A life cycle assessment of alternative materials for a Cubesat manufacturing

Mio Andrea, Dogo Federico, Slejko Emanuele Alberto

UNIVERSITÀ DEGLI STUDI DI TRIESTE

MolBNL
MOLECULAR BIOLOGY AND NANOTECHNOLOGY LABORATORY

Outline

- Our research target
- Life Cycle Assessment
- Case Study: Cubesat
- Results and Discussion
- Space Debris
- Take home message

Our research target

- The explosion of the **commercial space sector**, and the forecasted growing number of satellite in orbit, requires the investigation of the **potential impacts** of such activities on the **terrestrial** and **orbital** environment.

- Components for space applications are made of materials that differ from the ones for standard industrial applications:
  - they are produced in very **small quantities**;
  - they are produced by highly **advanced processes**;
  - they must operate in **extreme conditions** and environments and thus require particular properties to be controlled during **long testing** and qualification steps to comply with space industry standards
  - **Short operating lifetime**

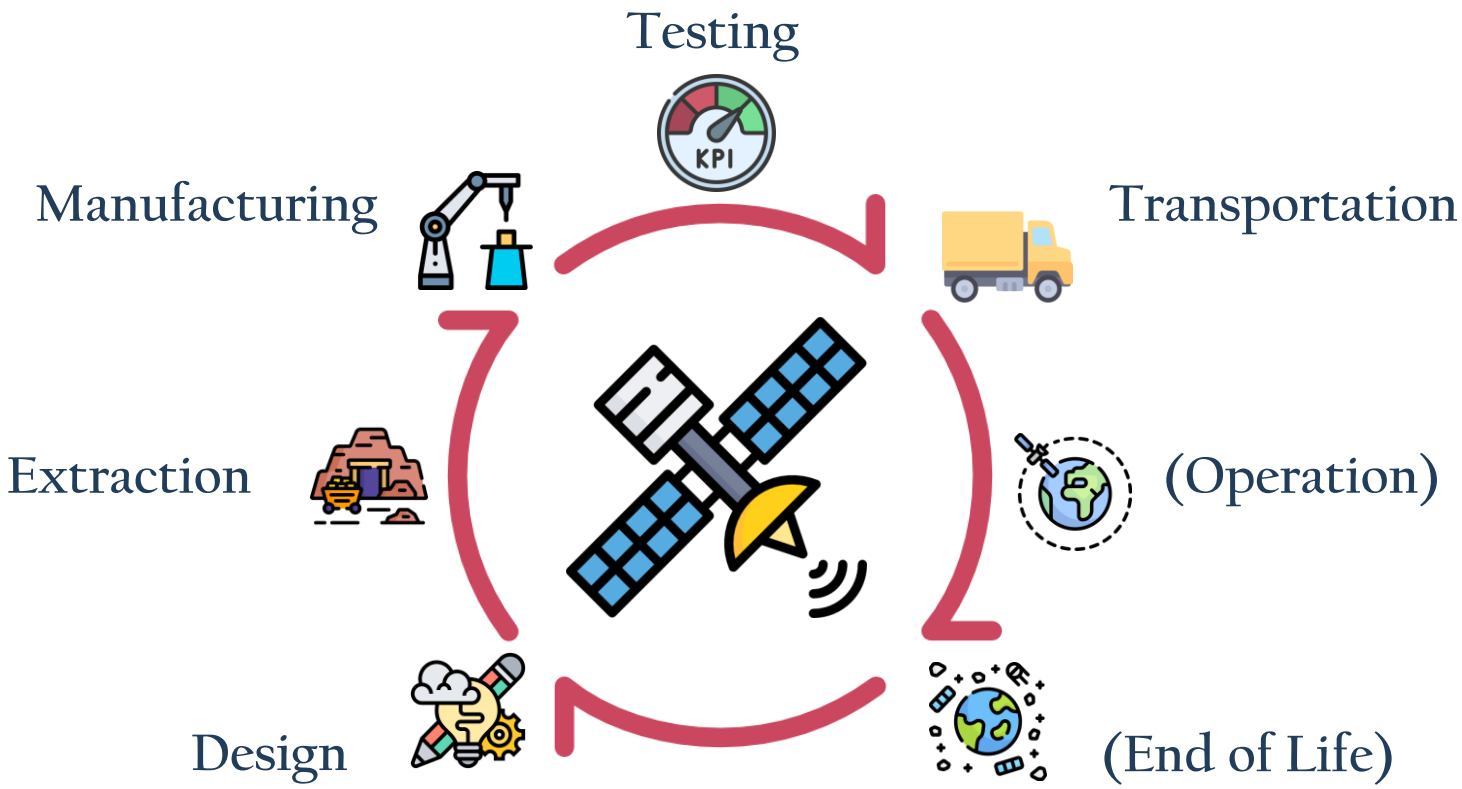
- Evaluate the potential impacts of different materials for the fabrication of a **1U-CubeSat structural bus** by means of **Life Cycle Assessment**

Life Cycle Assessment

- Life Cycle Assessment based on
  - **ISO 14040, ISO 14044**
  - Space system Life Cycle Assessment (LCA) guidelines by **ESA**

Level 1:
system level activities, such as space systems, including the space, ground, and launch segments

Level 2:
Equipment/component/material/process



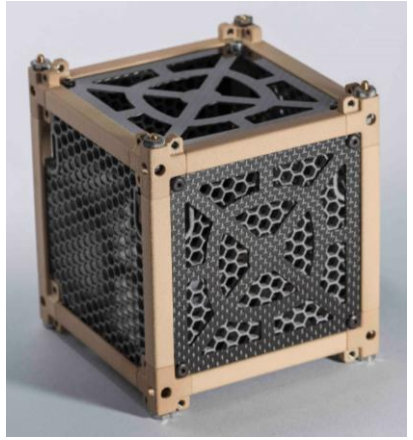
Case study - Cubesat

Goal and Scope

Functional Unit:

Standard structural bus for a 1U-CubeSat

- Length = 0.1 m
- Mass = 1 kg (maximum 1.33 kg)
- 3 target orbits: 200 km, 400 km and 600 km altitude
- Materials = Aluminium 7075-T6, PEEK (3D printed by Selective Laser Sintering)



