
END'25
électronique & numérique durables

Paper PCB for sustainable electronics

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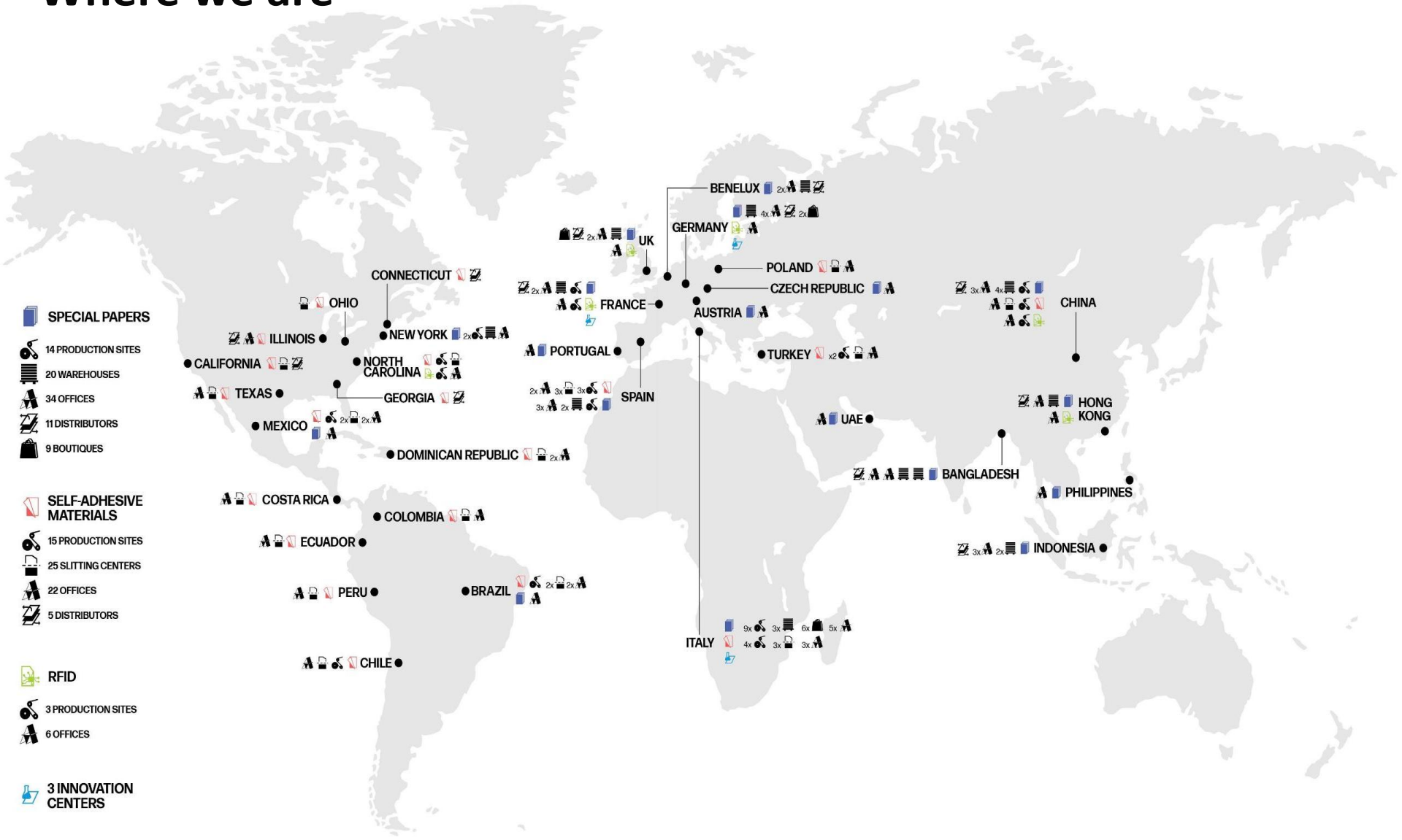
FEDRIGONI Group overview

Founded in **1888** in Verona, Italy, Fedrigoni is today synonymous with excellence in the world of labels and self-adhesive materials, special papers for luxury packaging and other creative solutions, RFID/NFC.

With about **6,000 employees** in **28 countries** and **25,000 products**, Fedrigoni sells and distributes in **132 countries** and, thanks to recent acquisitions, has gained the positions of first global player in wine labels and specialty papers for luxury packaging, second in art and design papers, and third in premium self-adhesive materials.

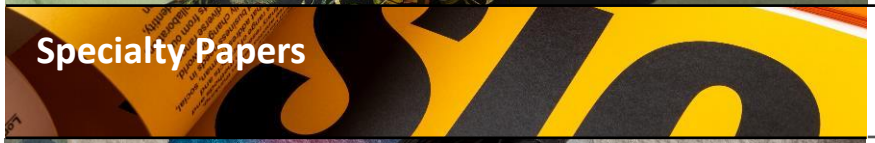
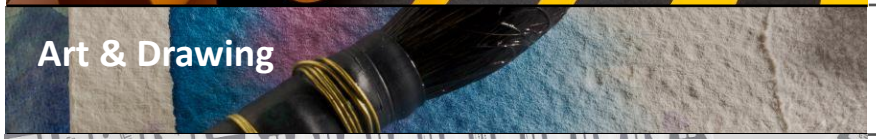
We guarantee the same excellence and commitment to sustainability at a global scale, with offices and warehouses all over the world.

