



## 2022 Clean Space Industrial Days



# Life Cycle Assessment of eco-design options for printed circuit boards and electronic assembly

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ESA CONTRACT NO. 400013313/21/NL/AS

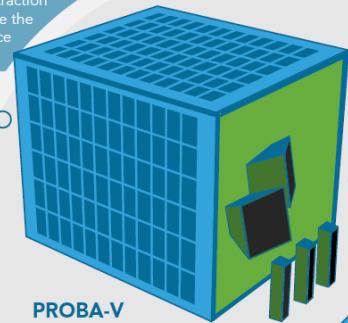
# (Space) electronics as environmental hotspot

From GreenSat to Green-eSpace

## THREE IMPACTFUL AND ECONOMICALLY FEASIBLE ECODESIGN STRATEGIES

### SUSTAINABLE GERMANIUM SUPPLY

Using recycled Germanium and having the material produced/extracted as a by-product of the zinc extraction for solar panels will reduce the impact on mineral resource depletion.



# greensat

### OPTIMIZATION OF ELECTRONICS

Reducing environmental impact of space electronics design and development by bringing space electronics closer to state-of-the-art technologies and industrial practice applied in other high-reliability electronics, while meeting the stringent requirement of operating in the harsh space environment.



More efficient on-ground data management by optimizing the use and 2nd life of the data-servers, more energy efficient cooling systems and state-of-the-art data storage equipment will reduce the environmental impact from energy consumption and critical raw materials.

### DATA PROCESSING IMPROVEMENTS

### ESTIMATED IMPACT

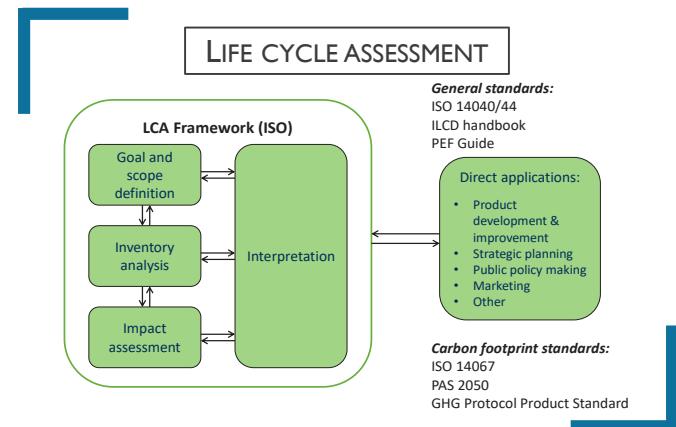
## Green-eSpace

Reducing environmental impact of space electronics design and development *by bringing space electronics closer to state-of-the-art technologies and industrial practice* applied in other high-reliability electronics, while meeting the stringent requirement of operating in the harsh space environment

# Green-eSpace project overview

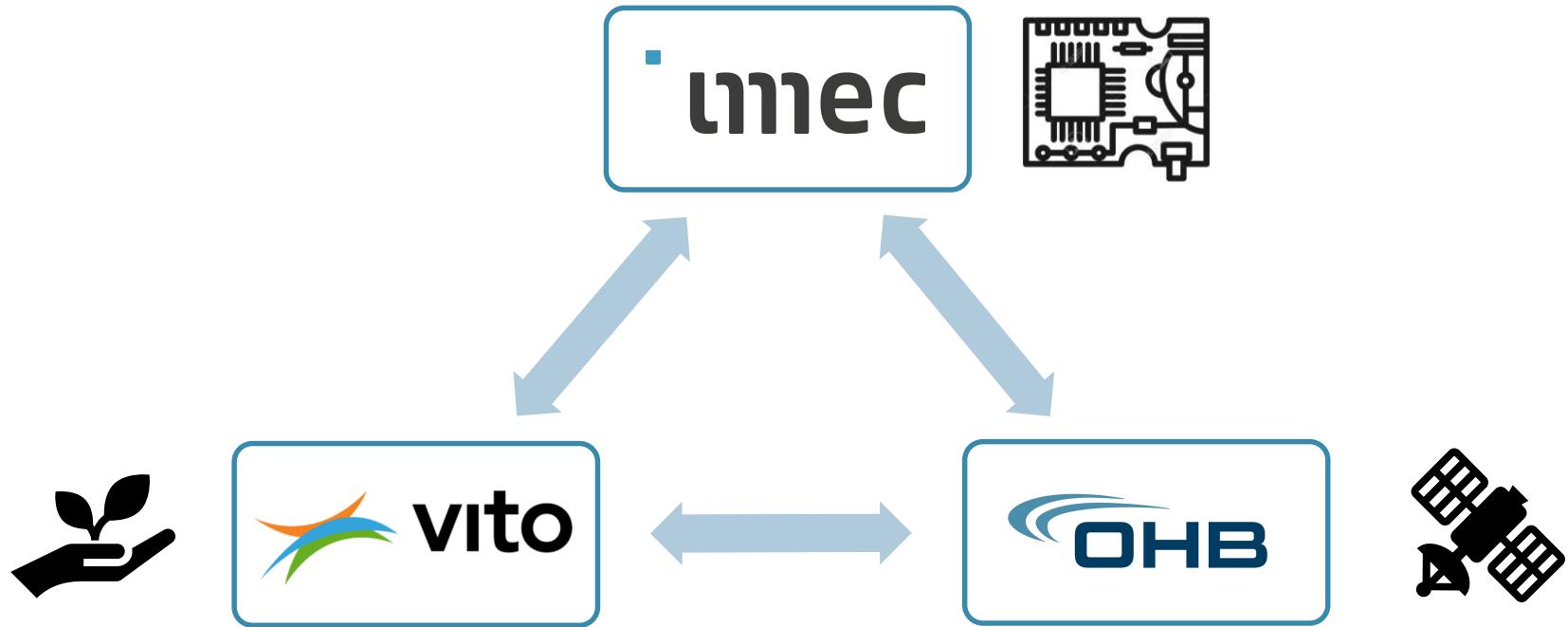
## Objectives

- To foster the adoption of **green electronics** applications,
  - To **improve the environmental impact** of space applications and
  - To **identify alternative** materials, processes for the manufacturing and testing of space electronic assemblies.
- 
- Initial TRL: 2 ⇒ Final TRL: 3



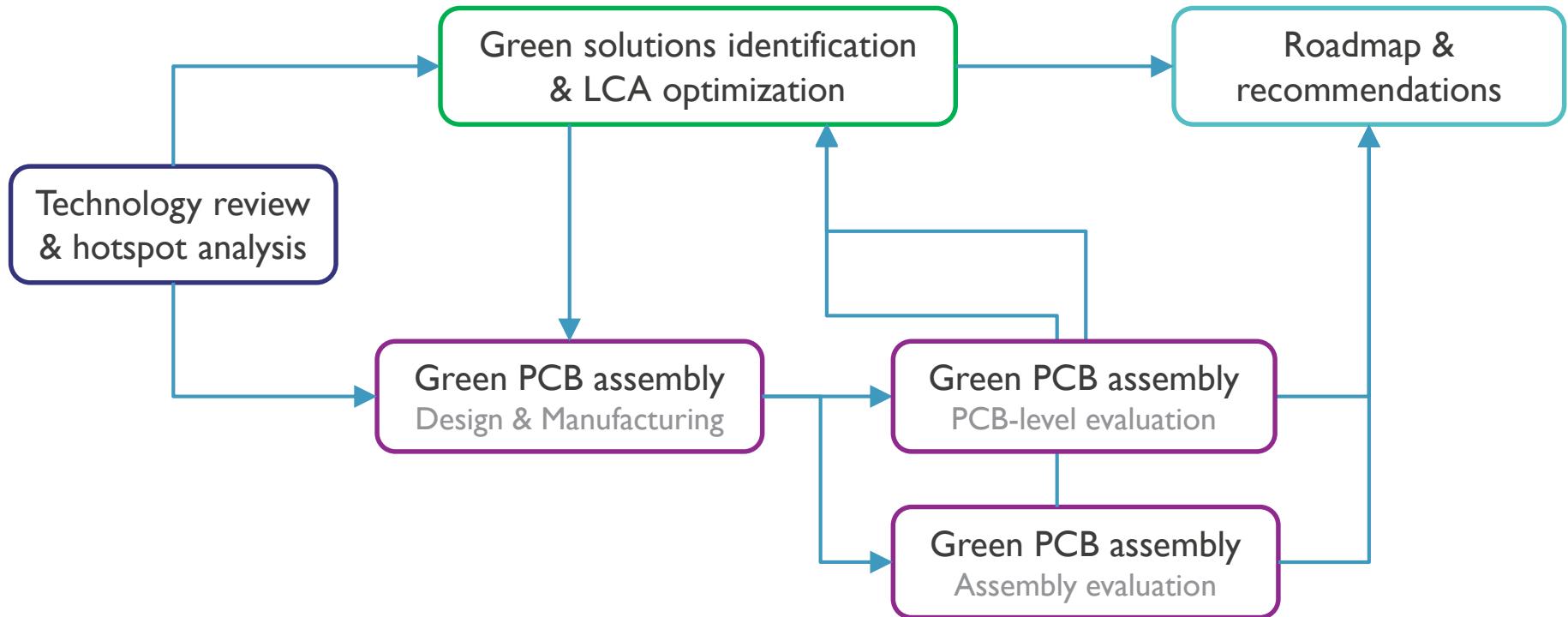
# Green-eSpace project overview

## Consortium



# Green-eSpace project overview

## Project concept



# Technology review and environmental LCA

## Mapping of space electronics



## Baseline LCA



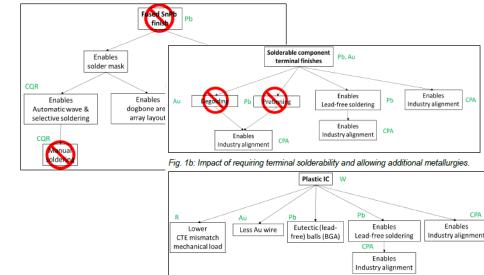
## Hotspot analysis

Impact category	Material	Component material X	Component material Y	Assembly process X	Assembly process Y	PCB technology X	PCB technology Y	Transportation	Wiring
Global warming									
Ozone depletion									
Human toxicity, non-cancer									
Human toxicity, cancer									
Resource depletion, fossil									
Resource depletion, minerals									
Photochemical ozone formation									
Particulate matter formation									
Freshwater eutrophication									
Marine eutrophication									
Land use									
Ionizing radiation									
Freshwater eutrophication									
Marine eutrophication									
Aridification									
Critical raw materials (kg)									
REACs emissions (kg)									
Primary energy consumption									
Water consumption									