Limitations and Assumptions:

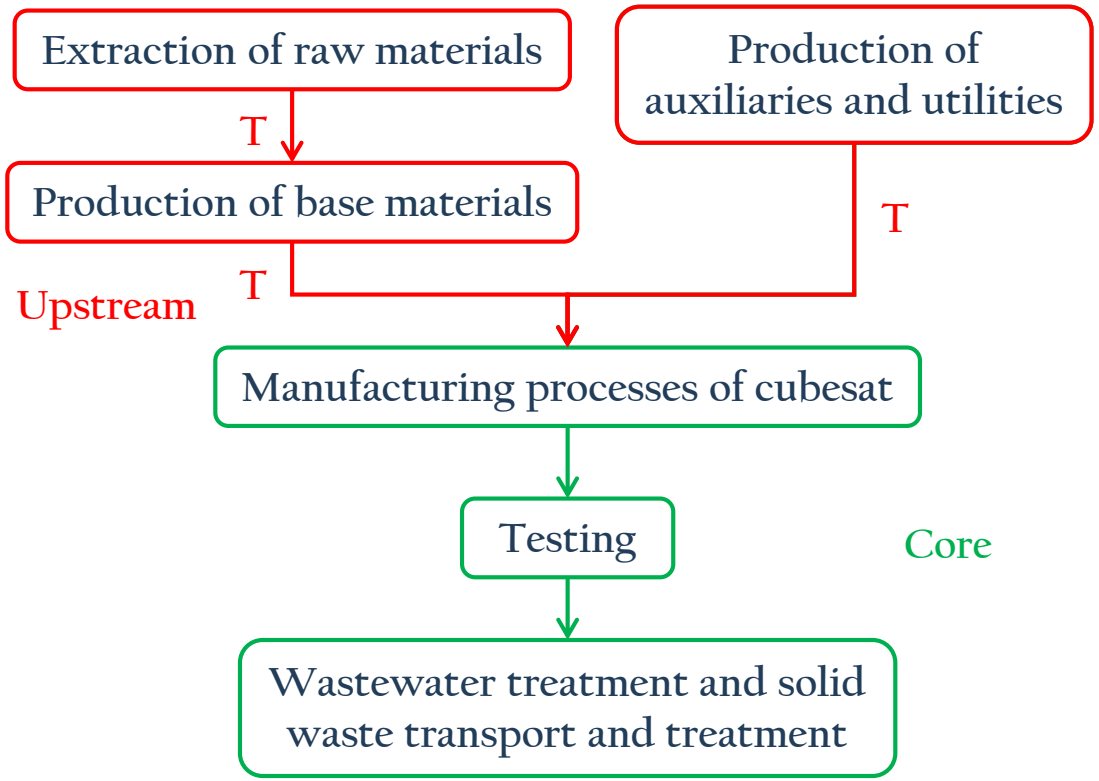
- Primary data: internal production of PEEK cubesat
- Secondary data: **IDEMAT** (ecoinvent-based DB) for raw materials; **ecoinvent** for core manufacturing processes
- Physical allocation

⚠️ Not specific for space sector ⚠️

Case study - Cubesat

Goal and Scope

System Boundary: Cradle-to-gate



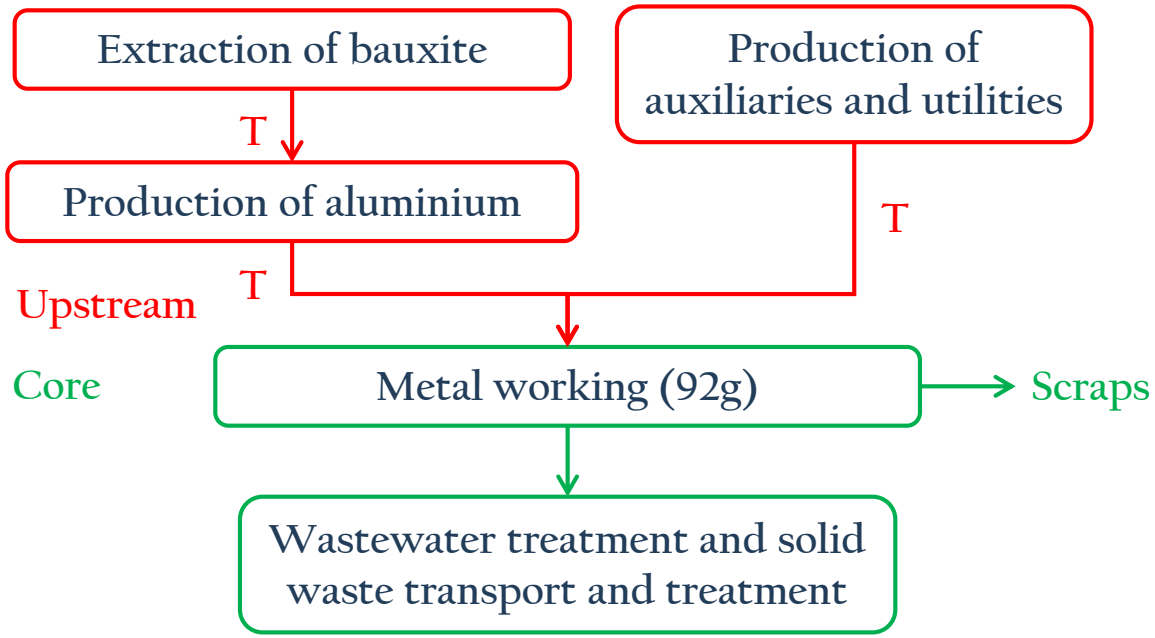
LCIA Method

Impact Category	LCIA Method
Global warming (GWP100a)	IPCC2013
Ozone layer depletion (ODP)	WMO
Human Toxicity Potential (HTP)	USEtox
Freshwater Ecotoxicity Potential (FETP)	
Photochemical oxidant formation (POFP)	ReCiPe
Particulate Matter Formation Potential (PMFP)	
Freshwater Eutrophication Potential (FEP)	
Marine Eutrophication Potential (MEP)	
Metal Resources Depletion Potential (MDP)	
Ionising Radiation Potential (IRP)	
Abiotic depletion (fossil fuels - FDP)	CML2002
Abiotic depletion (elements - EDP)	
Marine Ecotoxicity Potential (METP)	
Acidification Potential (AP)	
Cumulative Energy Demand (CED)	CED
Available Water Remaining (AWARE)	AWARE

