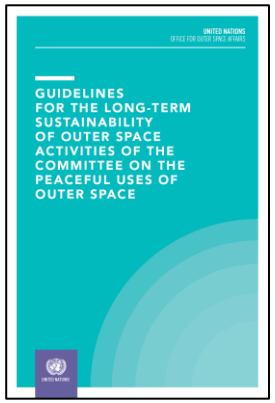
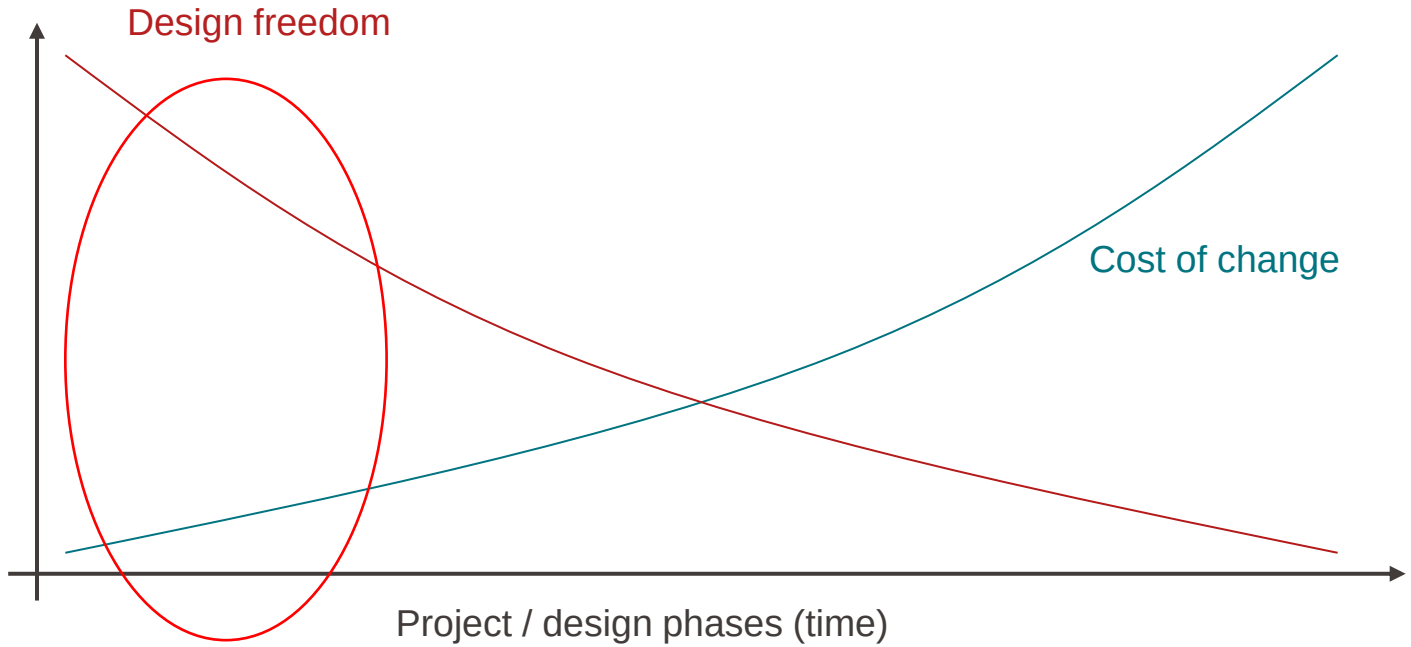
Rapid Life Cycle Assessment Software for Future Space Systems' Design
–
The Assessment and Comparison Tool

EPFL Space Center (eSpace), Ecole Polytechnique Fédérale de Lausanne (EPFL), CH

Context



UN Office for Outer Space Affairs, “Guidelines for the Long-Term Sustainability of Outer Space of the COPUOS” D1.3 :
[…] international intergovernmental organizations should promote the development of technologies that **minimize the environmental impact** of manufacturing and launching space assets […]



