Soaring into Space:

Exploring the Industrial Opportunities of the New Space Economy for Hong Kong

Research Report

香港工業總會
FHKI Federation of Hong Kong Industries

Contents

Foreword

The National 14th Five-Year Plan has identified aerospace as one of the key strategic emerging industries. Furthermore, during the 20th CPC National Congress, it underscored the goal of accelerating the establishment of a strong aerospace nation. This year, the 20th Central Committee of the CPC has also proposed to enhancements to the policies and governance system to promote the development of the aerospace industry, demonstrating the country's emphasis and determination regarding aerospace. Recently, the country's aerospace industry has developed rapidly, achieving remarkable accomplishments, while various provinces and cities have successively introduced policies related to the aerospace sector. These policies aim to strengthen the core competitiveness across different parts of the industry chain, from research and development to manufacturing and modern service industries. In 2022, the country selected payload specialists for the first time in Hong Kong, which not only reflects the central government's high level of trust in Hong Kong but also demonstrates confidence in Hong Kong's research talents, along with expectations for Hong Kong's contributions to national innovation and technology development. Hong Kong possesses a strong foundation in scientific research and has actively developed into an international innovation and technology hub in recent years, aiming to enhance new quality productive forces. We hope that the government, industry, academia, research institutions, and investors can work together to seize the opportunities presented by space exploration, thereby creating a new landscape for the development of industries in our region.

The New Space Economy encompasses a wide range of industrial sectors, leveraging the achievements of innovative technologies to create commercial value. It also facilitates the integration of cutting-edge technologies into existing industries, thereby enhancing manufacturing processes and significantly driving forward advanced industries. Although aerospace technology and the new space economy may seem distant, they are not beyond Hong Kong's reach. Hong Kong possesses a robust foundation in scientific research, with local university teams having participated multiple times in national-level aerospace missions. In recent years, several higher education institutions have introduced courses related to aerospace, training professionals in this field. Furthermore, Hong Kong boasts a highly open and internationalised business environment, along with excellent international communication infrastructure, providing favourable conditions for full participation in the new space economy.

This timing and context have fostered collaboration between the Federation of Hong Kong Industries and the City University of Hong Kong. Through this research, we aim to understand Hong Kong's advantages, potential, and key areas in developing the new space economy, as well as to provide relevant recommendations to stakeholders. The aerospace industry ecosystem in Hong Kong is gradually taking shape, and we hope that all sectors can leverage Hong Kong's research foundation to promote the transformation of top-tier research capabilities in aerospace engineering into part of the "New Industrialisation". This will enable the exploration of broader potential opportunities in the new space economy and support the growth and development of the nation's key scientific research and economic industries.

FHKI Chairman
Steve Chuang
December 2024

Introduction

For the past two decades, the global space economy has continued to grow steadily (OECD, 2022; Petroni & Bigliardi, 2019). Many advanced economies see space as the next new frontier and as unexplored territory for economic growth. According to KPMG (2020), more than 80 countries and territories are already operating satellites in orbit. The Space Foundation also reports that the overall space economy of the world increased from US$423.8 billion in 2019 to US$447 billion in 2020 despite the challenges of the COVID-19 pandemic and the decline of global government spending on space programs (Space Foundation, 2020; Werner, 2021). This shows the resilience and long-term potential of space investment.

What is "new" about the space economy is that it is driven, financed, and developed not just by the public sector, but by the combined efforts of public agencies, private entrepreneurs, venture capitalists, universities and research institutions, and even by individual consumers (Peeters, 2021). The new space economy has also shifted away from a limited focus on space exploration, scientific experiments, and military purposes to broader commercial interests and socio-economic development goals. Because of the advancement of rocket technologies and the rise of commercialization opportunities, many private aerospace companies have now emerged. These companies rely on cost-effective, recoverable rockets to do space-related activities and support a wide variety of industries, including satellite and telecommunication, new materials development, advanced manufacturing, mineral extraction, hazardous waste disposal, new agriculture, and space tourism.

Since the new space economy is supported by commercial interests and motivated by broad socio-economic benefits, it has stimulated many new opportunities and expanded international collaboration. In the 2020 Space Economy Leaders meeting, Hongliang XU, Secretary-General of the China National Space Administration, commented that the "[d]evelopment of space technology, communications, navigation and Earth observation play an important role in our daily lives, promoting social progress and achieving our way of livelihood. Space technology has become a pivotal part of the world economy and it will help our future economic development. We expect many benefits of space technology for all mankind…." (KPMG, 2020, p. 15). The United Nations Office for Outer Space Affairs (UNOOSA) also states that,

> "Space technology is the driving force behind numerous services and products that have become indispensable in our daily life and even more during the pandemic. Earth Observation, Global Navigation Satellite Systems and satellite communications have played a key role in addressing the COVID-19 crisis, for example enabling us to work from home and track the impacts on our environment. ….. As the world builds back better, space continues to contribute both directly and indirectly to

socio-economic development and help achieve the Sustainable Development Goals (SDGs)." (UNOOSA, 2022c, p. 2)

It is in this context that this report examines the significance of the new space economy and the implications for Hong Kong industries, education and research, and public policies. As a global financial centre with good access to venture capital and entrepreneurial talents, and as an international innovation hub in South China with top-ranking universities and research institutions, Hong Kong is well-positioned to become an active participant in the new space economy.

Based on documentary research, comparative policy analysis, and inputs collected from more than 30 stakeholders in various industrial and educational sectors,[1] the research team co-led by Prof. Alfred Tat-Kei Ho and Professor Yong Yang at City University of Hong Kong examines why Hong Kong should pay serious attention to the global development of the new space economy and considers what policies and cross-sectoral actions should be pursued to help Hong Kong achieve a stronger competitive advantage in the long run.

In the following, the report first provides a definition of the new space economy and highlights its key characteristics. Then it analyses the significance of this development, how it is linked to the long-term growth of many economic sectors and the global agenda of sustainable development, and what a few advanced economies have been doing strategically to position themselves as space economy leaders. Finally, based on a strategic analysis of Hong Kong's unique position and strengths, the report recommends sub-segments of the new space economy that Hong Kong may focus on, and policies and strategies that should be pursued by the government, businesses, universities and the research community, and primary and secondary schools in order to foster more cross-sectoral partnership and create new opportunities for Hong Kong in the new space economy.

[1] Insights and recommendations from more than 30 stakeholders, including representatives from electronic components, feedback control and intelligent equipment, industrial automation control systems, advanced materials, energy, advanced manufacturing, urban agriculture, secondary education, and university education, were collected through in-depth interviews and surveys.

Soaring Opportunities for Hong Kong: An Overview of the New Space Economy and Implications for Hong Kong Industries and Society

Definition and Characteristics of the New Space Economy

The term "space economy" refers to the economic activities and the production of products and services related to the exploration of space, the development of space technology, and the use of space resources. As a result of the Cold War between the Soviet Union and the West and the successful launch of the USSR satellite Sputnik in 1957, the West led by the U.S. began to invest heavily in space programs. This "old" space economy was motivated primarily by national defence and scientific research purposes. From the exploration of space and basic research, to the development and management of space-related technologies, the government was the primary funder of space-related economic activities.

During this stage of development, the scope of the space economy was quite limited, constrained primarily to the education sector, research, and military-defense industries. As a result, the immediate economic value contributed to the whole economy by these activities was relatively small. Nonetheless, research has shown that many space-related technologies and projects that were originally developed primarily for military or basic research purposes were later translated into highly valuable commercial products years or decades later (Crawford, 2016; Kratz et al., 2014). This phenomenon is known as dual-use technology, which refers to tools or methods initially developed for military applications that prove commercially viable enough to be adapted and manufactured for industrial or consumer purposes (Kratz et al., 2014). This allows expensive technologies created for defense to also benefit civilian commercial entities when not being utilized for their intended military role (Kratz et al., 2014).

Examples of dual-use technologies abound in various sectors. Military spending on research and development led to the creation of personal computers and networking technologies, ultimately paving the way for the Internet and e-commerce (Jorgenson et al., 2023). Similarly, jet engines, originally developed for military aircraft, significantly increased the speed of commercial planes, contributing to the growth of the aviation industry (Lohmann & Pereira, 2020). The Global Positioning System (GPS) in the U.S., initially designed for military navigation and positioning, has become indispensable in many commercial applications, such as car navigation systems, smartphones, and wearable devices (Cui, 2022). Satellites, originally intended for military and space exploration purposes, now play vital roles in global communication, remote sensing, climate observation, data collection, resource exploitation, transportation, and other commercial applications (Wouters et al., 2017). The precursor to the internet, known as ARPANET, was initially created by the U.S. Department of Defense's Advanced Research Projects Agency (DARPA) for military communication purposes (Özkula, 2021). This groundbreaking technology subsequently revolutionised global communication and information sharing.

Furthermore, the technology behind microwave ovens, originally developed for radar systems during World War II, found commercial use in cooking (Osepchuk, 2015; Posen et al., 2018). Unmanned aerial vehicles (UAVs), initially employed in the military, have expanded into the civil sector for commercial and research applications, including photogrammetry and remote sensing (Berra & Peppa, 2020). In fact, as Visionspace reports, numerous modern technologies used by the world today, such as the computer mouse, cell phone cameras, the technologies used by CAT scanners and radiography, memory foam padding, water purification systems, nutritional enrichment ingredients used in baby formula milk, and solar power technology, were originally developed by scientists and researchers of the National Aeronautics and Space Administration (NASA) of the U.S. to support space missions and program needs (Verissimo, 2021).

Additionally, NASA's space station research has led to a wide range of scientific and technological advancements for the benefit of life on Earth. These breakthroughs encompass fundamental disease research, the development of new water purification systems, drug development utilising protein crystals, and growing food in microgravity, methods to mitigate muscle atrophy and bone loss. They have also led to the stimulation of the low-Earth orbit economy, 3D printing in microgravity, and response to natural disasters, among other notable achievements (NASA, 2020a). The knowledge gained and technologies developed through space station science research contribute to advancements in fields such as healthcare, environmental monitoring, disaster response, wastewater management, food production, energy efficiency, and more. Hence, even for the "old" space economy, the long-term economic value and social benefits should not be overlooked (Gurtuna, 2013; Koshova, 2022; OECD, 2012; UK Space Agency [UKSA], 2022).

Indeed, public investment in the space economy does bring significant socio-economic benefits. Koshova (2022) emphasizes that space activities contribute to the effective development of national economies, strengthen national security, defence, and overall strategic competitiveness. Additionally, Crawford (2016) and Koshova (2022) highlight the role of government space programmes and investment as the driving forces for economic growth and the development of scientific and technological potential. Gurtuna (2013) further supports the socio-economic benefits associated with government investment in space activities.

These benefits include driving technological innovation across various industries, leading to economic growth and improved quality of life (Gurtuna, 2013). Investment in space activities stimulates economic growth, job creation, entrepreneurship, and innovation (Gurtuna, 2013). It also promotes infrastructure development, scientific research, knowledge generation, environmental monitoring, resource management, international cooperation, and diplomacy (Gurtuna, 2013). Moreover, space activities inspire and educate the public, particularly in the fields related to science and engineering (Gurtuna, 2013). In summary, space exploration and aerospace technologies offer extensive socio-economic benefits, spanning multiple sectors and contributing to societal progress (Crawford, 2016; Gurtuna, 2013; Koshova, 2022).

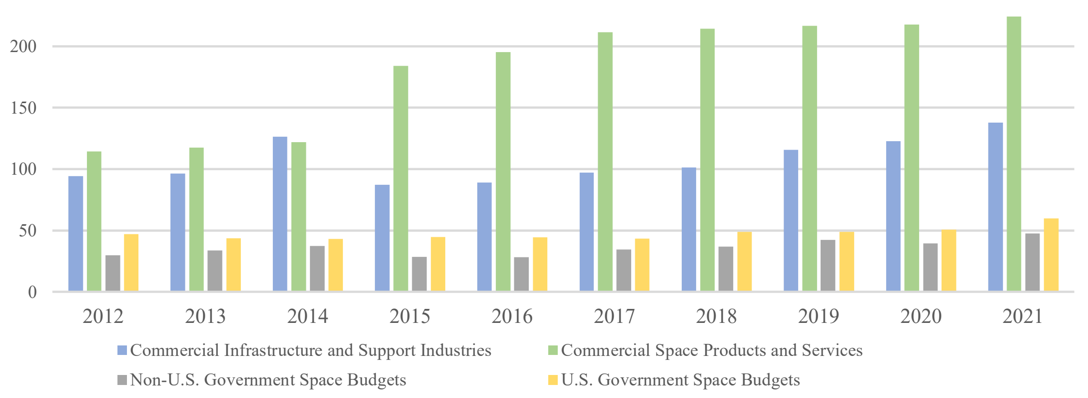
The economic impact of public investment in the space sector extends beyond socio-economic benefits, with studies indicating significant returns on investment. The Midwest Research Institute (MRI) report, commissioned by NASA, examined the relationship between NASA's research and development (R&D) expenditures and technology-induced increases in the U.S. Gross National Product (GNP) (Gurtuna, 2013). The research revealed that for every dollar NASA invested in research and development activities during the years 1950 to 1969, there was an associated average increase of somewhat more than $7.00 in the gross national product up until 1987 (Gurtuna, 2013). Furthermore, the economic impact of space programs is exemplified by the Apollo space program, where a $25 billion government investment resulted in an astounding $181 billion return to the economy (Holt, 2011). Similarly, the UK Space Agency (UKSA, 2022) highlights a noteworthy return on investment, with every £1 of public investment in space resulting in £3-4 in Gross Value Added (GVA) to the British economy. The above findings underscore the substantial economic returns on public investments in the space sector.

In the 1980s, the Soviet Union began to disintegrate, and the USSR no longer had the economic resources to invest heavily in space programs to compete with the U.S. In 1991, the Soviet Union collapsed. As a result, the West no longer had the Cold War as the backdrop and the motivating factor for space programs. Scientists and policymakers began to pay more attention to the potential of the peaceful, civilian usage of space technologies and resources.

The collapse of the U.S. space shuttle program was another triggering event that led to a paradigm shift for the space economy. In 1986, the space shuttle Challenger exploded during launch (Barbosa et al., 2023, p.28-29). Investigation of the disaster revealed many managerial problems at NASA and a lack of necessary funding to support a wide range of military and scientific research and programs (Edy & Daradanova, 2006, p.135; House of Representatives, Congress, 1986, p.136, 168; Romzek & Dubnick, 1987, p.232). Then in 2003, another disaster happened – the space shuttle Columbia broke up in the air when it returned to Earth, killing all seven astronauts (Sanger, 2003). Investigation of the tragedy again revealed many design problems of the space shuttle and program management issues of NASA that had remained since the Challenger disaster (Edy & Daradanova, 2006, p.143, 145; Guthrie & Shayo, 2005, p. 61, 64; Mahler, 2009, p.5-6; Stone & Ross-Nazzal, 2011, p.35). Many blamed the ineffectiveness and bureaucratic culture of government agencies involved in space programs (Columbia Accident Investigation Board, 2003, p. 195-202; Garrett, 2004, p.390; Guthrie & Shayo, 2005, p.62, 66; Leveson, 2008, p. 237; Romzek & Dubnick, 1987, p.232-234). The space shuttle program was finally retired in 2011 (Chang, 2011). Policymakers, the scientific community, and many private contractors of NASA in the U.S. began to argue for the development of private alternatives to the government-led space programs (Comstock, 2008; La Tour et al., 2014, p.11; NASA, 2023; Undseth et al., 2021, p. 23; Weinzierl, 2018; Yaeger, 2021, p. 6-7, 11, 13-16).

All of these developments opened the door to the "new" space economy, in which many U.S. private companies are now leading its development, including Boeing and new companies such as SpaceX led by Elon Musk (Wirbel, 2005). In the new space economy, governments are no longer the sole funders and leaders, as support may come from public-private partnerships and cross-sectoral collaborative activities. Figure 1 shows the growing importance of the private sector in the development of this new space economy.

Figure 1. Global Space Activity by Category, 2012-2021 (USD Billions)



Data Source: Space Foundation

With the wider participation of the private sector, the purpose of space-related activities and product development has broadened beyond the original scientific or military purposes. A wider set of participants and investors, including private investors, business entrepreneurs, and privately-funded research labs, are now involved to support business-oriented activities and technologies for readily available commercial usage (Weinzierl, 2018). These activities also have more civilian and social goals, especially related to sustainable development and humanitarian purposes (UNOOSA, 2015a). For instance, in 2020, the United

States unequivocally declared that the goals of its space initiatives encompass fostering economic expansion and enriching the well-being of both its populace and humanity at large through nurturing, advancing, and fostering space-enabled scientific and economic capacities (Office of Space Commerce [OSC], 2020, P. 1, 6).

Table 1 summarizes the paradigm shift from the old to the new space economy over the past two decades.

