2021 Clean Space Industrial Days

Life Cycle Assessment of Green Electronics for Space

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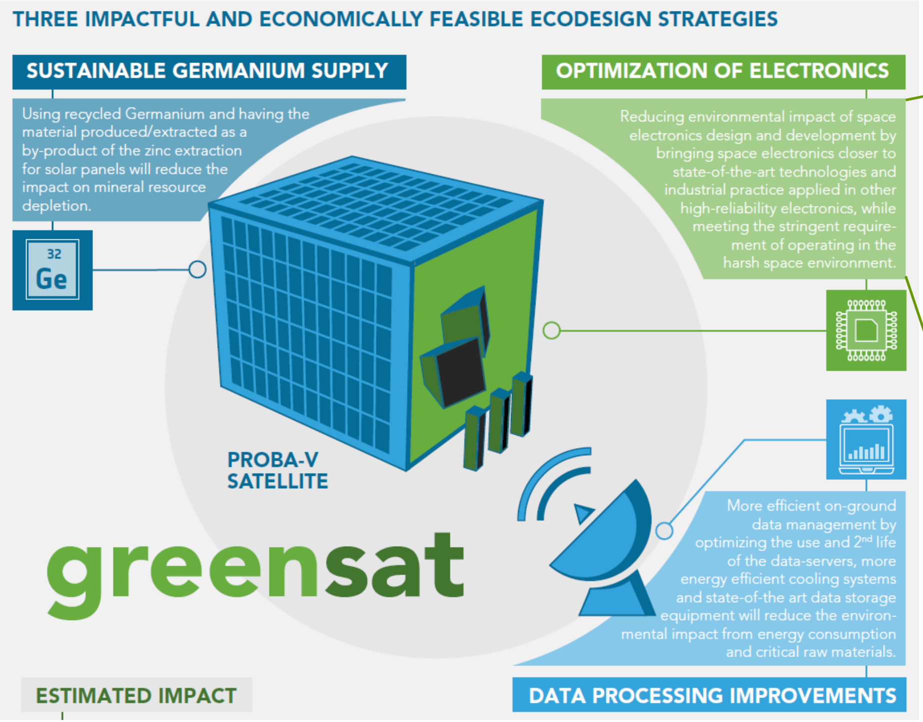
ESA CONTRACT NO. 4000133313/21/NL/AS

(Space) electronics as environmental hotspot

FROM GREENSAT TO GREEN-ESPACE



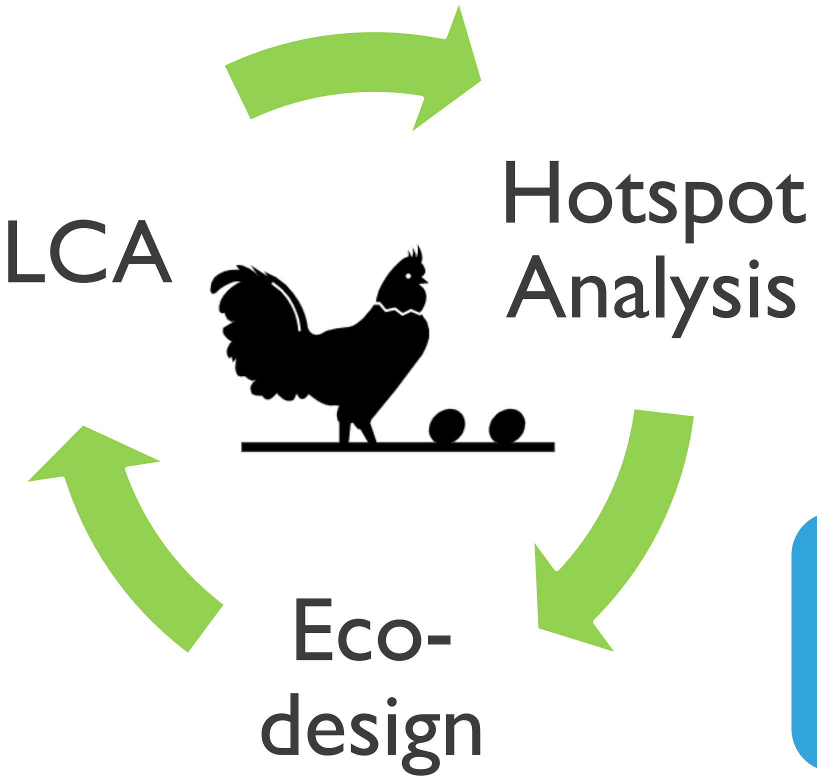
Green-eSpace

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

(Space) electronics as environmental hotspot

CIRCLE OF LIFE CYCLE ASSESSMENT

- Incorrect or incomplete data
- Inadequate LCA models



- Overemphasis on materials
- Confirmation bias

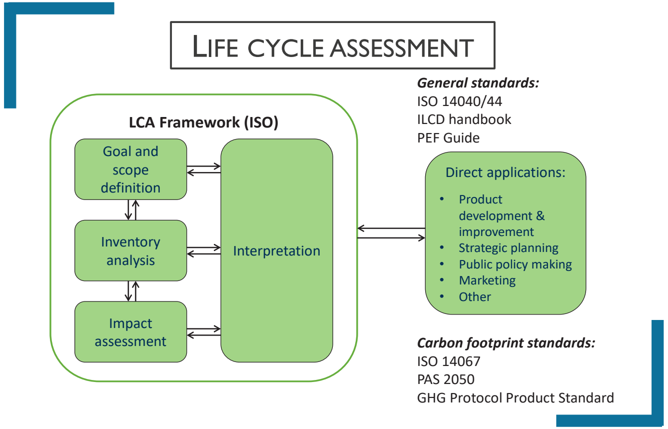
- Burden shifting
- Quantification of disruptive options
- Pro-innovation bias

