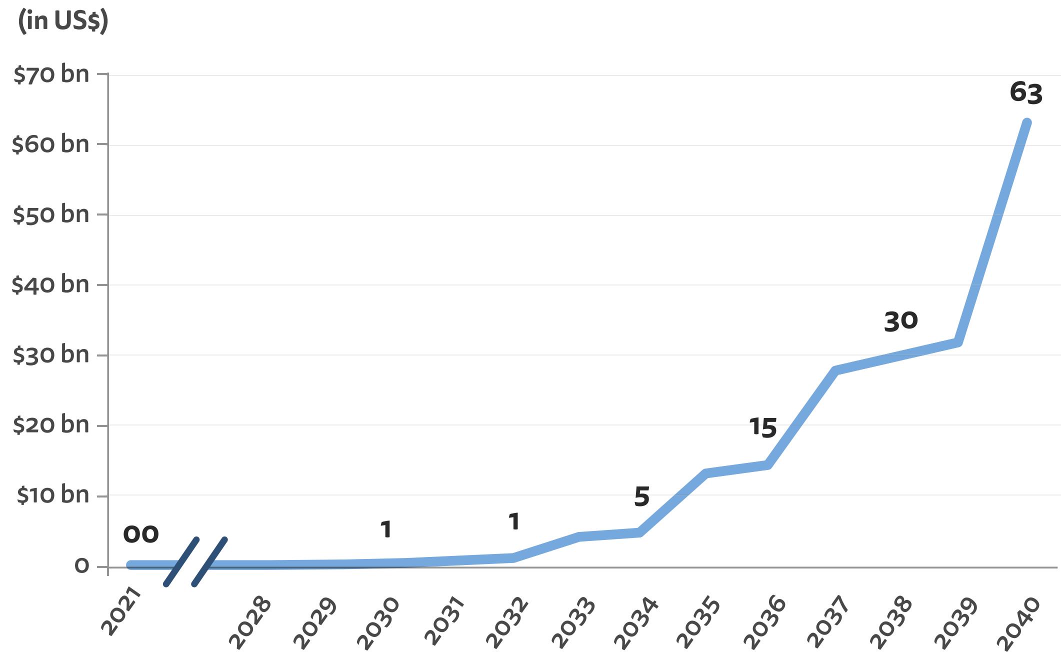
The broad strokes of a roadmap for expansive ISRU already exist within the *Global Exploration Roadmap*, which was published by the International Space Exploration Coordination Group (ISECG) in 2018 and updated in 2022. The roadmap lays out a shared international vision for space exploration that is based on the programs, initiatives and goals of the participating 27 space agencies, and builds on shared objectives beginning with the International Space Station (ISS) and extending to the Moon, asteroids, and Mars. The roadmap currently includes 12 lunar exploration objectives that were established across three phases:

- **Phase 1: Boots on the Moon:** This phase is where space agencies focus on sending humans to the Moon along with robotic exploration missions. This phase also aims to achieve objectives related to lunar surface exploration, including human landing and ascent and logistic cargo landers.
- **Phase 2: Expanding and building:** This phase emphasises the completion of lunar surface objectives primarily by exploring the lunar surface and identifying the optimal site for longer durations.
- **Phase 3: Sustained lunar opportunities**: Long duration habitation, crew health and performance, and in-situ resource utilisation are all key parts of this phase.

The *Global Exploration Roadmap* identifies new technologies that would begin their "proving" stage around 2027, which means technical validation and commercialization on Earth for any applicable technologies will happen years before.

ISRU encompasses a broad ecosystem of next-generation technologies, processes and advancements that are untapped for terrestrial advantage. Whereas today's common space tech applications for Earth involve satellites and related applications – imagery (earth observation), satellite communications and satellite

**_FIGURE 4:_** Estimates of the lunar space resource utilisation market over time




*Source: PWC, 2021.*

navigation – ISRU ventures into applied quantum sensing, artificial intelligence, autonomous systems and transformative energy solutions, to name a few.

Forecasting the development of new technologies and their applications to current and unforeseen industries is inherently difficult. Imagine drawing up a roadmap for internet-related industries when the technology was in its infancy, before smartphones, broadband or laptops existed. What's different about the space industry is there are certain end goals that will steer research and development along somewhat predictable lines.

ISRU's synergies with terrestrial industries will be closely linked to space technology roadmaps pursued by public and private organisations, including the missions outlined in the *Global Exploration Roadmap*. The Luxembourg government's analysis of the potential economic impacts of space resources utilisation found that their market revenues may reach anywhere from 73 billion euros to 170 billion euros through 2045, and employee years could be anywhere from 845,000 to 1.8 million full time. ISRU would also enable major cost savings across space exploration, which the Luxembourg government estimates at 54 billion to 135 billion euros over the same period.

Similarly, the European Space Agency says ISRU technology has multi-sector, commercial value in the near-term for existing terrestrial industries. The ESA also foresees technology and knowledge spillovers estimated at 2.5 billion euros over 50 years (European Space Agency, 2019).

> "We know that mining processes on Earth should be improved, not least to meet the UN Sustainable Development Goals. Importantly, some of the challenges and opportunities for terrestrial mining are similar to the ones we will face in space."
>
> – Rita Rinaldo, ESA Space Solutions

## 1.3 Canada's current space strategy is not enough

To date, the Canadian Space Agency (CSA) – part of ISECG – has led Canada's participation in international space programs and, correspondingly, Canada's space innovation strategy. The CSA, though, is too under-resourced to achieve the level of impact that is possible for Canada through ISRU. The CSA's Lunar Exploration Accelerator Program (LEAP) aims to support lunar technology development and in-space demonstration and science missions. The program plans to send payloads to the lunar surface by 2026, which will include a lunar rover and other important science or technology demonstrations to sustain a habitat on the Moon. Approximately $3 million has been awarded by the CSA for the development of potential Canadian lunar science instruments that the CSA has spread across dozens of missions, including NASA's contracts for surface deliveries and lunar robotics that began in 2022. Canada is also developing an intelligent robotic manipulator known as Canadarm3 for the Gateway, a NASA-led space station that will orbit the Moon.

More recently, Canada did make new commitments to its space exploration in *Budget 2023* (Government of Canada, 2023a). In addition to $1.1 billion over 14 years to the Canadian Space Agency to continue Canada's participation in the International Space Station, and $76.5 million over eight years in support of Canadian science on the Lunar Gateway station, Budget 2023 committed $1.2 billion over 13 years, starting in 2024-25, to develop and contribute a lunar utility vehicle to assist astronauts on the Moon. In that respect, the Lunar Rover is the next Canadarm – a high profile, necessary piece of equipment for space exploration.

Two spaces are also reserved for Canadians aboard the Artemis missions – the first crewed missions to the Moon in 50 years – with Canadian astronaut Jeremy Hansen announced to be on the Artemis II mission to the Moon in 2024.

## Vision Statement

***Space Strategy for Canada, 2019***

Canada recognizes the space sector is a strategic national asset and seeks to ensure Canada remains a spacefaring nation. Looking forward, Canada seeks to create a vibrant and sustainable space sector anchored by a whole-of-government effort that sets a new vision for Canadian space exploration, sees increased partnership with industry to create the jobs of the future, leverages the power of space to inspire youth, and harnesses the potential of space to solve everyday challenges for Canadians while unlocking the secrets of our universe.

This all builds on the goals of *A New Space Strategy for Canada*, released in 2019 by the federal government. It outlined a vision for Canada in space, and identified five activity areas to help realise it.

Each of the stated priorities are directly impacted by ISRU. Most notably: A whole-of-government approach; harnessing space to solve everyday challenges for Canadians, and; positioning Canada's commercial space sector to help grow the economy and create the jobs of the future.

The Space Strategy identifies that the space sector contributes $2.3 billion to Canada's annual gross domestic product, directly employs almost 10,000 Canadians, and is one of the most research and development (R&D) intensive sectors in the Canadian economy. In addition, small- and medium-sized businesses account for over 90% of all Canadian space firms and nearly 30% of space employment.

