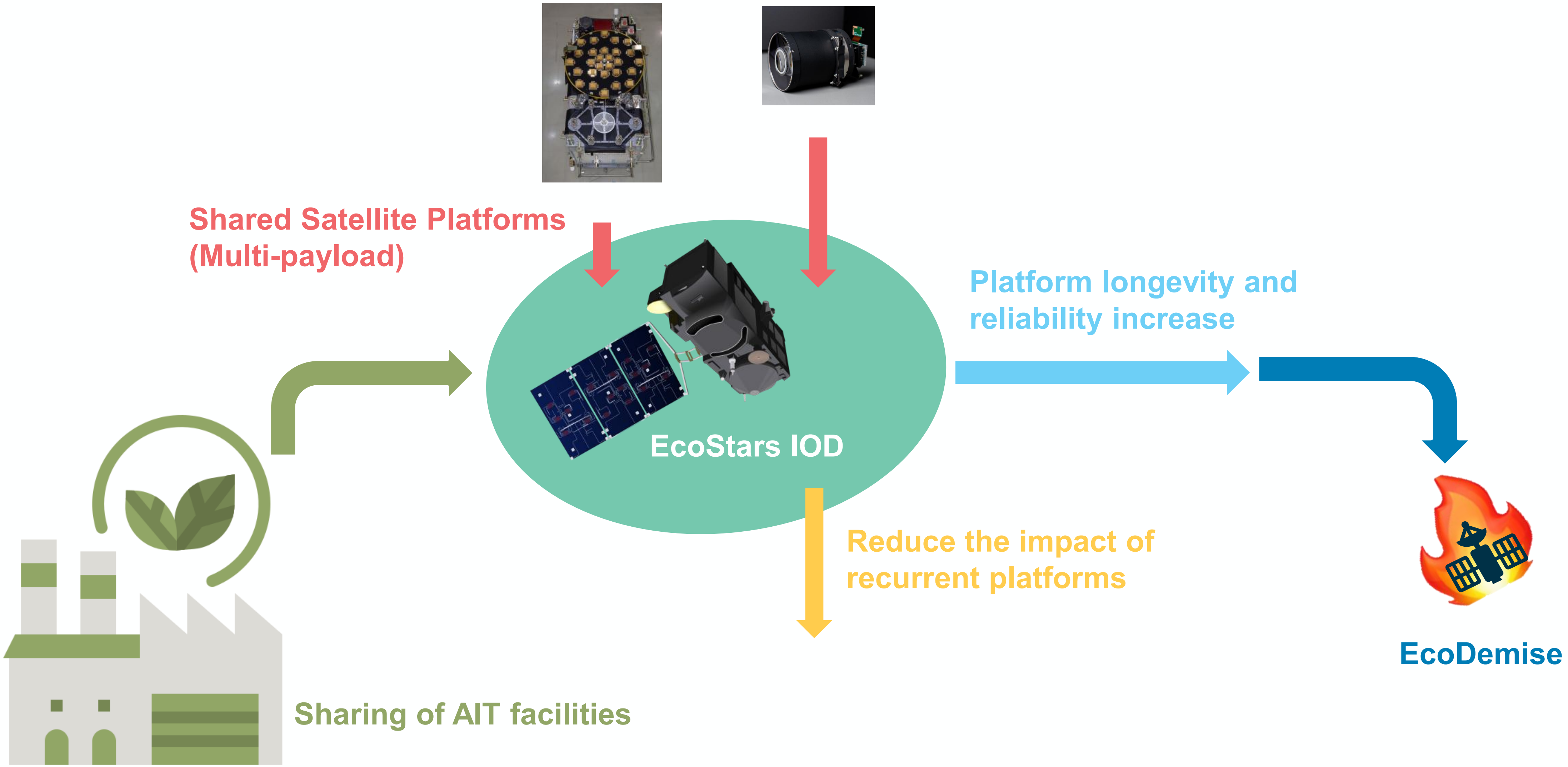
The Ecodesign Roadmap

Accelerating towards a more sustainable space!

System Studies (Industry View)



