THE EVOLUTION AND FUTURE VISION OF ISRU ACTIVITIES IN THE UK

Dr Hannah Sargeant

University of Leicester

UK-ISRU Representative Group

Outline

- Generating an ISRU Focus in the UK
- Historical UK Expertise
- UK Expertise for ISRU Applications
- A new vision for ISRU in the UK

Generating an ISRU Focus in the UK

PAPER

Detection of Water in the LCROSS Ejecta Plume

(Colaprete et al.)

Oct 2010

REPORT

Global Exploration Roadmap

Sep 2011

PAPER

Lunar Resources: A Review

(Crawford)

Apr 2015

CONTRACT

ESA ProSPA/PROSPECT

Apr 2016

MEETING

UK Strategies for the ISRU Grand Challenge

Dec 2017

MEETING

UKSA: The ISRU Workshop

Jun 2018

MEETING

ESA: Towards the Use of Lunar resources

Jul 2018

CONTRACT

ESA Oxygen Extraction Payload Demo

Feb 2022

REPORT

National Space Strategy

Sep2021

REPORT

Space Exploration Technology Roadmap

Jul 2023

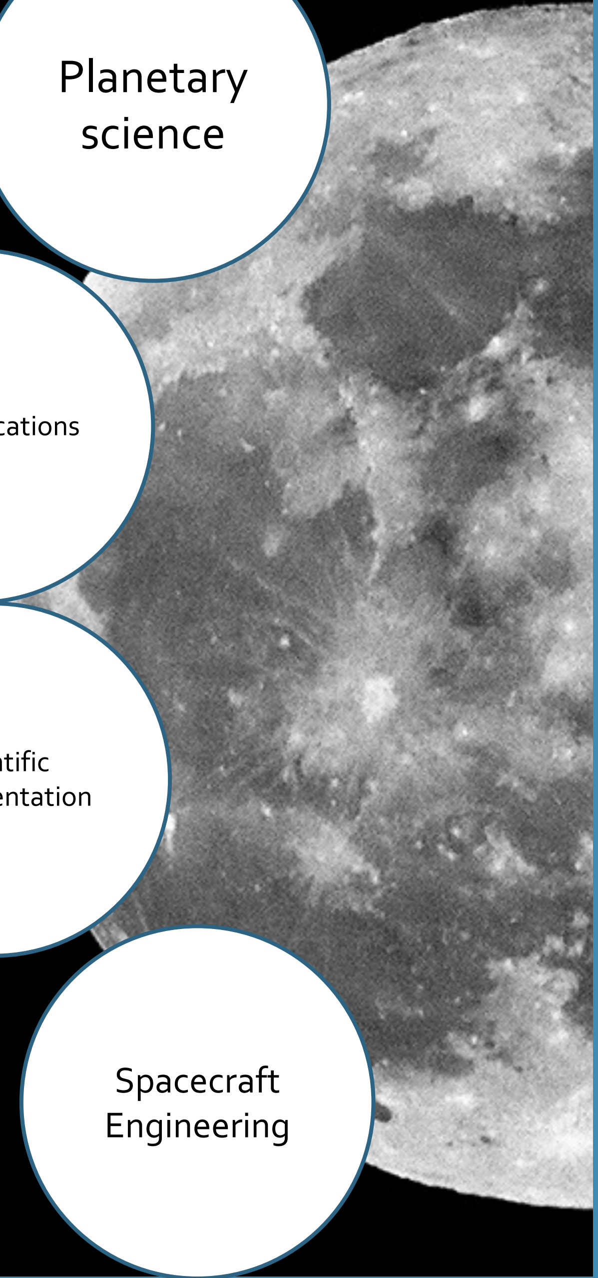
CHALLENGE

Aqualunar Challenge

Mar 2024

Historical UK Expertise

- Mineral extraction
- Materials processing
- Law, Policy & Regulation
- Finance



- Planetary science
- Communications
- Scientific Instrumentation
- Spacecraft Engineering

