Towards Sustainable electronic

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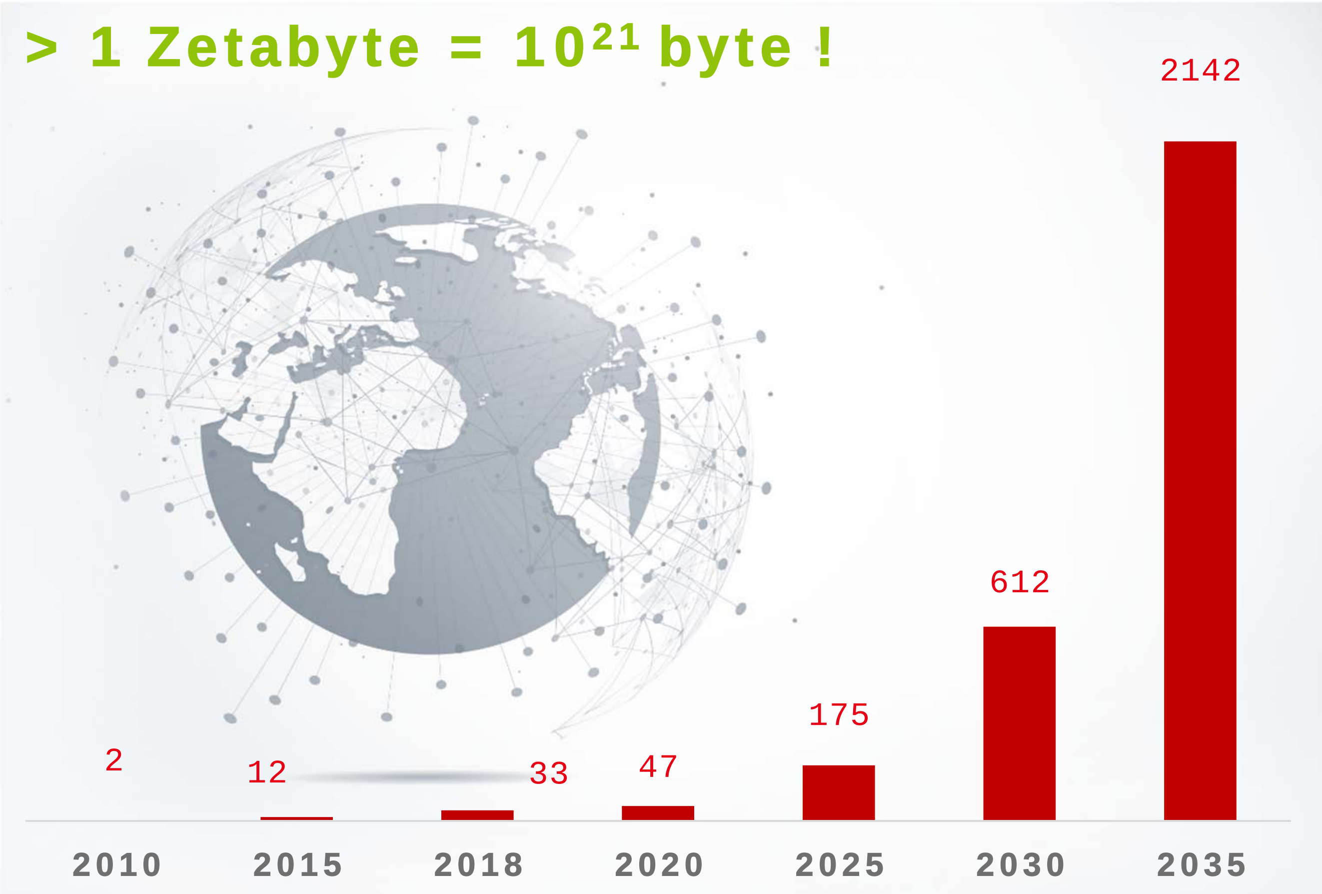
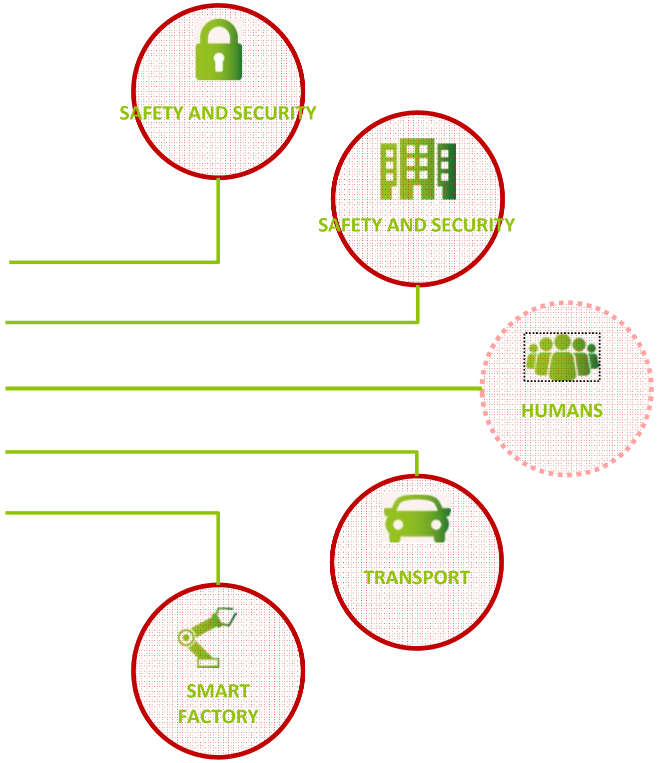
Outline