Green-eSpace project overview

OBJECTIVES

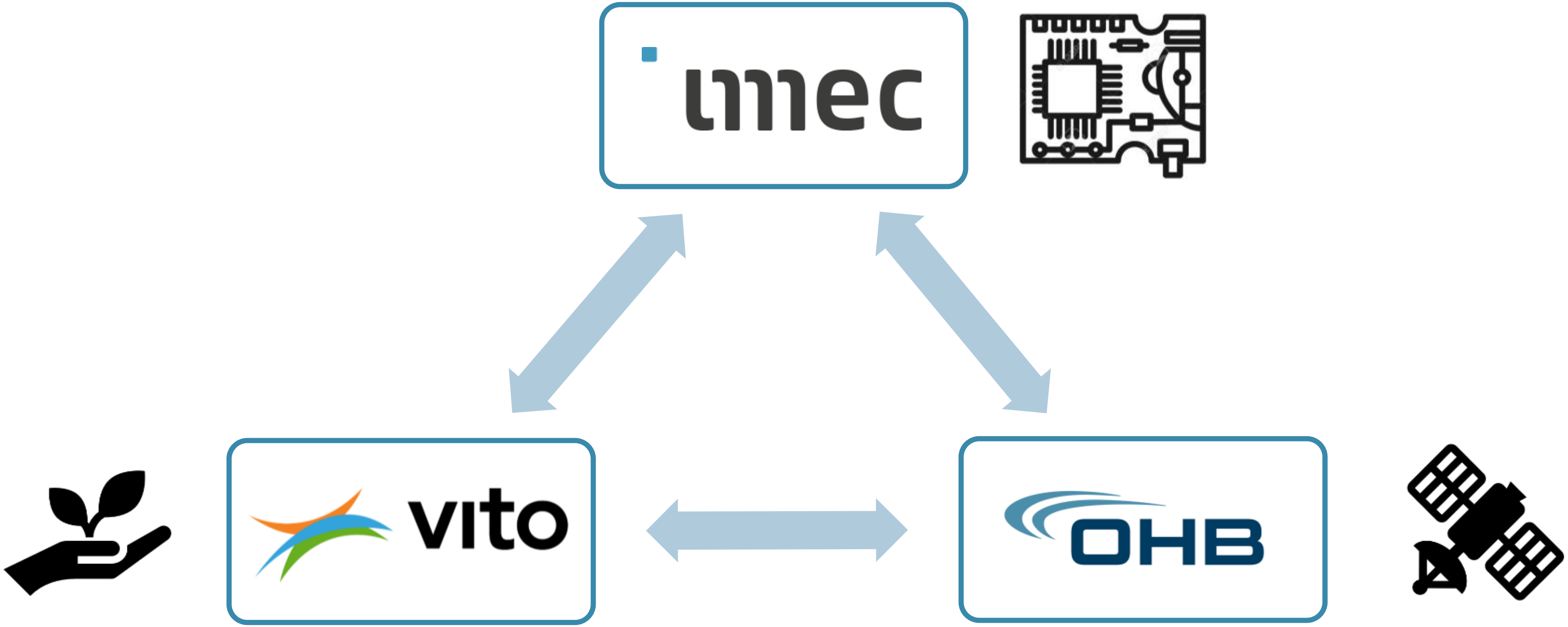
- To foster the adoption of **green electronics** applications,
- To **improve the environmental impact** of space applications and
- To **identify alternative** materials, processes for the manufacturing and testing of space electronic assemblies.

