ICOS
International Cooperation
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EU – India
Joint Researchers Workshop on Semiconductors
9 October 2024

European Commission

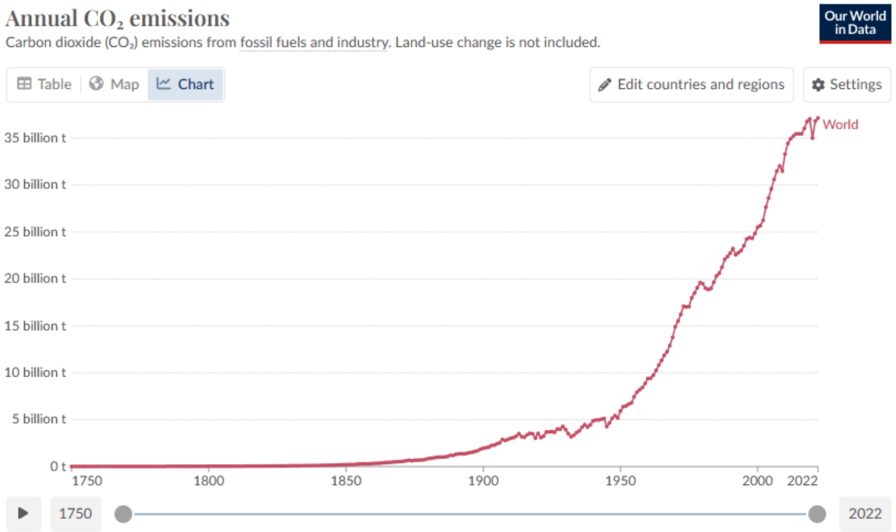
Bio-based materials and processes for PCBs: an example of pathway for sustainable micro-nanoelectronics?

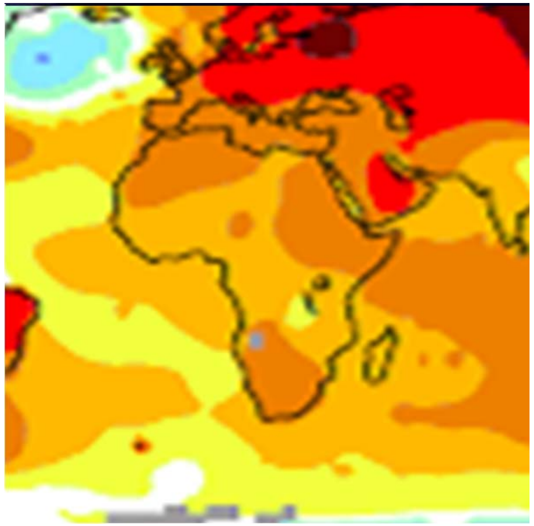
Pascal XAVIER

Full Professor at CROMA – Grenoble Alps University

General context: global environmental footprint of electronics

❑ Energy consumption: climate change





~~correlation~~ / causality

Geology.com *csas.ei.columbia.edu*

General context: global environmental footprint of electronics

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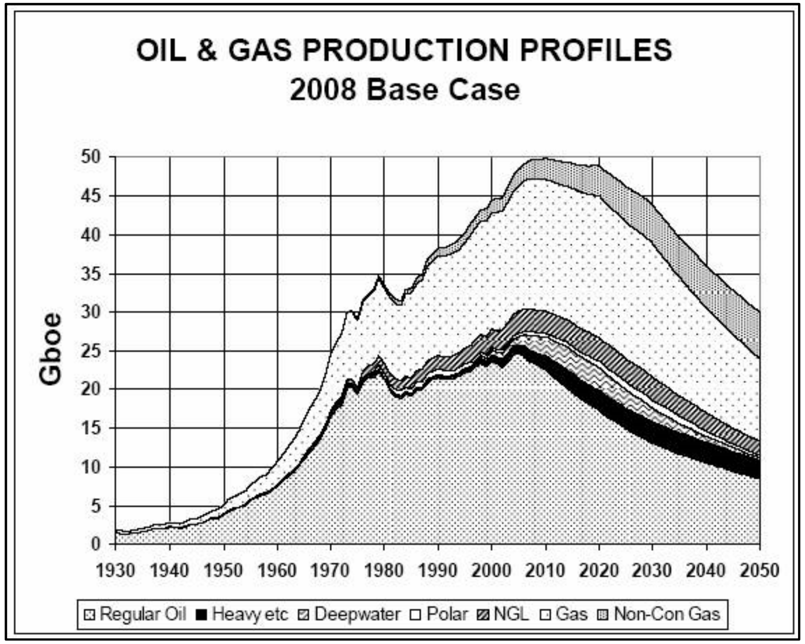
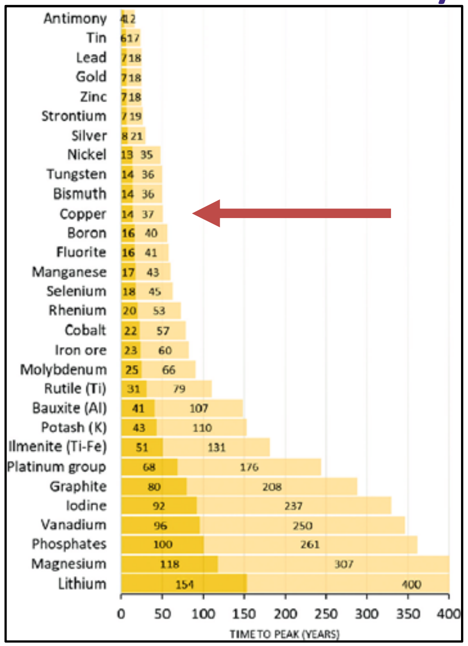
❑ Non-renewable resources consumption: sustainability

TNO Defence,
Security and Safety (NL)



