Update on the implementation of LCA and ecodesign in the development of a semi-reusable minilauncher

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2023 ESA Clean Space Industry Days
18/10/2023

Past participations and today's agenda

2021 Edition (ArianeWorks)

Preliminary LCA
Ecodesign vision

2022 Edition

Draft of sustainability strategy
Methodology (reusability, ecodesign)
Preliminary analysis of impact mitigation levers and their potentials
Analysis of the environmental benefits/drawbacks of reusability

2023 Edition - Agenda

1. Sustainability strategy and state of progress
2. Updated LCA
3. Methodological developments: focus on the derivation of GWP coefficients for launch
4. Ecodesign: methodology and tools, process, difficulties, first use case

MaiaSpace’s space transportation solutions

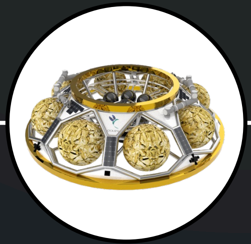
Reusable, eco-designed and dual-performance launcher

500kg SSO 500km (RLV) – 1500kg SSO 700km (ELV)

Regenerative in-orbit services

Last miles delivery, Debris Removal…

Prometheus engine



Colibri kick-stage

1st launch End 2025

To fulfill its targets and vision, MaiaSpace has set a sustainability strategy based on 4 axes

Managing our environmental performance	Sustainability since day 1	Estimation of our impacts	Ecodesign
Managing our vulnerability to global systemic risks	Climate resilience	Critical raw materials	
Contributing to sustainability through our activities	Develop IOS/ADR services	Launch satellites contributing to SDGs	
Contribute to wider space sustainability effort	Involvment in conferences and workshops	Disseminate methods and findings	Ethical communication

Today's focus: Managing our environmental performance

Lifecycle phases of MaiaSpace's launch service

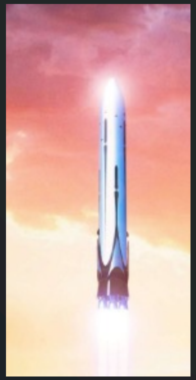
Research & Development

Manufacturing, Assembly, Integration and Test (MAIT)

Transport
Europe – French Guiana

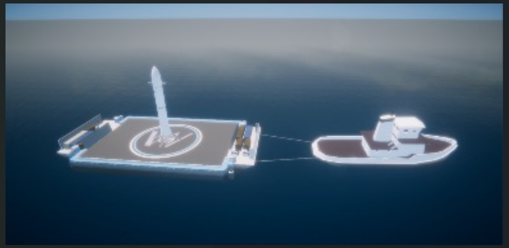
Launch Campaign

Propellant production



Launch Event

Recoverable launch vehicle (RLV)



Recovery & Refurbishment (of the lower stage)

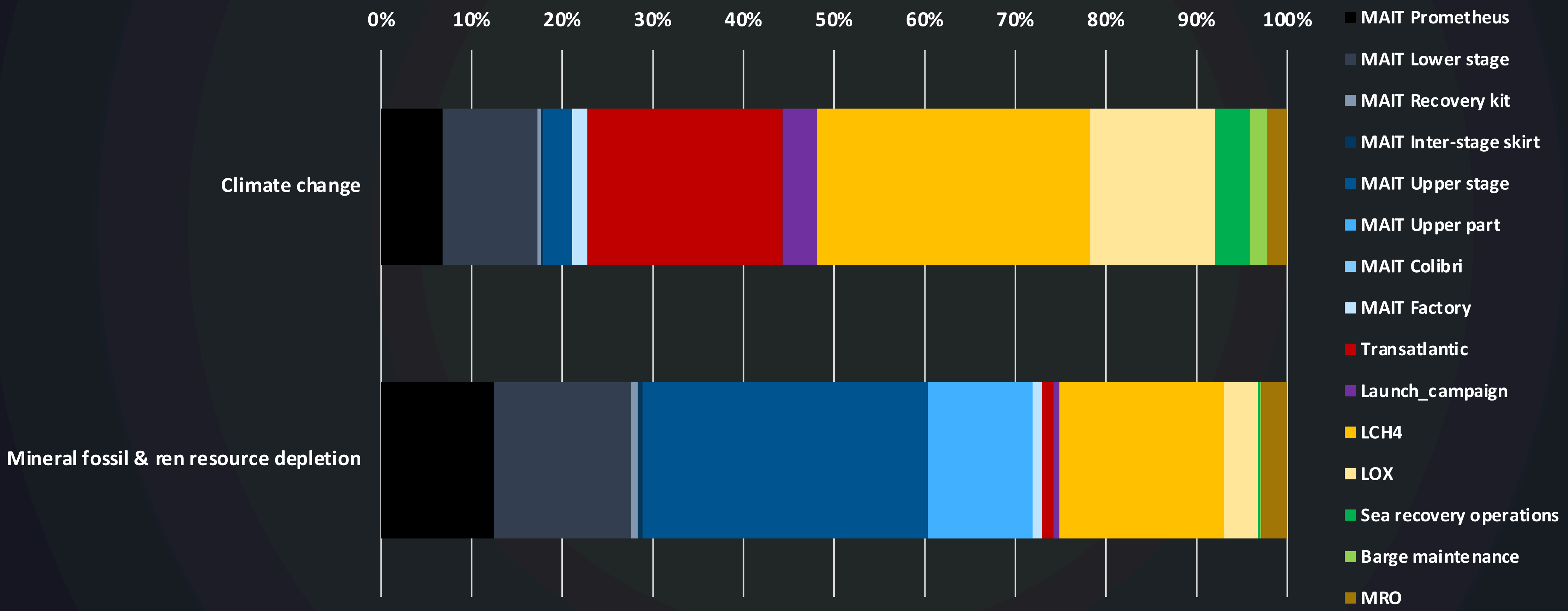
Disposal of the upper stage

Expendable launch vehicle (ELV)

