2.2 Technological Rationale

One of the most prominent reasons for establishing a human settlement on the Moon is the development of advanced technology. The lunar environment is extremely harsh relative to any environment settled by humans here on Earth. Therefore, in order to establish a lunar settlement, humanity must expand its capabilities by developing new technology that allows adaptation to, or management of, the conditions of this new environment. Closed-loop life support systems, advanced robotics, temperature control, In Situ Resource Utilization (ISRU), hypo-gravity effect mediation, and radiation protection are just some of the areas that must undergo technological development and advancement in order to sustain human life on the Moon.

All of these technological developments will have direct applications for further development or expansion of a lunar settlement, as well as having direct applications for the future settlement of other celestial bodies, such as Mars. Furthermore, advanced space technology has a very high "spin-off" potential, meaning that there is a high likelihood that these technologies could be applied in other fields on Earth completely unrelated to human space exploration, or even marketed independently as their own products.

2.2.1 Technological Rationale for Going

2.2.1.1 Direct Technology Transfer

The Moon is often looked at as a stepping stone for humans to explore further into deep space. For example, in the last few decades, there has been an increased interest, both public and professional, in sending humans to Mars (Oskin, 2012). However, many people believe that going to the Moon is a necessary step for humans to take in order to more efficiently reach Mars (Wall, 2018a). The proximity of the Moon allows for its use as a proof of concept for deep space human habitation. Humanity can experiment on the Moon and develop the necessary life support systems and other technology required for settlement on and for a lunar settlement, before sending humans on a multiple year mission to settle on Mars. Much of the technology developed to allow humans to live on the Moon will transfer directly to allowing humans to live on Mars, or even beyond to other planets or asteroids. Settling on the Moon is the first step in developing the technology required to expand the influence of humanity outside of the Earth-Moon neighborhood of the solar system.

Lunar Environment Enabled Technology

The lunar environment provides new conditions that could allow for specialized technology development. For example, the hypogravity conditions could lead to more precision in the creation of mixed substances, creating metal alloys, and growing crystals, all of which could have wide applications (NASA, 2015a). These products could be used on the Moon as lunar products, or sent back to Earth for specialized use. Furthermore, the Moon could provide a new location for the distribution of technological services. If launching technology can be developed on the surface of the Moon, such as launch pads and rockets, this could lead to much cheaper space transportation and missions relative to Earth and potentially, a new paradigm of human space exploration with the Moon at the center.

2.2.1.3 Spin-off Technology

Spin-off applications of space technology are the largest, most impactful reasons to encourage space program development of advanced technology. The world is filled with and shaped by products and technology that were developed as a direct consequence of research conducted for space missions (JPL, 2019). For example, the Apollo Missions, which were the only space missions to land humans on the Moon, were directly responsible for technology advancements in areas ranging from athletic shoes and fitness equipment, to kidney dialysis machines, to flame resistant clothing that keeps firefighters and soldiers safe (NASA, 2015b).

This pattern has been shown to continue in spite of the technological revolution of the 1980s and 1990s, and continues today. NASA has a publication entitled, "Spinoff," as part of their Technology Transfer Program in which they showcase approximately 50 technologies annually, for a total of almost 2,000 that have applications outside of the space field (NASA, 2015c). Additionally, ESA has reported 400 external companies that were created due to internal technology development between 2003 and 2016 (ESA, 2016). Table 2.5 below details the information published in the NASA "Spinoff" online database. This includes the number of spin-offs that have been featured and the different areas of application that their space-based spin-off technology has been observed.

Table 2.5. Information compiled from NASA's "Spinoff" online database (NASA, 2017a)

Spin-off Category	Number of Spin-offs 1976-2017	Example Spin-off
Health and Medicine	269	MicroMed DeBakey VAD heart pump. Provides critical patient life support while awaiting a donor heart. Enabled by computer program visualizing fluid flow through rocket engine (NASA, 2009a).
Transportation	173	Radar software for a turbulence warning system that allows commercial flights to prepare for or avoid turbulence (NASA, 2009b).
Public Safety	222	NASA developed biosensors that have been incorporated in screening food and water for potentially hazardous compounds (NASA, 2009c).
Consumer Goods	295	Memory foam, which was originally designed to increase the comfort of space suits and spacecraft seats (NASA, 2009d).
Energy and Environment	348	Lithium battery technology contributed to the development of fully electric vehicles (NASA, 2009e).
Information Technology	264	Artificial intelligence developments for complex scheduling and identifying errors in code during software development (NASA, 2009f).
Industrial Productivity	409	Open-lattice composite structure 12 times stronger than steel, cost less and is fully recyclable (NASA, 2009g).

2.2.2 Technological Arguments Against Going and Responses

As the technological justifications for a lunar settlement endeavor are explored, it is equally important to recognize the possible reasons to not go to the Moon, within a technological context. There are two clear reasons that arise.

