Moon Exploration Economics

CASE STUDY OF SPECIALIZED TRACK FOR SPACE BUSINESS

DELIVERABLE_1 - CASE STUDY

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Date:	04/11/2022

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1 EXECUTIVE SUMMARY

Moon is hot again! It was in the 1960s that Russia with its Luna missions pioneered the Moon Exploration making the 1st to reach the Moon surface, 1st crew around the Moon. It was soon followed by the USA achieving 1st men landing on the Moon with the Apollo 11 mission. As the competition between the USA and Russia during the Cold War was the main motivator to drive this research, the effort slow down as tensions deescalated.

With countries like USA, Japan and China being now behind the major missions to the Moon, the reasons for missions are very different - it is about creating viable economics and conquering the surface via presence.

The most invested projects nowadays are about landing on the Moon, using a rover to explore the surface for mining minerals valuable for both Moon and Earth use. Moon missions target self-sustainable Moon settlement (MS) for human inhabitants, whereas Earth-missions - towards extracting rare elements and bridging back, like He3.

Our suggested focus for Moon Exploration Economics is **Development of Moon settlement with oxygen & hydrogen extraction, visitable by space tourists**. Which is to be achieved by choosing favorable political and technology partners and rightfully managing education and legal environments.

After analyzing general information about Moon Exploration, the following conclusions are made:

1. Besides the obvious benefits, such as knowledge, experience, and further exploration of the Solar system, Moon Exploration programs result positively in job creation, private sector contractors, research and development deals, and tax revenues, thus creating money turnover and bringing economic benefits. Nevertheless, considering the enormous investments required to launch the program, it is doubtful that profits can be expected soon.
2. Mining lunar raw materials, beneficial at first glance, could lead to potential geopolitical conflicts.
3. Reconstruction of the existing legal and regulatory framework is necessary to clarify the basic principles and coexistence of different countries in Space. An international organization must be a regulator with independent representatives of all countries.
4. Humanity must understand and take responsibility for its actions in Space; thus, we must care about the Earth, Space, and the Moon environments.

2 INTRODUCTION

2.4 Abbreviations

ME - Moon Economics	ROI - Return of Investment
MEx - Moon Exploration	LEO - Low Earth Orbit
MExE - Moon Exploration Economics	GEO - Geostationary Earth Orbit

2.1 Context And Background

Exo-object Economics is not a new topic. There have been successful missions to get samples from the Moon and asteroids. While the samples turned out to be very expensive objects due to a very high cost of extraction demonstration missions, there has been no proven economic value to it, only scientific.
With the commercialization trend of the space industry, especially with lowering cost of space launcher services, the right topic to follow in search for break-even in ME is “launcher pricing”.
While the launcher cost is a very significant part in the overall picture of Moon Economics (ME), there are other important facilitating factors as well. Depending on the target of ME, various countries might leverage their political, competence and resource tools to gain national benefits from ME, especially the exploration segment of it.

2.2 Objectives

Overview what qualities are important for ME as enablers and business supporters. And propose an action list to achieve France's benefit in the Moon business in future, paying particular attention to the MEx segment.

2.3 Methodology

Analysis will start with reviewing what various segments and how those are impacted for ME and what are the key driving factors for its development.
Then it will be analyzed what are the key competitive advantages, how different countries might leverage to win against their counterpart in a Moon colonization effort.

Finally a strategy will be suggested for France to have an economically viable participation in ME.

3 MOON ECONOMICS

3.1 Historic Perspective

The following are the key successes of the Moon missions in the past [1]:

- Luna2 mission by the Soviets reached the Moon's surface in 1959.
- Luna3 mission by the Soviets delivered the first images from the far side of the Moon, 1959.
- Luna9 mission by the Soviets made the first spacecraft landing on the Moon, 1966.
- Luna10 mission by the Soviets achieved the first stable spacecraft orbiting around the Moon, 1966.
- Zond5 mission by the Soviets achieved the first living beings, tortoises, circling around the Moon and returning to Earth, 1968.
- Apollo8 mission by Americans with first astronauts accomplishing a few orbits around the Moon and returning back to Earth, 1968.
- Apollo11 mission by Americans with the first crew landing to the Moon, 1969.
- Chang'e4 mission by the Chinese achieved the first soft-landing of spacecraft on the far side of the Moon, 2018.