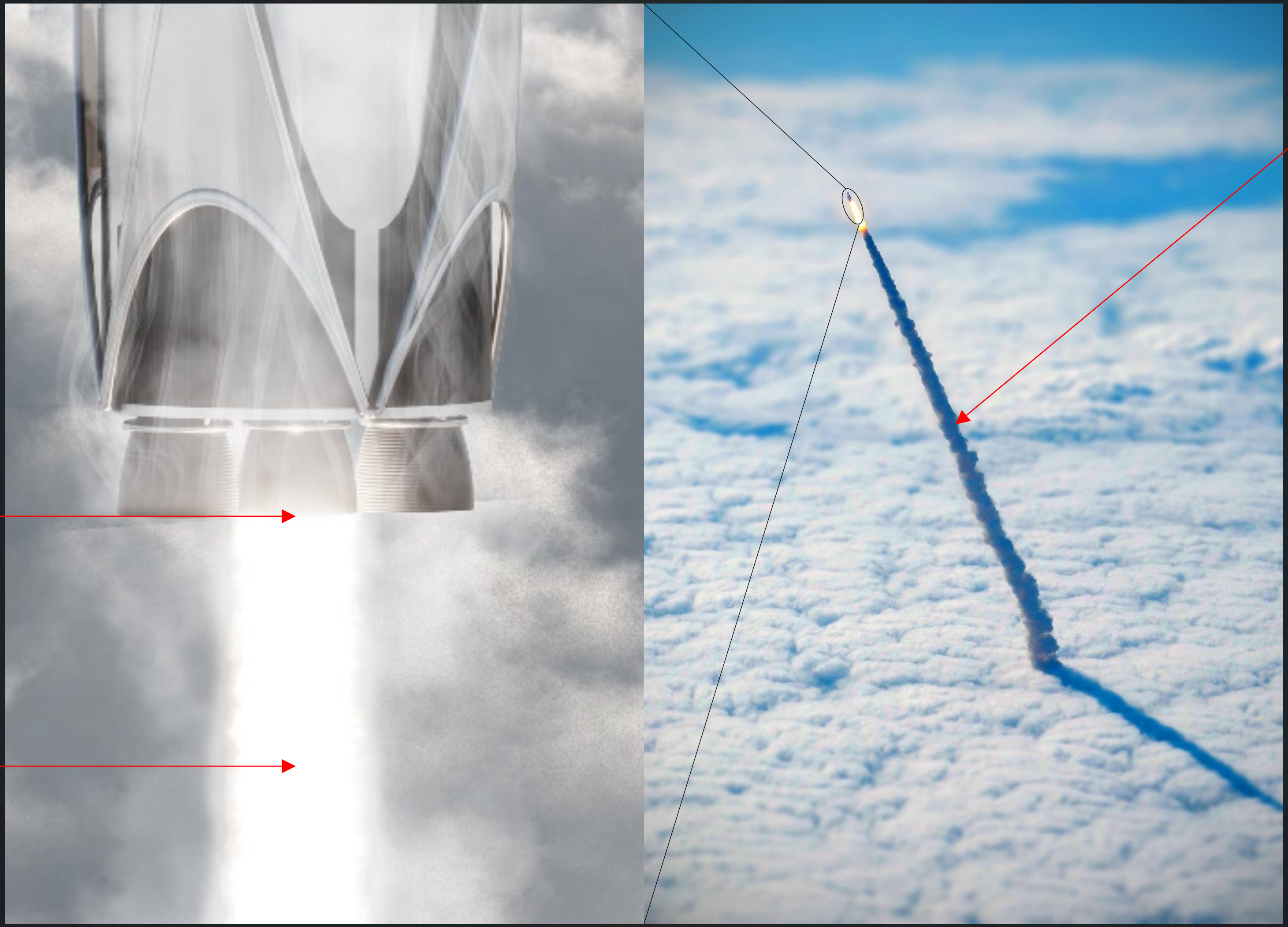
Disposal of all stages

Results over one year of operations

(at full operational capability)



Current knowledge gaps on the launch phase



Final emissions

Impacts on instantaneous radiative forcing, ozone destruction, atmospheric circulation,…

f(altitude, time of day, meteo,…)

Primary emissions

Plume/atmosphere interaction

f(altitude, time of day, meteo,…)

Long terms consequences on the troposphere translated in conventional metrics (GWP, ODP)

→ NO DATA

Necessity of comparing the impacts of launch VS the rest

Which one is best?

1

Standard material

Baseline atmospheric emissions

2

Heavier environmentally-friendly material

> or < ?

Increased atmospheric emissions

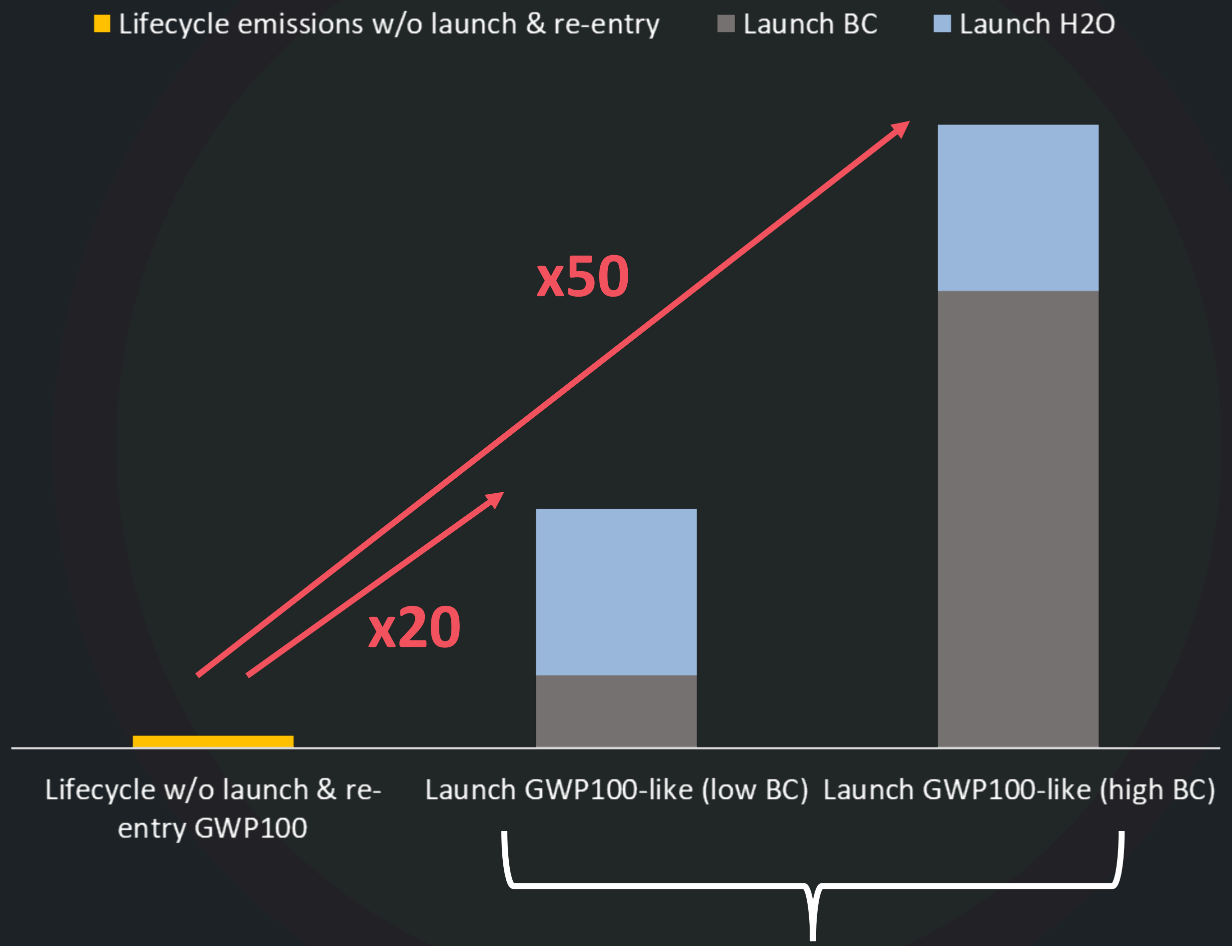
➔ **Ecodesign on the launcher is impossible without the answer**

