SCREENING LIFE CYCLE ASSESSMENT OF FAMILIES OF FUTURE REUSABLE LAUNCHERS FOR EARLY-STAGE ECODESIGN CONSIDERATIONS IN THE VOLARE PROJECT

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CleanSpace Days 2024

AGENDA

01 **1 PROJECT, 2 LCA TOOLS**

02 **DESIGN PROCESS WITH INTEGRATED LCA**

03 **LCA RESULTS, HOTSPOTS, AND GAPS**

04 **RECOMMENDATIONS**

01

1 PROJECT, 2 LCA TOOLS

CONTEXT

ESA elaborated a vision for the Future of Space Transportation in Europe by 2030+

VOLARE is one of four responses to a project built on this vision to consolidate a **future** European **family of reusable launch systems** and the associated set of **common building blocks** with specific attention to design to cost **and environmental sustainability**

Several topics have been identified to build the launcher family

- Market analysis
- Mission definition
- Preliminary design
- Consolidated preliminary design
- Technology maturation plans

Environmental analysis is done **throughout preliminary design and consolidated preliminary design**

LCA TOOLS

Assessment and Comparison Tool (ACT) – EPFL	SimaPro – ArianeGroup LCA team
-- Similarities --	

• Ecoinvent and ESA space-specific databases
• Similar inputs are used
• Same scope should be used
• Types of outputs
• Similar limitations:
    • Launch event and reentry impacts
    • Data availability (existing datasets in databases) → no time for data collection	

-- Complementarities --	
• Developed for ESA FLPP • Specific for future launch vehicles • Method to estimate atmospheric launch emissions • Space Debris Index • Integrates reusability option • Prospective databases propagating integrated assessment model (IAM) until 2050	• Made for LCA practitioners • More flexible modelling • Inventory freedom • Access to more impact indicators • Specific datasets from previous ArianeGroup studies

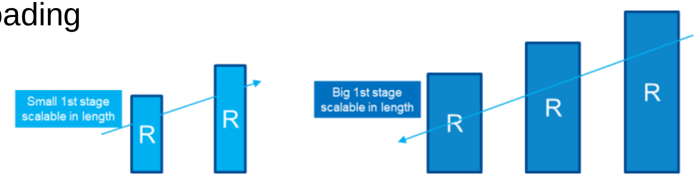
02

DESIGN PROCESS WITH INTEGRATED LCA

LAUNCH VEHICLES' FAMILIES

Each launcher of the family is made up of an association of different building blocks

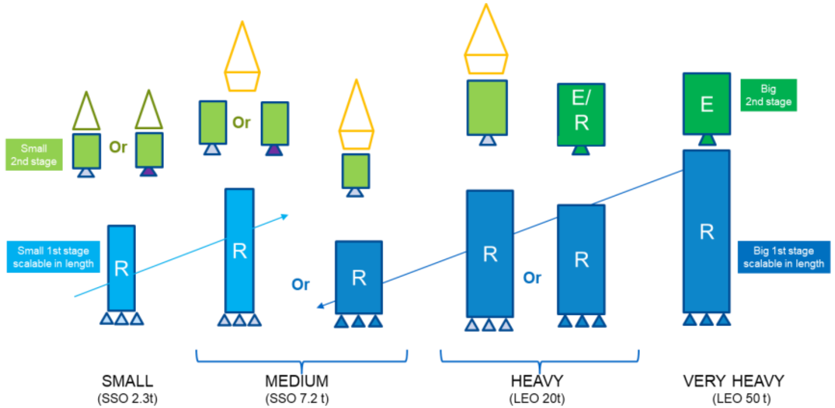
Lower stages: 2 types of tank scalable in length to cover the range of loading



Upper stages: 2 types are also considered to fit the lower stages diameters

Engines: Prometheus engines

Fairing: A set of 3 fairings is considered do deal the different diameters of the upper stages and of the payload

