Asia's Lunar Endeavours

Puneet Bhalla

> *Sending humans to the Moon changed the future of the human race in ways that we don't yet understand, but it has given us a new perspectives on them and caused us to look both outward and inward.*
>
> – Stephen Hawking, February 20, 2015

Interest in the exploration of the Moon, much like its phases, has waxed and waned since the beginning of space exploration. The quest for the Moon was an integral part of the space race between the Soviets and the Americans in the 1960s and 1970s, which resulted in a total of 65 missions, including the six manned missions by the US, before they both shifted focus to manned space stations and missions to Mars. Strategically or militarily, the Moon did not offer them much advantage. Scientifically, there was not much that was expected to be revealed after the first few missions. Economically, there was no great rationale for continuing a high cost programme from which few commercial gains could be expected at the time. Mars offered more opportunities for national prestige, scientific discovery as well as mining prospects. In the next few decades, although there were periodic statements about the potential of lunar exploration, these did not translate into actual efforts by any space-faring nation.

The last few years have seen a resurgence of interest in lunar exploration, supported in no small measure by the rapid technological advancement

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N.B. The views expressed in this article are those of the author in his personal capacity and do not carry any official endorsement.

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and proliferation. As the number of space-faring nations has increased, the established players have been compelled to look beyond the Earth's orbit to display their technological superiority for national pride. Showcasing technical expertise would also help them to garner a greater slice of the growing commercial space market. While missions to Mars have proved to be too demanding, leading to many failures, the Moon is closer, more accessible, with mission launches not dependent on astronomical windows, and it provides an ideal stepping stone to Mars.

The impending resource crunch is also motivating explorers to look at extra-terrestrial sources. Over billions of years, the Moon has been bombarded by the solar wind, a thin stream of gas that's constantly blown off the Sun, which, due to the lack of atmosphere, has been able to deposit many volatiles[1] on its surface. Also, impacting comets and asteroids have brought in different minerals, adding to its natural resources. Scientists have studied lunar samples brought back by the Russian and US missions, and subsequent missions launched by Russia, the US, Japan, China and India have mapped and analysed lunar resources over the years. A recent study by Ian Crawford titled "Why We Should Mine the Moon", while highlighting the findings from previous lunar missions, has provided a contemporary perspective on the resource potential of the Earth's natural satellite. There is now a growing interest in ascertaining the prospects for mining these resources, some of which would offer more value than others.

- **Helium-3:** The most sought after volatile is helium-3, an isotope rare on the Earth but abundant on the Moon that can be used as a fuel in nuclear fusion. Thermonuclear fusion can produce much more energy than fission reactions, while emitting very little harmful radiation, potentially allowing a significant reduction in the world's dependence on fossil fuels in the future. Helium-3 surface deposits are available up to a depth of a few metres on the Moon, requiring simple surface mining operations for its extraction. It can then be separated by straightforward heating of the extract to around 600°C.[2] Experts predict that one shuttle load of helium-3 would be equivalent to one billion barrels of oil.[3] Equally, there is potential for fourth-generation high yield nuclear weapons with little radioactive fallout, making their use more acceptable and also enabling such weapons to be employed tactically. When fused with deuterium, helium-3 can produce high levels of energy that offer the potential for spaceships powered by fusion propulsion to reach very high speeds, bringing down time for interplanetary travel appreciably.[4] US experts have estimated the total cost of a programme which includes rockets, lunar operations and the development of a workable nuclear fusion plant on Earth to be about £12billion over two decades.[5] But the pay-offs are expected to be equally significant and most nations are showing an interest in efforts to secure helium-3 from the lunar surface.

