The Value of Space Debris

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ABSTRACT

Space debris should not only be considered as a thread to space activities but as a valuable asset, too, similar to waste on Earth. Earning money with terrestrial waste depends on disposal fees or on recycling profits. As long as no international agreement on removal fees in space will be achieved, recycling profits could be a driver for commercial space debris removal. The market for recycled space debris material would be space manufacturing and the location with the highest material demand would be the Moon with the upcoming lunar ground station. Orbit Recycling calculated the total costs for recycled aluminium on the Moon`s surface to 150,000 euro per kilogram, a fraction of the costs for material transported from Earth. This is due to the fact, that the launch costs for the heavy material was already paid in the past. As an addition benefit of space debris recycling, the associated risks of the removed debris items are eliminated as well.

A method for aluminium casting using regolith as a mould was developed and first wall segments were cast out of Ariane 5 upper stage aluminium to show the feasibility of the proposed recycling process from Orbit Recycling.

1 The Recycling of Space Debris

Space debris is a serious problem. Since the launch of Sputnik 1 in 1957, thousands of unfunctional objects ended up in space [1]. Due to 'mega-constellations' like *Starlink* [2] for satellite broadband and others, this number is continuously growing. With that, the risk of collisions and even more space debris increases [3].

With more and more areas of modern life depending on functional space services [4], such as navigation services like Galileo or the Earth observation Copernicus program, a service failure due to a collision in space would cost much more than "just" the replacement of a satellite [5]. The *Organisation for Economic Co-operation and Development (OECD)* recently published its first report on the economic cost of space debris [6], stating *"Space debris protection and mitigation measures are already costly to satellite operators, but the main risks and costs lie in the future, if the generation of debris spins out of control and renders certain orbits unusable for human activities."*

The most effective way to stabilize debris population is to actively remove large non-functional objects from the most populated orbits which are the source of small debris [7]. Analyses by ESA and NASA show, that *Active Debris Removal* (ADR) could stabilize the space environment[8]. Several ADR technology assessment studies have already been performed by ESA [9].

Unfortunately, funding of ADR missions was so far (and still is!) challenging. This underlines the comment made by ESA's (former) Director General at the Paris air show of 2015 on the difficulty in getting member states to pay for 'waste removal' as it is typically "…*far more interesting to give contribution to an interplanetary probe."* [10]. ESA`s Council at Ministerial Level, Space19+ [11], finally committed a first ADR mission, *ClearSpace-1*, which has been procured as a service contract by ESA with a planned launch in 2025 [12]. But while *ClearSpace-1* is a first step in the right direction, the funding of following ADR missions remains unclear: who should pay for such a service, if there is no legal requirement for any owner of a space debris item to actively remove it? [13]

Orbit Recycling concept of space debris recycling addresses the challenges of such an ADR mission. Instead of depending solely on the "noble cause of space debris removal" [10], it shows a new business opportunity by highlighting the value of space debris: its recycling potential. On Earth, this potential is already fully recognized. The German recycling industry alone achieved more revenue [14] than the whole European space industry [15]. Nevertheless, this treasure was never lifted in space.

The identified recycling use case with the biggest potential for Europe is shown in Figure 1. By tugging old Ariane upper stages from their current positions in GTO further to the Moon, dozens of tons of aluminium could be regained and recycled. The aluminium could act e.g., as construction material for an upcoming lunar ground station. As space agencies around the world expressed their interests in such a lunar ground station in the *Global Exploration Roadmap* (GER) [16], the demand of construction material is given. The supply through this recycling approach would avoid costly material transports from Earth and could act as an interim solution until *in-situ-resource-utilization* (ISRU) technology will be available in the future.