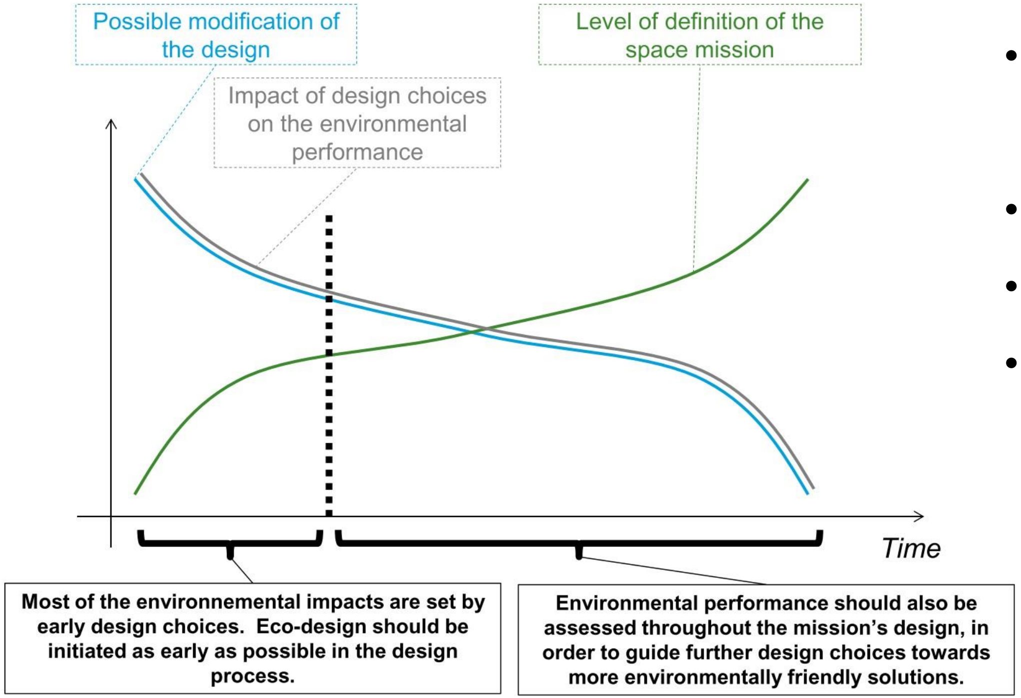


2 families distinguished by propulsion:

- a full methane family
- an hybrid family with H2 propulsion for the 2nd stage

LCA IN EARLY DESIGN

VOLARE = feasibility study (phase 0/A)

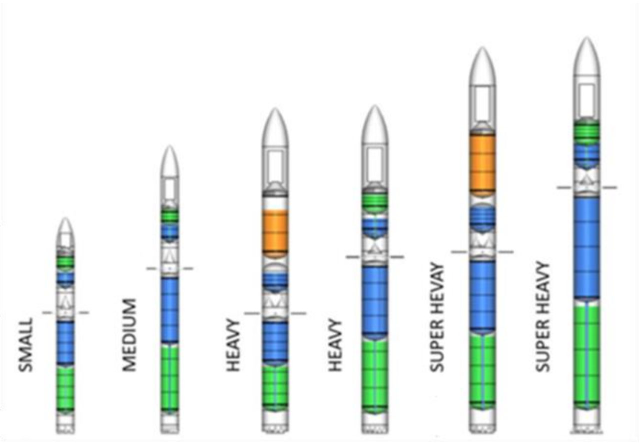


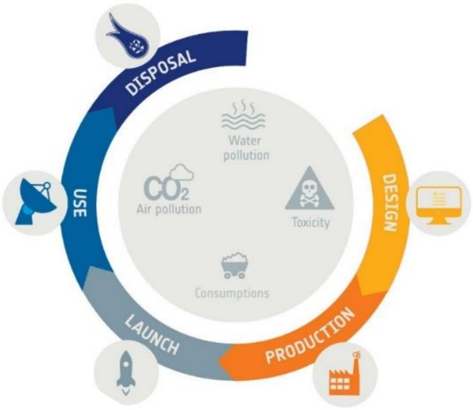
- Ecodesign needs to happen in early design phases
- But data availability is still low
- LCA is often used to support ecodesign
- Prospective data is useful (IAMs)

Augustin Chanoine et al. Integrating sustainability in the design of space activities: development of eco-design tools for space projects. Tech. rep. 145. 2015.

PLANNED ITERATION PROCESS

(Impacts
Ecodesign recommendations)





Up-to-date data (PBS)
ConOps
Technologies

03

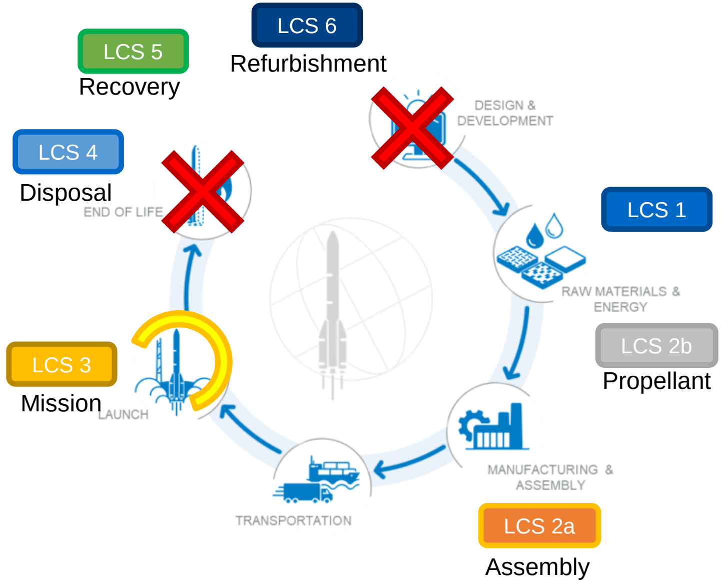
LCA RESULTS, HOTSPOTS, AND GAPS

LCA GOAL AND SCOPE

Goal: Compare two families of reusable launchers and compare equivalent systems with different propellants