## Literature

## Workshop

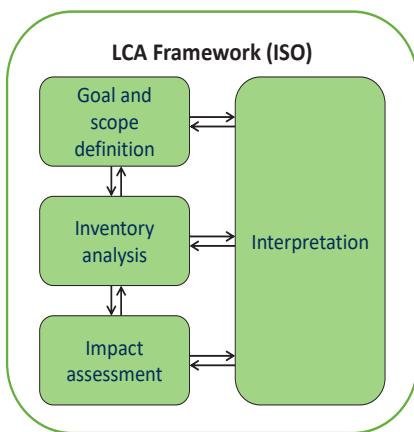
## Eco-design options



## Trade-off selection

# Baseline LCA for current space electronics

## Reference PBA – OHB µRTU Core Module



### **General standards:**

ISO 14040/44  
ILCD handbook  
PEF Guide

### **Direct applications:**

- Product development & improvement
- Strategic planning
- Public policy making
- Marketing
- Other

### **Carbon footprint standards:**

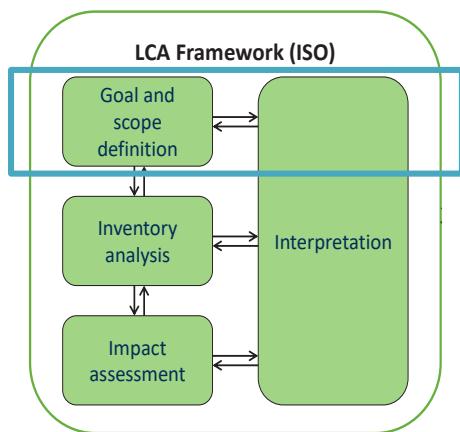
ISO 14067  
PAS 2050  
GHG Protocol Product Standard



The reference PBA is manufactured with qualified PCB / EEE parts / materials / processes

# Baseline LCA for current space electronics

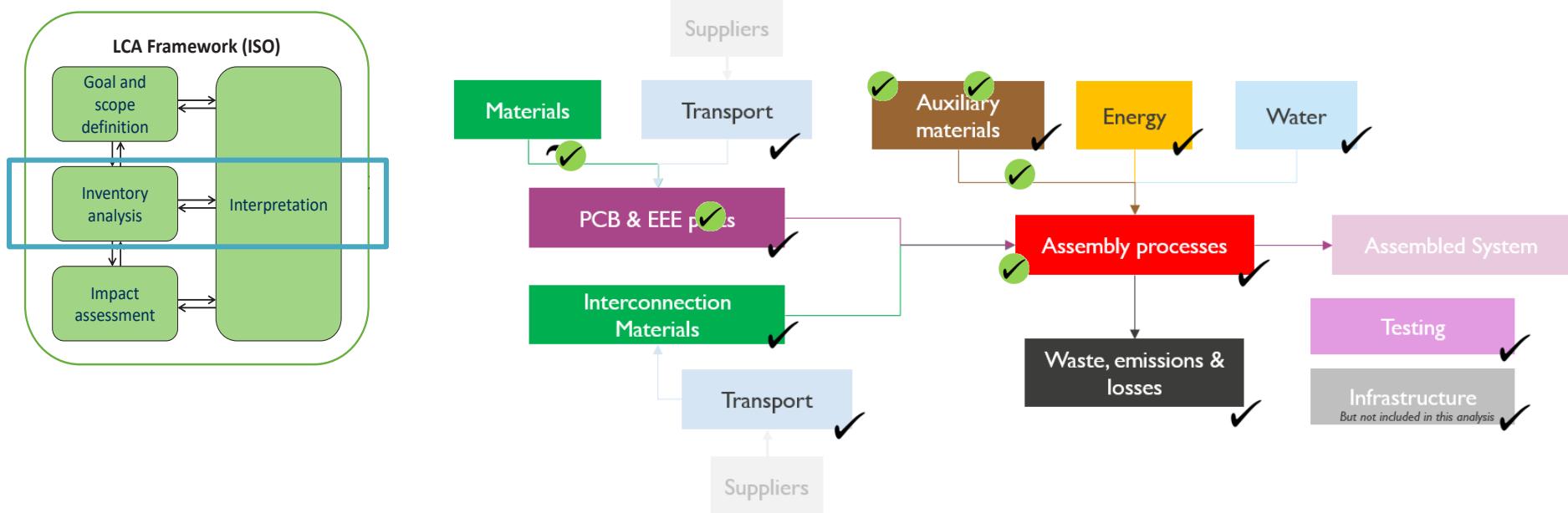
## Goal and scope definition



- **Overall goal**
  - reduce the environmental impact of the different levels of electronics used in any type of spacecraft
- **Specific goal**
  - compare the environmental impact of the reference PBA (baseline) to each of the selected eco-design option (at PBA level) to quantify the environmental impact reduction per eco-design option
- **Functional unit**
  - production, verification and validation of the Core Module of the µRTU (reference PBA)
- **System boundaries**
  - phases C&D

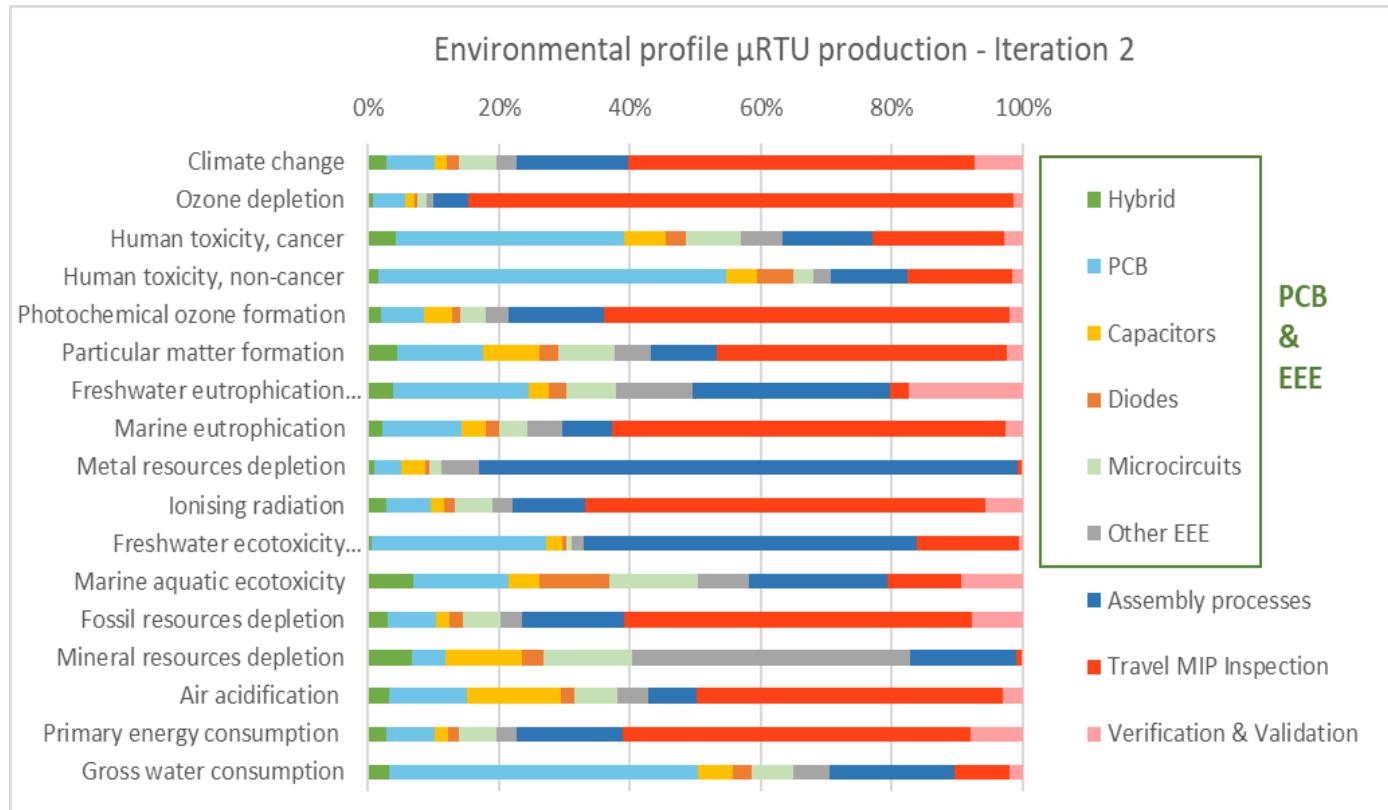
# Baseline LCA for current space electronics

## Inventory analysis



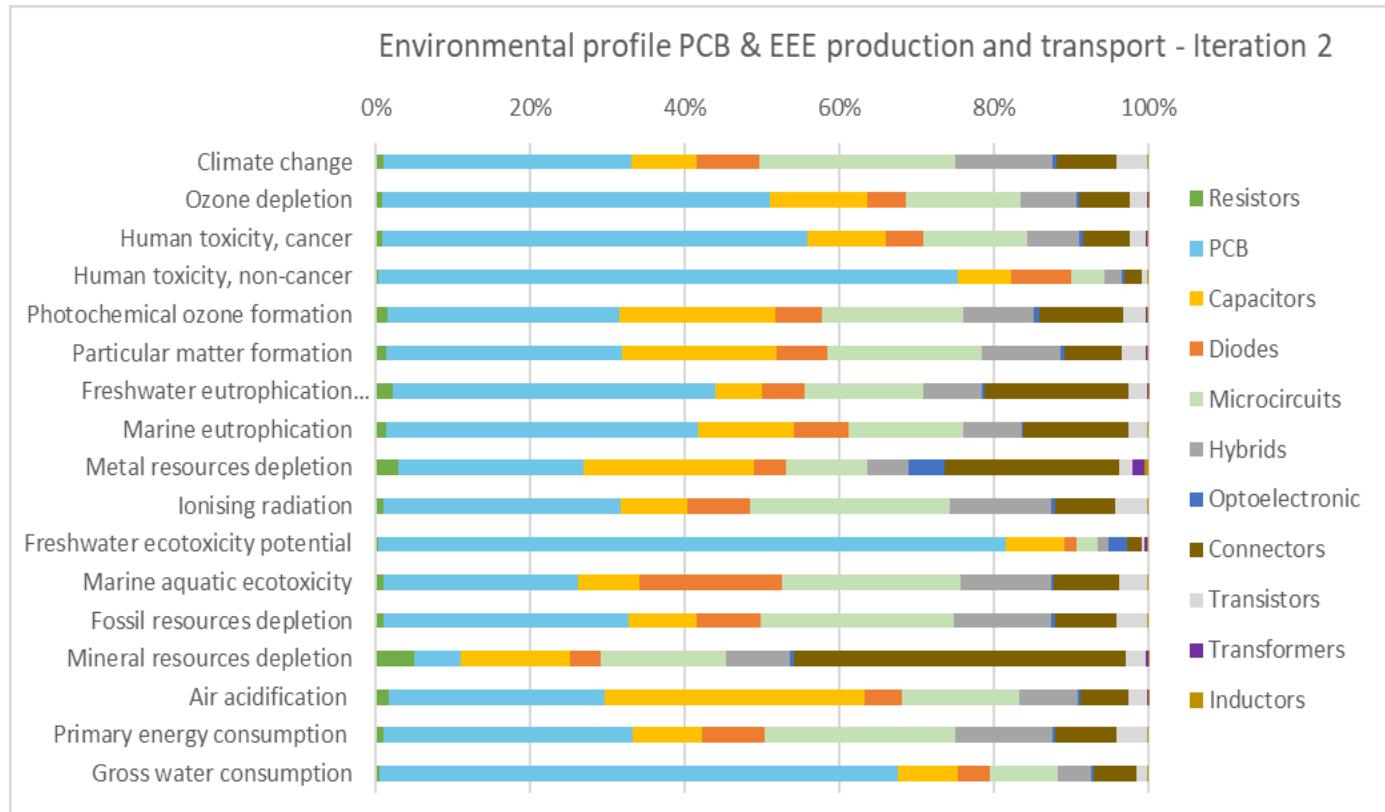
# Baseline LCA for current space electronics