Below are graphed all moonshot missions in a timeline [1]:

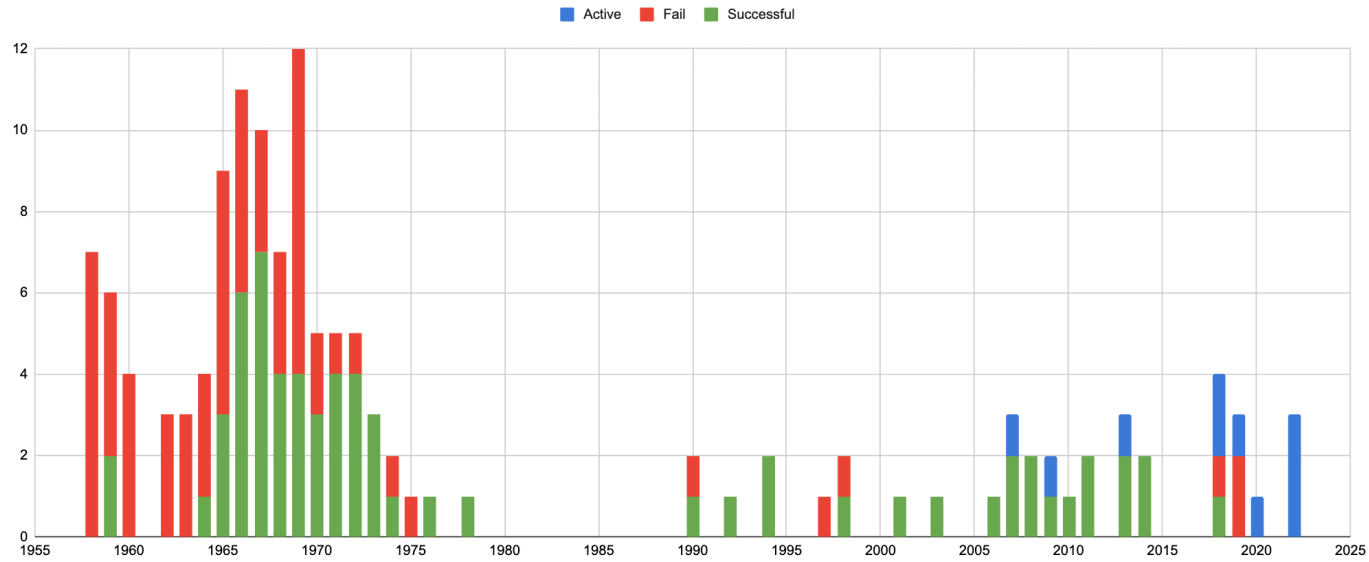

Fig-1: Timeline with status of moon missions

In the following graph we have plotted the mission success rate in three groups of time that seem to reflect early, mid, and late maturity phases of moonshot technologies [1].