Available Global Warming Potential (GWP) coefficients

Ground-based and aviation-based climate change characterization factors (GWP100)
as a function of altitude + filled with in-house methodology

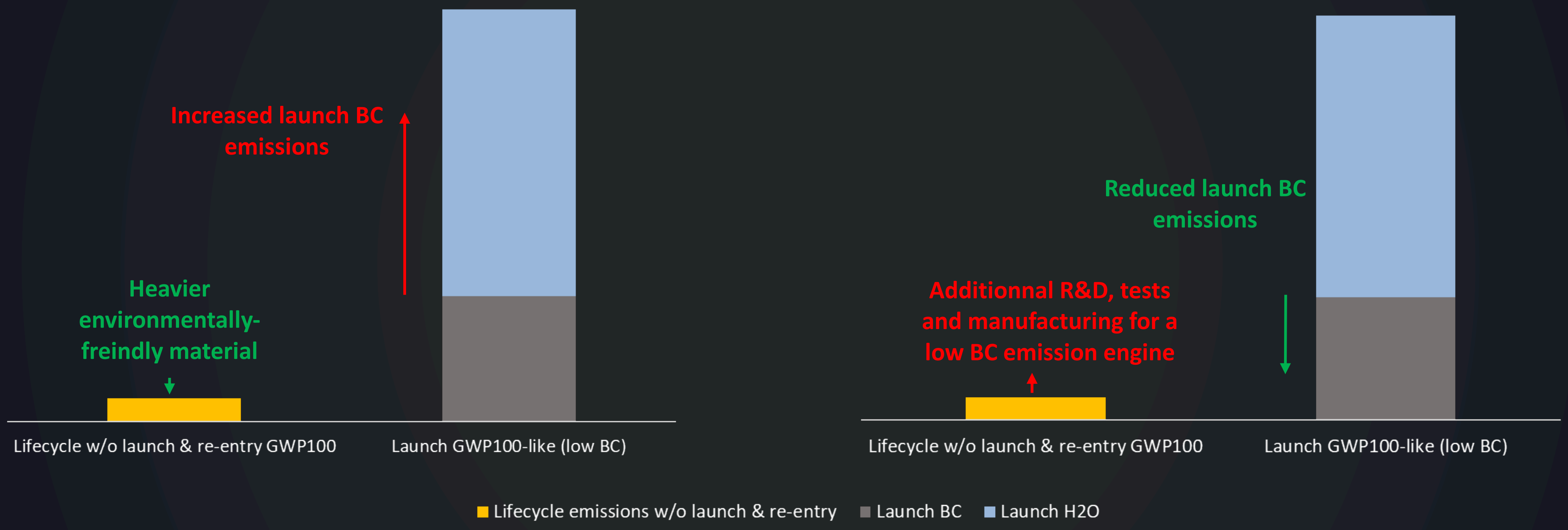
	Altitude (km)	BC	Al2O3	H2O	NOx
Lower troposphere	0-5	460	1.23	~0	8.5
Upper troposphere	5-15	1166	? -> 1.23	0.06	114
Stratosphere	15-50	310906	60156	854	? -> 114
Mesosphere	50-85	310906	60156	854	? -> 114
Space	>85	0	0	0	0

Lifecycle GWP100 is significantly smaller than launch GWP100-like



Methalox BC emission index uncertainty: 1-5g/kg (?)

Issues to manage a much larger effect and uncertainty



Precautionary principle: prevent the increase of atmospheric emissions?

Minimizing atmospheric emissions = N°1 mitigation strategy

→ **The case for performance optimization?**

Example: Colibri's structure trade-off

Methodology	Rankings	Order of magnitudes
		$\Delta CC_{41} = CC(4) - CC(1)$ Measures the "stake" of the tradeoff for CC

Direct impact only over 1 year

	CC	RD	Mass
A	4	4	3
B	3	3	1
C	2	2	2
D (fictitious)	1	1	4

$\Delta CC_{41} \approx 6\%\ of\ total\ MAIT/yr$

Impact including variation of launcher's performance

1kg gained in Colibri → 1kg gained on payload
No effect on filling rate

	CC	RD
A	3	[illegible]
B	2	2
C	1	1
D	4	4

Although D is much better initially, it performs worse due to higher mass

2kg of additional mass of D is enough to erase its CC benefits!

$\Delta CC_{41} \approx 100\%\ of\ total\ MAIT/yr$

Impact including variation of launcher's performance AND launch phase with high-altitude effects

	CC	RD
A	3	3
B	1	1
C	2	2
D	4	4

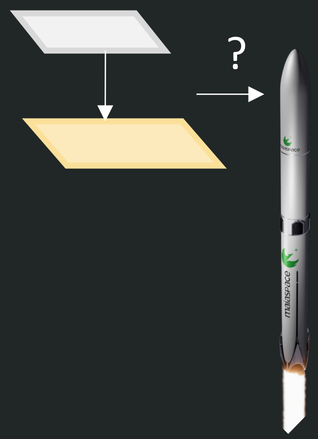
0.1kg of additional mass of D is enough to erase its CC benefits!