- **Hydrogen and Water Ice:** Another important discovery has been the deposits of water ice trapped in cold (less than minus 173 degrees Celsius) and permanently shadowed craters. Recent observations by a number of spacecraft, the latest being the National Aeronautics and Space Administration's (NASA's) Lunar Reconnaissance Orbiter (LRO) spacecraft in February 2015, suggest that the presence of hydrogen-bearing molecules, possibly including water, is not just restricted to the lunar poles but is more widespread, even though the concentrations are very low.[6] Besides, its requirement for human life support, water can be broken down into oxygen that can be used for life sustenance and as a rocket fuel oxidiser; and hydrogen, as a rocket fuel.

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- Other *raw minerals* of potential economic interest on the Moon are magnesium, aluminium, silicon, iron, uranium, thorium and titanium. There are also indications of valuable rare earth elements and platinum group elements.

Prospecting for mining of these resources will now require more widespread geological surveys and detailed mapping. Their quantities and concentrations would have to be evaluated to ascertain the economic viability of mining them and of bringing them back to Earth for terrestrial use. This is what the recent missions and those planned in the near future are seeking to achieve. In Asia, three space-faring nations have been in the news for their recent achievements in space, Russia, China and India, in that all three have ongoing lunar programmes, each distinctive, and at different stages of development. Besides the obvious scientific and commercial benefits, all three are looking at successes to contribute to their stature in the geo-political arena – something that all three have been pursuing relentlessly for their own diverse reasons.

Russian Lunar Programme

The Soviets, who already had achieved many firsts in space, dominated the earlier part of the race to the Moon as well. The Luna series of probes achieved the first visit to the Moon, the first man-made object to impact its surface, and return the first photographs of its far side – the part that is never visible from Earth, and first to achieve a controlled soft landing and send back the first close-up shots of the lunar surface and the first artificial satellite of the Moon.

The Soviets also had an active manned lunar programme that was split into two, the N1-L3 landing programme and the L1 orbital programme – under different design bureaus and rocket engineers and having separate teams of cosmonauts. The existing Russian rockets were not powerful enough to carry the heavy crew modules and the programme was dependent on the success of the under development N1 rocket, which could have inserted a 40-50-tonnes payload into Low Earth Orbit (LEO). Subsequent declassified reports have indicated that the programme suffered due to political interference that led to different competing bureaus having parallel running programmes with split priorities. There was no coordinated plan or centralised organisation for reaching the Moon.[7] Meanwhile, the more focussed approach allowed the Americans dual success – the first manned mission to enter the lunar orbit on December 24, 1968, followed by the Apollo II that resulted in the first human lunar landing on July 20, 1969. Beaten in the race and facing repeated failures of the N-1 rocket as well as cost overruns, the Russian leadership lost interest in the manned lunar programme.

The robotic programme, however, continued well into the Seventies, with their two series of probes, the Luna and the Zond achieving a few other firsts for the Soviets. They put the first lunar rover vehicle, the Lunokhod 1, on the Moon's surface in 1970 and followed it up with Lunokhod 2 in 1973. The Zond 6, 7, and 8 missions were circumlunar missions – going around the far side of the Moon without entering orbit and returning to Earth, where they were recovered. Luna 16, Luna 20 and Luna 24 collected samples of lunar soil and returned them to Earth. The USSR even claimed that its robotic missions were ten times cheaper than Apollo and far less risky than a manned mission.[8] Luna 24, in August 1976, was the last successful Soviet mission to the Moon after which the programme was cancelled. The Soviets also had plans for establishing bases on the Moon, designated Zvezda, which never fructified.

The Moon as a destination continued to be discussed by the Soviets in the 1980s but kept getting deferred mainly due to the financial constraints. The collapse of the USSR in the beginning of the 1990s, with the resultant crisis and dissolution of most industrial infrastructure dealt a major blow to all space initiatives from which it took a long time for Russia to recover. The lunar programme continued to lose out to Mars' ambitions but while the Soviet missions suffered a number of failures, repeated NASA successes gave the Americans a wide lead. After one such failure of the Mars-96 mission, a programme for a lunar lander mission (Luna-Glob) as a stepping stone to Mars was approved along with the future Luna-Geolog (Luna-Geologist) sample return mission.[9] However, soon after, in 1998, financial imperatives once again pushed the lunar missions lower in priority to the unique and more sophisticated mission to Phobos, one of the moons of Mars – a mission that would also serve national pride better than something that America had already achieved years before. The lack of a focussed approach was again evident.