## Impact assessment - μRTU production



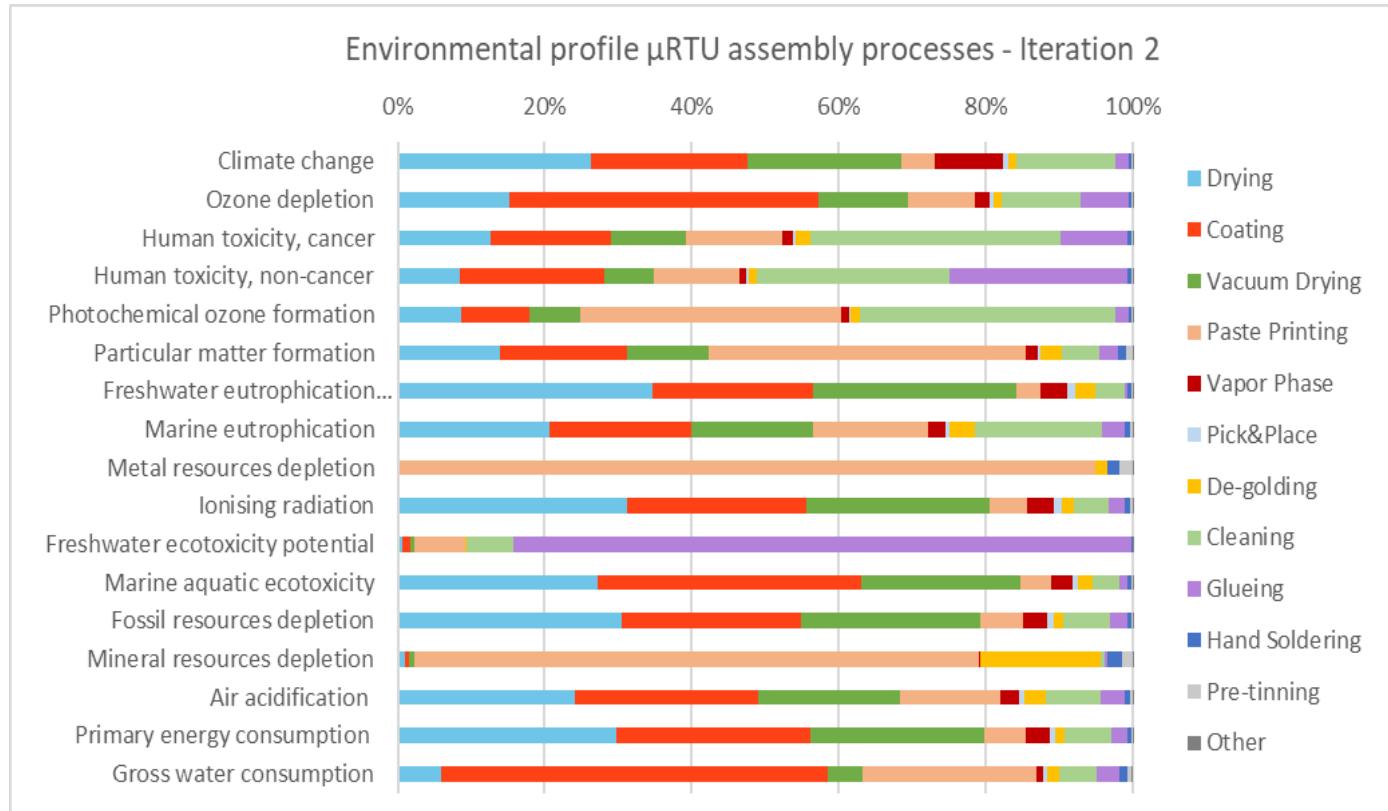
# Baseline LCA for current space electronics

## Impact assessment - PCB & EEE Parts production and transport



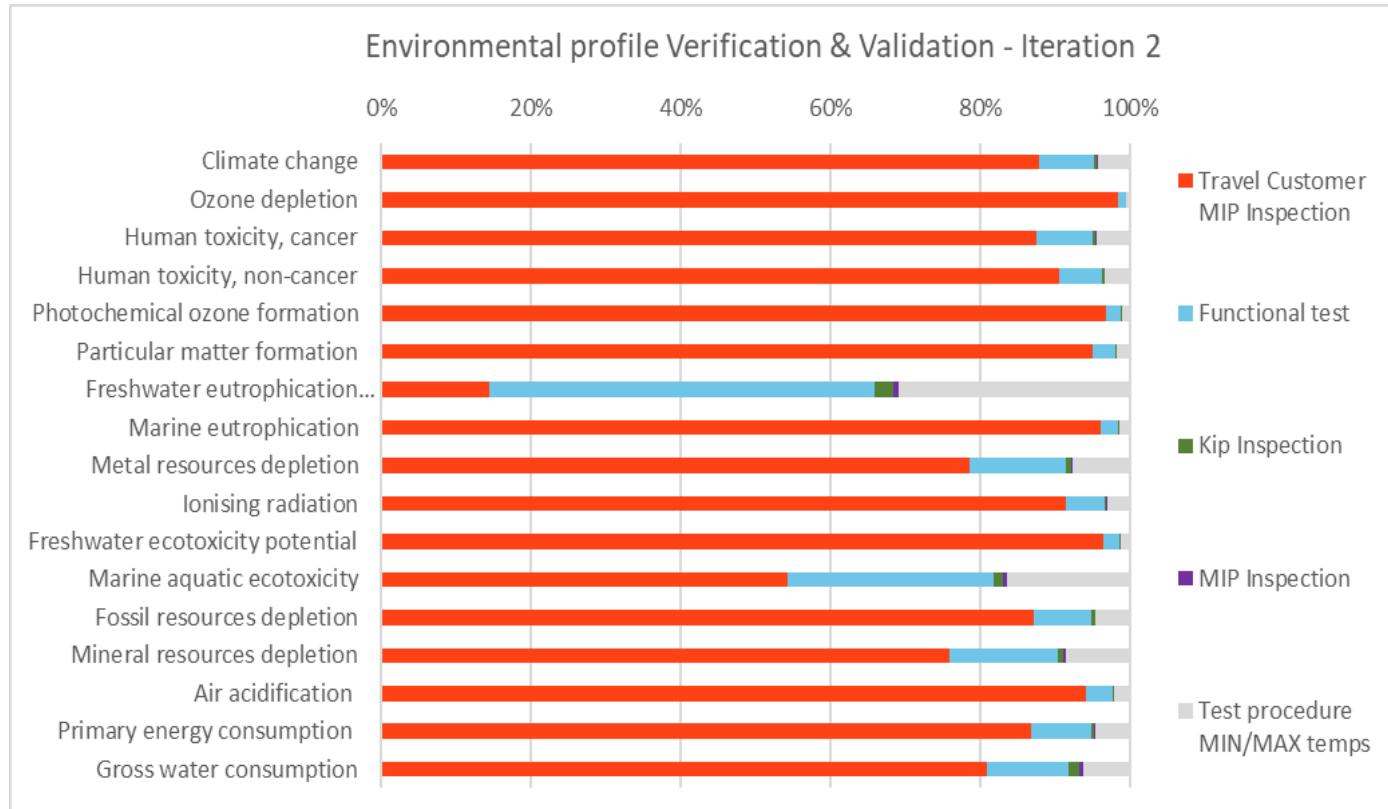
# Baseline LCA for current space electronics

## Impact assessment - μRTU Assembly processes



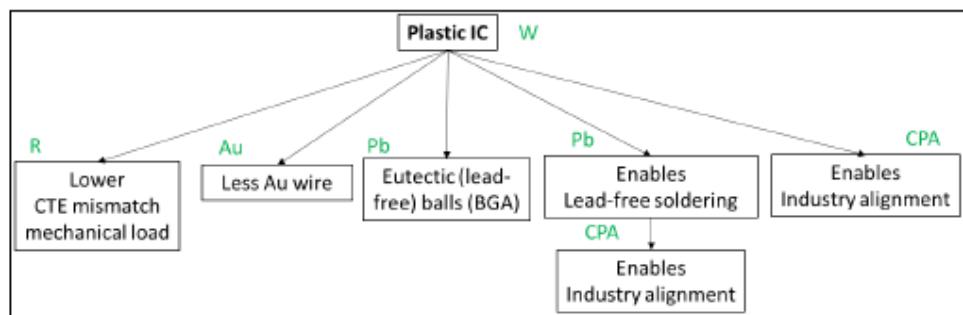
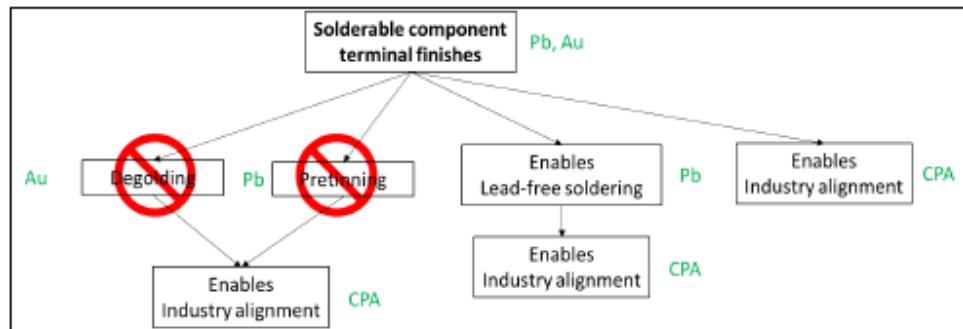
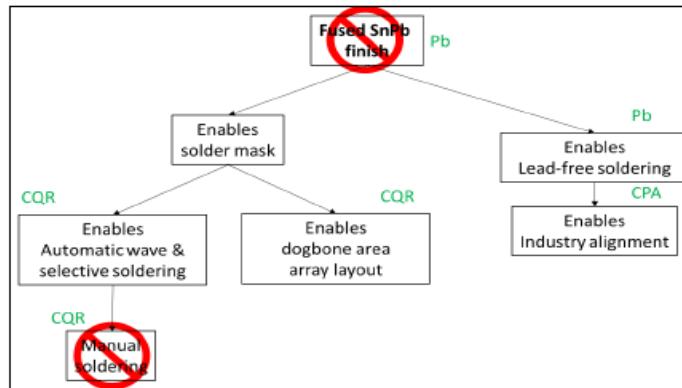
# Baseline LCA for current space electronics