- Context
- What means Sustainable Electronic?
- How to address Sustainability during manufacturing?
- How to achieve “greener” IC’s (during design, choice of technology?...)

Global data generation (actual & forecast)





> A true data deluge, not only generated by humans!

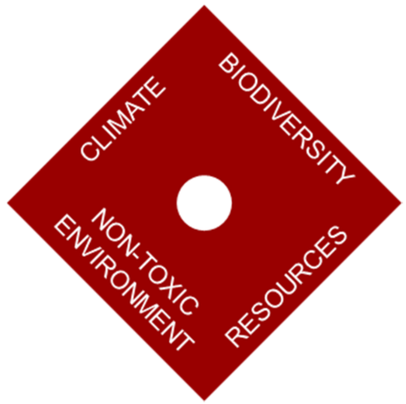
Planetary boundaries not be exceeded

Climate

- Tipping points, future climate stability, warming of the planet
- Paris agreement (1.5°C), 2030 – 70%, 2050 – 100%

Non-toxic environment

- Chemical pollution, particles, plastics
- Human health-based targets for pollution levels (food, environmental exposure)



Resources

- Availability of resources for current and future generations
- Renewable and non-renewable resources, occupation and dissipation

Today **seven out of the nine** boundaries **have been transgressed.**

Biodiversity

- Sixth mass extinction, loss of genetic and functional diversity and ecosystem functioning
- Land use, water use, nutrients, ecotoxicity, … – targets based on ecosystem thresholds

https://www.stockholmresilience.org/research/planetary-boundaries.html

Growing environmental impacts of ICT

2019, 34 billions of devices ~ 8 devices/user

- Share of ICT in Greenhouse gases emissions :

Global
2 to 4%[1]

→ **+60%** in **2040**


Reuters
World US Election Business Markets Sustainability Legal Breakingviews Technology

Deals | Grid & Infrastructure | Nuclear

Microsoft deal propels Three Mile Island restart, with key permits still needed

By Reuters

September 21, 2024 6:58 PM GMT+2 · Updated 10 days ago

[1/2] The Three Mile Island nuclear power plant, where the U.S. suffered its most serious nuclear accident in 1979, is seen across the Susquehanna River in Middletown, Pennsylvania in this night view taken March 15, 2011. REUTERS/Jonathan Ernst/File Photo/File Photo Purchase Licensing Rights

Main environmental impacts from :

- manufacturing phase(especially for impact on minerals and metals resource use)
- Use phase (electricity consumption)

[1] Bordage, F. (2019). The environmental footprint of the digital world. *GreenIT: France*.

Growing environmental impacts of ICT

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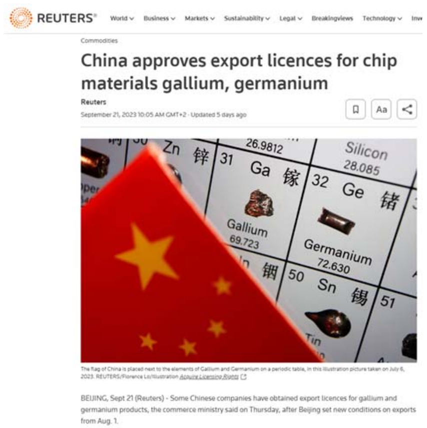
Global
2 to 4%[1]

→ **+60%** in **2040**

- E-waste is the fastest growing waste category
- Growing number of ‘critical raw materials’ (CRM) for the EU economy [2]

  Ex: Gallium
  - High Supply Risk
    - High ultimate reserves but low annual production
    - Europe imports 71% of Ga from China
  - Economic Importance



