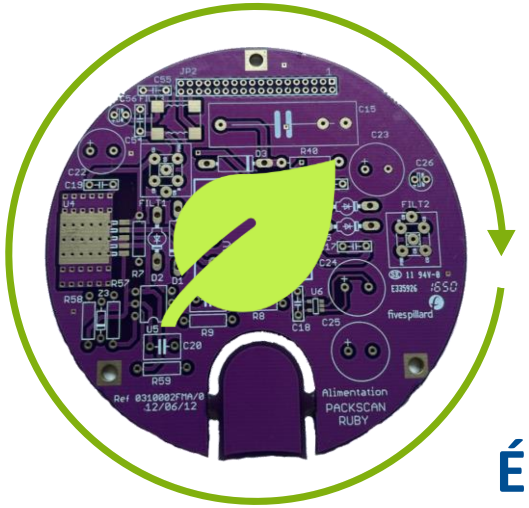
Symposium
pour l'électronique
& le numérique durables

Le 12 décembre 2024, Grenoble

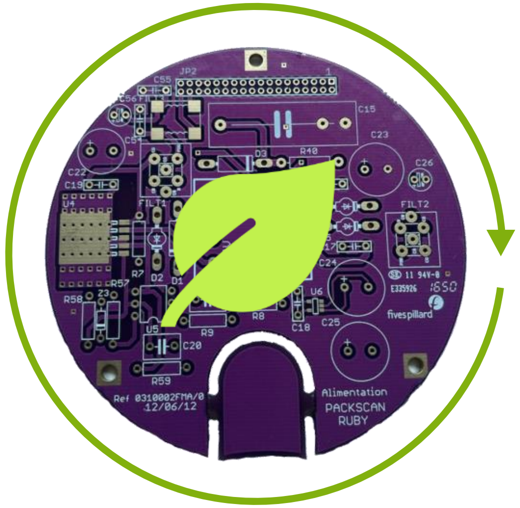
AVEC tech&fest



Vincent Grennerat
CROMA, équipe DHREAMS
G2Elab, équipe EP

Éco-conception du PCB : comment améliorer son cycle de vie grâce à des bio-matériaux et de nouvelles approches de conception de la carte électronique

Vincent Grennerat
Pascal Xavier (CROMA)
Pierre-Olivier Jeannin (G2ELab)



OUTLINE

Overcoming the electronic waste (WEEE) challenge

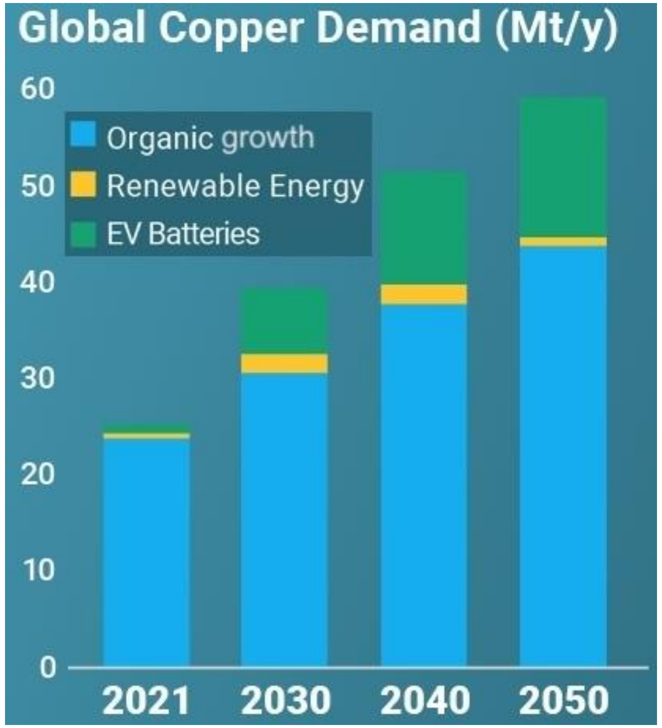
In 2030, projection of 75 Megatons of WEEE every year

Production and end of life ecological impacts

Economic growth and Net-Zero carbon by 2050:

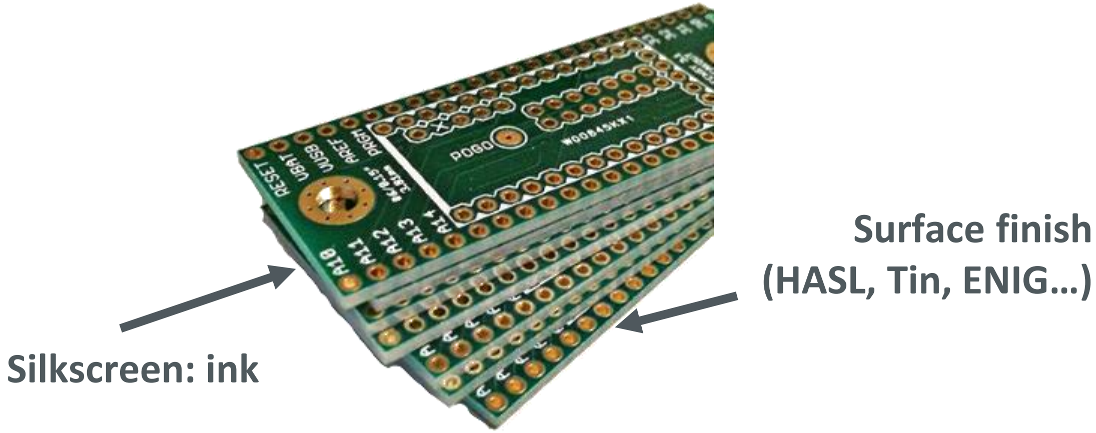
More copper to be extracted in the next **25 years** than during the last **2000** years