2.2.2.1 Opportunity Cost for Technology

As mentioned in Section 2.1.2.2, there is an opportunity cost of focusing on space, but this can be further explored, specifically in regards to technology. Spending resources developing space technology distracts time, money, and human capital from developing technology to solve issues here on Earth. For example, despite the progressing of anthropogenic global climate change issues, in the US, the NASA budget is more than twice that of the US Environmental Protection Agency (EPA, 2018; NASA, 2018a).

That being said, the technological and economic benefit of space technology investments have been demonstrated, and because the space technology sector operates at the frontier of technological advancements, there are few other investments that further the development and impact of technology as space related investments.

"NASA estimated that between 1976 and 2013, spinoff technology had directly generated 18,000 jobs, reduced costs by $5 billion USD, generated $5 billion USD in revenue and saved 444,000 lives"

(Planetary Society, 2014).

2.2.2.2 Using Space Technology for Violent or Destructive Purposes

The second reason is that the advanced technology developed for space could be used for violent or destructive means. The history of space exploration is rooted in the development of high altitude rockets with a high potential for weaponization (Hollingham, 2014). Space provides the ultimate high ground with respect to Earth based conflicts. From orbit, an inert object can be dropped to Earth and become a kinetic energy weapon, where mass destruction is caused simply by the object falling and crashing into the Earth (Preston, et al., 2002).

Space could also become a place where warfare is conducted and where peaceful exploration is not possible. If a lunar base can be established under the precedent of peace and cooperation, as the international law on outer space details, warfare and destruction in space can be deterred (UNOOSA, 1967a). This issue is further addressed by Goal 2: Peaceful Purposes in Section 4 of this report. Space is the heritage of all of humanity and if respected, can lead to the expansion of humanity's influence and knowledge, benefiting humanity here on Earth.

2.2.3 Technological Rationale Summary

Space exploration utilizes and creates new markets for existing technologies, and also inspires the creation of new technologies. The innovations that have taken place due to space activities have resulted in numerous spin-offs in every conceivable field, which benefits life on Earth. While space activities require significant investment of time, money, and human capital to develop new technologies, the societal impact of space spin-offs indicates that space is a worthwhile field in which to invest significant research and development effort. In regards to the possibility of violence, warfare or the misuse technology in space, these are threats that exist in all areas of technology or scientific development. To address this, innovation cannot be halted, but instead, it is important to monitor innovations, establish policy or regulations, and set precedence of good practice in regards to the use of these new innovations. The rationales discussed above are summarized below in Table 2.6.

Table 2.6. Summary of Technological Rationale

Rationale for Going	Arguments Against Going	Responses
Direct Technology Transfer ● Enable Deep Space missions ● Lunar Enabled Technologies	Technological Opportunity Cost ● Distracts human capital from other pressing issues	There are other places that have less societal impact than space from which to redistribute funding.
Spin-off Technology ● Health and Medicine ● Transportation ● Public Safety ● Consumer Goods ● Energy and Environment ● Information Technology ● Industrial Productivity	Use of space technology for potentially violent/destructive purposes	Any development can be misused, so the answer is not to refuse to innovate but to properly regulate.

2.3 Scientific Rationale

This section will build on Section 2.2 by discussing the scientific gains to be made through lunar missions and the development of a lunar settlement. While there is vast amounts of crossover between technology and science, there is a greater focus on the acquisition of knowledge in this section. The reasons that a lunar settlement may be undesirable are focused on the scientific barriers to building habitats on the Moon, and the responses to the critiques highlight the opportunities that scientific missions on the Moon provide, despite the difficulties of the lunar environment.

2.3.1 Scientific Rationale for Going

2.3.1.1 Scientific discoveries

Lunar Geology

Little is known about the inner structure of the Moon, the remnants of its magma oceans, or its craters. A lunar base would allow for an in depth study of lunar features, which remain untarnished by external factors that could prevent scientists from discerning the formation history on Earth, such as the wind, rain, tides, and tectonic movement. Examining lunar features could be the key to understanding how our solar system and planet Earth formed. For example, understanding the craters on the Moon helps to accurately determine the Moon's age, as well as the cosmological events that were happening at each stage of its life, in terms of prevalence of impact events (Jaumann, et al., 2012).

Development of lunar-based astronomy

The lunar environment has many specific attributes that make it attractive for astronomy: the near-vacuum, thin atmosphere, orbital stability, two-week long nights, and abundant surface area create an ideal environment for conducting astronomical studies (Burns, 1995). It is possible to use unique thermal conditions of the lunar south pole and the radio silent lunar far side to conduct astronomy research that would otherwise be difficult with Earth's radio interference, specifically infrared and radio astronomy.