In the first decade of this century, as the economy stabilised and the Russian space programme achieved many successes, the development of infrastructure and investment in technology brought confidence to once again conceptualise missions to the Moon and Mars, with Mars again gaining priority. In 2012, following the failure of the Phobos-Grunt[10] mission, the direction of the Russian space programme has once again shifted to unmanned lunar exploration. There now seems to be a realisation that the country would do well to build upon its rich legacy of successful lunar missions to enable the new age scientists to gain experience in deep space missions and planetary exploration on the relatively closer Moon and utilise the knowledge gained as a step toward future Mars journeys. In all, five launches have been planned, as part of the Russian Federal Space Programme. They are:

2015 — Luna 25 (Luna Glob Lander): To test a new surface landing platform. Initial plans of carrying a drilling device have been cancelled.

2016 — Luna 26 (Luna Glob Orbiter): Moon orbiter to globally map the Moon, carry out environmental evaluation and reconnaissance of landing sites for lunar exploration.

2017 — Luna 27 (Luna Resource-1): 'Luna-Resurs' lander to the Moon's South Pole to study lunar regolith and local exosphere and test for volatiles in the lunar subsurface. This lander would also test a drilling system.

Depending on the success of the first three missions, another two would be implemented:

2019 — Luna 28 (Luna-Resource-2): Delivery of lunar samples back to Earth. This mission would help develop return flight system technology for transiting between the Moon and Earth.

2020 — Luna 29 (Luna-Resource-3): To carry a Lunokhod Moon rover that would study the lunar surface for a distance of about 30 km.

The revised schedule, revealed in August 2014, indicates a domino effect of delays in the programme, with the Luna 25 mission being pushed back from 2016 to 2019. Notwithstanding, future plans also indicate manned missions that would survey areas for setting up a lunar base. A leaked draft strategy document purportedly prepared by the leading scientific and space institutions, and statements made by prominent Russian leaders have indicated plans for permanent Russian settlements on the Moon, starting 2030.[11] Sceptics deride the goals as ambitious, citing the persistent dilly-dallying of the Russian leadership and also the recent spate of accidents and incidents that have plagued the Russian space programme.

The Moon programme will utilise the heavier rockets of the under development Angara series of launchers and the successful maiden launch of the Angara A5 (25 tonnes to LEO) in December 2014 has been a shot in the arm for the programme. Serial production of the Angara A5 is expected to begin by 2018. The Angara A7, under development, is expected to carry 35 tonnes to LEO to support heavier space missions. Cosmodrome Vostochny, a new spaceport being built in Russia's Far East, is also expected to have a larger launch pad for the heavy-class Angara boosters by 2018. This, along with the lower latitude will allow larger payloads to be carried for manned space missions and interplanetary exploration missions. Russia has been seeking international cooperation for financing such a resource heavy and technology intensive programme and the European Space Agency (ESA)[12] and China have both shown interest in collaborations. While the economic sanctions in the wake of the Ukraine turmoil have not been extended to the space programme because of Western interests, they might still have an indirect effect on the progress of the programme. Private investments are also being sought, and in January 2015, a Russian company called Lin Industrial announced that it is capable of constructing a lunar base at a cost of about $9.3 billion.[13]

China's Lunar Programme

The Chinese lunar programme, also known as the Chang'e (Chinese mythological goddess of the Moon) programme, is part of a well defined and focussed space programme by the China National Space Administration (CNSA). The space programme has benefitted immensely from the sustained political and financial support that has allowed it to methodically conduct an incremental series of missions to refine the skills needed for space exploration, including missions to the Moon. Although there has been constant criticism of its reverse engineering practices, it is evident that China has learnt from the previous space missions, imbibed the best technology and techniques and improved upon them to save costs and time. The Chinese Lunar Exploration Programme (CLEP) has three key phases.