UK Expertise for ISRU Applications

Mineral extraction

Materials processing

Law, Policy & Regulation

Finance

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Lunar Resources

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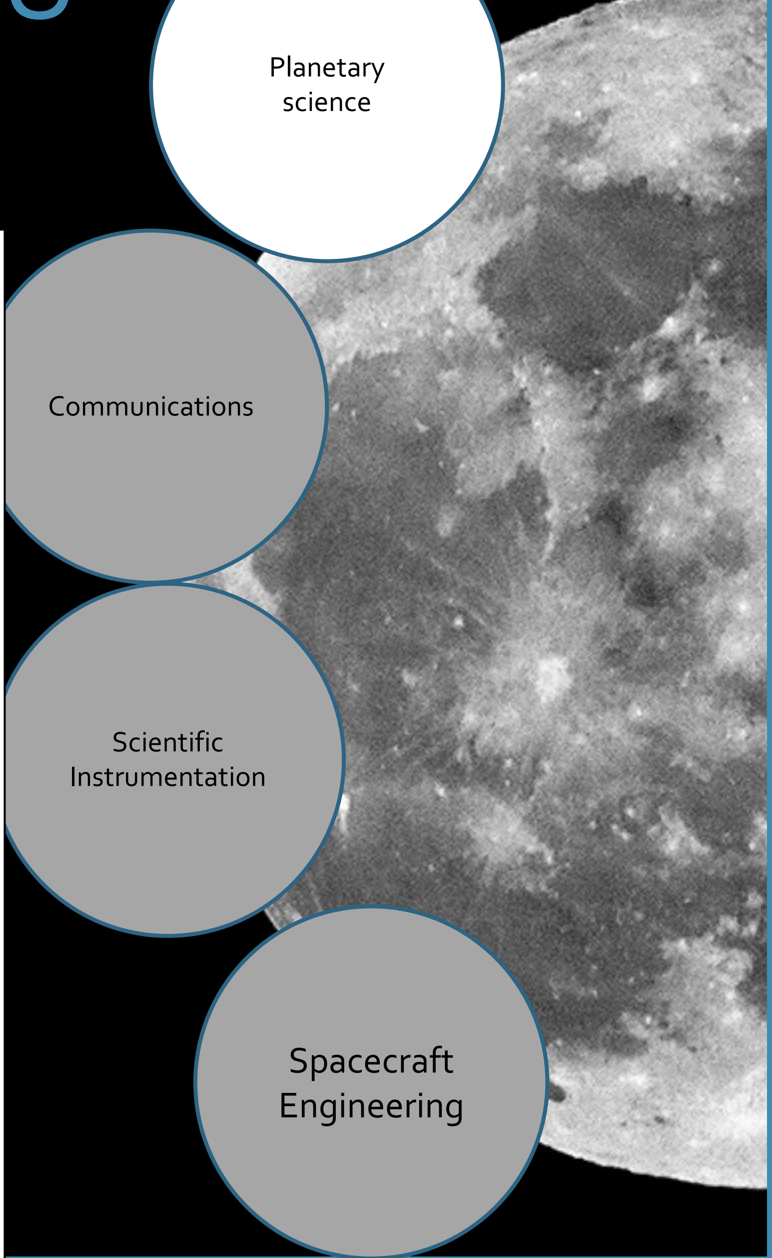
1. INTRODUCTION

It has long been recognised (e.g., Ehricke 1985; Spudis 1996, 2016; Duke et al. 2006;