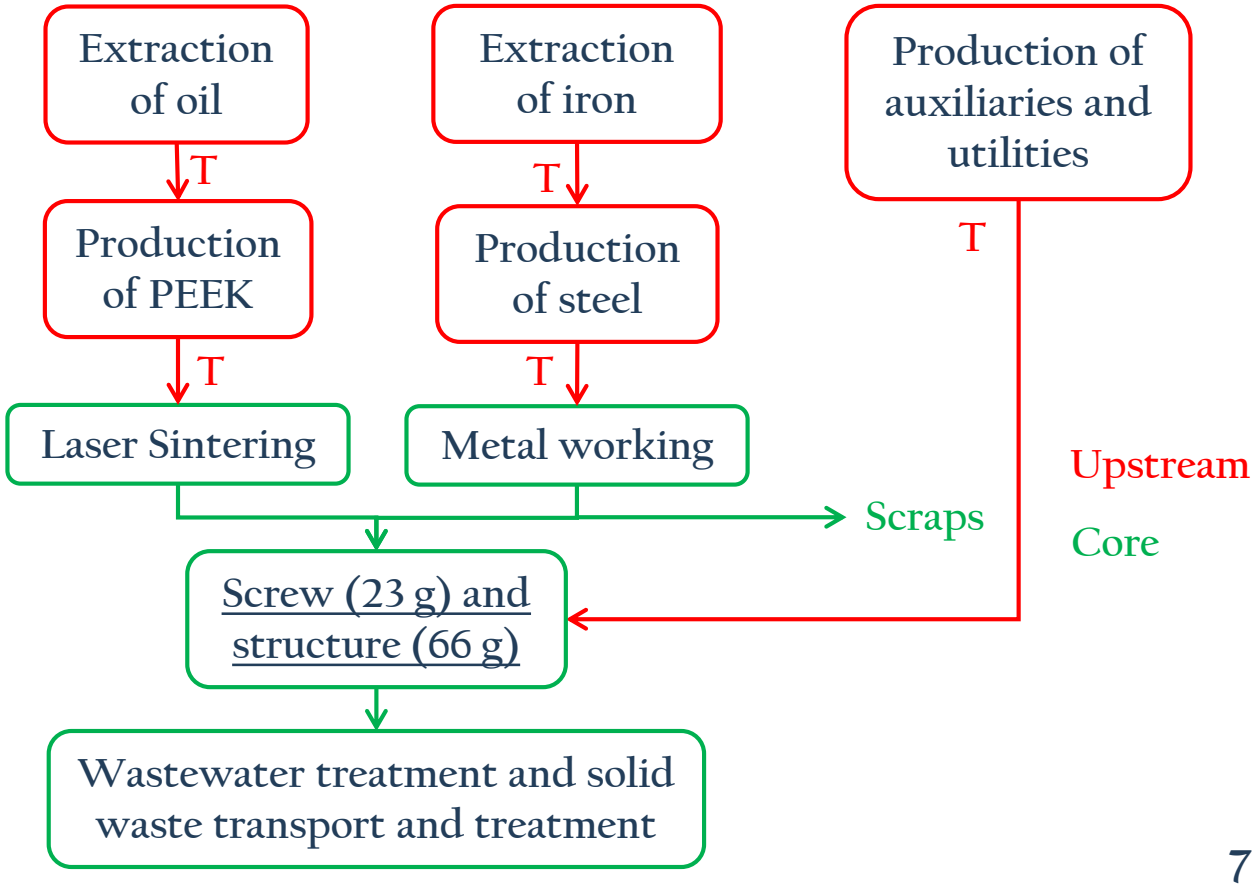
Case study - Cubesat

Life Cycle Inventory (LCI)