Table 1. Contrasting the Old and New Space Economy

	Old Space Economy	New Space Economy
Objective	National security concerns, military objectives, and geopolitical considerations; ambition for economic expansion and technological development; aspiration to sustain and elevate international status and prestige, thereby expanding political influence and military superiority (Diakovska & Aliieva, 2020; Genta, 2014; Rementeria, 2022).	Increased emphasis on innovation, commercialization, and profit orientation (Diakovska & Aliieva, 2020); strong focus on the commercialization of space resources and in-space manufacturing with the potential to create new industries and markets for space-based products and services. According to the OECD (2022), numerous modern goods and services, primarily in the digital realm, utilize products and technologies originally developed for the space sector as an intermediate component or as input in their creation. Spin-off technologies become important, which loop back into the emerging new space ecosystem (Gonzalez, 2023).
Participating countries/ regions	The U.S. and the USSR led other developed countries and a few developing countries (Diakovska & Aliieva, 2020). After the USSR collapsed, Russia's public funding for the space industry was surpassed by the US, China, the European Union, India and Japan (Diakovska & Aliieva, 2020). Ukraine, Kazakhstan and Argentina were also active participants in the old space economy (Blinder, 2022; Diakovska & Aliieva, 2020).	A wider range of developed and developing economies participate in the new space economy because of new technological possibilities and lower costs of entry (Cocchiara et al., 2022; Diakovska & Aliieva, 2020; Sweeting, 2018). The rise of developing countries as players in the new space industry has opened up new international cooperation opportunities in space exploration and technology development (Bezzubov & Borovyk, 2021; Peng, 2023; Rementeria, 2022). For example, developed space countries can offering financial resources and technologies for space resources development (Peng, 2023). Developing countries with insufficient capacity in space or

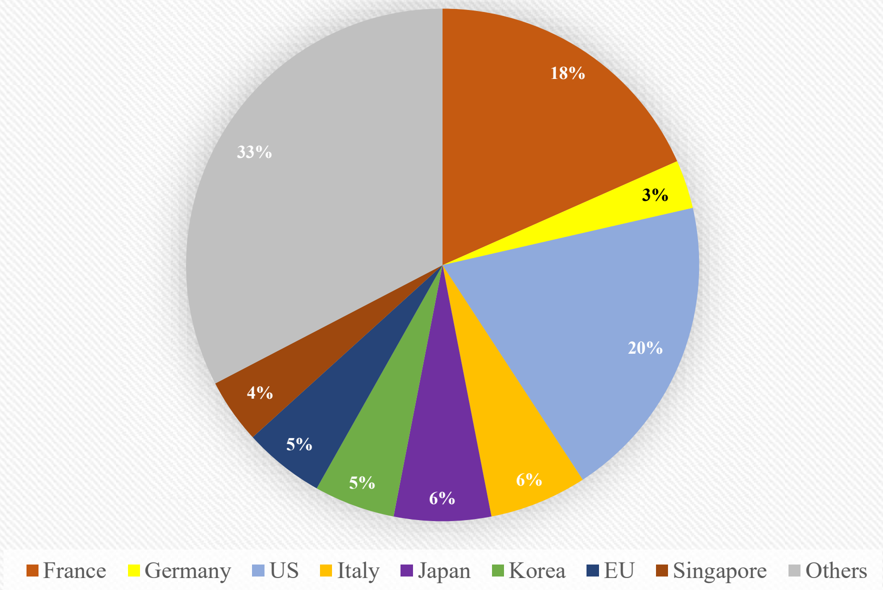
		science and technology, on the other hand, can provide mining labour and processing using information and data generated by satellites (Peng, 2023).
Leaders and their roles	The old space economy primarily focused on government-funded programs, such as NASA's space exploration and satellite launches for military and scientific purposes. Governments dictated the direction of space exploration and controlled access to space resources (Rementeria, 2022). Under the "traditional government-led model" and "public-sector centralised model" of space technology development, research, development, and manufacturing were implemented by publicly funded, state-owned organisations or highly regulated large corporations (Tchalakov, 2015; Weinzierl, 2018). This model did not facilitate extensive mass industrial manufacturing, meaning economies of scale and scope were not prominently at play, with companies primarily acting as contractors for government endeavor (Tchalakov, 2015). In addition, public goods were prioritized over commercial purposes in the past, which hindered the growth of the commercial space sector (Weinzierl, 2018).	Space is not the exclusive realm of governments, public organisations and aerospace and defense companies (Genta, 2014; Rementeria, 2022). Businesses that pursue emerging opportunities now may gain a first-mover advantage within the growing private sector. A range of new space actors, such as private investors, companies, and start-ups (a.k.a "astropreneurs") in both upstream and downstream markets, as well as new entrants from various relevant sectors, including data analytics firms in the information and communications technology industry, are investing and contributing to space exploration alongside traditional government agencies that are also increasingly adopting the new commercialisation approach to space development (Cocchiara et al., 2022; Diakovska & Aliieva, 2020; Gonzalez, 2023; OECD, 2022; Rementeria, 2022). Governments remain pivotal in space endeavours by participating in international treaties and, domestically, by creating a favourable regulatory environment, providing financial support, and committing to research and education (Genta, 2014; Kessler & Peeters, 2011).
Source of funding	For over five decades, space flights and exploration were viewed as programmes that	According to Gonzalez (2023), space companies in the new space economy can be private entities

	could only be financed by highly developed nations, hence making a country's achievements in space exploration directly dependent on its public sector's finance and economic status (Diakovska & Aliieva, 2020).	that operate independently of government space policies and funding. However, new space actors can still receive support from various sources, including government grants and services, participate in government-organized challenges, and win prizes and receive various forms of start-up support, such as incubator and accelerator support (OECD, 2022). Additionally, venture capital investment and crowdfunding campaigns can play significant roles in funding new players in the new space industry (OECD, 2022; Pomeroy et al., 2019).

Experiences of Selected Countries in the Development of the New Space Economy

Many countries have already launched special policy initiatives to encourage the development of the commercialised space economy. The leaders are the United States, France, Italy, Germany and Japan (UNOOSA, 2023c). However, many middle-income economies are also pursuing new space economic development because of its long-term growth potential and significant implications for multiple economic sectors, such as telecommunication, agriculture, and advanced manufacturing (Sommariva, 2018). For example, 98 companies from diverse countries participated in the International Astronautical Congress (IAC) 2022, which is a major annual event of the space economy (see Figure 2). As expected, advanced economies, such as the United States (20%), France (18%), Italy (6%), Japan (6%), and South Korea (5%), had a significant presence, indicating their leadership in the new space economy. At the same time, many smaller countries, such as Israel and Belgium, and even middle-income countries, such as Malaysia and Argentina, were also present.

Figure 2. Countries of Origin of Companies that Participated in the International Astronautical Congress 2022



One of the factors encouraging a wide spectrum of countries to participate in the new space economy is the efforts of the United Nations. Its Office for Outer Space Affairs (UNOOSA) has been doing capacity building and promoting space benefits among many countries, including developing economies. For example, UNOOSA helps countries to build capacity in science and technology development and applications of space tech products, such as leveraging space technologies to improve disaster and climate change mitigation, humanitarian aid, environmental surveillance, and natural resource administration (UNOOSA, n.d.a). UNOOSA also promotes the peaceful uses of outer space to advance international cooperation and helps countries develop legal frameworks and legislation in line with international space law.

The United Nations Sustainable Development Goals (SDGs) can also be integrated into the development of the new space economy, as shown in Table 2.

Table 2. Ways in which space can be leveraged in support of the 2030 Agenda for Sustainable Development (UNOOSA, 2015b)

Sustainable Development Goals	Relevancy with the new space economy
Goal 2: Zero hunger	Space tech development can help humanitarian relief organisations to use remote sensing satellite technologies so that they can provide key data to monitor soil, snow coverage, drought conditions and crop development to predict

	agricultural productivity and production in the world and prevent global hunger and related challenges.
Goal 5: Gender equity	Empowering women in STEM education by creating new education programs, providing opportunities for women scientists and encouraging new role models through space tech development.
Goal 6: Clean water and sanitation	The space economy can create new platforms to explore new technologies and knowledge transfer so that we can improve water purification, water conservation and other related topics.
Goal 10: Reducing inequalities	The new space economy can provide new opportunities to help the younger generation gain knowledge, practical skills and technological training so that they will be ready for a tech-driven economy.

In the following section, the experiences of selected countries are examined to draw potential lessons for Hong Kong, which has begun to explore possible participation in the new space economy.

Case Study: United States

The U.S. has always been a superpower in technological capabilities and the commercialisation of space. In 2021, the U.S. Government spent approximately US$54.6 billion on space programmes, making it the country with the highest space spending in the world (Daedal-Research, 2022, p. 62). With a total of US$28 billion invested in 3,086 companies in 2021, the U.S. is also far ahead in SpaceTech investments, roughly six times the amount invested in SpaceTech companies by China (SpaceTech Analytics, 2021, p. 27).

According to the U.S. Bureau of Economic Analysis (BEA), in 2019, the U.S. space economy accounted for $194.4 billion of the real gross outputs, $42.4 billion of private industry compensation, and 354,000 private sector jobs (Highfill et al., 2022, p. 1). Manufacturing, information, government and wholesale trade are the four largest industries in the U.S. space economy in terms of gross output (Highfill et al., 2022, p. 2).

As explained earlier, the U.S. space economy was initially predominately driven by national security and defense industries. The National Aeronautics and Space Administration (NASA), an independent governmental agency, was established in 1958 as a direct response to the Soviet Union's successful launch of Sputnik, the first artificial satellite (Chatzky et al., 2021). Historically, 85 to 90 per cent of

NASA's budget was spent on private contractors that designed and manufactured rockets and spacecraft, while the agency remained in charge of oversight and operation (Chatzky et al., 2021). However, the space economy landscape has changed drastically since the 1990s when NASA's share of federal funding was slashed and the private sector stepped up in spending. Currently, the major commercial participants in the U.S. space economy landscape are Space Exploration Technologies Corp. (or SpaceX), Blue Origin LLC, Virgin Galactic Holdings Inc., Boeing, Relativity Space, Orbital Sciences Corporation, Astra Space Inc., Firefly Aerospace Inc., Rocket Lab, Lockheed Martin and Jacobs Technology (a technical professional services firm), among others (Daedal-Research, 2022, p. 84-107; OECD, 2022). Among these players, SpaceX, Boeing, Lockheed Martin, and Jacobs Technology are the four largest NASA contractors (by procurement awards) in 2020 (OECD, 2022).

The U.S. government increasingly relies on and establishes Public-Private Partnerships (PPPs) to carry out space missions. NASA's Commercial Crew Programme (CCP) is an old major initiative where partnerships and collaborations with the private sector occur (Sadeh, 2015; Seedhouse, 2016; Weinzierl, 2018). The objective of the Programme is to establish an American commercial crew space transportation system capable of providing safe, dependable, and cost-effective access to and from the International Space Station (ISS) and low Earth orbit (LEO) (Seedhouse, 2016).

The year 2020 marked a milestone when the SpaceX Crew Dragon Demo-2 mission became the first commercially developed crewed mission to the International Space Station under the Programme (Council of Economic Advisers, Executive Office of the President, 2021, p. 232; NASA, 2020b). Under the Commercial Crew Program, two contractors, namely Boeing and SpaceX, are responsible for designing, developing, building, owning, and operating their spaceflight systems and infrastructures (Government Accountability Office [GAO], 2020). Simultaneously, NASA provides expertise and resources throughout the development process (GAO, 2020; NASA, 2019; Seedhouse, 2016). In this model, NASA engineers do not make design decisions, and NASA personnel have a reduced role in processing, testing, launching, and operating the crew transportation system (NASA, 2019). The Programme provided contractors like SpaceX with development funds and used firm-fixed-price contracts (rather than cost reimbursement or cost-plus), which are more conducive to innovation, as the contractors are incentivized to utilize their most efficient and effective manufacturing processes and business operating practices throughout the entirety of the development process (Council of Economic Advisers, Executive Office of the President, 2021, p. 232; GAO, 2020; NASA, 2019; Sadeh, 2015).

The firm-fixed-price contract model places greater responsibility on the contractors, who now assume maximum risk and full accountability for all costs incurred, potentially resulting in either profit or loss (Council of Economic Advisers, Executive Office of the President, 2021, p. 232; GAO, 2020). This approach provides maximum incentives for the contractor to control expenses and deliver effective performance, while imposing a minimal administrative burden on the contracting parties involved (Council of Economic Advisers, Executive Office of the President, 2021, p. 232; GAO, 2020). In contrast, the cost reimbursement or cost-plus contract models previously used by NASA may offer the wrong incentives for companies to increase costs and prolong the length of their contracts (Council of Economic Advisers, Executive Office of the President, 2021, p. 232). Therefore, the contract model employed is crucial, as it must provide appropriate incentives to ensure the efficiency and cost-effectiveness of PPP initiatives.

According to the U.S. Government, PPP has many benefits, such as reducing the costs of space products and services for taxpayers and accelerating the growth of the space economy (Council of Economic Advisers, Executive Office of the President, 2021, p. 232). PPP is now a key strategy to support the development of the space economy in the U.S. (Council of Economic Advisers, Executive Office of the President, 2021, p. 248). For example, in 2020, the Trump Administration announced the National Space Policy Directive providing direction for all space activities, in which the Administration committed to “promoting and incentivising private industry to facilitate the creation of new global and domestic markets for United States space goods and services” and “extending human economic activity into deep space in cooperation with private industry” (Higuera, 2022; Migaud et al., 2021; OSC, 2020, p. 5; Sinclair, 2020; White House, 2018). It also introduced regulatory reforms to enhance the efficiency of government procurement and encourage market entry by more companies (Council of Economic Advisers, Executive Office of the President, 2021, p. 248; Oltrogge & Christensen, 2020). In addition, the Office of Space Commerce (OSC) was created under the Department of Commerce (DOC), with the objectives of “fostering the conditions for the economic growth and technological advancement of the United States space commerce industry” while consolidating certain functions from overlapping government agencies such as the Federal Communications Commission (FCC), Federal Aviation Administration (FAA), and DOC (Higuera, 2022; Melograna & Johnson, 2023; Oltrogge & Christensen, 2020; OSC, n.d.). In conclusion, to ensure the successful implementation of the PPP strategic approach in the space sector, it is essential for governments to establish favourable policies and achieve effective coordination among various government agencies and the industry.

Case Study: European Union

The European Union is another significant power in the new space economy, occupying about 21 percent of the global business, employing more than 230,000 professionals, and generating about €46-54 billion in 2015 (Evroux, 2022, p. 4). The major EU companies in this sector are Airbus, Thales, Safran and Leonardo, which are directly accountable for more than half of the total employment in the EU space industry (Evroux, 2022, p. 4). Also, space manufacturing is a net contributor to the EU trade balance. From 2011 to 2020, space manufacturing accounted for €20.15 billion of EU exports (Evroux, 2022, p. 4).

The EU is particularly strong in the satellite industry. In 2017, the EU accounted for €238.2 billion or 79 % of the value of the global satellite-related business, and in 2021, it occupied 25 percent (€34.45 billion) of the global devices revenues (Evroux, 2022, p. 4). It also created many space technology applications, including the world's most extensive Earth Observation programme, Copernicus (Copernicus, 2022). The satellite industry is strategically important to the EU economy. For example, it is estimated that approximately 10 percent of the EU's GDP (over €1,100 billion) is supported by satellite navigation signals (Evroux, 2022, p. 5). According to the European Space Agency (ESA, 2022a, p. 5), EU member states' investment in satellite communication through its ARTES programme has directly created and sustained at least 17,700 jobs (Textbox 1 is a case study on the programme). Within the EU, France, Germany, and Italy are the top investors in the development (Evroux, 2022, p. 2-3). Traditionally, the ESA, which was established in 1975, is responsible for the development of space programs. For 2023-2025, ESA will have a record-high budget of about €17 billion, a 17% increase compared to the previous budget, in order to better compete with the other two space powers, namely the U.S. and China (European Parliament, 2022; Pultarova, 2022). In 2022, under the Directorate for Commercialisation, Industry and Procurement, the ESA set up a Space Economy Team to promote the exchange of space economy policies and assess the socio-economic impacts of its programmes (ESA, n.d.a). The Team submits a "Report on the Space Economy" to ESA Council annually (ESA, n.d.a).

At the same time, just as in the U.S., private companies have been playing an increasingly important role in the new space economy. To further promote the growth of space-related industries, the European Global Navigation Satellite Systems Supervisory Authority (GSA), which was established in 2004, was reorganised to become the European Global Navigation Satellite Systems Agency in 2010. Then in 2021, under the new EU Space Regulation, it was reformed further to become the European Union Agency for Space Programme (EUSPA) to enhance the socio-economic benefits of space programmes for European society and business (EUSPA, 2022). EUSPA is operated separately from ESA, though the two agencies work closely together.