$\Delta CC_{41} \approx 4500\%\ of\ total\ MAIT/yr$

➔ **Ranking of atmospheric impacts ↔ ranking of mass**

MaiaSpace's methodology objective

Tackle 3 issues not currently addressed by existing methodologies



Management of reusability

Functional Unit

Parametrization

Impact allocation conventions

✓

Management of vehicle performance implications

Highlight multiplicity of possible consequences

Mass → performance laws

Conventions

✓

Effects of launch and re-entry

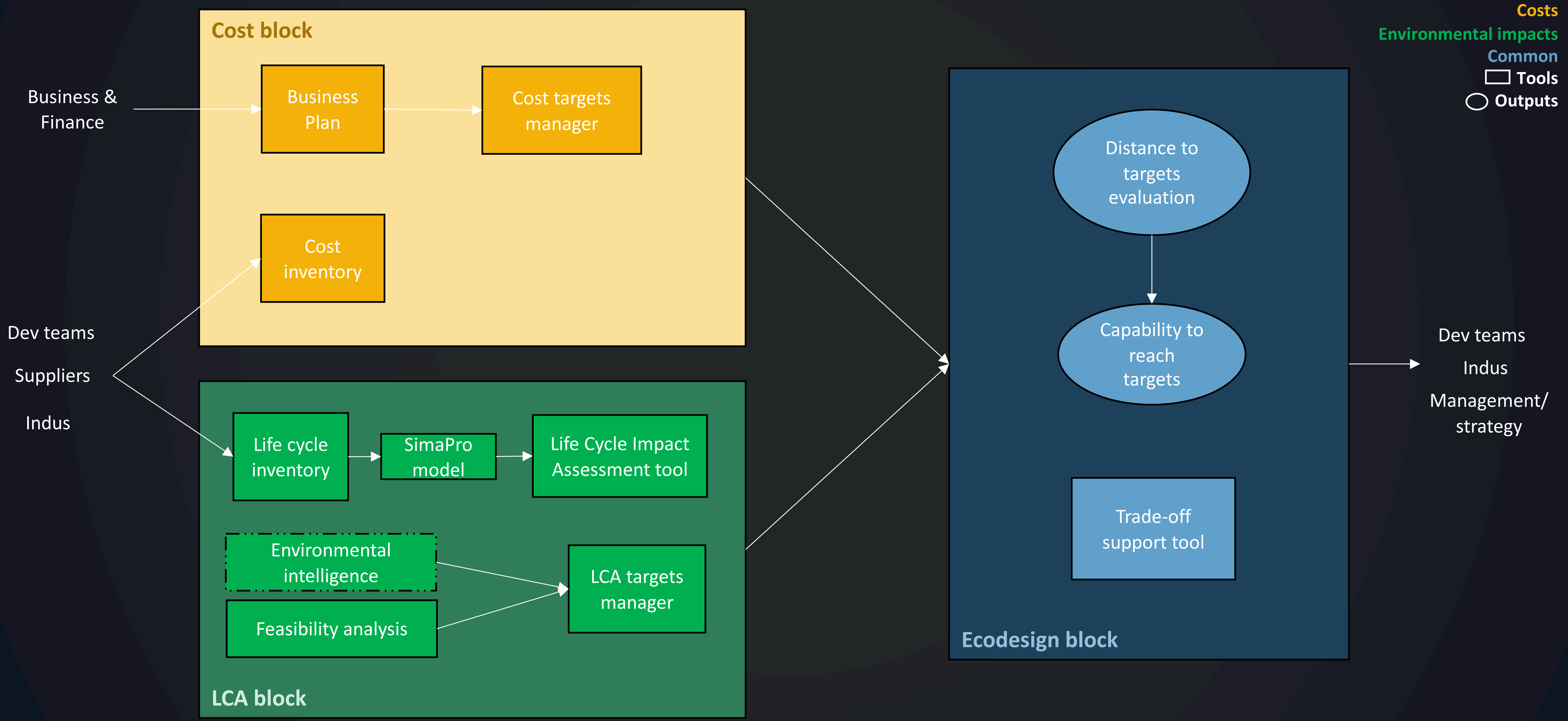
Approximative methodology proposal ✓

Critical reviews from atmospheric scientists ✓

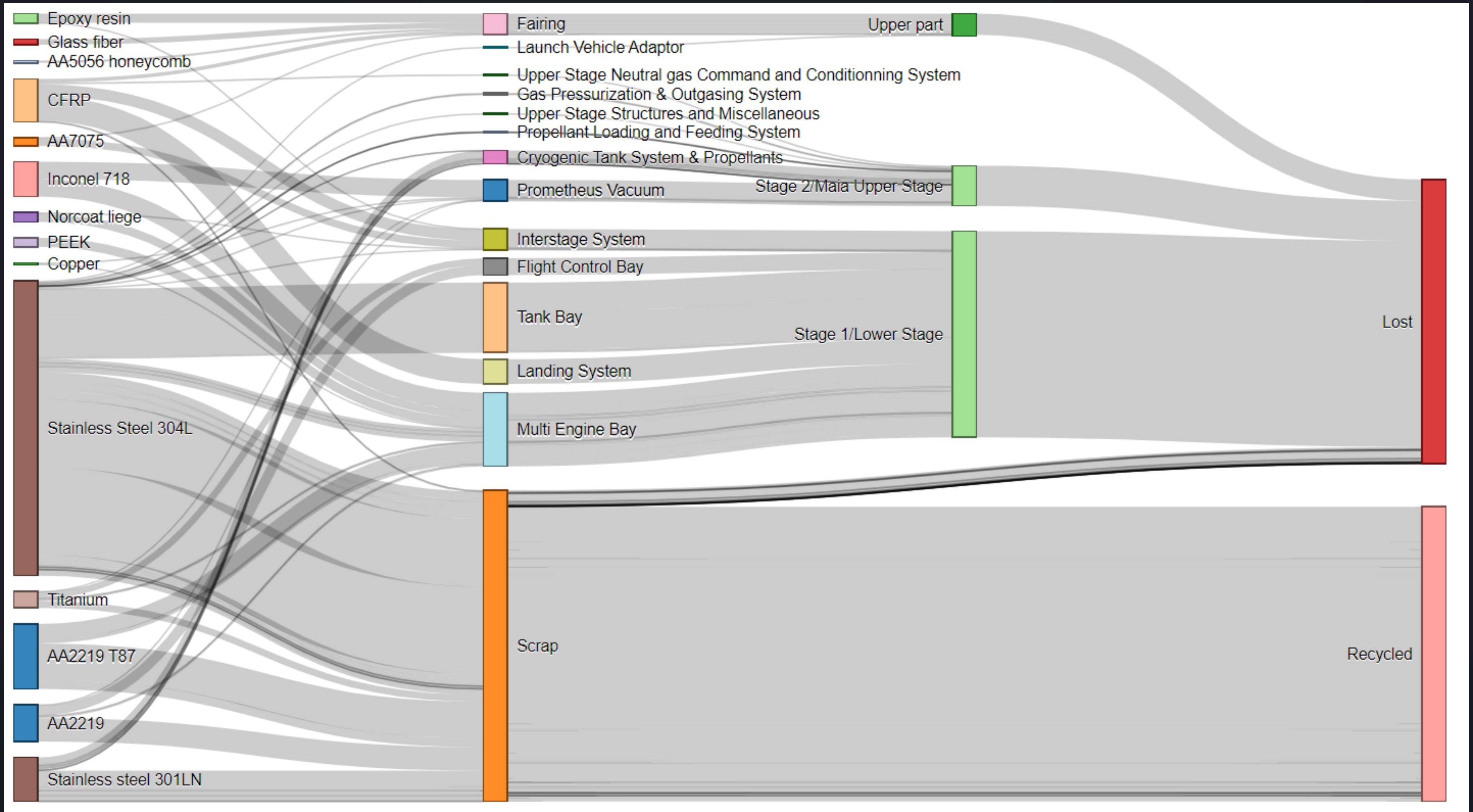
Co-funding of PhD

→ Provide a methodological brick to the standardization effort (ESA Handbook, EC PEF)

Ecodesign tools



Mapping material and energy fluxes: a 1st step for understanding vulnerability to systemic risks



Fictitious, illustrative purpose only

Key takeaways

MaiaSpace has made progress towards its sustainability objectives

- Methodological efforts conducted and disseminated
- LCA model updated
- First ecodesign cases (in addition to good early overarching design choices)
- Good feedback from potential customers and partners
- Many challenges must still be overcome

However, ecodesign on the launcher itself is currently not robust due to knowledge gaps on the launch phase

- Methodology to derive GWP100-like proposed
- Suggests that performance optimization reduces atmospheric impacts /kg payload
- PhD project initiated and co-funded on LOX/LCH4 emissions

“Sustainability” is not limited to LCA/ecodesign: first discussions on climate resilience and supply chain vulnerability initiated.