- Initial TRL: **2** ⇨ Final TRL: **3**



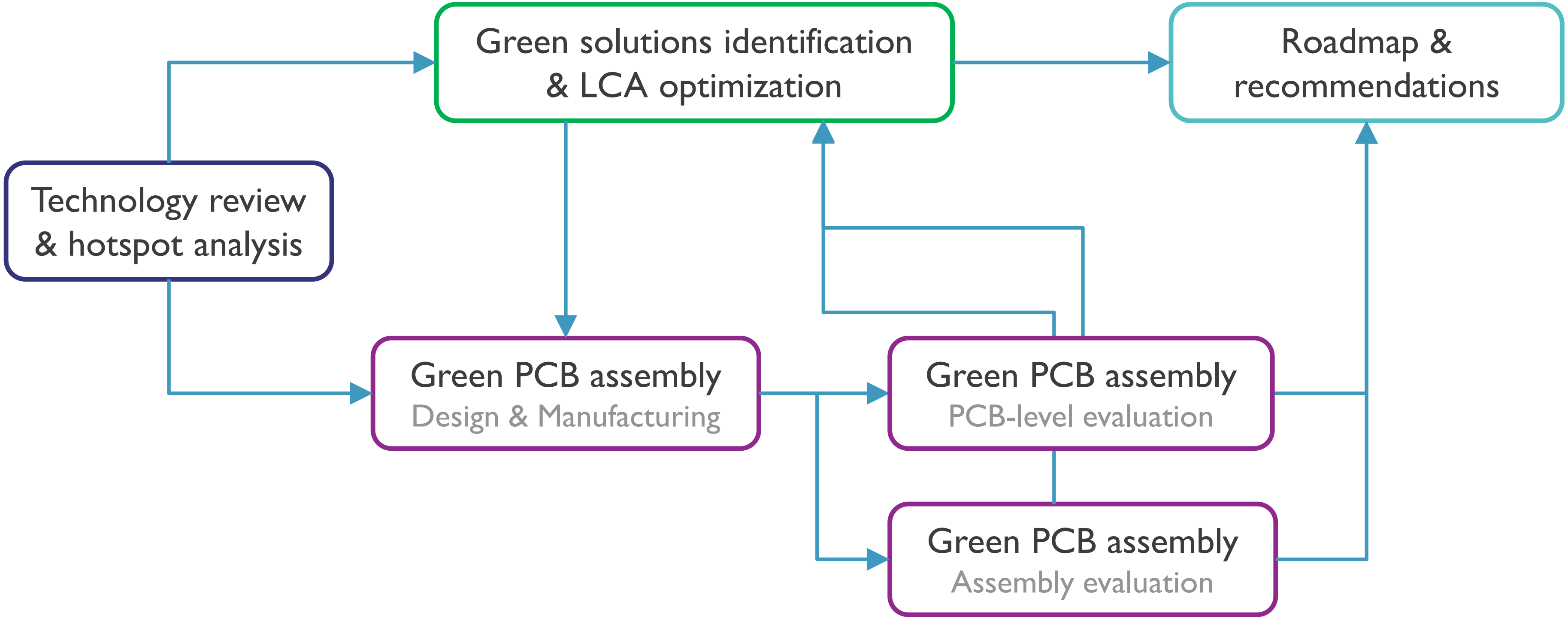
Green-eSpace project overview

CONSORTIUM



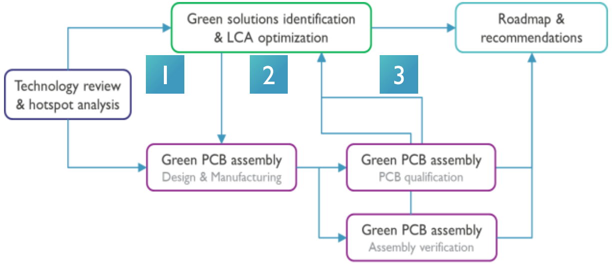
Green-eSpace project overview

PROJECT CONCEPT



Green-eSpace project overview

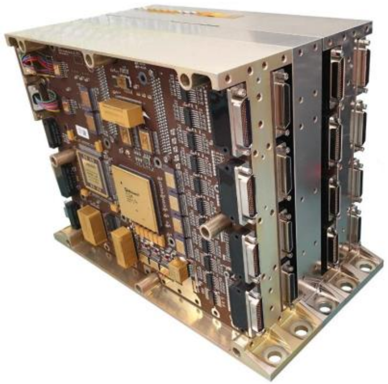
OVERALL LCA APPROACH



Iteration #	Objective(s)
Iteration 1 - baseline	LCA for the current electronic assemblies relevant in the space sector (baseline) → to identify the environmental hotspots
Iteration 1 – eco-design	LCA for the selected eco-design options → to support the design phase (on option level)
Iteration 2	Update Iteration 1 LCA models with more accurate data and compare each (selected) eco-design option with its 'baseline' (per option)
Iteration 3	Update Iteration 2 LCA models with more accurate data for manufacturing and testing and to compare the green electronic assembly with the 'baseline'

Technology review and environmental LCA

Mapping of space electronics



Baseline LCA

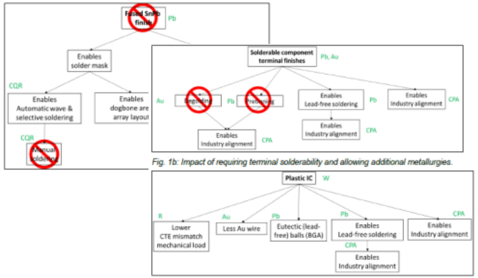
Hotspot analysis

Impact category	Manpower	Component material X	Component material Y	Assembly process X	Assembly process Y	PCB technology X	PCB technology Y	Transportation	Testing
Global warming									
Ozone depletion									
Human toxicity, non-cancer									
Human toxicity, cancer									
Resource depletion, fossil									
Resource depletion, minerals									
Photochemical ozone formation									
Particular matter formation									
Freshwater eutrophication									
Marine eutrophication									
Metal depletion									
Ionising radiation									
Freshwater ecotoxicity									
Marine ecotoxicity									
Acidification									
Critical raw materials (kg)									
REACh emissions (kg)									
Primary energy consumption									
Water consumption									

Literature

Workshop

Eco-design options

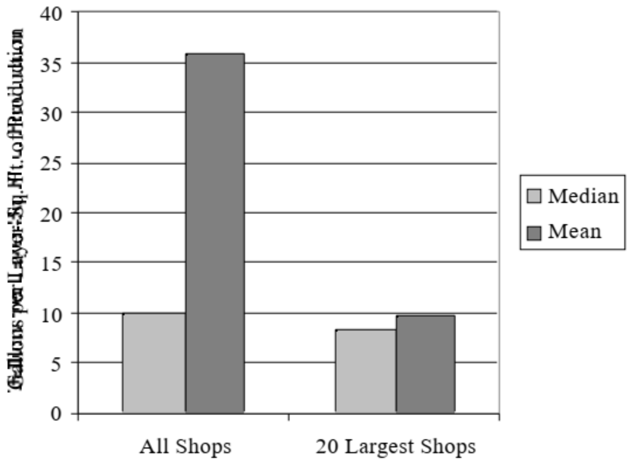


Trade-off selection

Mapping of space electronics

IMPACT OF LOW-VOLUME, HIGH MIX PRODUCTION

WATER USAGE DURING PCB MANUFACTURING



Printed Wiring Board Pollution Prevention and Control Technology: Analysis of Updated Survey Results, EPA DfE PWB project

ENERGY CONSUMPTION FOR ASSEMBLY

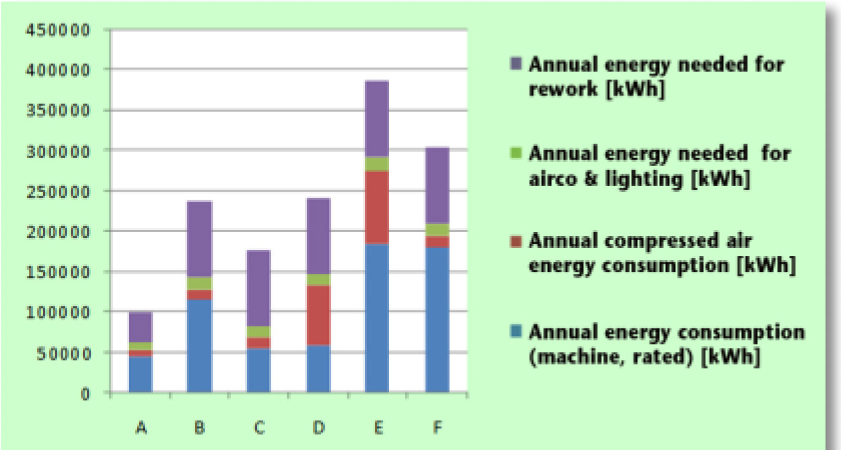


Figure 4.

Sjef Van Gastel, It pays to be Frugal, I.Connect007

Mapping of space electronics

TESTING OVERVIEW FOR QUALIFIED COMPONENTS

Recurring testing

Non-recurring testing

EEE components
- Qualification
- In-process controls
- Screening
- (Lot validation testing)
- Periodic testing

Printed Circuit Board
- Qualification
- In-process controls
- Acceptance testing
- Qual. Renewal (2 year)

PCB assembly
- Assembly verification
- In-process controls
- Acceptance testing
- Critical comp. (4 year)

Iteration 1 – baseline LCA

REFERENCE PBA – OHB µRTU CORE MODULE

LCA Framework (ISO)

- Goal and scope definition
- Inventory analysis
- Impact assessment
- Interpretation

General standards:
ISO 14040/44
ILCD handbook
PEF Guide

Direct applications:

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

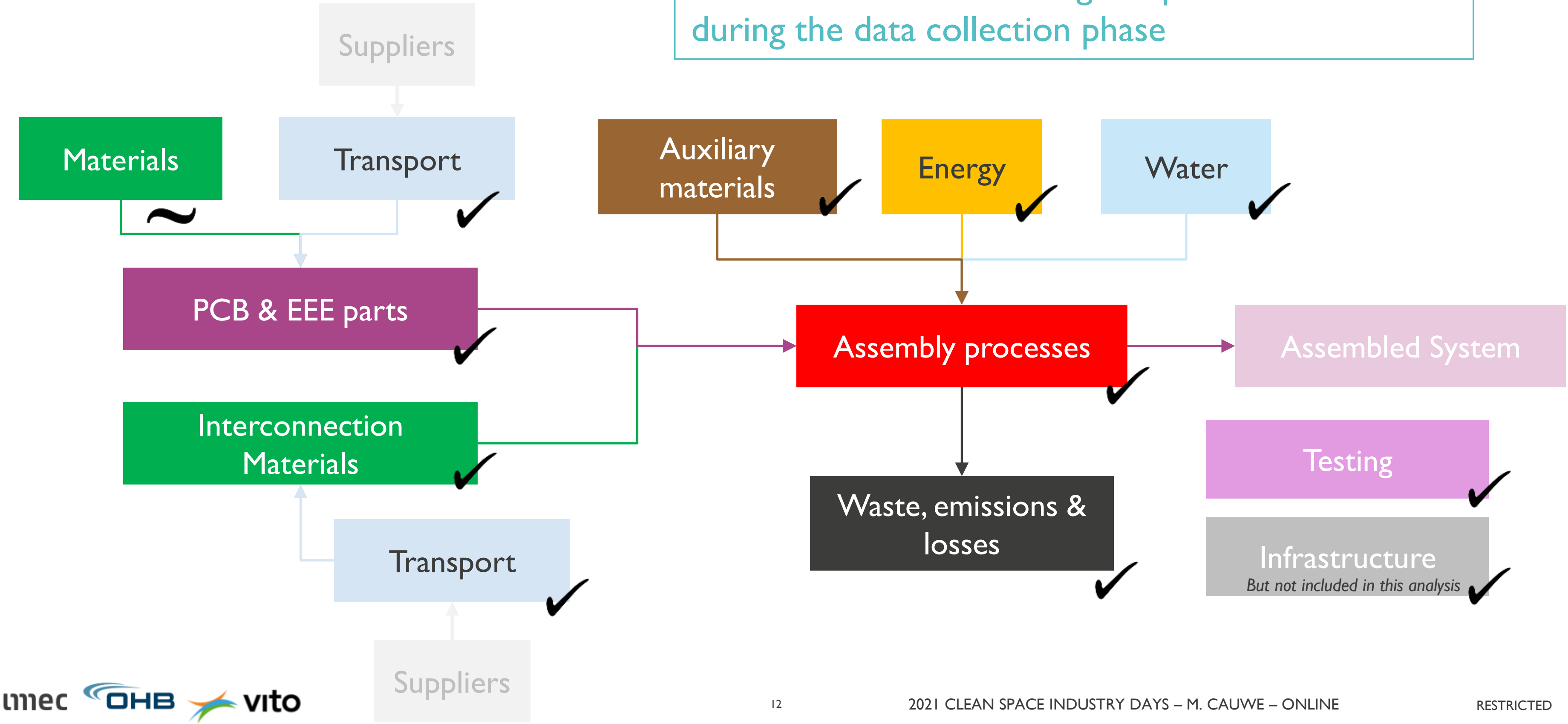
Carbon footprint standards:
ISO 14067
PAS 2050
GHG Protocol Product Standard

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

Iteration 1 – baseline LCA

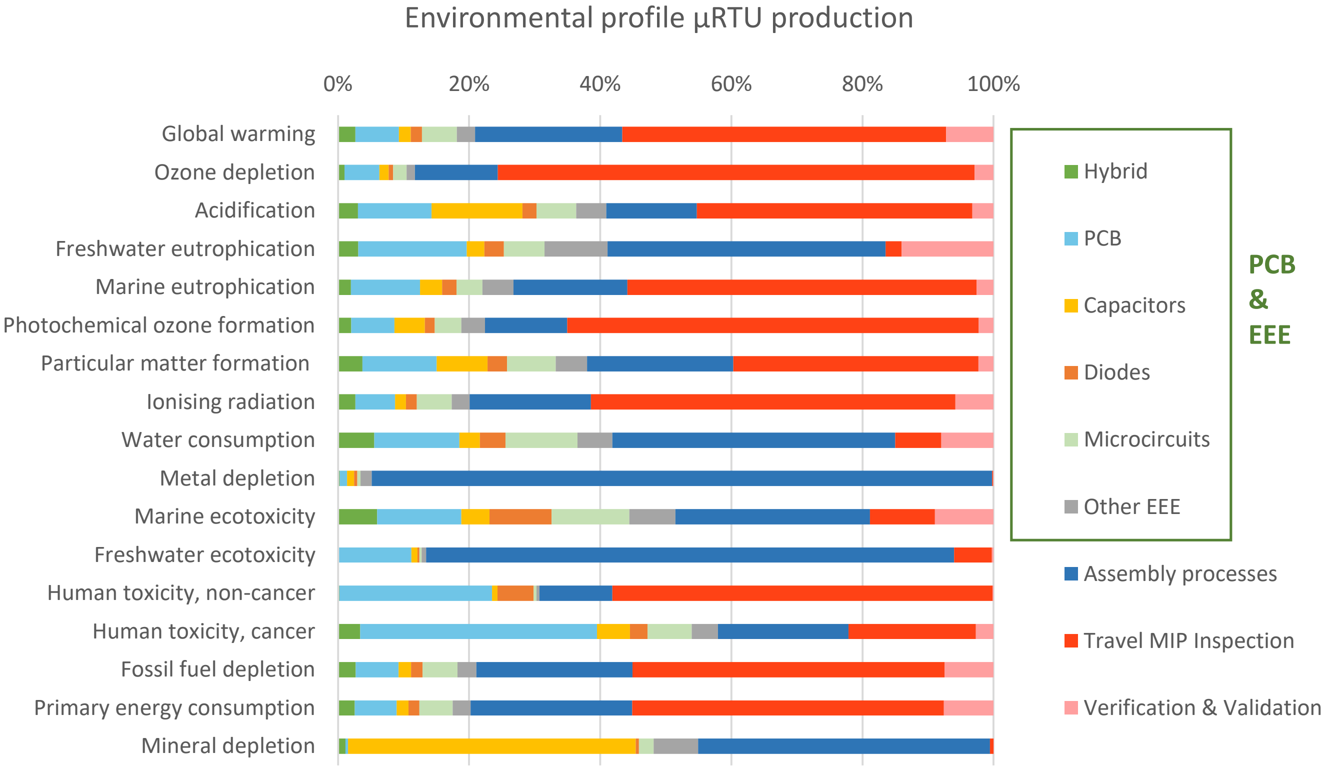
LIFE CYCLE INVENTORY

Close collaboration among the partners is essential during the data collection phase