The *first phase,* aimed at orbiting the Moon, involved two missions. Chang'e-1, launched on October 24, 2007, was followed by Chang'e

2 on October 01, 2010. Both successfully orbited the Moon, mapping it extensively in high definition 3D detail for future missions. They also carried instruments for mapping the distribution of various chemical elements on the lunar surface. While Chang'e 1 was intentionally impacted on the lunar surface after 16 months, Chang'e 2 left orbit and manoeuvred to the Earth-Sun L2 Lagrangian point – a stable libration point about 1,500,000 km from Earth, where the gravitational forces of the Earth and Sun balance the centrifugal effect on the spacecraft and minimal fuel is needed to remain here. After about eight months, in April 2012, the spacecraft departed for an intercept and flyby of the asteroid Toutatis in December 2012, before heading into deep space to further test the Telemetry, Tracking and Command (TT&C) network. It subsequently entered solar orbit, where it remains to this day.

As part of the *second phase,* in December 2013, Chang'e 3 soft landed China's first lunar rover Yutu (Jade Rabbit) on the lunar surface, the third country after the US and Russia and the first since Luna 24 in 1976 to do so. It is equipped with ground penetrating radar to survey the lunar crust up to a depth of 30 m and instruments to study the lunar surface topography and its geological structure and composition. In addition, Chang'e 3 also carried instruments to establish a Moon based astronomical observatory. Although the rover subsequently faced mechanical problems, making it immobile, its instruments continue to function and China has claimed success in achieving the mission's primary objectives. Chang'e 4, planned as a back-up to Chang'e-3 and originally scheduled for 2015, was to have a robotic lander and rover. However, it is yet to be launched and its future remains uncertain.

The *third phase* purports to bring a sample of the lunar surface back to Earth. On October 24, 2014, the Chang'e 5T1 mission was launched with the stated objectives of validating key technologies for the next lunar probe mission, Chang'e-5. As part of the mission, a lunar orbiter, called "Xiaofei" ("Little Flier") went on a circumlunar mission, similar

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to the Soviet Zond missions. The return capsule then returned to Earth where it was recovered through a "skip" reentry process, that involved "bouncing off the edge of the atmosphere" before reentering, to help slow it down. The complicated manoeuvre, requiring precise flight control and alignment, was aimed at handling reentry into the Earth's atmosphere at higher velocities – in this case, at nearly 40,000 km/h [14] – much higher than those of its earlier missions, including those of the Shenzhou manned capsules. Besides improving understanding of high-velocity reentry mechanisms, this also tested and validated guidance, navigation and control and thermal protection offered by the new materials and innovative space equipment design and trajectories, all of which would contribute to the Chang'e 5 mission.

Meanwhile, the service module separated from the return capsule and used the lunar gravity to manoeuvre to fly to the Earth-Moon L2 point, the first Chinese spacecraft to do so. In January, it manoeuvred back to the Moon and by January 13, had established into orbit, conducting more undeclared tests for the Chang'e-5 mission. Another achievement of the programme has been the piggybacking of the first private mission, the Luxembourg-based LuxSpace's 4M mission (the Manfred Memorial Moon Mission) 31-pound (14 kg) 4M payload, to the Moon. It stayed attached to the rocket's upper stage for a lunar flyby and return to Earth. Chang'e 5 is planned for launch in 2017 as a robotic sample return mission. The mission profile calls for a soft landing on the lunar surface, drilling 2 m deep into the lunar surface, collecting about 2 kg of lunar soil and rock samples, ascending of the sample-return vehicle to orbit (where it will autonomously rendezvous with the Earth return stage), and then firing of a rocket engine to leave lunar orbit and return to Earth. Rendezvous and docking has been achieved multiple times in Earth orbit and experts see the added complexity of achieving it in lunar orbit, rather than direct ascent and return of the module to Earth, as testing and certification of architecture for human missions to the Moon.[15] Exploitation of helium-3 resources on the Moon has regularly been cited as one of the objectives of the Chinese programme and the destination on the lunar surface for the Chang'e 5 mission (as was for the Yutu Jade Rabbit rover), is the Mare Imbrium also known as the Sea of Rains, a known repository of high concentrations of helium-3.[16] Western experts are wary that China's advances in helium-3 exploration could give it an edge economically and commercially, and also provide it geo-strategic leverage.