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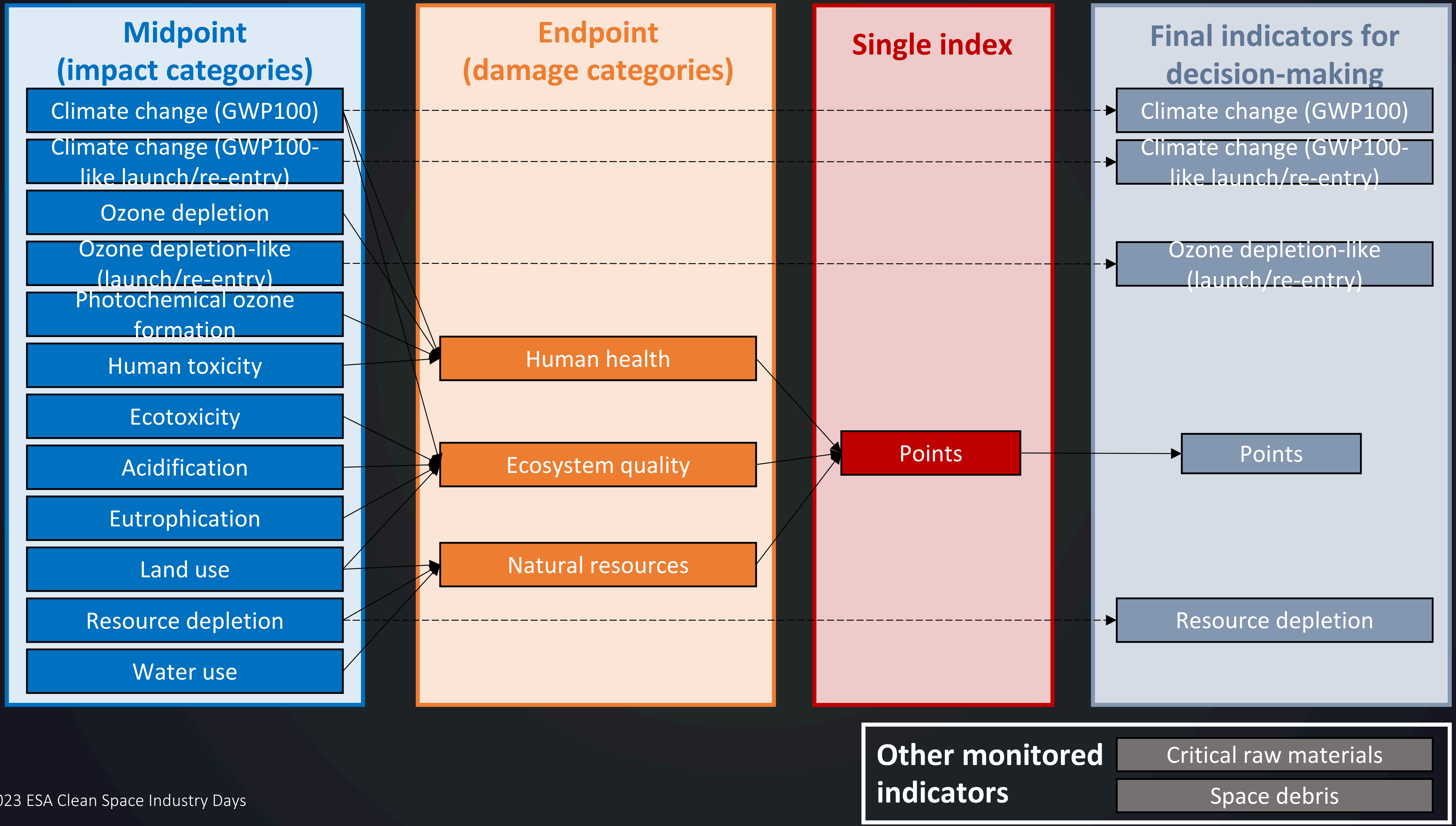
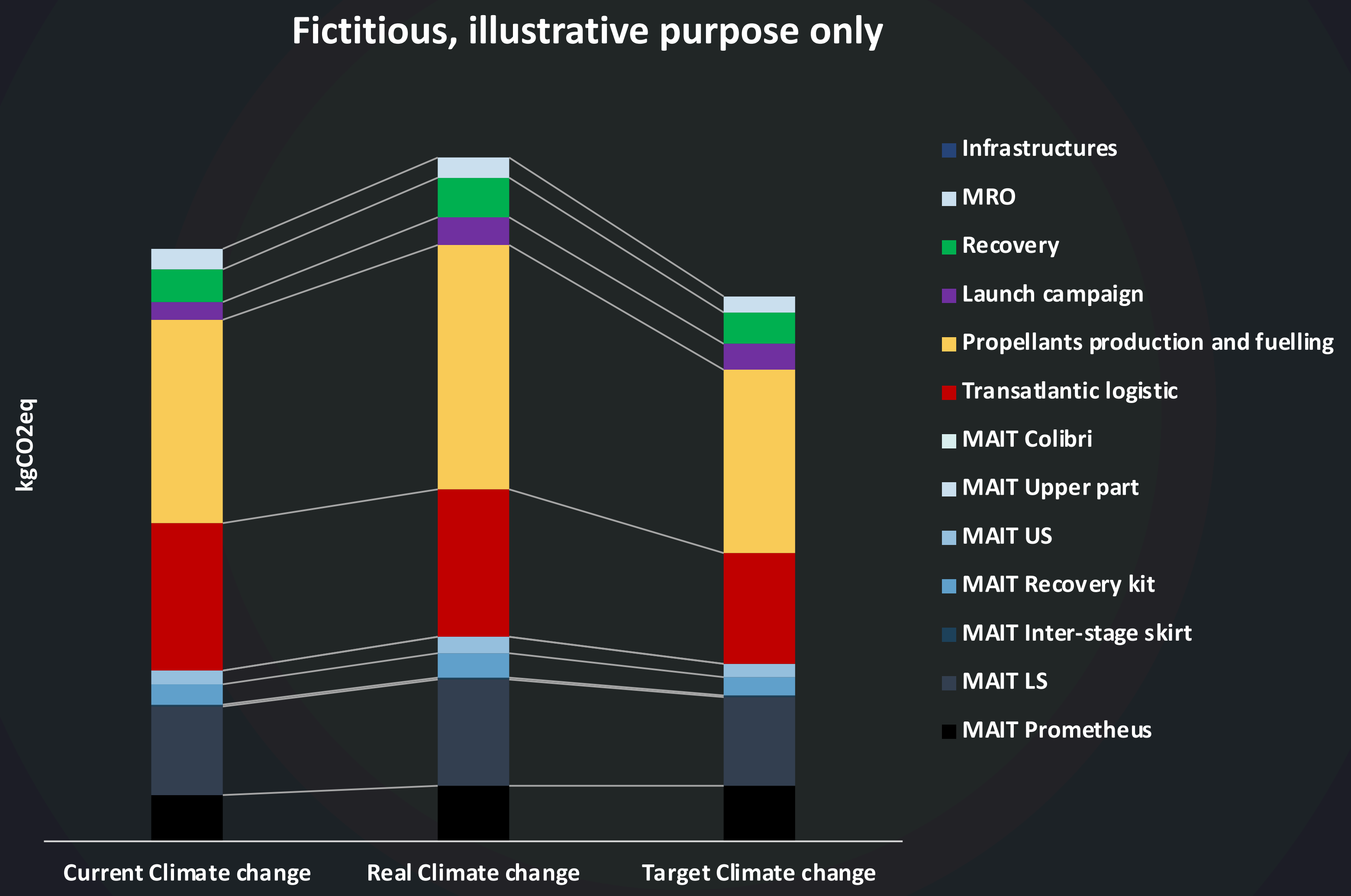
Backup