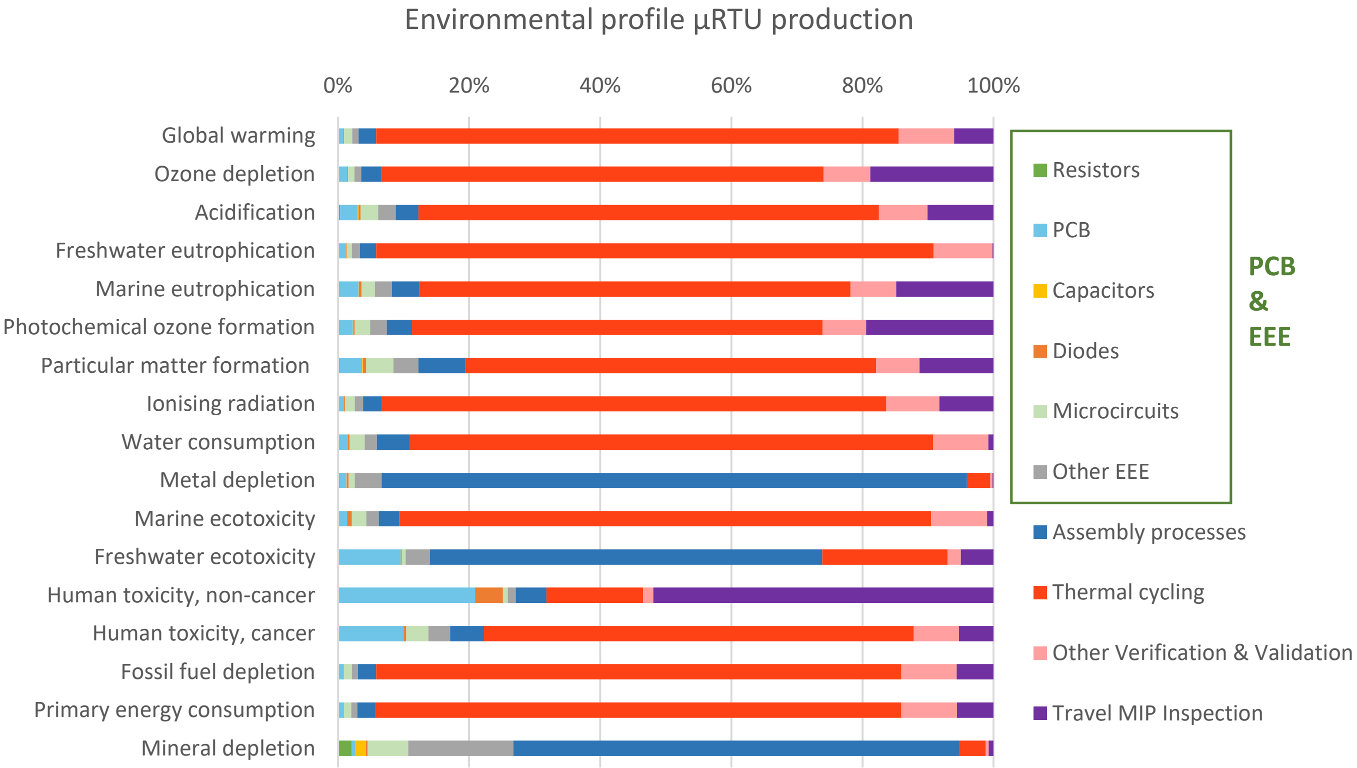
Iteration 1 – baseline LCA

IMPACT ASSESSMENT – µRTU PRODUCTION



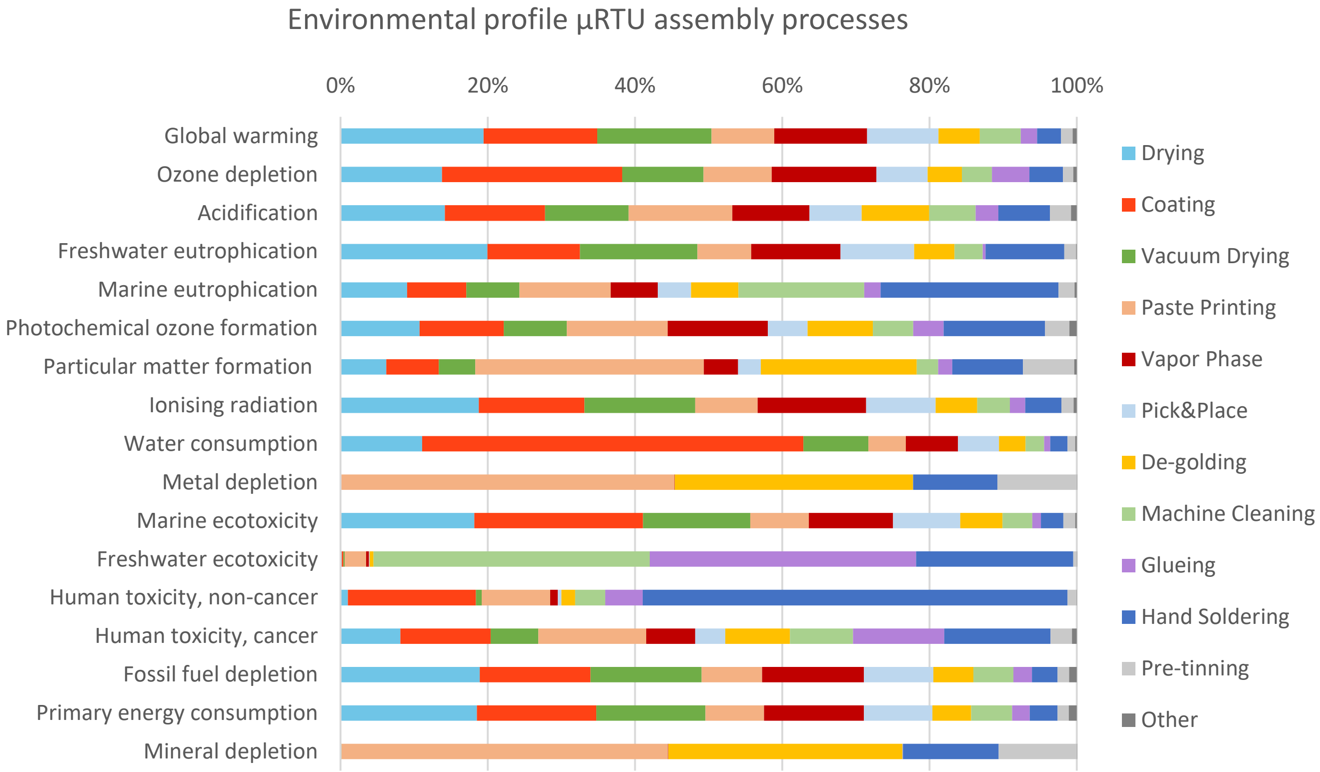
Iteration 1 – baseline LCA

IMPACT ASSESSMENT – µRTU PRODUCTION: IMPACT OF TESTING



Iteration 1 – baseline LCA

IMPACT ASSESSMENT – µRTU PRODUCTION: ASSEMBLY PROCESSES



Iteration 1 – baseline LCA

IMPACT ASSESSMENT – HOTSPOT MATRIX

	PCB & EEE production and transport						Assembly	Verification & Validation	
Impact category	PCB	Capacitors	Diodes	Microcircuits	Hybrid	Other EEE	Assembly processes	Travel MIP Inspection	Other
Global warming	Electricity			Electricity	Electricity	Au, electricity			
Ozone depletion	NaOH, fossil fuel						Electricity	Airplane	
Acidification	Cu, electricity	Palladium			Electricity, gold				Electricity
Freshwater eutrophication	Ultrapure water	Silver	Electricity, Mo	Electricity, gold					
Marine eutrophication	Ultrapure water, PEI, electricity	Ag, Pd				Gold (connector), electricity	Electricity, flux[1]		
Photochemical ozone formation	Electricity, Cu	Pd, Ag, electricity					Electricity	Airplane	
Particular matter formation		Palladium	Electricity, Mo				Sn solder[2]		
Ionising radiation				Electricity	Electricity		Electricity		