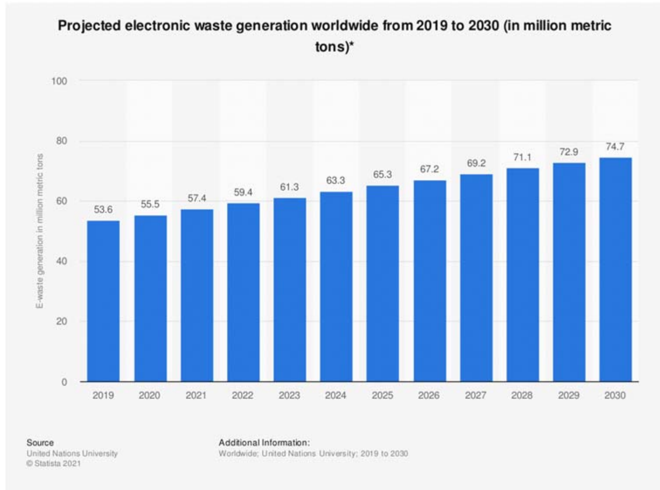


BAU
Current demand

B. Duchemin /
Le Havre University (2022)

General context: global environmental footprint of electronics

- Electronics sector contribution
  - Carbon emissions: ~4% of global emissions, mainly due to the fabrication phase (low power electronics) or use phase (power electronics)
    - increase due to IoT
  - WEEE
  - Ecotoxicity on water
    - TSMC: ÷ by 7 in the last decade, but volume +6%
    - SOITEC: ÷ by 2 in the same period, volume ~ constant



General context: global environmental footprint of electronics

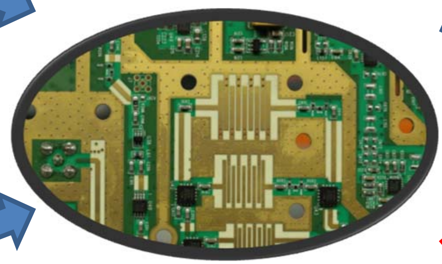
- ❑ Economical risks
  - ❑ Shortages
  - ❑ Price volatility
  - ❑ Protectionism and lack of cooperation

General context: global environmental footprint of electronics

❑ Sustainability

Energies & non-renewable resources, waste

Climate change

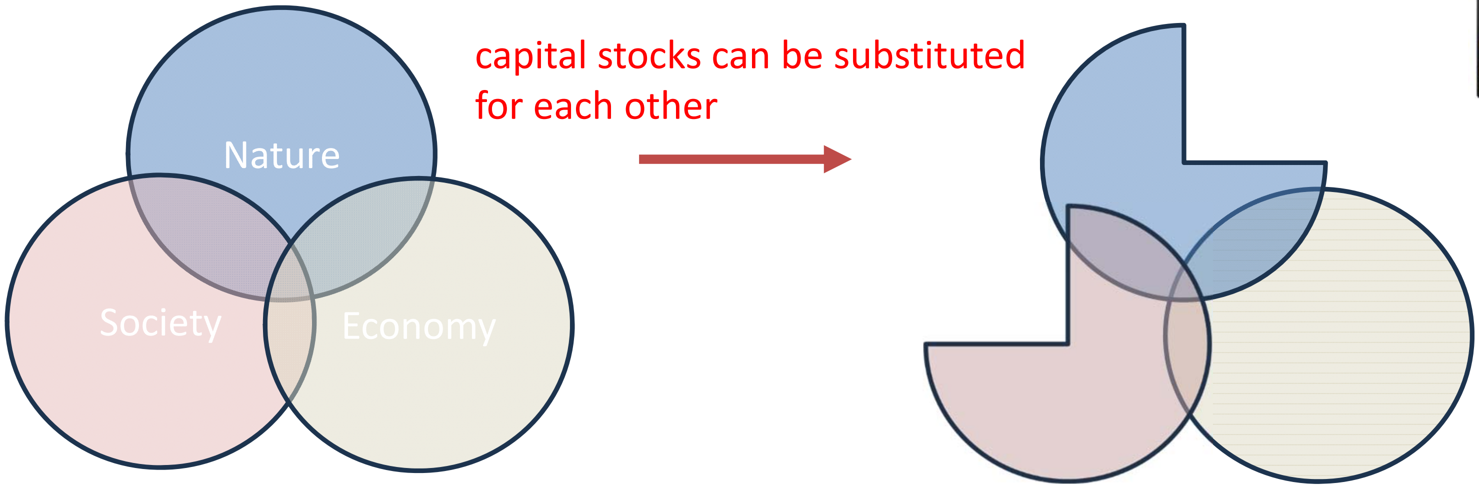


Living standards

Sustainable electronics ?
(Green Electronics – 1999 – UC Berkeley)

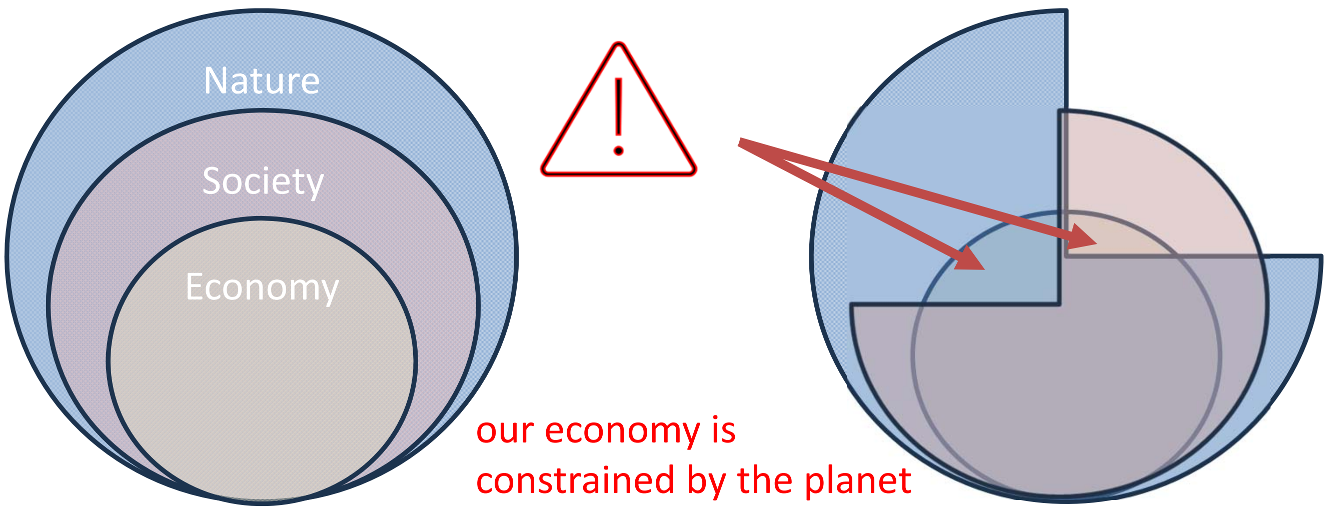
General context: global environmental footprint of electronics