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Relative sustainability

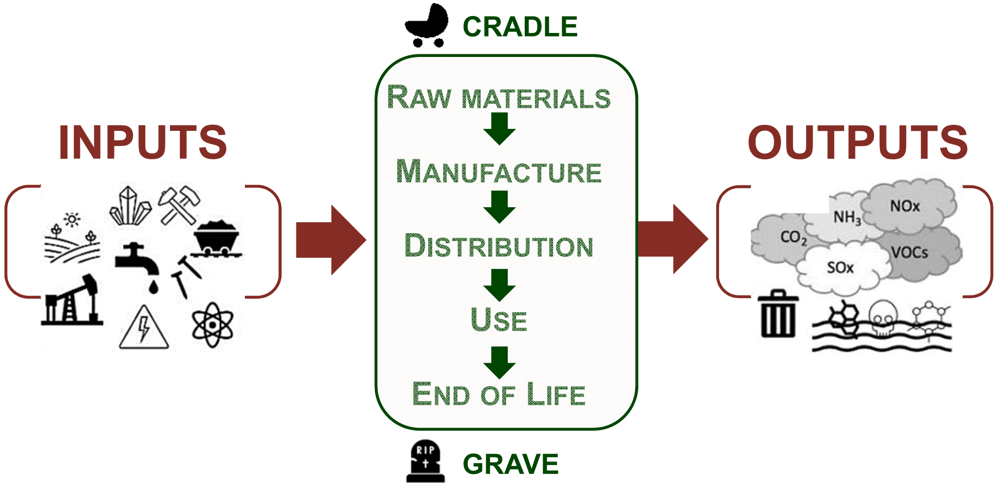
- **Reducing each device/technology footprint** (towards **« greener » devices**):

  - Ecodesign to lower the impacts during manufacturing, use phase, end of life

  - One of the tools: **Life Cycle Assessment (LCA) to identify the hotspots**

    - EF 3.1 impact method

Product Environmental Footprint (PEF)



Absolute sustainability

- Energy or resources savings initially planned thanks to a new greener technology can be partially or totally compensated by behavorial or other systemic response (rebound effect).

- To be sustainable, the environmental impacts of electronics should stay below the planetary boundaries.

- Reduction of the number of devices, with increased lifetime (towards a more circular economy) is necessary
- Sharing economy
- Repair & reduction of material and software obscolescence
- Refurbishing / Reuse

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Manufacturing hotspots

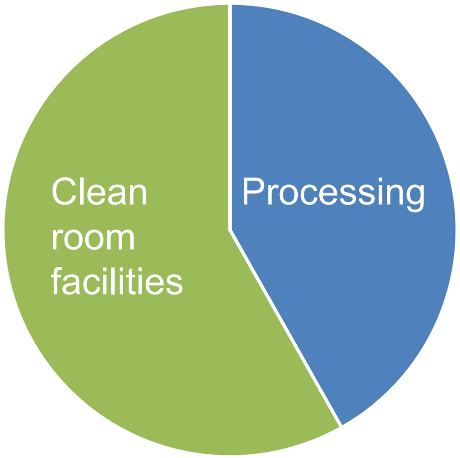
❖Life Cycle Inventory (LCI):

- **High electricity consumption**

Manufacturing of **a 200mm GaN on Si wafer with MOSc-HEMT transistors** in CEA-Leti clean room [1]:

Processing
286 kWh of electricity,
0.6 m³ of deionized water
and **61 kg** of chemicals

Clean room facilities
342 kWh of electricity,
9.8 m³ of process cooling water
and **2.8 kg** of natural gas



❖Life Cycle Assessment (LCA):

Large impacts on

- Ressource use, fossils (MJ)
- Ionizing radiation (kBq U-235 eq)

In case of French electricity mix, high share of nuclear

- Climate change (kg CO_2 eq)
- Ressource use,
- minerals and metals (kg Sb eq)

Electricity distribution and transmission network (copper)

[1] Vauche, L.; Guillemaud, G.; Lopes Barbosa, J.-C.; Di Cioccio, L. Cradle-to-Gate Life Cycle Assessment (LCA) of GaN Power Semiconductor Device. *Sustainability* **2024**, *16*, 901.