The EU has two general directions for policies related to the space economy. The first dimension is "policy for space", which is to promote the competitiveness of the European space economy, support its industries, and incentivise the adoption of space applications and data (Evroux, 2022, p. 8). For example, the EU and European space industries have a partnership through the Horizon Europe programme to promote technological advancement needed by the industries. The EU also provides funding to SMEs and start-ups and supports training and educational programs for new space professionals through the EU Space Programme, CASSINI, and the European Innovation Council.

The second dimension of EU space economic policies is about “space for policy,” which focuses on the impacts of the EU’s space investment and its connection with EU policy priorities, such as sustainable development and the promotion of the green economy (Evroux, 2022, p. 5). For example, the EU encourages the use of space data to support precision farming and smart cities so that greenhouse gas emissions can be reduced (Evroux, 2022, p. 8; UKSA, 2020).

Take precision farming as an example: the agriculture sector is a major source of greenhouse gas emissions, accounting for 19–29% of anthropogenic greenhouse gas emissions and 80% of tropical deforestation (Campbell et al., 2014; Schiavon et al., 2021; UKSA, 2020). Changes towards sustainable management practices in agricultural systems are thus required, which can be enabled by Earth Observation (EO) data (Pignatti et al., 2021; Schiavon et al., 2021). Leveraging EO data and other space-based technologies, precision farming can support the monitoring of agriculture, facilitating optimal and sustainable management of agriculture, reducing water usage and chemical inputs (e.g. fertilisers and pesticides), thereby mitigating the overall environmental footprint of agricultural methods, while concurrently boosting yield and profitability (Pignatti et al., 2021; Schiavon et al., 2021; UKSA, 2018; UKSA, 2020). Copernicus Climate Change Services (C3S), EU’s very own Earth Observation Programme, is precisely contributing to this end. C3S offers tailored climate indicators that are specifically designed for agriculture applications, thus providing farmers with information to make better planting decisions (Buontempo et al., 2020). To relay the aforementioned climate data and others, the Sectoral Information Systems are set up for both public and private sectors, especially climate-sensitive sectors, which include agriculture (Buontempo et al., 2020). To provide for the programme, the Sentinel-2 Satellite was launched. Its data are invaluable for remote sensing in precision agriculture, providing detailed and accurate information for crop monitoring, classification, yield prediction, and management decision-making (Segarra et al., 2020).

The EU considers that scientific and technological advancement should not be separate from the social and economic priorities of a society to create value.

Textbox 1.
European Space Agency (ESA)'s Multilevel Collaborative Mechanisms

The European Space Agency (ESA) is an international organisation with 22 member states. ESA promotes cooperation among European states in space research, technology, and their space applications for peaceful purposes and coordinates upstream research and development activities. The goal is to use these advancements for scientific purposes and operational space application systems beneficial to European and world citizens.

As enshrined in its Agenda 2025 titled "Make Space for Europe", ESA recognises the benefits of a vibrant commercial space sector and its ability to serve Europe's societal and economic needs and political priorities (ESA, 2021b). Hence, ESA has been rolling out programmes to facilitate the commercialisation in the European space sector with talent, access to capital and, fast innovation at its core (ESA, 2021b).

The Advanced Research in Telecommunications Systems (ARTES) programme is an example of how the ESA implements Partnership Projects (PPs) with public and private entities, namely the satellite communication industry and governments of member states, in the hopes of transforming investments in research and development into successful commercial products and services (ESA, n.d.c). The "Pacis 3" project is a case in point, in which Spanish private satellite operator Hisdesat, a group of Spanish space industries and ESA, supported by Spain's Centre for the Development of Industrial Technology (CDTI) – a public business entity under the Ministry of Economy and Competitiveness, collaborates with ESA to develop affordable, flexible and secure communications services (ESA, 2021c).

These Partnership Projects encourage innovation by greater risk sharing. ESA takes on the risks associated with developing innovative solutions, while the operators assume the commercial risks in response to market demands. Without this collaborative strategy, numerous experimental projects would not have materialised due to their high technical or commercial risk.

Another flagship programme to stimulate innovation in the commercial space sector is the ESA Business Incubation Centres (ESA BICs), which support space-related start-ups and entrepreneurs to become commercially viable companies based on a space technology or space data. After companies leave the incubation phase, they will join the alumni network with further access to contacts throughout relevant industries. Apart from easy access to capital (i.e. €50k funding, IP development, fundraising guidance, and opportunities), ESA BICs offer multifaceted support for start-ups to flourish, such as technical support from top experts in the region and from ESA, business coaching, workshops, and trainings, as well as legal advice. The programme's most valuable asset is perhaps its regional and national networks and its connection between ESA BICs and their local industries, universities, research organisations, government and investor communities.

To sum up, ESA's cross-sectorial collaboration approach that encompasses public-private sectors, universities, and research institutions, has been instrumental in fostering innovation and driving the commercialisation of space technologies.

Case Study: Japan

After WWII, Japan was not involved in the competition for space technology development due to sanctions against its military capacity building. Hence, for many decades, Japan lagged far behind the United States and the Soviet Union in exploring the potential of the space economy. Most of its work in the 1950s-1980s focused on basic scientific research (Takeuchi, 2019).

The 1990s was the turning point of space technology development in Japan. As the US and EU began to expand the commercialized space economy and focus less on the defense-oriented technologies, Japan had more opportunities to join other countries to explore the space economy. To speed up space technology development, the National Aerospace Laboratory, the Institute of Space and Astronautical Science, and the National Space Development Agency of Japan were consolidated to become the Japan Aerospace Exploration Agency (JAXA) in 2003. In 2008, the Basic Space Law was passed, outlining "the development and use of outer space" as two of its top priorities (Basic Space Law, 2008). JAXA was relocated from the Ministry of Education, Culture, Sports, Science and Technology to the Strategic Headquarters for Space Development (SHSD) within the Cabinet, under the direct leadership of the Prime Minister. In 2016, the Cabinet established the National Space Policy Secretariat (NSPS) (Kurasawa, 2018).

All these efforts signal the rising importance of the space economy to Japanese national policies. With these efforts and significant investment, Japan has successfully become a new space economic power in recent years. For example, the Institute of Space and Astronautical Science at the University of Tokyo launched Japan’s first artificial satellite, Ohsumi, making Japan the fourth country in the world to succeed in this endeavour. Also, with the successful development of its Hayabusa and Hayabusa2 spacecraft, Japan is now a leader in the field of asteroid exploration.

Hayabusa had approximately 100 Japanese companies involved in its development and operation, and this number increased threefold for the Hayabusa2 mission (JAXA, 2023; Kodama & Hoshi, 2019; Uesaka & Yano, 2015). JAXA was responsible for overseeing the project, while information technology company NEC took charge of development and manufacturing (Kodama & Hoshi, 2019; Uesaka & Yano, 2015). Apart from the involvement of private companies, the 600-person team of the Hayabusa2 project also includes hundreds of experts, including engineering staff from JAXA, international scientists, and young professionals ranging from graduate students to post-doctoral researchers (International Astronautical Federation, n.d.; JAXA, 2014). Upon the spacecraft’s return, the “Asteroid Explorer Hayabusa2 Initial Analysis Chemical Analysis Team” was formed by members from various research institutes and universities, such as Okayama University, the Japanese Agency for Marine-Earth Science and Technology (JAMSTEC), Kochi Institute for Core Sample Research, and the

Astromaterials Science Research Group. Textbox 2 illustrates the cross-sectorial collaboration involved in the Hayabusa2 project.

In recent years, Japan and the US have been working closely to develop joint space programs. For example, the NASA STS-124 Mission will launch the Japanese Experimental Module for the International Space Station (also known as Kibo) from the Kennedy Space Center in the U.S. (JAXA, 2022).

The development of satellite programs and launch capabilities is only one aspect of Japan's new space policy. In addition to "space exploration and space science," the Japanese government emphasizes "space development and utilization" and encourages private sector participation in space resource extraction. For example, the Space Resources Act on Promotion of Business Activities Connected to the Exploration and Development of Space Resources (Act No. 83 of 2021) was passed on June 23, 2021. The law authorizes private companies that have received the Japanese government's space activity permit to own space resources (Government of Japan, 2022). For example, under the 2021 Space Resources Act, a Japanese company that specializes in robotic spacecraft and technologies, Ispace, was given permission to mine the Moon's resources, claim ownership of them, and then sell them to NASA, making this the first commercial space corporation in the world that has started commercial activities on the Moon (Ispace, 2022). Other Japanese companies, such as Astroscale, specializing in space debris clearance; Axelspace, specializing in microsatellites for Earth observation; and GITAI, a robotic company, are the key Japanese company participants in the global new space economy (International Trade Administration, 2021). Japan is also active in earth science, human spaceflight, space science, aeronautics research, and space security, and has often partnered with the U.S. in these space-related commercial activities (Florida & Kenney, 1994).

The Committee of National Space Policy of the Japanese government has recently launched its 2030 vision for the space industry. One of its goals is to double its space market to approximately 2.4 trillion yen (US$21.1 billion) by the early 2030s. There is now a national policy to foster the development of new markets, grant private enterprises more unrestricted access to the government's satellite data, and encourage more PPPs (International Trade Administration, 2021).

Textbox 2.
Multi-level Collaborative Mechanisms in the Hayabusa2 Project

The project is a concerted effort across government agencies, the private sector, and academia at the domestic and international levels.

The Hayabusa2 mission team has an international profile with experts from around the world. It has been led by JAXA, in collaboration with DLR (German Space Center) and CNES (French Space Center), and was also supported by NASA, the ASA (Australian Space Agency) and other universities and institutes, including the University of Tokyo and the National Astronomical Observatory of Japan, among others, as well as around 300 companies (Kodama & Hoshi, 2019; Watanabe et al., 2017; Yada et al., 2022).

As the system manufacturer, NEC has a salient role throughout all phases of the mission. In this connection, JAXA and NEC established the "close review system for operation review," where the roles of both parties are clearly defined (JAXA, 2019). It is worth noting that these roles were deliberately overlapped so as to allow mutual checks (JAXA, 2019). For example, JAXA and NEC mutually checked over 1,000 cases during the manual confirmation of procedures (JAXA, 2019).

At the same time JAXA and NEC have a healthy, collaborative relationship. This is fostered by the "ONE TEAM" concept, which encourages open and equal discussions "on the same playing field" (JAXA, 2019). An example of this productive partnership is their seamless and efficient collaboration during the preparation for the first touchdown. When JAXA proposed policy changes in software, NEC promptly considered the proposal and performed simulations to ensure a successful outcome right before operation (JAXA, 2019; NEC Corporation, 2021).

The JAXA-NEC collaboration showcases that an effective collaborative mechanism is not just about having the robust institutional arrangements and procedures, but also about fostering a conducive working culture among the parties involved.

Case Study: Singapore

In an effort to seize the economic opportunities offered by the space sector, the Office for Space Technology & Industry (OSTIn) was established by the Singapore Economic Development Board (EDB) in 2013. OSTIn has been pursuing different strategic opportunities in the space economy, such as on-orbit servicing, in-space manufacturing and space life sciences. Its strategies are built upon the existing strengths of the Singaporean economy, including artificial intelligence (AI), robotics, materials science, and life sciences, with the goal of pivoting these industrial strengths to support space applications (OpenGov Asia, 2022; Soh, 2022). In February 2022, the Government of Singapore unveiled plans to invest S$150 million into research and development efforts focused on enhancing space capabilities. This initiative aims to bolster critical domains like aviation, maritime operations, and environmental sustainability, as well as drive the creation of disruptive technologies (Carberry et al., 2023; Ho, 2022; Kalyan et al., 2023; OSTIn, 2023a; OSTIn, 2023b, p.1; Yan et al., 2023). Textbox 3 outlines the development and history of OSTIn and its accomplishments.

Among many possibilities, Singapore is especially interested in technologies related to the application of Global Positioning Systems (GPS) and satellite technologies. Researchers in Singapore can apply for research grants under the Space Technology Development Programme (STDP) administered by the National Research Foundation and the Office for Space Technology and Industry. Since GPS services have wide applications, this segment of the space economy has strategic importance and high economic value. GPS is not separable from the satellite industry, and Singapore hosts more than 30 firms focusing on this technology development, including established giants like SES and Inmarsat and up-and-coming space companies like Astroscale (SES, 2016). The Singapore Space and Technology Association, presently known as Singapore Space and Technology Limited (SSTL), plays a key role in supporting this industry. Established in 2007, SSTL provides many services, including developing talent in the emerging industry and expediting the commercialization of technologies related to space, as Textbox 4 elucidates. It has specialized programs in the development of satellite parts and technologies for tiny satellites (SSTL, 2021).

Textbox 3.
From City-state to Spacefaring State: The Singaporean Space Journey

Development and History

Despite its small land size, Singapore has witnessed remarkable growth in its space industry, largely attributed to the efforts of the Office for Space Technology and Industry (OSTIn) over the past decade. Since its first satellite launch in 1998, Singapore has emerged as one of the top 25 countries globally in terms of the number of satellites it operates (Wilson & Dickey, 2023).

In 2009, the Economic Development Board (EDB), a statutory board operating under the purview of the Ministry of Trade and Industry (MTI), formed a dedicated space group within its New Business division (Ho, 2022). Singapore's inaugural domestically constructed satellite, X-SAT (eXperimental SATellite), took to the skies in 2011 (Ho, 2022). The triumph of the space team prompted the EDB to formally establish the Office for Space Technology and Industry (OSTIn) in 2013, in collaboration with six other involved ministries and agencies, in a concerted effort to build a thriving and globally competitive space industry and seize the economic opportunities it provides (EDB, 2013; EDB, n.d.b; Ho, 2022; OSTIn, 2023a; Wilson & Dickey, 2023).

Another significant milestone occurred in 2015 when Singapore's first commercial Earth observation satellite, TeLEOS-1, an electro-optical imagery satellite, was launched (Ho, 2022; Wilson & Dickey, 2023). In 2020, OSTIn was endorsed with an expanded mandate to act as Singapore's national space office. As per the government's plan, OSTIn is set to assume an expanded role as the central office overseeing all aspects of Singaporean space efforts, extending beyond industry development (Ho, 2022; Teo, 2020). In line with the global trend of creating and empowering new space agencies, OSTIn aspires to transform into the Singapore National Space Agency (Ho, 2022; Teo, 2020).

On the international front, Singapore joined the United Nations Committee on the Peaceful Uses of Outer Space (UNCOPUOS) in 2019 and has been actively participating in various regional and international forums (EDB, n.d.b; Ho, 2022; OSTIn, 2023a; Wilson & Dickey, 2023). Recently, in 2023, upon Singapore's membership in the Committee on Space Research, OSTIn was designated as the national scientific institute representing Singapore in the COSPAR council (OSTIn, 2023b).

Textbox 3. (cont.)
From City-state to Spacefaring State: The Singaporean Space Journey

Accomplishments Along the Journey

In the pursuit of the development and growth of Singapore's emerging space industry, OSTIn has made significant strides in terms of national capacity building, talent development, attraction of space companies, and commercialisation of space development.

1. National capacity building

OSTIn has been actively and selectively supporting research and development projects that align with critical domains and national priorities. The utilisation of the S$90 million Satellite Industry Development Fund has been instrumental in driving the development of Singapore's small satellite capabilities and the advancement of new sensor technologies (EDB, n.d.b; Wilson & Dickey, 2023). These endeavours cater to the country's emphasis on climate change and space-based environmental monitoring satellites (Wilson & Dickey, 2023). Notably, OSTIn has successfully funded 18 new satellite technology development projects (EDB, n.d.b). The city-state has successfully launched 13 satellites since 2011, placing it as one of the top 25 countries worldwide in terms of its satellite operations (EDB, n.d.b; Wilson & Dickey, 2023).

2. Talent development

OSTIn aims to cultivate local talent and expertise by providing funding for 4 satellite mission projects at universities and research institutes in Singapore. The goal is to build domestic workforce capabilities in advanced space technologies, with 215 researchers, engineers, and scientists receiving training to support Singapore's satellite industry (EDB, n.d.b).

3. Attraction of space companies

Currently, there are 50 local and international companies involved in diverse multidisciplinary activities within the space industry. These endeavors span a broad range of activities, encompassing the design and development processes for satellites and space-related components, as well as the delivery of services enabled by satellite technology. As a result, there is a thriving workforce of 1,800 space professionals engaged in various roles across engineering, research, and business within the sector. (Begum, 2022; EDB, n.d.b).

4. Commercialisation of space development

OSTIn established 9 company programmes with the aim of expanding the space business activities of companies in Singapore (EDB, n.d.b). As a result of these initiatives, more than 13 startups have emerged in the country, engaging in various activities across the satellite value chain (Begum, 2022; EDB, n.d.b).