Functional units (based on average market expectations): Sum(X_i kg of payload to orbit Y_i)

Boundaries



Launcher class	Avg. cadence (launch / per year)	Payload mass [kg] (to target orbit)
Small	15	2’300 (SSO)
Medium	9	7’200 (SSO)
Heavy	12	20’000 (LEO)
Super Heavy	1	60’000 (LEO)

→ 399’300 kg of payload total on different orbits

LIFE CYCLE INVENTORY (LCI)

Product Breakdown Structure (PBS) from design team

Confidential

HEAVY_v2_RLV		
UPPER PART		
	[redacted]	material
Payload	[redacted]	
Fairing	[redacted]	composite
total	[redacted]	
UPPER STAGE		
Primary structure (tank, skirt, MEB)	[redacted]	aluminum
ISS + LVA	[redacted]	composite
equipement fluids (lignes, vannes, platines...)	[redacted]	steel
engines	[redacted]	
Avionics	[redacted]	electronic
Re-entry system	[redacted]	steel/titanium
Fuel	[redacted]	lH2
Oxydizer	[redacted]	lox
Thermal insulation cold	[redacted]	
Thermal insulation hot	[redacted]	
dry mass	[redacted]	
total	[redacted]	
LOWER STAGE		
Primary structure (tank, skirt, MEB)	[redacted]	aluminum
ISS	[redacted]	composite
equipement fluids (lignes, vannes, platines...)	[redacted]	steel
engines	[redacted]	
Avionics	[redacted]	electronic
Re-entry system	[redacted]	steel/titanium
Fuel	[redacted]	lch4
Oxydizer	[redacted]	lox
Thermal insulation cold (tank + thermal shield) + pyrotechnic	[redacted]	
Thermal insulation hot	[redacted]	
dry mass	[redacted]	
total	[redacted]	

- Asked for more in-depth decomposition (e.g. for materials used in engines)
- Looked for associated processes
- Made additional assumptions
  - Refurbishment
  - Logistics (km, Europe / trans-Atlantic / recovery)
- Mapped to existing datasets

Iterative

LIFE CYCLE INVENTORY (LCI)

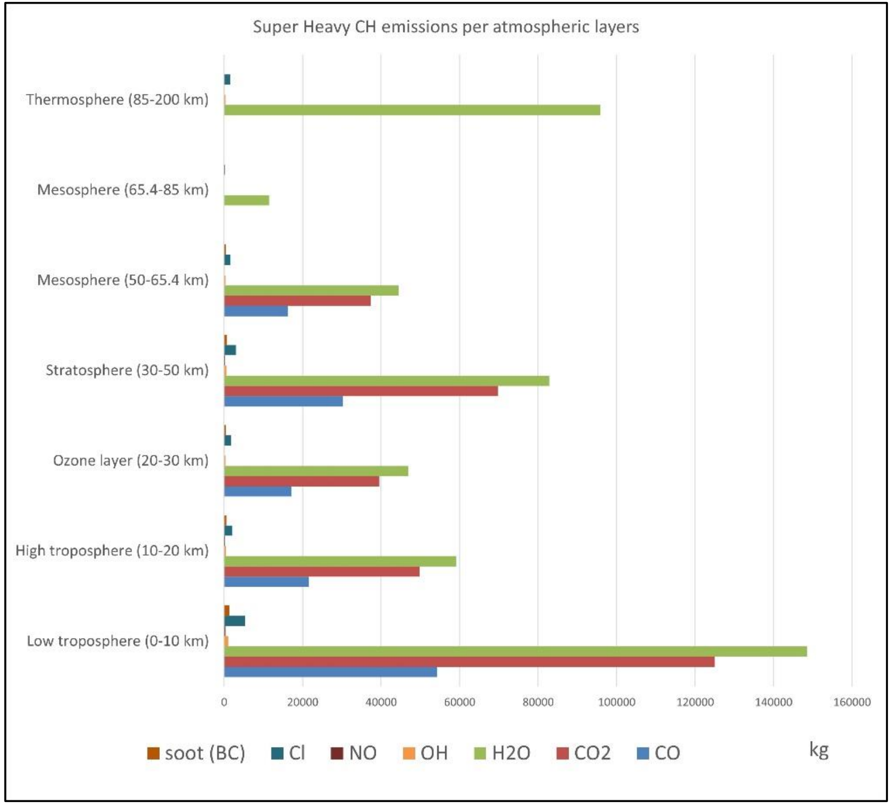
Launch emissions

Trajectory → propellant burnt in layers

	Layer	Lower bound altitude [km]	Upper bound altitude [km]	Propellant Type [-]	Propellant Consumption [kg]	Consumption Return Trajectory [kg]
1	Low troposphere	0	10	Methane	[redacted]	[redacted]
2	High troposphere	10	20	Methane	[redacted]	[redacted]
3	Ozone layer	20	30	Methane	[redacted]	[redacted]
4	Stratosphere	30	50	Methane	[redacted]	[redacted]
5	Mesosphere	50	85	Methane	[redacted]	[redacted]
6	Thermosphere	85	200	Methane	[redacted]	[redacted]