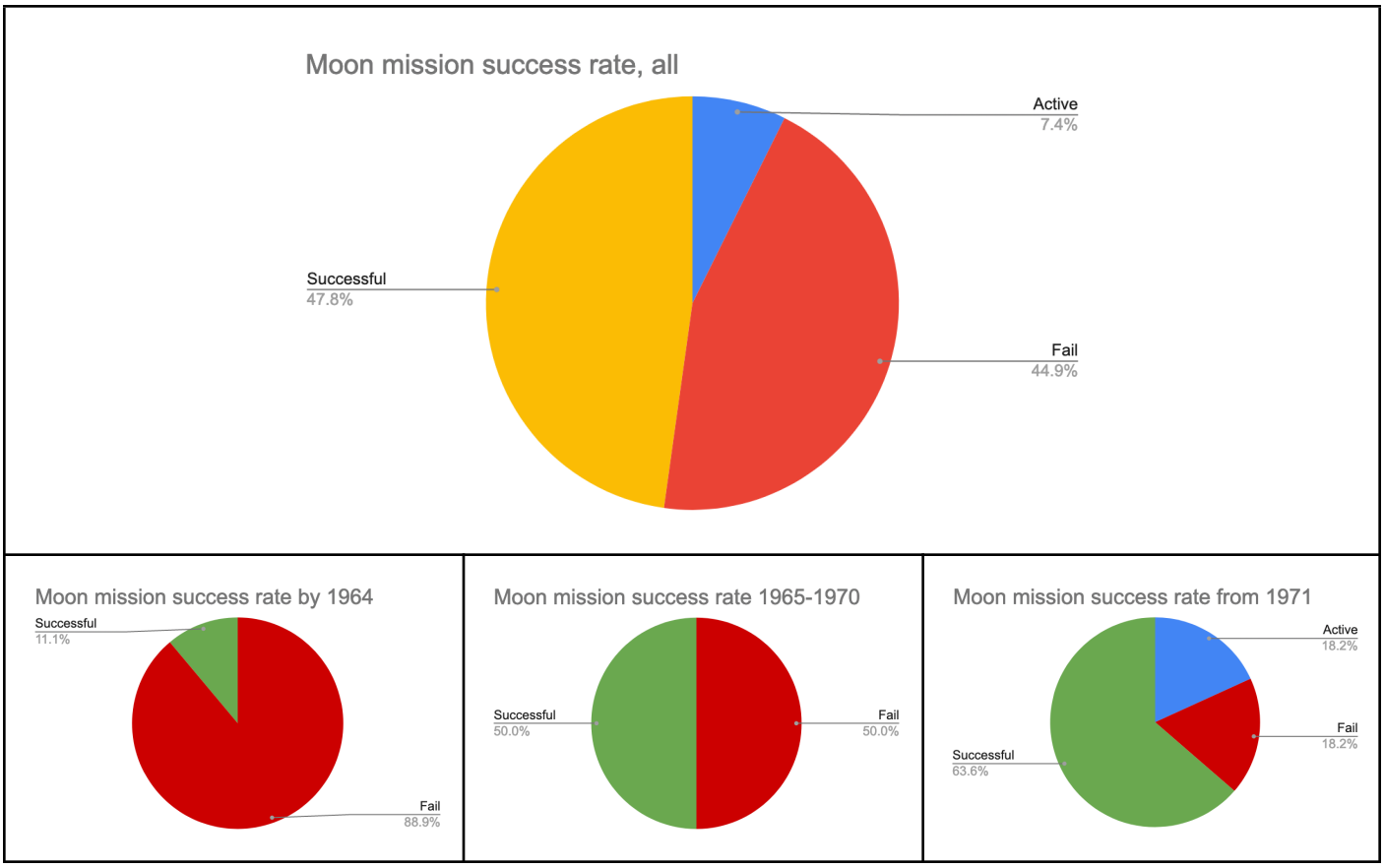

Fig-2a,b,c,c - Moon mission success rates (a) overall (b) till 1964, (c) 1965-1970, (d) 1971-2022

Thus we conclude about historic MEx events that:

- MEx used to be a hype around the 1960s, with main players being Russia and USA, with majority achievements on Russia's side.
- The MEx has gone through 3 phases:
    - Early development with ~90% of failures
    - Improved developments with 50-50% of failures
    - Technological maturity with <20% of failures
- However, a real ME phase has not started yet, as the majority of missions are scientific and deal with demos exploring feasibility of some technical tool, e.g. hydrogen, oxygen, water search and extractions. Only after scientists have proved feasibility and shown a way of how to do things,

businesses can start calculating viability of various Moon-services and search for break-even points in their costs and earnings.

3.2 Ongoing & Future Moon Missions

The Moon race landscape has changed a lot since the early days of Moon exploration. Now, it is China who is leading with the most active mission on the Moon currently [1].

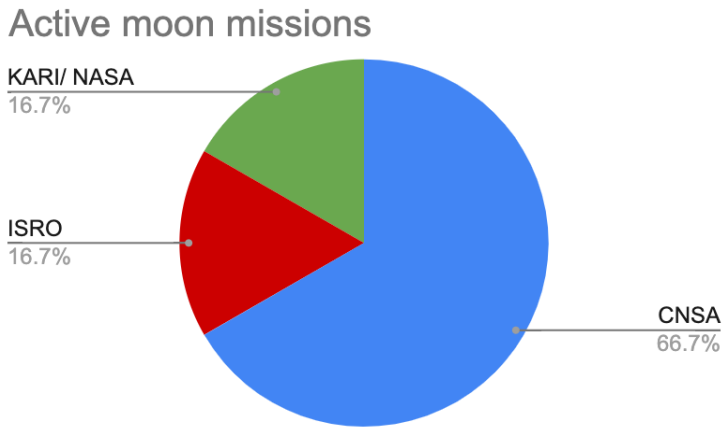

Fig-3: Active missions to the Moon

Exploring a more interesting topic - what are planned robotic Moon missions, the following landscape reveals:

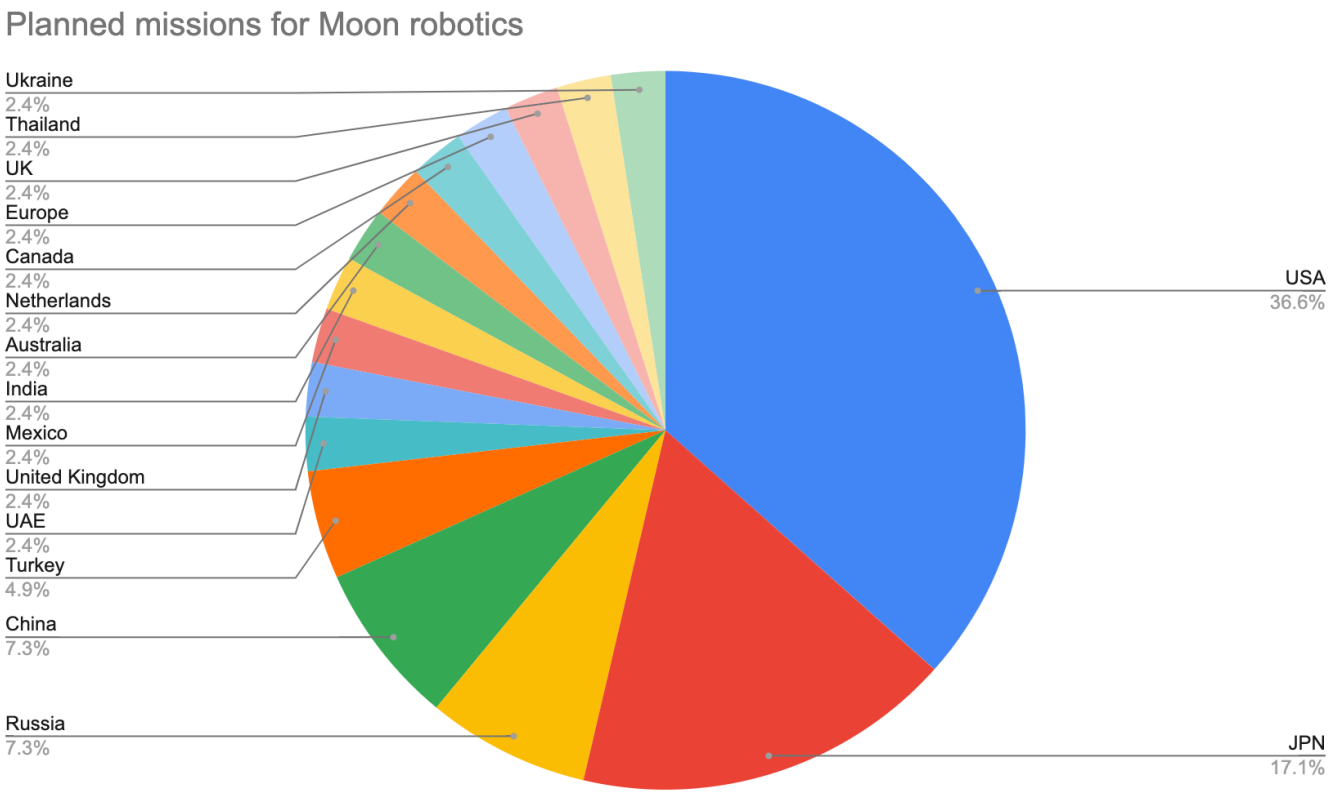

Fig-4: Planned missions for Moon robotics

In the above we can observe that the USA is the leader with 1/3rd of all missions, followed by Japan, Russia, China and Turkey. All other countries have only 1 mission planned. This points out the dominant players. The numbers should be treated with some sense of caution though - the source being american-made website might be listing american-centric perspective with overreporting USA's missions and underreporting those from the rest of the world.

If a country, e.g. France, wants to be serious about MExE, both at national and at ESA's level, it is time for a change. Not take stand that Turkey alone is more competent to have 2x more missions than the whole Europe altogether.

Although it is not a count of missions, but quality, significance and cost that matters, it is important to recognize that building up MEx competences & capacities matter for achieving real frontier in science and economic benefit.

The current biggest ongoing mission is ARTEMIS, led by NASA, with an aim to establish a long-term human presence on the Moon.

3.3 Market Segments of Future Moon Economies

Let us review what is moving and shaping missions to the Moon.

Motivators:

- Competitive prestige via demonstrating technical achievements, like RUS vs USA competition did,
- Achievement of something historic,
- Experience of walking on the Moon,
- Off-Earth settlement for serving and supporting activities in space.