Process and Material hotspots

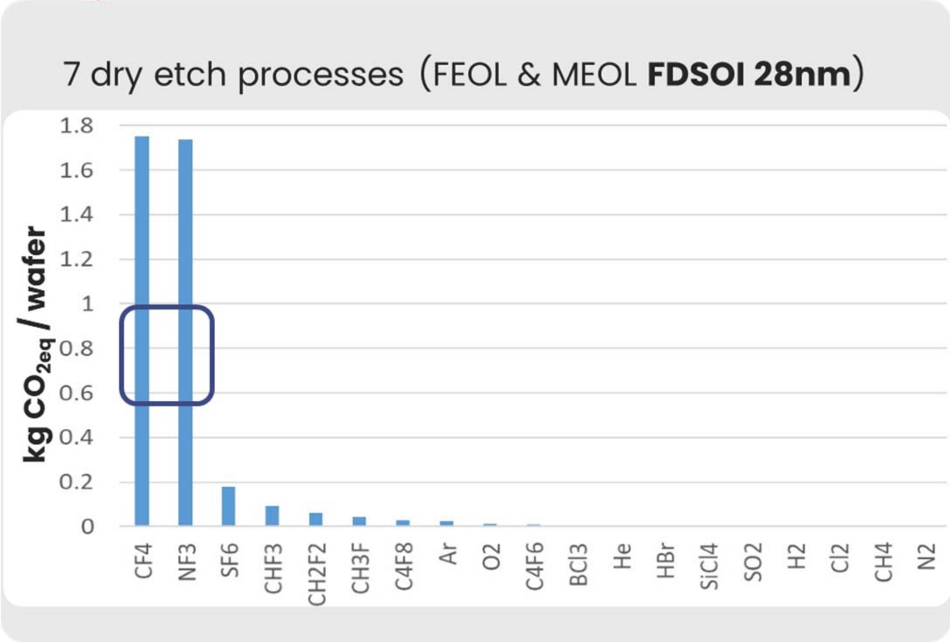
❖ Life Cycle Inventory (LCI):

- Direct emissions into air of fluorinated (PFC) gases with high Global Warming Potential (GWP)

Dry etch steps for FDSOI 28nm technology, 300mm [1]:
- CF4 weak abatement rate + GWP x6,600
- NF3 using in chamber conditioning at each step

❖ Life Cycle Assessment (LCA):

Large impacts on
- Climate change (kg CO_2 eq)



[1] Renaud M, Sarrazin A, Lopes-Barbosa J, Rivoira Y, Servin I, Boulard F. Life cycle assessment of etching processes for FDSOI transistors technologies. InAdvanced Etch Technology and Process Integration for Nanopatterning XIII **2024** Apr 9 (Vol. 12958, pp. 141-151). SPIE.

Process and Material hotspots

❖ Life Cycle Inventory (LCI):

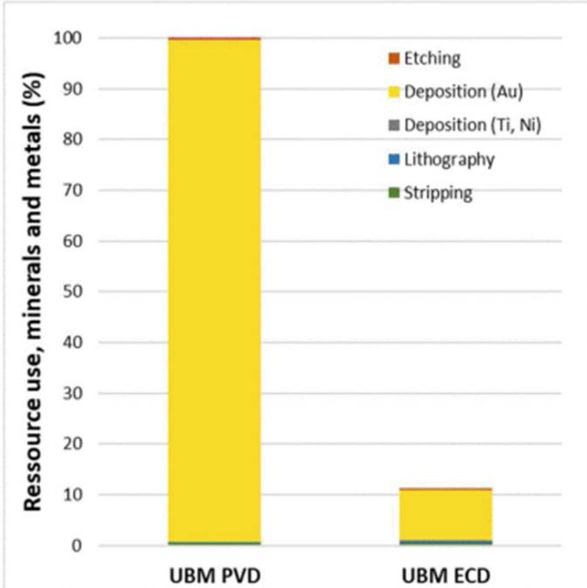
- Consumption of Gold Metal

Gold metal
by Physical Vapor Deposition or
by Electrochemical Deposition for
metallizations [1]

❖ Life Cycle Assessment (LCA):

Large impacts on

- Ressource use, minerals and metals (kg Sb eq)



[1] S. Guillou *et al.*, "Comparative Life Cycle Analysis of Redistribution Layer for 3D Integrations," *2024 Electronics Goes Green 2024+ (EGG)*, Berlin, Germany, 2024, pp. 1-11, doi: 10.23919/EGG62010.2024.10631207.er

Manufacturing | 4 major work areas

1 INFRASTRUCTURE

- **Energy efficiency**
  - ✓ Certification **ISO 50001**
  - ✓ Energy management system
- **Water efficiency**
  - ✓ Reclaim & re-use
- **Effluent treatment**
  - ✓ controls / regulations
  - ✓ Segregation / Recycling
- Gas re-use

2 EQUIPEMENTS

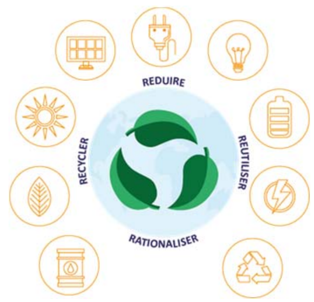
- Optimizing **parameters**
  - ✓ flow rate
  - ✓ mode idle
- Powerful abatement systems
- GHG emissions reduction with high destruction removal efficiency
- With limited additionnal consumption of water, gas, electricity

3 PROCESS

- **GWP gas** alternatives
  - ✓ Cleaning of deposition or plasma etching chambers
  - ✓ PFCs replacement (CF4, NF3, SF6,…)
- **Tailor to your needs**
  - ✓ For each process/technology
  - ✓ Volume, time
- **Effluents waste**
  - ✓ CMP (flow rate, novel slurry)
  - ✓ GRINDING : filters