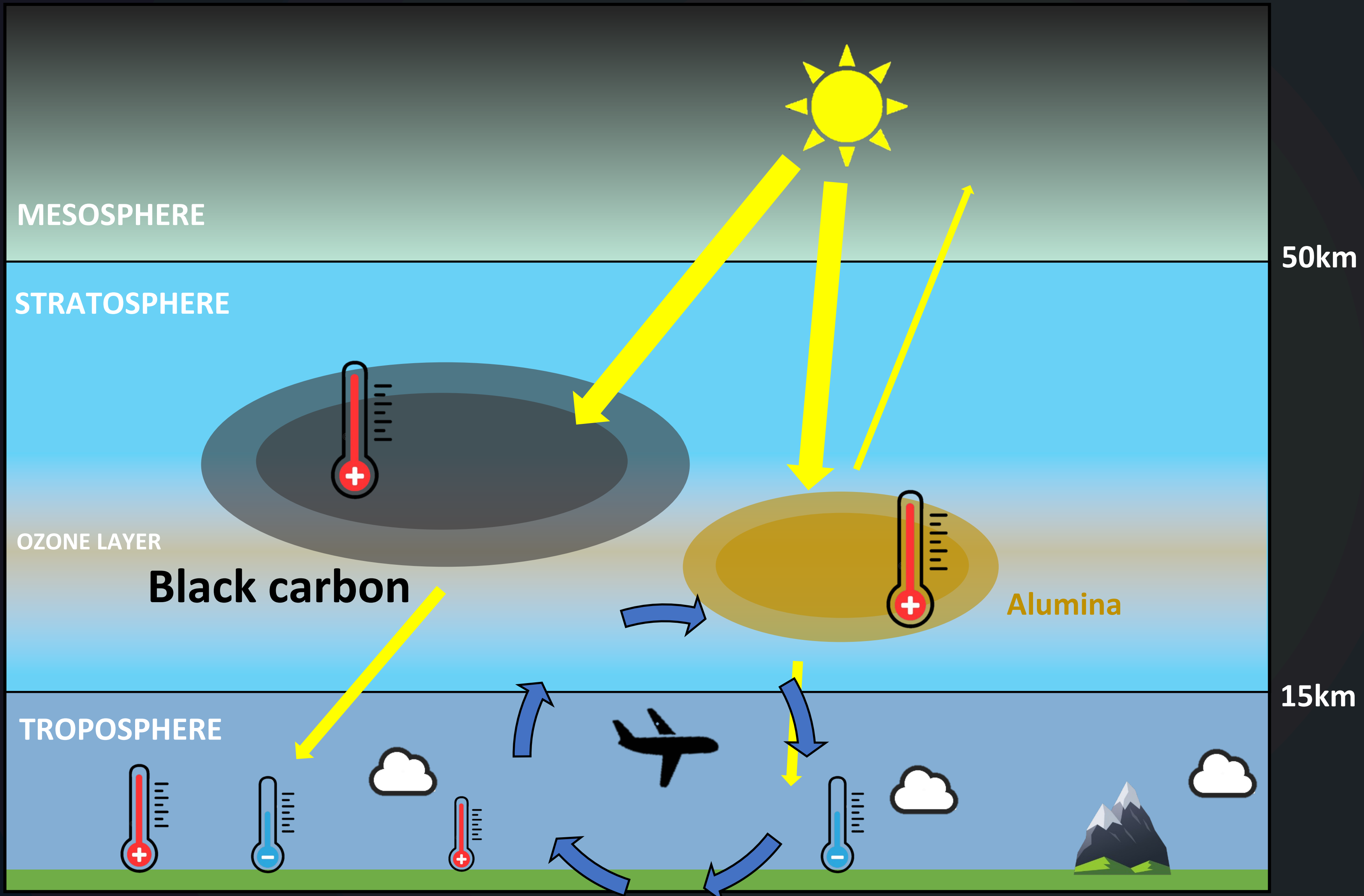
Environmental indicators



Target setting: based on feasibility analysis



The effect of particles



Atmospheric circulation change

Black carbon residence time:
Troposphere : a few days
Stratosphere : a few years

➔ Rocket BC 500x more efficient at warming than other sources of BC

Warming of the stratosphere

↓ ?

Complexes changes resulting in areas of warming and of cooling

Source: Miraux, 2021 adapted from Ross & Vedda, 2018

"GWP-like" calculation procedure for high-altitude effects

No indirect effects in GWP metric, expected to be significant ⚠

- Emissions profile available
- Computation of radiative efficiencies from literature $RF_i = A_i R_i$

Radiative efficiency Ai (mW/m2/t strato)

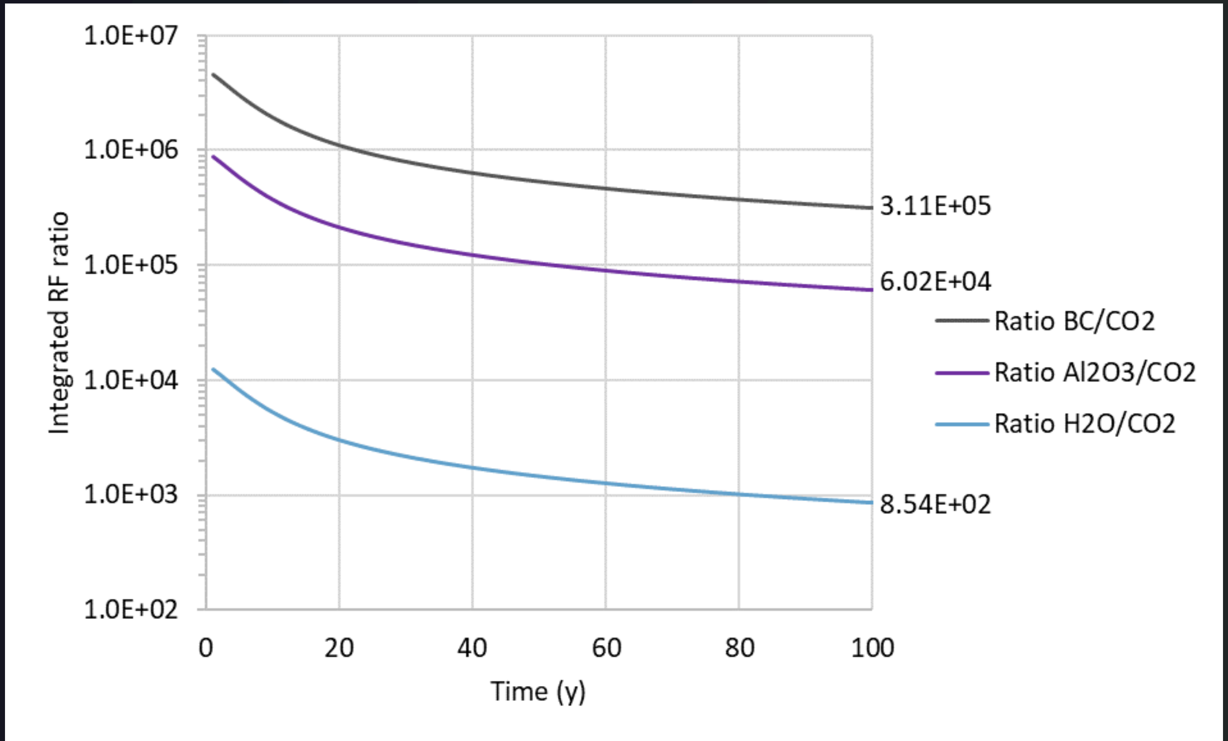
	Ryan et al.	Ross & Sheaffer	Selected value
BC	8.72E-03	2.74E-02	8.72E-03
Al2O3		1.69E-03	1.69E-03
H2O	-2.40E-05	4.29E-05	-2.40E-05

