LUXEMBOURG SPACE AGENCY

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EXPLORING NEW FRONTIERS

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New Insights for Enabling In Situ Resource Utilization

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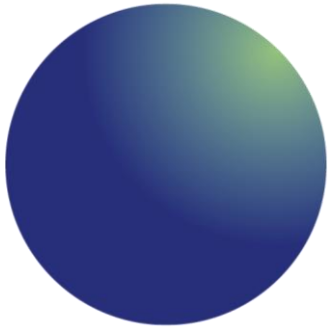
Golden, 11 June 2019



Since 2016, Luxembourg has implemented a comprehensive strategy to realize its vision of space resources utilization

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AN INITIATIVE BY THE LUXEMBOURG SPACE AGENCY

Luxembourg aims to contribute to the peaceful exploration and sustainable utilization of space resources for the benefit of humankind

Five Strategic Pillars

1. Ensure national political support and promote international cooperation
2. Build clear legal framework and engage internationally
3. Promote long-term public support and workforce engagement through education and R&D
4. Provide dedicated support for industrial research and development activities
5. Develop long-term funding instruments

Luxembourg has been promoting space resource utilization nationally and internationally, on all levels

International Engagements

ESA

European Union

United Nations

Bilateral agreements signed

Looking for suitable projects of common interest, in particular in utilization of Space resources

Promote investment in ISRU
Develop ISRU for exploration
Need for international framework

International media exposure

Organization and Engagement in Various Events

IAC BREMEN 2018

ASTEROID DAY 30 JUNE

Paris Air Show

SPACE FORUM

International Advisory Board

Luxembourg proceeds with a step-by-step approach to build a clear international framework on space resources

National law on the exploration and use of space resources (August 2017)

A first step for future space resources activities :

- *provides legal security and legal clarify for private operators*
- *Recognizes that space resources are capable of being owned*
- *fulfills its obligations under Art. VI of the OST (authorization and supervision)*

Hague International Space Resources Governance WG

Luxembourg strongly supports the activities of this working group.

A set of 20 building blocks were agreed at the last meeting in April, covering:

- *Non-interference*
- *Priority rights*
- *Period of use*
- *Environmental issues*
- *Assistance to developing countries*
- *Framework for dispute resolution*
- *… and many other topics.*

UN-COPUOS

Luxembourg encourages discussions on space resources exploration and utilization in all relevant international fora, in particular in the Legal Subcommittee of the UN-COPUOS.

The European Space Agency is a key partner for Luxembourg and more and more active in space resources

Specific agreement signed in 2017

Key studies developed and implemented together.

Cooperation in events

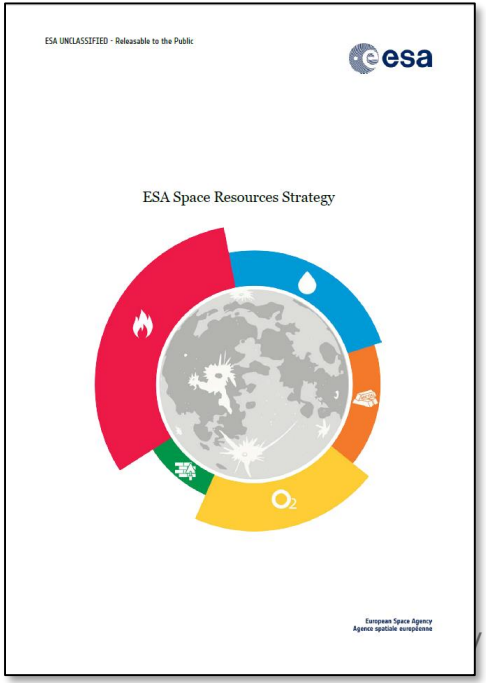
2018:

ISRU Workshop

2019:

Space Resources Week
7-11 October 2019
in Luxembourg-City

ESA Space Resources Strategy published in May 2019



Public research and educational programs have been developed through national and international partnerships

National research institutions have become active in ISRU

uni.lu
UNIVERSITÉ DU LUXEMBOURG

LUXEMBOURG INSTITUTE OF SCIENCE AND TECHNOLOGY
LIST

SNT
securityandtrust.lu

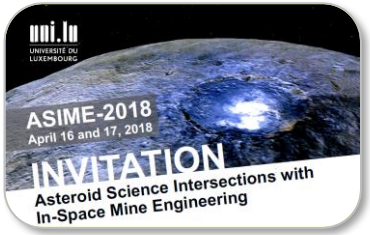
Fonds National de la Recherche Luxembourg