4 MATERIALS

- **5Rs scenarii**
  - ✓ Replace classified chemicals (CMR, REACH…) Ex: TMAH, PFAS…
  - ✓ Recycle PVD targets (**Au**), chemicals, etc.
  - ✓ Reduce **PFCs gases**
  - ✓ Replace by alternatives
  - ✓ Rationalise **Si** wafers



Developing initiatives to reduce our **environmental impacts**

Eco-score calculation within complete digitalization of our cleanrooms

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CLEAN Project -Stripping

International Cooperation On Semiconductors

Post-etch polymer removal

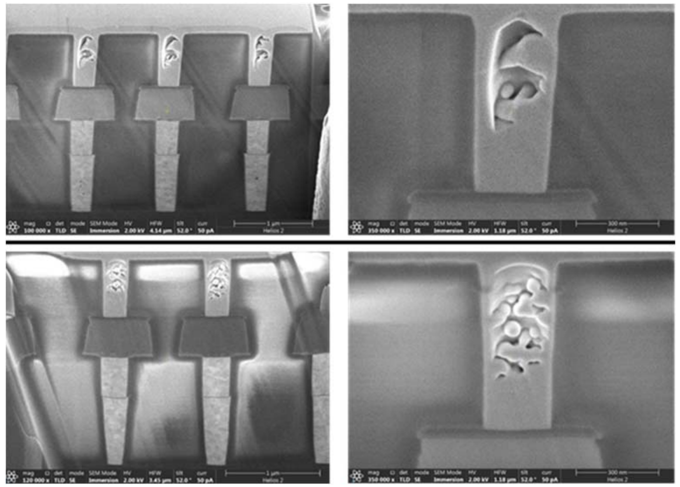
- With toxic-free compounds
  - Reduced toxicity vs POR chemistry
    - REACH compliant (no CMR, without cathecol and hydroxylamine)
  - Reduced carbon footprint
    - Lower temperature process (<50°C)
    - Reclaim mode and recyclability potential
    - Without IPA rinsing (if possible)
  - Secure and sustainable sourcing
  - Similar process performances
  - Life cycle assessment (POR versus new chemistry)