Proc. 8th European Conference on Space Debris (virtual), Darmstadt, Germany, 20–23 April 2021, published by the ESA Space Debris Office
Ed. T. Flohrer, S. Lemmens & F. Schmitz, (http://conference.sdo.esoc.esa.int, May 2021)

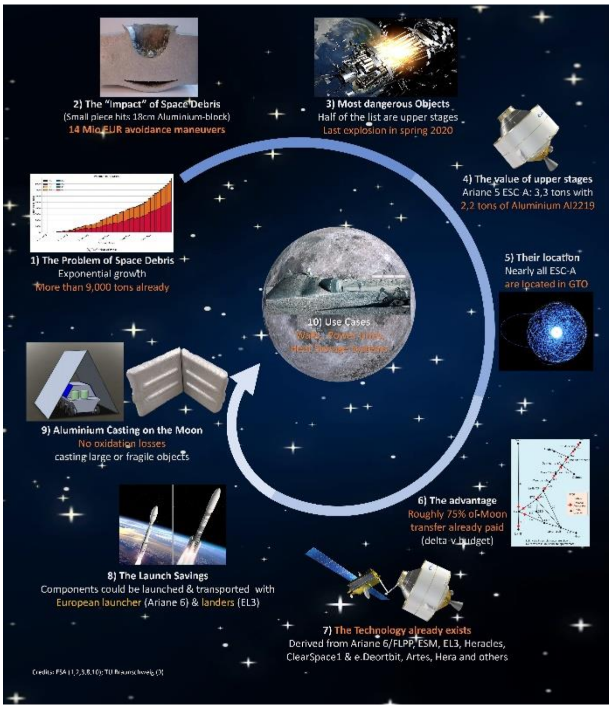

Figure 1 Space Debris Recycling Concept

This concept is within Europe`s current technical capabilities. The necessary technology can be derived from existing development programs and allows the involvement of different ESA member states. The space industry could refinance the recycling mission costs by selling the raw material on the Moon or allows Europe and ESA to use the raw material as "barter goods" with other space agencies, e.g., for European lunar astronaut missions.

Detailed information regarding the space debris recycling potential can be found in the ESA study executed by Orbit Recycling under the ESA contract 4000132842/20/NL/GLC, to be released in summer 2021.

2 The Case for Aluminium Recycling

One important aspect of the identified space debris value is the usage of the recycling material for constructions on the Moon.

In space, hardly any resource is easily available. But since the launch of Sputnik half-a-century ago, aluminium has been the material of choice for space structures of all types. Chosen for its light weight and its ability to withstand the stresses that occur during launch and operation in space, aluminium has been used on *Apollo* spacecrafts, the ISS as well as for the primary structures of NASA's *Orion MPCV* (Multi-Purpose Crew Vehicle) spacecraft [17]. Aluminium alloys consistently exceed other metals in such areas as mechanical stability, dampening, thermal management and reduced weight. This means in addition, that a large amount of the total space debris actually consists out of aluminium. As an example, the Ariane 5 ESC-A upper stage has a dry weight of around 3,4 tons with 2,4 tons aluminium [18]. More than 60 of them are still orbiting Earth for the next decades or even centuries [19].

Luckily, terrestrial aluminium recycling is well known and established. For Europe, up to 90 percent of the aluminium used comes from recycled aluminium, as Europe itself has hardly any natural aluminium sources. The *Circular Aluminium Action Plan* [*20*] from the European Aluminium industry summarizes the most important aspects with the key factors listed here:

- Aluminium is a circular material, capable of being recycled multiple times without losing its original properties.
- Aluminium recycling rates in Europe are among the highest, with over 90% in the automotive and building sectors.
- The aluminium recycling process requires only 5% of the energy needed to produce the primary metal, resulting in important energy and CO2 savings.

These aspects are relevant for space as well.

Beside a dedicated recycling site in higher orbits, the Moon should be an ideal recycling spot. The Moon offers (small) gravity forces, which makes processing of raw materials easier than under "zero" gravity as in the *Low Earth Orbits* (LEO) or *Geostationary Earth Orbits* (GEO) region. Machines, objects and materials could be placed on its surface and securely fixed to apply necessary forces during the recycling process.