However, between 2016-2019 Canada invested just $2.6 billion into its space industry (Government of Canada, 2019a). In 2022/23 the Canadian Space Agency budget was just $329M, representing 0.001% of Canada's total federal budget. Compare this to NASA's budget, which was USD $25.4 billion in 2023, representing 0.004% of the American federal budget. By this measure Canada is falling woefully short – with the Canadian Space Agency's annual budget measuring just 1% of NASA's, and representing a quarter of NASA's equivalent federal allocation.

Budget 2023 allocates an additional $150 million over five years, or $30 million per year, to LEAP to support Canada's space industry as it develops new technologies. However, a budget at that level can only sustain seed funding. For Canada to develop a leadership position and realise the national innovation benefits that comes with it, we will need to make a commitment to ISRU more along the lines of what has been provided to the Canadarm or Lunar Rover. The obvious difference is that space mining has even greater potential as an independent economic sector, with its associated technologies having very clear applications here, to the benefit of Canada's national strengths.

ISRU and space mining comprise a clear generational opportunity that aligns with Canada's strategic objectives. An investment towards clear and decisive action in space mining will drive outcomes across multiple facets of the Canadian economy, including advanced manufacturing, clean technology, geophysics, quantum science, robotics, artificial intelligence, and others, all while inspiring the next generation to reach for the stars.

## 1.4 An industry on the move

Canada needs to move with urgency. The space industry has changed, and Canada needs to reorient itself to this new environment. Our space strategy and regulatory framework, however, have been slow to adapt. Where there were once a handful of spacefaring nations, there are now dozens. The standards for technology are no longer as high as they once were, and as a result of a number of innovations, access to space has increased significantly. Where it once cost tens to hundreds of millions of dollars to put a satellite in space, the cost of cubesats and availability of commercial off the shelf ('COTS') parts has vastly lowered the rigours to put hardware in space.

As emerging space powers like Australia, Saudi Arabia, and the UAE have decided to focus on space, they have done so with significant amounts of capital and clear focus on national and industrial objectives. They are not only investing in the capabilities, but luring companies to establish operations within their borders by putting economic incentive programs in place to foster and attract this new industry. These countries pose other challenges for Canada's space program. Canada has long enjoyed a position as a partner to America in space. With the rapid evolution of the Artemis Program, these countries are quickly announcing what their contributions to the efforts will be. Canada risks running out of options by moving too slowly in an accelerating industry, is on the cusp of being left behind, and could cede its global leadership position in mining and resources in the process.

The competition is stimulating. Space resources laws have been passed in the USA, Luxembourg, Japan, the UAE, and most recently India. These countries have not only provided the regulatory clarity necessary for companies to raise and attract capital, but many of them are proactively investing in, supporting, and attracting companies from all over the world. Other countries like Australia have signalled to the globe a priority to establish a leadership position. They have created AROSE (AROSE, n.d.) as a clear part of their space strategy (Australian Government, 2019) to foster industry collaboration and synergies that drive commercial opportunities in resources for both Earth and space.

In repeated conversations with investment banks, venture capital firms, and angel investors, Canada's lack of regulatory clarity is an impediment to its space industry and Newspace companies. Capital is fungible, and investors seek returns on their capital, not strategic national goals. More often than not, financiers prefer a market with a proper regulatory regime. 50% of all monies related to Earth-based mining transit through Canada, and our disclosure process has been adopted internationally. This framework should be extended to space resources (NI43-101). Despite having the planet's largest capital markets for mining finance and investment, Canada's lack of regulatory clarity for space resources threatens to suffocate its space resources industry, to the detriment of its economy, global competitiveness, and self-stated strategic objectives.

Canada is a world leader in mining and natural resources. It has a clear mandate of "positioning Canada as the leading mining nation" (Trudeau, 2021). It identified in 2019 that "Early action from Canada regarding mining new frontiers would demonstrate leadership, signal that Canada welcomes innovation and investment, and support the transfer of technology between sectors" (Government of Canada, 2019d). Even though the time for early action may have come and gone, Canada still has an opportunity to become the global leader in space resources. However, this has not translated to the CSA, where Canada's Space Strategy (2019) lacks the words mining, resources, or ISRU. Canada must play to its strengths. We are already the world leader in mining, and it will require relatively little additional determination to propel us to leadership in space resources. Canada's lack of clear regulatory policy hampers its entrepreneurs, our competitive position globally, and signals to the rest of the world that we don't take mining dominance seriously.

# 2
# Impact on Canada


NASA

# 2
# Impact on Canada

**The impact of an ISRU moonshot** is far reaching, with benefits across next-generation technologies, strategic industrial sectors, social mandates, and government policy.

The downstream economic benefits of public investment in space technology programs cannot be understated. The CSA has indicated that for each dollar invested in CSA contracts, another $1.2 in spillovers were created (CSA, 2015). More recent estimates indicate an even greater return on investment, with the CSA's 2023 State of the Canadian Space Sector report indicating that for every dollar invested, $2.2 are returned in follow-on revenues. We can also observe the breadth of space industry innovation in Canada by examining space related patents. Applying the OECD's Revealed Technological Advantage index to patents, the Canadian government report Patents in Space showed that Canada had a technological advantage in the space industry. The study found 86,000 space patents worldwide from 1996 to 2015, of which more than 1,200 involved over 200 Canadian organisations, such as a Canadian business, government, academia, or research institution – excluding universities.

Focusing resources and coordinating stakeholders specifically in ISRU can achieve even more; stimulating a new interdisciplinary network, or what's been called a Galactic Supercluster. Table 5 is a preliminary list of those areas that intersect in support of ISRU.

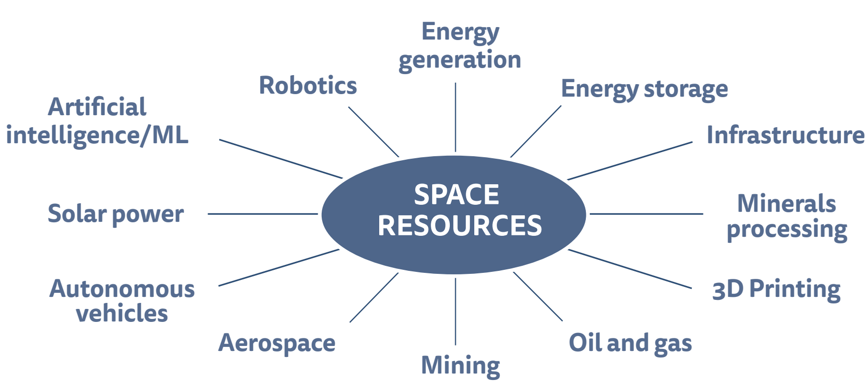
As previously mentioned, driving innovation across any one of these sectors would create significant opportunities for economic growth and job creation. Canada has been one of the leaders internationally in fostering space sector technology transfers for commercialization in the broader economy. A

## ***TABLE 2:*** Areas that intersect in support of ISRU

| Technologies | Industries | Social impact | Government mandates |
|---|---|---|---|
| • Autonomous vehicles<br>• Artificial intelligence<br>• Robotics<br>• Quantum sensing<br>• Geoscience<br>• Materials processing<br>• Additive manufacturing<br>• Energy generation<br>• Energy storage | • Advanced manufacturing<br>• Energy<br>• Aerospace<br>• Transportation | • Climate change<br>• Just energy transition<br>• Northern land stewardship<br>• Advancement of science and exploration | • Position Canada as leading mining nation<br>• Net-zero<br>• Support R & D<br>• Critical minerals<br>• Train and create green jobs<br>• Industrial transition<br>• Pan-Canadian geoscience strategy<br>• Pan-Canadian quantum strategy<br>• Pan-Canadian AI strategy<br>• Indigenous community development national strategy |

## ***FIGURE 5:*** CSMC Galactic Supercluster effect

Space resources is not just mining and space. It is highly interdisciplinary and multifaceted, which means that capital allocation can lead to a ***supercluster effect*** across the economy, driving competitiveness in key ares for the new global macro-economy.