In progress : evaluation of the selected chemistry at the pilot line of CEA Leti

Application: metal post-etch
Both 200 mm / 300 mm

POR

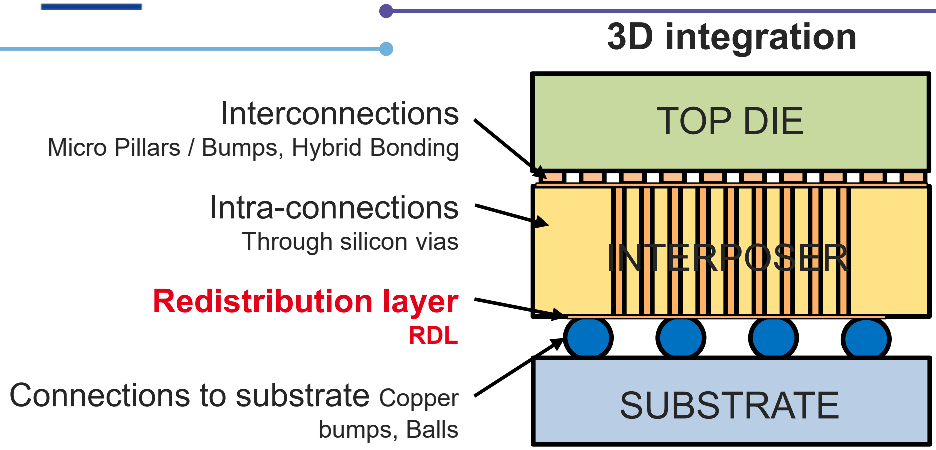
Without CMR

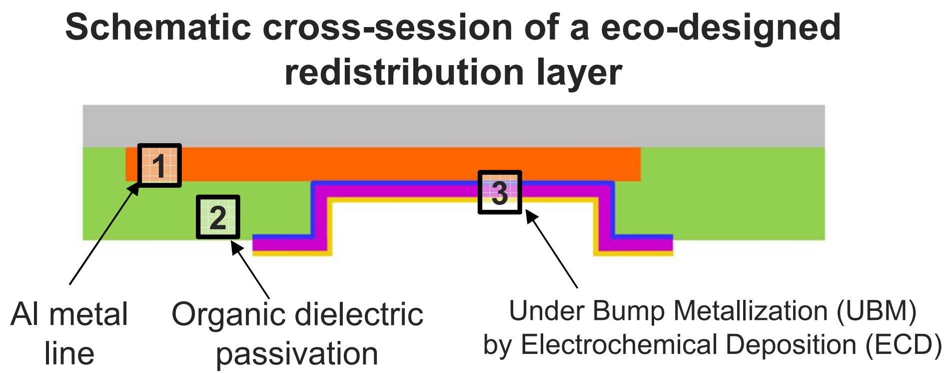


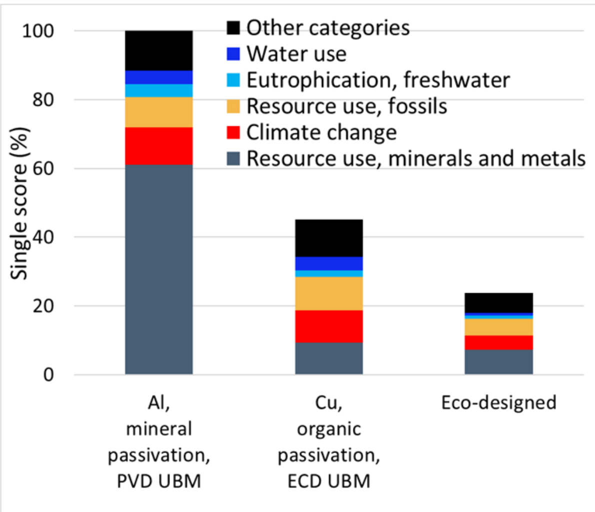
M. Stigliani et al. PESM, June 2024
Development of a sustainable post plasma-etch residues cleaning solution