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Spacecraft Engineering

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Materials processing

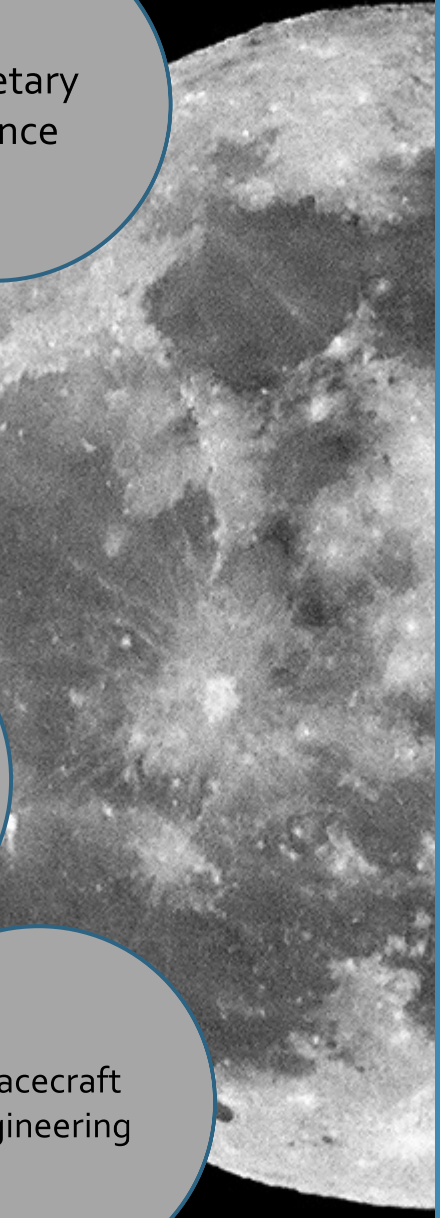
Law, Policy & Regulation

Finance

Comms infrastructure for a cislunar ecosystem

EXAMPLE: Moonlight

(Credit: ESA)



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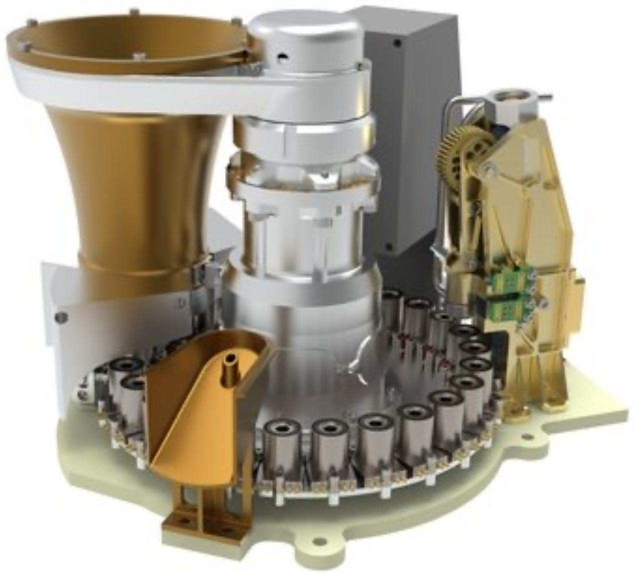
Developing prospecting instruments

EXAMPLE: ProSPA



(Credit: ESA)

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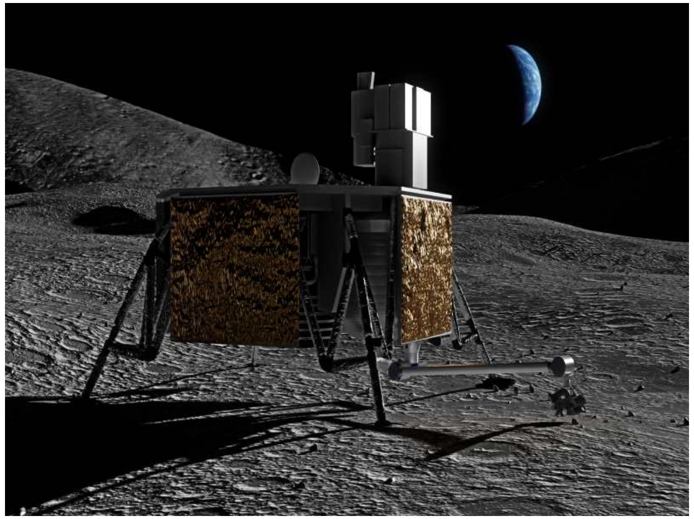
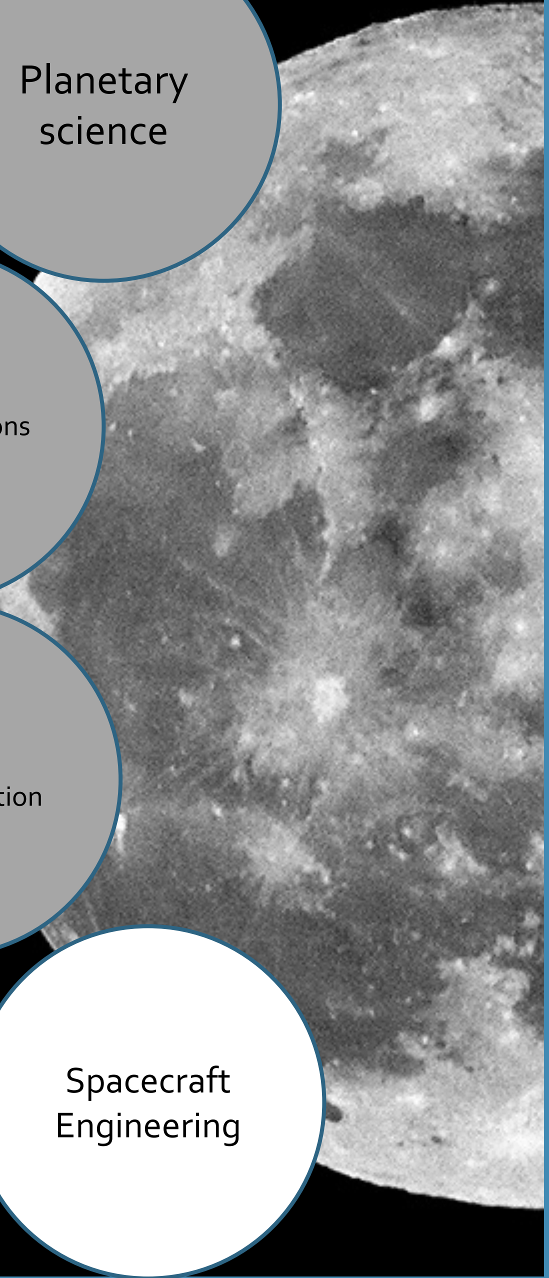
Developing ISRU hardware