Where we are



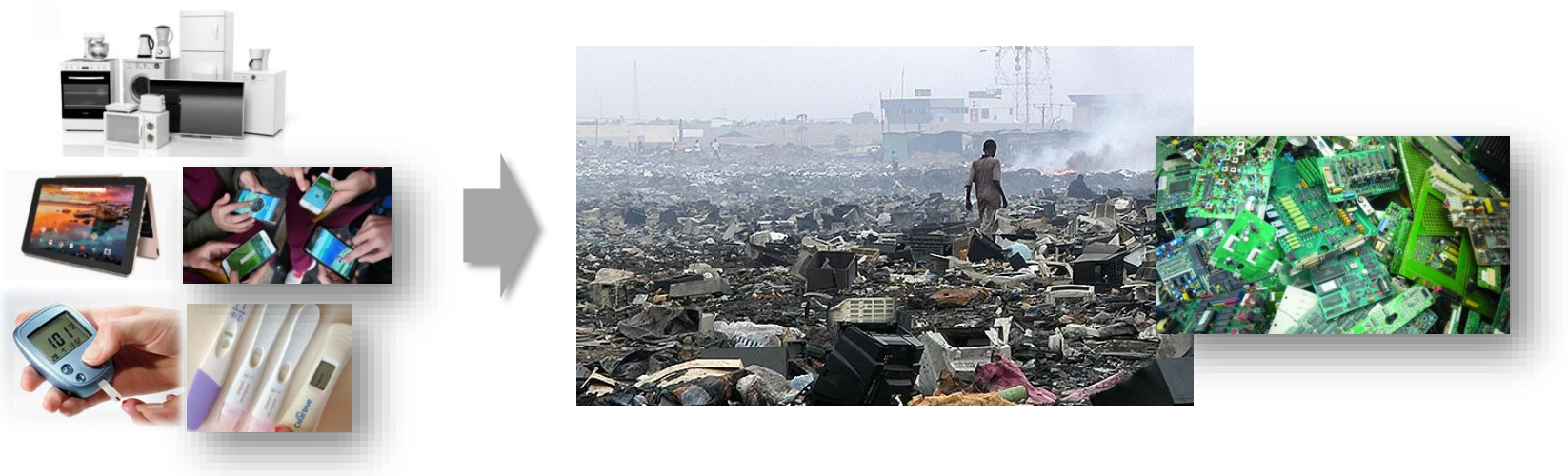
FEDRIGONI

Leading position in attractive premium niche markets

PRODUCT	END MARKET	MARKET POSITION
 Self-adhesive materials	Wine and Spirits, Home and Personal Care, Premium Food, Pharma	1 **Global** Wine 3 **Global** Self-adhesives
 Specialty Papers	Luxury packaging (rigid carton and shopping bags) and Creative Communication	1 **Global** Luxury Packaging 1 **Europe** Fine Paper
 Art & Drawing	Students, Artists, Hobbyists	2 **Global** Art & Drawing
 RFID	Apparel and Footwear, Food and groceries, Automotive, Aviation, Healthcare and Pharma, Logistics, Industrial Manufacturing, Public transportation and ticketing, Electronics	**TOP 5** **Global**

Source: market positions taken from a leading paper industry consulting firm report.

Introduction : Electronic waste issue



- 62 million tons/year of e-waste in the world in 2022 (1)

  increase of 82% since 2010, with 82M tonnes predicted in 2030

- PCBs make up 42% of e-waste by weight – the highest contributing polluter to e-waste

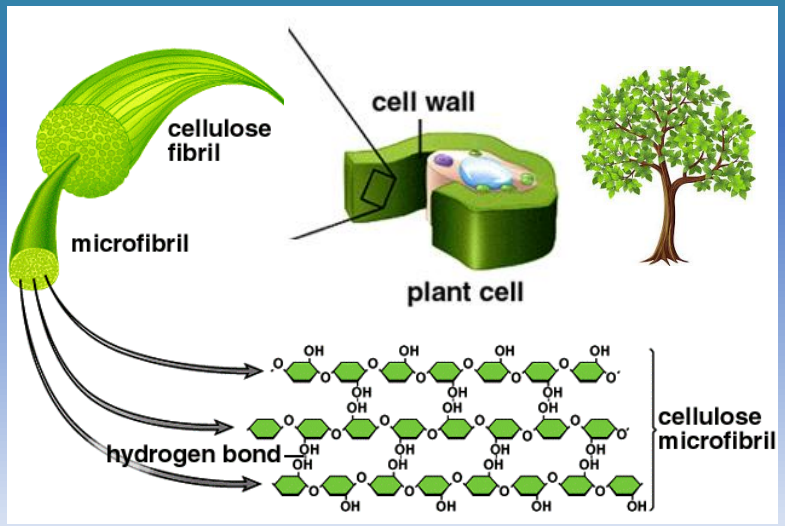
(1) S. Mahore, R.Y. Mahore, S. J. Dhoble, " Economics of electronic waste (e-waste): a critical review of negative externalities and the circular economy", Elsevier 360-Degree Waste Management, Volume 1, Pages 215-237, 2023.