ASIME 2016 Workshop

Advancing global understanding of available space resources

ASIME 2018 Workshop

Understanding the Composition of Asteroids



Interdisciplinary Space Master starting in fall 2019

Includes modules on space resources exploration & utilization

Luxembourg has enabled access to capital for commercial space companies through national and international partnerships

Different instruments available through partnership with ESA, SNCI and VCs

- **Grants:** Commercially oriented research and development grants
- **Early-stage and growth-stage financing:** Equity investments for strategic cases
- **Debt Financing** instruments for certain projects

esa

SNCI
SOCIÉTÉ NATIONALE DE CRÉDIT ET D'INVESTISSEMENT

LSTA.lu

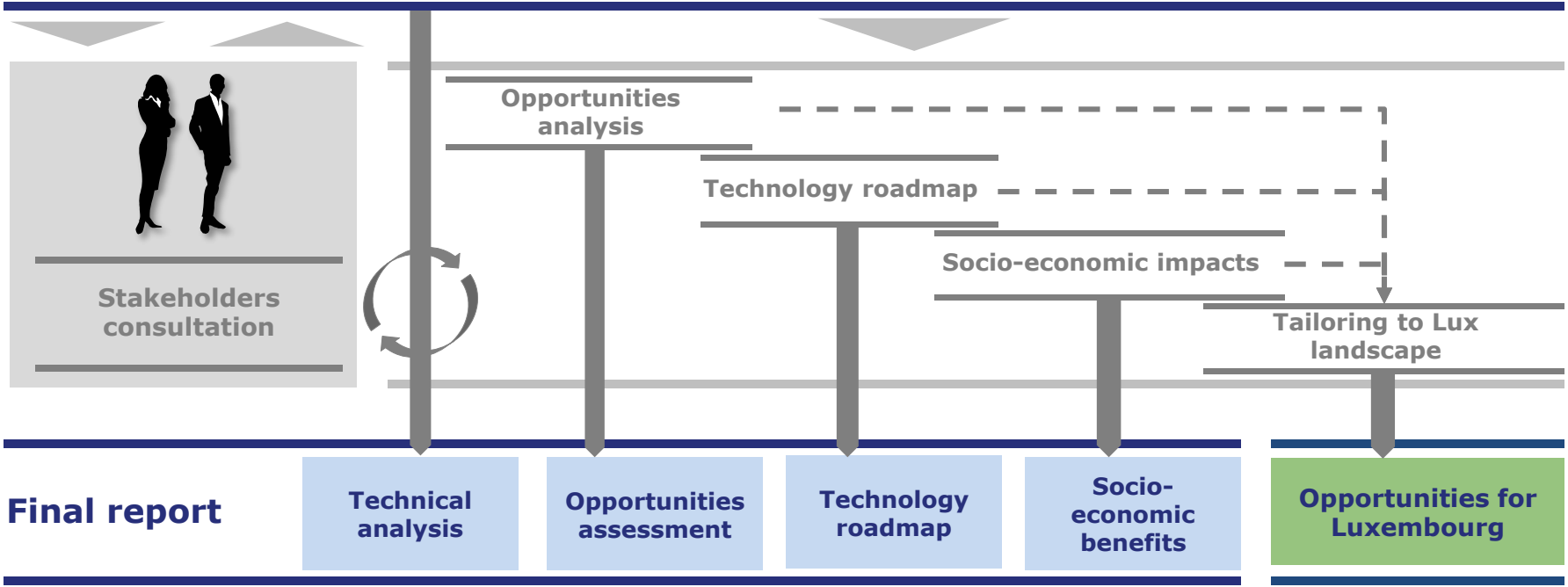
Cooperation agreement signed with the European Investment Band (EIB)

European Investment Bank

"The largest multilateral investment bank"

A large number of new companies have joined the Luxembourg ecosystem, many related to space resources utilization

In 2018, we ran a study to analyze the likely market, technology and socio-economic impacts, allowing us to focus our initiative



The potential value chains for SRU were characterized on the basis of applications, resources and mission profiles