Second, the huge distance between Moon and Earth makes transportation of (raw) materials very costly. Due to physics, the required transportation energy is not distributed linearly. Roughly ¾ of the energy is already spent to reach LEO. From there, just additional 25% are needed to reach the Moon. A transport of a heavy weight from LEO to Moon is therefore significantly cheaper than from Earth directly.

Third, customers for raw materials on the Moon exist. The upcoming *International Lunar Research Station* (ILRS) [21] or the planned *Lunar Ground Station* described the in the *Global Exploration Roadmap* (GER) [16] will require a significant amount of space manufacturing and therefore could benefit from recycled raw materials.

At present, the material requirements for such a lunar station can only be estimated, as there is no final concept for a station yet. A good starting point is the ISS with about 400 tons of metal constructions without interior fittings [22]. NASA alone has spent 37 shuttle flights or more than 100 billion US dollars for its assembling [23]. In the long term, however, the lunar station should be larger than the ISS, as the Moon is interesting in many ways: the mining of mineral resources on the Moon as well as the construction of observatories are already intensively discussed and planned [24]. Realistically, over 500 tons of metal could be required over time on the Moon. At present, no European rocket would be able to transport such a quantity of material from Earth to the Moon, while the described concept of space debris recycling would be feasible for Europe.

A competitive source for construction materials on Moon would be *In Situ Resource Utilization* (ISRU) [25]. Various methods and techniques are discussed to extract oxygen and metals from regolith [26]. However, their respective occurrences in regolith vary considerably depending on the location, mineralogy and even grain size. Although ISRU technologies may be promising in the future, they are still at a very early stage with many more years and decades needed for development.

Second, recycling material has an energy advantage compared to primary materials. While it takes a huge amount of energy and complex processes to gain primary aluminium out of its ore *Bauxite*, it takes just 5% of the energy to melt & recycle the corresponding amount of secondary aluminium due to its low melting point of around 660°C. This would be true for space, in this case the Moon, as well. To gain primary aluminium out of regolith, a similar amount of energy like on Earth would be needed [27]. As an alternative, secondary aluminium could be recycled in space or on the Moon as often as needed with far less energy needs, like on Earth.

3 Regolith as Substitute Mold Material for Aluminum Casting on The Moon

To show the potential of the proposed space debris recycling concept, Orbit Recycling developed an early recycling processes together with its research partners and casted first aluminium objects out of space debris material in regolith simulant.

Lunar regolith can be shaped and/or sintered to produce a mold similar to sand-casting or permanent mold casting [28]. TU Braunschweig and Orbit Recycling carried out first experiments with aluminum which is poured into molds out of regolith simulant TUBS-M [29,30]. These experiments took a closer look into the interaction between aluminum melt and simulant (raw and sintered) as well as the general casting behavior. Those first experiments and evaluations showed, that it was possible to cast a wide range of aluminum parts using lunar regolith as mold material. With the use of sintering techniques, the mold can be hardened [29]. Figure 2 shows a sintered mold on the left with the resulting casting on the right. With these sintered molds, it was possible to perform multiple casts before damaging the molds. This approach shows a new ISRU based adapted process which makes it possible to easily produce metal castings on the Moon out of space resources.

Figure 2: (Left) Sintered regolith simulant mould and (Right) resulting aluminium casting, J. Baasch, TU Braunschweig / TU Berlin

More information can be found at Orbit Recycling`s homepage at https://OrbitRecycling.space

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1 ESOC (2020), ESA`s Annual Space Environment Report, Ref GEN-DB-LOG-00288-OPS-SD

2 Federal Communication Commission (2020), Application for Modification of Authorization for the SpaceX NGSO Satellite System, FCC *Report SYSTEMSAT-MOD-20200417-00037*

3 H-D. Kim (2015), Statement on Large Constellations of Satellites in Low Earth Orbit (rev. 3), IADC

4 ESA (2005) The Impact of Space activities upon society, BR-237, ESA Publication Division

5 ESA: The cost of space debris. Online at https://www.esa.int/Safety_Security/Space_Debris/The_cost_of_space_debris (as of 16 April 2021)