Why cellulose could be a solution…?

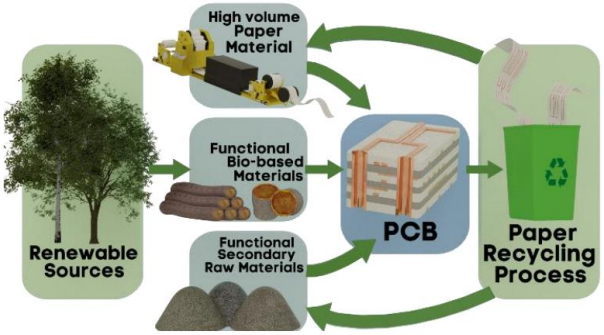
- ✓ Sustainable
- ✓ Biodegradable
- ✓ Renewable
- ✓ Recyclable (80 % of paper is recycled in Europe)
- ✓ Cheap
- ✓ Flexible

- ✓ **Cellulose:** Earth's major biopolymer

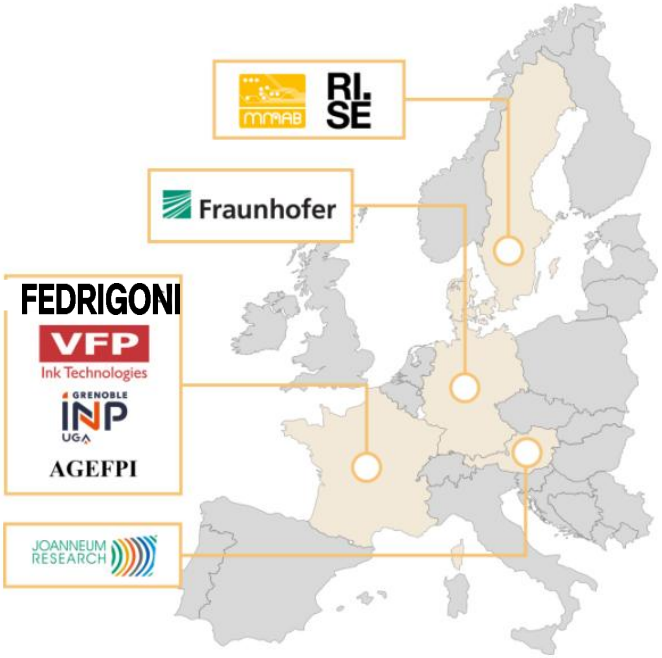
(e.g. 50% in wood; 90% in cotton)



CircEl-Paper : Circular Economy Applied To Electronic Printed Circuit Boards Based On Paper

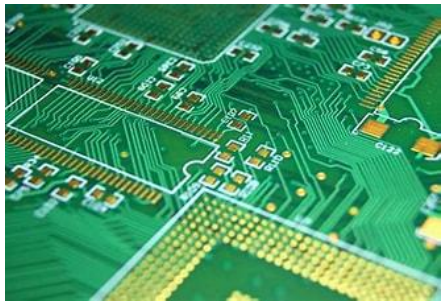


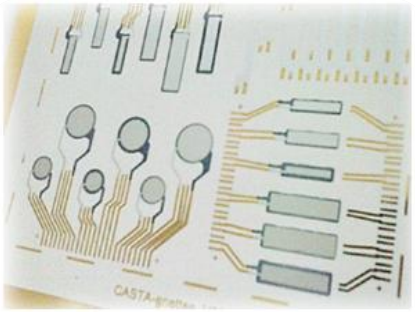
CircEl·Paper



MAIN OBJECTIVES

Developed an environmentally friendly alternative to FR4 glass epoxy PCB, which are extremely difficult to recycle. The cellulosic composite is a paper impregnated with bio-derivated polymer.





Funded by the European Union, Grant No.: 101070114
Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union. Neither the European Union nor the granting authority can be held responsible for them.

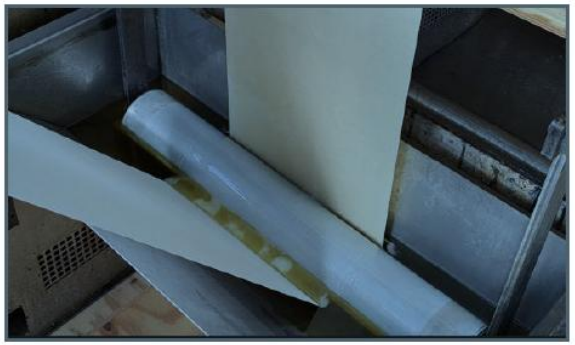
Manufacture of the paper

Paper was produced by Fedrigoni with 80 % recycled cellulosic fibers on the paper machine of Grenoble INP Pagora