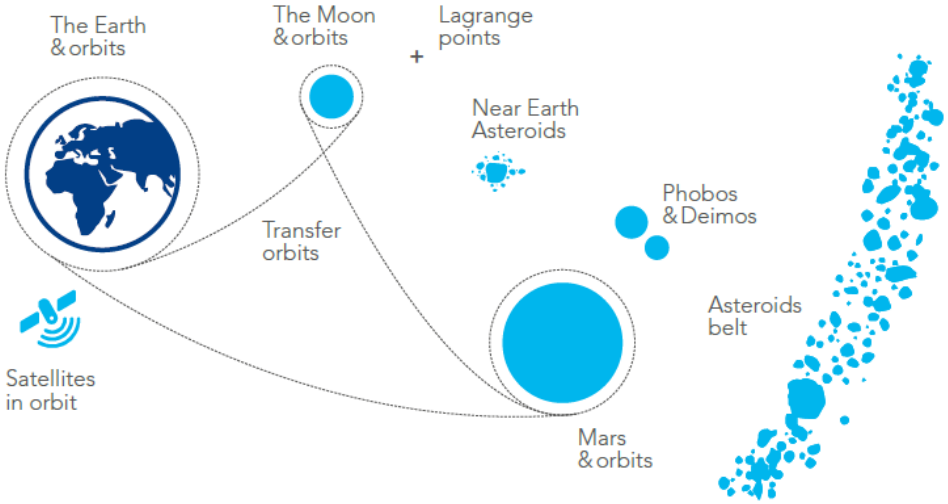
1 Applications

- Life support to astronauts
- Propellant for launch vehicles and other space vehicles
- Construction of in-situ infrastructure
- Radiation shielding
- Manufacturing of equipment in space
- Earth-based use of Platinum Group Metals (PGM)

2 Resources

- Water, and others: H, O, N, C
- Methane
- Metals (Fe, Ni, Co)
- Regolith
- Platinum Group Metals (PGMs)

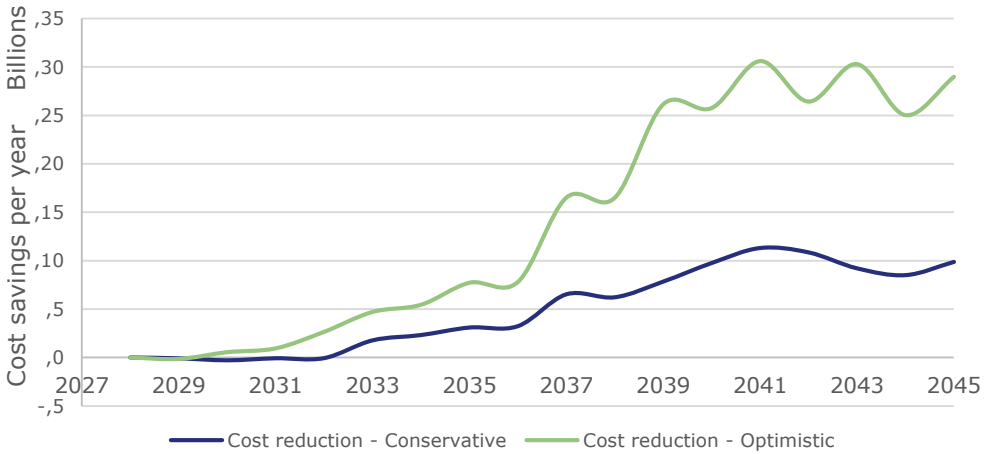
3 Mission profiles



Celestial bodies considered for the assessment of the space resources utilization value chains.

SRU value chain Prospect → Establish → Mine → Transport → Refine → Manufacture → Supply

The total costs savings up to 2045 were evaluated between 85 B€ (conservative scenario) and 254 B€ (optimistic scenario)