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Unlike the "Chang'e 5 T1" mission that was launched atop an advanced Long March-3C rocket from the Xichang Satellite Launch Centre, Chang'e 5 is planned to be launched atop a Long March 5 rocket (payload capacity 25 tonnes to LEO, about twice the current capacity), from China's new launch complex, the Wenchang Satellite Launch Centre in Hainan province that is expected to become operational shortly. The lower latitude of the launch site will allow for a substantial increase in payload and its presence on the coast will allow larger launch vehicles and spacecraft to be transported more easily by sea, rather than be subjected to the restriction of the land routes. Chang'e 2's and Chang'e 5 T1's services modules' manoeuvring in the vicinity of the Earth and Moon (cis-lunar space) is being seen by some analysts as early Chinese efforts at achieving both space permanence and space control – by positioning satellites at various points that can then be manoeuvred as required.[17]

There have been no official declarations on the manned space programme although the robotic missions are seen as precursors to manned efforts. China's 2011 White Paper on Space also points out its desire to achieve a human lunar landing. Analysts, looking for indications, have pointed to the official insignia of CLEP which has two human footprints at the centre.[18] They have highlighted the similarity of the return module of the Chang'e 5 T1 mission with the Shenzhou, the crew module of the manned space programme. Some statements by Chinese space officials have further reinforced these claims. Zhang Yuhua, Deputy General Director and Deputy General Designer of the Chang'e-3 probe system said in a speech early last year, "In addition to manned lunar landing technology, we are also working on the construction of a lunar base, which will be used for new energy development and living space expansion."[19] The world also watched with interest when China last year carried out a 105-day (February 3 to May 20) manned test in which three 'Moon dwellers' sustained themselves through bio-regenerative life support systems while being enclosed in a capsule called Lunar Palace 1. Low gravity and high radiation were not factored into the first of its kind tests by China but these would surely be included in the future. Long March 9, with a planned payload capacity of 130 tonnes to LEO, is under research, with the planned maiden launch being around 2028. The rocket that is similar to the American Space Launch System (SLS) is expected to support the manned lunar programme and also other deep space exploration projects.

India's Lunar Mission

India's Moon programme was announced by former Prime Minister Atal Bihari Vajpayee during his Independence Day speech on August 15, 2003, and its highlight has been the indigenous research and development of the technology involved. The Chandrayaan-1 mission launched on October 22, 2008, included a lunar orbiter and the Moon Impact Probe. The lunar probe was successfully inserted into lunar orbit on November

08, 2008, and carried out chemical, mineralogical and photo-geologic mapping of the Moon using 11 scientific instruments that were built by different countries. The mission achieved all its primary objectives before its premature termination in 2009. On November 14, 2008, the Moon Impact Probe separated from the Chandrayaan orbiter and struck the Moon's South Pole in a controlled manner, making India the fourth country to have landed on the Moon. The impact ejected sub-surface soil that was then analysed for the presence of lunar water ice – with positive results.

The success of the mission to Mars, wherein India became the first country in Asia to reach Mars as also the only country to reach the planet on its first attempt has further provided confidence to its space fraternity. Buoyed by these successes, Chandrayaan 2, the second mission to the Moon, with an aim to put an Indian lander and an Indian rover on the Moon, has been planned for 2016-17. Earlier, the lander to deliver the rover to the lunar surface was to be provided by Russia, but following the failure of its Phobos-Grunt mission, the Russian space agency proposed changes to the configuration that would have necessitated reconfiguration of the Indian rover. These developments led to reconsideration of the joint effort by the Indian Space Research Organisation (ISRO), resulting in a decision to indigenously design and develop the landing module. The mission is expected to be launched aboard the GSLV-Mk II. The lander will separate from the orbiter in the lunar orbit and carry out a soft landing at a specified site to deploy the rover. All three will carry scientific payloads to undertake mineralogical and elemental studies of the lunar surface. The proposed landing sites on the Moon have been identified.