Source: csmc

moonshot that defines a clear national objective for innovation across all of them can fortify Canada's global competitiveness for decades.

The effects of technologies developed for ISRU will have some ubiquitous impacts, such as on government mandates for positioning Canada as the world-leader in mining and maintaining our global competitive advantage in that domain. The growth of ISRU technologies will have a similar effect on generating high-quality jobs, talent and opportunity in next-generation fields. The following subsections detail some of the additional, more nuanced intersections and impacts of ISRU technologies on each strategic industrial sector, followed by a summary of their projected contribution to social mandates and government policy.

## 2.1 Autonomous vehicles, robotics, and artificial intelligence

Autonomous vehicles (AV), robotics, and artificial intelligence (AI) are three enabling technologies that stand to benefit most from the emergence of ISRU. Many of the technologies used across the three domains already have their roots in the space industry. For example, many of the requisite sensors, such as lidar and radar, were originally developed for use in satellites and other space-based systems. Lidar came to prominence after its successful use on the Apollo 15 mission in 1971 (Cremons, 2022), and in 2021 was estimated to be a USD $1.5 billion market that is expected to grow to USD $4.83 billion by 2030 (Spherical Insights LLP, 2023).

The Canadian government has indicated that investment advancing each of AI, robotics, and AVs is a priority, noting the safety, accessibility, environmental, and economic opportunities associated with their use (Government of Canada, 2019c). This commitment resulted in a 2018 round of investments by the federal government in multiple entities to pursue autonomous vehicle projects through the Program to Advance Connectivity and Automation in the Transportation System (Government of Canada, 2019b). In total, 15 projects led by a variety of different groups – including municipalities and provincial government departments – were funded, with the round of investment totalling approximately $3 million.

Accelerating development of these three enabling technologies further through an ISRU strategy will have profound impacts across Canada's strategic industrial sectors.

### 2.1.1 Advanced manufacturing

In addition to ISRU driving new demand for advanced manufacturing of next-generation products, the advanced manufacturing sector stands to benefit tremendously from the expected advancements across AI, AVs, and robotics; advancements that already have a history of being catalysed by isolated space-backed R&D programs.

Canada, for example, is a global leader in the use of industrial robots, with a robot density – the number of robots per 10,000 manufacturing jobs – of 1475; among the highest in the world according to NGen's 2021 "Canada's Adoption and Robotics Landscape" report. However, the same report's closer analysis of Canada's use of robots reveals that the country currently lags behind other developed nations in most other sectors outside of automotive. Canada's robot density excluding the automotive sector sits at 71, roughly half of the US's value. Additionally, NGen's research indicates that the rate of robot adoption similarly lags behind the US, with an increase in robot density of only 20 from 2016-2019 compared to the US's 39. Another study paints the Canadian robotics picture similarly, ranking Canada 14th globally for robot density and noting that the country sits 44% below its expected adoption rate – a metric that uses wage levels and estimated payback time for installing a robot to identify a nation's anticipated rate of robotics use (Atkinson 2019).

Addressing this lag in Canadian robotics adoption will undoubtedly require a complex, multi-faceted response. Canada has highlighted Industrial Transformation – a key area for robotics use – as one of three priorities for its Strategic Innovation Fund (Government of Canada, 2023c).

Notably, one of Canada's strengths in fostering the transfer of space technologies is rooted in its early space program, the Strategic Technologies in Automation and Robotics (STEAR) (1990-2000). STEAR was an R&D program whose goal was to create a new generation of small and medium-sized businesses for space robotics, and encourage technology transfers and spin-in technologies. The commercialisation process was a mandatory element within the STEAR Program.

The commercial viability of proposed projects was one of the key criteria for SMEs in the tendering process. An evaluation of the program concluded over 600 jobs were generated and a minimum of $10 million in sales was created over eight years. The program, which supported Canadian SMEs in their development of automation and robotics technologies, provided a foundation for Canada to maintain its advantage in space robotics. Resulting technology transfer includes the NeuroArm, an image-guided robotic system that assists neurosurgeons, based on Canadarm2 technology, which experts say could only have been pioneered in the demanding environment of outer space.

> Today, Canada's commitment to remaining a world leader in AI-enabled space robotics involves a government investment of $1.9 billion (...).

Today, Canada's commitment to remaining a world leader in AI-enabled space robotics involves a government investment of $1.9 billion to develop a next-generation, AI-enabled deep-space robotic system. Consisting of a large and small robotic arm, the system will be able to move around Gateway, and will be highly autonomous. Canada expects the tech developed for the mission to position Canadian scientific and commercial organisations as global leaders in the future in-orbit servicing market.

Similarly, benchmarks of Canada's AV and ML strength were originally seeded within isolated space R&D programs. The University of Toronto Institute for Aerospace Studies (UTIAS), for example, emerged as a global leader in Visual

Simultaneous Localization and Mapping (VSLAM); ML that leverages stereoscopic camera inputs to stitch together high-fidelity maps of unknown planetary terrain in real-time without the use of external localisation systems, such as GPS. The technology was developed in response to the CSA's requirements for its lunar and Mars rovers to autonomously localise and navigate in unknown planetary landscapes. Led by Prof. Timothy Barfoot, UTIAS's VSLAM has since been licensed to accelerate the autonomous vehicle industry in Canada, including to Clearpath Robotics, and now supports clients worldwide within mission-critical industrial applications each day (Gryfe, 2023). Clearpath also brings a second example of space innovation propagating into Canada's industrial sector, where its Warthog Unmanned Ground Vehicle (UGV) is a spinoff of Ontario Drive & Gear's (ODG) ARGO J5 utility vehicle that was originally developed under the CSA's 2008 micro rover development program. The Warthog is now deployed across several Canadian Military applications (Gariepy, 2023).

Over the next 10 years ISRU will establish ambitious new requirements for AI, AVs and robotics, which will drive both expected and unexpected innovations. Canada must start incubating those technologies now to prepare itself and ensure that our advanced manufacturing sector is well-positioned to remain globally competitive.

### 2.1.2 Mining

Mining is another sector that stands to benefit significantly from catalysed innovation in AI, AVs, and robotics, and where isolated examples of space R&D have proven heritage for creating terrestrial value. In order to address continued challenges and remain competitive, Canada's mining industry will need technological innovation to improve precision exploration, productivity, sustainability as well as reduce costs. AI, AVs, and robotics are being called upon to deliver that balance, by providing reliable, precise, unmanned and electrified solutions to more efficiently and sustainably explore, extract and process natural resources. The projected market for autonomous mining trucks, for example, is expected to grow from USD $1.6B in 2025 to USD $12.5B by 2035 (Allied Market Research, 2022). Even more glaring is the expected growth for industrial robotics, which was valued at USD $14.6B in 2020 and expected to reach USD $352.1B by 2030 (Mining Technology, 2022). Both the value of AVs and robotics are driven by underlying AI capabilities. As Eric Anderson, Executive Director for the Saskatchewan Industrial and Mining Suppliers Association (SIMSA) describes,

> “There are $58B of known projects here that require 150K jobs We don’t have 150K people. The only thing holding us back from billions of dollars of investment is labour. We need to find ways to automate.
> – Eric Anderson, Executive Director of SIMSA

Similar to the technology transfer detailed within Advanced Manufacturing, Canada has a proven track record for accelerating mining applications of AI, AVs, and robotics through space-backed R&D. Queen’s University, for example, offers a Space Mining program that attracts high-skilled students and yields disruptive intellectual property, which then gets seeded to terrestrial enterprises. According to the program’s director, Dr. Joshua Marshall (2022), the space mining program has a history of placing high-skilled space-mining graduates at Canadian mining companies that have otherwise struggled to attract next-generation engineering talent.

According to Marshall, the program has also successfully spun-off and licensed space-driven research – such as autonomous scooping software – to large terrestrial-mining corporations like Atlas Copco who have deployed the systems on underground mining vehicles worldwide. Dr. Marshall went on to explain his disappointment that Canadian industry was not properly developed to receive the innovation directly; instead, out of necessity, the program licensed the technology to a European manufacturer for it to be exported back to Canadian operations. Rio Tinto’s Chief Scientist, Nigel Steward (2022), has also reported that his R&D practices for autonomous mining are directly informed by ISRU requirements in space, citing the unique constraints as catalysing critical thinking for solving terrestrial problems.