Optimistic scenario

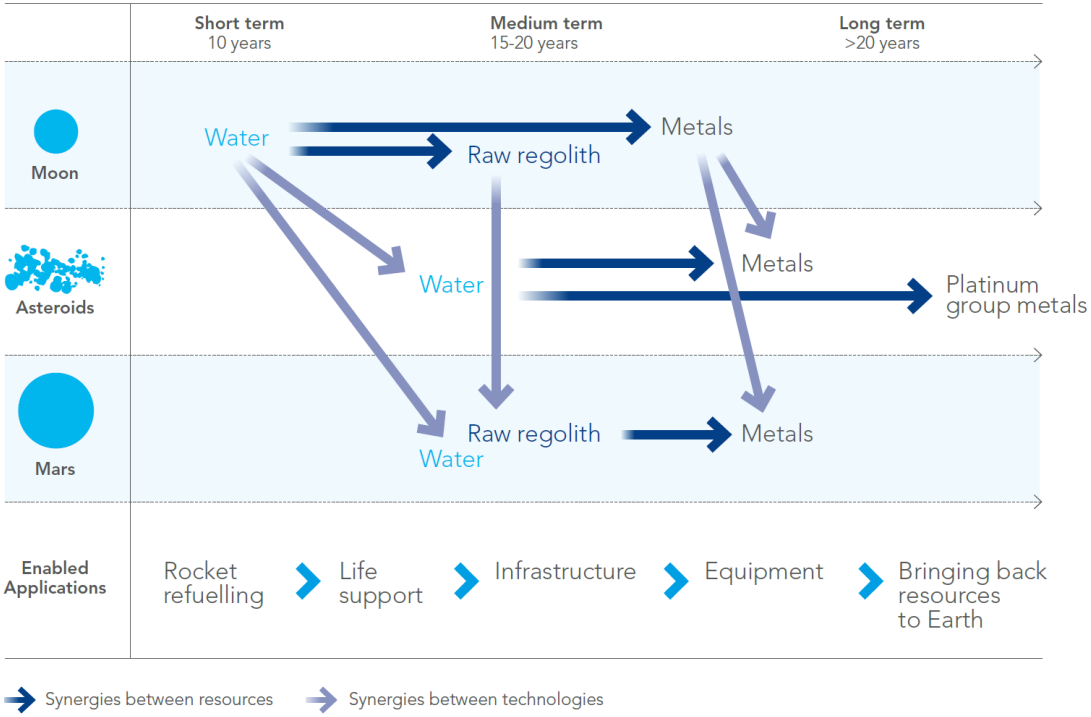
Cumulated savings of 254 B€
Average of 12 B€ euros per year

Conservative scenario

Cumulated savings of 85 B€
Average of 4 B€ per year

Cost savings per value chain	Conservative scenario	Optimistic scenario
Propellant for rockets	68 B€	166 B€
Water for life support	1 B€	3 B€
Regolith & Ni/Fe for construction	16 B€	85 B€

The main drivers and risks have been discussed, leading to conclusions which reflect the highest consensus within experts



- SRU will support exploration missions' feasibility, cost efficiency and autonomy
- Provision of propellant wil be the first application to target
- Scientific missions led by space agencies will be the first customers
- Earth mining industry needs to be involved for their expertise and practical understanding

- The challenge in refining the "geological" knowledge remains a strong barrier
- Strong scepticism on the realism of bringing back PGM

15 key technologies were selected and analyzed, with impact on multiple SRU value chains

1	Mineralogical analysis
2	Robotic excavation (partial gravity)
3	Regolith de-volatilization/water extraction (partial gravity)
4	Crushing, sieving, separation (partial gravity)
5	Production of Oxygen from Regolith and other non-volatiles sources
6	Directed Energy deposition AM and soil passivation (metal, regolith)
7	Long-duration, reliable, heavy duty robotic platform in dusty environment
8	Fully autonomous SRU spacecraft/vehicles/plants
9	Robotics operating in permanently or quasi-permanently shadowed regions
10	Supervised autonomy for Delay mitigation
11	Object Recognition and Pose Estimation
12	Fusing vision, tactile and force control for manipulation
13	Human-like dexterous manipulation in space
14	Full immersion, tele-presence with haptic and multi modal sensor feedback
15	Fuel depots

Using a set of assumptions and their evolution, socio-economic benefits have been modelled up to 2045

Industrial effects

Market revenues	**73 B€**
Total GVA effect	**49 B€**
Total employment effect	**845,000 FTE-years**

- *Cumulated values up to 2045*

Spillover effects

Market spillovers	**54 B€**
Technology spillovers	**2.5 B€**
Network spillovers	
Agglomeration effect	5/5
Development of standards	4/5
Critical mass adoption	4/5

- *Cumulated values up to 2045*

Wider effects

Environmental benefits	3/5
Strategic benefits	4/5

Catalytic effects

Reusable launch vehicles
Space tourism
In-space servicing
Small, budget-constrained missions

- ***NB: Conservative scenario***

Key outcomes and messages of the study

- **SRU** must and will materialise. **It is only a matter of feasibility timeline.**
- **Substantial costs savings** and added **autonomy** for space missions.
- **Prospecting** is key!
- Collaboration between the **space and the terrestrial mining industries** should be encouraged.
- Support activities, such as **legal and financial frameworks** or provision of **deep space communications** and **energy**, will be mandatory enablers.
- **Public actors** are expected to play a key role in the support of SRU activities, mostly as being the **first customers**.

Thank you for your attention!

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