Sustainable Technologies

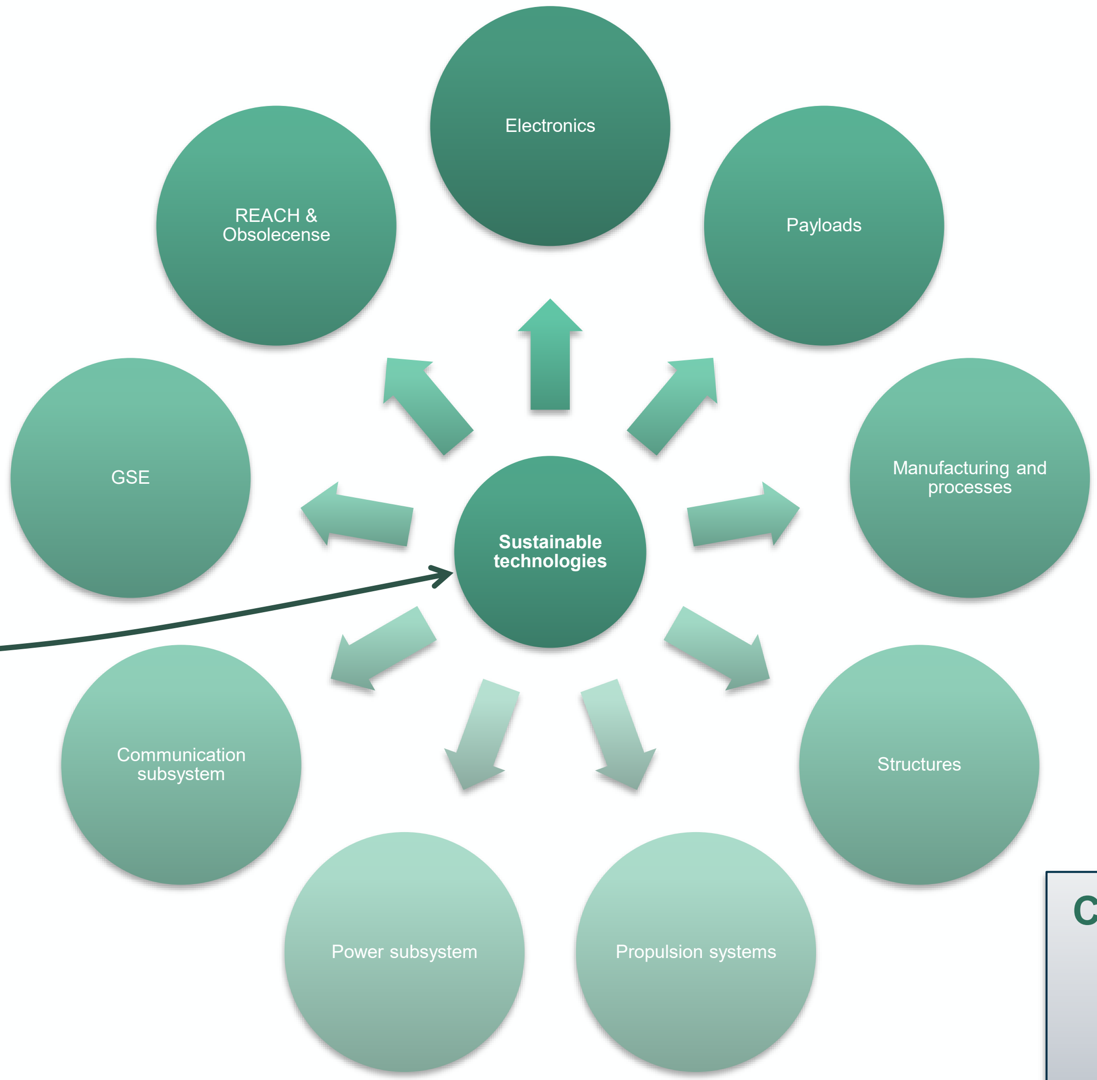
A chapter of the Ecodesign Roadmap for CMIN25

18th September 2025

ESA Clean Space

Sustainable Technologies

Environmental hotspots



Goal: To discover the innovative sustainable technologies being developed for space applications. From sustainable propulsion systems to more eco-friendly materials, this section will focus on the advancements that pave the way for greener space exploration.

Cross-cutting competences and Cross ESA Directorates

34 M€ Funding from various Technology Program*

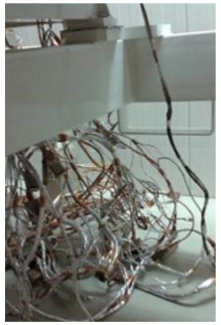
*pending CMIN25 outcomes

Sustainable and generic electronics

Achieve a 30-40% reduction of the environmental impacts of space missions by 2030
*→ Priority for **Sustainability for Technologies Expected to be Highly Recurrent***

Optimisation of mineral resource usage in space electronics

High Precision RDL Printing for Wafer-Level Packaging Integration



EcoDesign Harness for Space Applications

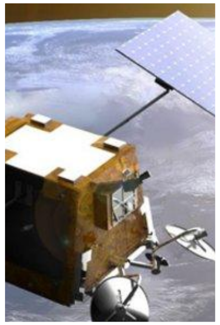
High Priority for Industry
(source Ecodesign Taskforce)

Payloads

Achieve a 30-40% reduction of the environmental impacts of space missions by 2030
*→ Priority for **Sustainability for Technologies Expected to be Highly Recurrent***

Ecodesign of optical payload architectures

Ecodesigned Radar system



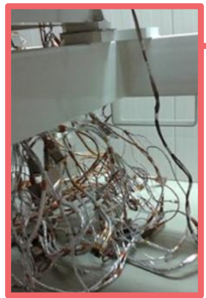
Ecodesigned Telecom payloads

High Priority for Industry
(source Ecodesign Taskforce)

Sustainable manufacturing and processes

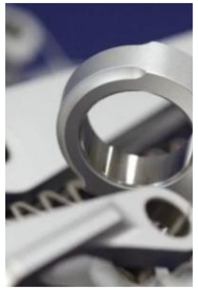
Achieve a 30-40% reduction of the environmental impacts of space missions by 2030
*→ Priority for **Sustainability for Technologies Expected to be Highly Recurrent***

Greener MAIT (phase 2)



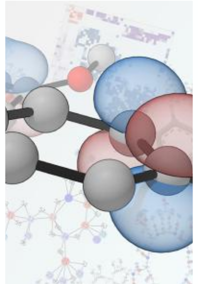
Mitigation of impacts of PTFEs in Harnesses