Textbox 4.

Singapore Space and Technology Limited (SSTL)

Apart from government agencies, non-profit non-governmental organisations (NGOs), like Singapore Space and Technology Limited (SSTL), play a pivotal role as the "third sector" in fostering multilevel collaboration and creating cross-sectoral synergy to advance the Singapore space economy.

SSTL's mission is to spearhead the promotion and adoption of space-related technologies, while fostering strong partnerships between diverse stakeholders (Ho, 2022). Connecting space industry players with the global business and tech community, SSTL accelerates the growth of the high-tech ecosystem and cultivates business-focused initiatives within the space sector and beyond (SSTL, 2021). To this end, SSTL sets up an extensive network of partnerships around the world across different sectors. SSTL collaborates with these partners to support its programmes and initiatives.

The SSTL community network
(https://www.space.org.sg/clients-partners-members/)

The SPACE Accelerator Programme (https://www.space.org.sg/accelerator-programmes/), supported by Enterprise Singapore (ESG), a statutory board operating under the Ministry of Trade and Industry's directive, offers specialised support for space tech startups, including fundraising support, mentoring and training sessions with subject matter experts, and connections to SSTL's network of international industrial and government partners. These venture-building initiatives, innovation competitions, and professional training workshops aim at industry relation and network building (Ho, 2022).

At the same time, SSTL enhances youth awareness and skills development through education programmes supported by its international collaboration with the public and private sectors and research institutes. The International Space Challenge (ISC) is a case in point. Through this challenge, students are presented with real-world problems and tasked with problem-solving by harnessing space technologies, with the specific theme of the challenge varying each year. The theme of ISC 2023 was Climate Change, in which participants from the Advanced Category were tasked to design a satellite mission to measure and monitor key climate change indicators (Space Faculty Asia, n.d.). ISC 2023 attracted over 3,000 participants from 150 institutions and 20 countries (Space Faculty Asia, n.d.). Initiative that received cross-sectoral support from the Singaporean government (i.e. OSTIn, the Infocomm Media Development Authority, and the National Youth Council), as well as the industrialization and private sector (i.e. Karman Space & Defense, Pacific Disaster Center, and Surrey Satellite Technology) and research institutes (e.g., the Defence Medical & Environmental Research Institute and Earth Observatory of Singapore, Nanyang Technology University), among others.

For more information, please visit: https://spacefaculty.asia/isc_2023/

Case Study: China

China's space programme has made significant strides over the years, making China one of the most active and ambitious space-faring nations in the world. China's space budget has nearly trebled since the early 2000s (Daedal-Research, 2022). The Chinese space industry broadly consists of national and commercial entities (Zhang & Yang, 2023). Until of late, the Chinese space landscape has been dominated by state-owned entities, such as the China National Space Administration (CNSA), the administrative apparatus steering the Lunar Programme and human spaceflights under the Ministry of Industry and Information Technology (MIIT), as well as two major state-owned enterprises, including China Aerospace Science & Industry Corporation Limited (CASIC) and China Aerospace Science and Technology Corporation (CASC) (ESA, 2021d; Patel, 2021; Zhang & Yang, 2023). However, in recent years, China's space economy has witnessed significant growth and commercialisation, with over 100 start-ups and companies emerging, raising approximately ¥40B (US$6.5B) (ESA, 2021a).

China's burgeoning commercial space industry encompasses the entire supply chain, ranging from satellite and rocket production to satellite applications, ground systems, satellite operations, and aerospace services (Zhang & Yang, 2023). China is now the second-largest spacetech investor globally, with a total of US$4.786B invested in 122 companies (SpaceTech Analytics, 2021). For example, investment by Alibaba was ranked 5th largest in the global commercial space sector (SpaceTech Analytics, 2021). It is estimated that the rapidly growing Chinese commercial space sector is positioned to emerge as a prominent competitor on the global stage by the year 2030 (Erwin, 2023). Further, China is likely to be a world-leading space power by 2045 (ChinaPower, 2020).

Table 3 highlights some of the key accomplishments in China's space exploration achieved by the public and private sectors over the years.

Table 3. Key accomplishments in China's space exploration

Mission	Year	Achievements	References
First manned spaceflight	2003	China independently sent an astronaut into the space with its own rocket. Astronaut Yang Liwei spent approximately 21 hours in space aboard the Shenzhou-5 spacecraft. With this achievement, China joined the U.S. and Russia as the third nation capable of executing such a feat.	Reuters, 2021
Lunar exploration	2013	China's Chang'e 3 mission successfully landed on the Moon, becoming the first Chinese spacecraft to achieve this milestone and the first craft of any nation to do so in almost forty years. The mission also deployed the first Chinese lunar rover, Yutu, which operated on the Moon for almost 1,000 days.	China Daily Global, 2022
Lunar exploration in unchartered region	2019	The successful landing of the Chang'e-4 lunar probe on the far side of the Moon, another world-first achievement on the moon.	China Daily Global, 2022; Nava, 2023
Developing commercial reusable rockets	2020	A space start-up, iSpace, successfully launched a reusable rocket, making it the first private company in China to do so.	China Daily Global, 2022
Mars exploration	2020	China launched an uncrewed mission, Tianwen-1, which successfully entered Mars' orbit and deployed a rover, Zhurong, on the Martian surface.	China Daily Global, 2022; Reuters, 2021
Establishing	2020	China's first commercial launch site, located in	Jones, 2023

commercial launch site		Hainan, was completed and commenced operation.	
Independent Navigation Satellite System	2020	China has finished constructing and now independently operates the Beidou Navigation Satellite System in its entirety. This system provides comprehensive global services, encompassing high-precision positioning, navigation, and timing capabilities.	China Daily Global, 2022
Developing a space-based 6G network	2020	China launched its first satellite for its space-based 6G network, anticipated to provide ultra-fast internet speed and support a range of applications, including autonomous driving and telemedicine.	He, 2020
Tiangong Space Station	2021-2022	China completed the construction of its Tiangong space station, comprised of three modules launched into the low Earth orbit. The space station has hosted multiple crewed missions, achieving milestones including China's first in-orbit crew handover and potentially the commencement of continuous human habitation aboard the station.	Dominguez, 2022; Jones, 2022
Launching a record-breaking number of satellites in a single mission	2023	The Chinese Long March 2D rocket launched 41 satellites into the orbit, breaking the previous national record of 26 satellites launched by the	Jones, 2023

		commercial company CAS Space.	

For more information, please visit: https://www.chinadaily.com.cn/a/202209/22/WS632bbd6aa310fd2b29e791f3_1.html

Textbox 5.
The Mandate of Heaven: Pursuit of the Great Chinese Dream in Space

Key National Policies and Strategies

In pursuit of its ambitious goal to become a fully comprehensive space power by 2045, China is prioritising the development of capabilities, infrastructure, and self-reliance in its space program (Jones, 2022). The Chinese government has come to increasingly acknowledge the importance of private sector involvement, recognising that commercial entities can complement state efforts to advance the space agenda (Patel, 2021). This enhanced level of governmental support for the private space industry is codified in the white papers on the national space program published every five years by the State Council since 2000 (Xin, 2022).

The 2022 white paper, titled "China's Space Program: A 2021 Perspective" (2021 中國的航天白皮書), outlines goals to expand China's commercial space industry. It aims to develop and expand the space application industry, including the commercial use of satellite technologies in wide-ranging industries like transport, e-commerce, agriculture, disaster assessment, insurance, and real estate (State Council Information Office [SCIO], 2022). The white paper additionally discloses the plans of the Central government to promote new business models aimed at expanding the space economy into areas such as space tourism, space biomedicine, debris removal services, and services facilitating space-based experiments (SCIO, 2022). It showcases the Chinese government's commitment to encouraging commercialisation, increasing government procurement of space products and services, providing companies with access to major research and development facilities and equipment, and involving private enterprises in significant engineering projects related to the space sector (SCIO, 2022; Xin, 2022).

In recent years, China has taken steps to open up its previously state-dominated space industry to greater private and foreign involvement.

- "Document 60", released in 2014, relaxed restrictions on large private investment in key technological domains, such as rocket launches and satellite manufacturing (Patel, 2021; Xin, 2022).
- The "Medium- and Long-Term Development Plan for National Civilian Space Infrastructure (2015–2025)" (國家民用空間基礎設施中長期發展規劃 [2015–2025]) set out priorities for the civilian space industry, with the goal of enhancing the nation's space-based capabilities (Tay, 2022; Xin, 2022).
- The "Industry Catalogue Encouraging Foreign Investment" (鼓勵外商投資產業目錄), in which restrictions were removed to allow foreign investment in previously closed industries, including satellite manufacturing (Xin, 2022).

These conducive policy changes have spurred substantial growth in China's commercial space industry (Erwin, 2023). Since the publication of "Document 60" in 2014, over 200 companies have registered in China, covering a wide spectrum of space activities, ranging from launch systems to rockets, satellites, ground systems, remote sensing, and navigation applications (Xin, 2022).

Key Lessons from Different Countries

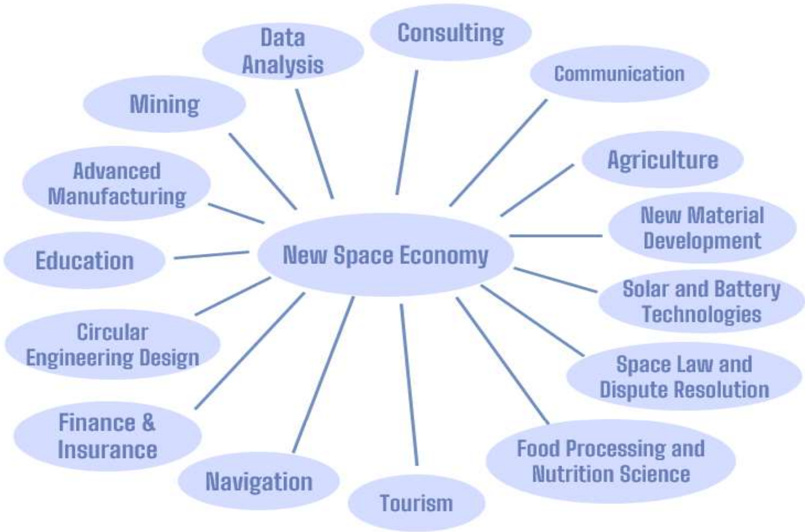
1. Thinking Broadly about the Potential of the Space Economy

The development of the new space economy is likely to create many business opportunities. Even though only a few countries have mastered rocket launching technologies and are the clear leaders, there is still much room for other countries to participate in the new space economy. Specifically, efforts to explore the use of space resources and technological frontiers may stimulate new development in the following high-tech sectors (see Figure 3):

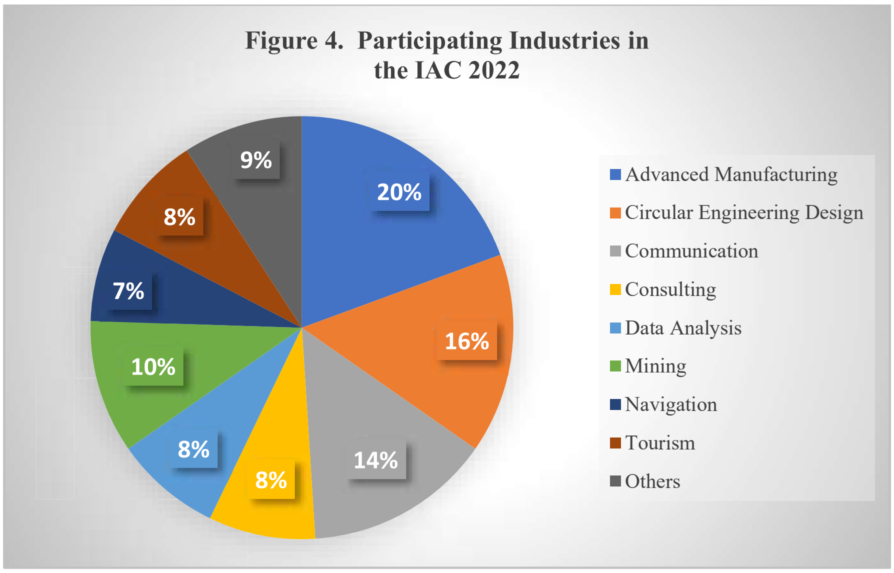
- Communication technologies, such as the development and maintenance of satellite, 5G, or 6G products;
- New materials development that can be used in space and other extreme conditions;
- New energy and battery technologies, because space travel requires highly efficient energy usage;
- The design and manufacturing of automobiles that can be more energy efficient and resilient despite adverse conditions;
- Food processing, storage, and nutrition science to serve the special needs of astronauts in a highly constrained space and under adverse conditions;
- New engineering design and smart manufacturing under a highly constrained environment that emphasizes circular logic and agility;
- 3D printing technology to manufacture and reproduce products efficiently, flexibly and precisely;
- Water purification technology;
- Data analytics applications, since space satellite technology can be used to collect data 24 hours a day, seven days a week;
- GPS applications to enhance precision farming and better supply chain management;
- Space tourism;
- Management of related services, such as support services and new logistic management, including the low-latitude drone economy.

All of these are new business opportunities. They may also stimulate the development of new academic programs and courses tailored to these industrial sectors (Parrella et al., 2022).

Figure 3. Industries for the New Space Economy



As an example, Figure 4 shows the industrial profile of the 98 companies that attended the IAC 2022. It shows that company participants in the new space economy can be highly diverse. They are not necessarily businesses that focus on rocket science or launching.



2. Leveraging Existing Industrial Strengths

Another lesson from the case studies above is that the advancement of the new space economy is often built upon existing strengths and capabilities. For example, with over 130 aerospace companies, Singapore is hailed as the "Aerospace City of the Future". It has one of Asia's largest and most diverse aerospace eco-systems. Singapore has strong expertise in electronics, aircraft, and supercomputing. All of these are leveraged to help Singapore develop new opportunities and make a successful transition into the space industry. For instance, veterans of the semiconductor sector in Singapore formed a local startup, Zero-Error Systems, to help with the design and manufacturing of specialized semiconductors that can survive in orbit and highly hostile environments. Leveraging employees' past experience and know-how, Zero-Error Systems has successfully created radiation-hardened circuits, which protect gadgets and increase the lifespan of satellites (Goh, 2023).

3. Leveraging the Joint Strengths and Capacity of the Public, Private, and University Sectors

The shift from the old space economy to the new space economy is characterized by the rising importance of private enterprises and investors in leading the development. However, as shown by the experiences of many countries, the government still plays a key role by supporting basic research in key technological areas, providing funding for start-up companies, investing in critical human capital, and creating opportunities for the industry through public procurement and contracting out. It can also stimulate new technological development by facilitating collaboration among universities and businesses and incentivizing knowledge transfer from university research to industrial application. Leveraging cross-sectoral strengths and capacity effectively is critical to the development of the new space economy of a jurisdiction.

4. Building Long-Term Sustainable Strength through Education and Research

The long-term competitive strength of a jurisdiction in the new space economy depends significantly on the scientific and technological capacity of the workforce and the ability to achieve technological breakthroughs in space-related industries. Hence, the government needs to invest in STEM education and also attract top talent to enter the science and engineering fields. A society also needs to provide attractive options for researchers and entrepreneurs to focus on technological exploration and start-ups.

Strategic Analysis for Hong Kong

Hong Kong is well-positioned to participate in the new space economy because of its strengths and competitive advantages:

- It has multiple top universities that have strong faculty in science and engineering fields;
- It is a world-class city that can attract top talents and scientists from different parts of the world;
- It is not too far from the key launching facilities in Hainan Province;
- It is geographically close to the industrial and high-tech centres in Shenzhen and Guangdong Province and can tap into their talents and research capacity in the region;
- It is a key financial centre of the world that can help raise venture capital for start-ups;
- Hong Kong has a globally respected legal system that provides good intellectual property protection;
- It has relatively strong primary and secondary education in science and mathematics.

At the same time, Hong Kong is facing some constraints and challenges that may limit its participation in the new space economy:

- Many young talents are interested in medicine, law, and business and are not thinking about careers in engineering and basic science;
- While there are many top universities in Hong Kong doing top-notch research in science and engineering, there is insufficient incentive and support for researchers in Hong Kong to explore commercial applications and create start-up companies;
- There are growing concerns about the tech war between China and the West, which may eventually limit the global talents Hong Kong may get and the opportunities for international collaboration in research and product development;
- The geo-political tension between China and the U.S. and potential sanctions against Chinese companies by the U.S. may make tech companies and entrepreneurs in Hong Kong feel reluctant to get involved in any sensitive industries, such as space-related industries;
- There is limited awareness of Sustainable Development Goals (SDGs) among students, researchers and company executives, and as a result, there may not be sufficient understanding of how technology and product development in the space economy can be linked to SDGs, which is strongly advocated by the United Nations and many countries.