Possible targets:

- R&D for scientific purposes:
    - Exploring the universe with telescopes shielded from Earth's aurora at the far side of the Moon.
    - Exo-planet inhabitation practice.
- Communications:
    - Comms relay between the Moon and the Earth,
    - Comms relay of Earth-orbiting satellites -> Lunar station -> Earth via optical link,
    - Comms for inter-satellite link beyond direct satellite-to-satellite visibility range.
- Mineral resource extraction, e.g.:
    - For bringing back to Earth:
        - Helium3 - is a fuel option for future-to-be-built thermonuclear fusion reactors. Small quantities extracted from the Moon would be capable of yielding huge energy wins on Earth.
    - For local use:
        - Oxygen, Hydrogen, Water.
- Leveraging the Moon as a jump-off point for logistics due it having only 1/6th of the Earth gravity:
    - To service deep-space observation assets in Lagrangian point,

- To simplify inhabiting the Mars,
- To simplify inhabiting the Galilean satellites of the Jupiter,
- Rockets carrying explosives for Earth protection from high-impact asteroids,
- Robotics to build and launch and serve satellites in orbit.

- Social experience:
  - Moon-tourism for short-term visits.
  - Moon-tourism for long-term visits helping to build a settlement on the Moon.
  - Creating self-sustained inhabitable space on the Moon.
    - Use an assist of lava tunnels to build meteorite-proof settlements.
  - Off-Earth settlement to back-up human species for possible future asteroid impact, that did wipe out previous civilizations of dinosaurs on the Earth already.

Commercial markets:

- He3 mineral resource extraction for use on Earth,
- Communication applications for Earth and satellites,
- Settlement installations for tourism, science, space-tech support and self-sustained living,
- Transportation to the Moon.

3.4 Impacting Factors

3.4.1 Facilitating factors for capturing ME

Here we define Enabling Factors as those resources that can distinguish one player from another, where the 1st can do something the 2nd can't. E.g. why a country like Latvia has no chances to go to the Moon, but France has more and the USA has plenty.

Enabling factors:

- Legal protection for Moon-activities.
- Financial resources to build things in space.
  - Governmental - to pave the way for industrialisation.
  - Commercial - companies and people having money to create and experience Moon activities.
- Pool of educated space-tech engineers.
- Previous experience in planning and executing space missions.
- Launching infrastructure, competence and capability.
  - Although the Moon is ~10x more far away from Earth than GEO orbit, a GEO launch vehicle ownership can be considered as a strategic stepping stone for moon missions.

- Autonomous spacecraft landing technology.

Scaling factors

- Favorable legal environment for excavation, settlements and use of the Moon surface.
- Frequent and very affordable launch services to orbit.
- In-orbit services are a good stepping stone.
- Surface exploration technologies:
    - Hyperspectral cameras for detection minerals.
    - Radar technologies for 3D surface scanning of terrain properties.
- Land-rover technology
    - E.g. rovers from previous the Moon and Mars missions.
- Minerals extraction technologies.

Knowledge factors

- Vegetation growth in low-gravity environment,
- Artificial lighting impact to vegetation and humans,
- What mineral resources are available on the Moon,
- Efficient ways to extract minerals of interest from the Moon environment,
- Exo-planet education,
- Settlement setup methods,
- Trained Edge-AI DNNs for autonomous rovers executing high-level tasks on surface.

3.5 Considerations about Strategy for France's National Success in ME

Authors of this paper don't have enough background to perform good quality PESTEL (Political Environmental Social Technology Economic Legal), 5Forces (Porter's 5Forces of Rivalry, Bargain power of Customers and Suppliers, Barriers of Entrance and Exit), KSFs (Key Success Factors) and VRIN (Valuable Rare Inimitable Non-substitutable) analysis without deeper studies. This has been added to the Future Studies section at the end of this document.

3.5.1 Stepping stones

Logical stepping stones for a strong ME development:

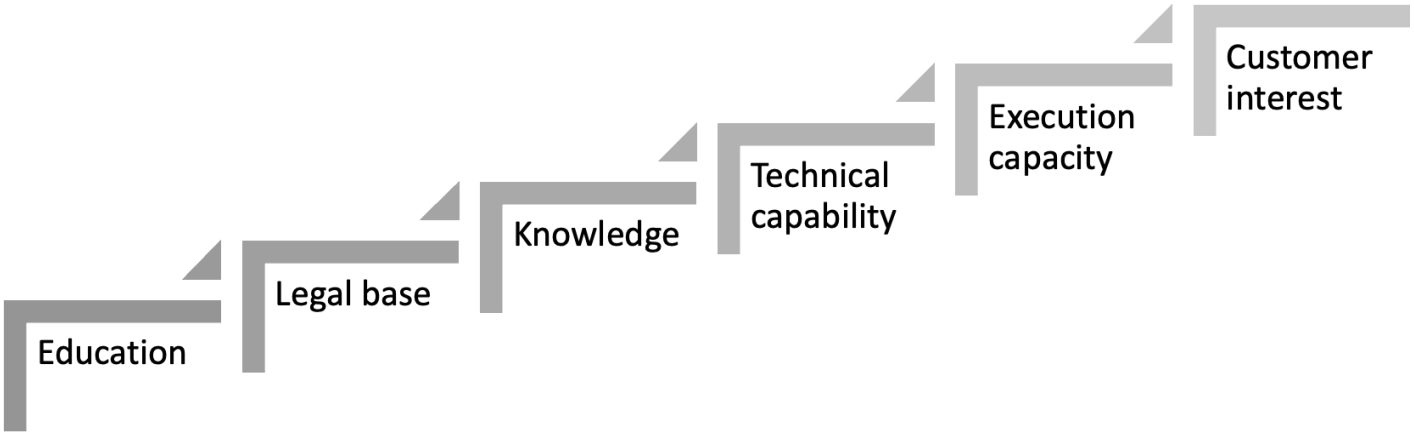

Fig-5: Logical stepping stones for MExE development

3.5.2 Focus

Based to France's unique position owning:

- GEO-launcher rocket, launchpad and competency of launch industry,
  - But not rocket-landing,
  - And not own fuel-resources
  - And not being the cheapest and fastest
- Participation in ESA and thus Mars and Moon rovers,
- Having good relationship with all major space-players,

the suggested national focus topic is: **Development of Moon settlement with oxygen & hydrogen extraction, visitable by space tourists**.

As the topic name implies, it is very wide. It can be from rockets to support the launches to boring machines for tunnels of settlement and water extraction from ice on the far side of the Moon.

Communications are emitted here, as benefits of it can be doubted due following technical factors:

- Very far distance from Earth thus broadband applications requiring low latency would need to be omitted.
- Earth vs Moon is moving around, thus continuous communication would inquire multiple GS on Earth.
- Laser comms would face issues with optical to Earth due cloudiness.

- Usage of the Moon as an optical comms-relay for LEO satellites would be directly competing with GEO satellite services that already exist and are cheaper to maintain than build new on the Moon.

3.5.3 Distribution of competencies

It is clear that building a MS alone might be too challenging to succeed. E.g. France alone would not have enough competencies and resources to do everything itself. Making partnerships with Europe's countries would be favored, as that would allow leveraging ESA's fundings. As it would make use of the very segmented Europe's space industry and complementary competencies. E.g. Germany could do land rover, Italy soil digging, Spain oxygen extraction, Luxembourg comms on the Moon, Norway comms to the Earth, Switzerland energy generation & storage, France the settlement housing, etc.

The good part is that there are many enough European countries to split many complex tasks. However, one can expect many disputes about "who does what" and how much investment each country is ready to devote to this topic. While MEx is exciting for scientists, space tourists and governments, for a generic person earning <5kEUR/month any government tax investments in the Moon sector will remain with minor benefit, as they won't be able to afford traveling to the Moon to benefit from infrastructure created there anyway.
The natural way of splitting "who does what" would be based on each country's current competencies in the space sector and on-Earth industries, accounting for financial strength to execute those duties. However, we will leave it unanswered here, as such study requires significant time going beyond the scope of this assignment.

For the above study an important factor is to consider the 1st mover advantage and disadvantage of it. E.g. from a historic point of view, Russia has lost many rockets in the Moon missions, creating its competitive advantage in this sector through trial-and-error. The race was very expensive for all the 3 frontline players - Russia, USA and China, but especially the 1st achiever Russia. Thus in terms of investment return value, the Moon race was merely the first mover disadvantage, as it required a lot of resources devoted to succeed into the unknown. With the recent maturity of launcher technologies, it is significantly easier for France to build a moon-launcher now.
The above comparison of 1st mover (dis)advantage is expected to repeat itself in solving other technological difficulties, especially under tight tech-racing conditions against time. And it could be yielding very low ROI due gained knowledge being easily transferable and repeatable, e.g. extracting oxygen, generating energy could be learned from a published paper of the 1st mover.
But it is different for some technology like underground tunnel creation, which is less about "scientific how" and more about "tactics of doing it", and when achieved there is little value for someone else repeating it

instead of leasing already created one or machines to create it. Thus some of the settlement creation competencies encompass 1st mover advantage and disadvantages. Legal protection of know-how is expected to be the key to reach a high ROI from MEx missions.