- Capital stock model
  - **Weak sustainability: a classical (but distorted) vision, everyday job of engineers → rebound effect!**

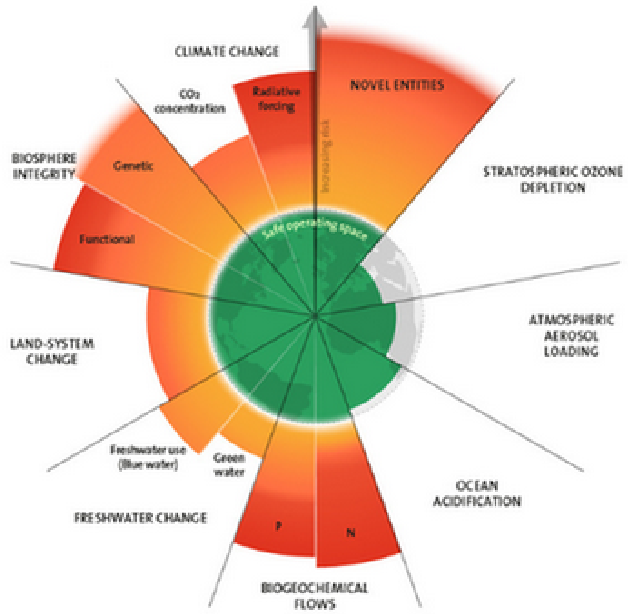


General context: global environmental footprint of electronics

- Capital stock model
  - **Strong sustainability:** losses are not recoverable



2023



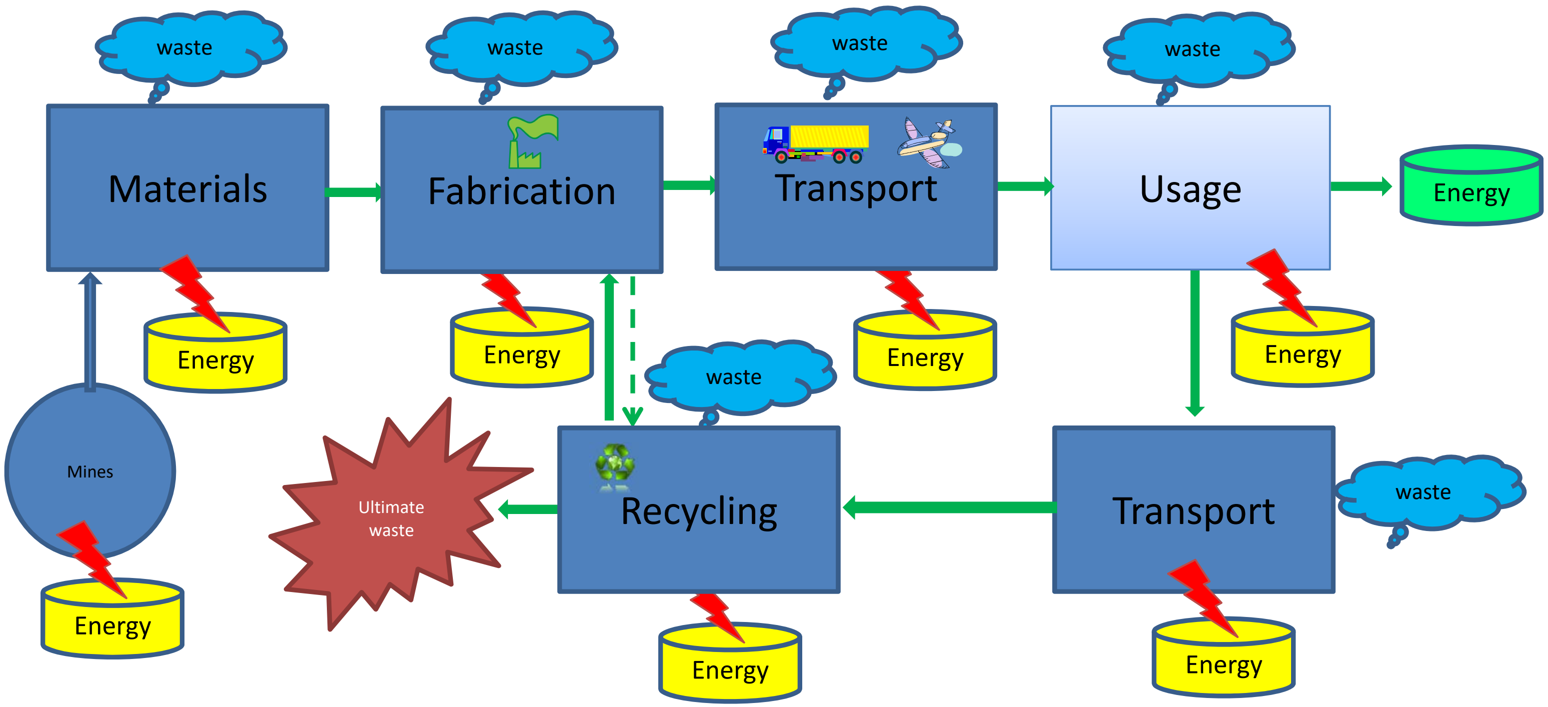
General context: global environmental footprint of electronics

Weak sustainability (Business As Usual): rebound effects, limits to growth…

Strong sustainability (need for a transdisciplinary approach): maintain an acceptable standard of living

How can you reduce the environmental impact of an electronic object?