EXAMPLE: ISRU DM



(Credit: ESA)



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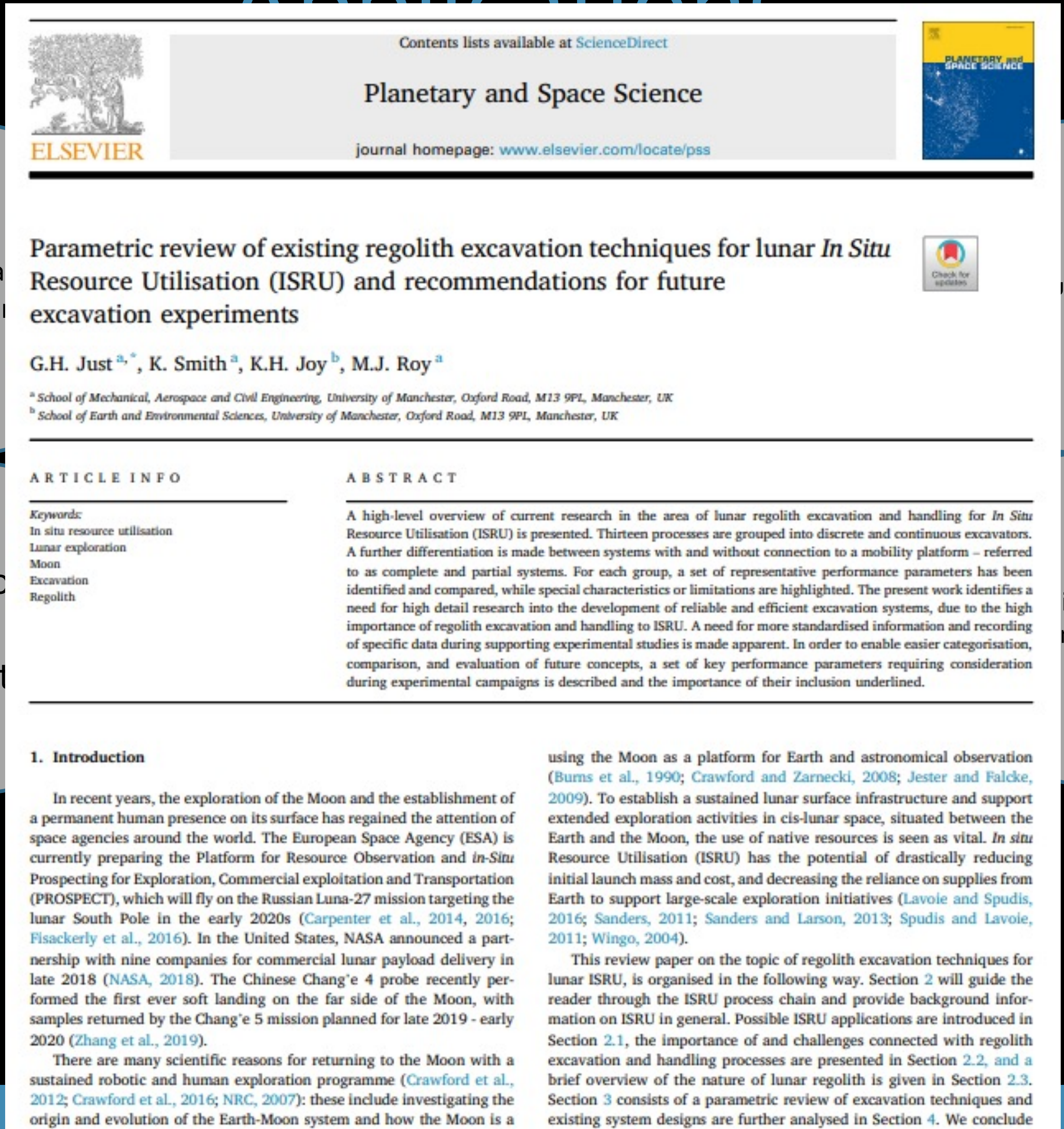