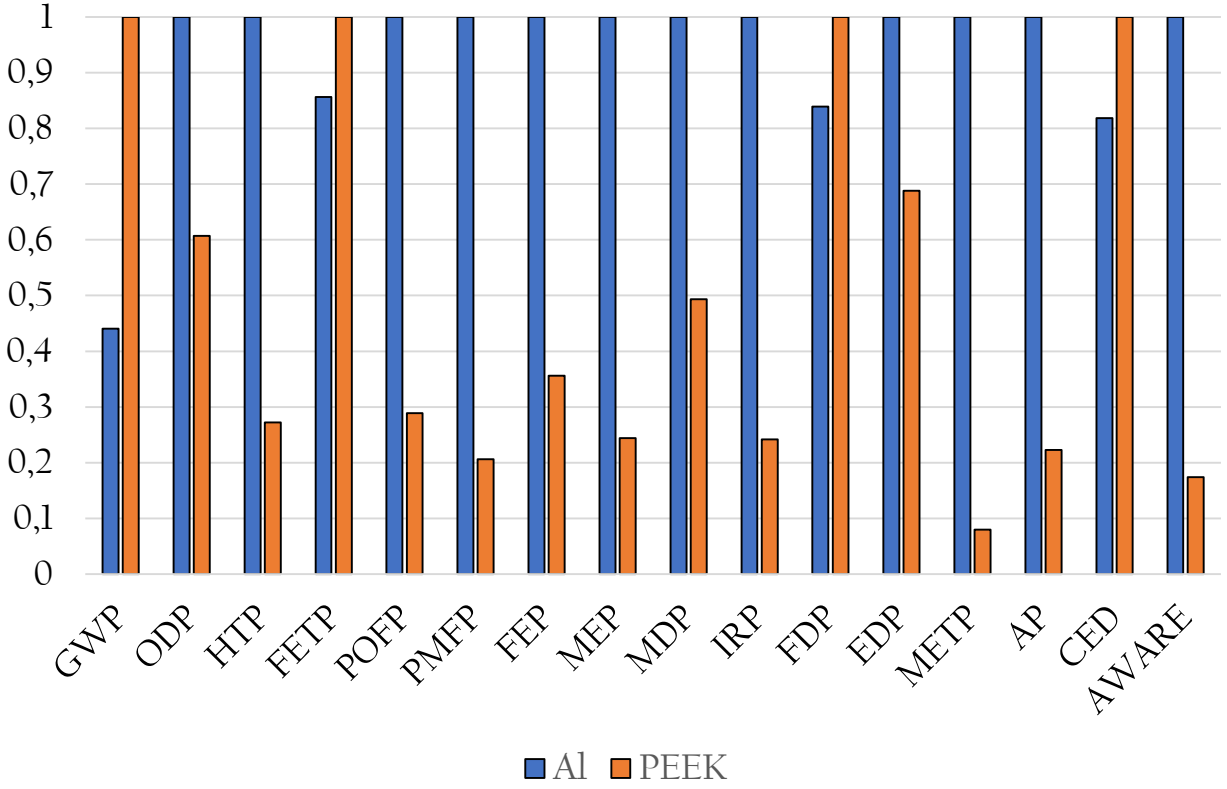
Aluminium



PEEK



Results and discussion

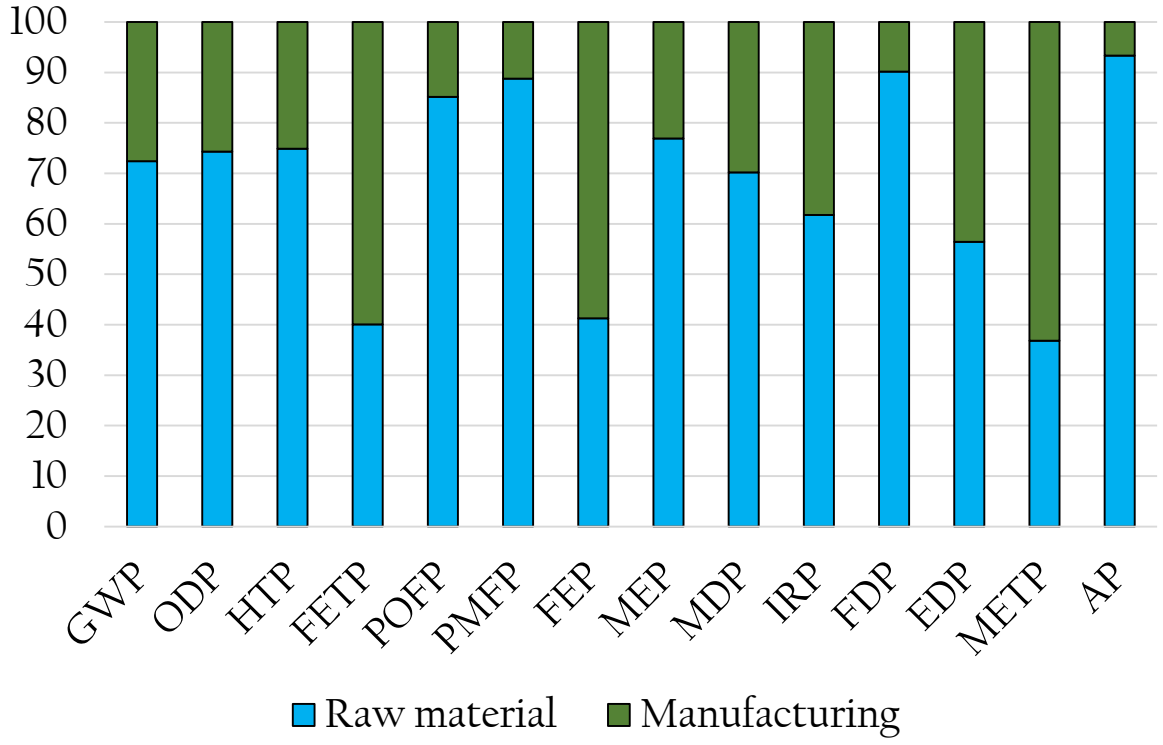


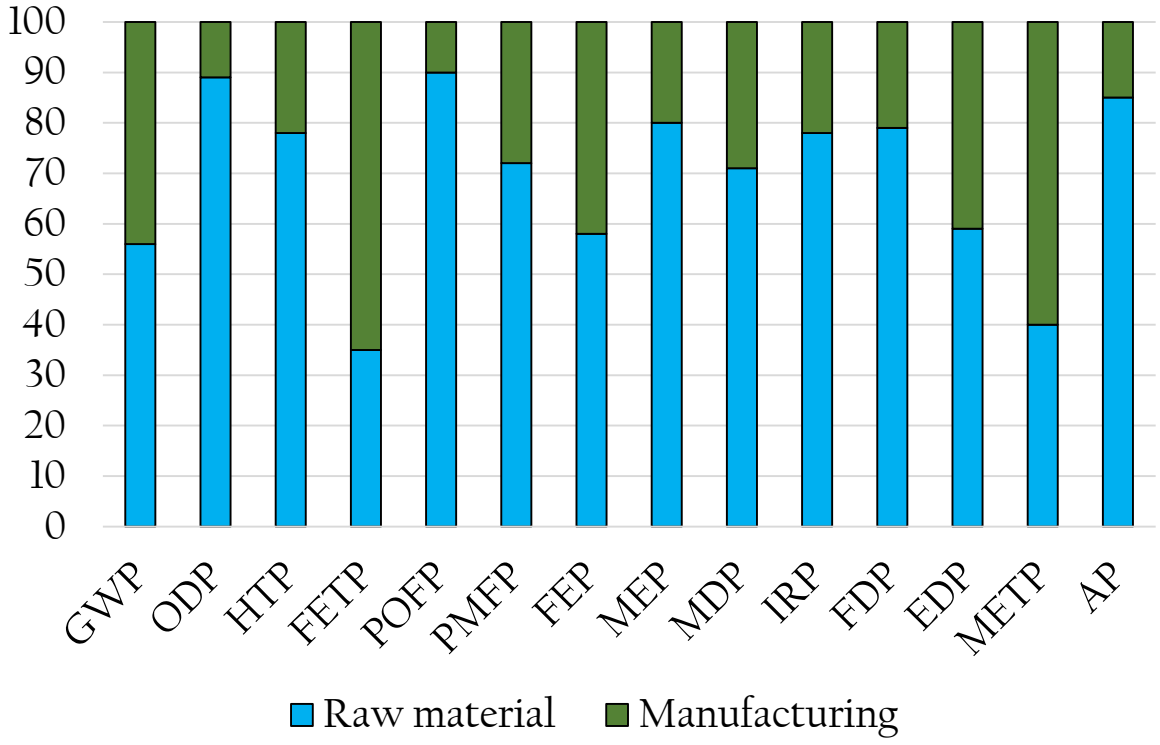
The laser **sintering** process for PEEK cubesat requires **more energy than metal working** for aluminium (CED) which results in a higher emissions of GHG (GWP)