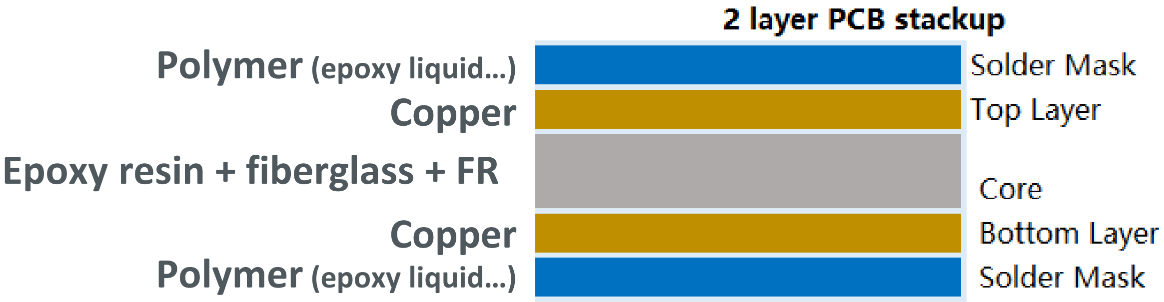
Resources depletion



Source : IFC, Technical report, 2023

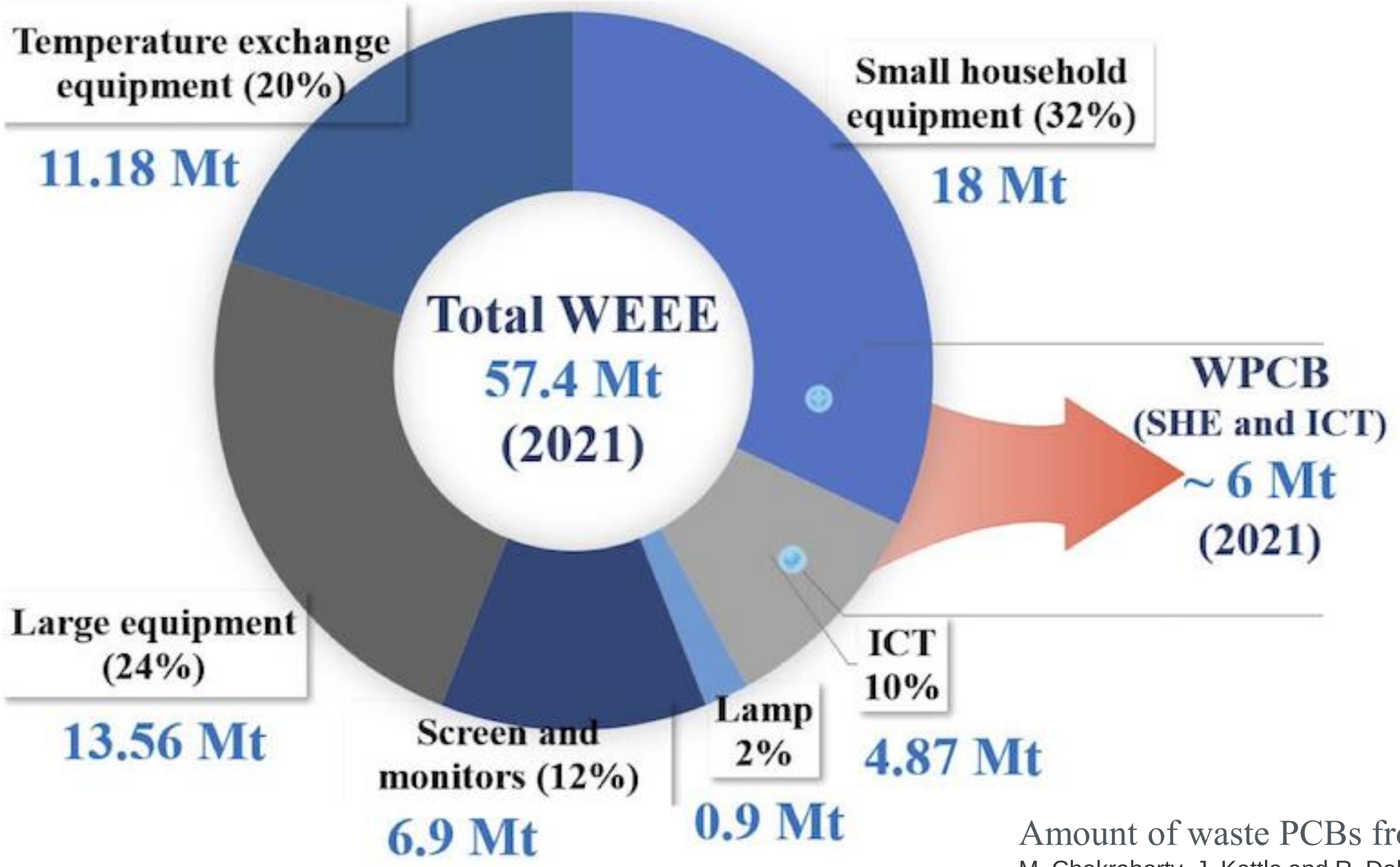
The main impacting materials in current PCBs





- Copper and a few other metals (and solder joints to be added-up)
- Petroleum products

The PCB part in WEEE

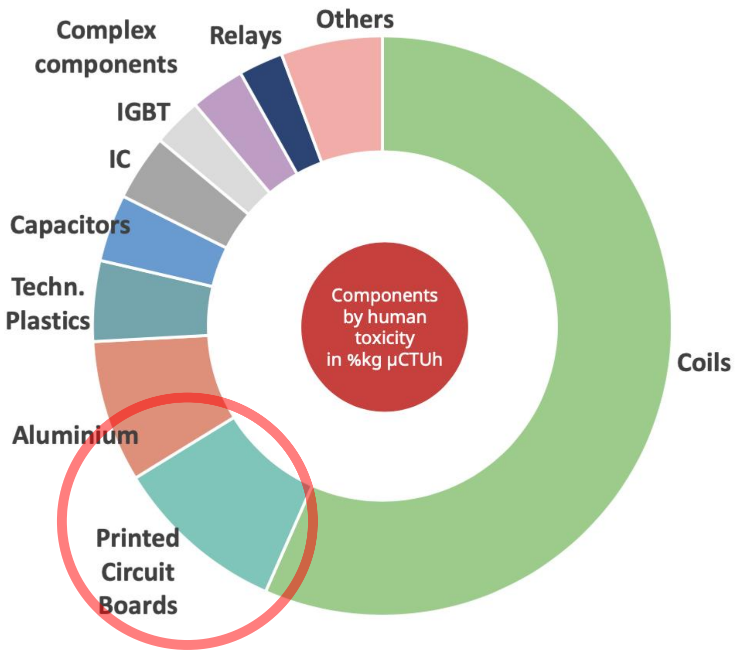


Amount of waste PCBs from WEEE in the year 2021

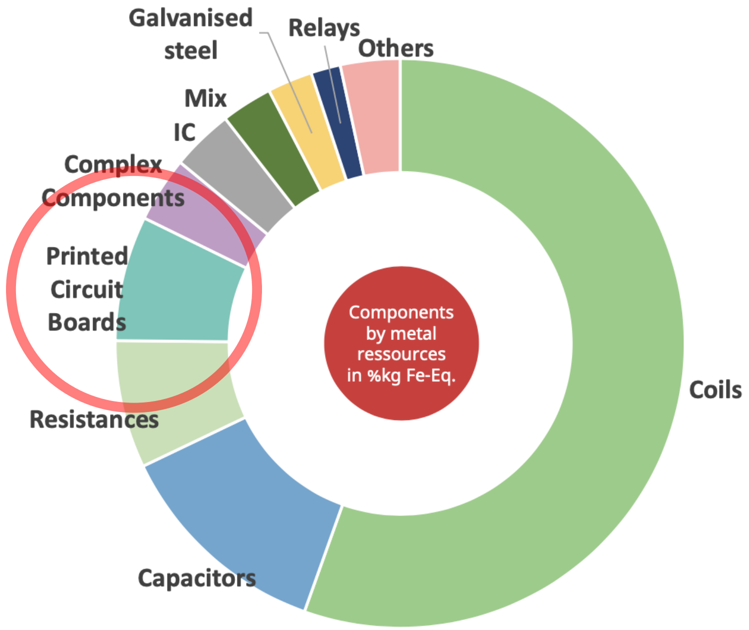
M. Chakraborty, J. Kettle and R. Dahiya, "Electronic Waste Reduction Through Devices and Printed Circuit Boards Designed for Circularity," in *IEEE Journal on Flexible Electronics*, vol. 1, no. 1, pp. 4-23, Jan. 2022, doi: 10.1109/JFLEX.2022.3159258 - 2022

PCB impacts ratio in electronic devices

Life cycle analysis (LCA) of a photovoltaic inverter (production impacts)



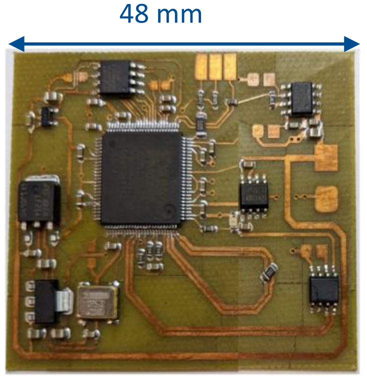
Human toxicity (based on PEF)

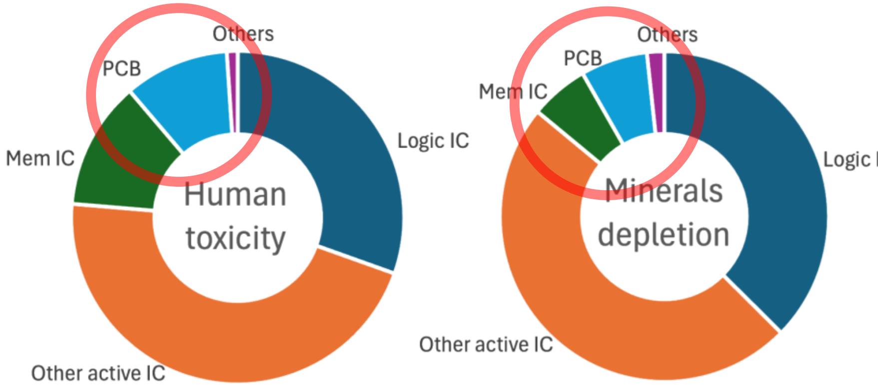


Minerals depletion (based on ReCiPe Midpoint)

Franz Musil, Fronius International GmbH

LCA of a small digital board with FPGA (production impacts)