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Parametric review of existing regolith excavation techniques for lunar *In Situ* Resource Utilisation (ISRU) and recommendations for future excavation experiments

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ABSTRACT

A high-level overview of current research in the area of lunar regolith excavation and handling for *In Situ* Resource Utilisation (ISRU) is presented. Thirteen processes are grouped into discrete and continuous excavators. A further differentiation is made between systems with and without connection to a mobility platform – referred to as complete and partial systems. For each group, a set of representative performance parameters has been identified and compared, while special characteristics or limitations are highlighted. The present work identifies a need for high detail research into the development of reliable and efficient excavation systems, due to the high importance of regolith excavation and handling to ISRU. A need for more standardised information and recording of specific data during supporting experimental studies is made apparent. In order to enable easier categorisation, comparison, and evaluation of future concepts, a set of key performance parameters requiring consideration during experimental campaigns is described and the importance of their inclusion underlined.

1. Introduction

In recent years, the exploration of the Moon and the establishment of a permanent human presence on its surface has regained the attention of space agencies around the world. The European Space Agency (ESA) is currently preparing the Platform for Resource Observation and *in-Situ* Prospecting for Exploration, Commercial exploitation and Transportation (PROSPECT), which will fly on the Russian Luna-27 mission targeting the lunar South Pole in the early 2020s (Carpenter et al., 2014, 2016; Fisackerly et al., 2016). In the United States, NASA announced a partnership with nine companies for commercial lunar payload delivery in late 2018 (NASA, 2018). The Chinese Chang'e 4 probe recently performed the first ever soft landing on the far side of the Moon, with samples returned by the Chang'e 5 mission planned for late 2019 - early 2020 (Zhang et al., 2019).

There are many scientific reasons for returning to the Moon with a sustained robotic and human exploration programme (Crawford et al., 2012; Crawford et al., 2016; NRC, 2007): these include investigating the origin and evolution of the Earth-Moon system and how the Moon is a using the Moon as a platform for Earth and astronomical observation (Burns et al., 1990; Crawford and Zarnecki, 2008; Jester and Falcke, 2009). To establish a sustained lunar surface infrastructure and support extended exploration activities in cis-lunar space, situated between the Earth and the Moon, the use of native resources is seen as vital. *In situ* Resource Utilisation (ISRU) has the potential of drastically reducing initial launch mass and cost, and decreasing the reliance on supplies from Earth to support large-scale exploration initiatives (Lavoie and Spudis, 2016; Sanders, 2011; Sanders and Larson, 2013; Spudis and Lavoie, 2011; Wingo, 2004).