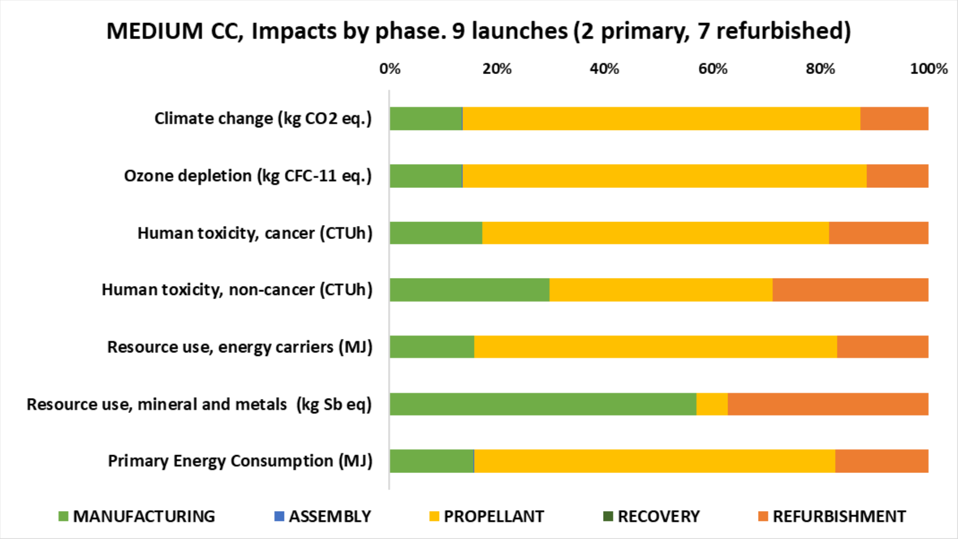
Confidential

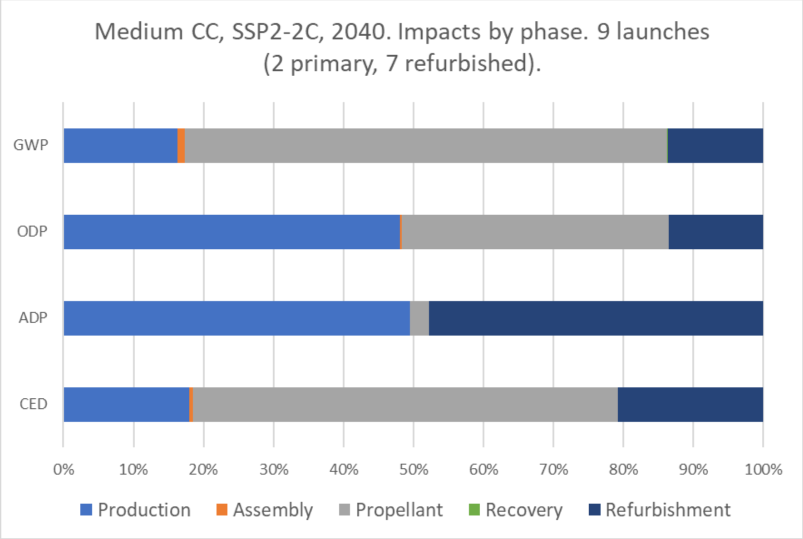
+ emissions factors (literature) → emissions



LCIA RESULTS AND INTERPRETATION

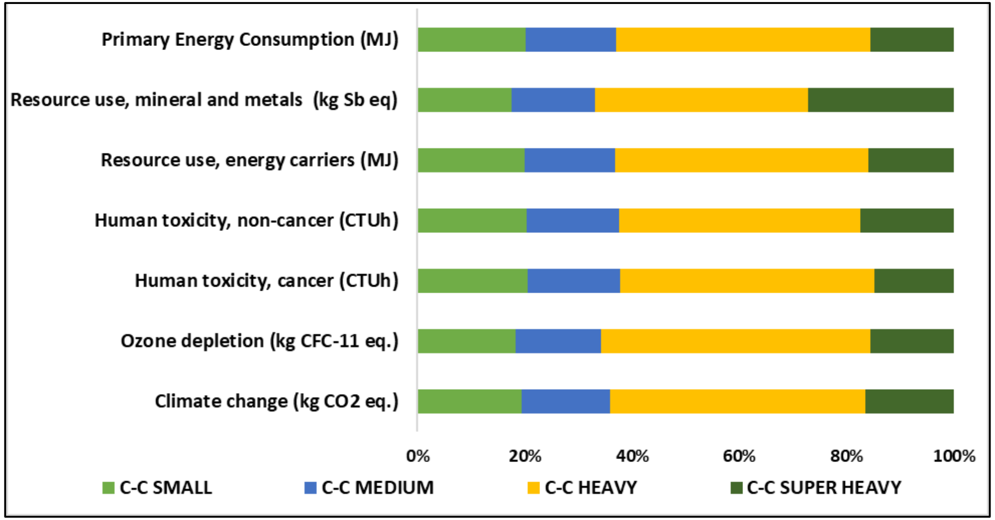
Single launcher (2 tools)