## Impact assessment - Verification & Validation



# Life cycle assessment of green electronics for space

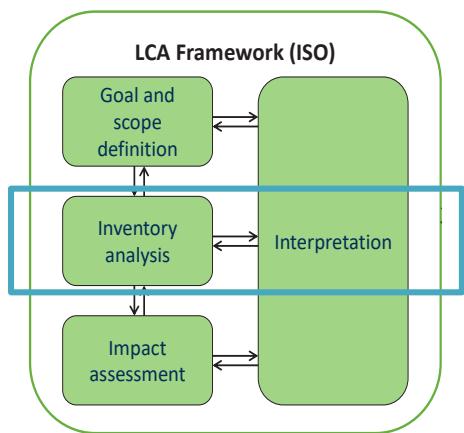
## Short-term eco-design options



1. No more reflow SnPb finish requirement
2. Eliminate degolding/tinning of terminals
3. Standardize the use of plastic IC packages
4. Lead-free solder as general purpose solder
5. Standardize the use of solder mask
6. Solderability requirements for component terminals

# Eco-design LCA for “greener” space electronics

## Inventory analysis – updated LCA/LCI models developed



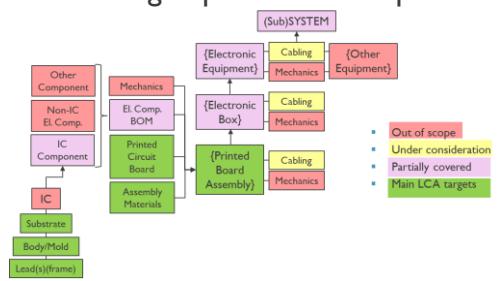
Material added per PBA	SnPb				Leadfree				SnPb → Leadfree savings									
	DeGold	PreTin	SHD	TH	Clean	Total	DeGold	PreTin	SHD	TH	Clean	Total	DeGold	PreTin	SHD	TH	Clean	Total
Solder (g/PBA)	0	0,79	2,84	1,48	0	8,12	0	0,87	2,39	1,41	0	4,37	0,00	0,13	0,45	0,37	0,05	0,85
Flux (g/PBA)	0	0	0,35	0,061	-0,412	0,00	0	0	0,30	0,051	-0,146	0,00	0,00	0,00	0,00	0,01	-0,07	0,00
<b>WASTE per PBA</b>	<b>DeGold</b>	<b>PreTin</b>	<b>SHD</b>	<b>TH</b>	<b>Clean</b>	<b>Total</b>	<b>DeGold</b>	<b>PreTin</b>	<b>SHD</b>	<b>TH</b>	<b>Clean</b>	<b>Total</b>	<b>DeGold</b>	<b>PreTin</b>	<b>SHD</b>	<b>TH</b>	<b>Clean</b>	<b>Total</b>
Solder waste (g/PBA)	98,03	98,03				196,07	98,03	98,03				196,07	0,00	0,00	0,00	0,00	0,00	0,00
Au waste (g/PBA)	392,14				392,14	392,14			392,14			392,14	0,00	0,00	0,00	0,00	0,00	0,00
Liquid flux waste (m³/PBA)	5,00	5,00			5,00	5,00			10,00			10,00	0,00	0,00	0,00	0,00	0,00	0,00
Cleaning waste (m³/PBA)	10,00	10,00			95,00	115,00	10,00	10,00	95,00			115,00	0,00	0,00	0,00	0,00	0,00	0,00
Waste water (l/PBA)					2,85	2,85			2,85			2,85	0,00	0,00	0,00	0,00	0,00	0,00
Removed flux (g/PBA)					0,60	0,60			0,35			0,35	0,00	0,00	0,00	0,00	0,24	0,24
Wiping solvent (g/PBA)		0,20			0,20				0,20			0,20	0,00	0,00	0,00	0,00	0,00	0,00
Solder paste (g/PBA)	103,29		103,29				0,81		0,81			0,81	0,00	0,00	102,48	0,00	0,00	102,48
Solder paste (g/m²)	2,13				2,13				2,13			2,13	0,00	0,00	0,00	0,00	0,00	0,00
UV fluid (g/PBA)	4,67				4,67				4,67			4,67	0,00	0,00	0,00	0,00	0,00	0,00
Solder wire (g/PBA)					6,72	6,72			6,45			6,45	0,00	0,00	0,00	1,07	0,00	1,07
<b>Material added per m² PBA</b>	<b>DeGold</b>	<b>PreTin</b>	<b>SHD</b>	<b>TH</b>	<b>Clean</b>	<b>Total</b>	<b>DeGold</b>	<b>PreTin</b>	<b>SHD</b>	<b>TH</b>	<b>Clean</b>	<b>Total</b>	<b>DeGold</b>	<b>PreTin</b>	<b>SHD</b>	<b>TH</b>	<b>Clean</b>	<b>Total</b>
Solder (g/m²)	0	43,63	177,49	105,00	0	336,22	0	35,70	149,28	88,22	0	273,19	0,00	7,93	28,41	16,79	0,00	\$3,12
Flux (g/m²)	0	0	21,96	3,81	-25,770	0	0	0	18,45	3,20	-21,650	0,00	0,00	0,00	3,31	0,61	-412	0,00

- Degolding/pretinning
- Lead-free assembly
- Surface finish and solder mask
- Plastic IC packages

Material added per m² PBA	Reflow SnPb	ENIG	Pb-free HASL
Sn (g/m²)	14,4174	19,6155	27,5026
Pb (g/m²)	13,2168	0,0000	0,0000
Au (g/m²)	0,0000	0,8685	0,0000
Ni (g/m²)	0,0000	18,4230	0,0000
P (g/m²)	0,0000	0,3276	0,0000
Ag (g/m²)	0,0000	0,0000	0,3540
Cu (g/m²)	0,0000	0,0000	5,040E-02
Solder mask (g/m²)	0,0000	9,30E+01	9,30E+01
<b>WASTE per m² PBA</b>	<b>Reflow SnPb</b>	<b>ENIG</b>	<b>Pb-free HASL</b>
(waste) water (m³/m²)	0,01	0,34	0,04
flux waste (g/m²)	495,00		495,00
oil waste (g/m²)	1087,50		
metal waste Sn strip (g/m²)		19,6155	19,6155
metal waste HASL (g/m²)			8,2915
Total chemical waste (g/m²)	1352,00	30410,90	16731,97
Hydrochloric acid waste (g/m²)	135,20		352,40
Nitric acid waste (g/m²)			352,40
Acetic acid waste (g/m²)		232,48	232,48
Solder mask waste (g/m²)		181,31	181,31
Sodium Carbonate waste (g/m²)		136,26	136,26
Phosphoric acid waste (g/m²)			18,96
Hydrogen peroxide waste (g/m²)			12,91
Copper sulfate waste (g/m²)		16,13	
Sulfuric acid waste (g/m²)			31,55
Hydrochloric acid waste (g/m²)			722,80