This review paper on the topic of regolith excavation techniques for lunar ISRU, is organised in the following way. Section 2 will guide the reader through the ISRU process chain and provide background information on ISRU in general. Possible ISRU applications are introduced in Section 2.1, the importance of and challenges connected with regolith excavation and handling processes are presented in Section 2.2, and a brief overview of the nature of lunar regolith is given in Section 2.3. Section 3 consists of a parametric review of excavation techniques and existing system designs are further analysed in Section 4. We conclude

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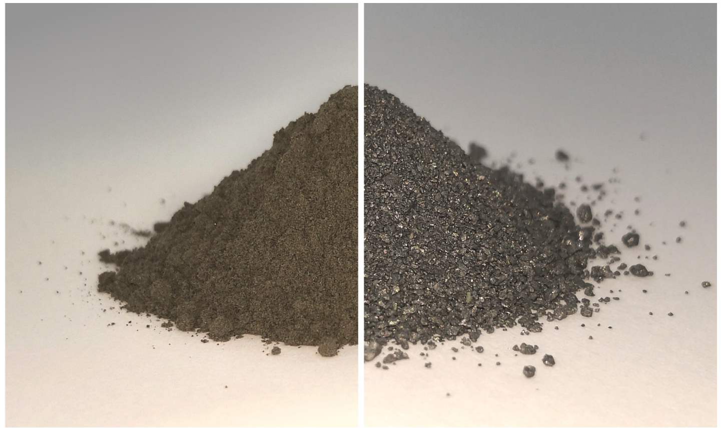
Finance

Resource Refining

EXAMPLE: Molten Salt Electrolysis



(Credit: Beth Lomax – University of Glasgow)

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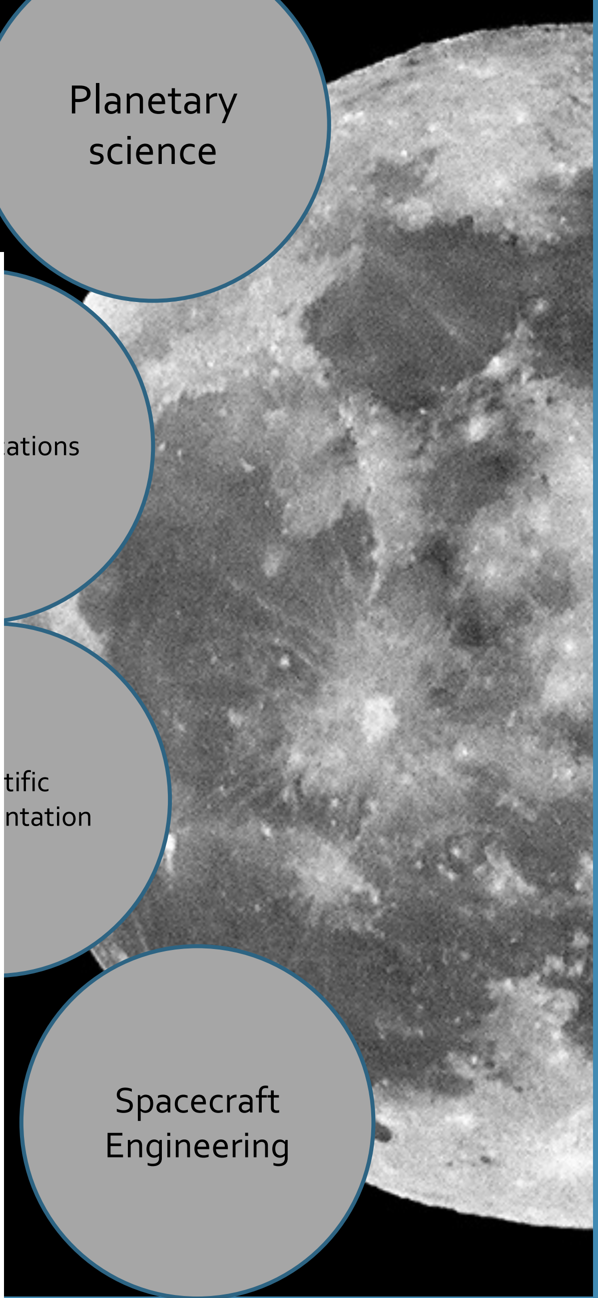