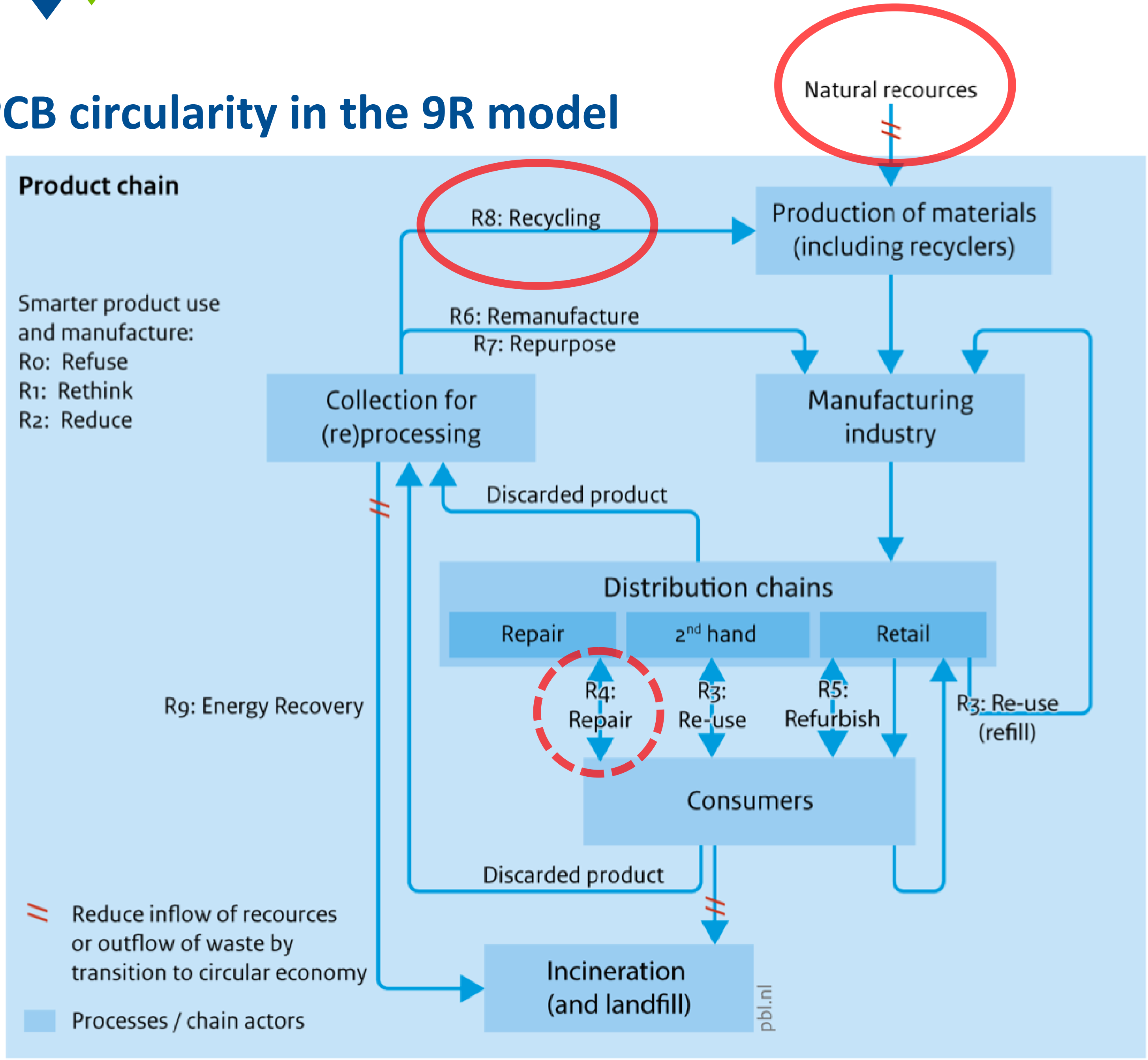




Human toxicity-carcinogenic and **Minerals depletion** LCA, based on ReCiPe Midpoint

Author FPGA board demonstrator, CROMA, 2023

PCB circularity in the 9R model



Smarter product use and manufacture	R0	Refuse	Make product redundant by abandoning its function or by offering the same function with a radically different product
	R1	Rethink	Make product use more intensive (e.g. through sharing products, or by putting multi-functional products on the market)
R2	R2	Reduce	Increase efficiency in product manufacture or use by consuming fewer natural resources and materials
Extend lifespan of product and its parts	R3	Re-use	Re-use by another consumer of discarded product which is still in good condition and fulfils its original function
	R4	Repair	Repair and maintenance of defective product so it can be used with its original function
	R5	Refurbish	Restore an old product and bring it up to date
	R6	Remanu-facture	Use parts of discarded product in a new product with the same function
	R7	Repurpose	Use discarded product or its parts in a new product with a different function
R8 Useful application of materials	R8	Recycle	Process materials to obtain the same (high grade) or lower (low grade) quality
	R9	Recover	Incineration of materials with energy recovery

pbl.nl

Source: PBL, Circular Economy: Measuring Innovation in the Product Chain

PCB circularity: technological barriers

Main barriers to reach a good circularity:

PCB substrate

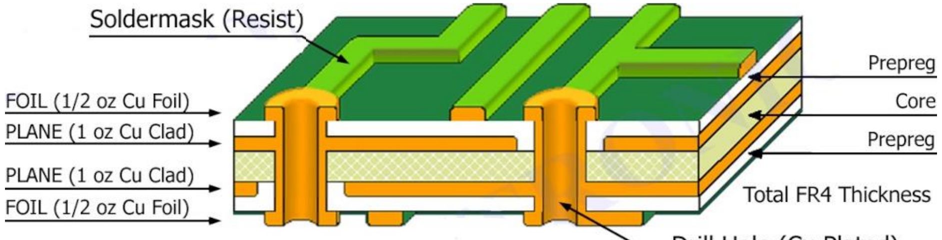
- Epoxy resin (oil product) is **not recyclable**
- Flame Retardants have high ecological impacts at end of life
- Glass fibers are difficult to isolate from epoxy at end of life

PCBA metals

- Poor yield of metals recovery with current technologies (mainly pyrometallurgy)

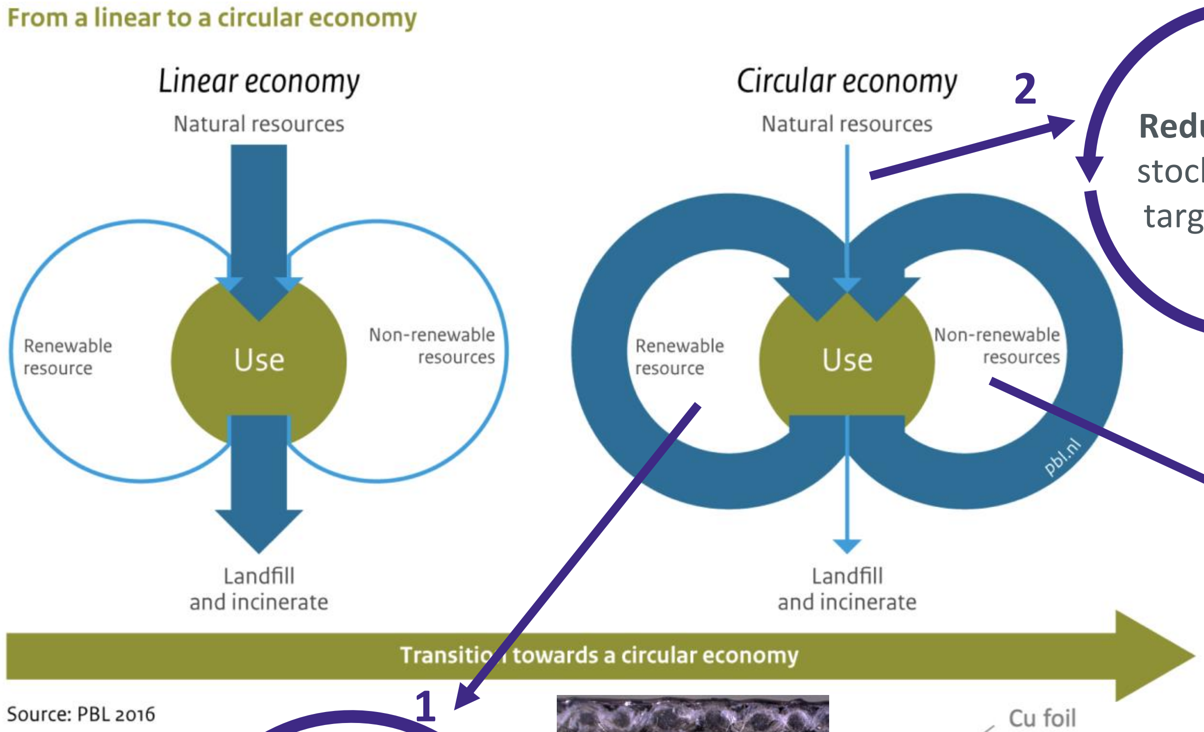
  Only the most precious metals (gold, platinum, the others as alloys) are recovered from boards with high density of critical metals (smartphone motherboards)

- With hydrometallurgy recovery technology, **multilayer** structures mean **complex** and lower yield **copper recovery**. It requires crushing in very small pellets (~1mm)



Source: CBS PCB

Increasing PCB circularity: our 3 main strands



2 — **Reduce** copper stocked in PCB, target 2 layers

Revisit usual **design rules** of boards layouts :

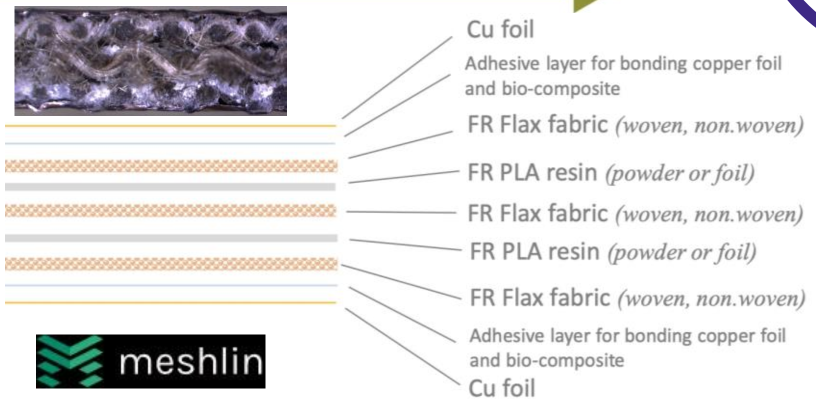
- **Refrain** using **copper pours** when they do not have an electronic function.
- Use **two layers** layouts when parts density or EMC constraints allow it.
- Explore the use of alternative solutions like jumpers or cape boards.