Adapted from https://innovativedelta.com/approach/

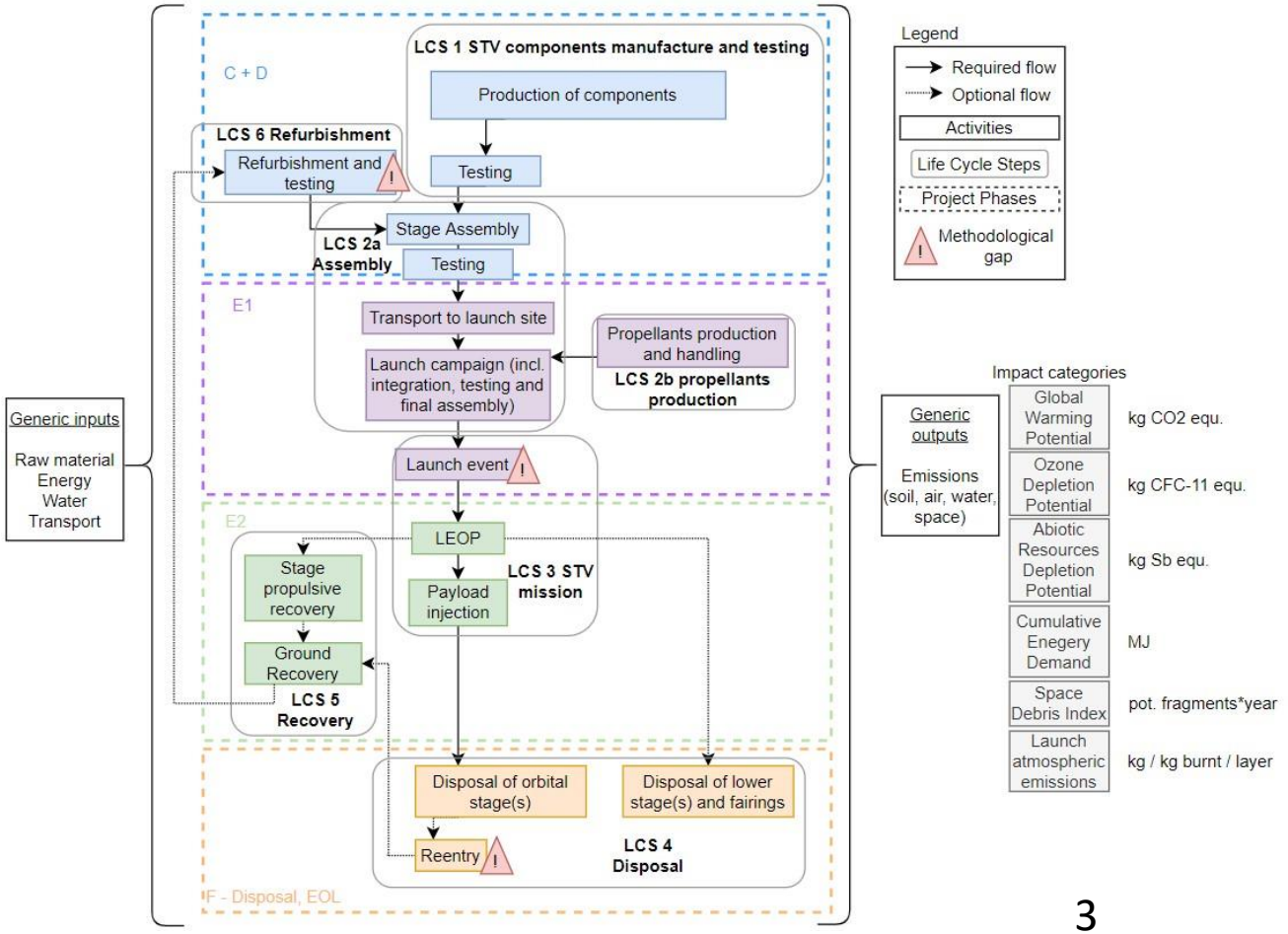
The Assessment and Comparison Tool

A proof of concept developed in 12 + 3 months for ESA FLPP

- To support engineers with little LCA knowledge
- To highlight environmental hotspots
- Using high-level system data
- Modular to allow improvements

It is not

- A complete, detailed LCA tool
- A generator of eco design options



Impact computation

FU: To place X tons of payload into orbit Y
with X and Y defined by the user

Precalculated impact **scores** · material/energy/etc. **amount** = **final impact score**
(background databases) *(specified in ACT)* *(environmental impacts of configuration)*

ecoinvent +

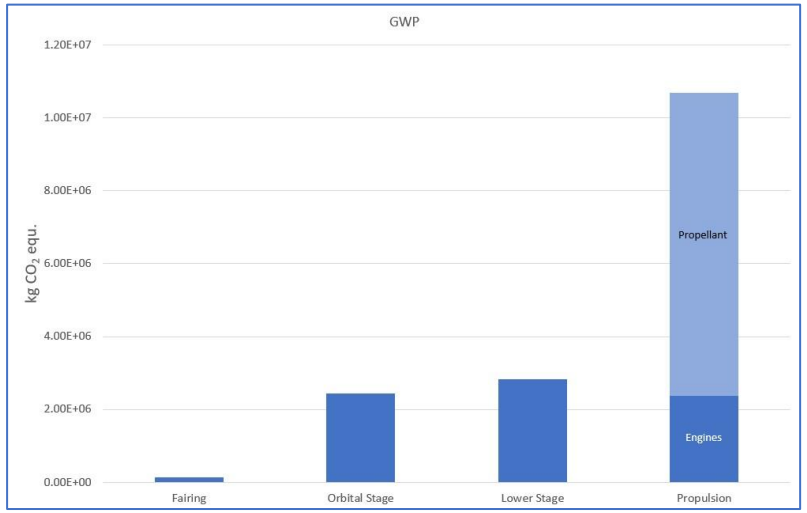
Adapted from ESA.

+ prospective

https://www.esa.int

Parameters:
- Dry mass
- Volume
- Recoverable ?
- Reusable ?

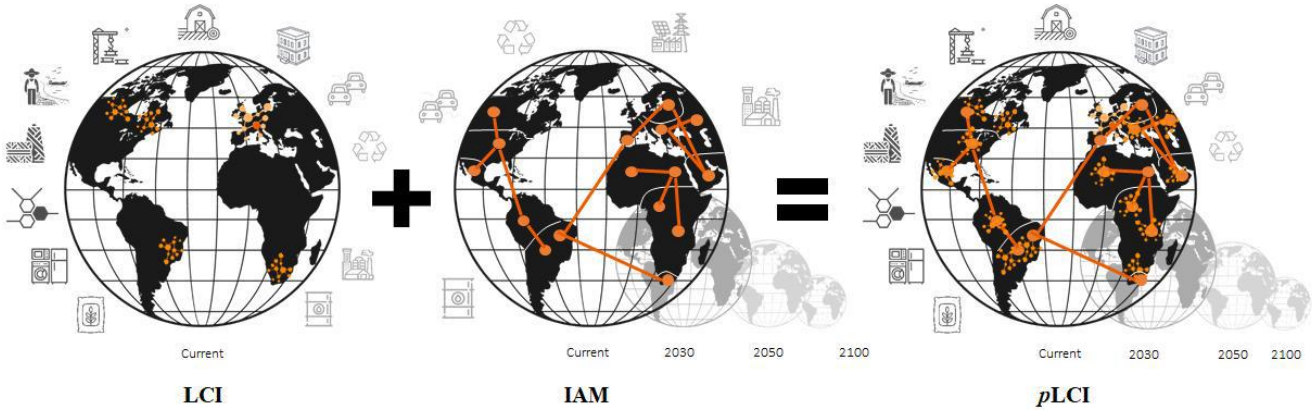
LCA datasets:

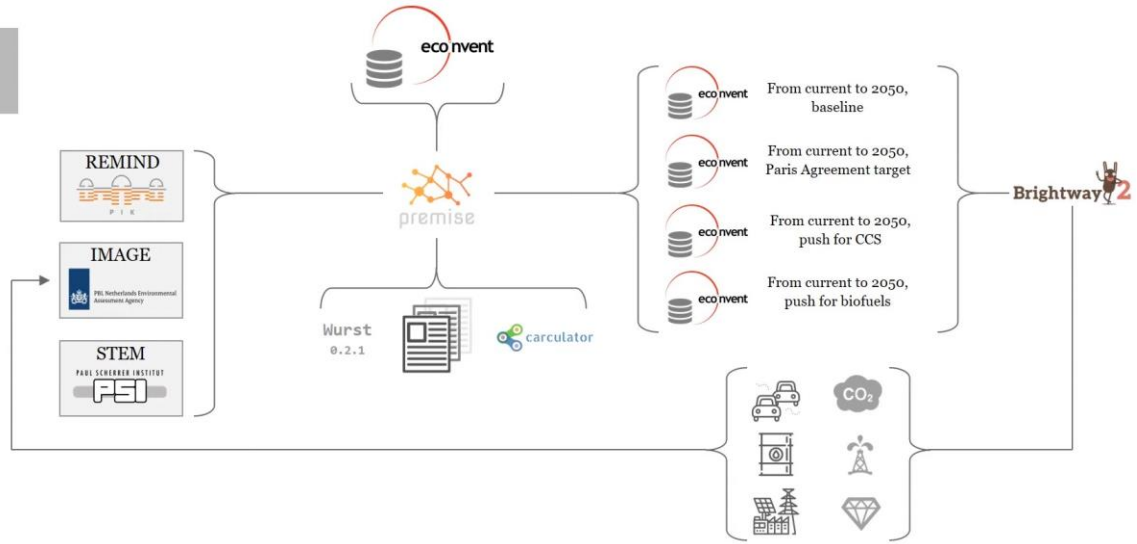


Impact indicators:
GWP
ODP
ADP
CED

Material / Component	Value
Aluminium	760 kg
Cork	100 kg

Prospective data





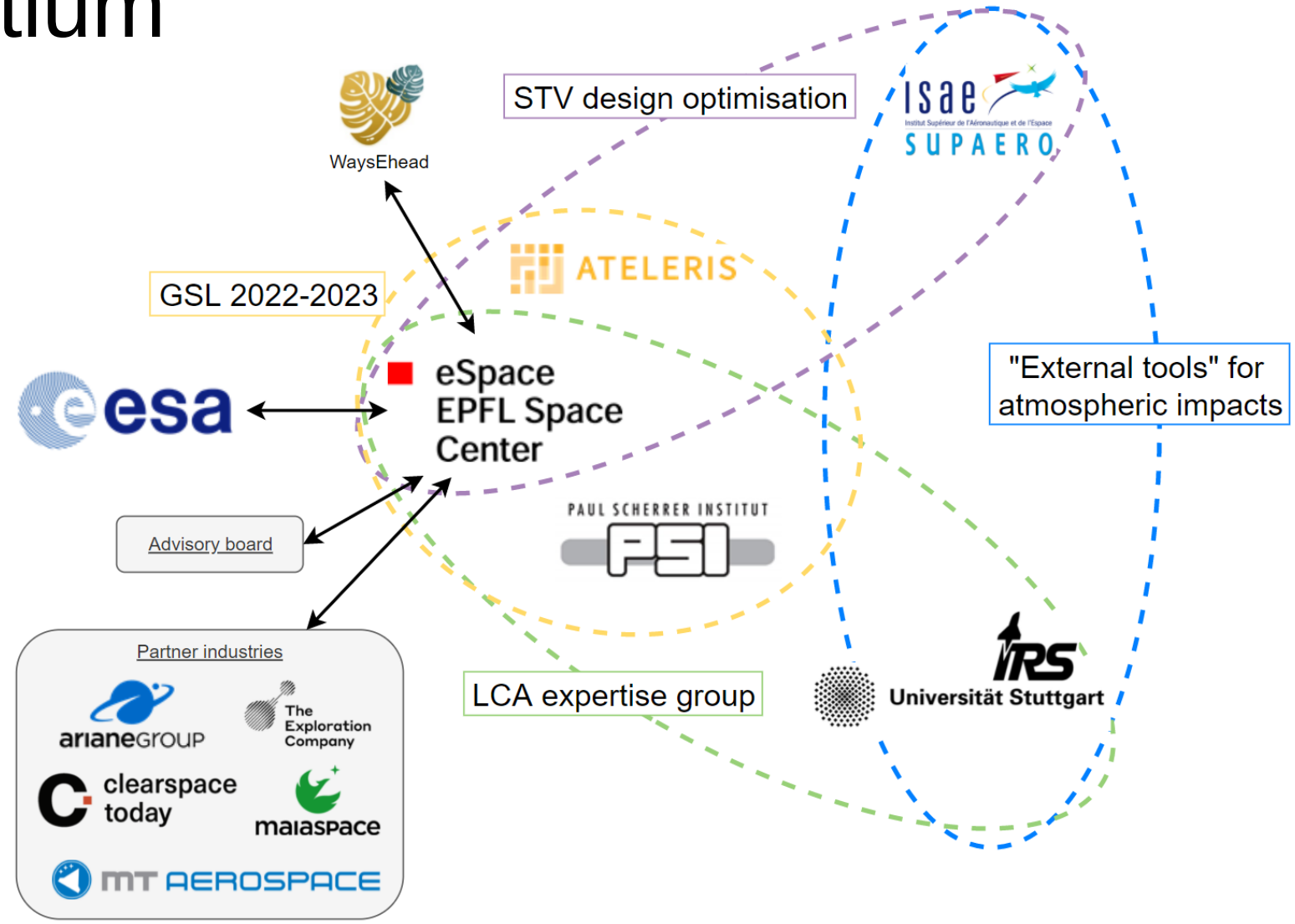
Integrated assessment models to assess *future* systems

- Future technologies
- Change in energy mixes
- New policies and regulations

Prospective LCA

Extended consortium

- ESA FLPP project
- Complementary expertise
- New advisory board
- Letters of interest from industries



→ Kick-off in November !

Tackling gaps - IAMs

IAMs are propagation models:

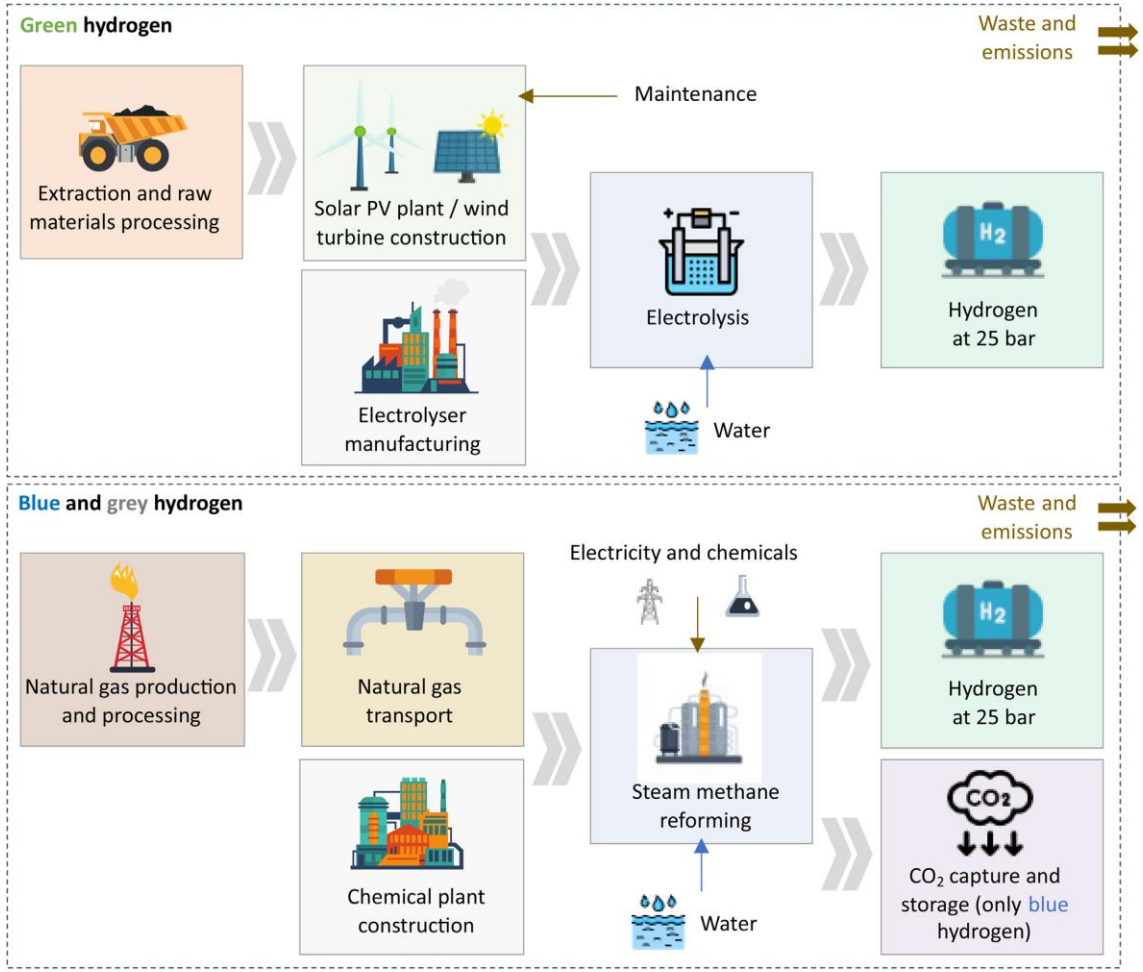
- Not all industrial sectors are modelled yet

→ Warnings, transparency in user manual

- Models cannot "invent" a future tech

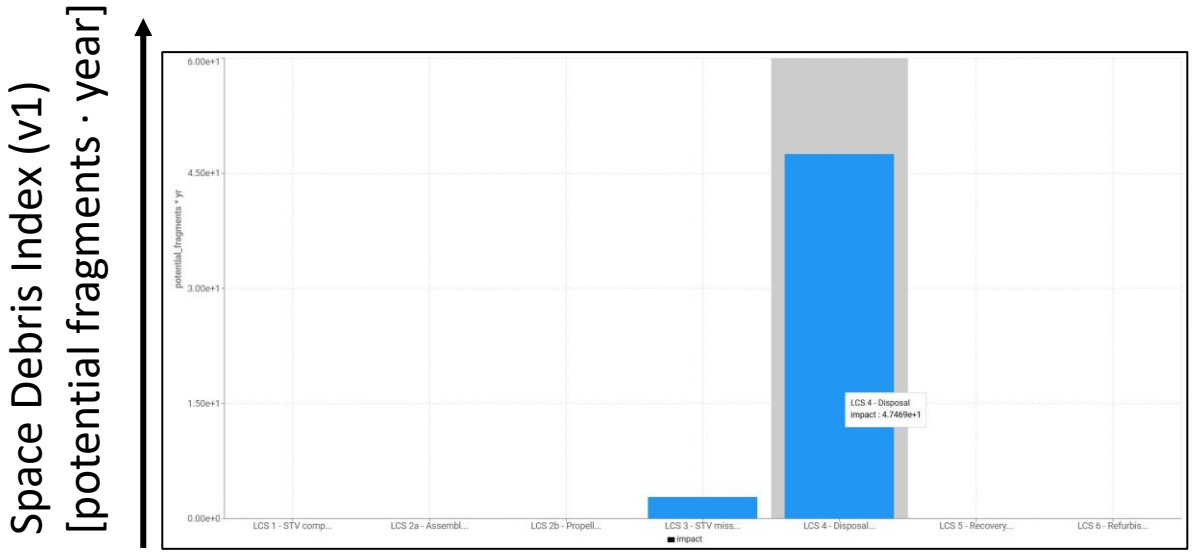
→ Planning to allow the creation of new datasets by authorized users

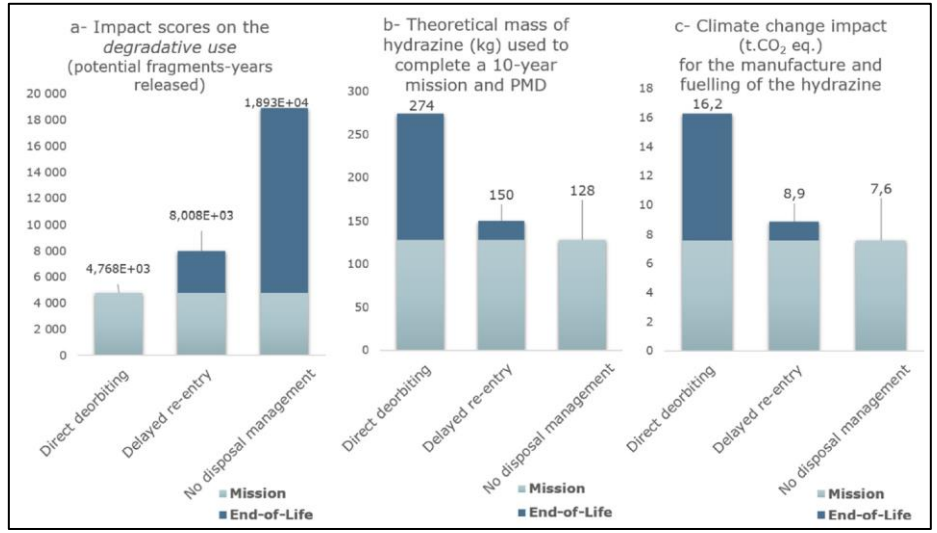
e.g. *future* high-grade hydrogen production: not in ESA DB, not modelled in IAMs yet



T. Weidner et al., "Environmental sustainability assessment of large-scale hydrogen production using prospective life cycle analysis", International Journal of Hydrogen Energy, Volume 48, Issue 22, 12 March 2023, Pages 8310-8327, https://www.sciencedirect.com/science/article/pii/S0360319922052570.