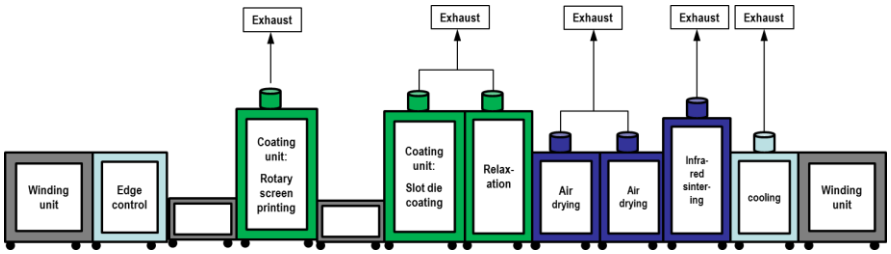
Impregnation of the paper

Impregnation with Fire retardant agent (poly-phosphate) at Fedrigoni

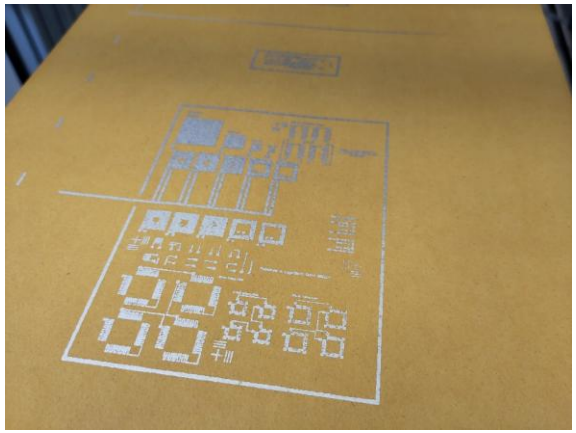
Impregnation with the bio-derivated resin in roll to roll



Roll to roll printing at Faunhofer ISC

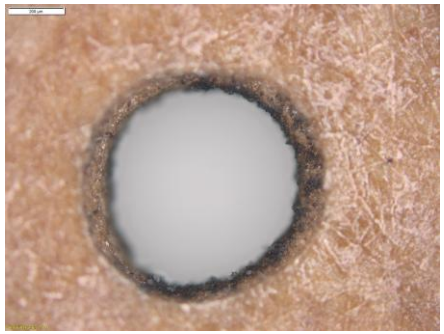


- Experimental setup
  - Substrate: Cellulosic composite
  - Rotary screen: 215 SP / 91 µm thickness / 7% open area / hole diameter 31µm
  - Use of silver Ink from VPF: **SECTR-I01**
  - Processing parameters
    - Printing speed 1- 2 m/min
    - Diameter of printing bar: 12 mm
    - Drying: Convection oven at 120 °C, 2 m length
    - Heating time according to printing speed



Hole drilling and VIA „filling“

- 0.6 mm driling with different processes

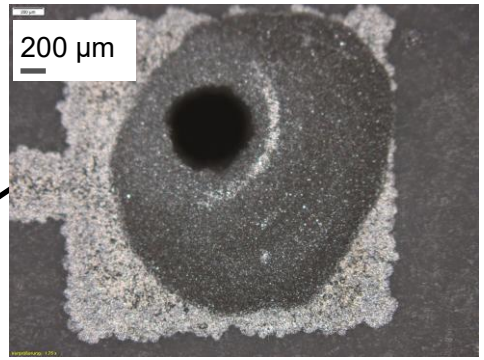


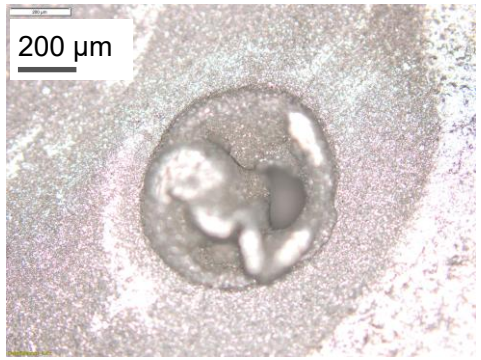
- CO2 Laser + post treatment by fiber laser
- Mechanical driling was also tested with success

- Silver dispensing with Henkel EDAG ink

- Before 2nd filling
- After 2nd filling

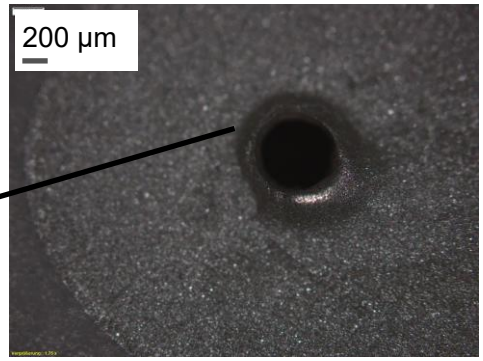
- Top Side





Printed Silver (R2R)

- Bottom Side



Silver dispensed (only the border of the hole is coated)

Demonstrator : Cold chain monitoring (RISE and Fraunhofer ISC)