Another important perspective to consider is New-Fringe-Detached breakthrough innovation market analysis. Sometimes by boosting fringe-market one could facilitate creation of a fully new market. Due fringe markets are using resources and customers of an existing industry. Example would be to use the Moon for comms relay networks, so that sat-comms players that are in the market already with existing customers can create some innovation, which then fuels the ME. Or another example would be adopting rovers created for Mars for missions on the Moon.

3.5.4 Finding the right technical partners

This would require analyzing competencies of all ongoing MEx missions, which might be a too complex topic, therefore adding it to the Future Studies section only.
From our group's standpoint, there are 3 generic categories to consider:

- Transportation,
- Building a settlement,
- Sustaining a settlement.

Any partners contributing to those competencies would be valuable for a partnership. The one of dominating importance, especially for scaling MExE, would be finding a cheap next-gen propulsion system for interplanetary travels. E.g. If a ticket to the Moon would cost <10kEUR, there would be many tourists willing to have a once-in-a-lifetime travel experience. Probably so much that one could build a Moon settlement based purely on volunteers who visit a temporary Moon base for a week or a month while staying at a temporary site. A cheap transport would literally convert the task of building a Moon base from a difficult and extremely expensive target of 10ths of billions of € into a multi-million € task with a big social volunteer support.

Technologies worth exploring into this direction would be:

- New ways of energy sources:
    - LENR (Low Energy Nuclear Reaction) - about how pressurized hydrogen under high intensity electrical fields can contribute to very tiny local fusions in metallic lattice creating base metal isotopes. This scientific topic at the time of Fleishmann and Pons was discarded, as the research results threatened state financing for nuclear fusion research scientists. There has been great scientific work done behind mainstream stages, with a personal favorite being [6] by Edmund Storms from Los Alamos National Lab. It is a must-read to understand why the

breakthrough discovery was dismissed for political and prestige, and selfishness reasons. The EU Commission has launched a recent project to investigate this phenomena [7], [8].
    - Nuclear fusion - this has become a very trendy race for a technological achievement, based on research for the ITER fusion reactor. Making it work, but more importantly, scaling for space use, is still a scientific objective with no working prototypes.
- Local gravity field altering technologies.
    - Torsion Field Theory - idea is that individual spins of matter are responsible for their mass and can be altered with certain techniques. Mostly all related literature is in russian with some translation in [9] and generic explanations in [10].
    - Gravito-magnetics - an ongoing research about electric field impact to local gravity [11]. With one French scientist working in this direction too [12]. A replica has been attempted by one author of this case study [13].
    - Searl Effect Generator - technology composed of gear-like spinning magnets, showing weight loss of the system while cooling itself down. Author of it is John Roy Rober Searl from Glasgow, claimed he achieved a controlled levitation of his system, with a picture from a local newspaper below. With a reported replica in Russia by Rochin and Godin. And with another replica in Canada by P.A.Murad [14].

Fig-6: The idea about daily trips to the moon is old. It is all about pricing. Could a breakthrough technology be created by our generation that allows us to achieve that dream? Some dismissed scientists claim there is a way [15]. Could their innovation have been just too early to comprehend or too politically competing with more powerful players for money?

3.5.5 Finding the right political partners

Globally the USA with its English speaking allies has started the majority of armed conflicts since WW2 [ref, ref, ref]. From that context it is uncertain if the USA and its closest allies will be balanced and equally cooperative in developing Moon economics without aiming for an upper hand relative to its partnerships. However, as the USA is investing massively in MEx already and thus has accumulated significant competence, it would be very challenging if not impossible to replace the country with someone else.
The most toughest competitor to Europe is promising to be China, with its steeply growing competencies and very resourceful industry.
A promising cooperation partner could be Japan, which is already cooperating with ESA and multiple EU's national space agencies. However it should be considered that Japan has very tight ties with the USA and thus might be inclined to favor the USA more than Europe.

Russia might be a technically interesting partner with its competence from early MEx and its relatively cheap and reliable rocket launchers. However, due to the current global geopolitical context, as long as the USA is colliding with Russia over the influence zone in East-Europe, such cooperation is out of reach.

3.5.6 Supportive action timeline

Using the Backscattering Method, which is often used by CNES for future mission studies, the above could be summarized in the table below.