Tackling gaps – space debris



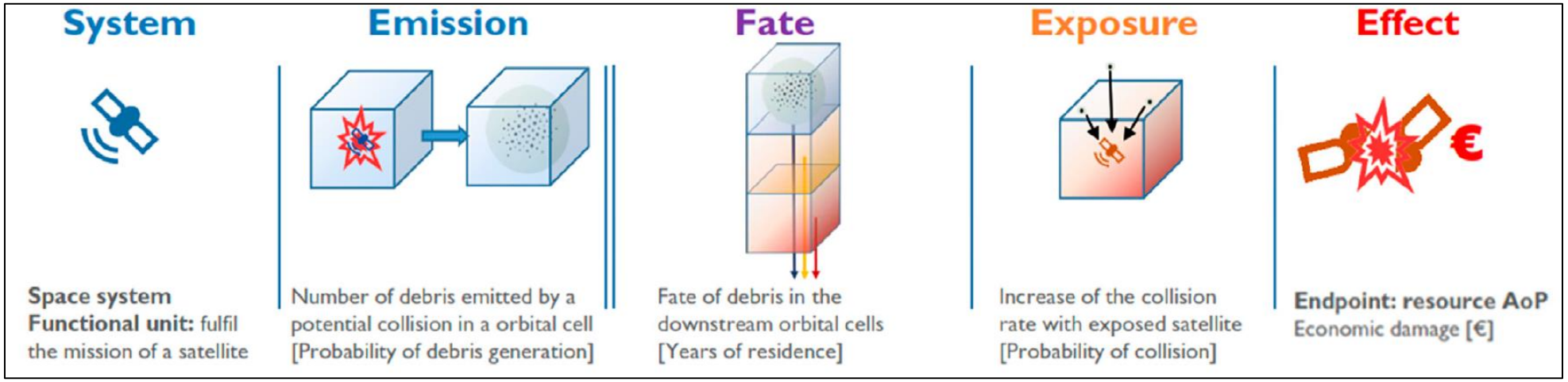


Example from T. Maury et al., "Assessing the impact of space debris on orbital resource in life cycle assessment: A proposed method and case study", Science of the Total Environment 667 (2019) 780–791

→ New model

$$I\ [k\$] = CF\ [k\$ \cdot debris^{-1}] \cdot N_D, j\ [debris]$$

$$I\ [k\$] = \underbrace{FF \cdot XF \cdot EF}$$



Adapted from Maury-Micolier T, Maury-Micolier A, Helias A, Sonnemann G and Loubet P (2022), A new impact assessment model to integrate space debris within the life cycle assessment-based environmental footprint of space systems. Front. Space Technol. 3:998064. doi: 10.3389/frspt.2022.998064

Tackling gaps – launch emissions

Unknown emissions characterization factors (aviation proxy ?)

→ Emissions flows

[CF/CF_ref]		H2O	CO2	CO	BC	Al2O3	NOx	ClOx	HOx
GWP 100Y	Ground	0.0005	1.0	1.57	460	1.23	8.5		
	Aviation	0.06	1.0	1.57	1116	1.23	114		
ODP					0.7	0.7	0.7	0.7	0.7

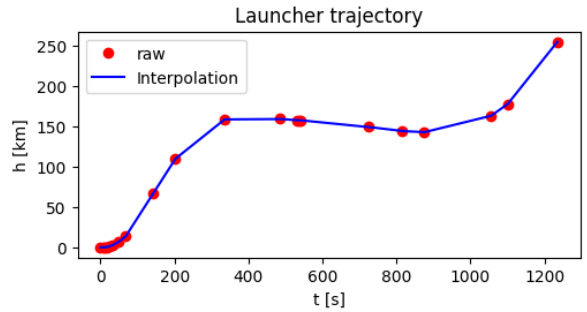
Dominguez Calabuig, Guillermo J. & Miraux, Loïs & Wilson, Andrew & Pasini, Angelo & Sarritzu, Alberto. (2022). Eco-design of future reusable launchers: insight into their life cycle and atmospheric impact. 10.13009/EUCASS2022-7353.