The manned mission to the Moon has often been talked about by ISRO and in January 2009, the then ISRO Chief G Madhavan Nair said that ISRO would attempt putting an Indian on the Moon by 2020. The issue again came up in December 2013, when the news of a Memorandum

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of Understanding (MoU) that was signed by ISRO with the Institute of Aerospace Medicine (IAM) was widely reported as the precursor to the selection of astronauts for a manned Moon mission.[20] However, the government denied any such plans, and stated that the facilities at IAM were being upgraded to cater to pre-project research and development for the human space flight to LEO. India at present does not have the launch capability for a manned lunar mission. GSLV III, successfully tested in December 2014, has a capability of 8 tonnes to LEO, insufficient for taking humans to the Moon. Developing a heavier rocket is still some time away. Also, the space programme is already stretched catering to the requirements of a rapidly growing nation and there are other requirements, both in terms of capability and capacity that need to be addressed first. It will serve India well to watch the progress of other lunar missions and take an incremental approach towards its own space exploration efforts.

A special mention is warranted for Team Indus, the only Indian team, comprising space enthusiasts, entrepreneurs and industry experts, among 18 contenders for the Google Lunar XPrize. The Google Lunar XPrize, launched on September 13, 2007, is a global competition with Google Inc. as one of the sponsors that encourages privately funded teams "to land a privately funded robotic rover on the Moon that is capable of completing several mission objectives, including roaming the lunar surface for at least 500 meters and sending video, images and data back to the Earth." They recently won the Terrestrial Milestone Prize for Landing Systems, one of the interim awards, making them strong contenders for the top prize. If they win the competition, then in late 2016, theirs will be the first Indian rover to soft land on the Moon.

The dormant interest in the Moon has been fired up in the recent years with more nations and even private players looking at its potential. Technical experience, financial commitment and economic potential would be the major determinants of the future of these missions. While there are some claims in the US of successful technology demonstrations of mining equipment on terrestrial analogue sites,[21] transporting these to the Moon and making them operational there would be laborious. Operating on the Moon would provide its own challenges in terms of the low gravity, non-existent atmosphere, high radiation and extreme temperature variations. Whenever lunar mining does become a reality, transportation of ore for terrestrial use would never be practicable and processing facilities would have to be established on the Moon itself (lunar bases), requiring huge costs and logistical efforts. Even then, it would make economic sense to transport only some high cost materials back to Earth.

A more logical concept being propounded is the In Situ Resource Utilisation (ISRU) – consumption of these materials in support of development of infrastructure on the Moon itself – for scientific and economic activity as well as in support of future deeper and more prolonged space exploration. The weaker gravity conditions on the Moon offer an opportunity to reduce launch costs as well as to look at futuristic alternate launch technologies such as electromagnetic mass accelerators that use stored solar energy. Crawford's report also suggests that it is more efficient to reach Geosynchronous Earth Orbit (GEO) and even LEO from the Moon than from Earth, and, hence, a lunar base could provide more efficient satellite repair and maintenance in orbit.[22] He has concluded in his study that lunar exploration would involve a hierarchy of future applications. It will begin with the use of lunar materials to facilitate human activities on the Moon itself and then progress to the use of lunar resources to underpin a future industrial capability within the Earth-Moon system. In this way, gradually increasing access to lunar resources

Going forward, global negotiations would be required to put in place regulations concerning garnering of lunar resources. Advanced space-faring nations that have made huge investments towards space exploration would not want to share the spoils, while those with lesser technological prowess would call for the resources to be used for "the larger good of mankind".