Similar process performances

Ecodesigned redistribution layer (RDL) integration





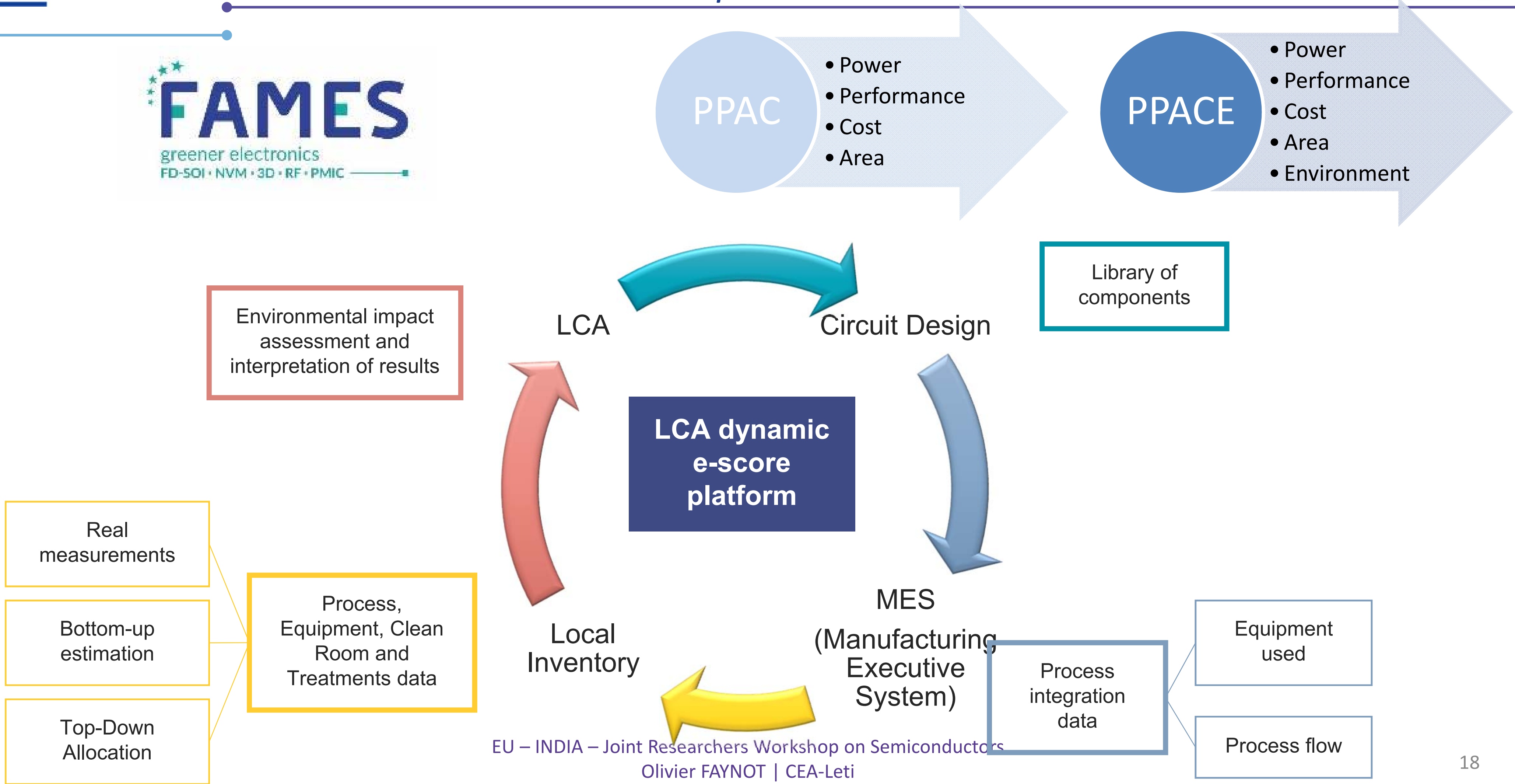


- ✓ **LCA single score clearly shows environmental benefits** in comparison with 2 state-of-the-art reference integrations : **reduction of 50-75% of the impacts**
- ✓ **Electrically valid** (leakage current, sheet resistance) initially & after JEDEC humidity storage and temperature cycling

S. Guillou *et al.*, "Comparative Life Cycle Analysis of Redistribution Layer for 3D Integrations," *2024 Electronics Goes Green 2024+ (EGG)*, Berlin, Germany, 2024,

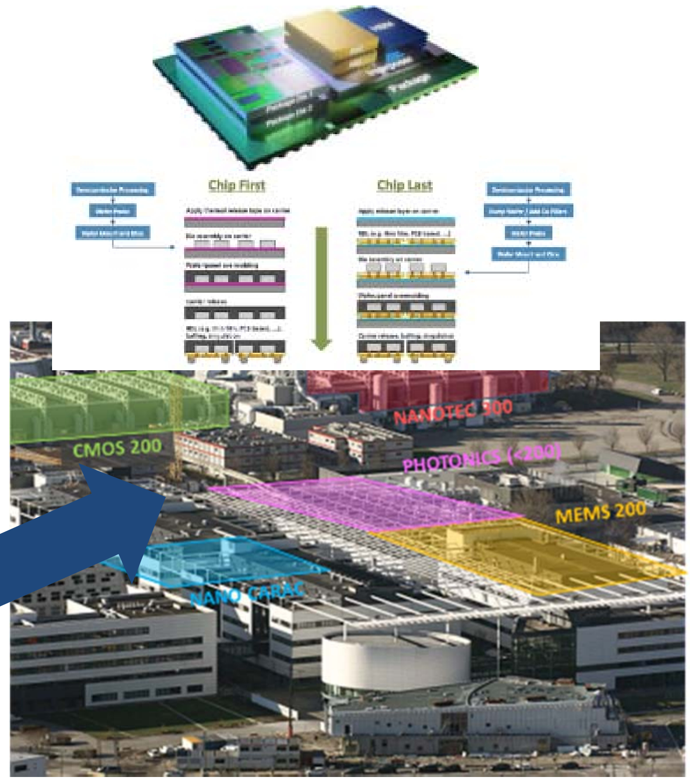
IC design improvement

Multi-criteria optimization



IC lifetime improvement

In-package chip repair solution



Open program focus

- Develop packaging solutions for repair & prototyping
  - Bumps & interconnect
  - Local isolation
- Program outcomes
  - Patterning morphology characterization
  - Material validation program
  - Electrical tests
  - Reliability
  - Economical aspects

Address SIP and associated packaging chip repair

Packaging metallurgy technology, repair strategy, CoO &LCA impacts

Reduce IC manufacturing footprint: *GENESIS project*

- **Consortium**
  - 63 partners from 12 pays – CEA-Leti coordinator
  - Duration 3 years
  - Expected start : Q2/25 (pending EU final approval)

Full proposal submitted
Pending to EU final approval

Gas & water monitoring & abatement: Edwards, Thermo Fisher Scientific, Pfeiffer Vacuum, centrotherm, Fath Group, VOCSens, Variolytics, Gasera, Topwerk, HQ-Dielectrics

Materials & chemicals: Arkema, Merck, PiBond, Heraeus, LayerOne, Molymem, Soitec, Mersen, Technic

Semiconductor manufacturing: GlobalFoundries, ST, Bosch, IBM, Infineon, Leonardo, intel, NXP

Communication: ArgYou.com, semi

Recycling: CS Clean Solutions, WEEECycling

Research: Tor Vergata, A?, UCLouvain, ICRA, University of Leicester

RTOs: cea, csem, Tyndall, VTT, SINTEF, imec, TNO, Fraunhofer

Equipment: Applied Materials, Besi, Trymax, TEL Tokyo Electron Europe, Schmidt Haensch, SCREEN, AIXTRON