### 2.1.3 Transportation

Autonomous vehicles are inextricably linked to advancements in transportation. All told, McKinsey & Company (2023) predicts that by 2035, AVs will generate anywhere from USD $300B to USD $400B in revenue. Canada stands to benefit, but must position itself to take advantage of the coming wave of innovations yielded from commercial ISRU efforts.

Like advanced manufacturing and mining, transportation has also been transformed by space R&D. Satellite GPS applications are being used today by over 23 million Canadians to help them get where they need to go. Space utilisation also closely serves air traffic control via communication, navigation and surveillance. Space-based ADS-B technology could allow airliners to fly more efficient routes, saving time, money and emissions. Euroconsult argues that more efficient routes would result in a total of 5,000 flying hours in Canada every day. In the shipping industry the CIS provides open source ice maps in which optimal routes through sea ice can be planned. Maps based on RADARSAT-2 and Sentinel-1 data lead to financial efficiency for the shipping industry by cutting travel time at sea, resulting in lower costs and fuel.

The link between investments in space and the rapid development of AI, AVs and Robotics is clear, where space acts as an accelerant for advancing these critical technologies. It will continue with greater ambition within the new era of exploration. One of the key contributions of Canada to the Artemis missions is the development, launch, and operation of a Canadian lunar rover, set to perform technology demonstration on the surface of the Moon. The rover will explore a polar region of the Moon as early as 2026. The mission will demonstrate key technologies and will gather scientific data to help find water ice and allow scientists to better understand the lunar geology and environment. In addition it will have the rover survive an entire night on the Moon. Lunar nights, which last about 14 Earth days, are extremely cold and dark, posing a significant technological challenge (CSA, 2022), which will have overlapping requirements to advancements in energy generation and storage. In the near future, autonomous technologies will be relied upon for resource exploration, extraction, and even in-situ mobile power and heat that can be cogenerated for materials processing.

## 2.2 Geoscience, materials processing, and quantum technologies

Advancements in geoscience and materials processing are at the heart of global supply chain demand, where the global demand for are Earth Elements (REE) has been intensifying for decades and is a bottleneck for global strategies towards sustainability and clean energy transition. China, however, has gained an almost complete monopoly of the REE supply chain; now with control of ~97% of all the processed REE worldwide. The international community is taking notice and are working urgently to diversify REE supply chains to include more trusted international partners. That urgency has led to Canada's publication of the Pan-Canadian Geoscience strategy in 2022 (National Geological Surveys Committee, 2022) and further supported by Canada's 2022 National Quantum Strategy (Government of Canada, 2022c). Canada's history as a global powerhouse in mining and our wealth of natural resources positions us at the forefront of REE innovation.

> Canada's history as a global powerhouse in mining and our wealth of natural resources positions us at the forefront of REE innovation.

ISRU technologies represent an immense opportunity for Canada to maintain its strategic interests and global competitiveness in this arena. This includes entirely transformative approaches to remote sensing that leverage quantum mechanics to characterise planetary compositions from orbit, as well as novel methods for materials processing that produce zero-waste and can manufacture drinkable water from oxidised metals.

### 2.2.1 Mining

In order to address continued challenges and remain competitive, Canada's mining industry will need technological innovation to improve precision exploration, productivity, sustainability as well as reduce costs. It will need to adapt to changing market conditions and consumer demands and find ways to reduce its environmental impact, while still meeting the growing demand for critical metals and minerals and other resources. In 2023, the head of the International Energy Agency, Fatih Birol, said:

> “Canada needs to ramp up production of critical minerals and play a global leadership role to defend against energy security crises triggered by countries using fossil fuels as weapons.
>
> – Fatih Birol, Head of the International Energy Agency

Birol continued on to say that the minerals, essential for solar and wind power, are central to net-zero energy sources on Earth. Among these are Rare Earth Elements that are also essential to everyday technologies, from smartphones to car batteries.

While searching for lunar ice in 2009, NASA's Lunar Reconnaissance Orbiter (LRO) discovered evidence of metal oxides, including iron and titanium, in the Moon's large craters. Some of the technologies and processes being developed to exploit those resources through ISRU could be deployed commercially on Earth years before they are ever tested on the Moon.

The Moon contains three crucial resources: water, helium-3, and REE, according to geological surveys. Water will be vital to support life and agriculture in space and will have to be converted to rocket fuel to power humans even deeper into space. Helium-3, a rare helium isotope, may be used for innovations related to nuclear fusion.

The cis-lunar supply chain for resources is still firmly in its infancy, however competing nations are already mobilising to secure their interests. China, for example, is urgently deploying surface prospecting equipment to the Moon's South Pole to identify deposits of lucrative resources, and became the first nation last year to capture and return helium-3 samples from the lunar environment.

***FIGURE 6:*** CSMC's satellite-based subsurface remote sensing technology QASM


Historically, China has been able to maintain its stranglehold on REE processing through its lack of concern for environmental impacts relative to other developed nations. ISRU, however, promises new technologies that allow for resource exploration, mining, and processing with transformative precision.

One such example is CSMC's QASM technology; a quantum-based sensor that will be flown on a satellite with the ability to generate 3D tomography to depths, resolutions, and speeds previously unimaginable. QASM is currently being funded through the Ontario Water Consortium represents an opportunity to develop a disruptive capability for identifying rich material deposits without harming the surrounding ecosystem. This type of capability is absolutely critical for ISRU functions, where the costs and risks in the space environments are much greater than analogous activities conducted on Earth, heightening the urgency and importance of access to precise information.

Another example is CSMC's novel process, HYDRO, for converting oxidised metals within lunar dust into critical volatiles for life-support, such as water and oxygen. This type of innovation holds untold potential for addressing Earth's growing clean water crisis as well as for separating critical metals and minerals in environmentally friendly and sustainable ways.

## 2.3 Energy generation and storage

The energy industry is a linchpin for the Canadian economy, contributing over $175 billion to the country's GDP, and employing over 276,000 people.

But the energy industry in Canada and globally is facing a number of challenges, including the need to transition to cleaner forms of energy, compete with renewable energy sources, and ensure energy security. ISRU promises to address many of those challenges, such as the need to diversify energy sources away from carbon, and create new economic opportunities, as well as contribute to addressing global challenges in the industry. Overall, ISRU represents a promising opportunity for the energy industry to address its challenges and seize new opportunities for growth and development.

Investments in the space industry have already led to significant advancements in energy technologies, including solar, small modular reactors, hydrogen, and storage.

### Small Modular Reactors and Nuclear Energy

One area of particular interest in recent years has been the development of small modular reactors (SMRs), which promise to deliver affordable, safe, and clean nuclear energy in a form factor that can be launched and landed on the Moon, deployed in isolated off-grid communities, or scaled up for basepower in urban environments and for industrial applications. These are compact, scalable nuclear reactors that can be used to generate electricity in a variety of settings, including in space. The development of SMRs for space applications has led to their use on Earth as well, providing a new source of clean energy for communities and industries. SMRs have several potential benefits over traditional large-scale

**FIGURE 7:** Conceptual image of ISRU activity on the lunar surface


nuclear reactors. For one, they are much smaller and more portable, making them easier to transport and deploy in a variety of settings. They also have the potential to be more flexible and adaptable, as they can be customised to meet specific energy needs and can be scaled up or down as needed. Additionally, SMRs have a number of safety features that make them particularly attractive, including passive safety systems that do not rely on external power sources to operate. If successful, these technologies could have a transformative impact on the way we produce and consume energy, both in Canada and around the world.