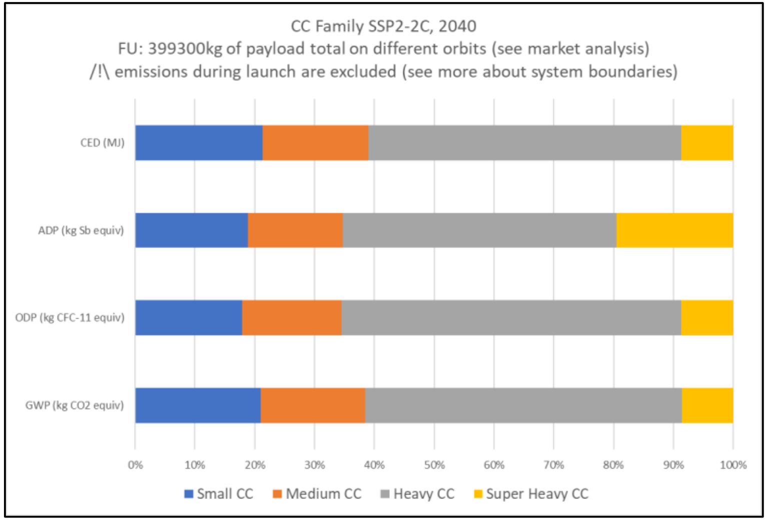




LCIA RESULTS AND INTERPRETATION

Families compared

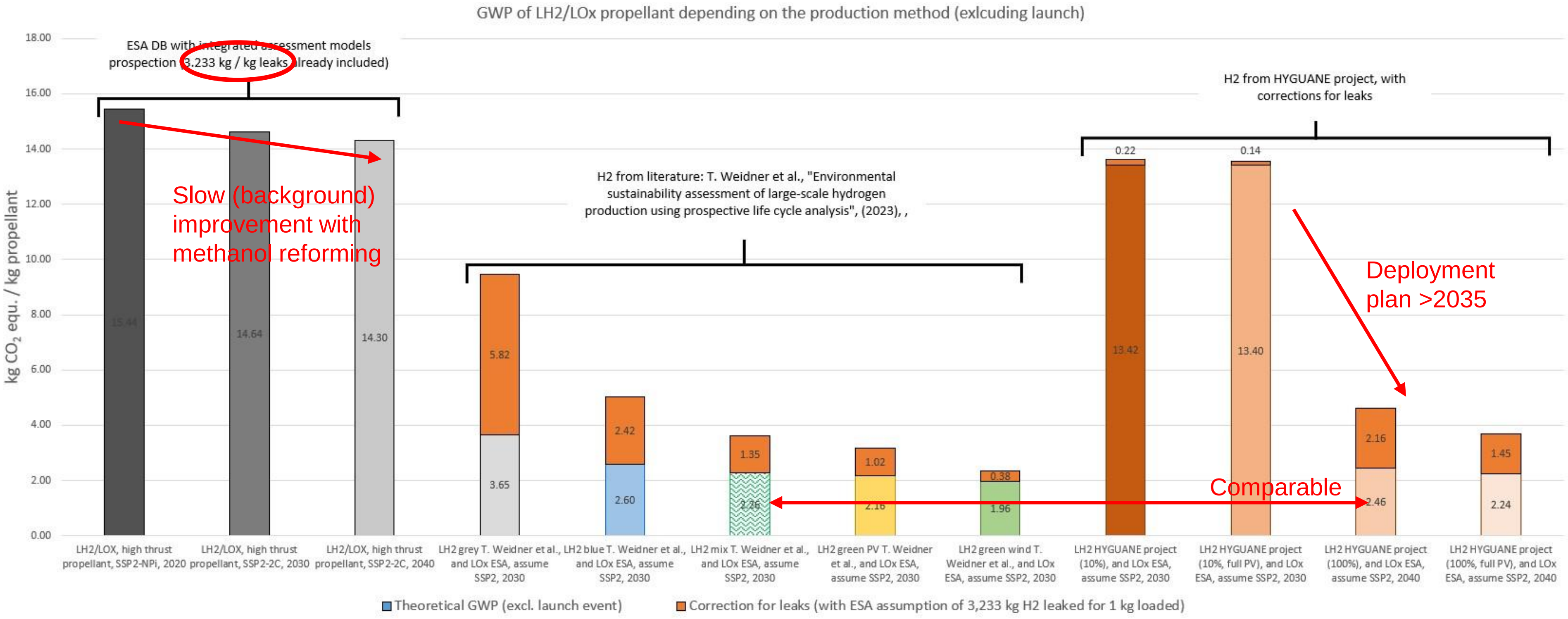




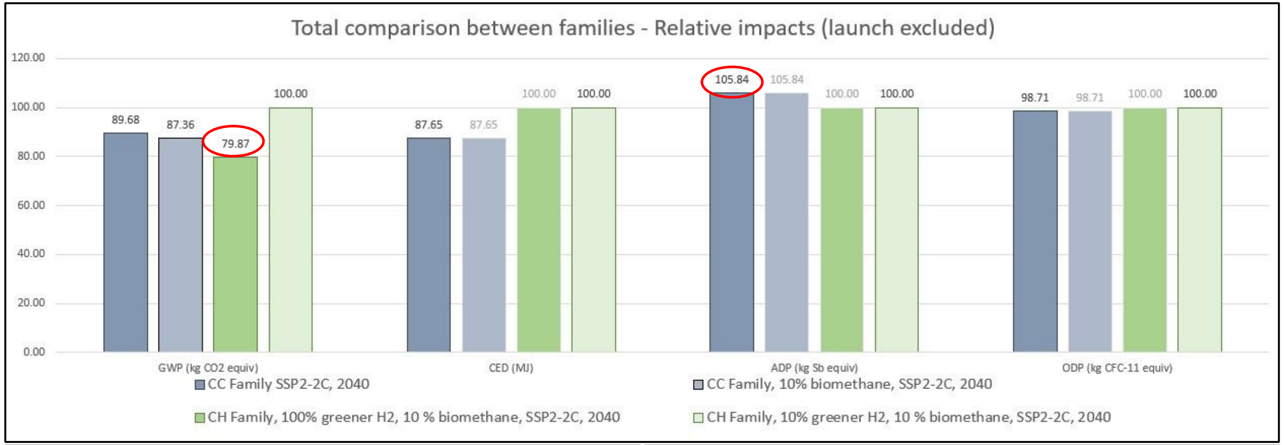
Launcher class	Small	Medium	Heavy	Super Heavy
Avg. cadence (launch / per year)	15	9	12	1