Water consumption	Electricity	Electricity	Electricity						Electricity
Metal depletion							Tin		
Marine ecotoxicity	Electricity	Electricity	HF emissions	Electricity, Au	Electricity, Au	Au, electricity	Electricity		Electricity
Freshwater ecotoxicity	BPA for PI						Adhesive[3] and cleaning agent[4]		
Human toxicity, non-cancer	DPGME		Xylene emissions				Flux[1]	Airplane	
Human toxicity, cancer	Ethylenediamine for PI	Plastic waste	Electricity, fossil fuels				Electricity and adhesive[3]		
Fossil fuel depletion				Electricity	Electricity	Gold, electricity			Electricity
Primary energy consumption	Electricity						Electricity		
Mineral depletion		Tantalum				gold	Tin		

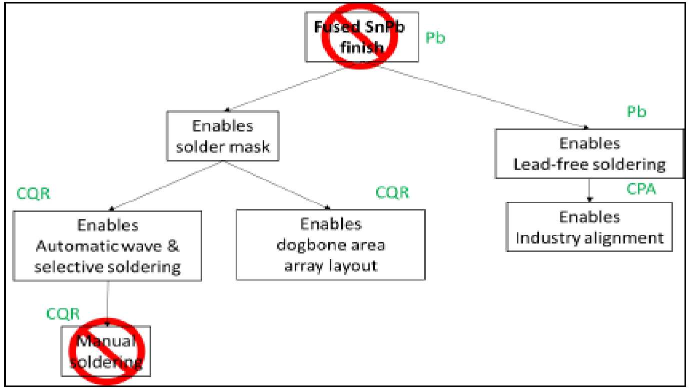
1. Flux for hand soldering
2. Sn solder for de-golding and paste printing
3. Adhesive for gluing
4. Cleaning agent for machine cleaning

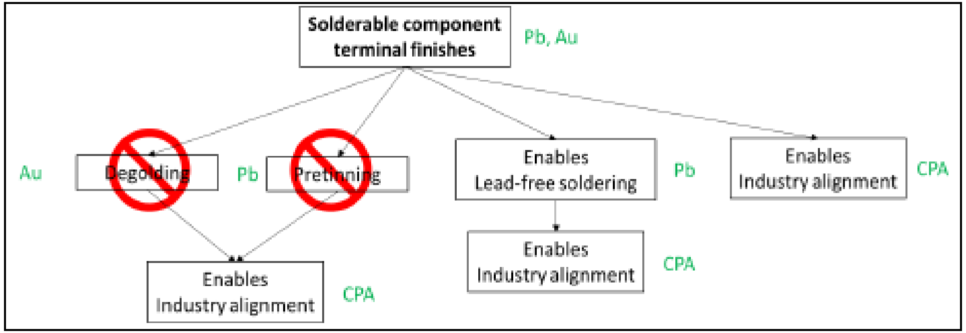
PEI = polyetherimide
BPA = bisphenol A
PI = polyimide
DPGME = dipropylene glycol monomethyl ether
HF = hydrogen fluoride

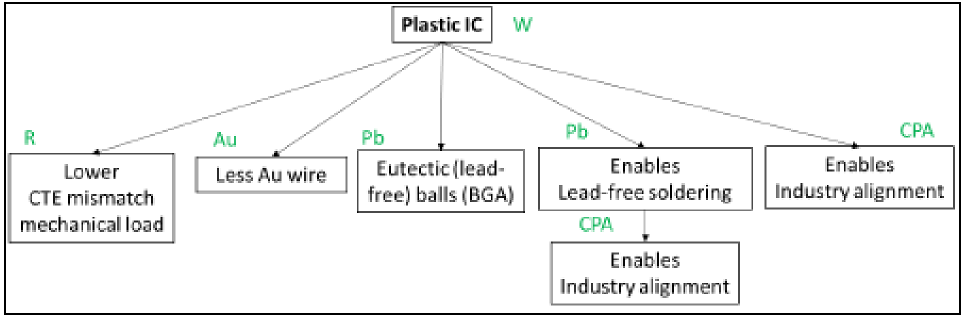
2,5% - 10%
10% - 25%
25% - 50%
50% - 100%

Eco-design option selection

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

LCA model improvement

KNOW THE LINGO (LCA, LCI, LCIA, DATA COLLECTION, RECORD, MODEL…)