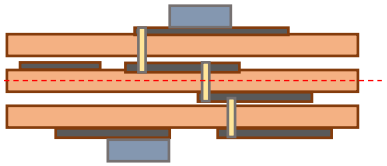
4 -layers PCB

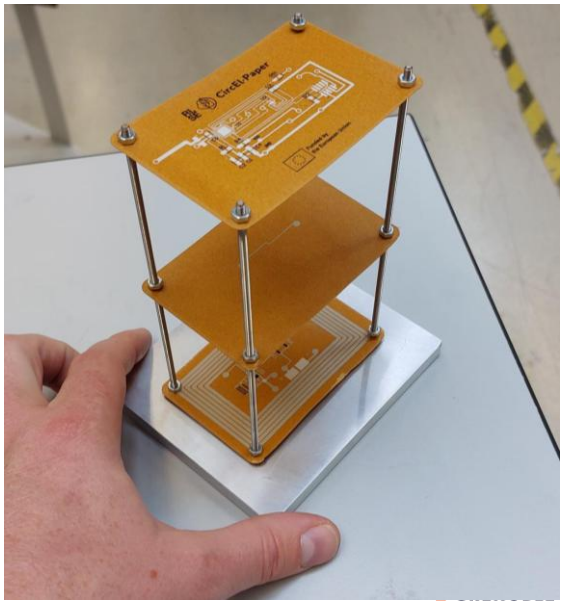
- Lamination by machines used at Fraunhofer ISC
- Alignment via holes drilled by laser

Layer by layer drilling of VIAs holes

Double sided printed structures face in different direction: 2 up and 2 down

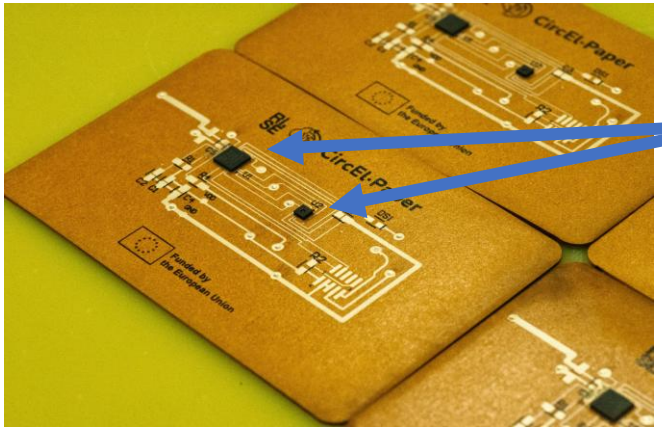
Components on top and bottom layer



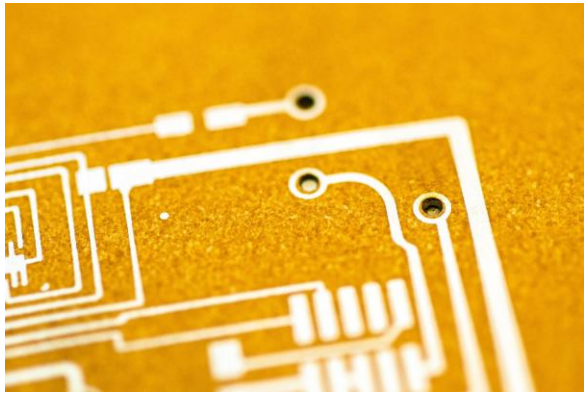


Cold chain monitoring : components mounting

First attempt of the 4-layer PCB demonstrator on cellulosic composite



With reported components

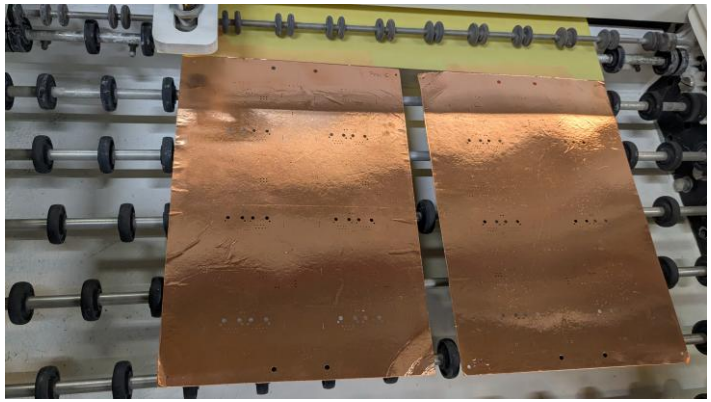


Test of the chemical etching process (ICAPE-MMAB)

Process to be tested :

- Brushing
- Tin plating bath
- Etching agent
- Screen

- Copper foil lamination : ok
- Mechanical Drilling : ok
- Microetching (permanganate) : test ongoing

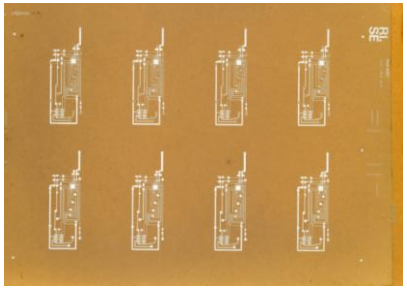


Parameters :
30°C
2,0 m/min

Recyclability tests (LGP2 - Grenoble INP)