❑ Product Lifecycle



How can you reduce the environmental impact of an electronic object?

❑ « 10R » strategy

1. Refuse (obvious…)
2. Rethink (eco-design)
3. Reduce (quantities – masses, volumes)
4. Reuse (second-hand)
5. Repair
6. Refurbish (renew)
7. Remanufacture (a new one from several)
8. Repurpose (other function)
9. Recycle (materials)
10. Recover (energy)

Some implementation Examples

- Different approaches
  - For digital, RF and low power signal electronics
    - production phase: new **materials & processes**
    - usage phase: **ultra low power** devices
    - end-of-life phase: **recycling**
  - For power electronics
    - production phase: new **system assemblies**
    - usage phase: higher **yields**
    - end-of-life phase: **reuse (modularity & standardization)**

Some implementation Examples

- PCB contribution in an electronic device environmental footprint

  - depends on the application (DOI:10.30420/566091368)

    - 5% (a small board with a SoC or WiFi chip for instance)
    - up to 20% (a low-density board with a few ICs)

Some implementation Examples

- ❑ Bio-sourced PCBs: -30% on environmental footprint of the fabrication phase (2011 – KUL)

  - ❑ Bio-sourced ≠ Biodegradable !
    - → protection layer!
    - ❑ Sometimes edible…

  - ❑ According to market experts, at least 20% of PCBs should be bio-based by 2033

Some implementation Examples

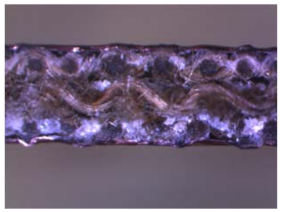
- Bio-sourced PCBs: state of the art
  - "FR4 like" rigid substrates (low TRL) with agricultural by-products
    - Epoxy + Lignin + BFR (2001 – IBM, 2005 - Fraunhofer)
    - Epoxy + Lin + melamine (2008 – UC Irvine)
    - Soy resin + feathers/glass fibers + melamine (2013 – Un. Delaware)
    - banana & wheat gluten (2016 – India)
    - PLA + hemp fibers (2019 – India)
    - PLA + cellulose acetate (2020 – Univ. Dresden)
    - PLA + cotton (2023 – Univ. Genoa)

Some implementation Examples

Benchmarking of rigid substrates

- Jiva Materials (UK) with Infineon: Soluboard → soluble in hot water (interesting for power electronics to recover some components but what about the reliability?)

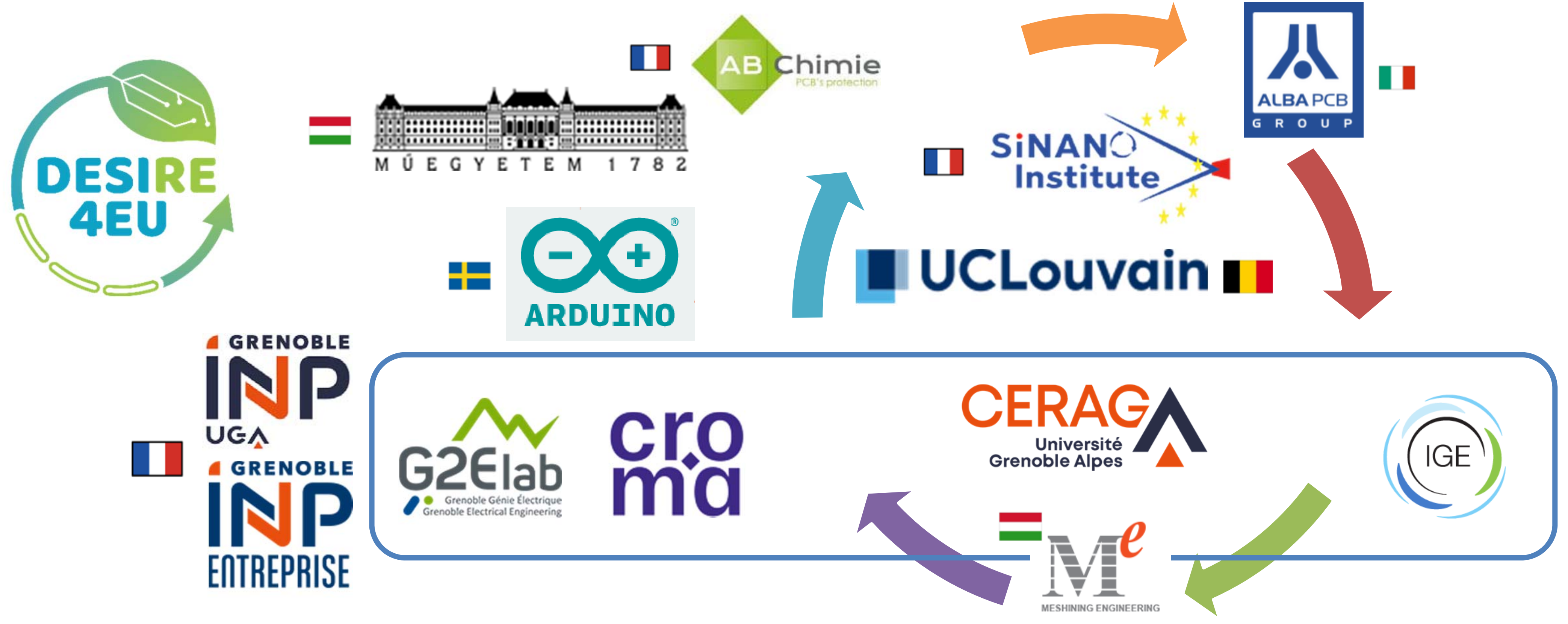
- Meshlin (Hungary) with Arduino → PLA/flax fibers, bio-sourced Flame Retardant (FR) instead of Brominated FR, no PFAS and bioleaching of PCBs