Given the above strengths and constraints, the research team of City University of Hong Kong has analysed the development of different sectors of the space economy and highlighted different possibilities for Hong Kong industries. The details of the analysis for different industrial sectors are provided in separate reports. In the following, the key findings of the analyses and recommendations are summarized.

Multi-level, Cross-Sectoral Governance Design for the New Space Economy

Potential Strategic Focus Areas for Hong Kong

As indicated earlier, there is significant growth potential and market demand for products and services in the growing space economy. These opportunities are not just happening in Hong Kong and the Greater Bay Area, but also nationally and internationally.

Based on the feedback of various stakeholders[2] interviewed in this project and the strategic analyses by the research team, Hong Kong may focus on these industries and sub-sectors related to the space economy:

- Satellite-related industries and services, especially those related to communication, remote sensing, spatial data management and mapping, satellite design and maintenance;
- Drone-related industries and services, especially logistic management in the Greater Bay Area;
- Sensor-related technologies and applications, especially Internet-of-Things (IoT) applications, lean manufacturing, and driverless vehicle development;
- Precision and lean manufacturing, especially in advanced manufacturing, production automation services, and the usage of 3D printing technologies;
- Design and development of robotics technologies;
- New materials science, including lightweight and strong alloys, materials that can withstand high temperature or are inflammable, polymer matrix composites, metal matrix composites, and anti-bacteria and anti-viral materials;
- Precision farming and urban agriculture;
- Ecological management, especially in water and air purification and water conservation technologies;
- Space law and regulation, and related international dispute resolution;
- Financing services for private space tech companies.

Special attention should be paid to the possibility of developing Hong Kong to become an international satellite data service centre. As indicated above, many countries have already launched and owned one or more satellites in the orbit. However, due to technological limitations, satellites, especially the small ones with limited space and capacity to have huge solar panels, need time to be re-charged

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[2] During the project, the viewpoints and insights of more than 30 stakeholders were solicited through interviews, surveys, and panel discussions. Please see footnote 1 for more details.

before they can take pictures or collect other types of data while orbiting the earth continuously. As a result, there may be significant gaps in the data collected. To fill these data gaps, satellites in different orbit positions can help each other, so that the joint-up data collectively may provide a more comprehensive and continuous understanding of a phenomenon. Due to its internationally respected legal system, sound intellectual property protection, well-established networks with international businesses, ability to attract global talents, and growing ties with many Belt-and-Road countries, Hong Kong has the potential to become an international satellite data trading and service centre for countries.

Hong Kong may also leverage its locational proximity to Hainan Island in South China Sea, Nanshan District of Guangdong Province, and Yangjiang City of Guangdong Province, to launch various R&D and private satellite services. Hainan Island, which is about 470km southwest of Hong Kong and is accessible by air and train, has the first Chinese commercial space launch site. In the future, the site is expected to provide domestic and international rocket and satellite launch services for commercial and civilian purposes (Hua, 2024). Yangjiang City of Guangdong Province, which is about 230km west of Hong Kong and accessible by car or high-speed train, also has a commercial rocket and satellite launch site in its nearby ocean. In February, 2024, it worked with the Taiyuan Satellite Launch Center and helped several companies launch 9 commercial satellites successfully (Lei et al., 2024). Hong Kong is also next to Nansha District of Guangzhou City, which is only 85km northwest of Hong Kong and is accessible by car and high-speed train. Nansha District is hosting the research base of CAS Space, a Chinese commercial spaceflight and satellite launch service company (Southcn.com, 2024). All these have created many new good opportunities for Hong Kong industries and businesses to develop joint ventures, R&D support, and other logistic, financial, and legal services related to satellite launches.

Table 4 provides a summary table of the rationales for the recommendations and the potential markets for the recommended development.

The contents of Textbox 6 provide further details on how space technologies can benefit various industries.

Table 4. Summary of Potential Industrial Development in Hong Kong in Anticipation of the Space Economy

	Industries & Sub-sectors	Rationales	Potential Markets
Satellite-related applications	Software development related to global navigation systems, especially the BeiDou Navigation System	- The BeiDou system is relatively less popular than the US-invented GIS system, but its usage is spreading because of rising Chinese influence in different parts of the world. - Hong Kong companies and researchers can build upon this technology and develop business software and applications using the BeiDou system. Such navigation system has potential usage be used in many areas.	- Transportation, logistics management, emergency management, and many other areas. All these can be used in different parts of the world.
	GIS data management and analytics services	- A lot of mapping and traffic data can be collected from different navigation systems. The data can be used to develop business intelligence, predict market trends, and assist facility and logistic management. - GIS data and analytics can be used to process and analyse satellite-derived carbon emission data, supporting carbon accounting, and facilitating the monitoring and verification of emissions for carbon trading purposes.	- Transportation, logistics management, emergency management, carbon trading and many other areas. All these can be used in different parts of the world.
	Application of 3D mapping and remote sensing	- In addition to 2D mapping, new satellite technologies can be used to capture 3D data. Satellite imagery data provides new opportunities to monitor urban landscape and design. - Furthermore, carbon satellites can capture data on carbon dioxide (CO_2) and other greenhouse gas emissions in the atmosphere, which could be processed to assess emissions as a key performance indicator (KPI) for urban areas,	- Urban planning and agriculture; environment monitoring (e.g. monitoring of crops, and water quality); on-demand satellite imagery services; building information services in Hong Kong and many cities

		monitor changes over time, and support decision-making for emission reduction measures.	
Drone-related applications	The drone economy and related products and services; development and use of low-altitude unmanned aerial vehicles	- Using satellite technologies, sensors, and AI technologies, drones are now very safe and can be used in many services in different parts of the world. Hong Kong universities and Shenzhen already have established strengths in this area. Shenzhen has already pilot-tested drone taxi services.	- Great potential to use drones in remote and rural areas in different parts of the world. - In urban areas, with proper regulations, drones can also be used in many businesses, including product delivery, construction, cleaning, traffic monitoring, and entertainment.
	Multi-hop communication network applications and development by drones	- In remote, rural areas, where traditional cable and wire communication cannot be reached easily and cost-effectively, drones can be used to establish multi-hop communication networks to supplement satellite communication, which may not be fast enough.	- extensive application potential in rural and remote areas and in developing countries
Sensor-related technologies	Sensor development and application, IoT	- Audio and video capture devices, combined with sensors, satellite imaging and mapping, and other data collected from personal devices, can be used to monitor the operation of a city and facilitate all kinds of urban management. They can also be used to support the usage of driverless vehicles and logistics management.	- Wide applications in urban management, environmental monitoring and management, traffic control, and policing.

Precision /lean manufacturing	Lean manufacturing with 3D printing technologies	- 3D printing and lean manufacturing used in a space station to produce spare parts or emergency equipment needs can be applied to support on-the-ground industrial needs. This may be especially applicable to Hong Kong where large factory or inventory space is limited and just-in-time, lean manufacturing is needed.	- Potential applications in many industries, including manufacturing, construction, facility management, and research labs.
	Smart manufacturing using remote control, VR, image processing, machine learning, and AI	- RFID, all types of sensors, and audio and video devices, can be used to generate data so that a central office can monitor the condition of a worksite or a production process remotely. This technology is useful not only in space station operation, spacecraft maintenance, and satellite docking, but also in many businesses or production facilities. This may also foster more industrial collaboration between Hong Kong and other manufacturing centres in the Greater Bay Area.	- Potential applications in many industries, including manufacturing, construction, facility management, and research labs. The Global Defect Detection market is projected to reach USD$5.1 billion by 2027.
Robotics	Design and development of space robotics	- Many space station operations and satellite maintenance have to be done by robotics, the space robotics market was valued at USD2.97 billion in 2021 and will reach USD7.1 billion by 2030. Hong Kong universities have strong competencies in electrical engineering and robotics research.	- Potential applications not just in space travel and space station maintenance and operation, but also in manufacturing and production automation.

Material science	Development of non-flammable materials	- New materials developed for space travel and space stations need to be durable, flexible, and non-flammable. These materials can also have commercial value in the Earth economy.	- Potential applications in the construction industry, medical and public health facilities, elderly homes, and industrial sites that have high fire risk.
	Development of anti-bacterial and anti-virus materials	- New materials developed for astronauts and space station users to reduce bacterial or viral infection can have commercial value in the Earth economy.	- Potential applications in fashion and clothing, medical and public health, schools, elderly homes, and many other areas.
	Composite materials research	- Advanced composite materials are mostly developed by the UK, European countries, and Japan. China, South Korea, and Turkey are the emerging powers in this area. Because of the research capacity and excellence of Hong Kong universities and research labs and its close collaborative relationship with Chinese industries and universities, Hong Kong may be positioned to play some roles in this development, especially in the R&D process, design, and applications.	- Potential applications not just in the aerospace industry but also in many other sectors, such as manufacturing, automobile, automotive, yacht and shipbuilding, equipment, and construction industries.
Ecological and energy management	Water purification and conservation applications	- Water purification and conservation are essential functions in space, but the technologies and products developed can also have commercial value in the Earth economy, especially in countries that are in the drought zone or face significant climate change risks. Water purification is also needed in emergency management, medical facilities, and hotel management and tourism in remote areas.	- Wide application and growing needs given the climate change risk, increasing drought conditions in many countries, and expansion of urban areas that do not have sufficient water supply.

	Air purification, oxygenation	- Air purification and oxygenation are essential functions in space, but the technologies and products developed can also have commercial value in the Earth economy, especially in medical and health facilities, hotel management, and advanced manufacturing facilities.	- Wide applications in facility management and appliance design and manufacturing.
	Precision vertical agriculture / urban farming	- Technologies developed to support agriculture in the space station can also be used to support urban farming and other areas that face very hostile natural environments. Many cities also plan to develop urban farming to diversify agricultural supply, support the development of the circular economy, and promote local organic farming.	- Potential market in many urban areas in different parts of the world, such as countries in the Middle East where natural farming is very difficult or limited.
	Solar energy and battery technologies	- Solar energy is a key source of technology in space stations, satellites, and space vehicles, and advanced battery technology is needed to propel different devices in space.	- Solar energy is already widely used in many countries; it will continue to gain more cost-effectiveness and wider utilization.
Legal and financial services	Space law and regulations; international dispute resolution	- The growth of the space economy globally and the rising number of countries and companies participating in its development will eventually lead to more commercial disputes and legal conflicts; Hong Kong has a legal system that is globally respected and can develop itself further to be an international centre for space law and regulation research, dispute resolution, and an international adjudication centre.	- Potential development in this area with the assistance and support of the central government and international organizations.

	Space finance, especially related to insurance and financing mechanisms	- The growth of the space economy globally and the rising number of private companies participating in the development will eventually lead to more financing needs for the industry. Related financial services, such as insurance, venture capital raising, and debt financing and risk management, may also be needed.	- Potential development in this area, especially for companies in China, S. E. Asia, the Middle East, and Central Asia.

Textbox 6.
The Sky is Not the Limit: Space Tech's Bountiful Yields in Earth Sectors

The investment made in space technology over the past several decades has led to spillover effects and yielded technological advances, spin-off technologies, and applications that provide enormous benefits and commercial value to a broad range of industries, including automobiles, automotive, manufacturing, construction, facility management, healthcare, agriculture, materials science, and more (Sadlier et al., 2018). UKSA (2018) also points out that the beneficiary industries of the spillover effects span across agriculture, shipping, environmental monitoring, transport, forestry, oil and gas, mining, fishing, surveying, construction, and a wide range of other industrial sectors.

One of the most direct crossovers is in the automobile industry. Several sky-high aerospace innovations have brought about transformative on-the-ground improvements for car and trucks, including anti-lock brakes and GPS navigation. (Hadhazy, 2011; Wagner, 2020). Another invention that uses a vehicle's waste heat to generate electricity is now being used by several companies such as, BMW and GM, to produce thermoelectric generators (Hadhazy, 2011). These generators leverage exhaust system heat, offsetting energy requirements for onboard electronics, and creating more fuel-efficient automobiles (Hadhazy, 2011). Additionally, space technologies have stimulated the development of emission-free land vehicles, such as electric cars and solar-powered vehicles (ESA, 2022b; Hadhazy, 2011). Furthermore, integrating hydrogen fuel cells, originally used in Apollo modules and space shuttles, to produce electricity, heat, and water from hydrogen and oxygen, offers a green transportation alternative, especially for fleet vehicles like buses (Hadhazy, 2011). Enhanced battery technologies, management systems, and power electronics that originated from space missions are also making electronic vehicles safer and more effective (ESA, 2022b; Hadhazy, 2011). Similarly, having studied the posture astronauts' bodies naturally assumed in microgravity, NASA was able to design Space Station work areas and spacecraft interiors, in turn, enabling car manufacturers to develop safe and comfortable car designs (Wagner, 2020).

There are other examples that show how the automotive industry has benefited from space technologies and research. The automotive equipment sector is one of the beneficiaries (Venturini & Verbano, 2014). For example, NASA's supersonic gas-liquid cleaning system and turbine-driven pipe-cleaning brush were transferred to industrial applications for air atomizing in automotive equipment (Venturini & Verbano, 2014). Spacecraft tire pressure sensors, which use technology that converts pressure into electrical resistance to generate real-time readings, were adapted for implementation in everyday vehicles (Wagner, 2020).

Textbox 6. (cont.)
The Sky is Not the Limit: Space Tech's Bountiful Yields in Earth Sectors

Space technology innovation has also impacted non-manufacturing commercial sectors, enabling businesses to reduce costs and increase efficiency, improve the quality and lifespan of products, and rework product design and assembly. For example, the controlled sterility attained for the ExoMars Rover has potential applications in terrestrial environments requiring hyper-sterility, while advancements in welding methods have reportedly resulted in a 12% reduction in raw material expenses within aluminium manufacturing (UKSA, 2022). Other notable examples include the development of light-duty utility arms for space robotics by the Canadian Space Program. Space techniques also extend to thermal modeling and analysis software for nuclear electronics and manufacturing industries (Venturini & Verbano, 2014). Similarly, gears and bearings originally devised for planetary speed reducers at NASA's Goddard Space Flight Center have transitioned into the manufacturing industry (Venturini & Verbano, 2014). Additionally, NASA's breakthrough in thermal stir welding technology, originally designed for joining dissimilar materials in space, has been effectively reinvented for diverse applications, including automotive manufacturing, shipbuilding, storage-tank manufacturing, and construction sectors (Venturini & Verbano, 2014).

Indeed, the benefits of space technologies extend beyond their primary applications. For example, the design and development of spacesuits have resulted in spin-offs such as flexible ski boots, light allergy protection, firefighter suits, and even golf shoes with inner liners (Gurtuna, 2013). These advancements are rooted in the specific needs of space exploration in which astronauts require lightweight, insulated gear with optimal insulation to navigate the extreme environment in space (Pierce, 2022). For this purpose, cold-weather gear manufacturers have developed ultra-lightweight fibers infused with aerogel insulation. Initially intended for spacesuits, this technology is now prevalent in hats, gloves, jackets, boots, and sleeping bags (Pierce, 2022).

Another example is that NASA has driven the development and research of air-quality technologies, such as air purifiers, photocatalytic oxidation, air-quality sensors. Maintaining fresh air supply is important to space travel and space station operation (NASA, 2022; Pierce, 2022; U.S. Mission to International Organizations in Vienna [UNVIE], 2022). The need has led to many technologies, including OXY 4 air purifiers engineered to integrate into the ducts of heating and cooling systems, capable of purifying the air within expansive commercial and public venues (NASA, 2022). Photocatalytic oxidation together with activated-carbon filters were also developed to remove chemicals and particulate matter, enhancing indoor air quality (Pierce, 2022). Photocatalytic oxidation technologies were also developed to be incorporated in air purifiers, fit in air ducts, cars, or elevators (Pierce, 2022). In conjunction with air purifiers, the "electronic nose" sensor technology was developed to detect volatile organic compounds, dangerous gases, humidity, ambient noise, and lighting (NASA, 2022). This automated air-management system ensures optimal indoor conditions, alerting users to potential issues and providing regular reports and recommendations (NASA, 2022). Gauging levels of carbon dioxide and other human by-products, the HVAC system can introduce more fresh air to dilute exhaled breath and activate air purifiers in scenarios where room occupancy increases (NASA, 2022). These enhanced air purification systems help hospital patients breathe easier in hospital wards (ESA, n.d.b).

Textbox 6. (cont.)
The Sky is Not the Limit: Space Tech's Bountiful Yields in Earth Sectors

Space-driven air-quality technologies have also found their way into practical applications in the original equipment manufacturing industry where air sensors are integrated into appliances. For instance, air sensors are being incorporated into appliances like range hoods, which activate automatically upon detecting cooking odors, as well as automobile ventilation systems.