→ Based on instantaneous RF ⚠

- Assumption of exponential decay, with e-folding time from literature $R_i(t) = \exp\left(-\frac{t}{\tau_i}\right)$
- Calculation of absolute GWP at horizon H $AGWP_i(H) = \int_0^H RF_i(t)\,dt = A_i\tau\left(1-\exp\left(-\frac{H}{\tau}\right)\right)$
- Ratio with AGWP(CO2) at horizon H → Comparing relaxed tropospheric RF to instantaneous TOA ⚠

$$GWP_i(H) = \frac{AGWP_i(H)}{AGWP_{CO_2}(H)} = \frac{\int_0^H RF_i(t)\,dt}{\int_0^H RF_{CO_2}(t)\,dt}$$

"GWP-like" results for high-altitude effects



Climate change characterization factors (GWP100 and GWP100-like) as a function of altitude

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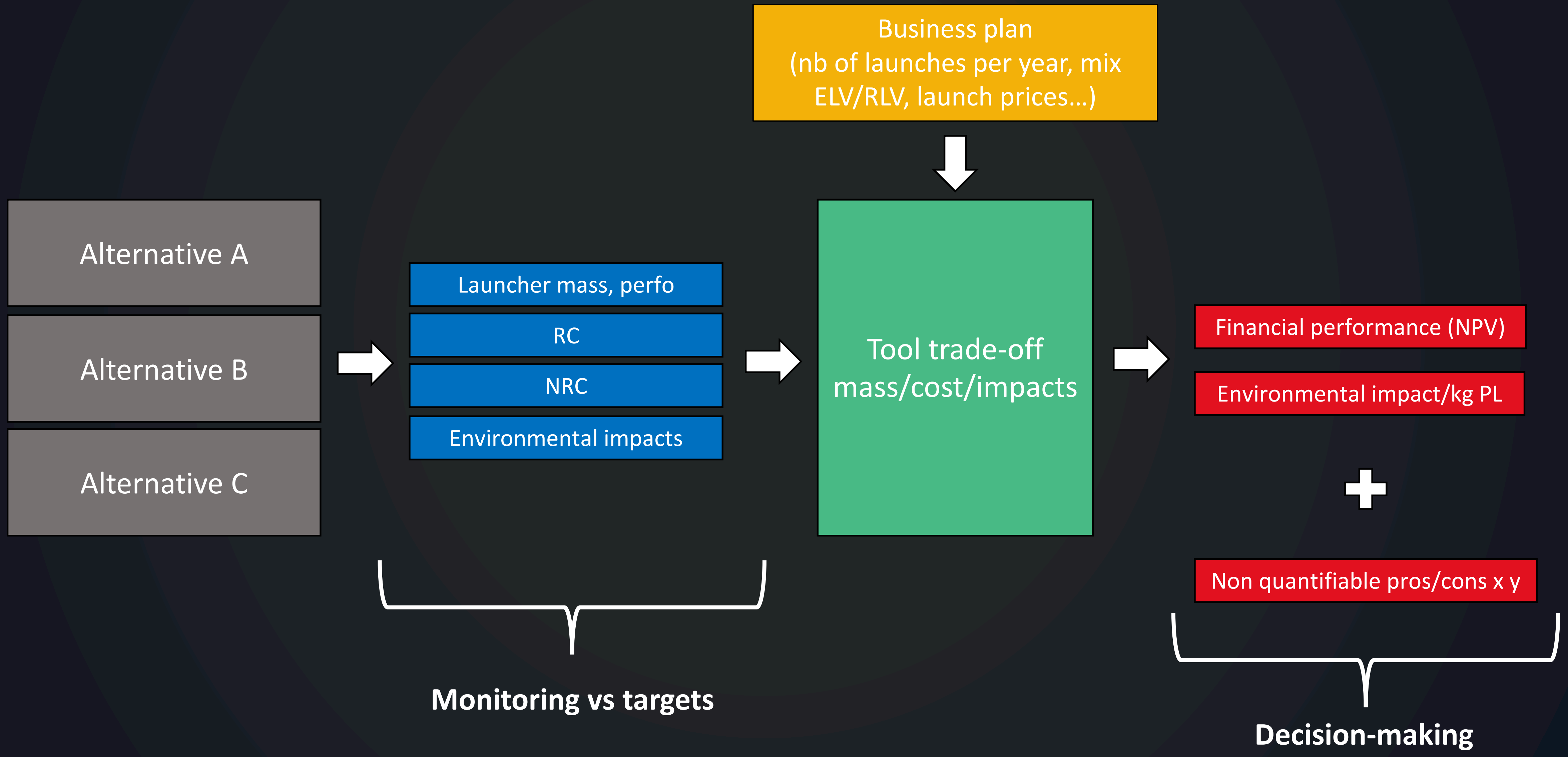
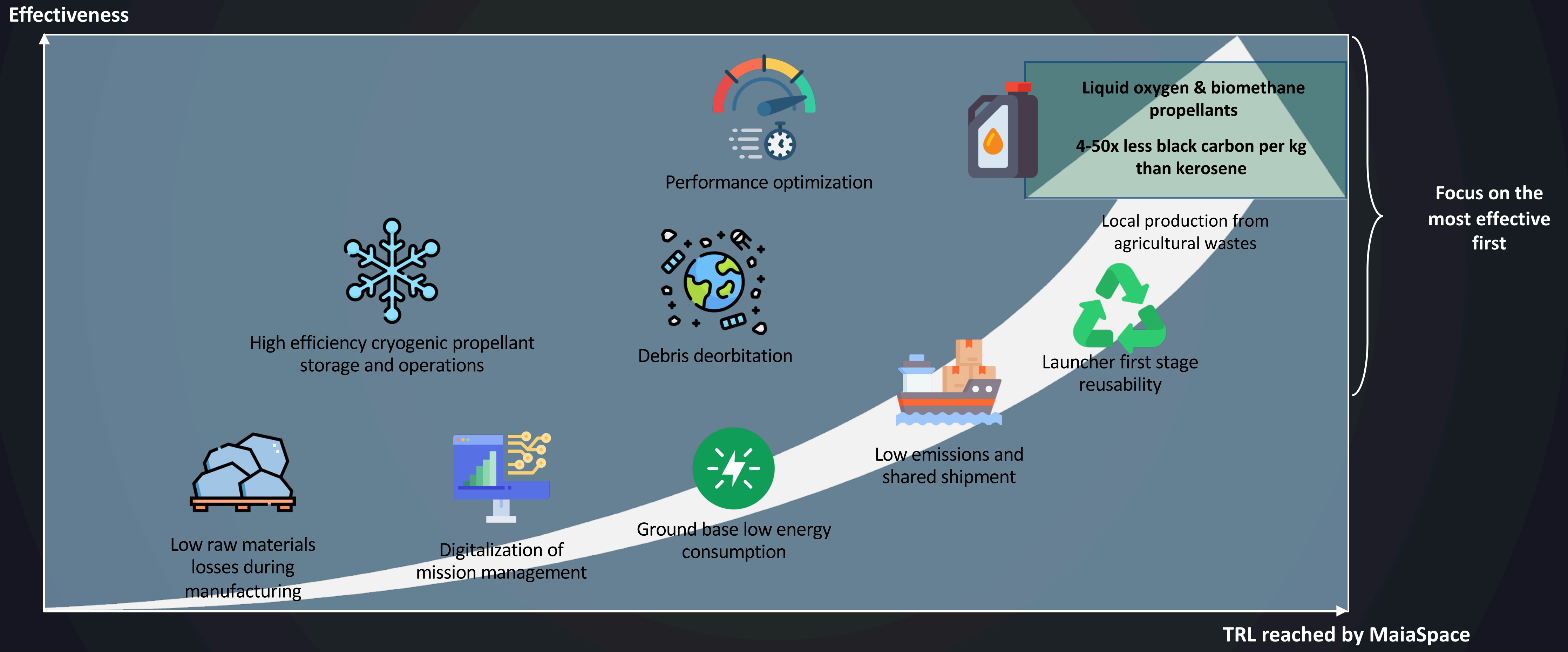
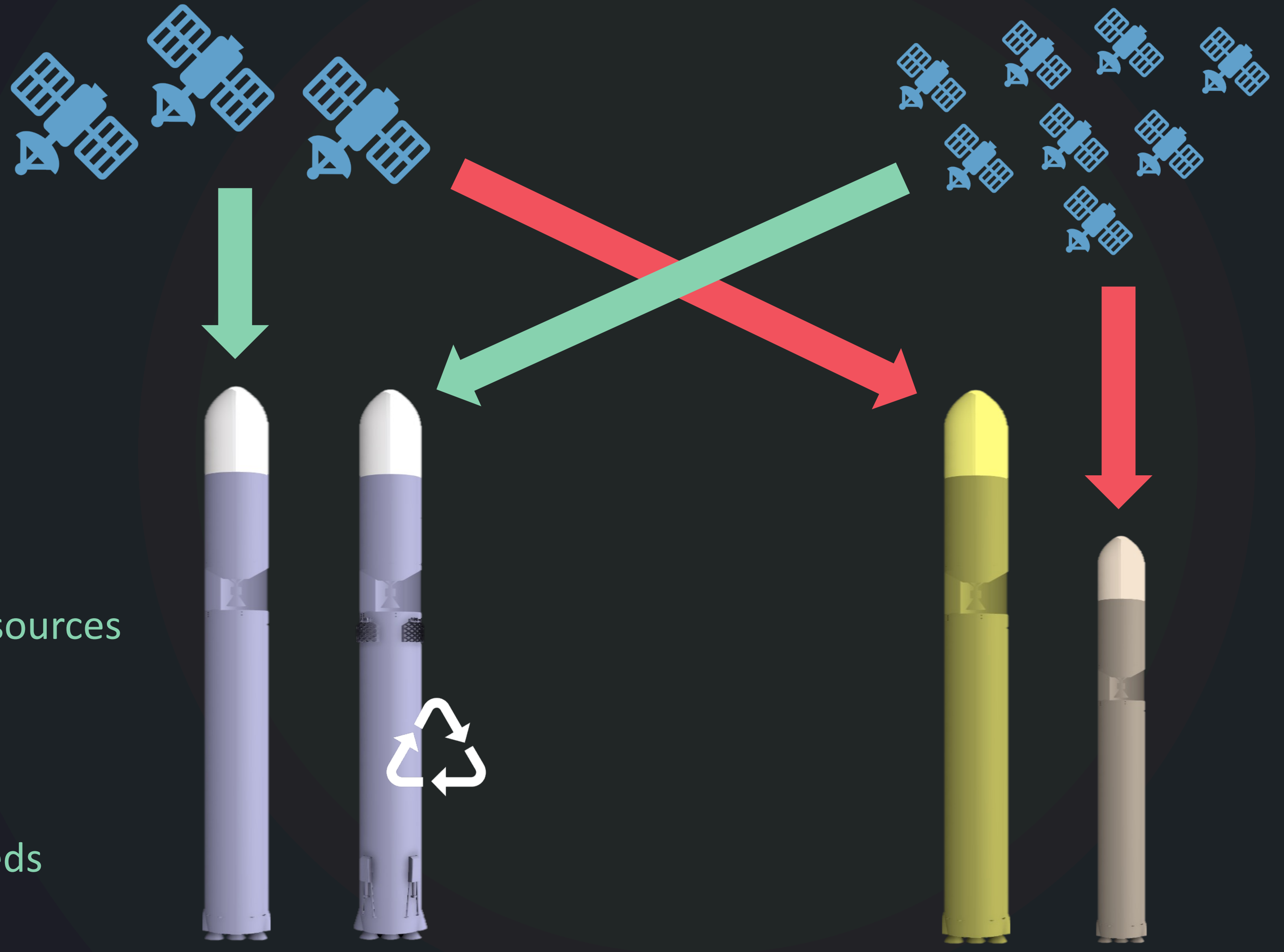
Trade-off mass/cost/environmental impacts



Eco-design levers implemented and planned by MaiaSpace



Comparaison service ELV/RLV VS full ELV



-10 à -25% sur les ressources
+0 à +5% sur le climat
A consolider !

Lower production needs
Common means

MaiaSpace's ELV/RLV mix

Two expendable launchers (same technology than MaiaSpace)

B Semi-reusable RLV vs expendable-only

Additional value brought by reusability not valued in FU

New hardware production avoided

+

Decreased transport requirements

Degraded payload capacity
➔ Larger launcher, more propellants

+

Recovery kit to produce

+

Crash probability at recovery

+

Recovery operations and refurbishment

+

Increased atmospheric emissions / ton of payload

\- +

Preliminary results on environmental criteria*
Worse on climate change (+5 to 20%)
Better on resource depletion (-5 to 30%)

*Semi-reusable RLV ecodesign levers not activated
Worst case scenario

Methodology for tradeoffs affecting vehicle performance