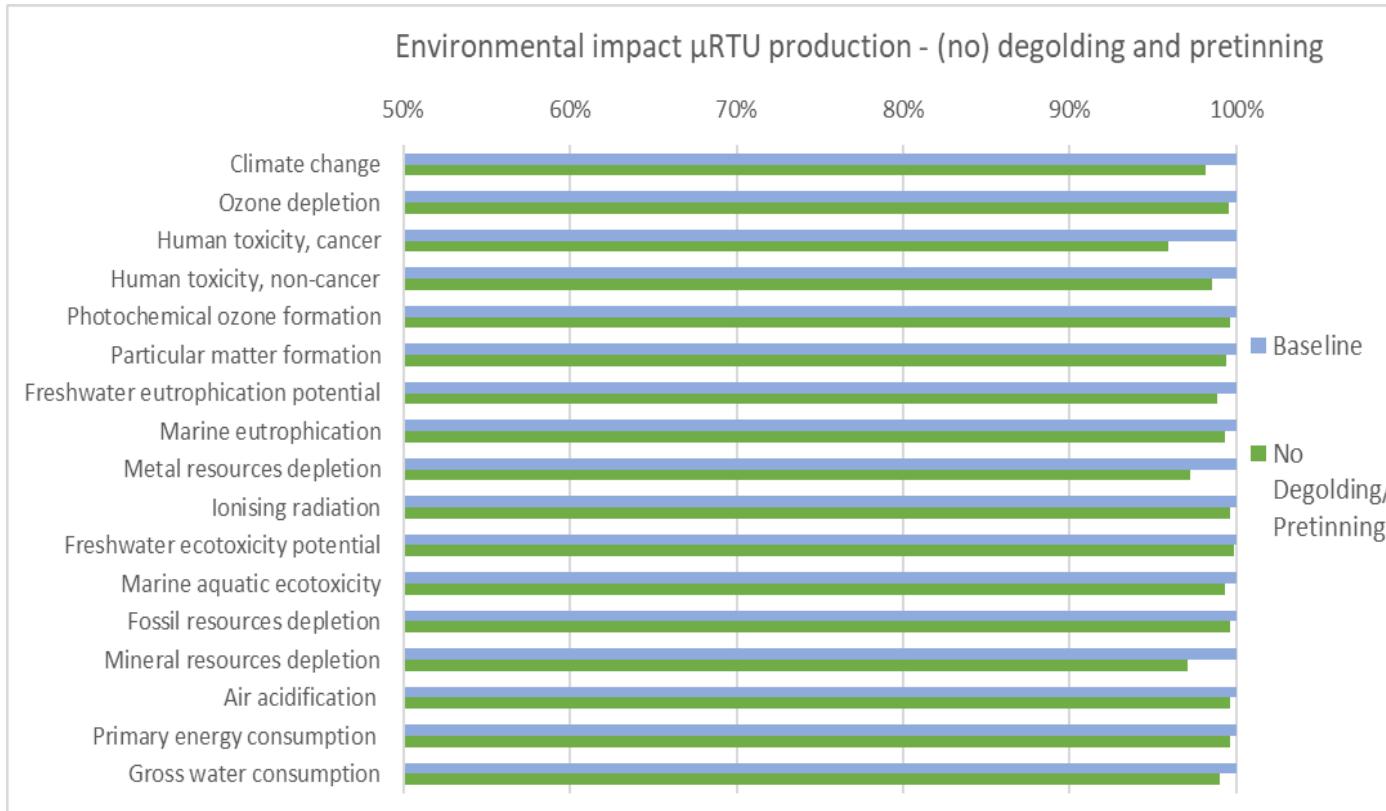
## Modelling improvement scope

Material added per component	Ceramic Area Array Package				Plastic Area Array Package				Delta			
	Substrate	IC-Terminals	Ball	Total	Substrate	IC-Terminals	Ball	Total	P+C			
Technology	HTCC	Flip-Chip							1,100	BT	[g]	
Material	Alumina		SnPb							1,922	-0,800	Au [mg]
substrate [g]	6,88675			6,887	1,099776					44,345	-18,462	Ni [mg]
Au [mg]	2,722		1,922	0,000						0,000	-0,303	V [mg]
Ni [mg]	62,808		62,808									
W [mg]	0,303		0,303	0,000								
Mo [mg]	1120,470		1120,470	0,000								
Cu [mg]	0,000		0,000	0,000	160,621	20,115	0,000	181,316	181,316	Cu [mg]		
Ag [mg]	0,000		0,000	0,000		3,740	0,000	3,740	3,740	Ag [mg]		
Sn [mg]		277,248	277,248			7,265	593,677	600,942	323,693	Sn [mg]		
Pb [mg]		2451,522	2451,522			544,238	544,238	544,238	-190,285	Pb [mg]		
Al [mg]				0,000					0,000	0,000	Al [mg]	
Underfill epoxy [mg]		300,000		300,000						-300,000	Underfill epoxy [mg]	
SiO <sub>2</sub> [mg]				0,000		452,744		452,744	452,744	SiO <sub>2</sub> [mg]		
Unfilled epoxy [mg]				0,000		256,344		256,344	256,344	Unfilled epoxy [mg]		
Mold/SiO <sub>2</sub> + epoxy [g]				0,000		4,785		4,785	4,785	Mold [g]		



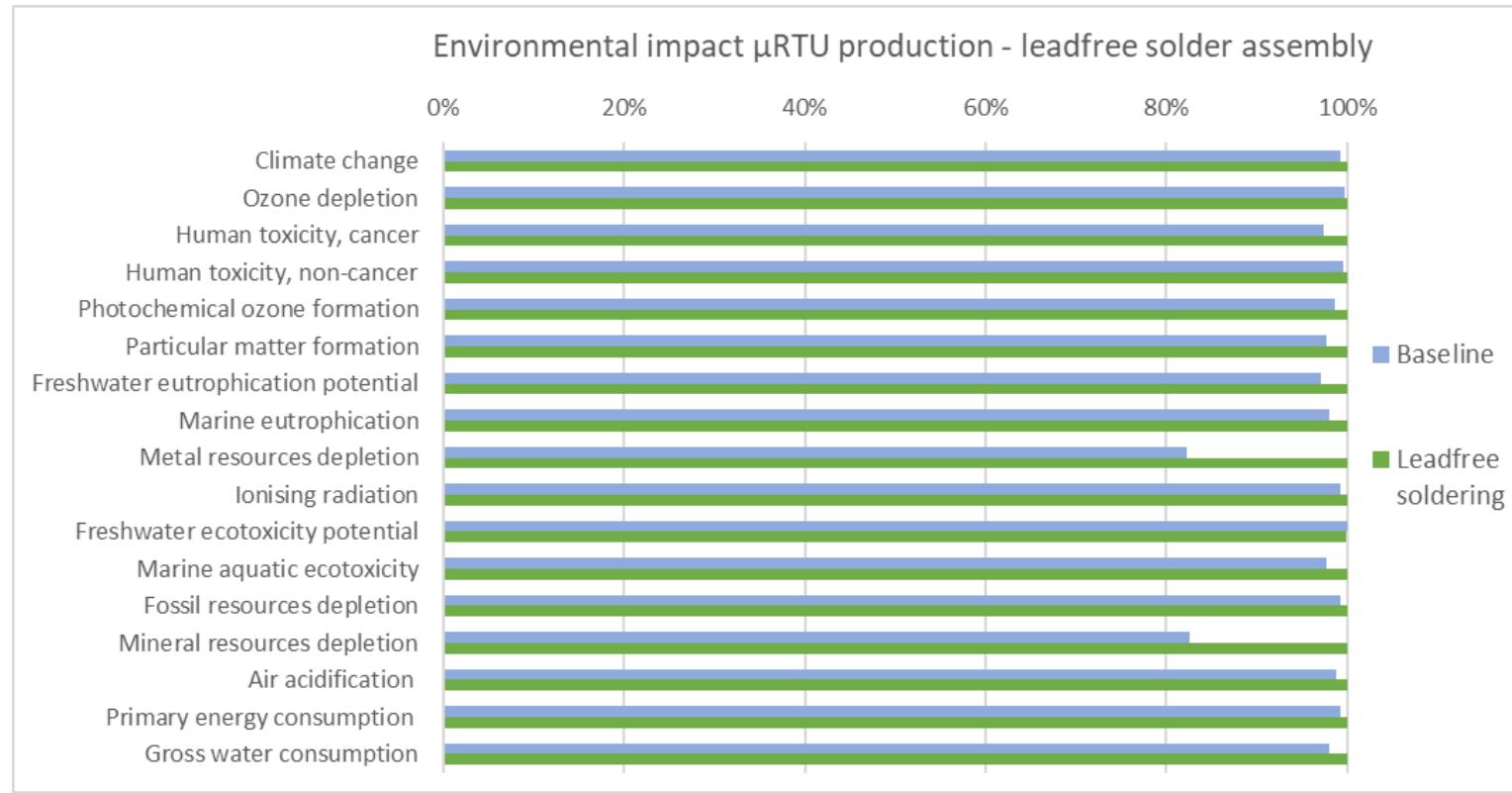
# Eco-design LCA for “greener” space electronics

## $\mu$ RTU production with and without terminals degolding/pretinning



# Eco-design LCA for “greener” space electronics

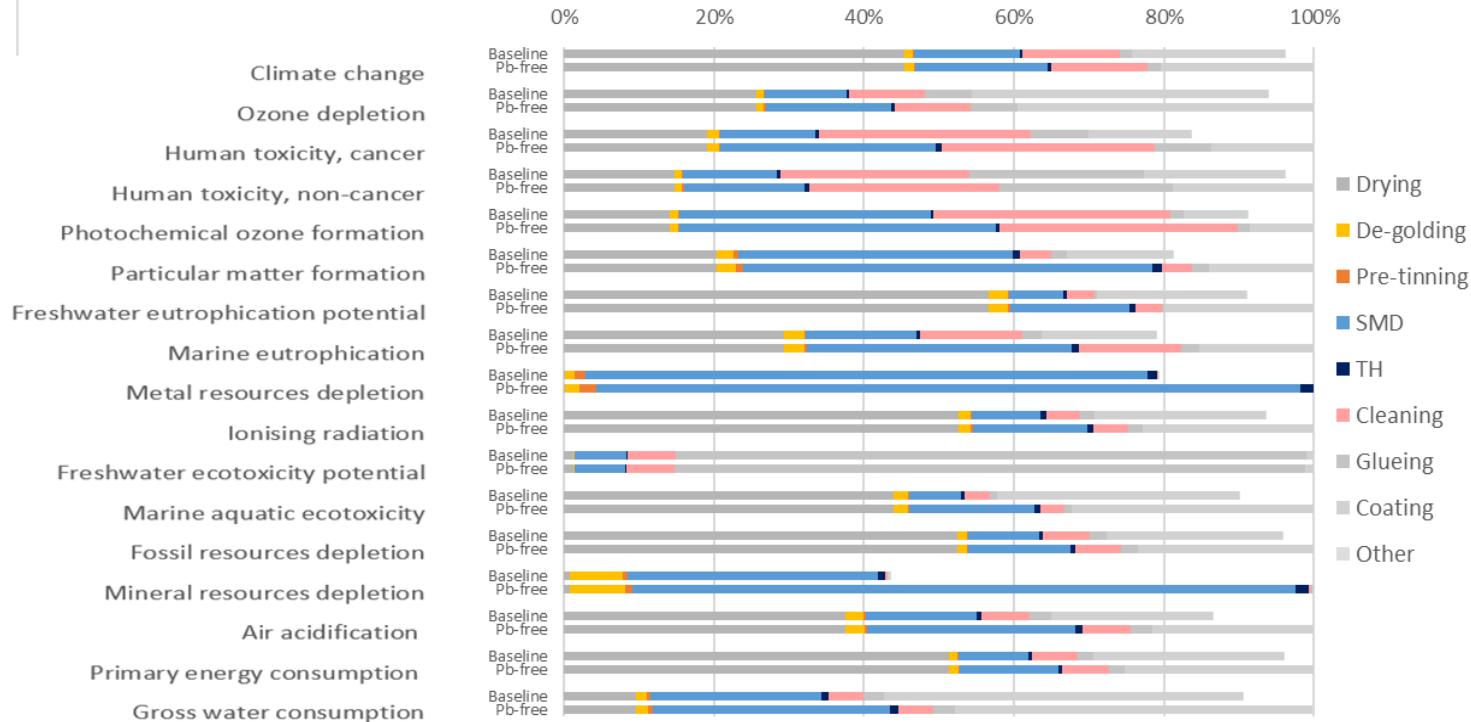
## $\mu$ RTU production – SnPb versus Pb-free solder assembly