Air-quality technologies have assumed a crucial role in combating the transmission of airborne viruses like COVID-19, which were utilized in in diverse settings including schools, medical facilities, shopping centers, office buildings, airports, and buses (NASA, 2022; Pierce, 2022; UNVIE, 2022).

Space technologies and applications have also benefitted the agriculture sector, enhanced its efficiency, productivity, sustainability, and resilience (ESA, 2023b; Hall, 2015; Khlystov et al., 2023; UNOOSA, 2015a). Earth observation (EO) data such as satellite data and analytics can be harnessed to benefit the sector in the following ways:

- Precise yield estimations: enabling accurate projections of crop production by type and region. These estimations not only quantify food demand gaps and predict crop prices but also facilitate the alignment of logistics with harvest areas (Khlystov et al., 2023).
- Satellite-driven analytics optimize yield by detecting intra-field crop defects, informing resource-efficient actions and operations to maximize production per acre (Khlystov et al., 2023). For instance, infrared and microwave satellite imagery may provide weather forecasts, including rainfall estimations, in turn, helping farmers in scheduling the timing and volume of irrigation for their crops (UNOOSA, 2015a).
- The integration of satellite insights bolsters sustainable practices, contributing to reduced emissions, efficient water usage, and the promotion of regenerative techniques (Khlystov et al., 2023).
- The capability of Earth observation (EO) data helps develops climate-smart agricultural solutions to enhance disaster management by remotely monitoring conditions before and after these events. Satellites, for one, can be leveraged to predict, verify, and mitigate damage from natural disasters, such as droughts, fires, floods (Khlystov et al., 2023; UNOOSA, 2015a). For example, the creation of the Agricultural Stress Index System relies on data from the Meteorological Operational Satellite-Advanced Very High-Resolution Radiometer (METOP-AVHRR). By analysing composite imagery spanning a specific timeframe at a resolution of 1 km, this system can identify agricultural regions worldwide that are at a heightened risk of drought. In particular, the above space technologies can benefit vulnerable rural and small-scale food producers by enhancing their adaptability to climate change (ESA, 2023b; UNOOSA, 2015a).

While often associated solely with space exploration, innovations in space technology have proven to generate enormous benefits beyond their original purpose. As shown through numerous examples, spin-offs from space technologies have resulted in improvements and benefits in varied fields. Ultimately, space technology represents a key driver capable of uplifting entire industries and enrich life on Earth.

Recognizing Challenges and Barriers Ahead

To pursue the potential strengths of Hong Kong in the above-recommended sectors and expand its market presence, many challenges remain. Various stakeholders interviewed by the research team are especially concerned about the following issues:

- Many top talents in local secondary schools in Hong Kong are not interested in engineering and basic science; many local students only think about pursuing careers in the medical, law, and finance fields;
- Many university students in engineering do not have sufficient internship and job opportunities related to the space economy locally in Hong Kong because Hong Kong's manufacturing sector has declined to only about one percent of the local economy (measured by Gross Domestic Product); as a result, many engineering graduates are pushed to join the financial or business sector despite their training and research background;
- A number of existing industries in Hong Kong have the potential to explore opportunities in the growing space economy, but they need to be more informed about its potential development and receive more incentives and encouragement from Hong Kong Government to work closely with local universities and research institutions to explore the potential;
- Many industrial development opportunities in the space economy may be located in Mainland, and as a result, Hong Kong students, researchers, and companies need to find more opportunities to network with Mainland companies and research institutes more closely;
- Hong Kong needs to attract a few key national and global companies related to the space economy to set up headquarters or their main branch offices in Hong Kong to pull up other related industries in the value chain;
- Local faculty members and researchers should be incentivized more to work with industries, conduct applied research, and contribute to the reindustrialization efforts of Hong Kong; the current university incentive system may focus too much on academic publications and basic research;
- Local industries need to invest more in research and development and think beyond short-term financial return, and Hong Kong may need to do more to incentivize this;
- Local industries and research institutes related to the space economy need land and lab space provided or subsidized by Hong Kong Government to survive financially, especially because the return on investment is more uncertain and long-term;
- Local industries and research institutes need more international collaboration and should attract overseas and Mainland talents to come to Hong Kong to support the development of the space economy and reindustrialization in general;

- Local industries need to explore new market opportunities for space-related products and services, especially in rising economies, such as Saudi Arabia, S.E. Asia, and Central Asia;
- Local industries, universities, and research institutes need to manage geo-political risk carefully and be mindful of the threat of sanctions by the U.S., the UK, and some European countries that have become more hostile to China and see the technological advancement of China as national security threats.

Recommendations for Governance Strategies and Policy Responses

Given the above concerns, a number of cross-sectoral, cross-disciplinary, and cross-departmental strategies are suggested to equip the industrial sector, Hong Kong governmental agencies, and stakeholders in the educational and research sector, to be more prepared to capitalize on the growth of the space economy globally:

Cross-sectoral collaboration

To address some of the human capital needs and research and development constraints, Hong Kong needs to develop more cross-sectoral partnerships between the government, businesses, universities, and research institutions, strengthen their mutual communication, and develop economic development and educational strategies that can effectively address the needs of industrialisation 4.0 in Hong Kong. Other jurisdictions and international organisations have already deployed a lot of successful models for Hong Kong to consider. For example:

1. An Agency-Led Model

   The Singaporean Government has adopted an agency-led model and established the Office for Space Technology and Industry (OSTIn) in 2013. In 2020, OSTIn was mandated to act as Singapore's national space office and is responsible for working with governmental, business, educational, and international organisations to help develop the space industry, enhance the technological capacity of Singapore, nurture space talent and workforce, and foster international collaboration (OSTIn, 2023a).

   Similarly, the U.S. OSC serves as a powerful catalyst for fostering cross-sectoral collaboration and driving the economic growth of the commercial space industry. With the OSC as a dedicated governmental body overseeing space commerce, the U.S. effectively coordinates space commerce policy issues and fosters interagency and stakeholder collaboration across federal, state, and international levels. The strategic consolidation of regulatory functions and approvals within the OSC yields a streamlined approach, effectively reducing redundancy and alleviating bureaucratic hurdles for businesses and stakeholders operating in the commercial space sector. Optimised organisational structures, creating new entities, and regulatory reforms led by government agencies not only enhance efficiency but also empower innovation and growth in the industry. (Please refer to Textbox 7 for more details of the agency-led model in the U.S.)

Another agency-led model is the United Nations Office for Outer Space Affairs (UNOOSA). UNOOSA is set up to promote international cooperation in the development and usage of space technologies and peaceful exploration of space. Under UNOOSA, many annual cross-sectoral activities are organised to facilitate informational exchange and collaboration. For example, in 2022, UNOOSA worked with the Ministry of Science and Information Communication Technology of Korea and the Korea Aerospace Research Institute and organised the Space4Women Expert Meeting in Daejeon, Korea, gathering academic, business and governmental leaders from 27 countries to discuss how to encourage greater participation of women across the space sector (UNOOSA, 2023c, p.12). In 2022, it also worked with the Chinese Government to organise the "United Nations/China Second Global Partnership Workshop on Space Exploration and Innovation" and brought stakeholders from space agencies, international organisations, academia, industry, and private sectors to discuss peaceful utilisation of outer space and international cooperation (UNOOSA, 2023c, p.21).

Hong Kong Government may adopt this model and establish a special department or office to take the lead and facilitate activities and initiatives related to the development of the new space economy.

2. A Foundation Model

Instead of relying on a government agency, Hong Kong may work with industries and philanthropic organizations to establish a non-governmental foundation to focus on cross-sectoral dialogue and collaboration related to the space economy. The government may provide the first round of seed capital to establish the foundation and encourage private industries to donate and contribute to the foundation regularly after that. It may also sustain the operation of the foundation in the long-run through grants and contracts. The foundation could then focus on providing grant funds to support space-related research, organize seminars and conferences to encourage cross-sectoral dialogue, and develop policy research that can advise Hong Kong about the long-term strategic needs of space economic development.

Textbox 7.
The U.S. Office of Space Commerce (OSC)

Prior to the establishment of the Office of Space Commerce (OSC), there was no single dedicated governmental body that governed and regulated the commercial space sector (Higuera, 2022). The fragmented regulatory approach to commercial space activities and the overlapping nature of burdensome requirements that come along led to the creation of OSC (Higuera, 2022). OSC fills this void by serving as the principal unit for the coordination of space-related issues, programs, and initiatives within the Department of Commerce (DOC) and beyond, encompassing stakeholders from Federal, state, and international levels.

OSC performs the various functions to fulfil its mission to foster the conditions (i.e. policy and advocacy, regulation, and space situational awareness) for the economic growth and technological advancement of the American commercial space industry. These functions include creating an environment that encourages the industry's development, coordinating space commerce policy matters and actions within the DOC, representing the department in policy development and negotiations with foreign entities to promote U.S. space commerce, advancing geospatial technologies concerning space commerce in collaboration with other government workgroups, and providing assistance to federal organisations involved in Space-Based Positioning Navigation and Timing policy, one of which is the National Coordination Office for Space-Based Position, Navigation, and Timing. Through these activities, the OSC plays a crucial role in facilitating the progress and prosperity of the U.S. commercial space sector.

Later, Congress passed the American Space Commerce Free Enterprise Act of 2019 ("ASCFEA"), which enumerates additional responsibilities for the OSC to oversee (Higuera, 2022). These include ensuring that commercial space activities comply with international obligations, supervising the certification process for such commercial activities, managing the mitigation of space debris, evaluating the progress of commercial space development through the Private Space Activity Advisory Committee, and maintaining the U.S.' position as a global leader in commercial space endeavors. This legislation empowers the OSC to regulate and advance the U.S. commercial space industry, while also safeguarding international duties and promoting the States' leadership in this field.

OSC, which is responsible for inter-agency coordination, is a perfect example of the agency-led model. The OSC engages in the coordination of regulatory functions with the goal of enhancing competitiveness and bolstering legal certainty for space businesses. To this end, most of the commercial space-related approval processes of the DOC are being consolidated within the OSC (Oltrogge & Christensen, 2020; DOC, 2022). Several mechanisms were set up to facilitate interagency collaboration:

(1) coordination with a variety of partner organisations across the DOC. For example, OSC works with the Bureau of Industry and Security to streamline space export controls.
(2) hosting the National Coordination Office for Space-Based Positioning, Navigation, and Timing (PNT), composed of interagency staff focusing on GPS policy issues
(3) participation in whole-government deliberation of the space policy agendas, and internal endeavors to increase National Oceanic and Atmospheric Administration's use of commercial space solutions
(4) taking the lead in an interagency workgroup tasked with enhancing technical, economic, and industry aspects in order to provide better insights for Federal Communications Commission (FCC) rulemaking on space safety initiatives undertaken by the U.S. government, such as the orbital debris issue.

OSC also represents the U.S. in international cooperation. For example, OSC took part in the 12th Space Dialogue between the U.S. and the EU, where topics of shared interests, namely space situational awareness and spaceflight safety, Earth observation, GNSS, were discussed (https://www.space.commerce.gov/commerce-participates-in-12th-u-s-eu-space-dialogue/).

3. A Grant-Funding Model through the Existing Innovation and Technology Fund

Hong Kong Government may also use the existing institutional structure and establish a new grant scheme on the space economy under the Innovation and Technology Fund (ITF) operated by the Innovation and Technology Commission (ITC) to encourage more collaboration and joint research between industries and academic institutions. It may provide matching funds to private investment to supplement the capital needs of the industries. Also, it may provide seed funding to existing industries to encourage them to take some risks and apply their existing technologies and know-hows to explore the market potential of the new space economy. Talent development funds can also be provided to support existing businesses, new start-ups, universities, and research institutions to hire engineers and scientists to support the long-term needs of the space economic development in Hong Kong.

The Innovation, Technology, and Industry Bureau and ITC may also consider providing financial assistance and policy support in land use to targeted emerging industries to alleviate the financial burden associated with the initial investment and operating costs.

4. A Tax Incentive Model

Hong Kong Government may also let businesses take the lead, set their own business agenda, hire their own personnel, work with university researchers, and invest in operational and research development activities that are deemed most important. To encourage such development, Hong Kong Government may simply provide tax exemptions or credits to some of these activities to lower the business costs. Under this model, Hong Kong Government will take a more passive role and allow the market and the business sector to pursue their agenda more openly.

Cross-disciplinary collaboration

In addition to cross-sectoral partnerships, Hong Kong Government also needs to encourage more cross-disciplinary research collaboration to stimulate space research. To support various needs of space travel and living, multiple disciplines, such as physics, electrical engineering, mechanic engineering, aviation science, biochemistry, material science, biology, and environmental science, among many others, need to work together. Space science itself is an interdisciplinary science.

To facilitate this type of inter-disciplinary research, the Research Grants Council (RGC) may establish a new grant scheme, like the “Space Topics” seed fund program of the U.S. National Science Foundation, to support research that will develop “revolutionary satellite and vehicle hardware or systems innovations involving propulsion systems, navigation systems, energy collection and power generation systems unique to space environments, and in-space manufacturing systems and services", and solicit proposals that are related to "Earth imaging and sensing; planetary physical surveying, mapping, and prospecting services; extraction and processes of water and volatiles," and "analytic algorithms based on data collected extensively from space-based systems, either alone or in combination with terrestrial systems." (seedfund.nsf.gov/topics/space/).

Given that universities in Hong Kong have different areas of expertise and conduct various types of advanced research on space technologies, implementing a unified grant/funding scheme could consolidate and coordinate research efforts. Such a funding scheme can also facilitate cross-border cooperation among these local universities and Mainland universities, which would further enhance their research capabilities.

Cross-departmental collaboration

Because human capital concerns, research and development bottleneck issues, financial capital constraints, and land and physical infrastructure needs are the barriers to the potential development of the new space economy in Hong Kong, the following bureaus and departments within Hong Kong Government also need to work together and coordinate a long-term strategic plan:

- The Commerce and Economic Development Bureau, which oversees Invest Hong Kong and the Trade and Industry Department;
- The Innovation, Technology, and Industry Bureau, which oversees the Innovation and Technology Commission;
- The Education Bureau, which oversees the University Grants Committee and its affiliated Research Grants Council;
- The Development Bureau, which oversees the Lands Department and the Planning Department;
- The Agriculture, Fisheries and Conservation Department;
- The Transport and Logistics Bureau, which oversees the Civil Aviation Department and the Transport Department;
- and the Financial Services and the Treasury Bureau, which oversees the Company Registry, the Inland Revenue Department, and the Rating and Valuation Department.

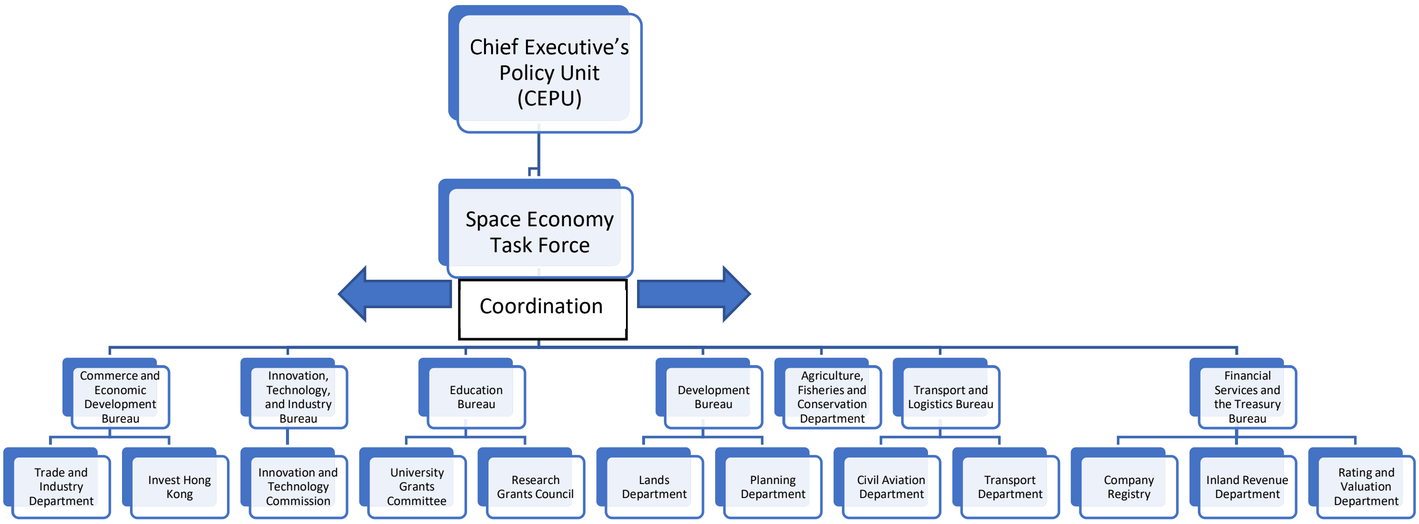
Cross-departmental initiatives and collaboration are always a challenge in public administration and are well-recognized in many countries and jurisdictions. To address this concern, Hong Kong may again refer to the agency-led model and set up a designated department or office to coordinate different bureaus and departments. Please refer to Textbox 8 to see an example from Singapore.