The impacts related to **raw materials extraction** (ecotoxicity, eutrophication, resource depletion) are usually **higher** for aluminium-based cubesat

As a general **preliminary** trend an aluminium cubesat gains worst environmental performance than a PEEK-made one

Results and discussion





In general, **raw materials extraction and refinement** provide a **higher share** of the overall environmental impacts than manufacturing for a the investigated cubesat

Space Debris

- The **impact score (IS)** on the orbital environment has been calculated recurring to the formulation of Maury et al. (2019), considering:
  - The **exposure** to space debris in a given orbit (XF_i), and
  - The **severity** of a potential spacecraft breakup leading to the creation of new debris (SF_i)

$$k = 0.1 \cdot L_c^{-1.71} = 5.13$$

$$IS_{mission} = A_c \cdot k \cdot (M)^{0.75} \cdot \sum_{i}^{orbits} t_i \cdot CF_i$$

Satellite-specific data

$$CF_i = XF_i \cdot SF_i \; [potential\ fragment.years]$$

$$XF_i = \bar{\phi}_{h,inc,t} \; [\#.m^{-2}.yr^{-1}]$$

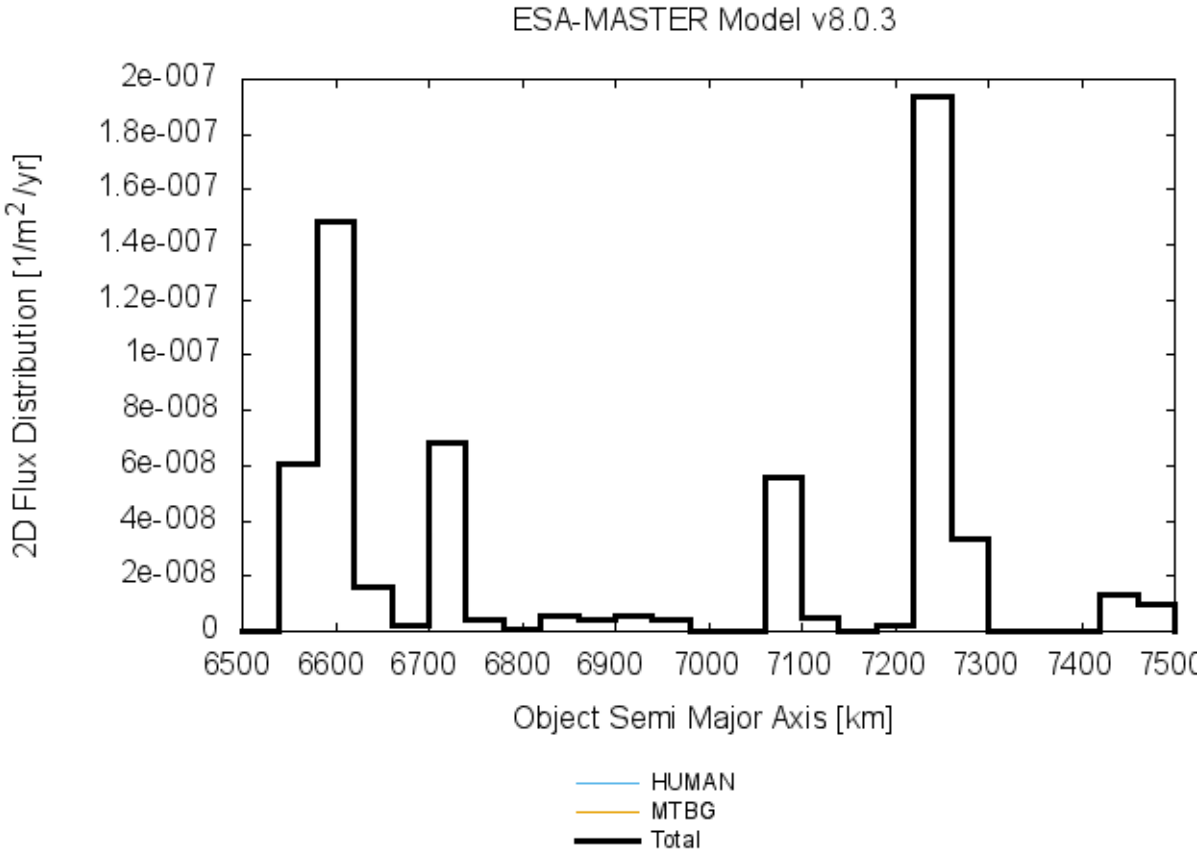
$$SF_{i,200\ yrs} = \int_{0\ yr}^{200yrs} e^{-\frac{t}{\rho}} = \left[-\rho \cdot e^{-\frac{t}{\rho}}\right]_{0\ \mathbf{yrs}}^{200\ \mathbf{yrs}} \; [\text{years}]$$

$$P(th) = e^{-\frac{t}{128.3 - 0.585892 \cdot h + 0.00067 \cdot h^2}} \; [\%]$$

Maury T, Loubet P, Trisolini M, Gallice A, Sonnemann G, Colombo C. Assessing the impact of space debris on orbital resource in life cycle assessment: A proposed method and case study. Sci Total Environ 2019;667:780–91. https://doi.org/10.1016/j.scitotenv.2019.02.438.