- Usage of printed cellulosic composite done in roll to roll

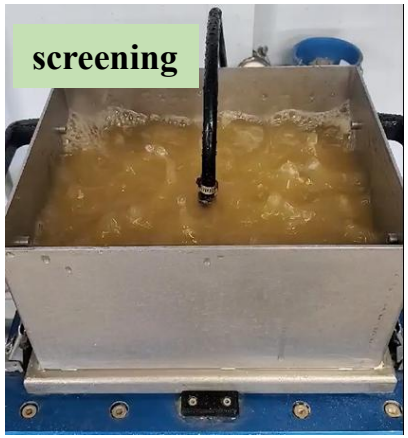
- Laminated printed composite



- Laminated printed composite + silicone encapsulant

Recycling of cellulosic composite (LGP2 - Grenoble INP)

Conventional paper recycling units



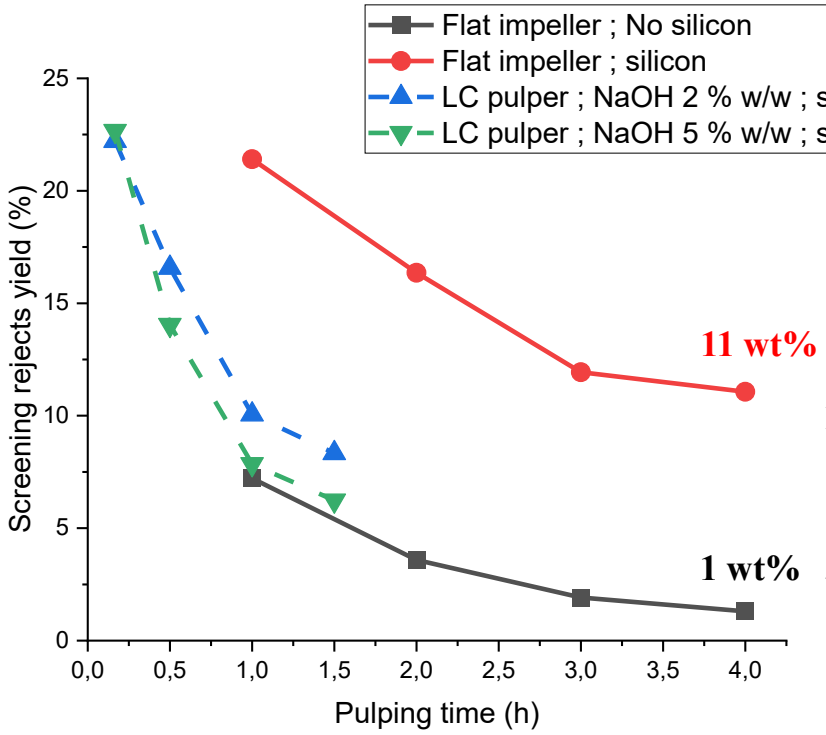
Disintegration

Separation by Dimensions
-
Screen 150 µm

Separation by density
-
Efficiency decreases with small elements

Separation by surface energy
-
Recovery of hydrophobic elements and small fillers

Best pulping conditions for reels



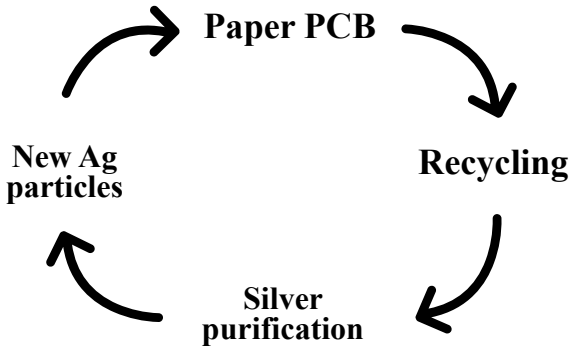
Best Pulping conditions for reels

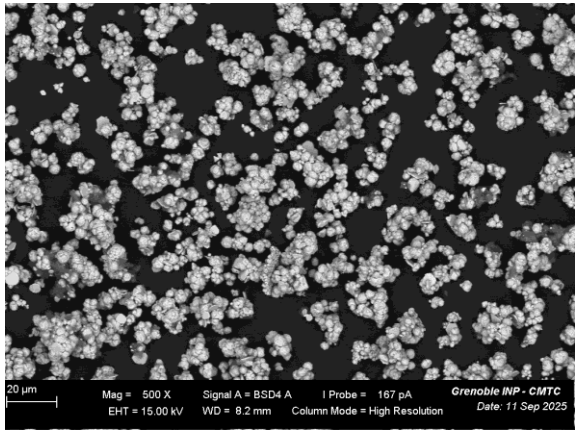
- **Cp ≈ 4 %**
- **NaOH = 5 wt% ≈ pH 12**
- **4h**
- **Hot water ≈ 60 °C**
- **Flat impeller = more turbulence**

Silicone = lower water uptake, aggregates fibers/silicone ?
Rejects yield acceptable.