Alternatively, Hong Kong may establish a special task force under the Chief Executive's Policy Unit (CEPU) to facilitate the space economy development initiatives and other reindustrialization concerns. In December, 2022, the CEPU was established to conduct forward-looking, strategic policy research, coordinate and track the implementation of the Chief Executive's Policy Address initiatives, coordinate and network with think-tanks, academia, and other leaders in society. The space economic development initiatives proposed in this report fit perfectly with the following policy priorities of the 2022 Chief Executive's Policy Address:

- To attract strategic enterprises and recruit top talents to Hong Kong;
- To promote innovation and technology development, facilitate commercialization of research and development, encourage re-industrialization, and enhance technology talent schemes;
- To step up STEAM education, encourage more students to study STEAM subjects.

Hence, the CEPU may establish a special task force to coordinate and monitor cross-departmental initiatives related to the space economy (see Figure 5).

Figure 5. A Proposed Space Economy Governance Structure



Textbox 8.
Singapore's Office of Space Technology and Industry (OSTIn)

OSTIn was established in 2013 under the Ministry of Trade and Industry. It is led by an Executive Director, a Deputy Executive Director, a Director/VP for Technology, a Director/VP for Industry, and a Director/VP for Strategy and Policy & Partnerships (OSTIn, 2023c). The main goals of OSTIn are:

- To serve as the designated office to plan and execute economic strategies to grow Singapore's space industry (Ho, 2022);
- To seize economic opportunities and develop a thriving space industry by collaborating with the satellite industry to support their business and innovation initiatives, fostering research capabilities and a talent pool to sustain industry growth, and establishing partnerships with governments, space agencies, and organisations for mutual economic benefits (EDB, 2013);
- To support the country's push for developing space capabilities for national priorities;
- To promote the conversion of government research and technology into commercially viable solutions;
- To build partnerships with other spacefaring nations and to build a talent pipeline for the space sector.

To achieve these goals, OSTIn has to coordinate with the following ministries and agencies:

- Agency for Science Technology and Research (A*STAR)
- Economic Development Board (EDB)
- Ministry of Defence (MINDEF)
- Ministry of Education (MOE)
- Ministry of Foreign Affairs (MFA)
- Ministry of Trade & Industry (MTI)
- The National Research Foundation (NRF) – a department within the Prime Minister's Office, responsible for the national direction for government research and development

It also helps Singapore pursue international collaboration and partnerships with other countries' and jurisdictions' space agencies and organizations, industries, and professional associations. Here are a few examples of its international engagement:

- Signing the Memorandum of Understanding with the European Space Agency on space technology collaboration (Wilson and Dickey, 2023, p.6)
- Signing a Memorandum of Understanding with the Geo-Informatics and Space Technology Development Agency (GISTDA) of Thailand (OSTIn, 2023b, p.2)
- Working with the French Centre National D'Études Spatiales (CNES, the national space agency to promote space cooperation between France and Singapore (Ho, 2022).

Cross-border collaboration

As indicated above, Hong Kong has lost most of its manufacturing. As a result, even if Hong Kong researchers and students want to pursue careers in some of the recommended industrial sectors related to the space economy, they will not have many opportunities to practice what they study unless they are willing to travel to the Mainland and work in some of the advanced manufacturing and research facilities there.

Currently, many Hong Kong universities have established campuses in the Greater Bay Area. These provide a new channel for Hong Kong to develop and attract talents in engineering and science (see Figure 6). In addition, Nansha District of Guangzhou City has some aero-space establishments. Since the District is not far away from Hong Kong (within 2 hours of driving distance from Lantau Island, Hong Kong) and is accessible by train, boat, or car, it can be a great support base for space-related industries in Hong Kong.

Given these advantages, Hong Kong is recommended to pursue more regional collaboration and work more closely with companies and governmental entities in the GBA to create internship and job opportunities related to the new space economy. There are already many amazing stories about start-ups in the Greater Bay Area established by Hong Kong entrepreneurs. Hong Kong government should provide more incentives and support to further facilitate this trend. In addition, Hong Kong Government, the Federation of Hong Kong Industries (FHKI), and other professional and business organizations should encourage more talents and businesses in different parts of China to come to Hong Kong and the GBA. These influxes of talent, if possible, will address some of the human capital bottleneck issues facing Hong Kong.

With regard to the research and development of space-related industries and technologies, Hong Kong should fully leverage the new opportunities presented by Hong Kong-Shenzhen Innovation and Technology Park located at Lok Ma Chau Loop. Leveraging the area for collaboration between the two cities can harness their unique strengths and resources, creating regional synergy in the new space economy. As aforementioned, Hong Kong is renowned for its international connectivity, access to the global financial market, and strong intellectual property protection. These attributes make it an ideal location for business development, and international research collaboration. Utilising these advantages, Hong Kong can attract space-related businesses, startups, and research institutions to establish a presence in the Innovation and Technology Park. This will foster a vibrant ecosystem for space innovation and entrepreneurship.

On the other hand, Shenzhen is a thriving technology hub with a robust hardware and manufacturing ecosystem. Its expertise in hardware development and manufacturing complements Hong Kong's strengths in law, business and finance. The collaboration between the two cities can facilitate the efficient development of technological products and land utilisation for space-related industries.

Not only does the Innovation and Technology Park encourage cross-border collaboration and innovation, it also provides a platform for inter-disciplinary and cross-institutional applied research and knowledge exchange between academia, research institutes, industry, government, and society, which is one of the core missions of the Park.

Figure 6. Campuses in the Greater Bay Area Established by Universities in Hong Kong

CityU – City University of Hong Kong
CUHK – Chinese University of Hong Kong
HKU – University of Hong Kong
HKBU – Hong Kong Baptist University
HKMU – Hong Kong Metropolitan University
HKUST – Hong Kong University of Science and Technology
PolyU – Hong Kong Polytechnic University

Capacity Building Strategies

In addition to asking Hong Kong Government to do more and provide more support for companies to pursue R&D and invest in human capital, the industrial and education sectors in Hong Kong should also do more to supplement governmental-led initiatives. Specifically, below are some recommended actions:

1. For the Industrial Sector

   Currently, Hong Kong Government already provides some incentives and grant schemes under the Innovation and Technology Fund (ITF) to incentivize business-academic collaboration. However, the percentage of the R&D budget of Hong Kong companies is still very low (see Figure 7). For example, the total R&D expenditure was only about 1 percent of GDP in 2020, compared with 2.4 percent in Mainland China, 3.6 percent in Taiwan Region, 3.3 percent in Japan, 4.8 percent in South Korea, and 3.4 percent in the U.S. R&D expenditure by businesses in Hong Kong is also low. In 2020, the percentage of business R&D in Hong Kong was only 0.4 percent of GDP, compared with 1.84 percent in Mainland China, about 3 percent in Taiwan Region, about 1.8 percent in Singapore, 2.6 percent in Japan, 3.8 percent in South Korea, and 2.6 percent in the U.S.

   Hence, Hong Kong industrial leaders need to think about their long-term development needs and competitive strategies and invest in R&D more. Hong Kong Government, in collaboration with the Federation of Hong Kong Industries and other business and industrial groups, may need to organize more business-academic exchanges and facilitate more knowledge transfer activities so that businesses can take advantage of the research strength and faculty excellence in Hong Kong. These exchange programs may also involve some of the top universities and research centres in Mainland China that are doing pioneering research related to the space. These opportunities may lead to more industrial-academic collaboration and knowledge-transfer activities, which may create new development opportunities for Hong Kong industries.

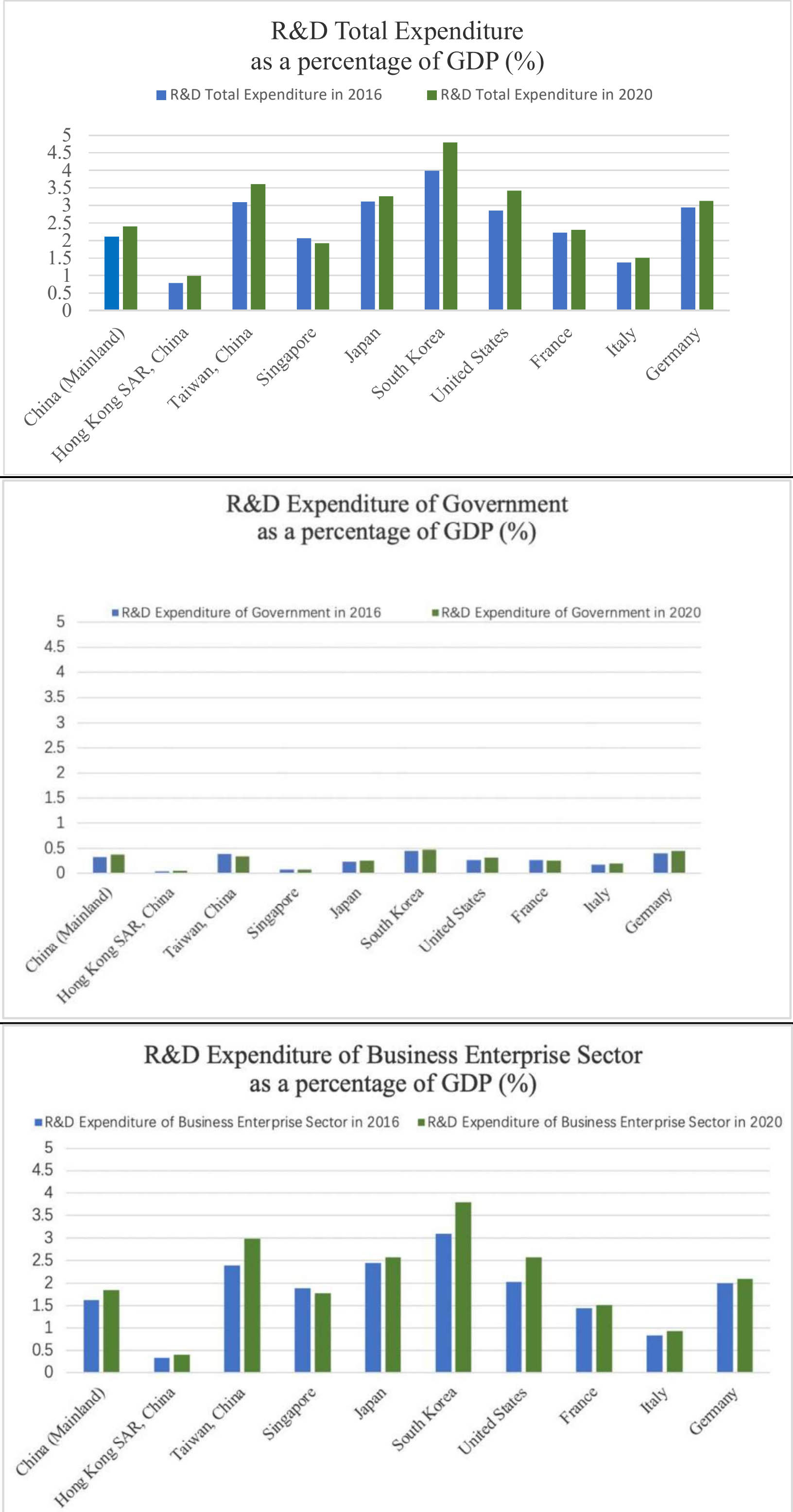
   Also, many universities have knowledge transfer programs. For example, City University of Hong Kong has a Tech 300 program to encourage start-ups (see Textbox 9). Polytechnic University of Hong Kong, HKUST, and the Chinese University of Hong Kong also have special programs to encourage technology entrepreneurship (see Textbox 10). Hong Kong industries may leverage these programs more and develop new technological applications to support the space economic development of Hong Kong.

Textbox 9.
The Tech 300 Program of City University of Hong Kong

City University of Hong Kong launched the HK Tech 300 in 2021, with the goal of creating 300 start-ups in three years. By early 2022, more than 300 student teams have already received seed funding to start their businesses, and by June 2024, the number has increased to more than 600 companies. These start-up companies cover many hi-tech domains, such as big data application, bio-technologies, new materials applications, machinery design, and robotic technologies and systems, and wastewater treatment technology. They may develop products and applications that contribute to the overall development of the space economy in Hong Kong.

For more information, please visit: https://www.cityu.edu.hk/hktech300/

Figure 7. International Comparison of R&D Expenditures as a Percentage of GDP



Source: Multiple data sources compiled by the authors, including the World Bank, IMF, OECD, and different statistical offices.

Textbox 10.
Tech Transfer Programs of Other Major Universities in Hong Kong

Bridge the Gap Fund (BGF) is a funding scheme established by the Office of Knowledge Transfer at HKUST with the goal of enhancing the commercialisation of technology developed at HKUST. The primary objectives of the BGF are to license technology to industry, establish technology start-up companies, foster industry collaboration, and facilitate funding applications with industry partnerships. BGF aims to transform the research outcomes of HKUST into valuable intellectual property, thereby attracting and motivating industry partners to engage with HKUST in generating both commercial and societal impact.
For more information, please visit: https://okt.hkust.edu.hk/bridge-gap-fund#2

TSSSU@HKU (Technology Startup Support Scheme for Universities at HKU) is an award scheme implemented at HKU to foster entrepreneurship. It offers financial assistance to technology start-up companies that are established by members of HKU. The main objective of the program is to facilitate the transformation of innovative ideas and research accomplishments into commercially feasible products and services, thereby making a tangible impact on society.

For more information, please visit: https://tto.hku.hk/public/tsssu/index.html

PILOTS Lite Programme X HKSTP Co-Ideation Programme, organsied by the CUHK PI Centre (managed by Venture Acceleration Team, Office of Research and Knowledge Transfer Services), offers CUHK start-ups seed funding, training and workshops, networking opportunities with industry experts and business partners, consultancy/mentoring services and free co-working space for the teams in the 1-year programme.

For more information, please visit: https://www.orkts.cuhk.edu.hk/en/event/85-competition/3755-call-for-entry-cuhk-pi-centre-20th-round-pilots-lite-programme-fall-2023-x-hkstp-co-ideation-programme

PolyU Entrepreneurship Investment Fund (EIF) is an early-stage equity investment fund to support further scale-up of start-ups involving PolyU members with promising innovative technologies and/or business models. The aim of the EIF is to foster knowledge transfer and impact through commercialization of PolyU's research/innovation outputs through technology venturing.

For more information, please visit:
https://www.polyu.edu.hk/kteo/entrepreneurship/funding_investment/polyu-entrepreneurship-investment-fund/

2. For the Higher Education and Research Sector

Some changes should also happen in the higher education and research sectors to support the development of the new space economy. Specifically, the following are recommended:

- More experiential learning opportunities, such as internships, practicums, and client-led project learning, should be included in the university curriculum so that students and faculty members may apply what they learn and connect academic learning and research with the industrial needs of Hong Kong;
- Universities should place greater emphasis on industrial attachment programmes, potentially through mandatory internship and placement requirements, so that students can gain firsthand experience and insights into industry standards, culture, and expectations, in turn, better equipping students for their future careers and enhancing their employability. To support this initiative, the University Grants Committee (UGC) could incentivise and subsidise enterprises to offer industrial attachment opportunities. One possible approach is to establish a matching fund for employers to cover the costs associated with interns and their training. City University of Hong Kong is already adopting this model in its CityU CAReer Launch Scheme 3.0 (CARLS 3.0), which is a job matching fund for employers that aims to enhance students' employability. The scheme subsidises a third of graduates' pay for up to a duration of three months, resulting in the creation of over 2,280 job opportunities for 2022 graduates (https://www.cityu.edu.hk/media/press-release/2022/07/18/cityu-career-launch-scheme-returns-additional-funding-creating-near-2300-job-opportunities-graduates);
- Some courses may allow co-teaching by faculty members and industrial leaders so that students may learn the latest trends and needs in their classroom before they enter the work setting;
- More company visits, internship opportunities, and project-based learning should be organized with companies in the Mainland so that students are required to go into the Greater Bay Area and apply their skill sets;
- More student competition and joint projects with Mainland university students should be organized so that Mainland and Hong Kong students have opportunities to work together and understand each other's learning and working styles;
- As indicated earlier, the University Grants Committee (UGC) and the Research Grants Council (RGC) of Hong Kong Government need to encourage more applied research and business-academic collaboration, which often take more time and effort than traditional research that stays within a university office space or lab. While knowledge transfer is important and should be encouraged further, it happens only at the end of the knowledge generation value chain when the research is already done and the results are also published and then transferred to industries. If the research questions and topics can be co-developed with industries early on, the relevancy and usefulness of research can be further strengthened;

- The incentive system for faculty members should also be re-considered by the UGC and RGC. Right now, too much weight and emphasis in the promotion or substantiation process is put on peer-reviewed publications. Whether the publications are relevant and useful to industrial needs is not considered much. The UGC and RGC may consider the latest practices of the U.S. National Science Foundation, which has put more emphasis on industrial and societal applications of research (Please see Textbox 11);
- Entrepreneurship can be promoted by offering more incentives and rewards, and encouraging faculty spin-offs through clearly defined IP policies, royalty or revenue-sharing agreements, streamlined commercialisation processes, and IP assignment with flexible licensing agreements.