- LCA model improvement can be performed at data level or in the model itself
- LCA model: methodology to obtain the environmental load parameters
  - Full simulation of a process (virtual twin)
  - Crude proxy (e.g. fixed energy use per kg)
- The data level refers to the input data/parameters that are put into the model

Model name	FU	LCI name
Electronic Unit - High IC	kg	LCI_Mounted_PWB_low_IC_1kg
Electronic Unit - Low IC	kg	LCI_Mounted_PWB_high_IC_1kg
Electronic Unit - High IC - Memory only	kg	LCI_Mounted_PWB_high_IC_memory_only_1kg

Description		1 kg of Electronic unit, high IC		
FU		1,0	kg	
Name	Breakdown	Quantity	Units	Life cycle inventory
Material inputs				
Integrated circuit (logic type)	8%	0,08	kg/FU	Integrated circuit (IC), logic type, at plant/GLO U
Integrated circuit (memory type)	2%	0,02	kg/FU	Integrated circuit (IC), memory type, at plant/GLO U
Other electronic components	56%	0,56	kg/FU	PWB surface mounted components, incl. tantalum capacitor, no ICs /GLO U
Printed Wiring Board, empty	32%	0,32	kg/FU	Printed wiring board, surface mount, lead-containing surface, at plant/GLO U
Silicone coating	2%	0,02	kg/FU	silicone product, at plant, RER
Transports raw materials				
Truck		0,5	tkm	Transport, lorry >16t, fleet average, RER
Manufacturing Processes				
Mounting of PWB		0,307	m2	Mounting, surface mount technology, Pb-containing solder/GLO U
Electricity for bake-out		0,00826	kWh	electricity, medium voltage, production RER, at grid, RER

LCA model improvement

LCA CHALLENGES

State-of-the-Art:

- Most recent IC LCA data dates from 2010 (Sarah Boyd)
- Insufficient data about PCB production to assess impact of manufacturing choices
- Insufficient data about IC component assembly (packaging) to assess the impact of introduction of plastic packages, non-gold plated leads, Cu-wire, etc.
- Insufficient data about PBA assembly to assess the impact of a change of PCB, component and/or solder material

Need:

- **Parametric material use and production models** for ICs (and other components), IC assembly, PCB, PBA assembly. Input parameter(s): design or build-up.

⇔ Caveats: complexity, number of components/processes, accessibility of data...

LCA model improvement

SCOPE FOR GREEN-ESPACE

Other Component

Non-IC El. Comp.

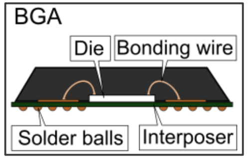
IC Component

IC

Substrate

Body/Mold

Lead(s)(frame)



Mechanics

El. Comp. BOM

Printed Circuit Board

Assembly Materials

{Printed Board Assembly}

Cabling

Mechanics

{Electronic Box}

Cabling

Mechanics

{Electronic Equipment}

Cabling

Mechanics

{Other Equipment}

(Sub)SYSTEM

Out-of-scope

Under consideration

Partially covered

LCA target

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…

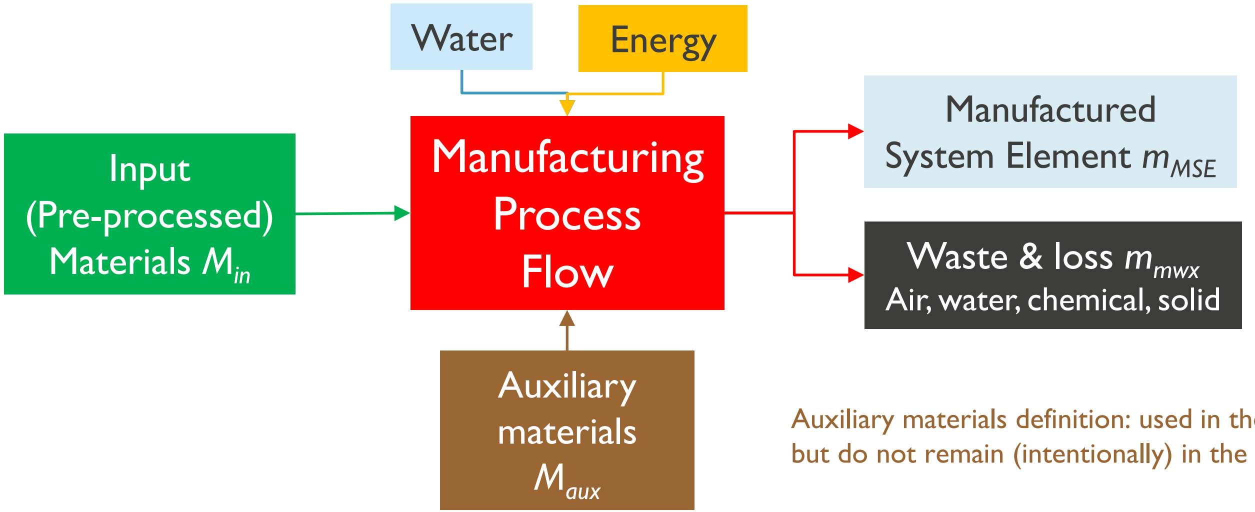
Solderable finish per m² of PCB			
A_{pcb} (m^2)	1		
PCB A_{Cu_t} (m^2)	0,2	PCB A_{Cu_t} (%)	20
PCB A_{Cu_b} (m^2)	0,12	PCB A_{Cu_b} (%)	12
# PCB/panel	3		
Solder Mask?	Yes		
PCB A_{NoSM_t} (m^2)	0,0003	PCB A_{NoSM_t} (%)	0,03
PCB A_{NoSM_b} (m^2)	0,0002	PCB A_{NoSM_b} (%)	0,02
PCB A_{finish} (m^2)	**0,0005**	PCB A_{finish} (%)	**0,05**

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

MANUFACTURED PARTS



Auxiliary materials definition: used in the production process but do not remain (intentionally) in the product

Per manufactured element: primary parameter set

- Materials: M_{in}(type)+M_{aux}(type)=M_{mc}(type), m_{MSE}(ID), m_{mwx}(ID)
- Water: Consumed (volume, type), waste water (volume, m_{mww}(ID))
- Energy: consumed, type
- Waste: volume/mass/type
- MWEW parameters of input and auxiliary materials