# Eco-design LCA for “greener” space electronics

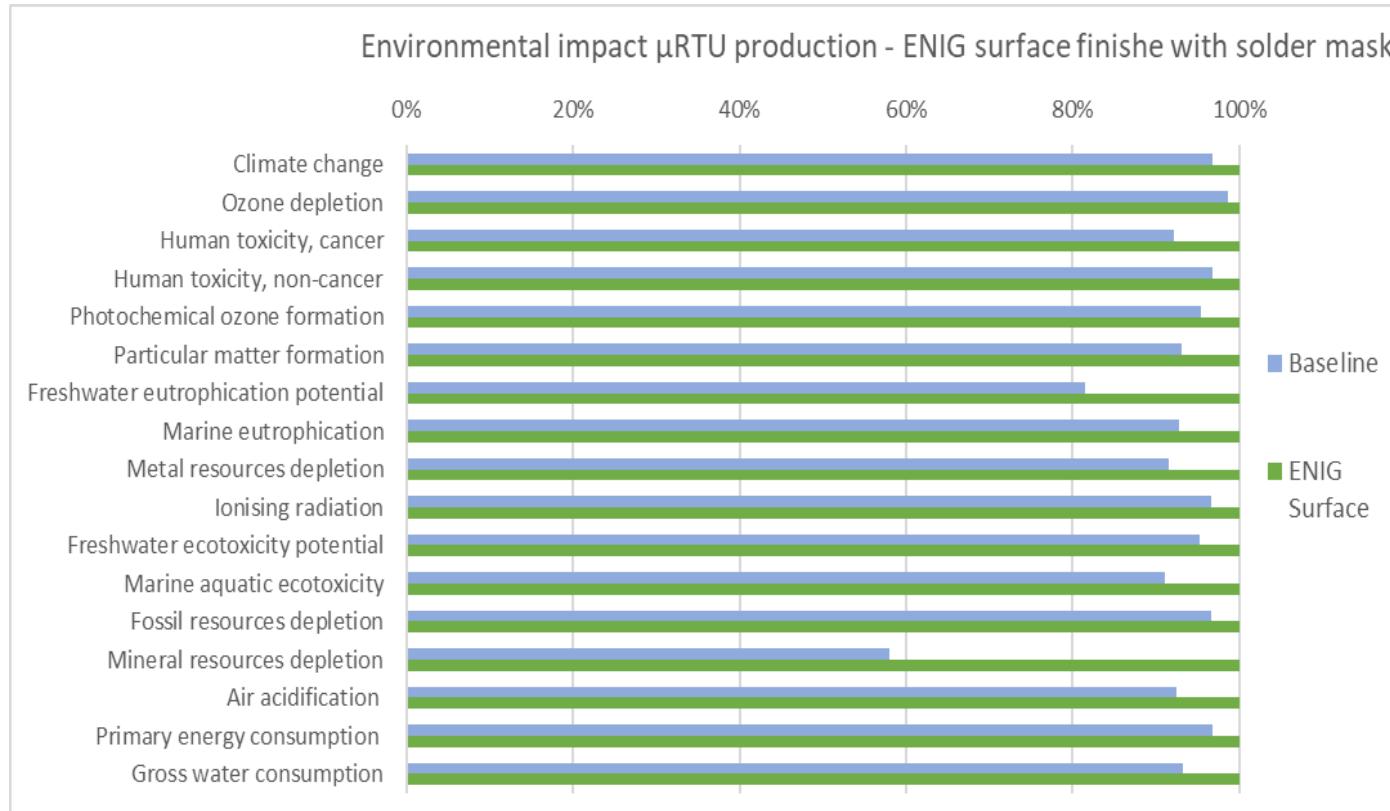
## $\mu$ RTU production – SnPb versus Pb-free solder assembly

Environmental impact assembly processes - SnPb versus Pb-free solder - details



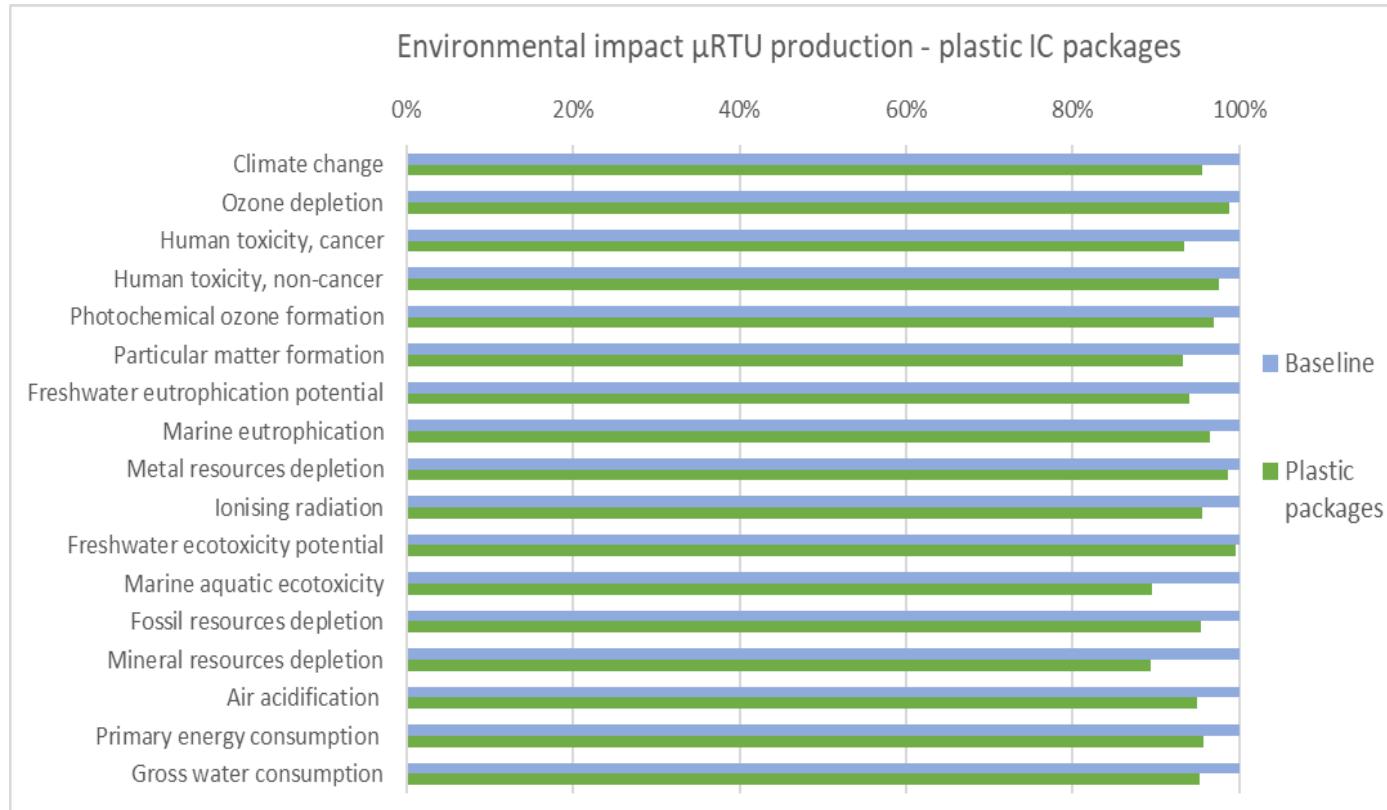
# Eco-design LCA for “greener” space electronics

µRTU production – reflow SnPb versus ENIG surface finish + solder mask



# Eco-design LCA for “greener” space electronics

## $\mu$ RTU production – ceramic IC packages versus plastic packages



# Eco-design LCA for “greener” space electronics

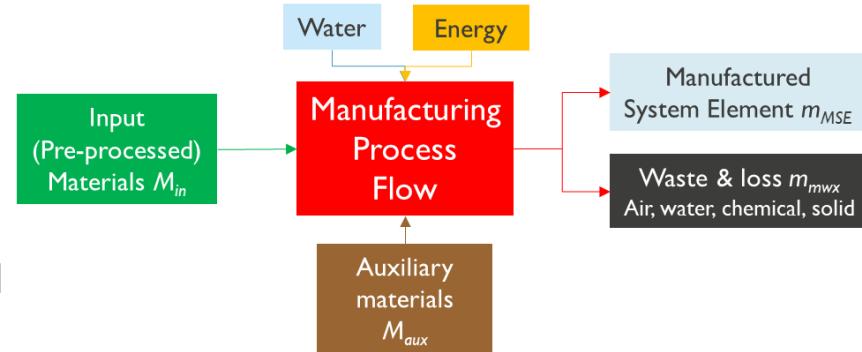
## Conclusion and lessons learnt

- Parametric LCI approach leads to significant improvements for more accurately quantifying the environmental impact of the chosen reference PBA
  - Except for two environmental impact categories, the impact of the reference PBA was overestimated with the 1<sup>st</sup> iteration
- Eliminating degoldng and pretinning as well as the use of plastic IC packages is beneficial to reduce the overall environmental impact of the μRTU production
- Lead-free solder assembly as well as using the ENIG surface finish in combination with a solder mask leads to an increased environmental impact
  - These eco-design options enable secondary improvements in environmental impact for PCB production steps as well as in assembly
- The final LCA iteration will evaluate the actual mitigation potential of all selected eco-design options when all integrated in a same record

# LCA model improvement

## Parametric modeling

- Use parametric LCI approach to calculate mass and energy flows
  - Output: materials added or removed, energy, water, auxiliary materials, waste produced
  - Input: PCB materials and size, PCB build-up and design, PBA Bill-of-Materials, assembly flow...



Solderable finish per m <sup>2</sup> of PCB	
A <sub>pcb</sub> (m <sup>2</sup> )	1
PCB A <sub>Cu,t</sub> (m <sup>2</sup> )	0,2
PCB A <sub>Cu,b</sub> (m <sup>2</sup> )	0,12
# PCB/panel	3
Solder Mask?	Yes
PCB A <sub>NoSM,t</sub> (m <sup>2</sup> )	0,0003
PCB A <sub>NoSM,b</sub> (m <sup>2</sup> )	0,0002
PCB A <sub>finish</sub> (m <sup>2</sup> )	0,0005
PCB A <sub>Cu,t</sub> (%)	20
PCB A <sub>Cu,b</sub> (%)	12
PCB A <sub>NoSM,t</sub> (%)	0,03
PCB A <sub>NoSM,b</sub> (%)	0,02
PCB A <sub>finish</sub> (%)	0,05