Space Debris - Evaluation of XF_i

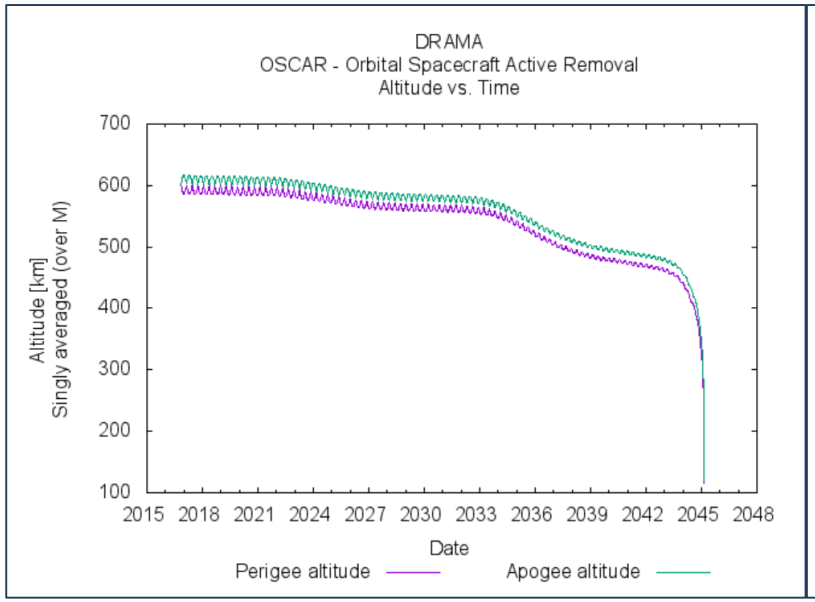
XF_i



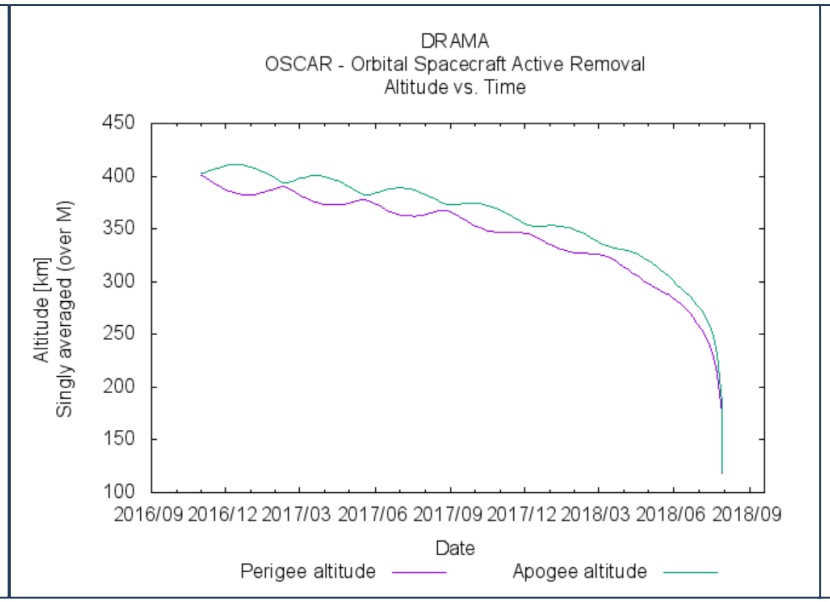
- The Exposure Factor evaluates the distribution of space debris at different orbit