*DESIRE4EU aims at revolutionize the life-cycle of electronic boards by introducing **bio-based processes and materials** both in their **design, fabrication and end-of-life** phases, to get **fully circular and sovereign European electronics value chains** (1st sept. 24 – 31 aug. 28)*

This project has received funding from the European Union's Horizon Europe EIC Pathfinder Challenges programme under GA N°101161251

desire4eu-eic.eu


DESIRE 4EU
MŰEGYETEM 1782
AB Chimie
PCB's protection
ALBA PCB GROUP
SiNANO Institute
ARDUINO
UCLouvain
GRENOBLE INP UGA
GRENOBLE INP ENTREPRISE
G2Elab
Grenoble Génie Électrique
Grenoble Electrical Engineering
croma
CERAG
Université Grenoble Alpes
IGE
MESHINING ENGINEERING

Some implementation Examples

- ❑ Bio-sourced PCBs
  - ❑ Flexible substrates examples:
    - ❑ Paper: Fedrigoni group (Italy)
    - → European project « Circel-Paper »

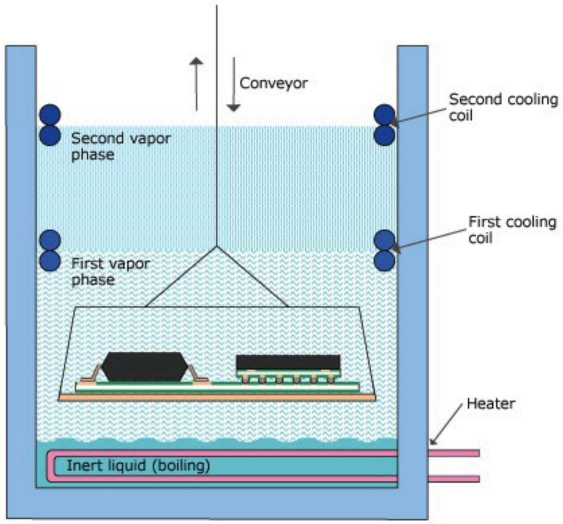
Fraunhofer LGP2

- ❑ Cellulose Laurate: « PET like »

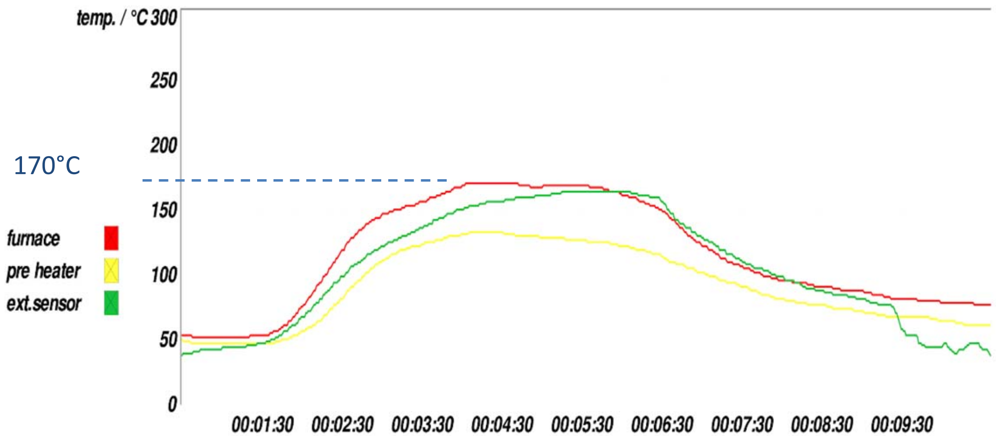
iemn

Some implementation Examples

- Bio-sourced PCBs: assembly
  - Lower Tg (120°C max) → Vapor Phase Soldering (VPS) but CFCs…