Much of the advancements for microreactors are being driven by recent and international efforts to return to the Moon, in particular the Artemis mission. SMRs have been identified as a gating factor to enable a sustainable human presence and industrial activities on the lunar surface. In June 2022, NASA and the US DOE (Department of Energy) awarded USD $5 million to each of 3 parties – Lockheed

Martin, Westinghouse, and the joint venture between Intuitive Machines and X-Energy (IX) – as part of the Fission Surface Power (FSP) Project. This funding is to develop initial design concepts for a 6,000 kg, 40 kWe fission power system to last more than 10 years and to be launched for demonstration by the end of the decade. The Canadian Space Agency (CSA) has followed suit, funding two projects for prominent Canadian space engineering companies, McDonald Detwiler and Associates (MDA) and the Canadian Space Mining Corporation (CSMC), to develop concepts and capabilities for FSP, respectively. CSMC's CSA-funded project is of particular interest, as it represents a unique opportunity to leverage an iconic Canadian technology to lead the adoption of SMRs on the world stage.

It is difficult to find details about NASA's selected SMR concepts; they are restricted for both intellectual property and national security reasons. However, available data shows that novel SMRs can cost upwards of USD$500M to design and advance to commercial readiness. These projects also face large bottlenecks for getting demonstration plants built when their terrestrial counterparts are years ahead of them in queue for space at Idaho National Labs (ANS, 2022). Like their terrestrial counterparts, these SMRs are estimated to be 8-10 years away from commercial viability. Based on scant public disclosures it appears MDA's concept is just a rehashing of X-Energy's solutions, with questionable Canadian content at best.

## Solar

The development of solar energy technologies for use in space has a long history. Solar panels on spacecraft and satellites have been used for decades to power their systems, and the technology has continued to improve over time. These improvements have been transferred to terrestrial applications, leading to the widespread adoption of solar panels for electricity generation on Earth. The space industry has also driven the development of more efficient and durable solar cells, as well as the use of new materials such as gallium arsenide and copper indium gallium diselenide, which have higher energy conversion efficiencies compared to traditional silicon solar cells (Green et al., 2015).

Blue Origin has developed a technology to make power systems on the Moon directly from materials that already exist on the surface, without materials imported from Earth. "We have pioneered the technology and demonstrated all the steps. Our approach, Blue Alchemist, can scale indefinitely, eliminating power as a constraint anywhere on the Moon," the company announced in February 2023.

## Hydrogen

Hydrogen has emerged as a green alternative to combat climate change, emitting only water vapour and no harmful greenhouse gases. The hydrogen production market was valued at $130 billion in 2020-2021 and is projected to grow at a rate of 9.2% annually until 2030 (Kane & Gill, 2022). Advances in solar technology have facilitated the generation of hydrogen through solar water splitting, making it a clean and renewable energy carrier. The space industry's pursuit of efficient technologies has contributed to the development of advanced hydrogen applications, including the use of new materials in fuel cells. Hydrogen's storage potential addresses intermittency issues in renewable energy, allowing excess solar energy to be stored and converted back to electricity when needed. Embracing hydrogen as a green alternative holds the potential to transform the Canadian energy landscape and build a sustainable future. Countries like Japan, Germany, and South Korea have embraced strategies to promote hydrogen adoption, investing in research, infrastructure, and industry integration. These efforts reflect a growing global interest in hydrogen as a clean and versatile energy solution.

## Energy storage

The global market for energy storage is expected to attract $622 billion in investment by 2040, driven largely by the growth of electric vehicles (EVs). The International Energy Agency predicts that EV production could reach 43 million units per year by 2030, valued at over $567 billion annually (Government of Canada, 2020a). The development of advanced materials and technologies for use in energy storage systems, such as advanced batteries and fuel cells, is crucial to meeting this increasing demand for EVs and other applications. These materials and technologies can withstand the harsh conditions of space travel, such as extreme temperatures, radiation, and other environmental stresses, making them ideal for use in energy storage systems on Earth.

In addition to the development of new materials and technologies, space exploration and research can also advance our understanding of energy storage and the fundamental science behind it. For example, research conducted on the International Space Station has led to the development of advanced lithium-ion batteries and high-capacity supercapacitors, which have the potential to significantly improve the performance and efficiency of energy storage systems on Earth.

The space industry has played a significant role in the development of new technologies and techniques for energy generation and storage. These innovations have led to the adoption of clean and efficient energy sources, as well as more efficient and environmentally responsible methods for the exploration and extraction of fossil fuels. As the space industry continues to push the boundaries of innovation, it is likely that we will see further advances in energy technologies that will have a profound impact on the way we generate, store, and use energy on Earth.

## 2.4 Additive manufacturing

Additive manufacturing refers to the process of generating objects from 3D model data, typically layer upon layer. This directly contrasts with subtractive manufacturing which involves altering or moulding a larger object until it takes on its desired design (Dassault Systems, n.d.).

The use of additive manufacturing will undoubtedly be critical in building the structures to facilitate a long-term presence on the Moon, and the associated advancements will likely have substantial implications for advanced manufacturing and construction techniques for Canada's industrial sector.

The Chinese space program has already identified this as an area of focus, and has plans to test additive manufacturing technologies with a view to using them to construct buildings on the Moon during its Chang'e 8 mission planned for 2028 (3Dnatives, 2023). NASA has similarly identified the potential for additive manufacturing to facilitate further space exploration, agreeing to a USD $57.2 million contract with construction technology company ICON to explore means of building lunar infrastructure including landing pads, habitats, and roads (NASA, 2022). Additionally, NASA operates the Additive Manufacturing Center (AMC), a research lab and production facility operating out of the Jet Propulsion Facility (JPL). The AMC's work focuses on manufacturing space flight hardware and mechanical ground support equipment for NASA missions (NASA, n.d.).

The scholarly community has responded with enthusiasm to the potential for additive manufacturing in space. In recent years, state of the art research related to a trade-off analysis of existing additive manufacturing technologies for use in space (Labeaga-Marinez et al., 2017), and experiments testing the performance of additive manufacturing systems under lunar gravity and microgravity (Reitz et al., 2021) have surfaced.

Beyond space, additive manufacturing has countless applications on Earth including developing machinery parts, generating medical implants or prosthetics, and efficiently printing custom tools (Hexagon, n.d.). The market for additive manufacturing has been identified as a cornerstone of advanced manufacturing practices, and is in fact projected to grow at a CAGR of 21% to $44B by 2027. ISRU promises to drive innovation around materials processing and in-situ construction, with requirements to leverage complex materials derived from lunar regolith to form roads, launch sites, and other equipment necessary to survive in austere environments. As has been the case throughout the history of space exploration, technological advancements that occur as a result of its use in space will undoubtedly cascade to terrestrial applications, resulting in more complex and value-driving use of additive manufacturing.

## 2.5 Indirect innovation sector: healthcare

Healthcare has been identified as one of the key support activities that would need to be improved to sustain a permanent human presence on the Moon. Two aspects have been identified: health services (such as pharmaceutical dispensing, clinics, health checks) and training centres (for instance, treadmills and other exercise).

Technological advancements in the delivery of healthcare services for astronauts in low-earth orbit and deep space could also lead to near-term improvements in healthcare in Canada, since some of the same challenges facing astronauts also apply to unique Canadian circumstances, in particular in remote and northern communities. As humans reach further into space, astronauts will need more autonomous healthcare solutions independent of Earth assistance. The Canadian Space Agency's Health Beyond initiative is one of Canada's contributions to the international space program and aims to come up with solutions to these challenges. Canada's contribution is a transformative approach to the delivery of remote healthcare that increases and facilitates on-site medical capacity and autonomy. This on-site "deep space healthcare model" would address the healthcare challenges to be faced by astronauts during long duration missions to the Moon and beyond.

Canada's new space strategy notes how keeping astronauts healthy in deep space has direct applications in health care in Canada. The federal government is pledging to work with provincial health partners and northern communities so advanced knowledge and technologies gained from the space program can be utilised for tangible benefits for Canadians.

Space industry investments have already improved healthcare in Canada. For instance, Carré Technologies of Montreal developed the bio-monitor for the Canadian Space Agency. Bio-Monitor is a wearable technology that monitors and records vital signs of astronauts aboard the International Space Station. An early version of the tech could be beneficial for athletes, while future versions of the wearable device could help Canadians who are bedridden, housebound, or living in rural communities with limited access to medical support.