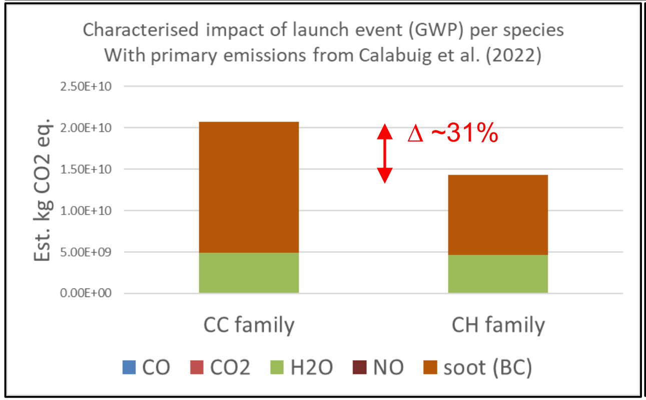
PROPELLANT PRODUCTION TECHNOLOGIES – H2

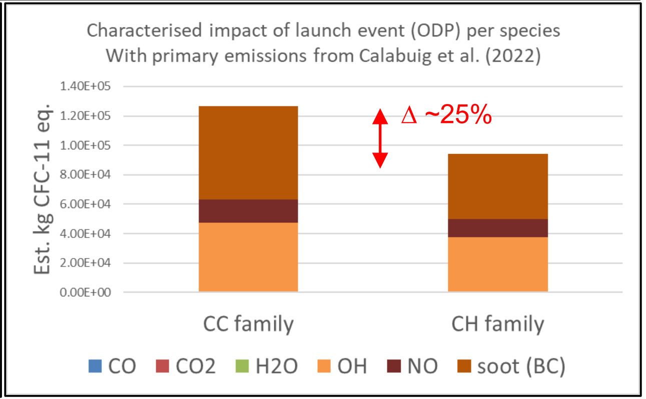
Prospection and model



INTERPRETATION







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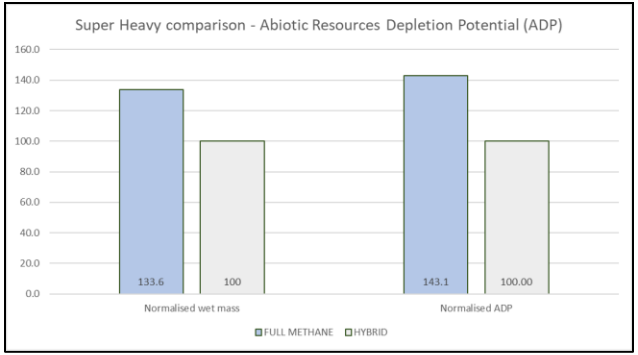
RECOMMENDATIONS