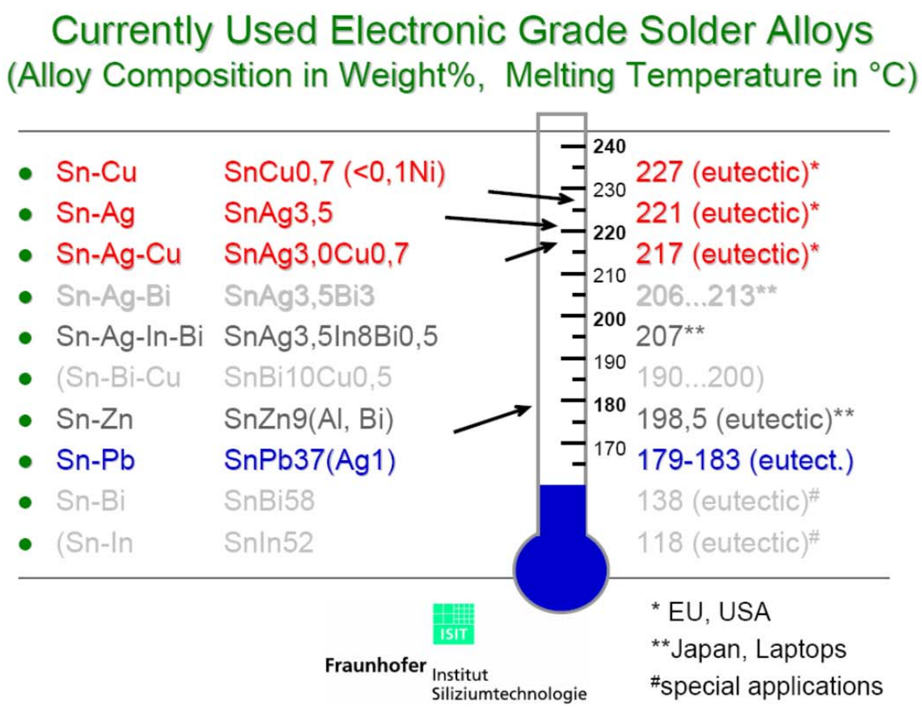


totalmateria.com



VPS reflow profile

Some implementation Examples



- Bio-sourced PCBs: assembly
  - ❑ Sn-Bi soldering (reflow: 139°C)
    - ❑ Caution ! Bi resources = 4 kilotons / yr = 2% of global electronic boards...

Some implementation Examples

❑ Bio-sourced PCBs: Ecological metal recovering

- ❑ Copper, a critical metal (MC)
- ❑ European directive: 85% of MC must be recovered
  - ❑ We are far from that!...
- ❑ Limits of current recycling methods
  - ❑ They are energy consuming and polluting
  - ❑ Some elements are difficult to recycle (epoxy resin, packages…)
- ❑ Europe owns the largest amount of stocked copper in WEEE

Copper mine of Chuquicamata (Chile)

WEEE

ecosystem – recycler c'est protéger

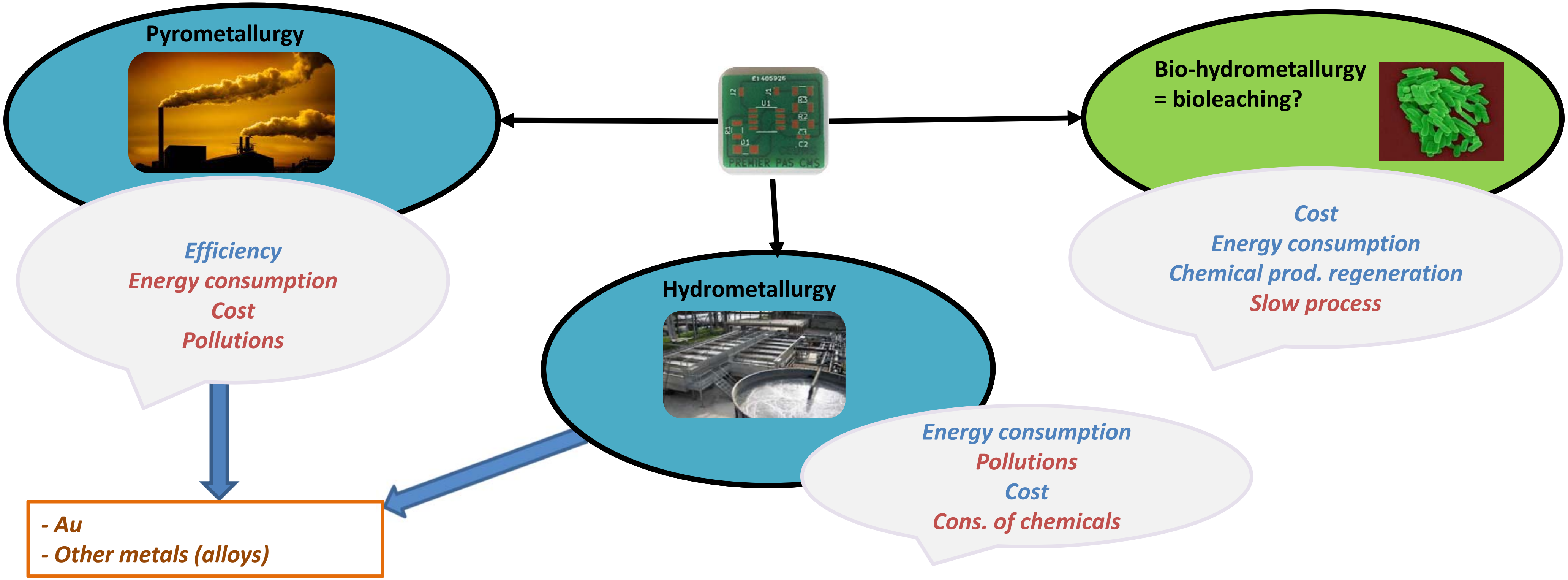
EcoLogic

suez

envie – Nos valeurs redonnent de la valeur

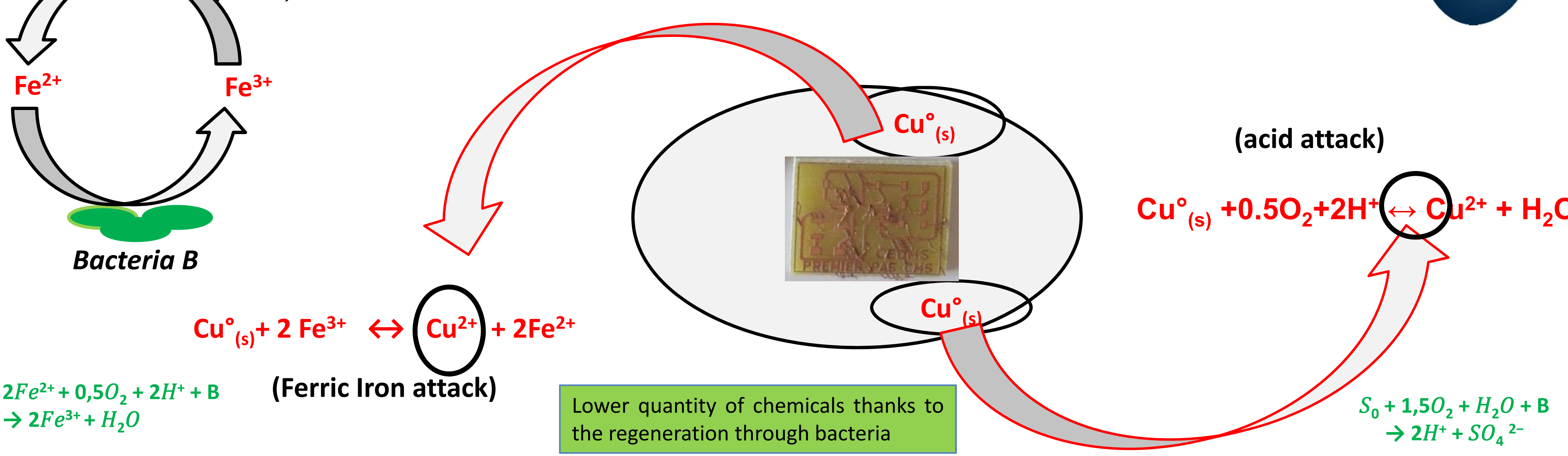
Morphosis – Déchets Électriques et Électroniques