3 — **End of life:** metals recovery from PCB and from remaining parts through **bioleaching**

Hydrometallurgy = dissolving (and then precipitating) metals in an acid medium using chemical agents.

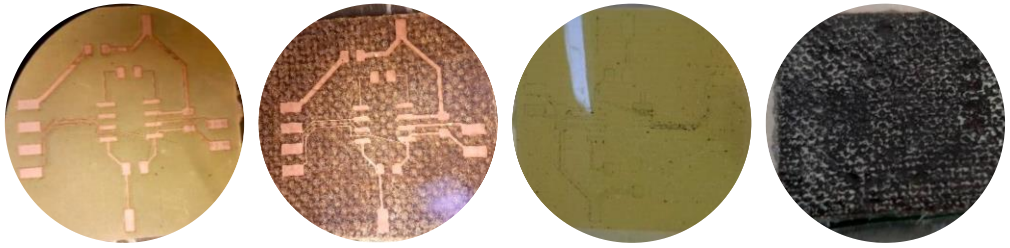
Bio-hydrometallurgy (bioleaching) = on top of hydrometallurgy, use of acidophilous bacteria to **reactivate** the chemical agents.

1 — Use of **biosourced** and **biodegradables substrates** => much lower impacts



meshlin

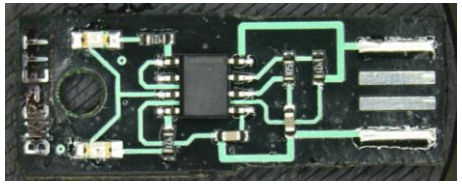
Cross section view & diagram of PLA-Flax biosourced & biodegradable composite