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Spacecraft
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Planetary Protection in the New Space Era: Science and Governance

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Committee of Space Research's Planetary Protection Policy is a triumph of technocratic governance in the global sphere. The Policy is produced by a group of scientific experts and subsequently enjoys high regard among the scientific and space community. However, as Committee of Space Research is an independent organization without any legal mandate the Planetary Protection Policy is an example of so-called "soft law" or a non-binding international instrument, in short, no one is under any legal obligation to comply with them. The policy is linked to Article IX of the Outer Space Treaty and its provision calling for the avoidance of "harmful contamination" of the Moon and other celestial bodies. While space activities beyond Earth orbit have been the exclusive preserve of government scientific space agencies this has posed little problem. However as private and "non-science" space activities proliferate and begin to spread their reach beyond Earth orbit, the Planetary Protection Policy is being tested. This paper will examine the challenges of developing and maintaining an effective planetary protection regime in this "New Space" era. This will involve looking at the existing policies, as well as the governance framework they sit within. However, it is also necessary to consider and understand the scientific basis not just for the specifics of the policy itself but the necessity of it. Finally, this paper will consider whether a broader "environmental" framework is needed as space activities diversity in type and location.

Keywords: COSPAR, planetary protection, space law, space governance, enforcement, environment, astrobiology

INTRODUCTION

The Committee of Space Research's (COSPAR) Planetary Protection Policy (PPP) (COSPAR 2020a) has sought to protect the space environment from "harmful contamination" which would endanger the integrity of the scientific exploration of outer space including the search for life. The PPP predates

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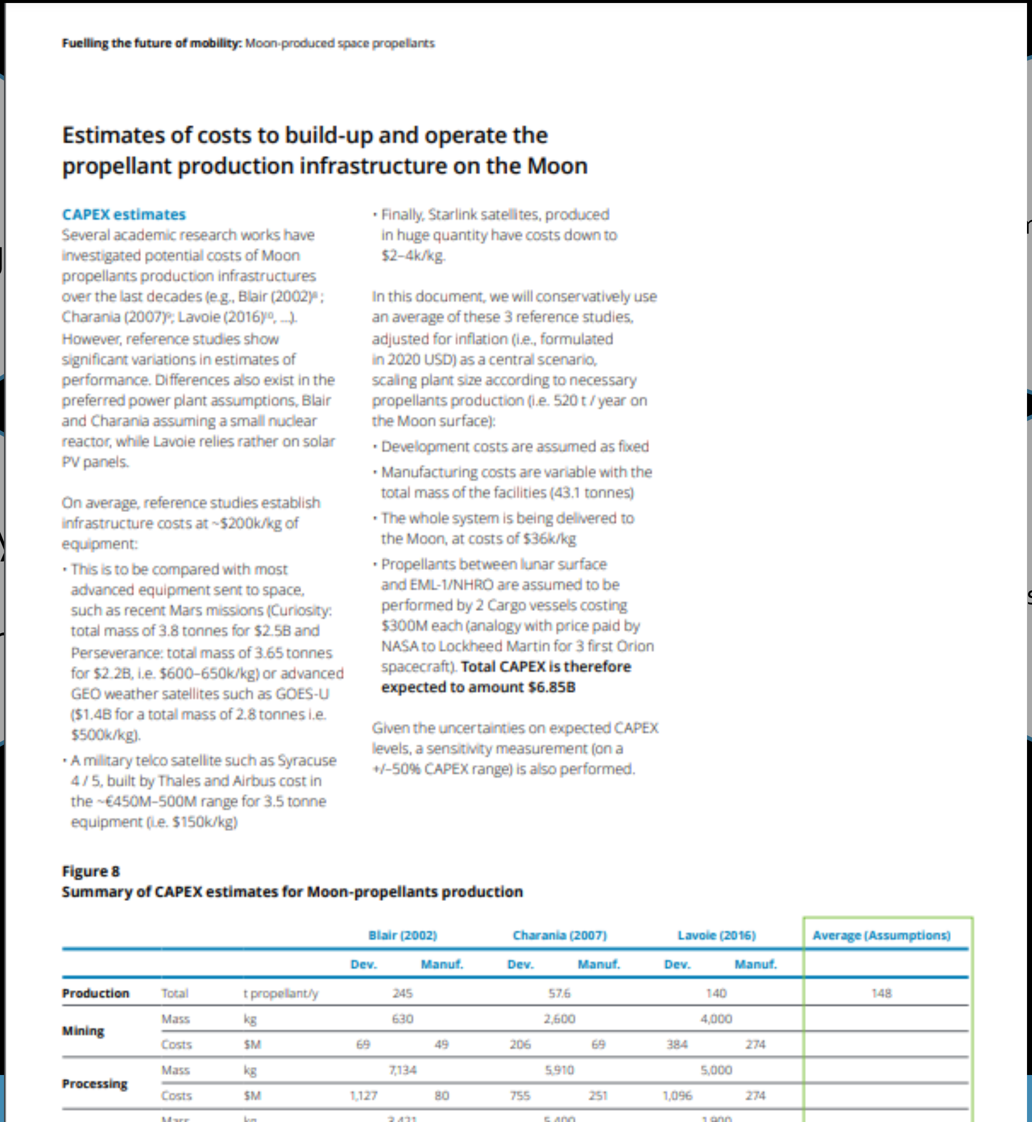