Mitigation impacts of adhesives



Mitigation solutions for Green Surface Treatments

Full Thermoplastic Spacecraft Platform



Establish a quantum-chemistry -based model to predict the performances of new (greener) materials under space environment

High Priority for Industry
(source Ecodesign Taskforce)

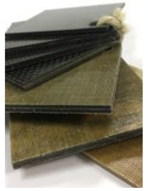
Sustainable structure manufacturing

Achieve a 30-40% reduction of the environmental impacts of space missions by 2030
*→ Priority for **Sustainability for Technologies Expected to be Highly Recurrent***

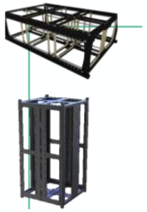
Waste treatment & Recycling structures manufacturing

Greener composite structures by Out of Autoclave improvement

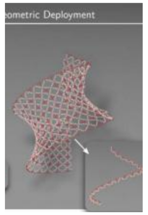
Multi-Functional Composites for Future Sustainable Space Missions



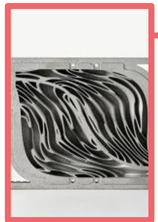
100% Biobased composite



Modular Assembly Structures for Space Exploration



Self shaping structure



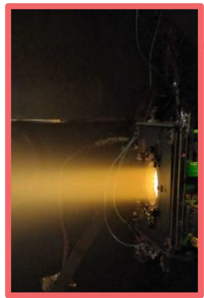
Advanced sustainable manufacturing of space-qualified components from recycled high-value feedstock

High Priority for Industry
(source Ecodesign Taskforce)

Sustainable propulsion systems

Achieve a 30-40% reduction of the environmental impacts of space missions by 2030
*→ Priority for **Sustainability for Technologies Expected to be Highly Recurrent***

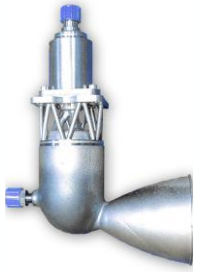
Green Tanks and pressurisation systems for high thrust propulsion



Iodine-fed electric propulsion systems for small to medium LEO contellations

Water-vapor electric propulsion system

Greener cryogenic insulation for propulsion tanks

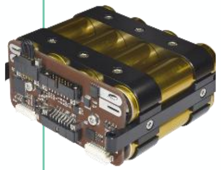


Green propellants

High Priority for Industry
(source Ecodesign Taskforce)

Sustainable power subsystem

Achieve a 30-40% reduction of the environmental impacts of space missions by 2030
→ Priority for ***Sustainability for Technologies Expected to be Highly Recurrent***



Sustainable batteries packs production

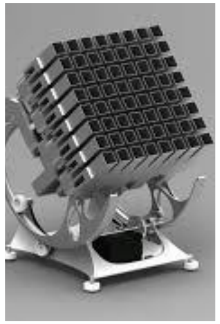
Lithium free batteries for low earth orbit spacecrafts

Greener solar cells

High Priority for Industry
(source Ecodesign Taskforce)

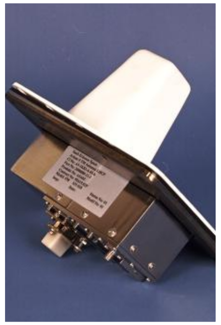
Sustainable communication subsystem

Achieve a 30-40% reduction of the environmental impacts of space missions by 2030
*→ Priority for **Sustainability for Technologies Expected to be Highly Recurrent***



Phased Array Antenna with Eco-Friendly 3D Printed Microelectronic Components

Advanced ecodesigned low-signature materials, coatings and surface treatments (to comply with dark and quiet skies)



Eco-design of Antennas for launchers

High Priority for Industry
(source Ecodesign Taskforce)

AIT

Achieve a 30-40% reduction of the environmental impacts of space missions by 2030
*→ Priority for **Sustainability for Technologies Expected to be Highly Recurrent***

Reusable GSE

High Priority for Industry
(source Ecodesign Taskforce)

REACH & Obsolescence

Achieve a 30-40% reduction of the environmental impacts of space missions by 2030
*→ Priority for **Sustainability for Technologies Expected to be Highly Recurrent***

LCA into REACH tool

Sustainable substitutes of priority toxic substances - integration of multiple materials into MAIT,

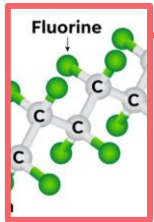
Sustainable corrosion protection primers

Sustainable ionic fluid substitutes for PFA-based lubricants

Sustainable solvent alternatives to replace Toluene

Sustainable production of Foams - Green polyurethane materials

Obsolescence: Risk mitigation action linked to PFAS Obsolescence: Beta Cloth



Obsolescence: Risk mitigation action linked to PFAS Obsolescence: 3M PFAS materials facing discontinuation

Transition to European-made, controlled-volatility and low toxicity, high performance silicone elastomers

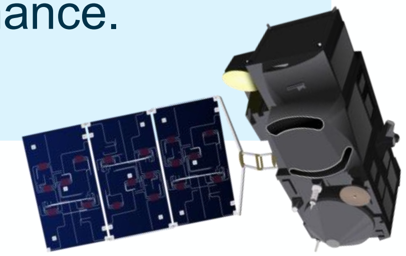
High Priority for Industry
(source Ecodesign Taskforce)

The Ecodesign Tools

The champion enablers for the ecodesign vision

Ecodesign Tools Roadmap

Goals: Development of **tools supporting ecodesign** efforts, which include simplified Life Cycle Assessment (LCA) methodologies and tools, AI-driven tools for data collection and interpretation, and LCA tools for electronics modelling. Additionally, get updates on the ESA LCA database, a vital resource for tracking and improving environmental performance.