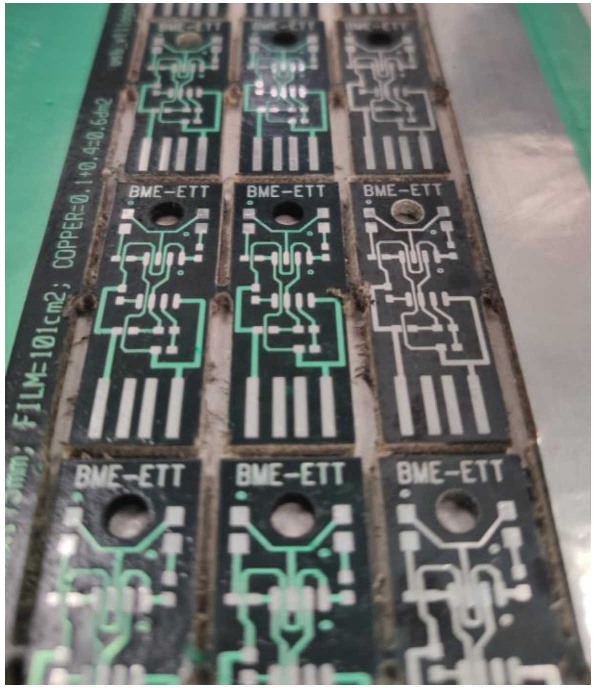


FR4 PCB and PLA-Flax: Before copper leaching - After copper leaching

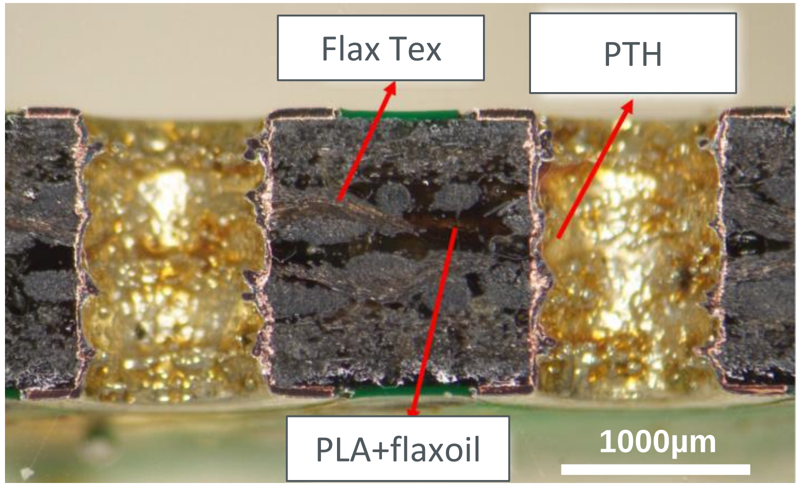
1 Bio-substrate PLA-flax

Blinkers and Arduino Nano-like on PLA-Flax bio-substrate, reliability tests

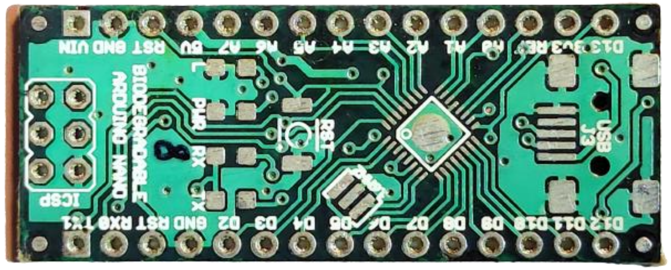




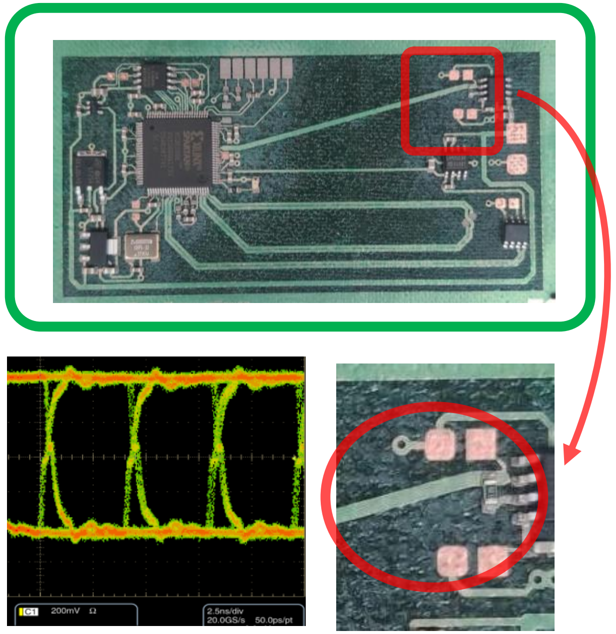
Large batches of simple SMD blinker



Cross section of PLA-Flax board with plated through holes

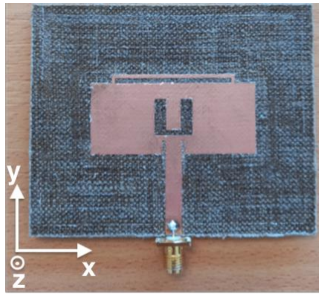


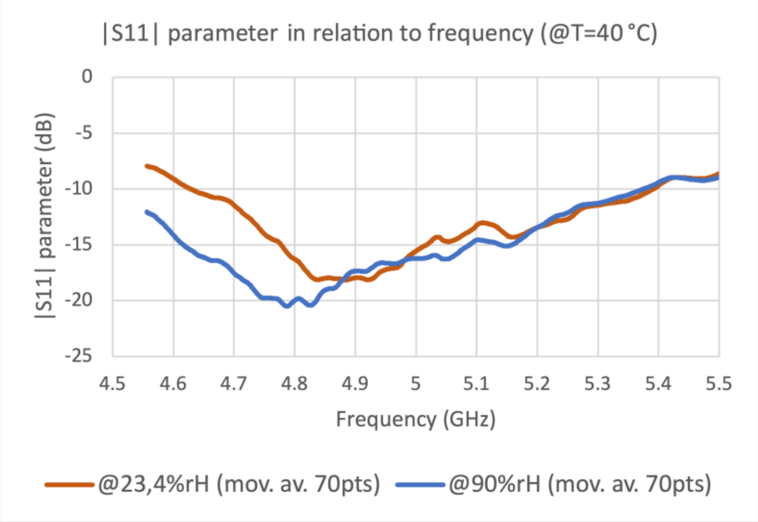
FPGA board on PLA-Flax



Eye diagram on matched impedance lines

PLA-Flax Patch Antenna – humidity study





1 Thermal challenges related to the use of bio-substrates

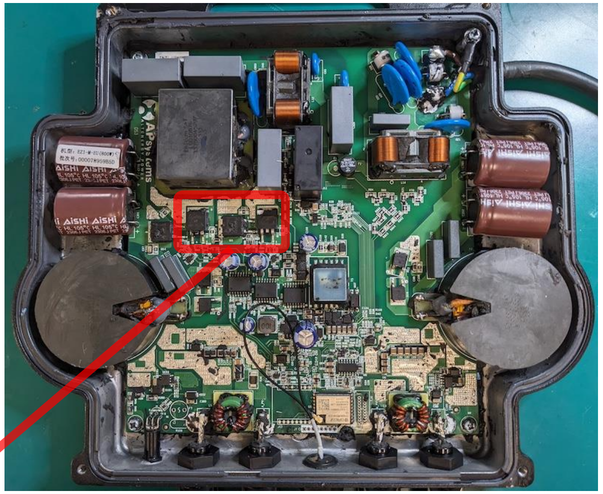
Thermal conductivity is lower (~ 2x) than that of epoxy-fiberglass FR4
When dissipating through the PCB, the thermal conductivity is decisive

→ Higher use of cooling techniques like thermal vias to the backplane dissipator.

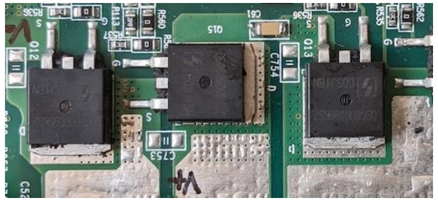
Glass transition temperature (Tg) is lower than FR4 one
=> assembly with traditional SnAgCu soldering can be problematic

→
- Research to create bio-substrates with higher Tg
- Develop new low temperature alloys? (~~Bismuth~~)

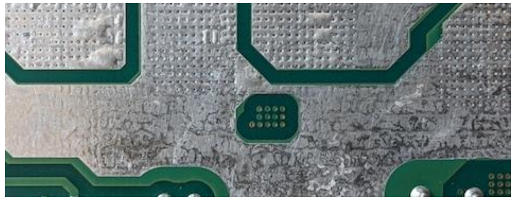
Photovoltaic panel microinverter demonstrator



FR4 reference design (APsystems commercial inverter)



Top side (TO263 packages)



bottom side

Cooling through a backplane of the DC-AC bridge

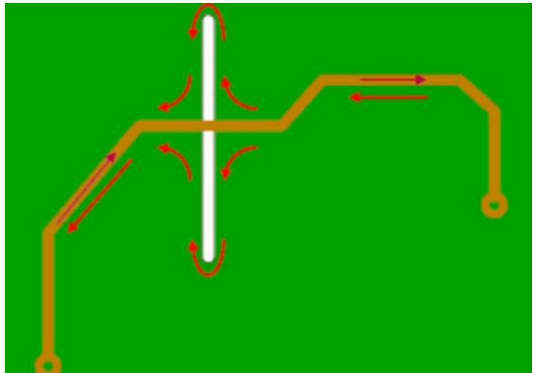
2 Challenges related to the decrease of copper usage

Reducing the copper circularity loop: it is stocked in the PCB for the lifetime of the product => each gram of copper which is not in the PCB is freed for other applications

Average lifetime of an EEE consumer product in France is 5 to 10 years
(ADEME, "Etude du potentiel d'amélioration du recyclage des métaux en France")

Why do I need a multilayers PCB?

- Unsegmented ground plane underneath matched lines
- Unseg. ground plane for EMC requirements
- Routing of BGA and PGA packages
- High density boards

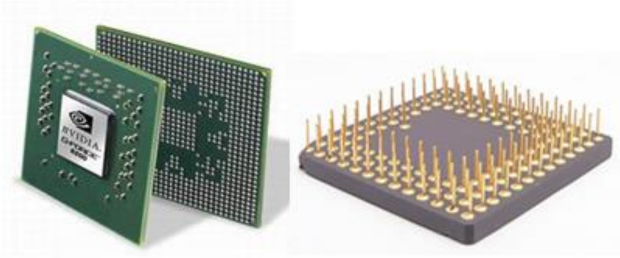


Signal – Top layer
GND plane - Inner layer
Current round trip

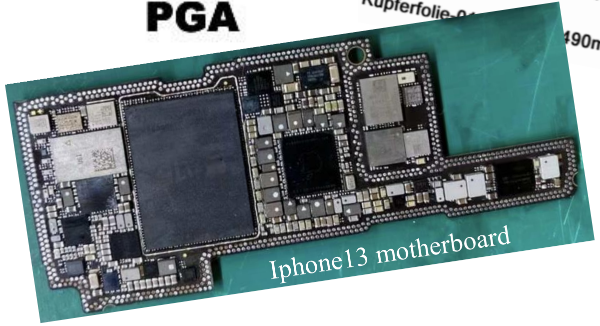
Segmented ground plane effect
Credits: Jean-Marc Neuville

Where do I need large amounts of copper in my PCB?

- Power supplies traces
- Ground plane underneath matched impedance lines
- 70µm layers for power application
- Ground traces
- Copper pour for thermal dissipation
- Power planes to reduce parasitic inductances
- Ground plane for EMC requirements



BGA PGA

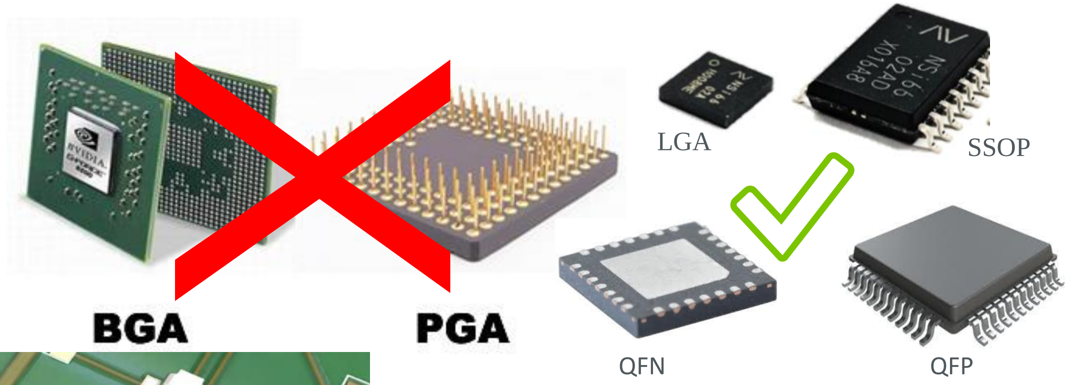


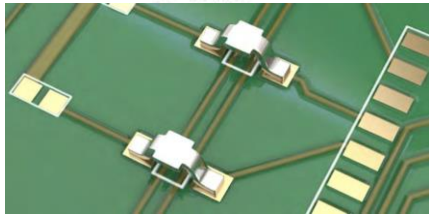
2 Challenges related to the decrease of copper usage

On consumer applications where parts density is not critical:

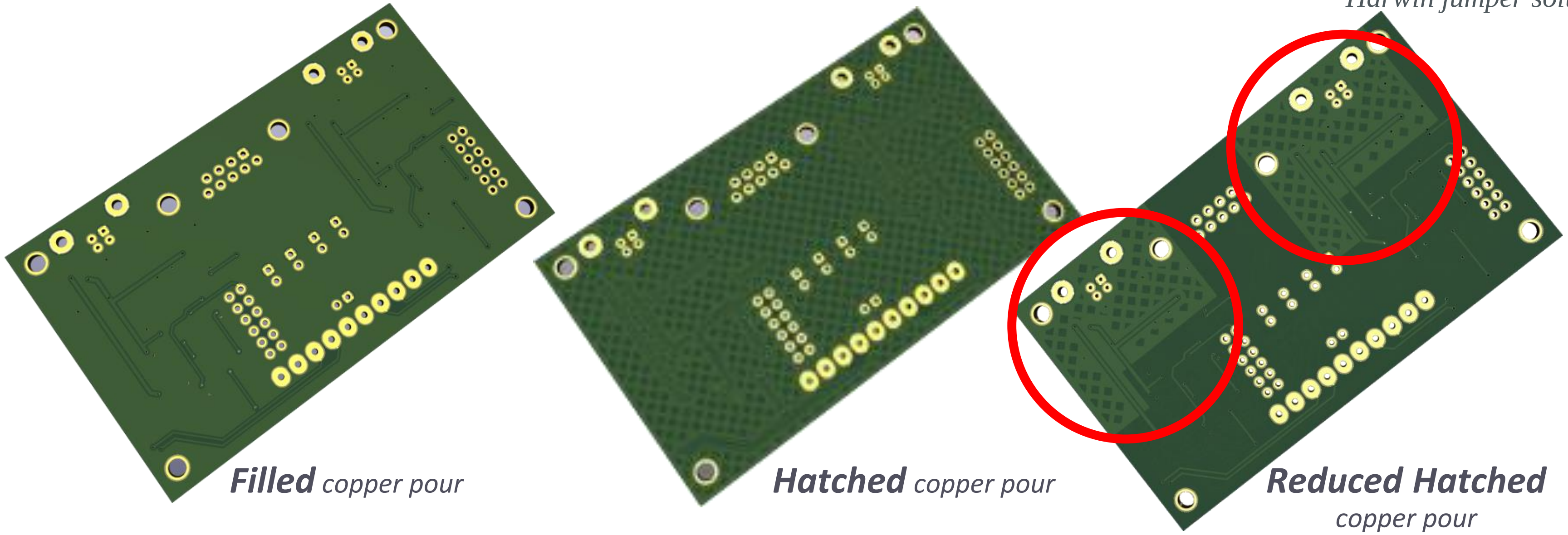
- **Grid array** packages should be avoided
- Alternative solutions like jumpers can help reduce the number of copper layers of the PCB, target being 2 layers
- Use a multilayers cape PCB for the high-density part of the design

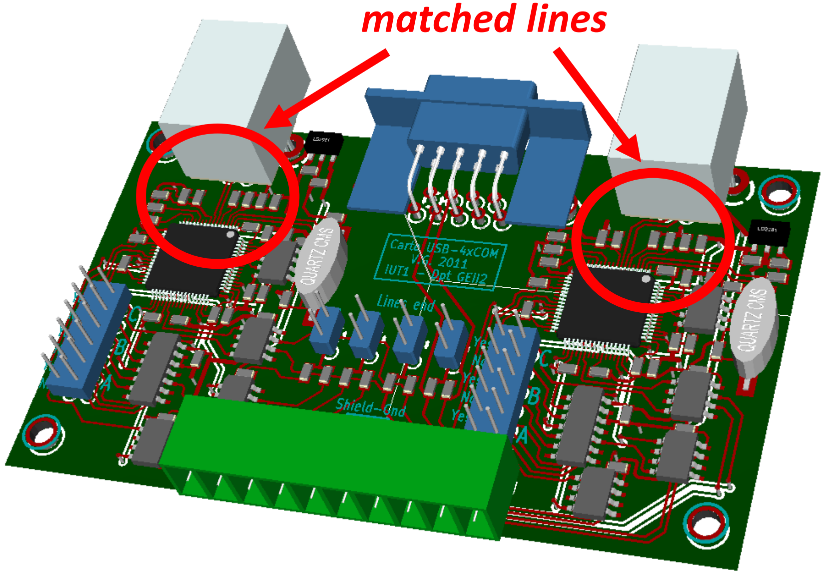
- Use of **copper pours** only where it is useful





Harwin jumper solutions





Ground plane layout: reduce useless copper

3 PCB end of life: bioleaching

WEEE

Pyrometallurgy

- High production flow
- Energy intensive
- Air pollution & GHG emissions

- Au, Pt
- Alloys (grey muds)

Hydrometallurgy

- Energy efficient
- Low air pollution & GHG emissions
- Chemicals residues

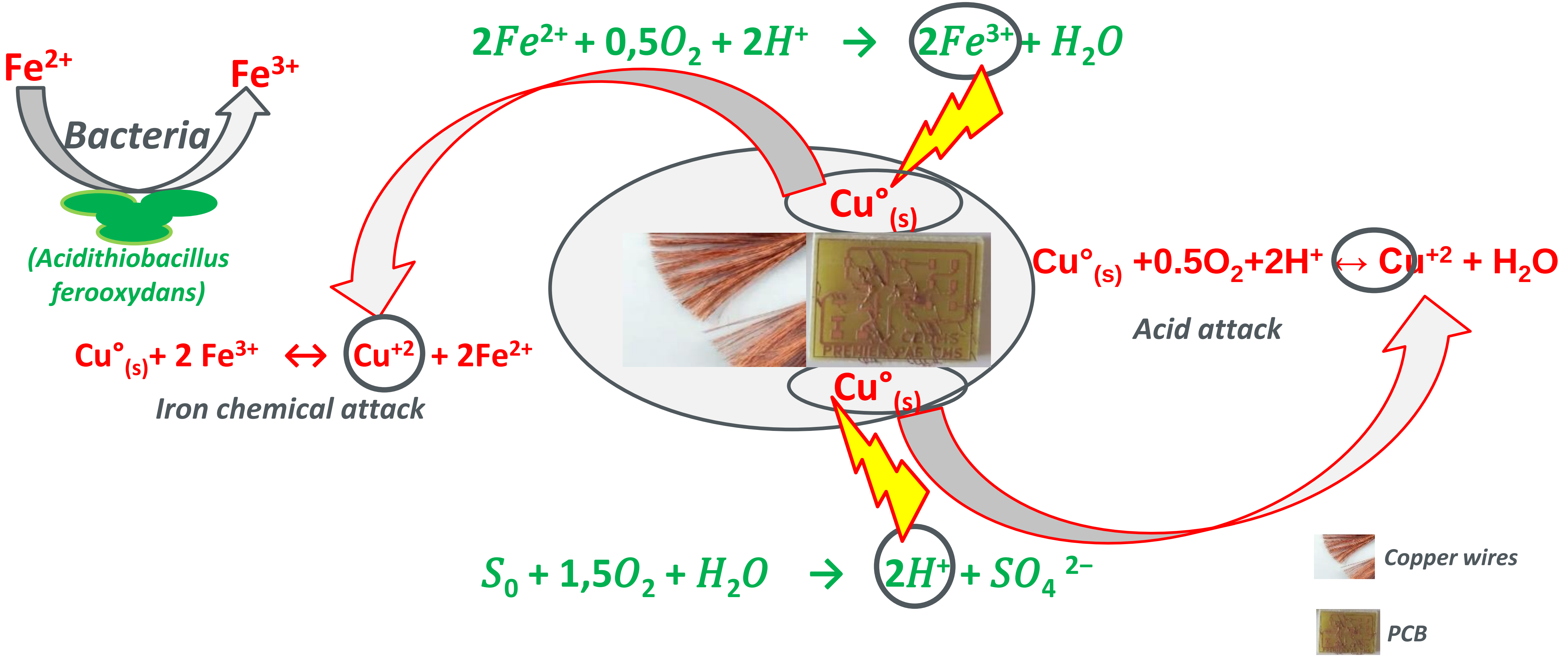
Bio-hydrometallurgy = bioleaching

- Energy efficient
- Chemicals in closed loop
- Slow process

- Pros
- Cons

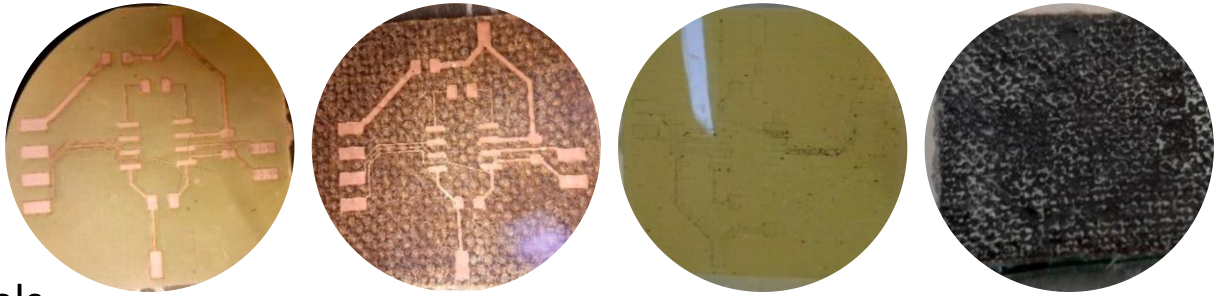
3 PCB end of life: bioleaching

Microbiology and chemical coupling



Reduced chemical impacts thanks to bacterial regeneration of some reagents

③ PCB end of life: bioleaching



Before copper leaching. - *After copper leaching*

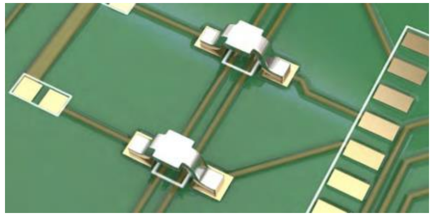
Copper leaching on glass-epoxy FR4 and PLA-Flax substrates

PCB design for bioleaching?