Very good disintegration, almost no fibers flocs

New silver particles from paper PCB recycling (VFP ink)



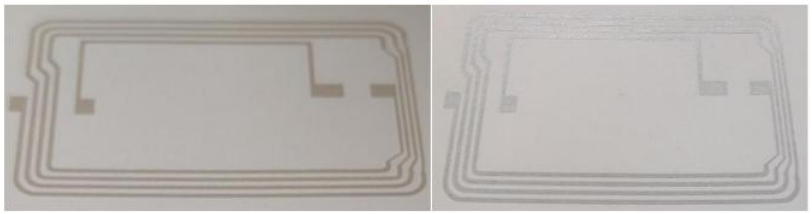


PVA 9-10 kDa

Particles : ≈ 5 µm

Yield ≈ 80 %

Ink formulation by VFP



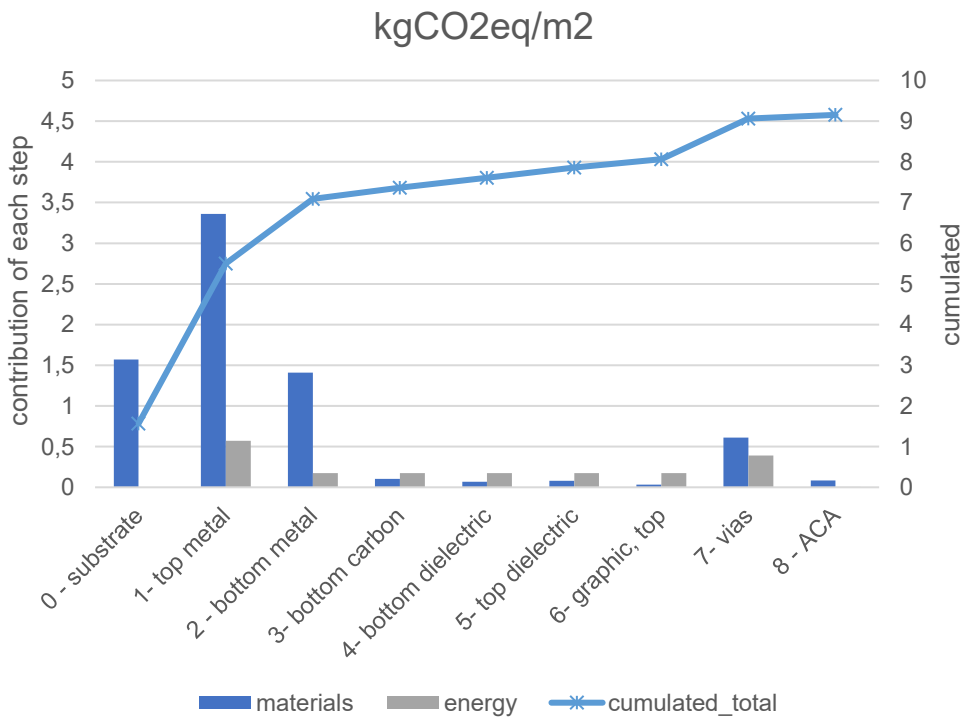
Work ongoing

Figure 1: Left – Printing ink with recycled silver. Right – Printing ink with usual silver.

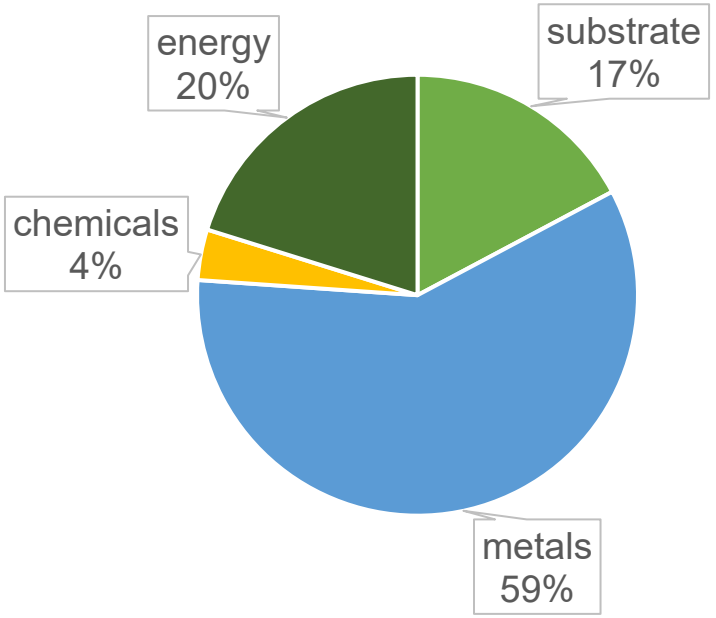
LCA Analysis (Joanneum Research)

2-layers PCB, 80 % recycled content (TTI demonstrator without components)