Space Debris - Evaluation of t_i

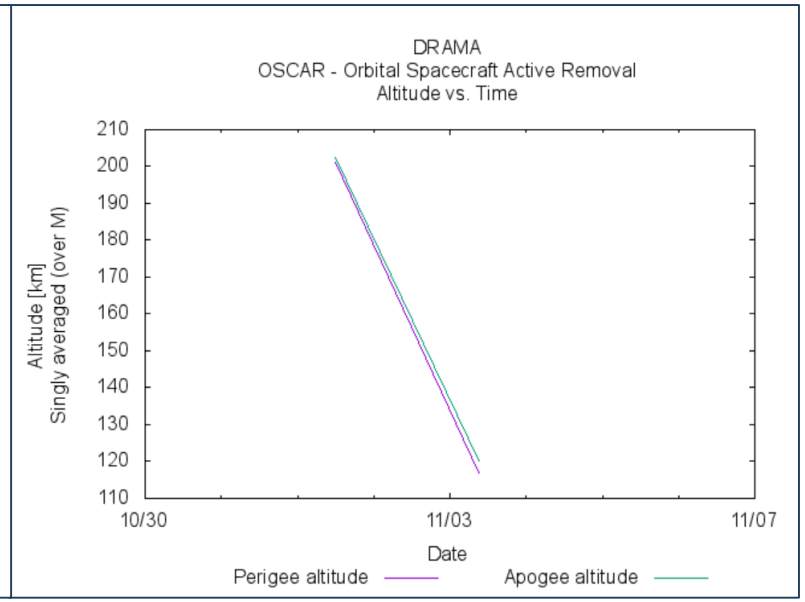
600 km



400 km



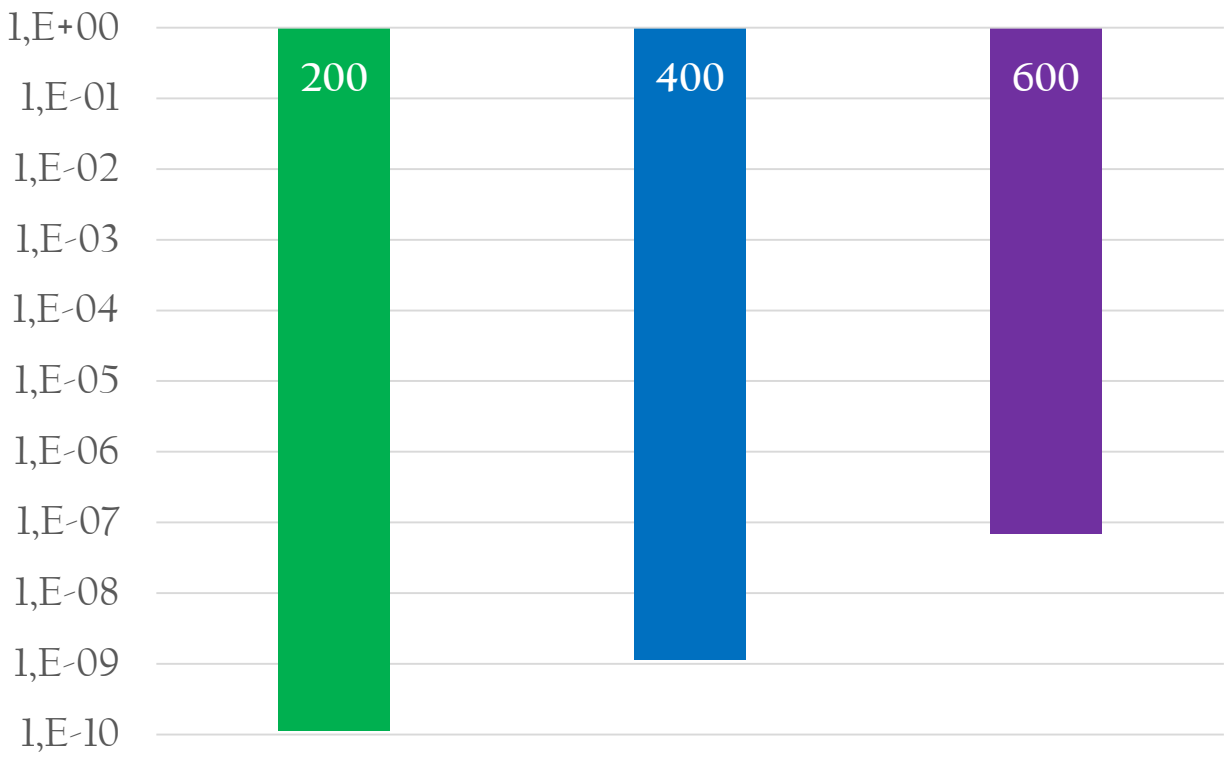
200 km



Space Debris - IS

- The impact score indicate a **fairy low degradative use of the orbital resource**, expresses in terms of potential fragments-year released. The lowest score is measured for the 200 km altitude, as the orbital time is extremely reduced in this case. Obviously, the **largest IS** is referred to the **600 km altitude case scenario**.

Impact Score [potential fragment years]



Take home message

- It is **not** possible to identify a material that **outperforms** the other for all the impact categories

- A trade-off is required, depending on **KPIs** and specific needs

- The generation of **more accurate inventory data** for PEEK are essential for future studies. Other materials will be also evaluated **(LCP)**

- Multiscale Modelling to LCA
  - ESA LCA DB(?)

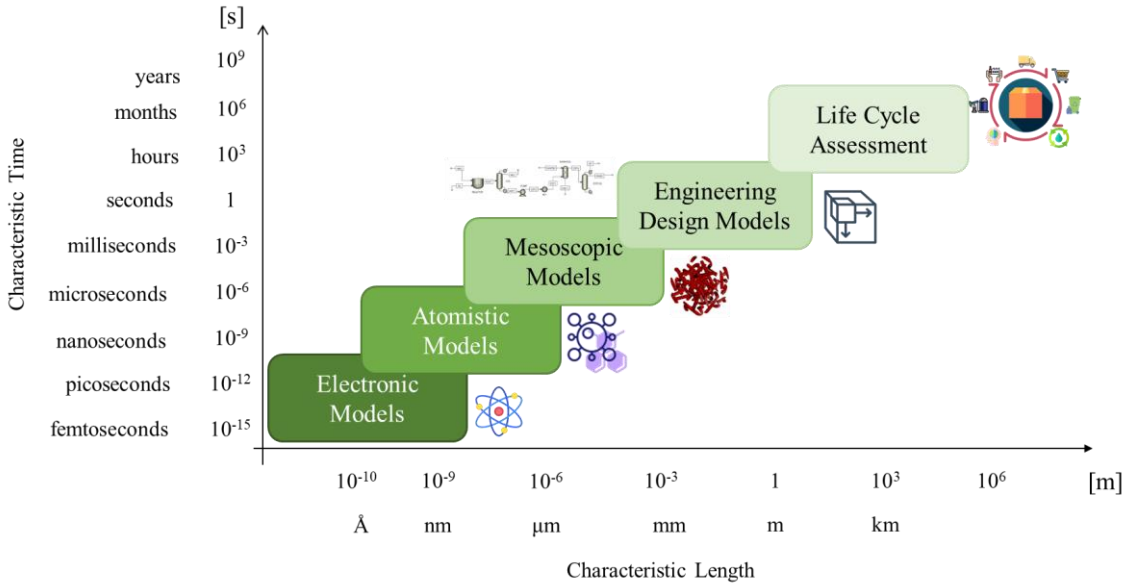
- The impact score proposed in combination to conventional LCA does not consider the potential effect of **different materials** in the generation of space fragments. While complex to quantify, a more accurate evaluation would be beneficial for evaluating and modeling the use of orbital resources.