Five Canadian companies were selected to build prototypes of the Connected Care Medical Module, which have developed a state-of-the-art technology to increase crews' medical autonomy so they can independently manage their healthcare during deep-space missions in the coming decade. Those could also be dual-use technologies to help solve existing healthcare challenges in remote communities in Canada and elsewhere.

> Space industry investments have already improved healthcare in Canada.

This may involve technological advancements allowing astronauts to diagnose and treat conditions on their own, plus those enabling remote monitoring of astronaut health. The CSA is already working with partners on the development of wearable devices to monitor astronaut health and transmit data for analysis to healthcare professionals on Earth. The CSA says these types of advancements could benefit astronauts during long-term missions to the Moon and may also have near-term applications in Canada.

The remote delivery of medical care in distant areas of Canada is already happening and could benefit from technological advancements associated with the remote delivery of healthcare in space. Euroconsult estimated that nine northern communities in Canada utilised remote telemedicine/E-health solutions and saved $600,000 in 2017 because they didn't have to travel to a doctor. There could also be near-term applications on Earth from Canada's development of wearable devices to monitor astronaut health. Euroconsult estimated that in 2018 over 300,000 Canadians downloaded health and fitness related applications, and one-third of them rely on GPS technology linked to Global navigation satellite systems (GNSS) (Government of Canada, 2020b).

Other dual-use healthcare solutions for space and Earth could have even broader applications. Citi suggests pharmaceutical R&D is an area of particular focus because of the impact of microgravity on atoms and molecules. Pharmaceutical R&D in space could potentially lead to the discovery of new proteins and drug treatments. Assuming microgravity R&D becomes approximately 4% of all pharmaceutical R&D spending by 2040, Citi estimates a potential market value of $14 billion in annual sales by 2040 (Citi, 2022).

## 2.6 Indirect innovation sector: agriculture

Canadian agriculture is reaping benefits from space-based technology in a number of ways. Satellite imagery has helped provincial governments save $75 million to prevent soil erosion. Precision agriculture enabled by GPS satellite navigation has saved farmers up to $550 million per year in terms of improving yield, and reducing fertiliser and irrigation costs, translating into savings of $10-25 per acre. Further, Euroconsult estimated that using satellite imagery to support the canola industry opened up a $100-200 million per year export market for Canadian farmers to the European Union (CSA, 2019).

Another example is NithField Advanced Agronomy, a company based out of southern Ontario, which helps farmers make more efficient use of their land by leveraging satellite-based products such as Canada's RADARSAT data. The company says space-based resources can boost farming productivity, enabling farmers to assess and manage field conditions remotely.

Research conducted by CSA into soilless farming techniques enabled plants to be cultivated in arctic environments with limited resources, making them ideal for space missions where weight and space are critical. By mastering these techniques, space agencies like the CSA and NASA aim to supplement astronauts' diets with fresh and nutritious plant-based food during long-duration missions, enhancing their nutrition and well-being while exploring other worlds. Additionally, the knowledge gained from space-based experiments can have practical applications on Earth, contributing to more sustainable and efficient agricultural practices for a growing global population. This is evidenced by the CSA's work on the Naurvik project in Nunavut (CSA, 2021).

Canada's new space strategy says technology used to grow food effectively in Canada's most remote regions, which often have the harshest environments, could one day be matured to grow food for astronauts on the Moon or in deep space. By fostering this ability, Canada is solving two challenges – food security in the remote regions of the country, and feeding astronauts on the Moon.

As humans travel further into space, technological innovation is going to be required to grow food on-site using lunar water. This in-situ resource utilisation is going to require significant technological advancement in the agriculture industry that could have dual-use benefits with terrestrial agriculture. PWC notes that agriculture on the lunar surface will be key to producing food and sustaining life (PWC, 2021). This could possibly be done by using "biosphere" cylinders and lunar greenhouses. Agriculture on the Moon isn't something that might happen; it must happen.

In fact, Canadians are already working on applications for lunar agriculture. And those solutions could help solve challenges in Canada and beyond. University of Guelph researchers are working on techniques that could one day allow for the growth of crops on the Moon, and later, Mars. The task on earth is immense: by 2050, food production must increase by 70% just to manage Earth's current forecasted population growth.

Goldman Sachs (2016) noted how space-asset utilisation technologies are already playing a bigger role in agriculture on Earth, for instance via the more frequent use of drones, automated farm-vehicles and in the utilisation of remote sensing. These technological advancements enabled by space-asset utilisation have only just begun to impact agriculture on Earth.

In the near future, greater use of space-asset utilisation, then in-situ asset utilisation, will bring more efficiencies and innovation to agricultural businesses. The benefit to Canadian farms by satellite navigation alone could reach over $1 billion per year if all farms adopted satellite navigation. Today, about 45,000 farms use satellite navigation in some way, representing over 50% of total farmed acres, creating $575 million per year through cost savings.

## 2.7 Summary of existing policy alignment

Space Mining and ISRU align with a number of Canada's existing policies and mandates at a federal level. It is the thesis of this report that supporting ISRU as a moonshot is not only in line with current policy, but helps to achieve those key policies while balancing Canada's commitment to industry, its citizens, and its social responsibilities. The following details those effects across strategic government mandates.

### 2.7.1 Global mining leadership

Canada is a world leader in natural resources. It is a key priority of the government to maintain Canada's mining dominance and competitiveness globally. The 2021 Mandate letters include the words "positioning Canada as the leading mining nation" (Trudeau, 2021). Canada's key mining policy document, the Canada Mines and Minerals Plan lays out a vision for "Canada is the leading mining nation" as its centrepiece. It laid out a strategic opportunity for Canada in space mining, not only for our competitiveness, but also for the opportunity of innovation to help our mining industry today in efficiency and cost. Canada identified "Early action from Canada regarding mining new frontiers would demonstrate leadership, signal that Canada welcomes innovation and investment, and support the transfer of technology between sectors". Space is the new domain of mining, and therefore should formally be considered a part of Canada's leading mining nation strategy.

### 2.7.2 Critical minerals strategy

An extension of Canada's leadership in natural resources is its critical minerals strategy. There is a very strong tie between the innovation from ISRU and contributing to the government's critical minerals strategy, with both ISED and natural resources. Not only will ISRU and ISRU-related technologies drive innovation in mining exploration, development, and processing, but the Moon itself is considered the next strategic domain for critical minerals, with China having made statements towards that recently (Modern Diplomacy, 2023).

> “Support the Mines to Mobility Strategy by attracting anchor investments in key areas like minerals processing, cell manufacturing and zero-emissions vehicle parts and assembly manufacturing, and use all tools, including the *Investment Canada Act*, to ensure the protection and development of our critical minerals. This will include working with the Minister of Natural Resources to develop and launch a Canadian critical minerals strategy to position Canada at the forefront of critical mineral exploration, extraction, processing and manufacturing, as a global leader in the production of batteries, and other clean and digital technologies, as well as to develop a sustainable battery innovation and industrial ecosystem in Canada, including to establish Canada as a global leader in battery manufacturing, recycling and reuse.

The urgency around critical minerals has already given rise to other national strategies, including the Pan-Canadian Geoscience Strategy, and the National Quantum Strategy. Each of these calls for novel innovation in sensor technologies that can explore and identify natural resources with transformative precision. As previously discussed, ISRU technologies are closely linked to each of these priorities and – if pursued with ambition and determination – will innately drive Canada towards its critical mineral objectives.

### 2.7.3 Net-zero goals

ISRU’s potential for affecting net-zero goals cannot be overstated. From emission-free energy generation and storage solutions for advanced manufacturing, the electrification and decarbonization of industrial equipment, and sustainable REE processing, to advanced quantum and geoscience technologies to revolutionise mining and reduce unnecessary ecological damage caused by traditional exploration methods, ISRU technologies promise to reduce the carbon footprint from industries that are well established as the largest GHG contributors worldwide.