LCA model improvement

ASSEMBLED PARTS

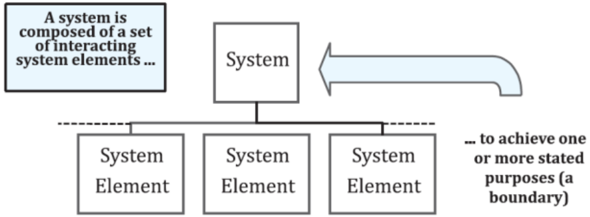
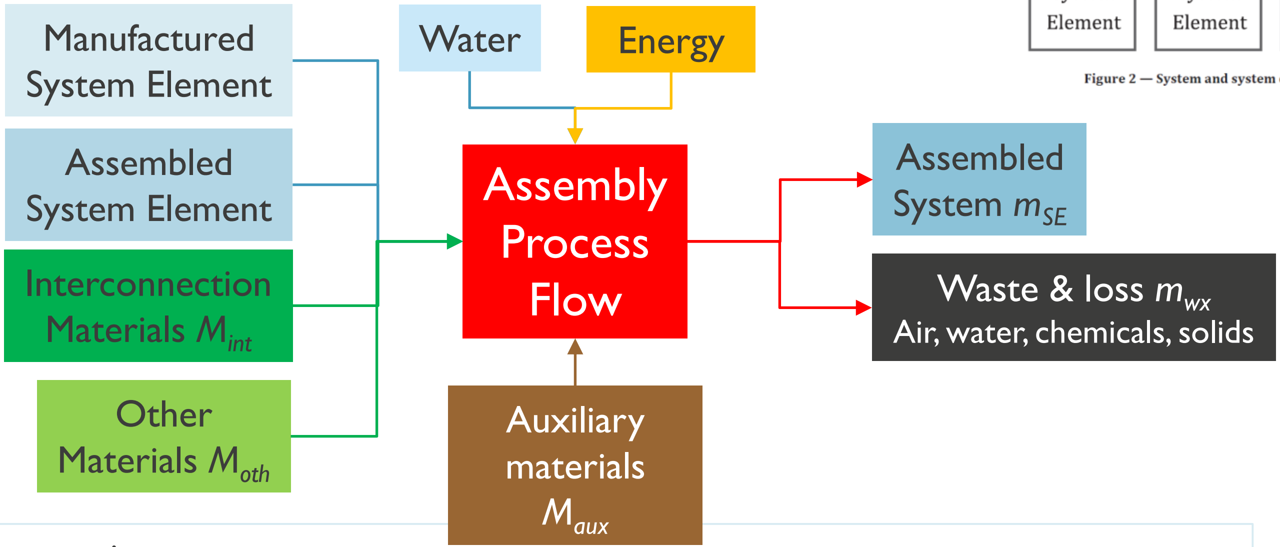


Figure 2 — System and system element relationship



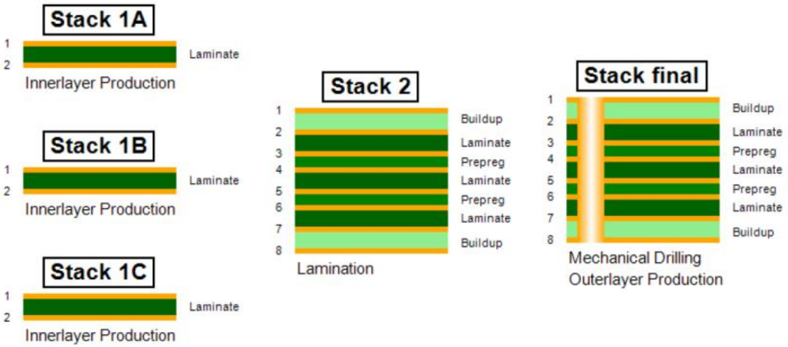
Per manufactured element: primary parameter set

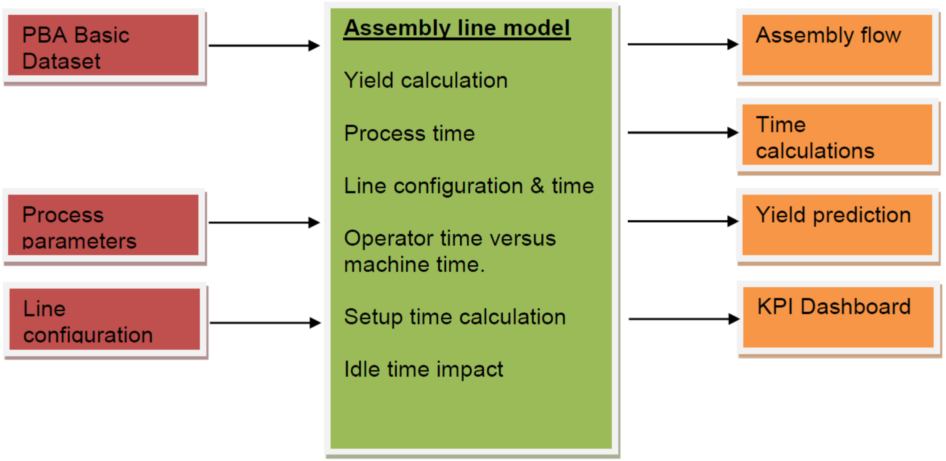
- MWEW parameters for all input parts and auxiliary materials
- Materials: M_{int}(type), M_{oth}(type), M_{aux}(type), M_{ac}(type), m_{SE}(ID), m_{wx}(ID)
- Water: Consumed (volume, type), waste water (volume, m_{ww}(ID))
- Energy: consumed, type
- Waste: volume/mass/type

LCA model improvement

PCB MANUFACTURING AND ASSEMBLY MODELS

- Process flow models PCB manufacturing
- PBA assembly line model
- Full Material Declaration sheet database





Homogeneous M...	Material Group	Mass	UoM	+	-	Level	Substance Category	+	-	Substance	CAS	Exe...	Mass	UoM
Bond Wire		3.57	mg	+	-	Supplier	Gold and Gold Com...	+	-	Gold	7440-57-5		3.57	mg
Leadframe Plating		4.55	mg	+	-	Supplier	Silver and Silver Co...	+	-	Silver	7440-22-4		4.55	mg
Die Attach Material		5.04	mg	+	-	Supplier	Silver and Silver Co...	+	-	Silver	7440-22-4		3.9312	mg
				+	-	Supplier	Proprietary Material...	+	-	Epoxy (EP)			1.1088	mg

Life Cycle Assessment of Green Electronics for Space

Takeaway message

Garbage input data → Good Model → Garbage results

Good input data → Garbage Model → Garbage results

Good input data → Good Model → Good results embracing a better life