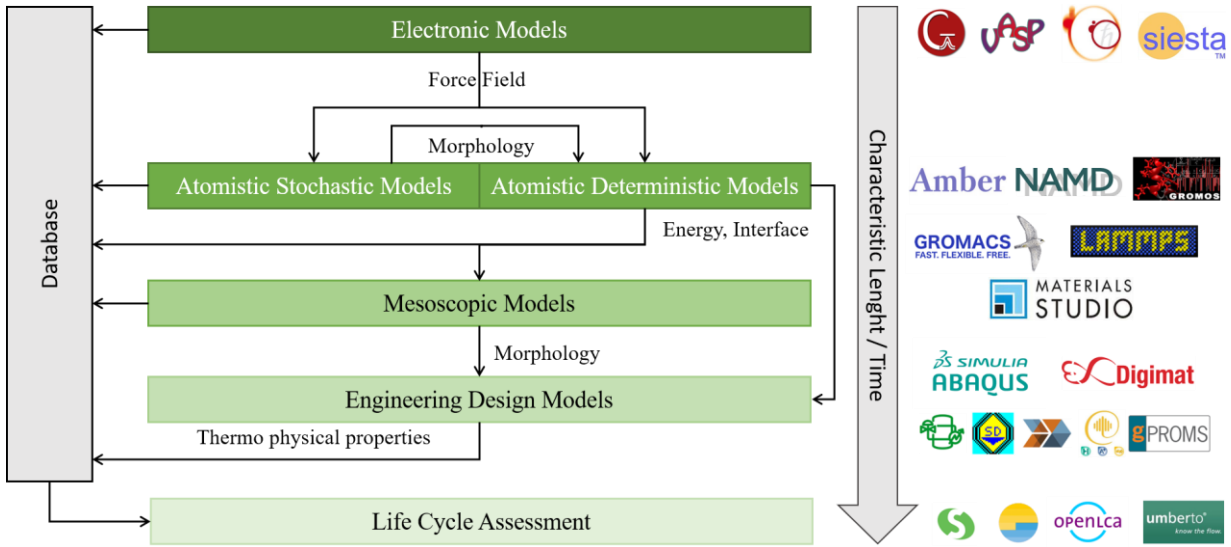
- Experimental campaigns or modelling

- Move to 2nd round of LCA calculation

Take home message

Multiscale Modelling





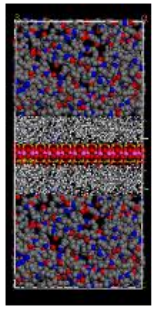
Mio A, Bertagna S, Cozzarini L, Laurini E, Bucci V, Marinò A, Fermeglia M, Multiscale modelling techniques in life cycle assessment: Application to nanostructured polymer systems in the maritime industry. Sustain Mater Technol 2021;

Take home message

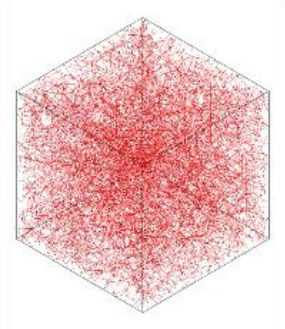
Multiscale Modelling Examples

Nano Engineered Thermoplastic Polymer (NETP)

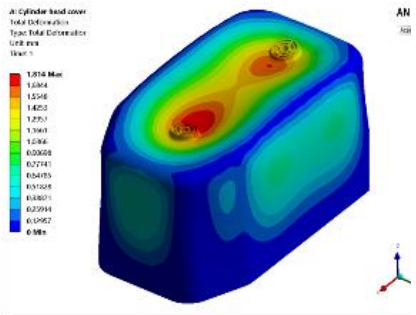
MD



MicroFEM



FEM



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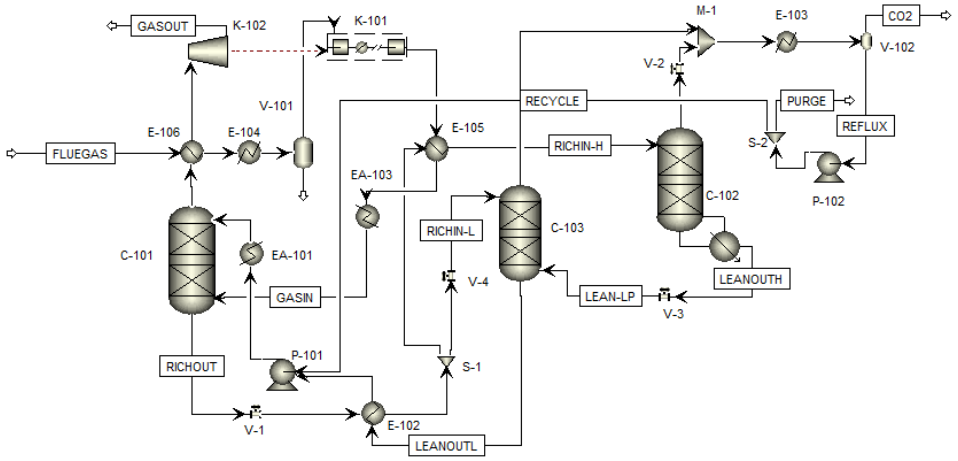
Carbon Capture and Storage (CCS) process



Barbera E, Mio A, Pavan AM, Bertucco A, Fermeglia M. Fuelling power plants by natural gas: An analysis of energy efficiency, economical aspects and environmental footprint based on detailed process simulation of the whole carbon capture and storage system. Energy Convers Manag 2022;252.

Research group

MolBNL
MOLECULAR BIOLOGY AND NANOTECHNOLOGY LABORATORY

Molecular Biology and Nanotechnology Laboratory @ University of Trieste

Prof. Sabrina Pricl
Chemistry
Nanomaterials
Biological Systems

Dr. Suzana Aulic
Biology
Experimentalist

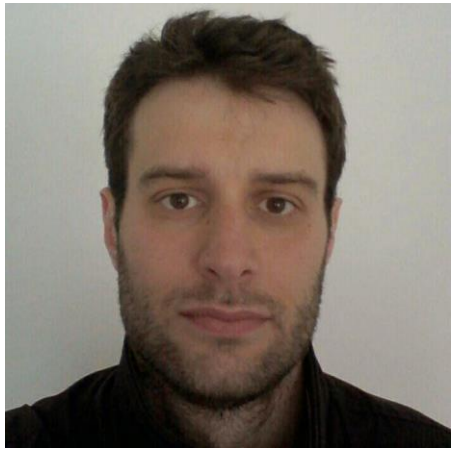
Dr. Emanuele Alberto Slejko
Materials Engineering

Prof. Maurizio Fermeglia
Chemical Engineering
IT
Nanomaterials

Prof. Erik Laurini
Chemistry
IT
Biological Systems

Dr. Andrea Mio
Chemical Engineering
LCA practitioner
Nanomaterials

Dr. Domenico Marson
Chemistry
IT
Biological Systems



Dr. Federico Dogo
Physicist

Questions?

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