may help "bootstrap" a self-sustaining space-based economy from which the global economy will ultimately benefit.[23] Putting human beings on the Moon might be more attention grabbing but robotic missions would continue to offer safer and cheaper options. Advances in Artificial Intelligence (AI), nanotechnology and 3D manufacturing would go a long way in supporting these missions. Innovations in support of these projects will continue to provide spinoffs and applications for the betterment of humanity. If the prospects of exploiting the Moon are interesting enough, it would encourage wider global interest that in turn might lead to the current national missions transforming into international collaborations.

Legal Aspects: However, global interest would also result in a rush by all major space-faring nations to secure mineral rich spots on the lunar surface for mining without interference. This is bound to throw up discussions on the legality of such efforts at securing of resources from the Moon, which the Outer Space Treaty (OST) has called the "province of mankind" and the Moon Treaty, a more communal "common heritage of mankind".[24] While they clearly lay down that the land on the Moon might not be appropriated by any nation, the language is ambiguous when it comes to the exploitation of the lunar resources. Some Western experts are already espousing the extrapolation of terrestrial laws that allow mining without giving ownership rights to the land.[25] Going forward, global negotiations would be required to put in place regulations concerning garnering of lunar resources. Advanced space-faring nations that have made huge investments towards space exploration would not want to share the spoils, while those with lesser technological prowess would call for the resources to be used for "the larger good of mankind". Much like prized orbital slots, there are areas on the Moon that are more resource rich than others and, hence, an authority would have to be established with sufficient powers to ensure free and fair distribution of mining rights. Private participation in missions to the Moon being encouraged by the US would increase the number of stakeholders, making the debate more invigorated. In a recent action, the US Federal Aviation Authority approved a "payload review", a bureaucratic action required to recognise the ownership of extracted resources when carried on a spacecraft, for Bigelow Aerospace – a private company that has plans for lunar mining and setting up lunar bases. It has already stirred discussion within the US because of its international policy implications, the US having ratified the OST, and this debate is only going to heat up in the times to come.

Notes

1. In planetary science, volatiles are a group of chemical elements and compounds with low boiling points that often comprise a large portion of the crust or atmosphere of the planets or their moons. Examples include nitrogen, water, carbon dioxide, ammonia, hydrogen, methane and sulphur dioxide.
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4. Jan Mortier and Benjamin Finnis, "China Leads Race to the Moon", *The Diplomat*, January 07, 2015, available at http://thediplomat.com/2015/01/china-leads-race-to-the-Moon/
5. See more at Els, n. 3.
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7. Marcus Lindroos, "The Soviet Manned Lunar Program", available at http://www.fas.org/spp/eprint/lindroos_Moon1.htm
8. Ibid.

9. "Spacecraft: Planetary: Moon Missions", RussianSpaceWeb.com, available at http://www.russianspaceweb.com/spacecraft_planetary_lunar.html
10. Phobos-Grunt, intended to return samples from the Martian Moon Phobos, was the nineteenth Soviet/Russian mission to Mars since 1960, none of which achieved full mission success. Launched in November 2011, along with a Chinese-built Mars orbiter, it never made it out of Earth orbit due to a propulsion system failure. It reentered the atmosphere and was destroyed in January 2012.
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16. Jan Mortier and Benjamin Finnis, "China Leads Race to the Moon", *The Diplomat*, January 07, 2015, available at http://thediplomat.com/2015/01/china-leads-race-to-the-Moon/
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18. "China Considering Manned Lunar Landing in 2025-2030," at http://news.xinhuanet.com/english/2009-05/24/content_11425131.htm May 24, 2009.
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22. For more details, see Crawford, n. 2.
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24. For more details, see Els, n. 3.
25. Leonard David, "Mining the Moon? Space Property Rights Still Unclear", *Space.com,* July 25, 2014, available at http://www.space.com/26644-Moon-asteroids-resources-space-law.html