Multiple letters reinforce the need for Canada to hit its net zero targets. Advanced manufacturing, mining, and energy will all play important roles in achieving them, with the call to "meaningfully transform Canadian industry to lead and compete in a net-zero emissions future" (Trudeau, 2021). ISRU technology delivers next-generation capabilities to fortify our competitive strengths while still meeting net-zero requirements.

### 2.7.4 Indigenous community development national strategy

Responsible and sustainable methods for managing natural resources will also help Canada manage its obligations for respecting northern Indigenous land, while balancing the country's need for resources and for securing the northern passage from foreign threats. As of 2019 the value of mineral production across Canada's Northern Territories was CAD $3.3B (Government of Canada, 2021c). According to the Canadian Northern Economic Development Agency (CanNor) (2023):

> "Much of Canada's mineral resource potential lies in the territories. There are existing mineral deposits with the potential to support resource extraction projects within the territories, including diamonds, gold, base metals and silver, tungsten, uranium, rare earth element, iron ore, zinc, and copper. The government of Canada supports sustainable mining including the mining of critical minerals that will help move Canada to a low carbon/green economy. Critical minerals are essential building blocks for renewable energy and clean technology applications (e.g. batteries, permanent magnets, solar panels and wind turbines), advanced manufacturing, consumer electronics and other applications.

The introduction of precision exploration and clean processing methodologies that are driven by ISRU innovation, such as QASM and HYDRO mentioned previously, can be deployed to ensure non-disruptive and responsible strategies for co-developing mining sites with our Indigenous communities.

Another critical consideration for Indigenous communities is the inequitable access to power, heat, and health care in Canada's North. In British Columbia, for instance, only 40% of people living on reserve have access to natural gas to heat their homes, compared to 95% of other BC residents (Ecotrust Canada, n.d.). Nationwide, estimates indicate that as many as 200 Indigenous communities are not connected to an electricity grid (McCarthy, 2016). ISRU technology, like micro-reactors and modular health infrastructure, will be specifically created as sustainable and efficient innovations for delivering necessities to remote, off-grid industrial operations in the most extreme environment. As a result, Canada's Indigenous communities can be among the largest beneficiaries of these technologies.

### 2.7.5 Inspiring the next generation of STEM innovators

GoC mandates include supporting STEM pursuits at every level, which include: a leadership role for the Ministry of Education; integrated roles for NRCan, ISED, and many others to find opportunities to support and inspire STEM activity; and of course CSA's primary mandate to inspire the next generation of STEM innovators. STEM is a clearly identified priority across almost all ministries. Space has always captivated minds, inspired curiosity, and focused talent in ways never thought possible. The space race of the 60's was the first such example, where America's Apollo moonshot catalysed talent in unprecedented fashion. An ISRU moonshot will do the same for Canada and, as discussed throughout this report, will serve to disseminate that talent across strategic industries that traditionally have challenges attracting the most innovative Canadians.

# 3
# Key recommendations

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# 3
# Key recommendations

**The opportunity to leverage** a unified national focus on ISRU has clear and permeating benefits to Canada, its citizens and its industry. However, budget alone is not going to deliver latent potential for jobs, talent and motivation that is contained within ISRU. There are clear regulatory and procurement frameworks that need to be considered as well. The following are 5 key recommendations that integrate funding, regulatory and procurement frameworks that can propel Canada to the forefront of this generational opportunity.

## Recommendation 1

### Pass a two-phased space resources law and adopt a clear regulatory regime in order to create the right regulatory clarity for industry to thrive.

There is no perfect space resources regulatory framework. The recommendation is for a two-phased approach, firstly establishing a simplified Phase 1 space resources law based on the work that has been done by other allied nations (USA, Japan, Luxembourg). This will permit industry and capital formation to take place. As the industry evolves into the late 2020s, Canada can revisit the framework and put in place a more holistic Phase 2 law that incorporates all of the necessary nuance.

Delaying Phase 1 by attempting to go directly to Phase 2, will only be detrimental to Canada's economic and strategic interests, and risk suffocating a young industry. An approach similar to that with commercial launch in Canada would be appropriate, where an announcement is made supporting space resources to signal the country's intentions and establish a clear timeline for implementing the two phases. Canada needs to send a clear signal to the rest of the world that we are leveraging our world leading capabilities in mining to the benefit of our allies and the international community.

## Recommendation 2

Amend the *Income Tax Act* to allow the Mining Specific Tax Provisions to include space (including the Moon, asteroids, and other celestial bodies), in order to make Canada the most financially attractive space mining jurisdiction, as it has done with terrestrial mining.

Much of the strength of Canada's resource industry originates not just from its endowment of natural resources, but from Canada's unique investment environment. Through the use of Mining Specific Tax Provisions, Canada has created the ideal jurisdiction for mining companies to reside, operate, and more importantly raise capital. As a result, Canada has the single largest capital markets for natural resources on the planet, one which finances 52% of all mining deals on an annual basis. Extending those provisions to space, would give Canada an advantage in competing at a global level for space resources.

All space resources activities and sale of products will occur outside the jurisdictional boundaries of Canada, therefore taxation would be considered extraterritorial and so mining operations in space could be considered as "foreign operations". In order to ensure economic benefits flow to Canada along with potential tax revenue, careful crafting of the definition of what constitutes eligible exploration expenses is required.

While it is uncommon for a Canadian mining corporation to conduct foreign activities directly, where this occurs the Canadian mining corporation computes its income (or loss) from those activities under essentially the same rules that apply to Canadian-source activities, with some exceptions:

- most expenditures related to the foreign mining activities are treated as foreign resource expenses (FRE), being the foreign equivalent of CEE and CDE under the Canadian income tax regime;

- foreign mining activities are located on the Moon, asteroids or other planetary bodies, but since there is no formal taxation treaty with these bodies, Canada's rights to tax are not limited by the terms of a tax treaty; and
- to the extent that income or profit taxes are levied in the foreign jurisdiction where such activities are carried on, the Canadian mining corporation would typically be entitled to a foreign tax credit (FTC) under Canadian tax rules, which reduces Canadian tax otherwise payable on the same income that the foreign jurisdiction is taxing. Because no tax is deducted at source, then all taxation flows to Canada.

Since much of this activity will be occurring within the jurisdiction of Canada, the economic benefits and tax revenues will be maximised within our borders. Space mining will be a boon to Canadian companies specialising in high tech industries with high knowledge requirements and high pay. In addition, this will likely benefit Canadian university programs that specialise in mechanical engineering, robotics and aerospace technologies.

The Emerson report (2012) called for extending the favourable tax treatment currently afforded to investors in flow-through shares of mineral exploration companies to investors in commercial activity in space, whether or not that activity is mining related. This measure has the potential to encourage private sector efforts over the long term. Given that Canada has a small number of commercial space firms, annual expenditures for this measure would be marginal.

Flow-through shares (FTS) can provide mining companies with a reduced cost of capital on a net basis, which would make Canada one of the most attractive global jurisdictions for space resources. It would also allow Canadian space resource companies an opportunity to catch up globally in terms of capital raising, where they lag peers in US, Japan, and Luxembourg.

Furthermore, extending the Mineral Exploration Tax Credit to Canadian corporations engaging in space resource exploration with specific intent to mine in space would give this industry an advantage over international peers. The Mineral Exploration Tax Credit (METC) is designed to help exploration companies raise equity funds and can be used in addition to the regular tax deductions associated with flow-through share investments. The METC is a 15% non-refundable tax credit on eligible exploration expenses including costs related to prospecting, geological, geophysical, or geochemical surveys to search for base and/or precious metal deposits. This program has been highly successful in stimulating private equity investment in Canadian Exploration and Mining companies and has contributed significantly to making Canada the world capital for mine finance, mining exploration, and development.

These means of financing space are net positive for the government as it funds the development of innovation that is already a positive cash flow for the country. Technology that can enter the rest of the economy and extend our stronghold on terrestrial mining.

## Recommendation 3

### Allocate a sufficient amount of capital in the upcoming budget for space resources companies, technologies, research and development, and projects.