3. For the Primary and Secondary Education Sector

Changes should also be made in the primary and secondary education sector to address the fact that insufficient numbers of local students are interested in STEM subjects to support Hong Kong's reindustrialization needs and may not know too much about the potential importance of the new space economy. Hence, the following recommendations are suggested:

- More partnerships with universities and research labs to develop extra-curricular activities and summer schools focusing on the sub-sectors of the new space economy suggested earlier;
- More partnerships with universities to develop extra-curricular programs for the mathematics subject under the "Optimise the Four Senior Secondary Core Subjects" program (please see Textbox 12 for more details);
- Establishing more magnet schools in Hong Kong focusing more on science and engineering (please see Textbox 13 for more details);
- Collaboration with national space programs and research labs to organize special events for students to trigger their interest in the space economy (please see Textbox 14 for more details);
- More partnerships with universities to provide curricular support to teachers and "train the trainers" so that they can integrate more space-related subjects into primary and secondary education, such as mathematics, sciences, information and communication technology, technology and living, and economics (see Textbox 15);
- More partnerships with university research labs, Hong Kong Science and Technology Parks, and companies, such as Hong Kong Aerospace Technology Group, to create more experiential learning opportunities, such as summer intern programs and competitions, for students who are interested in the space-related subjects;
- Partnership with universities and the Gifted Education Program of Hong Kong Education Bureau to develop curricula on space-related subjects (see Textbox 16);

- Encouragement and provision of financial and logistic support for primary and secondary schools to organize joint after-school programs and extra-curricular activities tailored for students who are interested in space-related subjects.

Textbox 11.
Encouragement of Industrial and Societal Application
by the U.S. National Science Foundation (U.S. NSF)

The National Science Foundation of the U.S. is a major funder for science and engineering research in the U.S. In its strategic goals, it emphasizes “impact” and encourages scientists to develop breakthrough technologies and scientific research that will improve society for generations. In designing programs and solicit research proposals, the U.S. NSF views its research funding as long-term societal investment that “connects new knowledge to innovations that drive the nation’s competitiveness and fuel the nation’s economic growth” and “addresses present and emerging societal needs” (U.S. NSF, 2022, p. 39).

Some of the NSF funding programs require “engaged research” – it wants business and academic institutions to co-produce knowledge, scientific advancement, and technological breakthroughs, so that the discovery can be translated into social, business, industrial, and defense-related applications more easily and readily. The U.S. NSF also encourages inter-disciplinary research so that innovative ideas and technological breakthrough can happen more dynamically through cross-disciplinary inspiration and team work.

An example is its “Convergence Research” program (https://new.nsf.gov/funding/initiatives/convergence-accelerator/program-model). In the first stage, the program funds community workshops to develop and frame big ideas for inter-disciplinary research. In the process, researchers from different disciplines and stakeholders from industry, nonprofit, government, and other communities of practice gather to discuss societal and industrial needs and research topics that may address the challenges. Then in the second stage, the NSF funds use-inspired research and asks inter-disciplinary research teams to develop solutions that can show real impact and have sustainability beyond NSF support.

The NSF also encourages diversified outputs and impacts. Besides publishing research papers in journals and conferences and developing patents, it also encourages grant recipients to think about implications for education and training, develop innovative educational programs, and create start-up enterprises and technology licenses.

U.S. technological supremacy has been built on decades of successful and impactful research, and the NSF plays a key contributing role to this development. Hong Kong Government, industries, and the academic community may learn from the experience and rethink how research should be organized, incentivized, developed, and disseminated.

Textbox 12.
The Program for "Optimise the Four Senior Secondary Core Subjects" by Hong Kong Education Bureau (優化高中核心科目—為學生創造空間和照顧學生多樣性)

Hong Kong Government introduced an education reform in 2021, trying to give more time and flexibility to senior secondary school students to focus on core subjects such as mathematics, and use more interesting, personalized, and experiential learning opportunities to trigger their interest in these subjects. Students are encouraged to participate in internship, projects, and site visits to apply what they learn in classroom and to understand a core subject more thoroughly. The program gives an opportunity to secondary schools to work with universities and co-develop a special curriculum relating space technology and mathematics, through which students may learn more about the future development and possibilities of the new space economy. Below is the Chinese description of the educational program. For more information, please visit: https://www.edb.gov.hk/tc/curriculum-development/renewal/opt_core_subj.html

現時不少學校的高中四個核心科目已佔去逾半或更多課時，學生缺乏多元化的學習經歷。是次高中四個核心科目不同程度的優化可產生協同效應，騰出課時和增加課程彈性，為學生創造空間。當優化措施落實後， 高中四個核心科目的課時將不超過總課時一半。學校可透過是次優化課程機會，整體檢視和規劃課程，按校情和學生需要釋出不同程度的空間，照顧學生的多元學習和發展需要。所釋放的課時可以便利學校提供更多元選擇，如讓學生增修一個選修科目（包括應用學習）；更深入學習修讀科目（基於優化高中核心科目是為學生創造空間和照顧學生多樣性的原則）。讓部分學生在修讀數學科的必修部分外再修讀延伸部分（單元一／單元二）；及／或更積極參與「其他學習經歷」、全方位學習活動、發掘其他個人興趣，以照顧學生的不同興趣、能力和抱負。

Textbox 13.
Magnet Schools

Magnet schools are non-traditional schools that try to focus more on certain subjects, such as science, technology, engineering, and mathematics (STEM); fine and performing arts; or world culture and languages, and use a more open and innovative approach to let students dive more deeply into these subjects. They may emphasize more on hands-on, experiential learning, team work, and community or business engagement that go beyond a traditional classroom setting. They also try to help students who may be less interested in the traditional subjects, such as English, Chinese, and Mathematics, and want to develop a more specialized subject focus to reach their best individual potential.

This approach can be explored more in Hong Kong, allowing students who are more interested in engineering and mathematics to join a specialized magnet school in this subject and give these students more exposure to space technology applications and technical, industrial training. Students graduating from this type of magnet schools may be admitted to universities under more flexible admission standards, putting more weights on the DSE subject scores and less on the traditional core subjects, such as English and Chinese. This may help the educational system in Hong Kong to develop more specialized industrial talents in the long run.

For more information about the purpose and rationales of magnet schools, one may look at the experience of the U.S. by exploring the following website:

https://magnet.edu/about/what-are-magnet-schools

For information on a magnet school in Chicago focusing on agricultural sciences:

https://magnet.edu/fulfilling-a-unique-mission-at-chicago-hs-for-agricultural-sciences

For information on a magnet school in California focusing on space aeronautics:

https://www.usnews.com/education/k12/california/space-aeronautics-gateway-to-exploration-magnet-academy-268619

For information on a magnet school in Rockville, Maryland focusing on mathematics, science, aerospace, satellite, and robotics:

https://www2.montgomeryschoolsmd.org/school-info/msmagnet/parkland

Textbox 14.
Youth Engagement with National Space Programs

For the past few years, different organizations and secondary schools in Hong Kong have organized special programs and events to help students learn more about the national space program and let them develop more interest in space technology and exploration. In these programs, students have opportunities to visit some rocket launch sites in Mainland, China, visit national labs, meet with astronauts, and attend academic exchanges with scientists and fellow students who are interested in STEM subjects and aerospace technologies.

參觀組裝大樓

太空人訓練

太空廚房

參觀国家天文台興隆觀測站

For example, in 2023, Hong Kong Award for Young People organized a special program called, "飛繁任務 Mission S", to help participating students learn more about aerospace technology, space exploration, and subjects related to "Space", "Sky", and "Stars" (https://www.ayp.org.hk/mission-s-2/).

More collaboration with national labs, space centers, and academies in Mainland China should be launched in the future so that students can be given more exposure to the exciting development of space technology and exploration and be inspired to pursue academic studies in related subjects.

Textbox 15.
"Train the Trainers" Programmes offered by The University of Central Florida (UCF)

According to the U.S. Department of Education (DOE, n.d.), career and technical education (CTE) refers to courses designed to prepare students for careers in current or emerging professions, such as space exploration, which created many interdisciplinary opportunities.

The University of Central Florida (UCF) offers different types of CTE programmes, including summer intensive courses, online bachelor's, and bachelor's, to nurture CTE teaching talents.

The Middle Grades Career and Technical Education (CTE) Accelerator, funded by a $110,000 project grant from the Department of Education, is a two-week summer intensive that helps prepare middle school teachers to include space-related career planning contents into their curriculum, effectively broadening the pool of potential talent in the emerging and highly sought-after space industry field (Fedor, 2023).

Luminary Labs, an innovation consulting firm, which is operating this programme on DOE's behalf, finds that grades 5-8 are critical for developing perceptions of career pathways (Luminary Labs, 2023). Hence, it is important to build teachers' capacity to integrate space-related content and activities into their curriculum and inspire young people to pursue STEM careers.

A professional development training session for career and technical educators (Fedor, 2023).

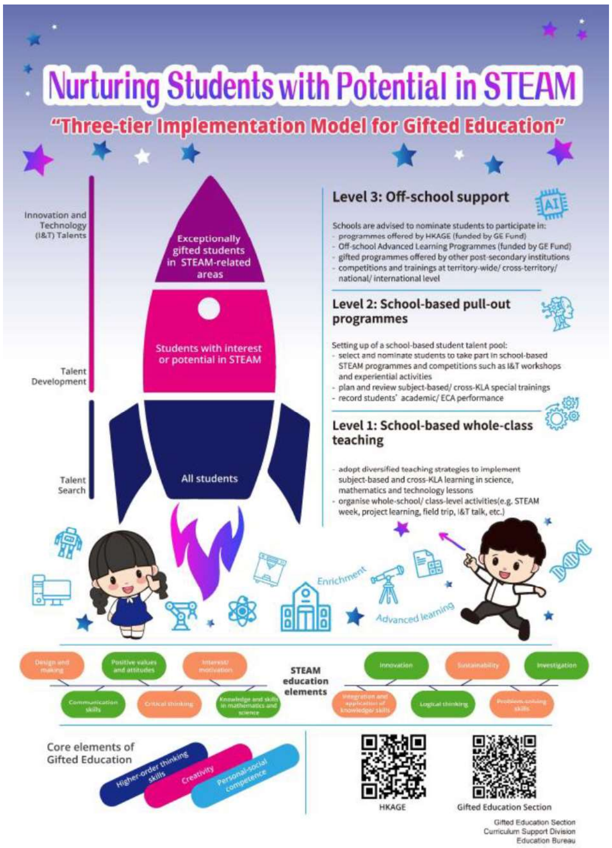
In addition to short-term courses, UCF offers degree level programmes to cultivate CTE talents. The Bachelor of Science in Career and Technical Education (CTE), for example, is a four-year programme that equips experienced subject-specific experts to become career and workforce education and training leaders, whose career paths include serving as CTE teachers in high schools and colleges after graduation. In the programme, students will gain first-hand experience and learn about the principles and practices of technical education, curriculum development, and acquire pedagogical skills, among other things.

For more information, please visit: https://www.ucf.edu/degree/career-and-technical-education-bs/

Textbox 16.
The Gifted Education Model to Support Space-Related Curricular Development

Hong Kong Government can also help talent development through the Gifted Education Program. The program uses a "Three-Tier Implementation Model" and helps schools develop school-based curricula for talented students to study different subjects, including STEAM (science, technologies, engineering, arts, and mathematics), more deeply and thoroughly.

Currently, the Gifted Education Program has curricular materials on microelectronic engineering, DNA analysis, reinforced materials, physics, biology, and chemistry- related topics. It is possible for universities and secondary schools to co-develop some new materials focusing on space technologies and sub-fields recommended in this report.



With the new development of the Northern Metropolis and the policy intention of Hong Kong Government to provide new land for technological innovation and high-tech industries (https://www.nm.gov.hk/en/northern-metropolis), Hong Kong Government may consider using part of the new land to construct and develop a new space museum and education centre, so that it may stimulate the interest of secondary students in aerospace development and the space economy. The proposed centre may regularly invite former astronauts to come to Hong Kong and give seminars about R&D work related to the space economy. The centre may also invite these astronauts to share their training experience and space travel experience to stimulate student interest and nurture the next generations of space researchers. Visits to space technology companies in Hong Kong and other parts of the Greater Bay Area, as well as site visits of the ocean rocket launch base in Yangjiang City, Guangdong may also be beneficial and inspiring to primary and secondary school students so that they may choose careers related to the new space economic development.

4. Greater Bay Area and National Engagement

Besides strengthening the local capacities in various sectors, Hong Kong industries also need to work more closely with companies, research labs, and governmental agencies in the Greater Bay Area and other parts of Mainland China to explore the new frontiers of technological application and business opportunities. Specifically, the following actions are recommended:

- Working with aero-space companies in the Greater Bay Area, especially companies in Shenzhen and Nansha District of Guangzhou, to develop business partnerships and research collaboration;
- Exploring business opportunities and research partnerships with other companies in other parts of Mainland and leveraging the strength of collaborative partnerships between the governmental, industrial, university, and research sectors in Mainland China;
- Developing more research partnerships with other national labs through partnerships with local university research labs to explore the new frontier and technological application possibilities.

International Engagement and Geo-Political Risk Management

Hong Kong should leverage its international connection and collaboration to develop its space economy programs. Many universities in Hong Kong have research collaboration with overseas universities and research labs. Many faculty members and researchers in Hong Kong are from overseas or have worked in overseas academic institutions or companies. All these give Hong Kong a unique advantage over most Mainland Chinese universities and research labs, allowing Hong Kong to be a critical connector between China and the rest of the world in space science and related technology development.

In addition, Hong Kong is a key global financial centre, and its common-law legal system is well respected and trusted by most countries and companies in the world. As a result, it has the potential to be a major fundraiser for space industries that are growing in different parts of the world, and a possible centre for intellectual property management for projects and services developed through international research collaboration.

As more countries will launch tens of thousands of mini- or small satellites into the space, disputes and conflicts over space usage and exploration will be inevitable. Given the prestigious legal system of Hong Kong, Hong Kong Government should try to work with the Chinese National Government, the United Nations, and other international organizations to help Hong Kong become a designated space law and regulatory dispute resolution centre of the world.

At the same time, Hong Kong researchers and policymakers should be aware of the political and business risks given the tense geo-political relationship between China and the U.S. Some of the aerospace technologies developed for civilian purposes may also have dual-use capabilities for military and defense purposes, which may cause other countries to launch sanctions against universities and businesses in Hong Kong. Hence, very careful risk management, clear legal and contractual agreements, and transparent and well-monitored contractual execution by Hong Kong universities and companies should be pursued in international collaboration so that industrial and business applications and services are pursued and developed for civilian purposes and support the sustainable development goals of the United Nations.

Conclusion

This report provides an overview of the growing market of the space economy and the exciting possibilities for Hong Kong industries. Also, it analyses the competitive advantages of Hong Kong and potential barriers, and suggests a series of governmental, business, and educational strategies that may help equip Hong Kong to participate in the new space economy.

Currently, the Chinese space ecosystem is expanding. Its value chain is growing, and the strategic priorities of the Chinese government placed in the space economy, satellite communications, and earth observation, will create a lot of potential business opportunities for Hong Kong industries. Given the long, historical strengths of R&D of Hong Kong universities, if the educational and industrial sectors of Hong Kong partner carefully and effectively with mainland Chinese academies, research labs, and companies, there are great business opportunities from Hong Kong participation in the Chinese space ecosystem.

In addition, Hong Kong has a globally reputable legal system, a well-managed monitoring and auditing system in the manufacturing, legal, and financial fields, and many business and academic partnerships across the globe that have been established for decades. As a result, despite the geo-political tension between the U.S. and China and the associated business risk, the academic and industrial communities of Hong Kong should be able to manage the risk and still participate in the growing space economy. After all, this is an economic sector that is now promoted by the United Nations and has been embraced by many developed and developing countries since it is closely linked to the future sustainable development of the world. Many neighbouring economies, such as Singapore, Korea, and Japan, as well as emerging markets, such as Saudi Arabia, India, Southeast Asia, and Central Asia, have already participated and have invested heavily in the development. It is, therefore, important for Hong Kong to catch up and take advantage of this new economic possibility. It is also consistent with the long-term vision of reindustrialization under the Chief Executive’s 2022 policy vision and supports the national priority of “New Quality Productivity” development.

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