ESA LCA Database

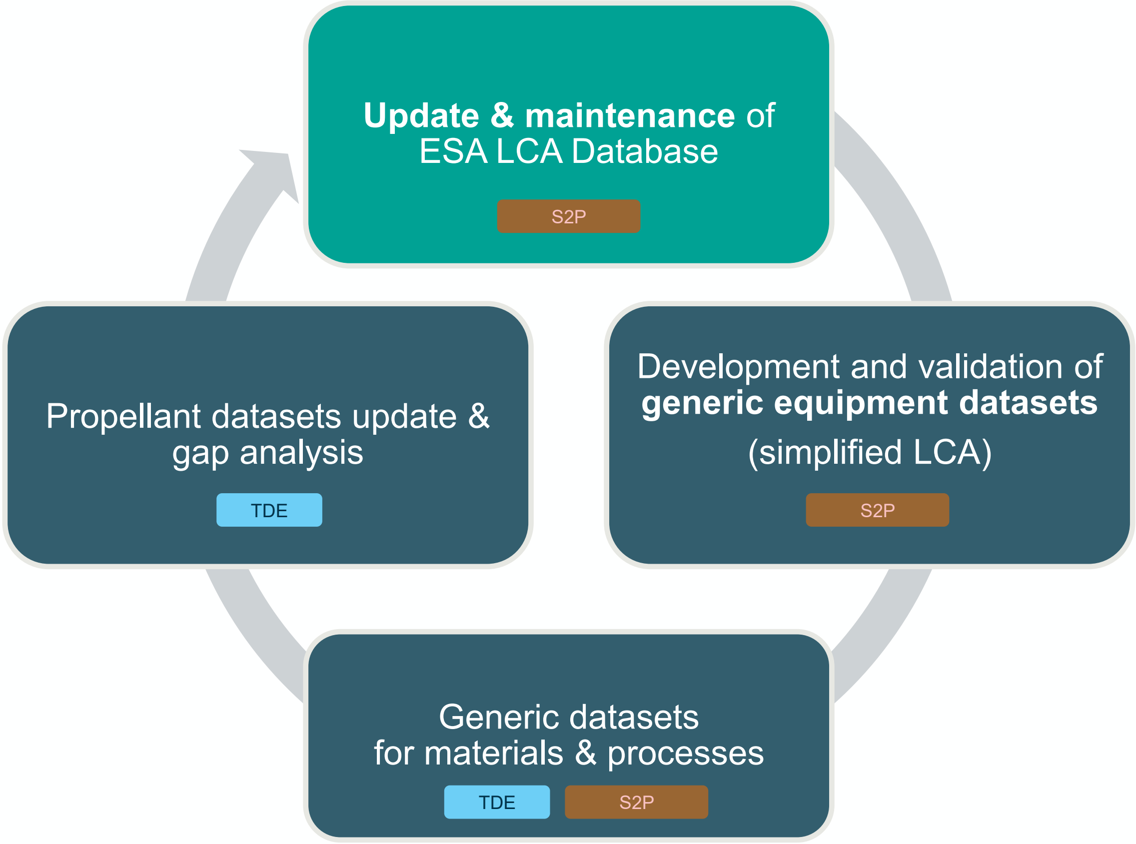
Specific tool for space LCA experts:

- Compilation of space specific datasets built upon raw data collection, literature review and ecoinvent database (commercial database)
- Compatible with two LCA software (SimaPro and OpenLCA)
- **Ecoinvent** (background database) **licence is mandatory** for access, as it is already integrated in the ESA LCA DB

New ESA LCA DB version (v1.3.0) **released** in the Space Debris User Portal: https://sdup.esoc.esa.int/lca/

Updated ESA LCA DB Public User Manual (v2.2) also available in the portal

Activities:



ESA LCA Database – Generic datasets

Targets:

- **LCA Hotspots**
- **LCA Blind spots**
- **Recurrence of Use**

Evolving methodology:

Generic datasets

Manufacturing → Transport → Testing

Staff

- Materials
- Components
- Processes
- Energy

→ **Validation** → **Scalability**

❖ **For Simplified LCA**

Ecodesign Tools

Simplified LCA Tool

Simplified LCA Tool for Missions / Ground Segment / Infrastructures

- Enables prospective LCA
- High Priority for phases A/B1
- Trade-offs at equipment level
- To be compatible with CDF inputs
- Includes a simplified data questionnaire for suppliers
- Dedicated activity for electronics tool (inc. development of generic dataset)

Electronics LCA Toolbox

Parametric Lifecycle Inventory tool for printed board assemblies cradle-to-gate

- Electronics are often a hotspot in ESA missions, and are particularly hard to model
- User-friendly SW tool for LCI of printed board assemblies
- Basic building blocks of electronic modules and systems.

Ecodesign Tools

AI-Driven Tools

AI Tool for ESA LCA Database

- AI tool to extract LCA data from documentation
- LCA models generation from extracted data and documentation
- LCA models generation from supplier data collection file.