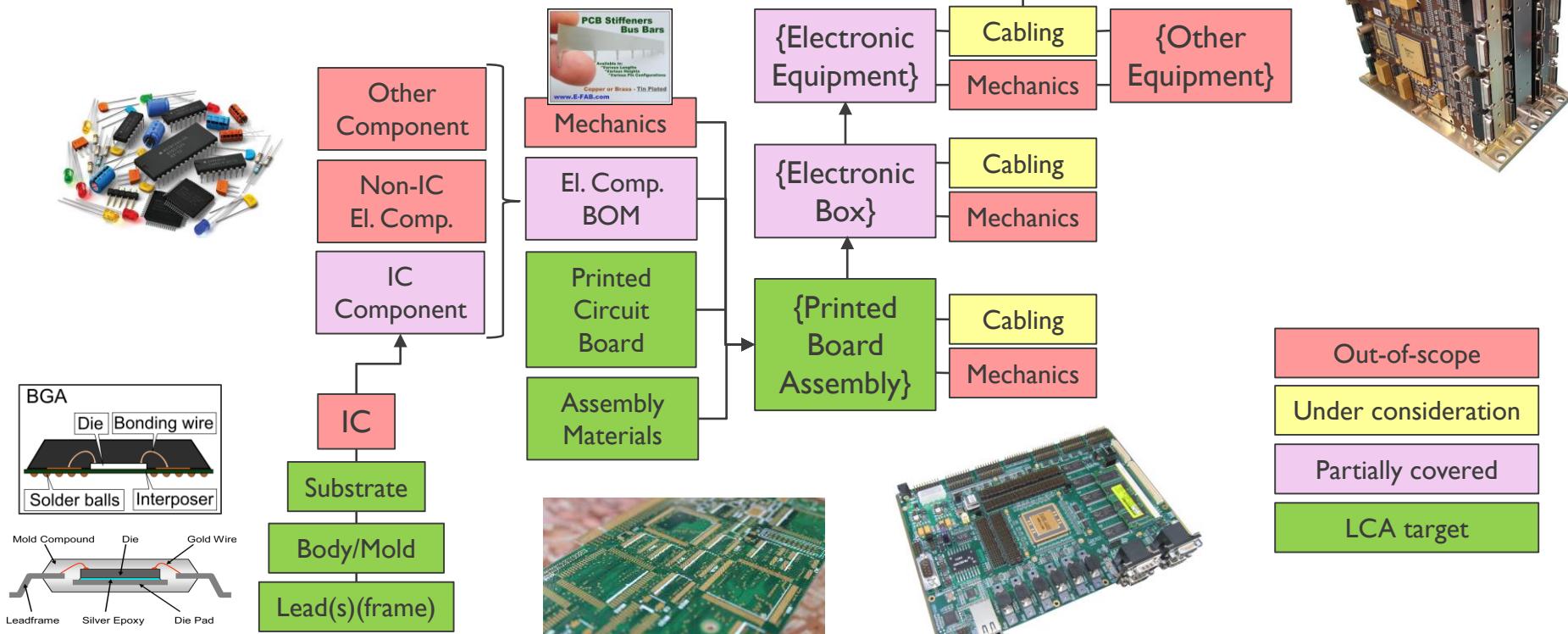


SOLDER MASK	Clean	Deposit	Cure	Image	Develop	Final Cure	Total
(waste) water (m <sup>3</sup> /m <sup>2</sup> )	0,03	0,00	0,00	0,00	0,00	0,00	0,04
chemical waste (g/m <sup>2</sup> )	0,00	3,33	0,00	0,00	6,67	0,00	10,00
energy (Wh/m <sup>2</sup> )	150,00	150,00	150,00	150,00	150,00	150,00	900,00
FTE/m <sup>2</sup> (min)	0,60	0,80	0,60	0,60	0,60	0,60	3,80

- Process data collected from space-qualified PCB manufactures and assembly houses

# LCA model improvement

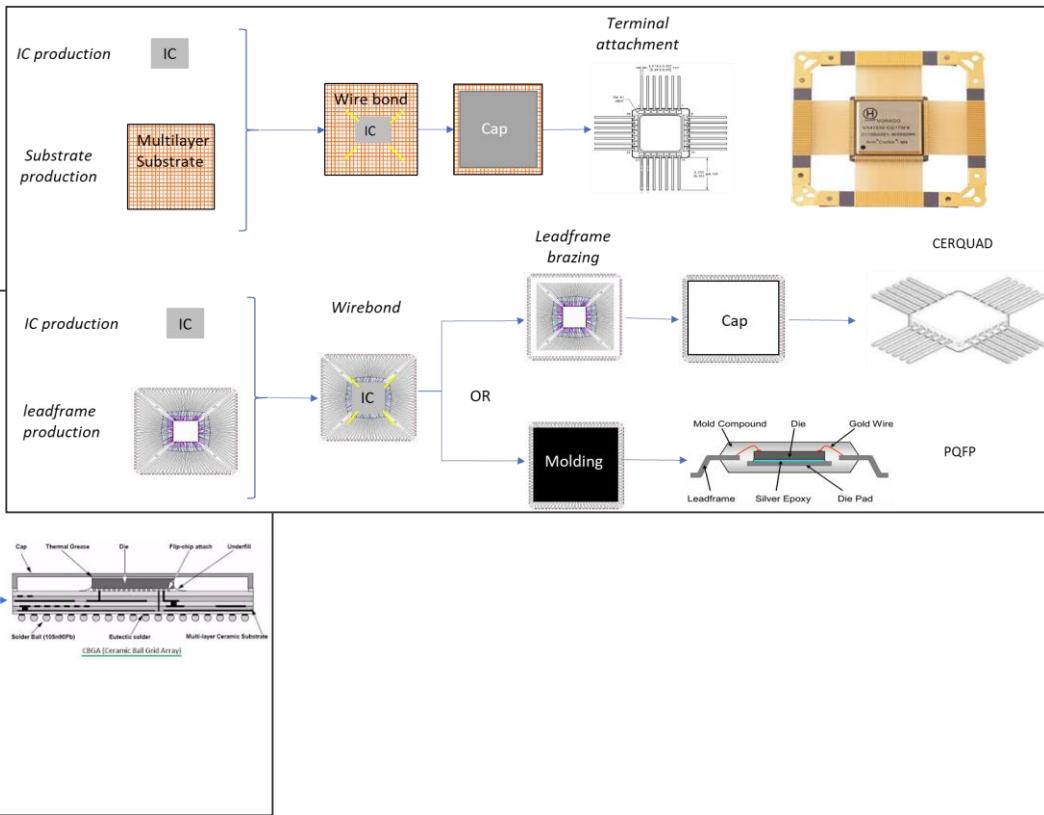
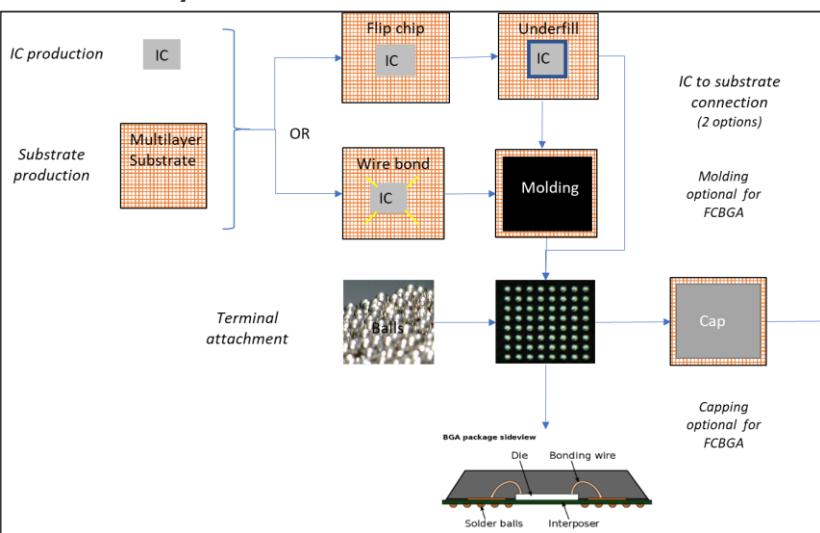
## Scope within Green-eSpace project