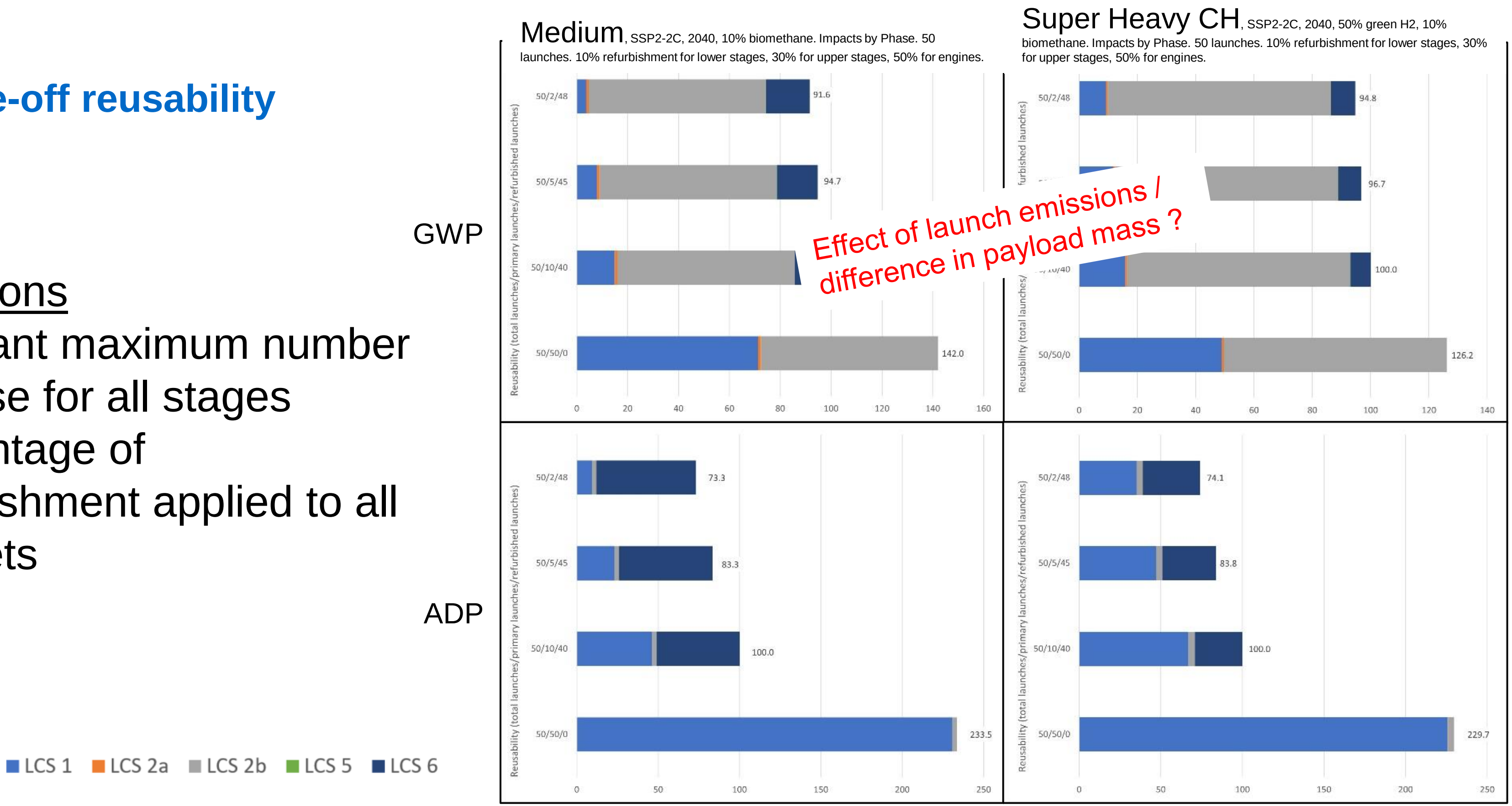
RECOMMENDATIONS ON THE DESIGN

- **Trade-off propellant: pointing towards hybrid**
- **Hydrogen production mix can shift the GWP results (excluding launch)**
- **Launch emissions with hybrid launchers seem less harmful (GWP, ODP)**
- **System “ripple” effect: Hybrid launchers are lighter → less propellant and less materials (ADP)**



RECOMMENDATIONS ON THE DESIGN

- **Trade-off reusability**



<u>Assumptions</u>

- Constant maximum number of reuse for all stages
- Percentage of refurbishment applied to all datasets

RECOMMENDATIONS ON THE PROCESS

LCA team should work more closely with the design teams and other members

- **To set hypotheses**
- **To improve the inventory**
- **To coordinate and influence the design iterations**