- Hydrometallurgy is slowed down by the concentration of metals
- Internal layers of multilayers PCB are problematic because leaching is prevented by substrate

➡

- Reduce useless copper in the PCB
- Favor 2 layers design by adapting design rules
- Favor packages with fewer metallic mass



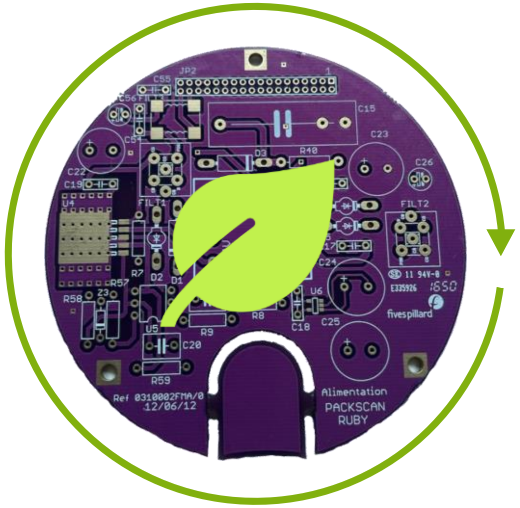
Harwin jumper solutions

NOVOSENSE NSi66 MOSFET driver in two different packages

LGA package - *SOIC package*

Takeaways to boost PCBs circularity

- Low impact biosourced biodegradable substrates are part of the solution
- Some design rules can be revisited to:
    - Reduce copper and other metals on the board
    - Favor 2 layers designs for low and intermediate density PCBs
- Packaging is part of the challenge
- Bioleaching technology is promising but to be combined with metals degrowth
- Life cycle analysis



Thank you for your attention

Vincent Grennerat
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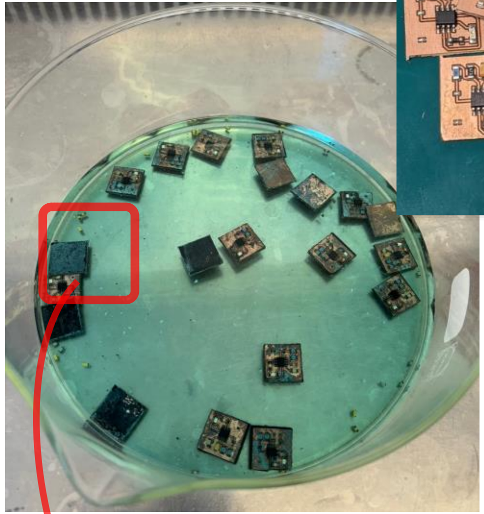
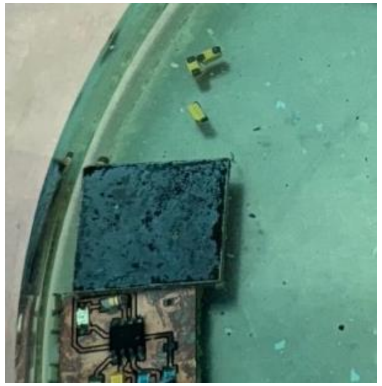
Pierre-Olivier Jeannin

Éco-conception du PCB : comment améliorer son cycle de vie grâce à des bio-matériaux et de nouvelles approches de conception de la carte électronique

3 PCB end of life: bioleaching

Calibrated WEEE



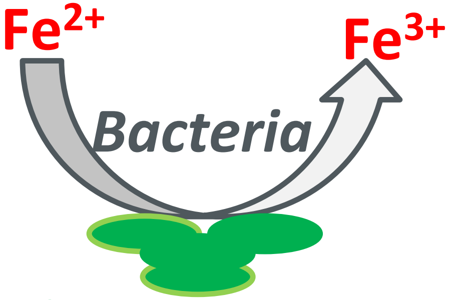


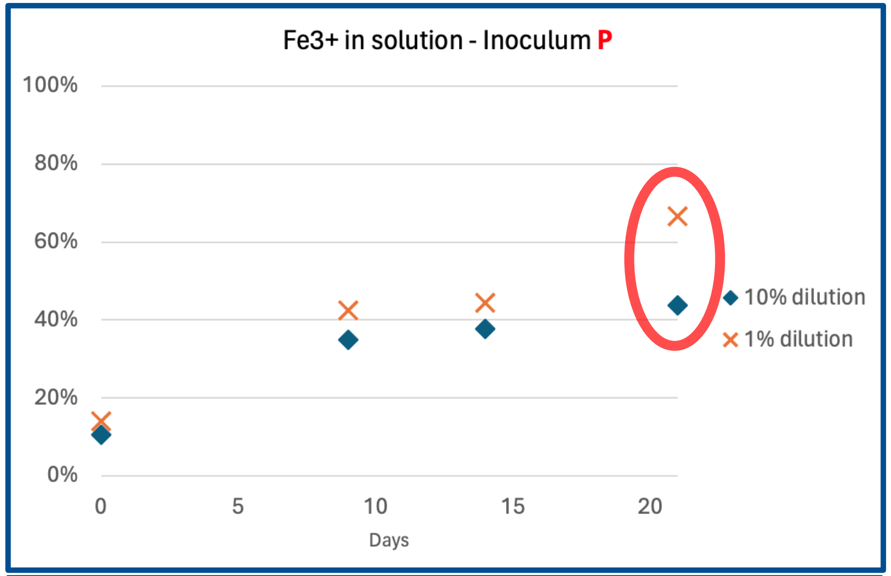
Leachate of copper (+ a bit of Sn, Ag…)

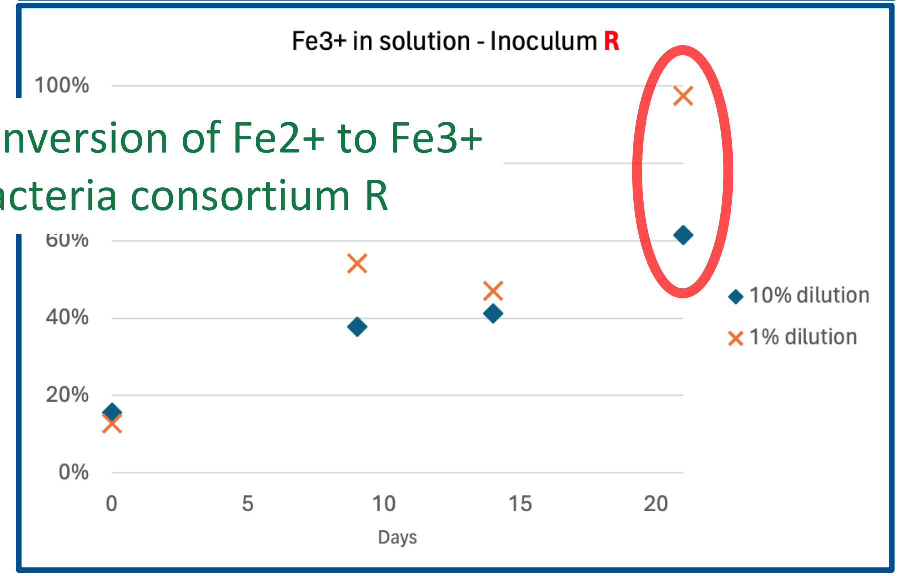
1/10 & 1/100 dilutions

Selected Bacteria consortium insertion into the **diluted leachate**

How toxic is the leachate for the bacteria?