umicore


Pyrometallurgy
Efficiency
Energy consumption
Cost
Pollutions
Hydrometallurgy
Energy consumption
Pollutions
Cost
Cons. of chemicals
Bio-hydrometallurgy
= bioleaching?
Cost
Energy consumption
Chemical prod. regeneration
Slow process
- Au
- Other metals (alloys)

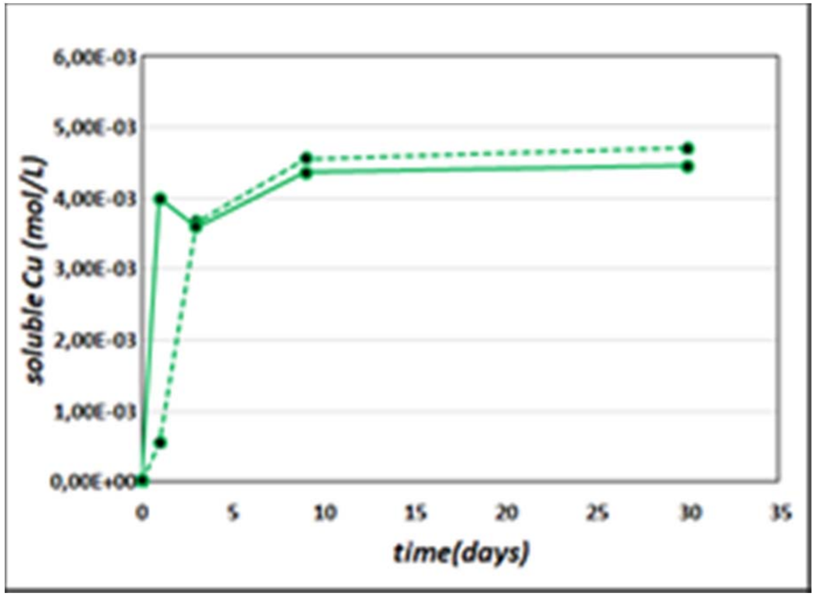
❑ Microbiological and Chemical coupling - Solubilization of metals favored by bacteria

This work has been partially funded by the MITI program 2023/2024 of the French National Scientific Research Center (CNRS)



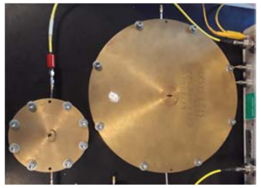
Some implementation Examples

- Bio-sourced PCBs: Ecological metal recovering
  - First results in a single bio-reactor
    - Acid production / sulfate oxidation by microorganisms
    - Accelerated dissolution of copper / oxidation by Fe(III)
    - Dissolution of 100% of copper in 6 days
      - BRGM: 96% of copper in 2 days with FR4 PCBs and a double bio-reactor
    - New design rules for the PCB to speed up the process: the higher the effective surface of metallic tracks, the faster the process is.

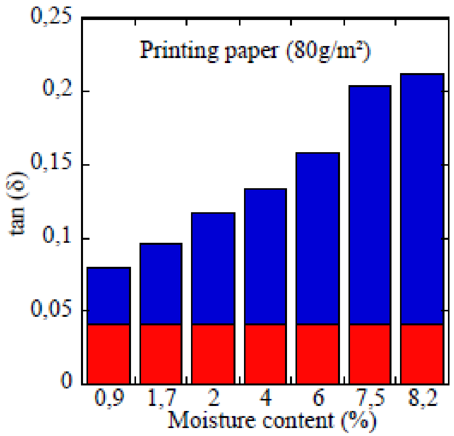


Some implementation Examples

- Bio-sourced PCBs in RF
  - Electromagnetic properties:



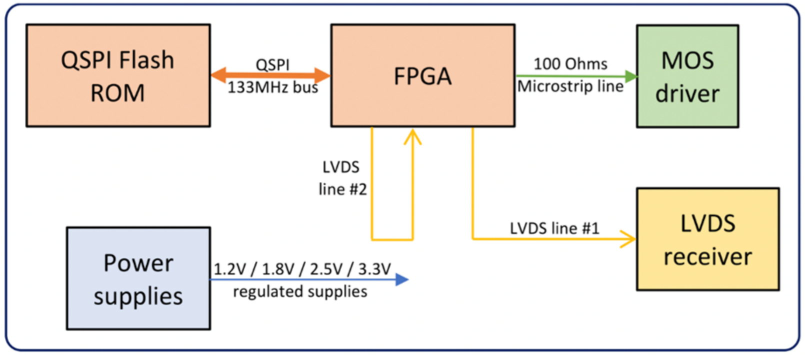
    - Dielectric constant: 2-4, loss tangent ~0,01 (~FR4)
    - Losses @900 MHz - paper 80 g/m² - dry (in red) & volumetric moisture content contribution (in blue)