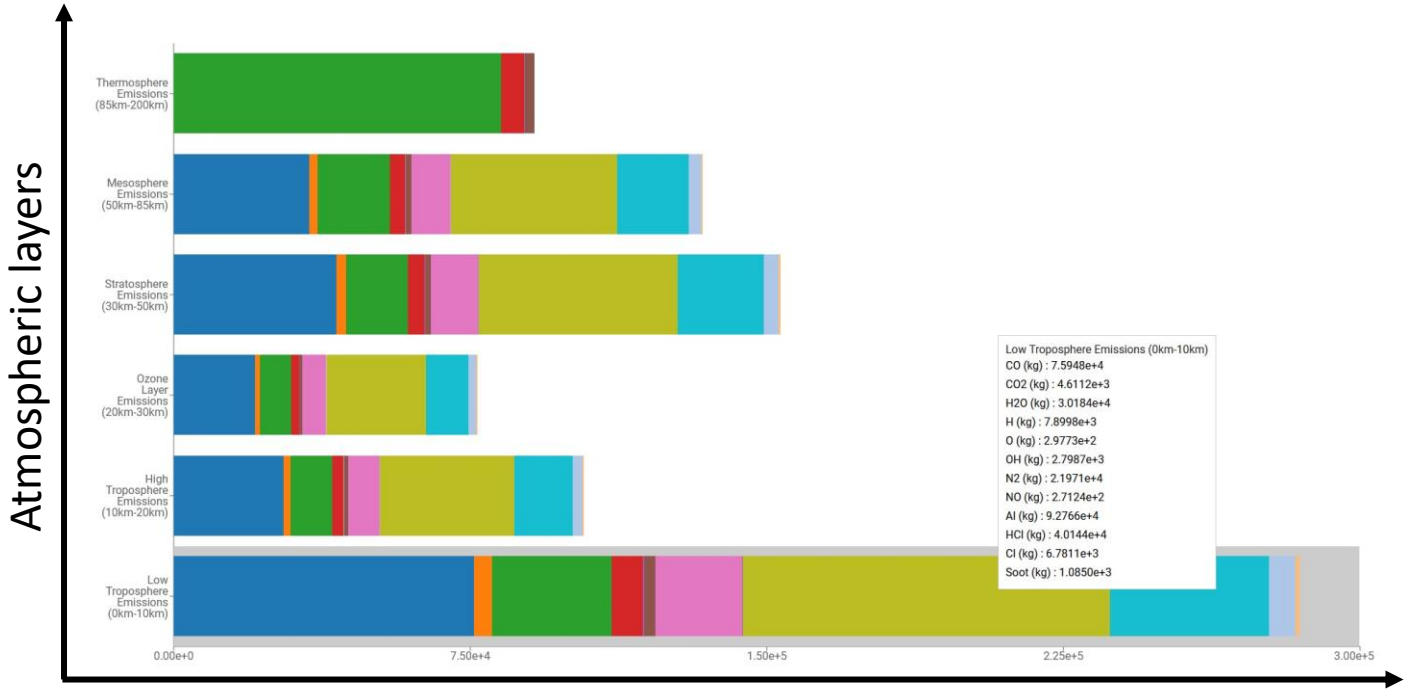
P. E. Schabedoth, "Life cycle assessment of rocket launches and the effects of the propellant choice on their environmental performance.," MSc thesis, Department of Energy and Process Engineering, NTNU, Norway, 2020.

Table 3 – Overview over the exhaust composition of the five propellants. Results are given in kg per kg propellant combusted.

Propellant	CO	CO_2	H_2O	H	O	OH	N_2	NO	Al	HCl	Cl	BC
LOx&RP-1	0.456	0.222	0.250	0.012	0.011	0.029	0	0	0	0	0	0.020
LOx&LH_2	0	0	0.907	0.064	0.002	0.027	0	0	0	0	0	0.000
LOx&LCH_4	0.344	0.187	0.422	0.018	0.005	0.024	0	0	0	0	0	0
NTO&UDMH	0.227	0.114	0.258	0.013	0.006	0.020	0.353	0.005	0	0	0	0.004
APCP	0.280	0.017	0.067	0.026	0.001	0.009	0.081	0.001	0.342	0.148	0.025	0.004

Engines' parameters +



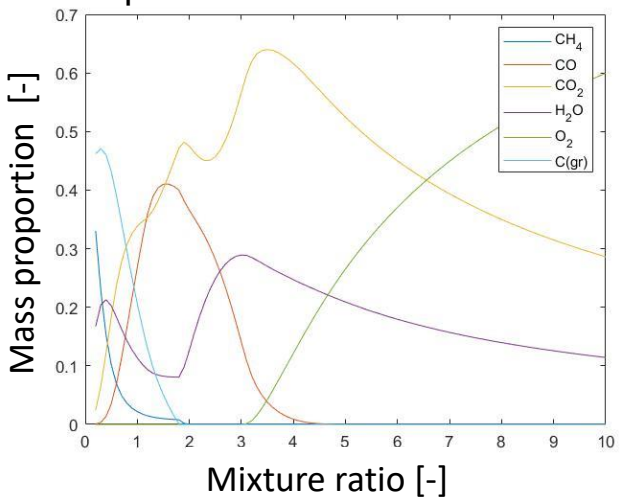


Approximations to be replaced by improved models →

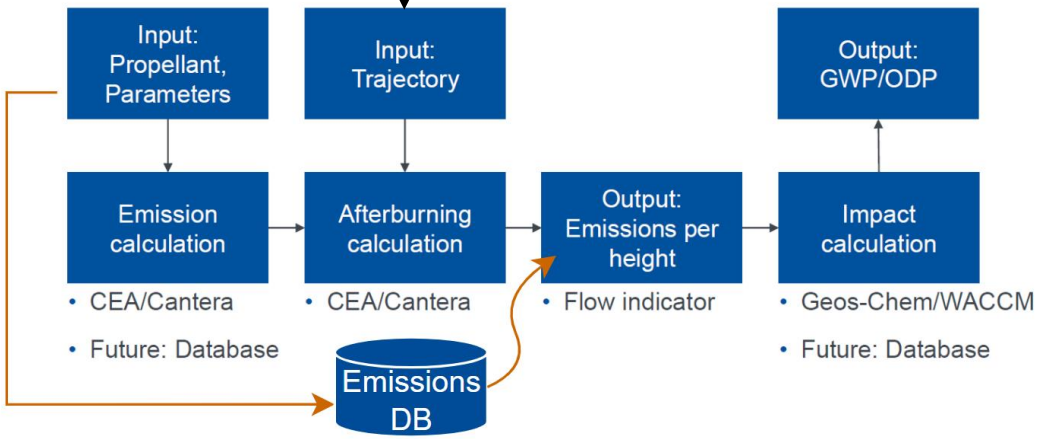
Tackling gaps – launch emissions (2)

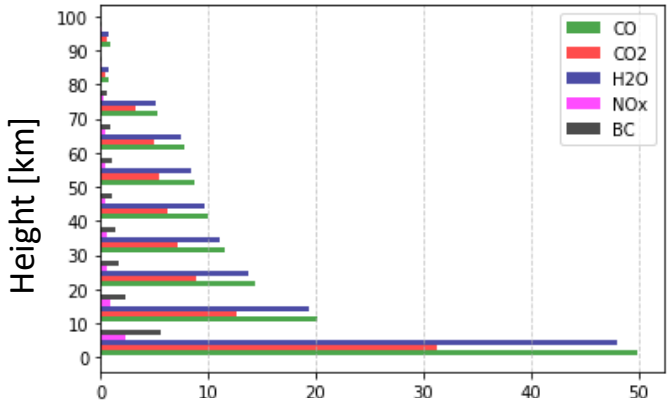
Approximations to be replaced by improved models
ACT compatibility with Stuttgart's Emissions Impact Calculation Tool (Launch + re-entry)

Example for LOX/RP-1 from Falcon 9



Launch Analysis and Sizing Tool (ISAE SUPAERO)





Emission calculation depending on:

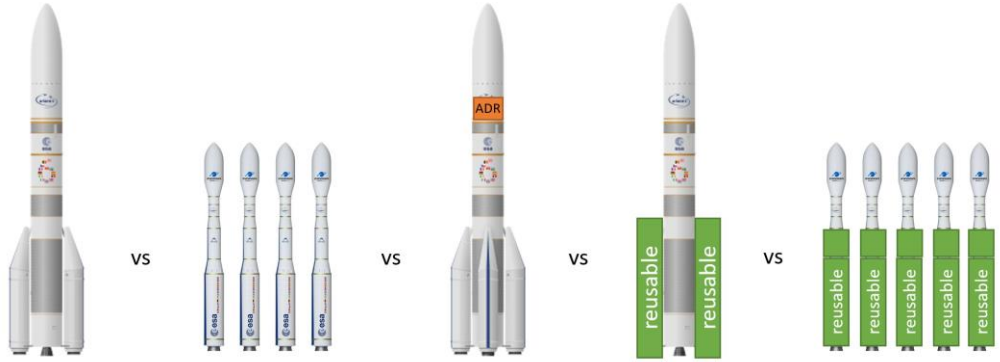
- Launch: Engine parameters (e.g. mixture ratio) and propellant
- Re-entry: Structure, Heat flux
- Surrounding

Calculation of impact on climate & ozone

- Common models (GEOS-Chem/WACCM)
- Integration into a useful LCA methodology

+ Participation to MCSA doctoral network on the topic

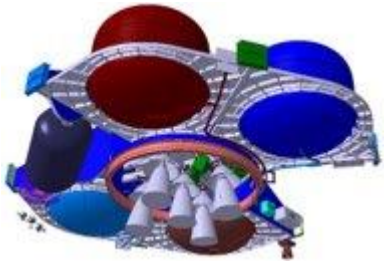
E2E STS functional units



So far only for launch vehicles:
To place X tons of payload onto orbit Y

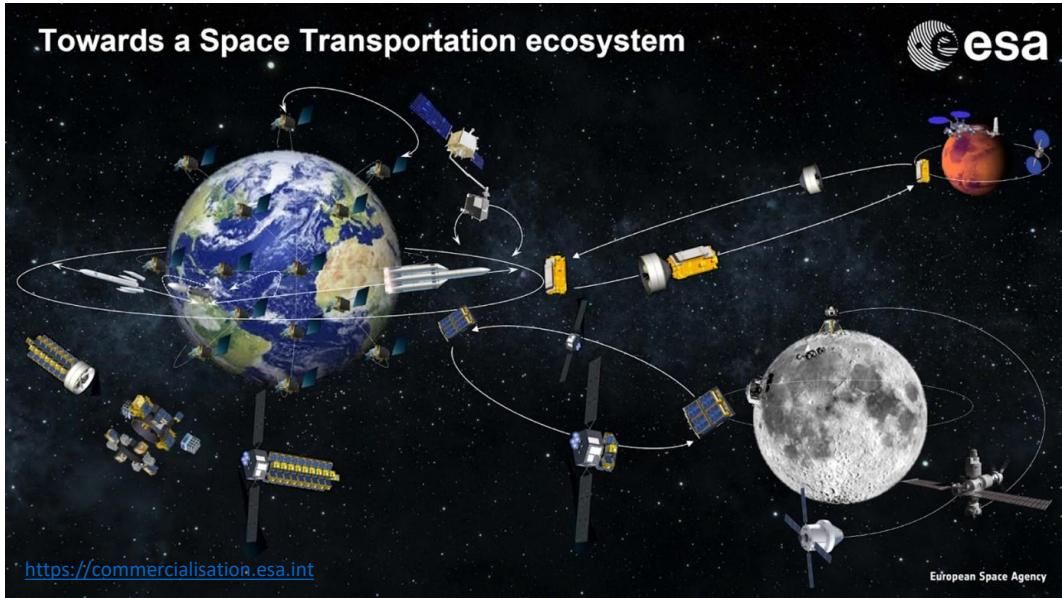
Extension to other (space transportation) systems → new FUs to be defined

- In-Space Transportation Vehicles
- Active Debris Removal servicers
- Re-entry vessels
- Ground segment and infrastructure



T. Büchner da Costa et al. "Per ASTRIS ad astra – how Ariane's kick stage propels Europe into future in-orbit applications", IAC 2022