MBSE Methods in LCA

Implementation of MBSE in the LCA methodology

- To be implemented in later mission phases (from phase B1 to C)
- MBSE integration in a Dual Twins framework for simplification and improvement of the LCA process

Conclusions

The Ecodesign tools roadmap aims to:

- Improve existing LCA methodology and address technological gaps
- Update and maintain the ESA LCA DB
- Facilitate the development and validation of generic datasets at equipment level (including electronics)
- Enable prospective LCA in early mission phases through Simplified LCA
- Implement AI to improve data collection and modelling

~ 5.5 M€
Across all of ESA

~ 3 M€
In S2P Subscription

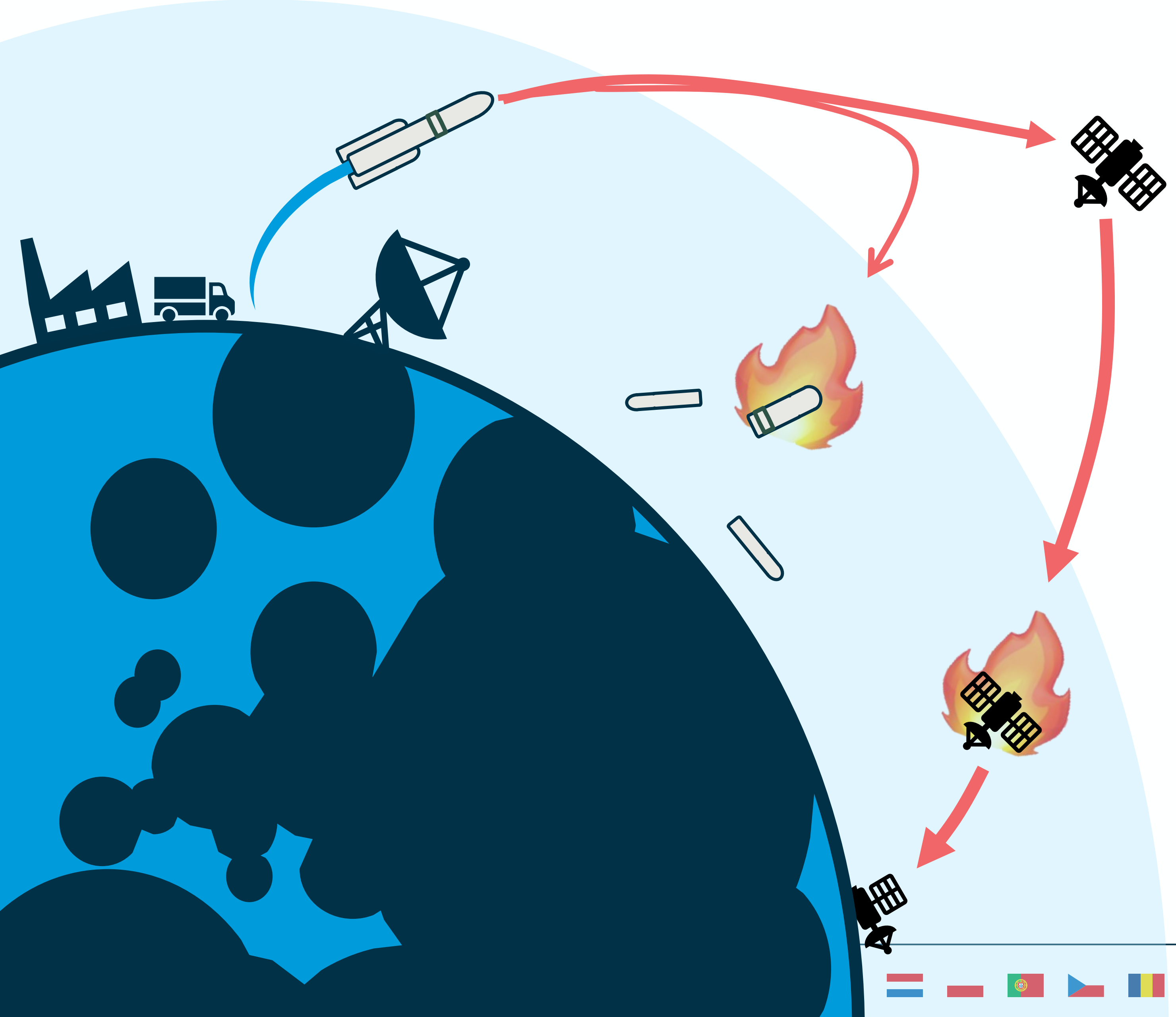
❖ Activities pending the outcome of the 2025 Ministerial

Thank you for your participation!