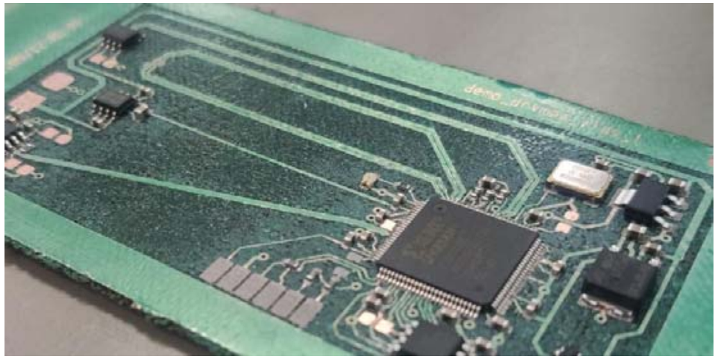


    - Moisture sensitivity of these dielectric properties

Some implementation Examples

❑ Devices: first digital and RF circuit using a bio-sourced PCB





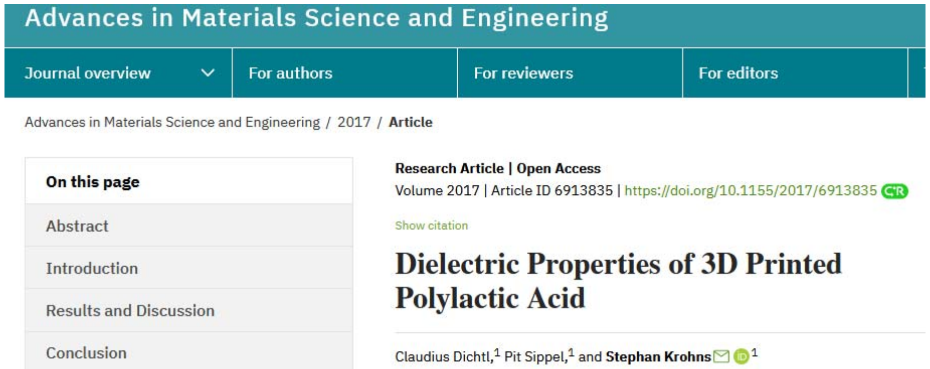
❑ Modification of line widths (impedance matching)

❑ Assembly: some minor manual repairs

1 on-going PhD — 1 best senior paper award @ ISSE23

Some implementation Examples

- Devices: antennas on PLA/Flax substrate
  - Reconfigurable antenna for massive MIMO < 7GHz
    - ANR NF-PERSEUS project – French PEPR 5G
    - In RF, no variation of dielectric constant above Tg
      → power amplifiers compatibility


Advances in Materials Science and Engineering

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Advances in Materials Science and Engineering / 2017 / Article

On this page
Abstract
Introduction
Results and Discussion
Conclusion

Research Article | Open Access
Volume 2017 | Article ID 6913835 | https://doi.org/10.1155/2017/6913835

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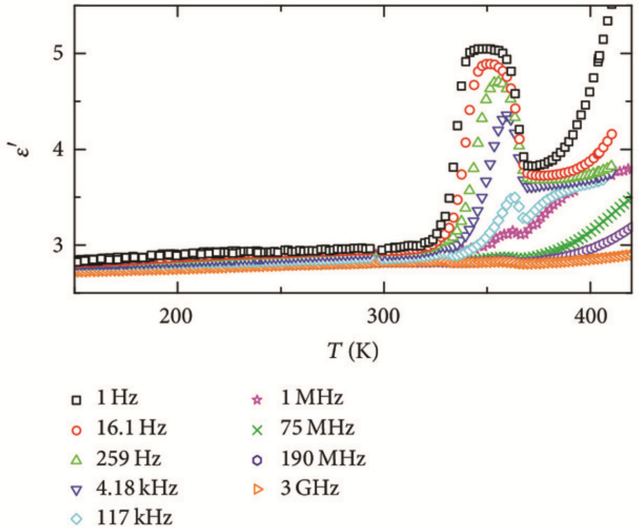
Dielectric Properties of 3D Printed Polylactic Acid

Claudius Dichtl,[1] Pit Sippel,[1] and Stephan Krohns[1]



1 on-going PhD

What about these technologies' maturity?

- Materials
  - Tg and biodegradability of biopolymers → interdisciplinarity!
  - Do not modify current industrial processes
    - Lead free soldering was an expensive, difficult and complicated experience
    - Same mechanical and thermal properties (as in alternative resins for cleanroom processes such as chitin-based ones),
    - … Unless a technological breakthrough (sticking for instance)

European Commission

What about these technologies’ maturity?

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- Design rules: by 2030

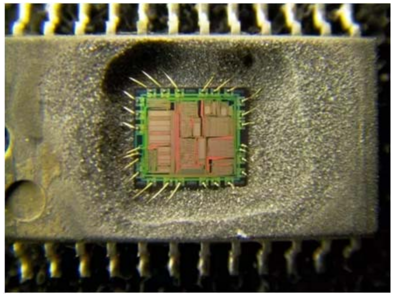
DESIRE 4EU

ARDUINO

  - Multilayers capabilities → chiplet approach (Fraunhofer IESE)
  - Surface roughness?
  - Consider the recycling process: -70%wt on ultimate waste is a target
    - Crushing or not?
    - Delamination by biodegradation (enzymes)? (CARBIOS)
    - Consequences on track widths, gaps between tracks, number of layers…

What about these technologies' maturity?

- Possible consequences in micro and nano-technologies
  - Middle term: new bio-sourced materials in clean room processes, packages and interconnexions



  - Long term (because of geometrical and materials complexities): new design rules for ICs, thus requiring LCA databases improvements

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THANK YOU

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