A national strategy, or moonshot, calls for the government to allocate sufficient capital through non-traditional departments to highlight the importance of space investments as a national, mission-oriented innovation strategy and enable Canada to catch up to the rest of the world in space resources. In combination with the above recommendations designed to give Canada an advantage, a sufficient allocation in the budget across multiple departments would allow Canadian industry the ability to be on even footing with the rest of the world from a capital perspective. This is best done utilising a whole-of-government approach, driven by NRCan, ISED, and the CSA, among others.

## Recommendation 4

### Consider the opportunity in space nuclear when updating its regulatory regime, and clear a regulatory pathway for the solutions provided by industry.

Building on decades of leadership in nuclear technology development, and a trusted position as global partner, Canada has a clear opportunity within the domain of space nuclear. CSA needs to be able to authorise and validate the launch of a reactor into low earth orbit or the lunar environment. Clearly there is no path to permit this activity within Canada, and it will likely need the cooperation of other nations partners as NASA.

In order to demonstrate and validate this capability for operation in space, CSA will need to coordinate with GAC, NRCan and other agencies to create a regulatory pathway. Canada will need to find a way to do this without getting the US to sign the *Non-Proliferation Act*. This work and the challenges associated with it should likely have been charted out as part of the work conducted by CSA in its studies with NRCan and CNL, as well as the work conducted by MDA as part of LSEI in the Power category.

## Recommendation 5

That the government rethinks its approach to space in order to create a healthy sandbox environment that allows private capital to flow into the Canadian space industry so that the government is not the sole funder.

The CSA should take a multitiered approach to ensuring that Canada has a functioning space industry. It is crucial to ensure that a proper sandbox environment is created in order to support entrepreneurship, capital inflows, and opportunities, all while mitigating the government's risk and protecting Canada's strategic interests. Some immediate steps are as follows:

- embracing an approach where the CSA acts as anchor customer, with risk-gated commitments to purchasing goods or data that allow space companies to use government credit as a prime customer to finance the development and commercialization of technology;
- supporting the inflow of private capital into the industry through a fund leveraged by institutional equity or venture capital. This could be administered through a PPP arrangement, or through a dedicated BDC

Venture fund that would target space and aerospace, driving strategic investment into space, and ensuring sufficient capital to support emerging Canadian industry;

- consider modernising procurement processes towards a faster moving newspace approach as has been done in competing nations. CSA's Health Beyond C2M2 initiative is a great example of this rapidly iterating approach, rather than the long drawn out prime contracting method which worked in a less competitive global environment;
- provide sufficient regulatory clarity for novel parts of the industry to allow private capital to flow into the industry that would be otherwise hampered by a lack of timely regulation; and
- consider CSA's use of its capital with respect to its ability to issue and guarantee debt within the *Canadian Space Agency Act.* A program could be established which allows for low or zero interest loans to be administered within the program that would allow for not only capital outflows, but would provide a mechanism for an "evergreen fund" through which the CSA can realise a return of capital. This would provide an ability for the CSA to support industry, while growing its capital base over time, even if there was static budget growth.

# 4
# Conclusion
# Opportunities for Canada

NASA

# 4
# Conclusion
# Opportunities for Canada

**Space has always captivated minds** and propelled our civilization. From the first steps of humankind we have looked to the stars with wonder. They have been pivotal in our asking of the great questions of who we are and where we came from. Millenia later, a generation was captivated as the Apollo astronauts took "one giant leap for mankind"; a moment that still resonates. A generation of Canadians were transfixed as we saw the Canadarm on the space shuttle, and later its big brother on the ISS. Today, an entire generation around the world is in awe of every image that comes out of the James Webb Space Telescope, chipping away at the same big questions we've been trying to answer for millenia. Space has a unique ability to inspire, creating a generation of scientists, engineers, and explorers with every watershed moment. All of these have driven immense innovation with direct applications to the missions at hand, and indirect applications in ways unforeseen. Space mining could be our next moment, our next moonshot.

In-situ technologies and their dual-use applications on Earth could be part of the solution to the biggest challenges facing Canada today, from carbon neutral energy generation moving Canada closer to its net-zero emissions target by 2050, portable healthcare applications to meet the needs of our ageing population, to direct economic opportunities in the burgeoning trillion-wdollar space industry.

An important question is whether Canada is keeping up, losing ground or maintaining its competitive advantage in the space industry. Measuring the space industry in revenue shows that global space revenues grew 74% from 2005 to 2015, whereas Canada's space revenues grew 44% over the same period. An opportunity exists to increase Canadian investments in the sector to recognize a greater share of global revenue.

This report has identified the opportunities in the space economy for Canada, in particular with regards to ISRU and space mining. Meeting our full potential and becoming global leaders in these areas will require concerted support and collaboration. To that end, the report recommends that Canada develop an ISRU strategy; provide meaningful financial support at the level of that provided to the Canadarm and lunar rover programs; and coordinate the development of a Galactic Supercluster to bring together the necessary stakeholders and creative minds in industry and academia.

# About CSMC

**The Canadian Space Mining Corporation** (CSMC) is a vision-oriented infrastructure firm focused on enabling a sustainable presence in space by solving large challenges on earth in the areas of resource utilisation, healthcare, and energy. These operations will support the development of the infrastructure and technology necessary to support a robust ex-terran economy, with dual uses on earth, benefiting Canadians well on the way to getting to the Moon.

In true Canadian spirit, CSMC intends to achieve its Lunar objectives through the establishment of a robust and cooperative consortium of value-based organisations, spanning industry, academia, and government, both domestically and abroad. This ex-terran project will seek to extend Canadian leadership in sustainable mining practices beyond Earth, into the next frontier of resource development.

Its five core team members bring decades of experience managing high profile complex projects in Canada, for NASA, and abroad. These include the most high profile mission critical space missions for Canada like Radarsat missions (1, 2, & RCM), Canadarm 1-3, the privatisation of Canada's nuclear energy industry, as well as dozens of space instrumentation and mining projects. CSMC's principals have extensive experience in development and construction of properties and infrastructure in both urban and remote environments, something which is relevant to their mission.

Since its founding in 2020, CSMC has won three major contracts with the CSA, including the Lunar Surface Exploration Initiative (LSEI), where it is leading the work for Space Mining and In-situ Resource Utilisation (ISRU) for Canada. CSMC is the only start-up competing for Canada's next large space exploration program with LSEI. CSMC also built a prototype hospital for the CSA as an early-stage concept for a lunar medical clinic as part of the C2M2 program. This shipping container medical clinic provides a disruptive infrastructure technology for delivering healthcare to remwote and indigenous communities in the most extreme and harsh environments. In addition CSMC has only one of five funded projects for space nuclear power on the planet, and the only major funded one in Canada.

CSMC has approximately 15 employees between Toronto and Montreal. CSMC is going to the Moon. We believe that doing so is in Canada's national interest, ensuring Canada's continued competitiveness going forward, especially in the resource sector. The CSMC is Canadian at our core, galactic in our vision, and international in our approach.

**csmc-scms.ca**

# About NGen

**Next Generation Manufacturing Canada (NGen)** is the industry-led, not-for-profit organization leading Canada's Global Innovation Cluster for Advanced Manufacturing. NGen is dedicated to building world-leading advanced manufacturing capabilities in Canada, for the benefit of Canadians.

We aim to strengthen the Canadian economy and create high value jobs for Canadians while contributing solutions that address some of the world's most pressing challenges in areas like health care, energy and resource management, and environmental sustainability. NGen Canada works to achieve these objectives by leveraging the research, technology, and industrial strengths of Canada's advanced manufacturing ecosystem.

We create new opportunities by combining the capabilities of our country's manufacturers, engineering and technology companies, business services, researchers, academic institutions, innovation centres, business networks, and our high-quality workforce. By enhancing collaboration, NGen aims to improve Canada's industrial innovation performance, connect and strengthen our advanced manufacturing ecosystem, and increase the competitiveness and growth potential of Canada's advanced manufacturing companies.

**ngen.ca**

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