Knowledge and data gaps

What is preventing us to complete the life-cycle vision

The Mission Lifecycle



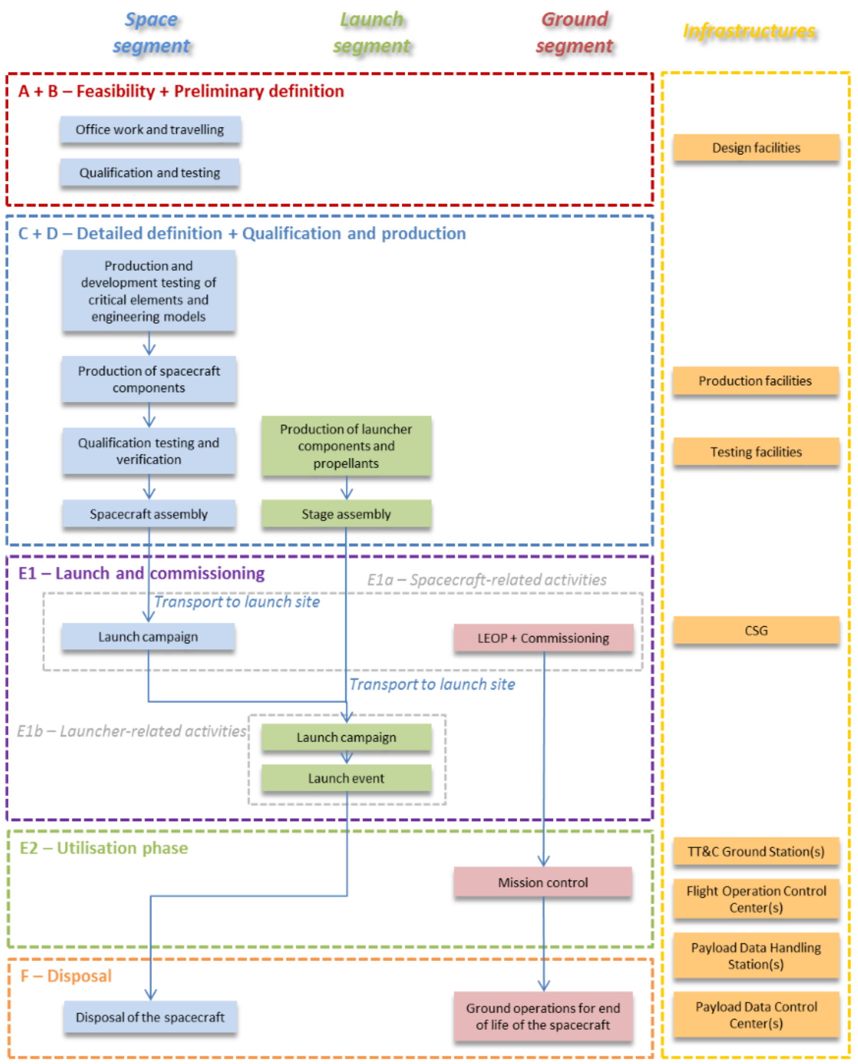


Figure 7-1: Space mission system boundaries

Current System Boundaries for LCA

ESA UNCLASSIFIED – For Official Use

esa

DOCUMENT

Space system Life Cycle Assessment (LCA) guidelines

Prepared by	ESA LCA Working Group
Reference	ESSB-HB-U-005
Issue	1
Revision	0
Date of Issue	31 October 2016
Status	Approved
Document Type	Handbook
Distribution	ESA internal

European Space Agency
Agence spatiale européenne

7.2.2 Space segment

the system boundaries include:

Spacecraft end of life

NOTE No emissions are considered; spacecraft disposal is addressed by assessing the dry mass of the spacecraft that re-enters the atmosphere.

7.2.3 Launch Segment

the system boundaries include:

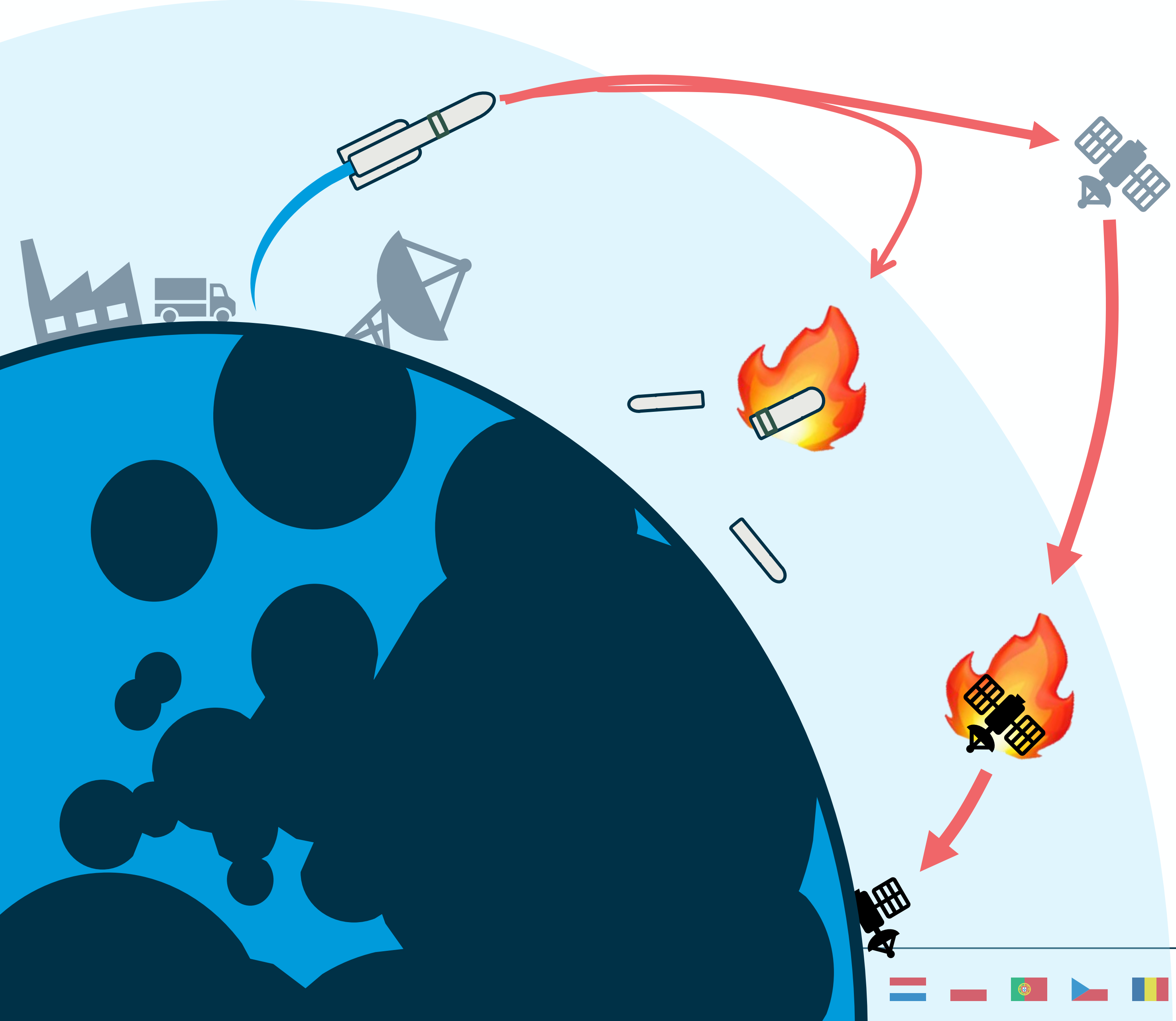
- **Launch Event**, including:
  - — Quantity of waste falling in on earth (only the mass per material type is calculated and reported).
  - — Space debris generated (only the mass is calculated and reported).