# LCA model improvement

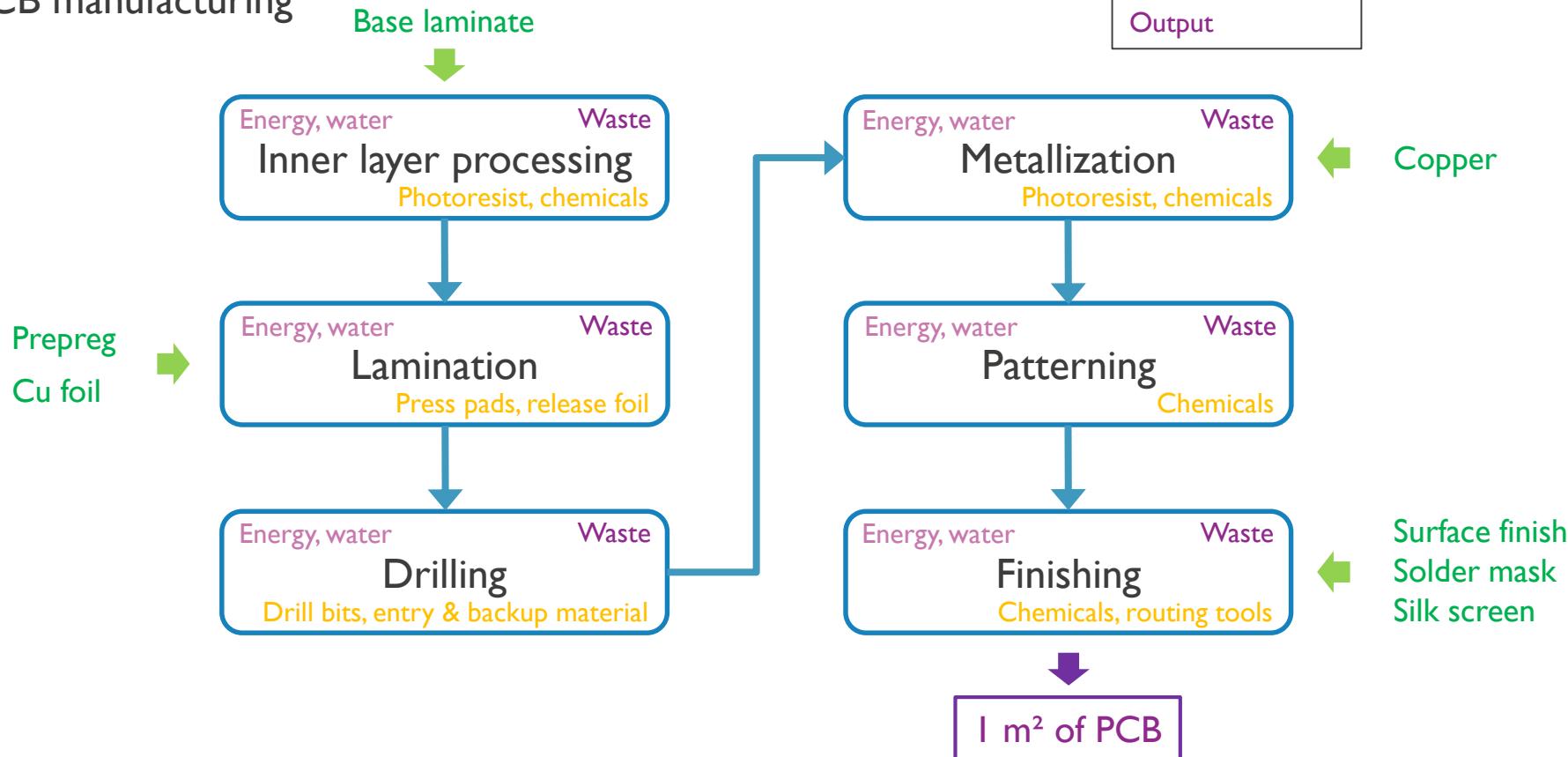
## LCI model for component packaging

### Area Array Devices



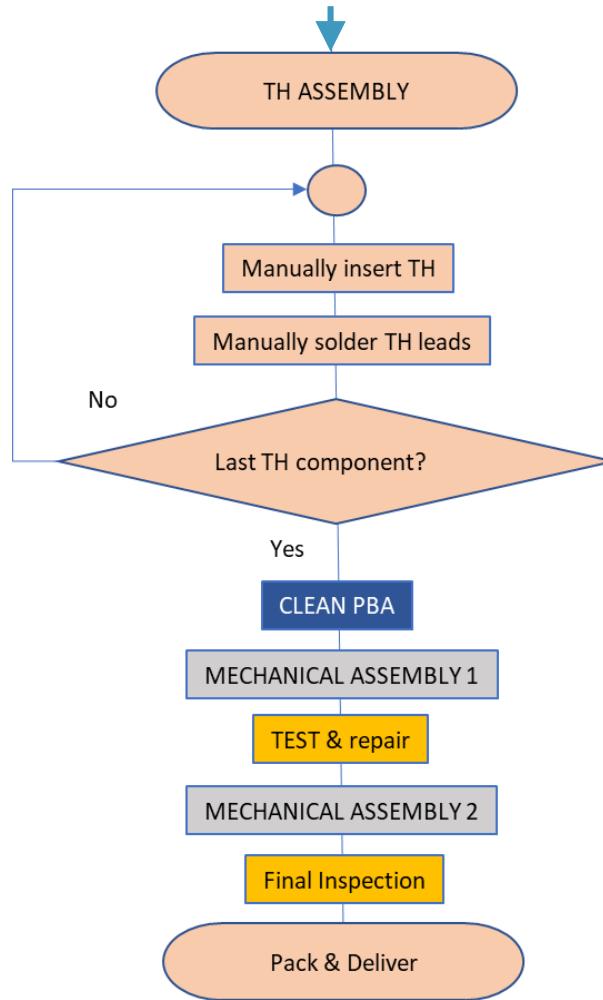
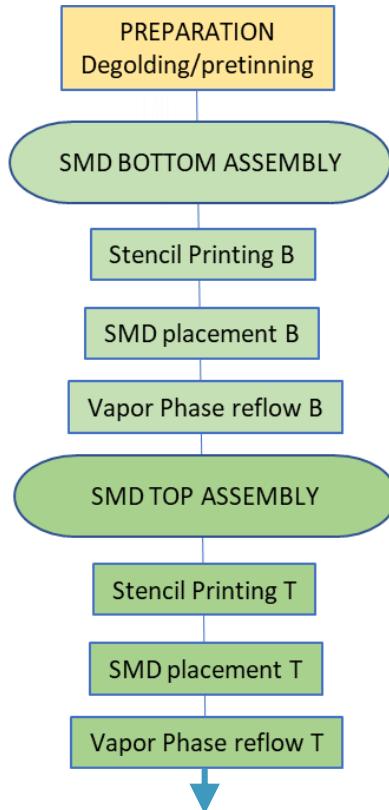
# LCA model improvement

## PCB manufacturing

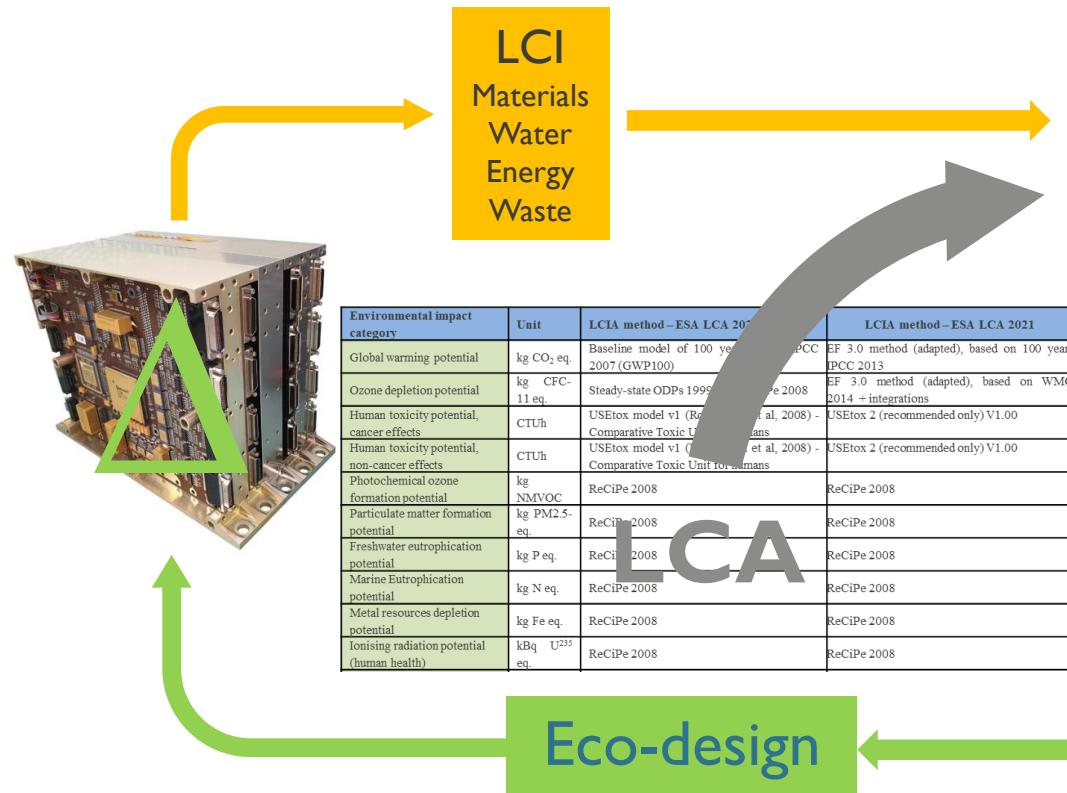


# LCA model improvement

## LCI model for PCB assembly

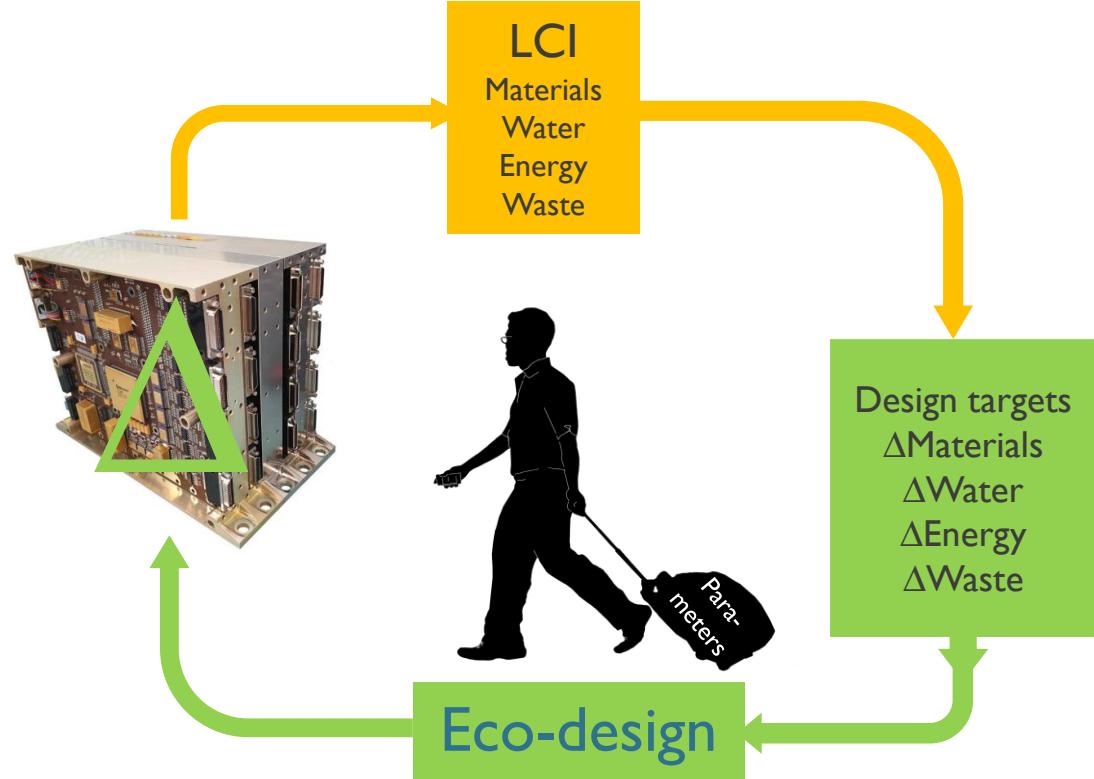


# From LCA-based eco-design...



**Eco-improvement targets**  
 ΔMaterials  
 ΔWater  
 ΔEnergy  
 ΔWaste

# ... to lean LCI-based eco-design



Environmental impact category	Unit	LCIA method – ESA LCA 2020
Global warming potential	kg CO <sub>2</sub> eq.	Baseline model of 100 years of the IPCC 2007 (GWP100)
Ozone depletion potential	kg CFC-11 eq.	Steady-state ODPs 1999 as in ReCiPe 2008
Human toxicity potential, cancer effects	CTUh	USEtox model v1 (Rosenbaum et al, 2008) Comparative Toxic Unit for humans
Human toxicity potential, non-cancer effects	CTUh	USEtox model v1 (Rosenbaum et al, 2008) Comparative Toxic Unit for humans
Photochemical ozone formation potential	kg NMVOC	ReCiPe 2008
Particulate matter formation potential	kg PM2.5 eq.	ReCiPe 2008
Freshwater eutrophication potential	kg P eq.	ReCiPe 2008
Marine Eutrophication potential	kg N eq.	ReCiPe 2008
Metal resources depletion potential	kg Fe eq.	ReCiPe 2008
Ionising radiation potential (human health)	kBq U <sup>235</sup> eq.	ReCiPe 2008

+ Non-LCA sources

One-time generic hot spot analysis



# imec

embracing a better life