Fuelling the future of mobility: Moon-produced space propellants

Estimates of costs to build-up and operate the propellant production infrastructure on the Moon

CAPEX estimates

Several academic research works have investigated potential costs of Moon propellants production infrastructures over the last decades (e.g., Blair (2002)[8]; Charania (2007)[9]; Lavoie (2016)[10], ...). However, reference studies show significant variations in estimates of performance. Differences also exist in the preferred power plant assumptions, Blair and Charania assuming a small nuclear reactor, while Lavoie relies rather on solar PV panels.

On average, reference studies establish infrastructure costs at ~$200k/kg of equipment:

- This is to be compared with most advanced equipment sent to space, such as recent Mars missions (Curiosity: total mass of 3.8 tonnes for $2.5B and Perseverance: total mass of 3.65 tonnes for $2.2B, i.e. $600–650k/kg) or advanced GEO weather satellites such as GOES-U ($1.4B for a total mass of 2.8 tonnes i.e. $500k/kg).
- A military telco satellite such as Syracuse 4 / 5, built by Thales and Airbus cost in the ~€450M–500M range for 3.5 tonne equipment (i.e. $150k/kg)
- Finally, Starlink satellites, produced in huge quantity have costs down to $2–4k/kg.

In this document, we will conservatively use an average of these 3 reference studies, adjusted for inflation (i.e., formulated in 2020 USD) as a central scenario, scaling plant size according to necessary propellants production (i.e. 520 t / year on the Moon surface):

- Development costs are assumed as fixed
- Manufacturing costs are variable with the total mass of the facilities (43.1 tonnes)
- The whole system is being delivered to the Moon, at costs of $36k/kg
- Propellants between lunar surface and EML-1/NHRO are assumed to be performed by 2 Cargo vessels costing $300M each (analogy with price paid by NASA to Lockheed Martin for 3 first Orion spacecraft). **Total CAPEX is therefore expected to amount $6.85B**

Given the uncertainties on expected CAPEX levels, a sensitivity measurement (on a +/–50% CAPEX range) is also performed.

Figure 8
Summary of CAPEX estimates for Moon-propellants production

			Blair (2002)		Charania (2007)		Lavoie (2016)		Average (Assumptions)
			Dev.	Manuf.	Dev.	Manuf.	Dev.	Manuf.	
Production	Total	t propellant/y	245		57.6		140		148
Mining	Mass	kg	630		2,600		4,000		
	Costs	$M	69	49	206	69	384	274	
Processing	Mass	kg	7,134		5,910		5,000		
	Costs	$M	1,127	80	755	251	1,096	274	

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A New Vision for ISRU in the UK

Advise government and allocate ESA funding

UK SPACE AGENCY

Update UKSA about ISRU activities and funding requirements

Request guidance on current trends and focus areas

Consolidate updates from the ISRU community

Feedback opportunities and promote community interaction

Satellite Applications Catapult 2023 v3.0
Space Enterprise Community: Subject to change

Thank You