The system boundaries exclude:

— Emissions of launchers in atmosphere during flight are not part of the LCA (in the sense that they are not characterised) but are reported as elementary flows. Furthermore, their impacts are reported under Additional environmental information, if they have been calculated.

No emissions need to be calculated for either case!

The Mission Lifecycle



- The impact of some parts of the mission lifecycle is not considered when performing an LCA
- This represents a “blind spot” of our current methodology
- Impacts all layers of the atmosphere, as well as our oceans

Why aren't these taken into account?

Fragmentation- particle size

Environmental persistence and toxicity

Altitude ablation

Atmospheric dynamics

Environmental impact of orbital launches and re-entry events?

International collaboration

Atmospheric modelling

Field data

Heterogeneous nucleation and cloud condensation

Optical-chemical properties

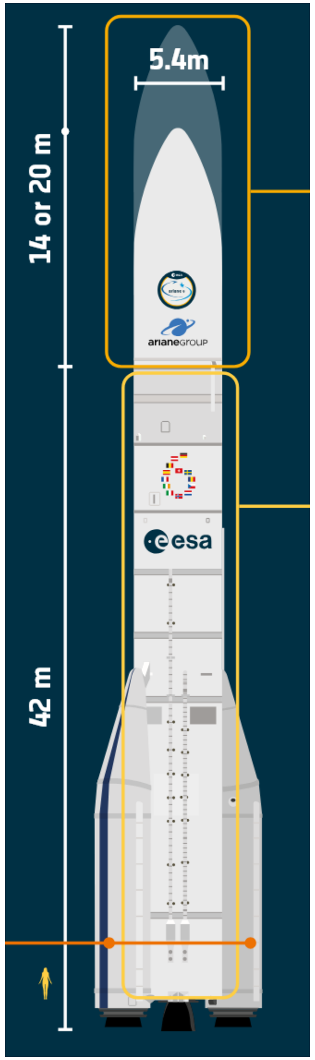
Ground testing

…because it is difficult to, and a lot of the needed research is missing

I will be presenting ESA's roadmap for addressing these gaps

Atmospheric Impacts of Launch

- Hundreds of tonnes of propellant are burned as a rocket is launched
    - This releases combustion products and water vapour into all layers of the atmosphere
    - Current characterisation factors **cannot account for this**
- Preparatory activity was running to measure the effect of the rocket plumes (FIREWALL)
    - Another two activities would prepare **ground-based measurement methodologies to allow for easier characterisation**, and perform systematic measurements of available launchers
- With the output of these activities, **the impact can be implemented into the LCA methodology and handbook through another planned activity**: (LIMIL)

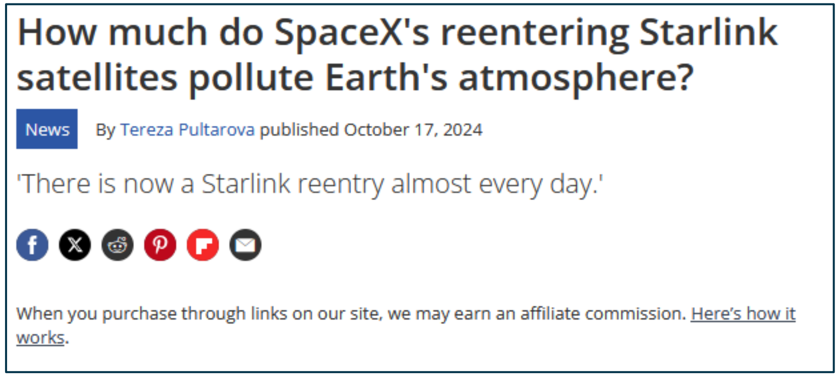


Atmospheric Impacts of Re-entry: Ground Testing/Remote Sensing

- **The chemistry of space objects as they ablate and re-enter is not fully characterised**
  - Conditions are extreme, and very hard to replicate