STEPS	Regulation/Law	Society/Behaviour	Economy	Techno
2025	Ensure private property rights for installations on exo-planets. Clarifying who protects, under what country's governance.	Start education programs about resources on the Moon and benefits of a moon-base.		
2030	Ensure patent rights for the Moon, e.g. 1st to create or build or demonstrate is the owner of that tech.		Promote business-incubators for commercializing moon-rovers' exploration activities	Milestone: A Moon-Bus (MB) with tech-robots few times a year
2035	Clarify how mine ownership on the Moon is to be established. E.g. do not allow to own all ice by single party.	Promote idea of having socially-contributing vacation on Moon, by building a settlement	Promote development of He3 extraction business, bringing it back to Earth with the Moon-bus	Milestone: MB with human-engineers flying back-and-forth a few times a year. Engineers are helping to build safe settlements.
2040	Clarify how interactions across borders act. E.g. if France makes a lander at a gold-mine on the Moon as 1st, are Americans and Chinese allowed to come and steal that gold? And if France shoots an American rover, will that cause a war between America and Europe? On		Milestone: The cost for going to the Moon is <10k$/pax, assuring the tourist is a well-educated engineer, capable to build the settlement on Moon for 10hrs/day.	Milestone: Moon-bus is flying every month, traveling to the Moon is assured to be safe. Travelers are mass-helping to build a safe settlement and extract mineral resources.

	Earth or on the Moon then?			
2045	Create regulations of safety for space-travels.	Shape society perception that moon is achievable travel destiny, "safe and effective" travel		
2060	Create Moon-imigration check-in regulations.	Promote ida that commuting to Moon is "easy"	Milestone: Skilled Moon-visitors pay for their travel by working on Moon-settlement expansion.	Milestone: Self-sustainable and safe settlement that can maintain 100 visitors for 1year has been built.

4 FUTURE STUDIES SUGGESTIONS

Following list of items our group is identifying as a necessary to analyze to better estimate MExE:

- Do PESTEL (Political, Environmental Social, Technological, Economic, Legal) analysis for MExE.
- Do Porter's 5Forces analysis for the following 2 products:
  - Moon-Rovers for various mineral extractions and surface exploration
  - Moon-Settlement building for human inhabitance
- Do Key Success Factors analysis for MExE.
- Analyze how premature various rover and human-life supporting technologies for the use on the Moon are and suggest the best timing for activating national level competencies in these areas. Targeting the right balance of avoiding expensive 1st mover disadvantages but benefitting from being a frontline player.
- Make a graph per country showing competences in a pie chart for:
  - Technical strengths from past missions
  - Technical strengths expected to earn from future missions
  - List technical strengths necessary for building Moon-settlement and surface exploration camp.
- Estimate size of different markets of ME. And make an effort to predict how those markets might grow in future till year 2100. Pay extra attention to the size of the Moon-Exploration segment, by splitting it in sub-segments and noting size of those. E.g. finding ice.

5 CONCLUSIONS

Moon exploration was the trend in the 1960s due the Cold War between Russia and America, both mega-powers competing for pride to be better than the other. Due to NATO's expansion to the East to include UKR, America has created an earthquake in the political power positions in UKR and as expected resulted in proxy-war of the USA with RUS in UKR [ref]. With Europe dragged into this collusion to support USA's influence zone expansion. Thus the political stage is similar to the Cold War. Similarly to 50 years ago, now we can observe a rise in Moon-exploration activities again. However, this time it is not for prestige, but for a hunt on resources and ownership on the Moon. Also Russia is not any more a major actor, but it is USA+Japan's rivalry against China. Russia has lost its frontier-role for MEx, as it has been solely focused on launching services for commercial customers, rather than using the launcher capacity for its own scientific goals.

The hottest topics currently are: landers, rovers and mineral extractors to support life on the Moon.
The He3 extraction from the Moon to Earth is not yet, as the fusion reactor development on the Earth is still work-in-progress due difficulties controlling the high-temperature high-pressure plasma. With Russia successfully delivering main magnets for building ITER in France this month [ref], the science in fusion reactors might move forward in upcoming years, for everyone's benefit on the Earth and the Moon.

While we are decades away from comfortable tourism to the Moon with self-sustained settlements and "hotels" built in the exo-planet, it is now the right time to act to ensure national competitive advantage for ME. Legislation, education and technology are the biggest impact tools to achieve that goal.

Highly likely due western countries having accumulated a plenty of wealth, with many billionaires in USA and China, space-investments and tourism might be realistically considered viable. As space-tech developments usually produce great spill-overs to other industries, it might be of great national interest to long-term invest in this sector at national level too. Although we are very far from having positive ROI for ME, the MEx segment currently is the closest to positive ROI. Thanks to various national support for Moon-business actors, the transportation, landing, surface exploration and mineral extraction techniques are explored with increased intensity and can be expected to become economically viable within the next 15 years.

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