6 Undseth, M., C. Jolly and M. Olivari (2020), "Space sustainability: The economics of space debris in perspective", OECD Science, Technology and Industry Policy Papers, No. 87, OECD Publishing, Paris,

7 ESA: Active Debris Removal. Online at https://www.esa.int/Safety_Security/Space_Debris/Active_debris_removal (as of 16 April 2021)

8 B. Virgili, DELTA (Debris Environment Long-Term Analysis), ESA/ESOC

9 Biesbroeck, Soares, Hüsing, Innocenti (2013) e.Deorbit CDF Study: A Design Study for the Safe removal of Large Space Debris, ESA

10 Biesbroeck, Soares, Hüsing, Innocenti (2013) e.Deorbit – ESA's Active Debris Removal Mission, ESA

11 ESA: ESA ministers commit to biggest ever budget – ESA, Online at http://www.esa.int/About_Us/Corporate_news/ESA_ministers_commit_to_biggest_ever_budget (as of 16 April 2021)

12 ESA: ESA commissions world's first space debris removal. Online at https://www.esa.int/Safety_Security/Clean_Space/ESA_commissions_world_s_first_space_debris_removal (as of 16 April 2021

13 C. Belbusti (2019) Industrial commitments on legal aspects of active debris removal, *Space Legal Issues*
14 Statista Industry Report (2020) Waste Management & Recycling in Germany 2020 - Statista Industry Report WZ Code 38
15 E. Mazareanu (2020) European space industry turnover 2010-2019 - Statista
16 ISECG (2020) Global Exploration Roadmap Supplement – Lunar Surface Exploration Scenario Update - ISECG
17 The Aluminum Association (2019) Aluminum in Aerospace. Online at https://aluminum.org/product-markets/aircraft-aerospace (as of 16 April 2021)
18 Bernd Leitenberger: (2015) "Europäische Trägerraketen 2", Books on Demand, ISBN 978-3738642964
19 D.-A. Handschuh et. al (2013), Estimations of Lifetime for Launchers Debris in GTO, *Safety is Not an Option, Proceedings of the 6th IAASS Conference*
20 European Aluminium (2020) Circular Aluminium Action Plan, *A Strategy for achieving Aluminium`s full potential for circular economy by 2030*, European Aluminium, Brussels
21 Order of the Government of the Russian Federation dated 11.02.2021 No 304-r
22 ESA: Building the International Space Station, Online at http://www.esa.int/Science_Exploration/Human_and_Robotic_Exploration/International_Space_Station/Building_the_International_Space_Station3 (as of 16 April 2021)
23 Robert Walker (2015), Is the International Space Station the most expensive single item ever built?, amazon eBooks, ASIN B014TREH94
24 NASA: Moon 2 Mars, Online at https://www.nasa.gov/specials/moon2mars/ (as of 16 April 2021)
25 NASA: ISRU, Online at https://www.nasa.gov/isru/ (as of 16 April 2021)
26 ESA (2020) ESA opens oxygen plant making air out of Moondust. Online athttps://www.esa.int/Enabling_Support/Space_Engineering_Technology/ESA_opens_oxygen_plant_making_air_out_of_moondust (as of 16 April 2021)
27 Alternative processes are currently studied, but haven`t reached the required maturity level so far.
28 Baasch J. (2019), Investigation of mold materials for the melting of lunar regolith simulants as well as processing and characterization of melting specimen, *unpublished student research thesis at TU Braunschweig*
29 Baasch J. Windisch L. Koch F. et al. (2021), Regolith as substitute mold material for aluminum casting on the Moon, *Acta Astronautica*, Vol. 182
30 Linke S., Windisch L. et al., (2020) TUBS-M and TUBS-T based modular Regolith Simulant System for the support of lunar ISRU activities, *Planetary and Space Science*, Vol. 180