- contribution of single process steps



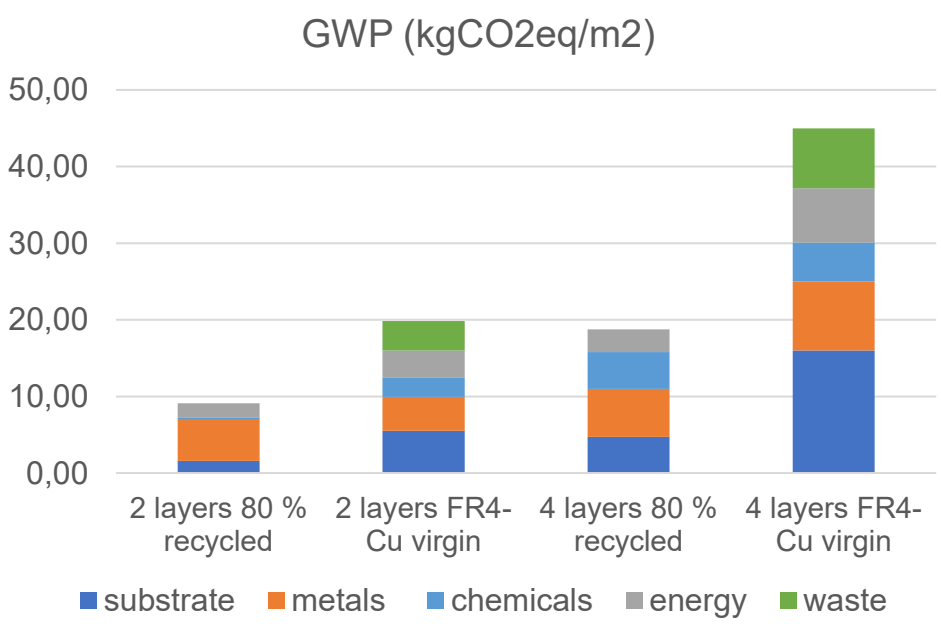
- Contribution of resources



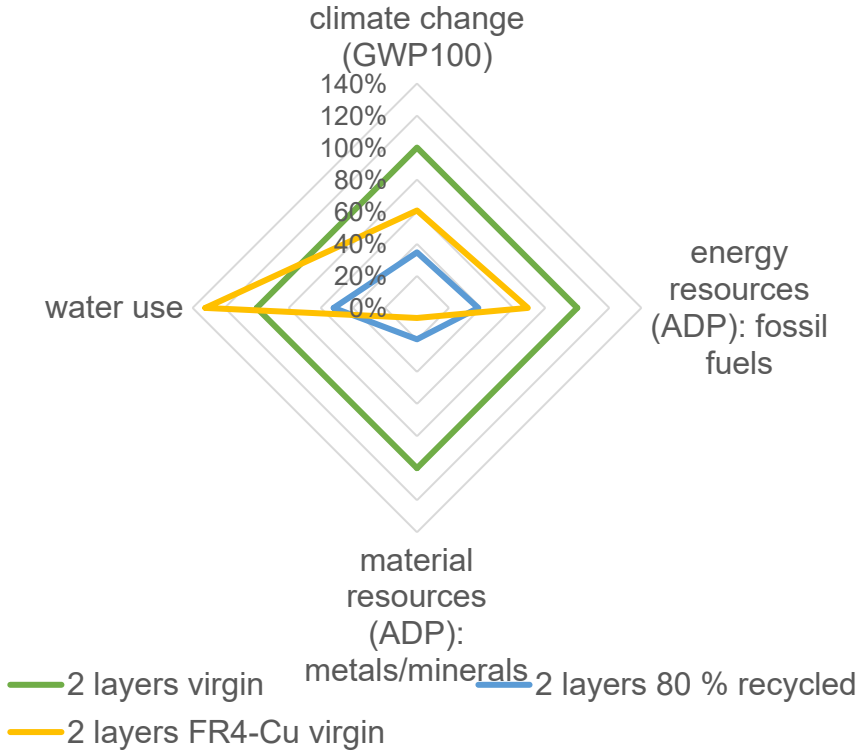
Supersmart (1-layer ECD+antenna): 15.5 kgCO2eq
Nassajfar 2023: 4.6 kgCO2eq (inconsistent inventories)

LCA Analysis (Joanneum Research)

- 2- and 4-layers PCB, recycled content (Ag, paper) 80%, manufacturing in Europe
  - contribution of resources



  - The other impacts

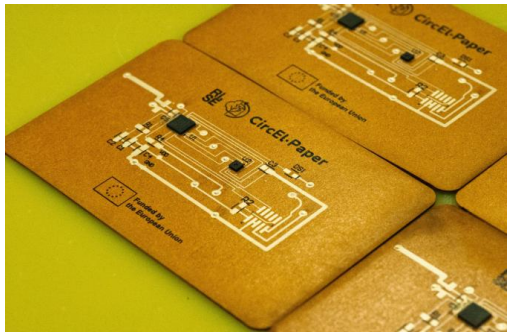


Reduction of half of the Carbon footprint vs FR4

Conclusion

- Growing need for a more responsible and recyclable electronics industry
- After 3 years working on the EU CircEl-Paper, significant progresses have been made :
  - Manufactured cellulosic composite with a mix of cellulosic fibers and bio-derivated resin
  - Proved the ability to make multilayers PCB, using printing technics and via
  - Testing the usual chemical etching methods
  - Proved the recyclabilty of the cellulosic composite
  - Reduction of half of the Carbon footprint using LCA analysis
  - Possibility to recover the metals

CircEl·Paper



THANK YOU FOR YOUR ATTENTION

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