    ➔ Insights into the Chemistry of Atmospheric Re-entry of jUnked Spacecraft (ICARUS) currently running; follow-up planned to look at toxicity

    ➔ Others looking at synergies with lunar dust, and the creation of a toxicity database
- **Similarly, the dynamics of these materials in the upper atmosphere is not fully understood**
  - ➔ Study looking at characterising the effect of aluminium particles on climate change and ozone depletion
  - ➔ Aerosol Interaction and Dynamics in the Atmosphere (AIDA)
- **Remote sensing is planned to be investigated through Ground-based LIDAR**
- Finally, creation of a simulator is planned to calculate emissions at different altitudes



How much do SpaceX's reentering Starlink satellites pollute Earth's atmosphere?

News By Tereza Pultarova published October 17, 2024

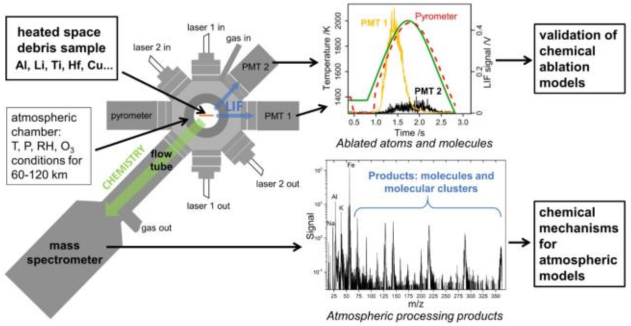
'There is now a Starlink reentry almost every day.'

When you purchase through links on our site, we may earn an affiliate commission. Here's how it works.

https://www.space.com/spacex-starlink-reentry-pollution-damage-earth-atmosphere

ICARUS (Ground Testing simulation)

Atmospheric Chemistry Simulator for Spacecraft Demise



Atmospheric Impacts of Re-entry: Field Data and Modelling

- To collect field data, a variety of methods are plane:

→ Several studies using stratospheric balloons for in-situ measurements of anthropogenic particles at different altitudes, and the effect of space missions compared to other industries

→ Aircraft campaign for satellite ablation probing

→ Soil Sediment and Ice Core sampling

→ NOx emissions measurements for re-entry vehicles.

→ Soil Sediment and Ice Core sampling for accumulation of space debris

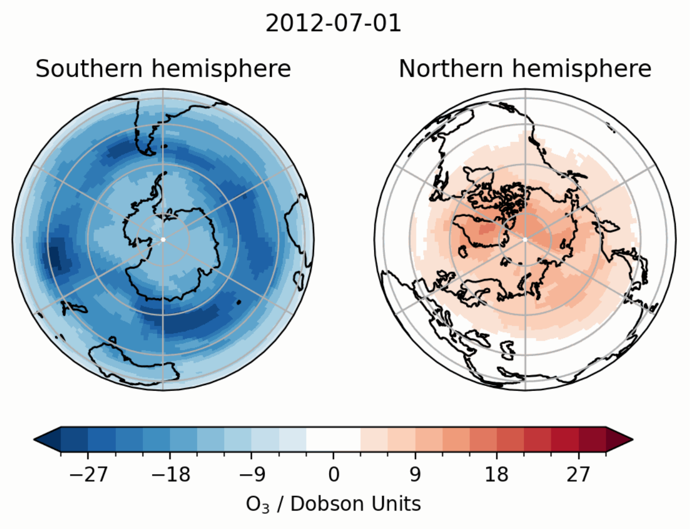
- Once data is collected, they can be fed into models

→ Integration of spacecraft demise environmental impact into LCA methodologies

→ The creation of better climate models that include spacecraft emissions

→ Integration into space debris tools (DRAMA)

IDEAS (Atmospheric Modelling)



Environmental Impact of Re-entry into the Oceans

Image credit: [Ada Cukminski]()

- Anything that doesn't burn up in re-entry arrives back on Earth, and most likely in the ocean
  - SPOUA used as a spacecraft cemetery for decades to minimise human casualty risk
  - **The environmental effect of this is not fully understood, and not integrated into LCAs**
- ESA has run the activity "Plunging of Large Objects into the Oceans and their environmental Fallout"
  - Looking at both launchers and spacecraft
  - ➔ 2 follow-ups are planned to take a deeper look at marine toxicity, acidification and ecosystems
- Once the impact is understood, the next step is integration into LCA methodologies and CFs

  ➔ **Spacecraft marine end-of-life inclusion in LCA** (SMELIL) - Launchers + Spacecraft

Conclusions

- Space LCAs do not currently calculate the impact of all parts of a mission's lifecycle
    - This is because the impact on the atmosphere and oceans is still poorly understood
- ESA has roadmapped activities in order to address these gaps, and allow for a more holistic assessment of environmental impacts without any blind spots
- Running these activities is pending the outcome of the 2025 Ministerial

~18 M€
Across all of ESA

~2 M€
In S2P Subscription

Thank you for your participation!