RECOMMENDATIONS ON THE LCA METHODOLOGY

Transverse topic maturation plan

- **Improve and standardize the (simplified) LCA methodology**

- **Populating the (space-specific) database(s) with more datasets**

- **Define and test new impact categories specific to space systems**

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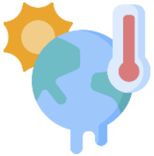
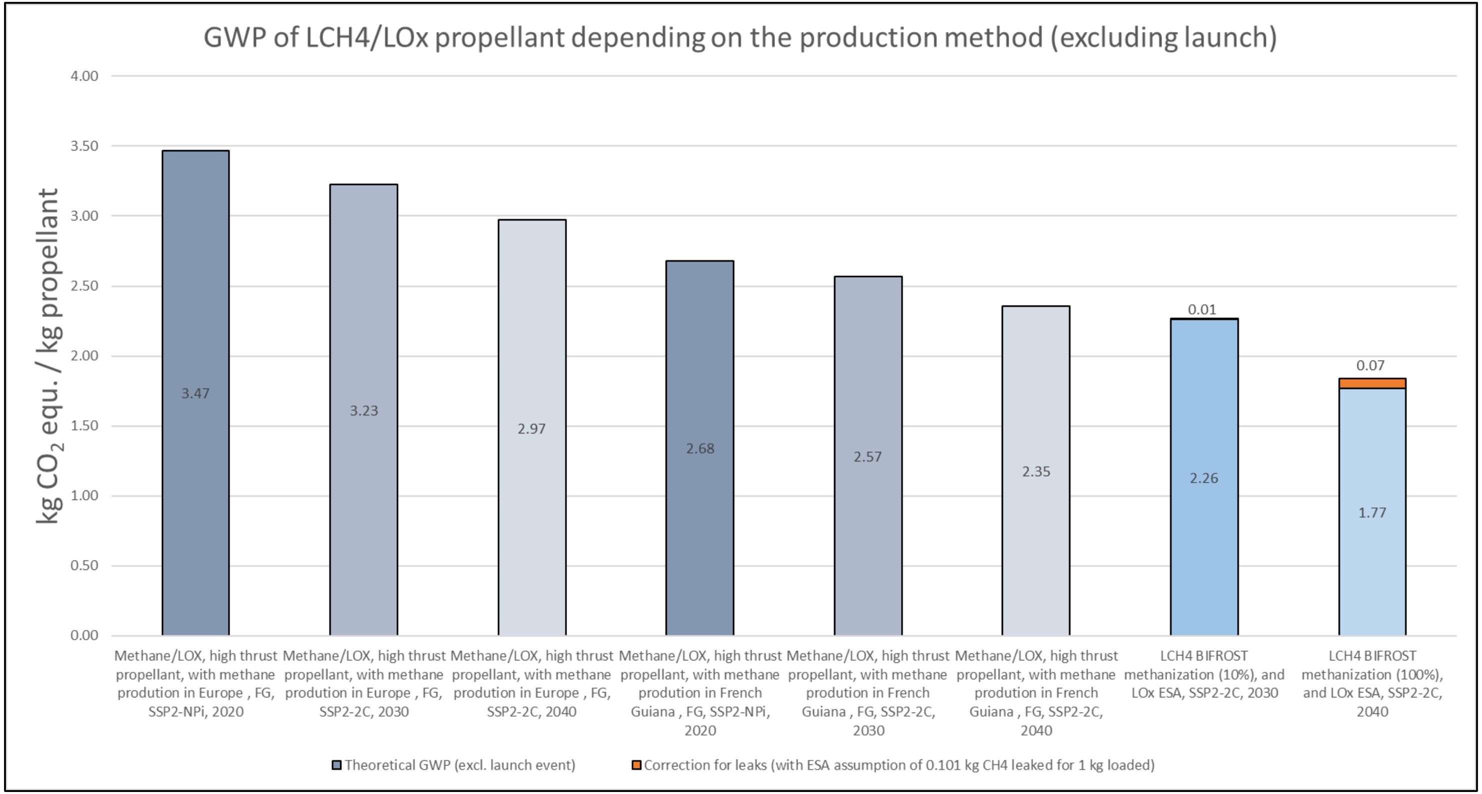
BACKUP SLIDES

ASSESSMENT INDICATORS

Environmental impact indicators	Unit	LCIA method
Global Warming Potential (GWP)	**kg CO_2 eq**	**IPCC 2013**
Metal Resources Depletion Potential	kg Fe eq	Recipe
Ozone Depletion Potential	**kg CFC-11 eq**	**WMO 2014**
Human toxicity, cancer	CTUh	USEtox model 2.1 (Frankte et al. 2017)
Human toxicity, non cancer	CTUh	USEtox model 2.1 (Frankte et al. 2017)
Abiotic resource depletion potential (fossil fuels)	MJ	CML 2002
Abiotic resource depletion potential (metal and mineral resources)	**kg Sb eq**	**CML 2002**
Primary Energy Consumption Potential (PRENE)	**MJ**	**ESA LCA 2016 (CED, Ecoinvent)**
Atmospheric launch emissions	kg in different layers	Newly developed, in ACT



PROPELLANT PRODUCTION TECHNOLOGIES – CH4



SCENARIOS – PROPELLANT PRODUCTION