→ And combinations of those to assess entire missions



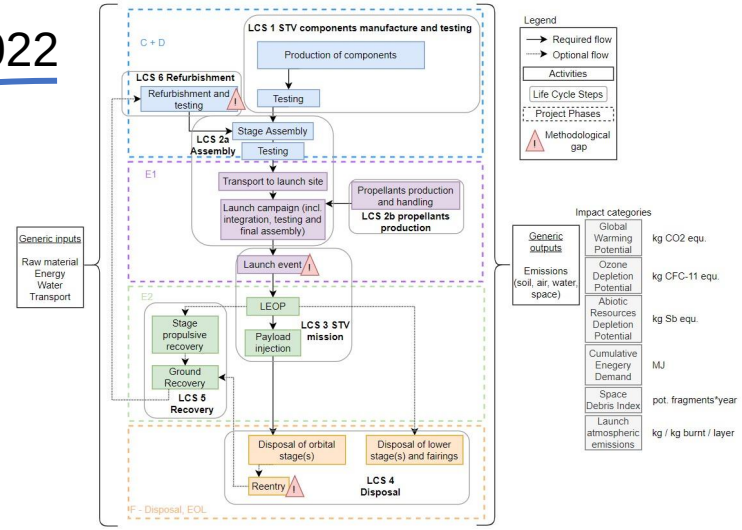
MT Aerospace AG

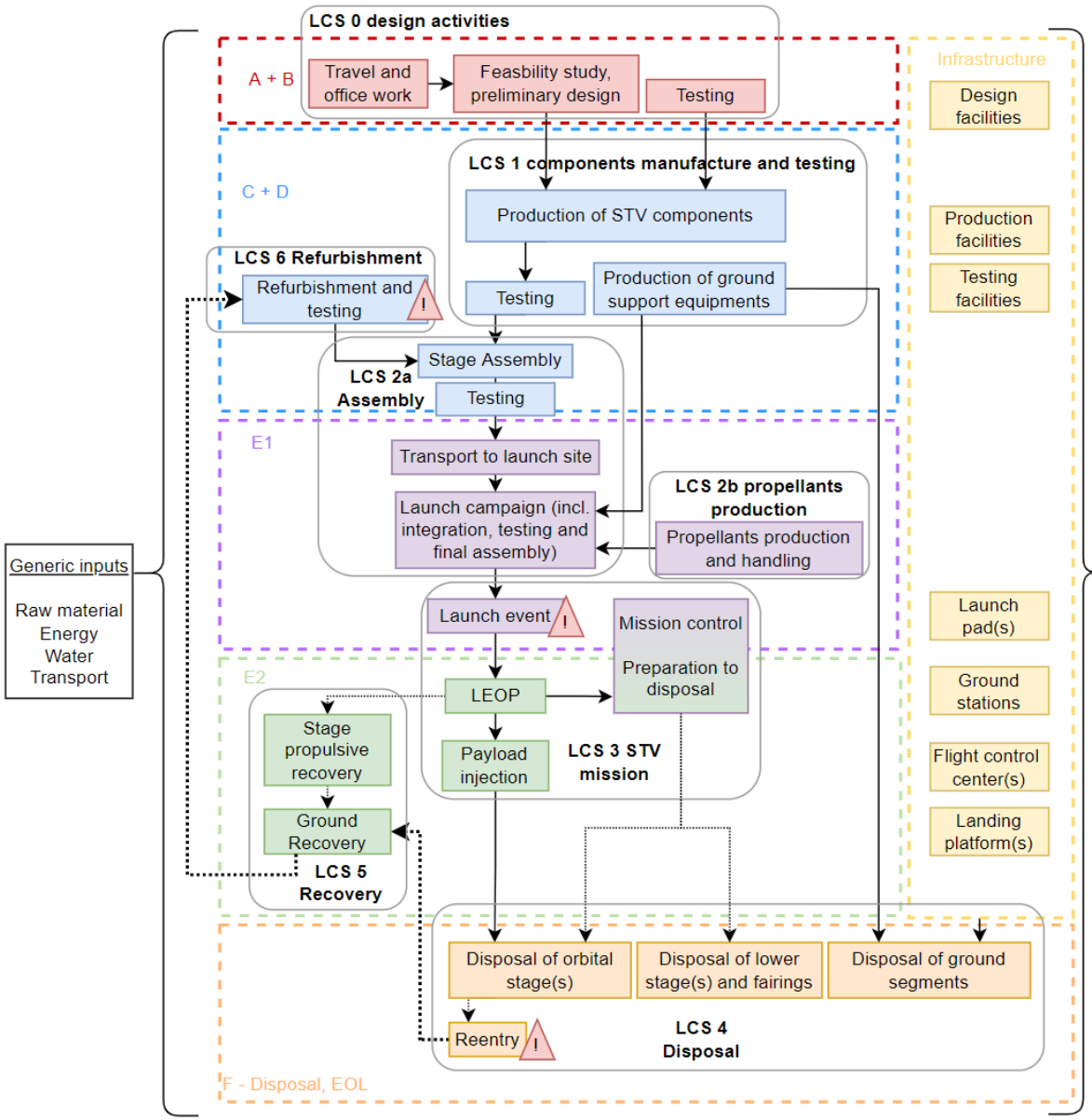
ESA

Extended scope

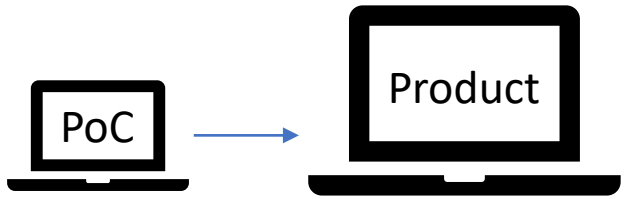
2022

2023+





Improving the UI / UX

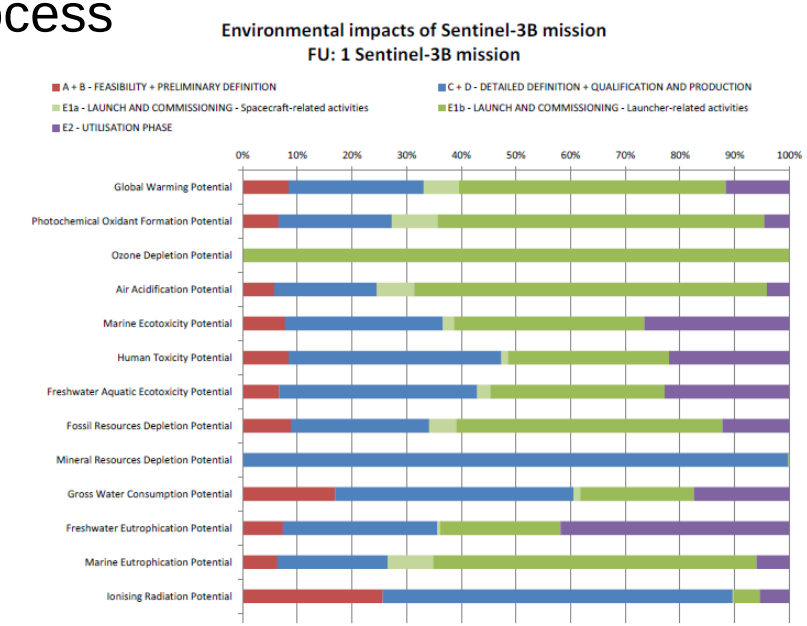


- Import/export of data
- Connect to MBSE tool

- Validation of values
- Implement new LCA requirements and smoothen the process
- Connect to other software tools

- Results visualisation
- Add CRMs and REACH = more useful info

- … TBD



ESA Space system Life Cycle Assessment (LCA) guidelines

→ Needs to be collected and prioritized, to develop the SW in an Agile way

Conclusion

- Proof of concept LCA software tool including prospective data
- Tool can be used with future systems to trade-off and de-risk
- For now LCA results must be handled with care (gaps)
- Foreseen extensions in: scope, LCA modelling, data availability, user friendliness, compatibility, etc.

To learn more:

M. Udriot et al. “Rapid Life Cycle Assessment Software for Future Space Transportation Vehicles’ Design - The Assessment and Comparison Tool”, Aerospace Europe Conference, July 2023

Thank you

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https://espace.epfl.ch/research/ssl/
https://espace.epfl.ch/education/

Mathieu Udriot

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