→ Improve the entire manufacturing sustainability chain value

1 GASES & CHEMICAL
- PFAS free materials (litho, bonding, eqpt)
- Low GWP gas (etch & clean)

2 PROCESS
- Technology sustainable alternatives (FEOL- BEOL – Packaging)

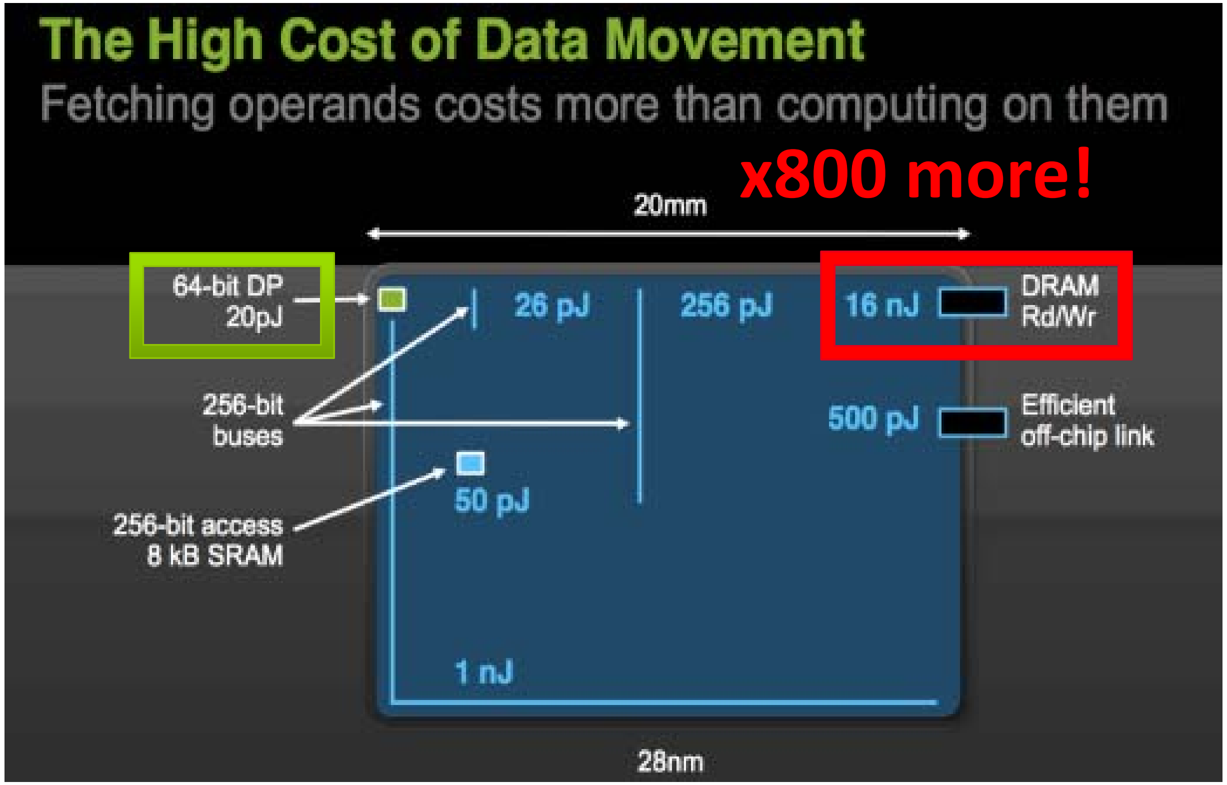
3 WASTE MONITORING & TREATMENT
- By-products & wastes sensing & monitoring
- Filtration and adsorption solutions (PFAS…)
- Reuse

4 AIR EMISSIONS
- Reduce gas emission
- Abatement
- H2 gas carrier re-use (MOCVD)

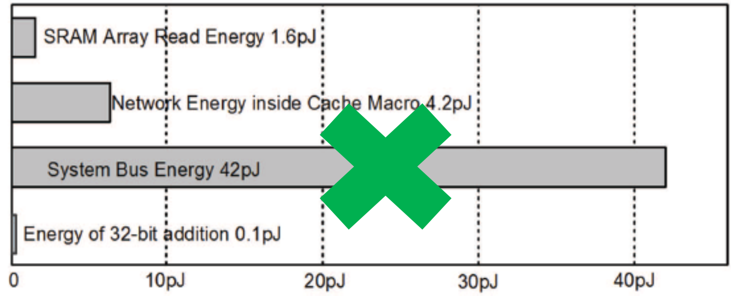
5 FINAL TREATMENT
- Reduce aqueous emission
- Water abatement
- Develop CRM recycling & valorization solutions

The cost of moving data

[J. Wang – ISSCC'19]



Bill Dally, "To ExaScale and Beyond", 2010



~90% of energy is in **data transfer**
→ IMC could lead **8x reduction**

Operation energy is negligible

Memory access and control energies dominate

ICOS
International Cooperation On Semiconductors

European Commission

EU – INDIA – Joint Researchers Workshop on Semiconductors

This project has received funding from the European Union's Horizon Europe research and innovation programme under GA N° 101092562

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