97% conversion of Fe2+ to Fe3+ with bacteria consortium R

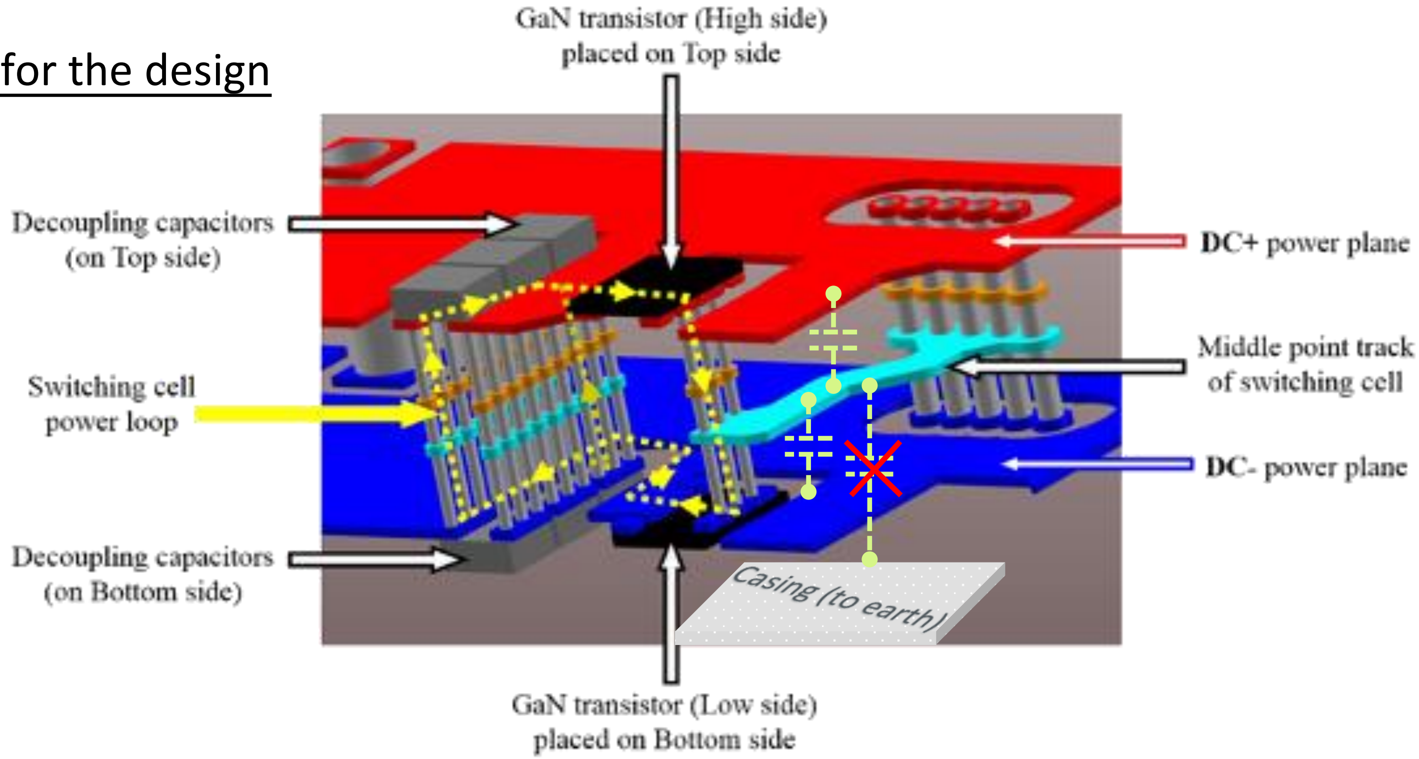
Acknowledgments to CNRS MITI which has financed the bioleaching experiments

2 Challenges related to the decrease of copper usage

The use of multilayers PCB provides flexibility for the design

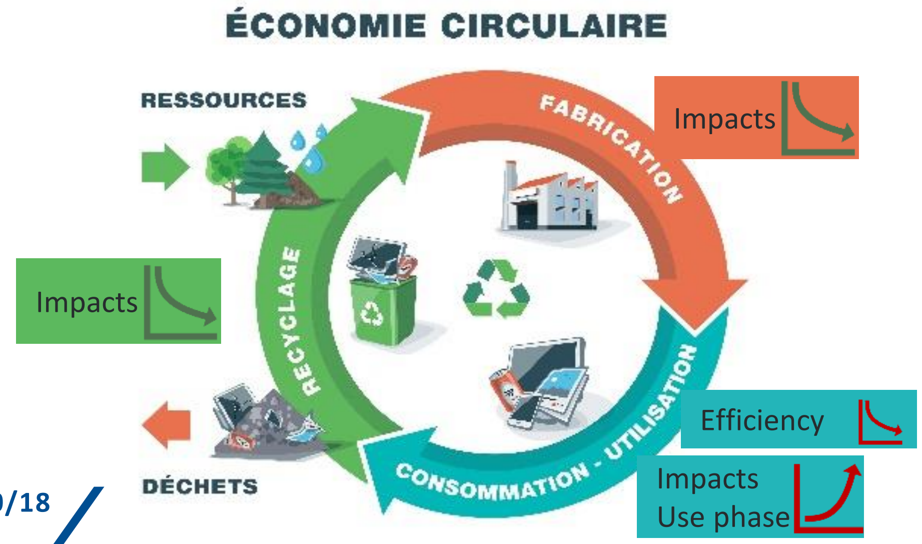
Ground and power planes help to:

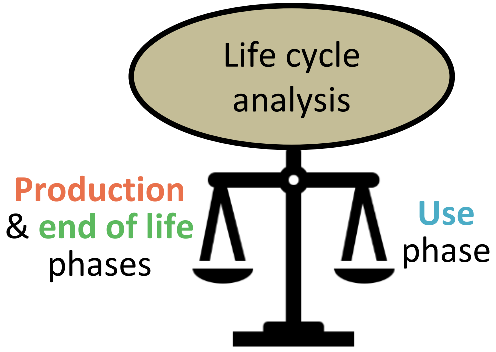
- Reduce parasitic inductances
- **Reduce conducted EMC**



Switching cell track shielding, Pawel Bogdan DERKACZ

- Evaluate alternative solutions like cover shields.
- Can a small decrease of the efficiency be acceptable? (LCA on whole life cycle will tell)



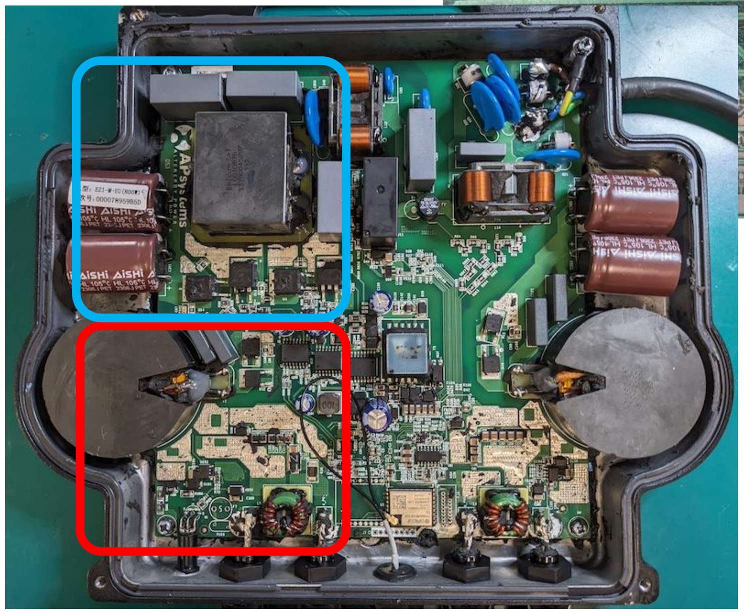


Perspectives

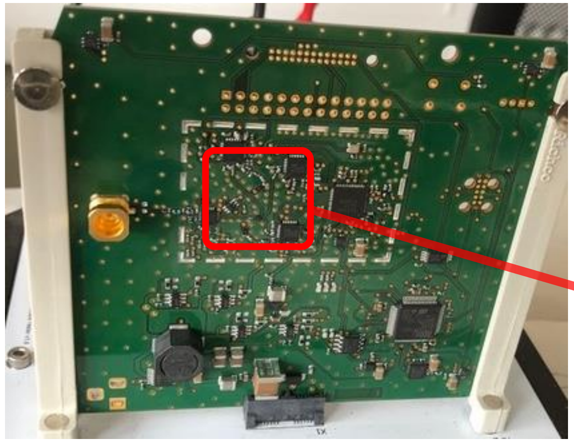
- After a previous high frequencies board demonstrator, evaluate the methodology on a power electronics application, a commercial photovoltaic microinverter:
  - **DC-DC** sub-system
  - **DC-AC** sub-system

- A radio frequencies demonstrator, focused on radio signal integrity (move the current design to a 2 layers solution with limited losses on RF signals)

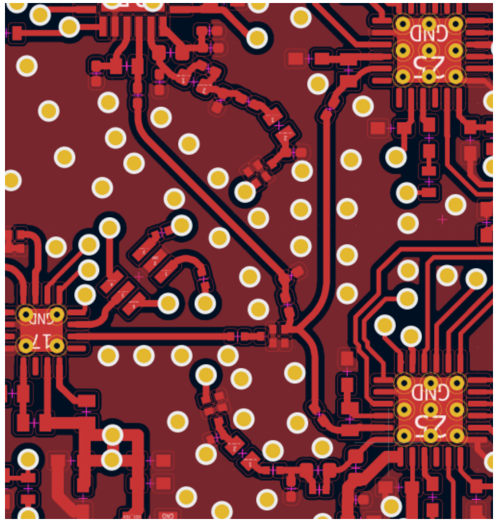
FPGA



APSystems EZ1-M microinverter



Gateway LoRa – Nano-satellite ThingSat
Centre Spatial Universitaire de Grenoble



Zoom on the 868MHz RF lines layout