

# Sustainability in information and communication technologies

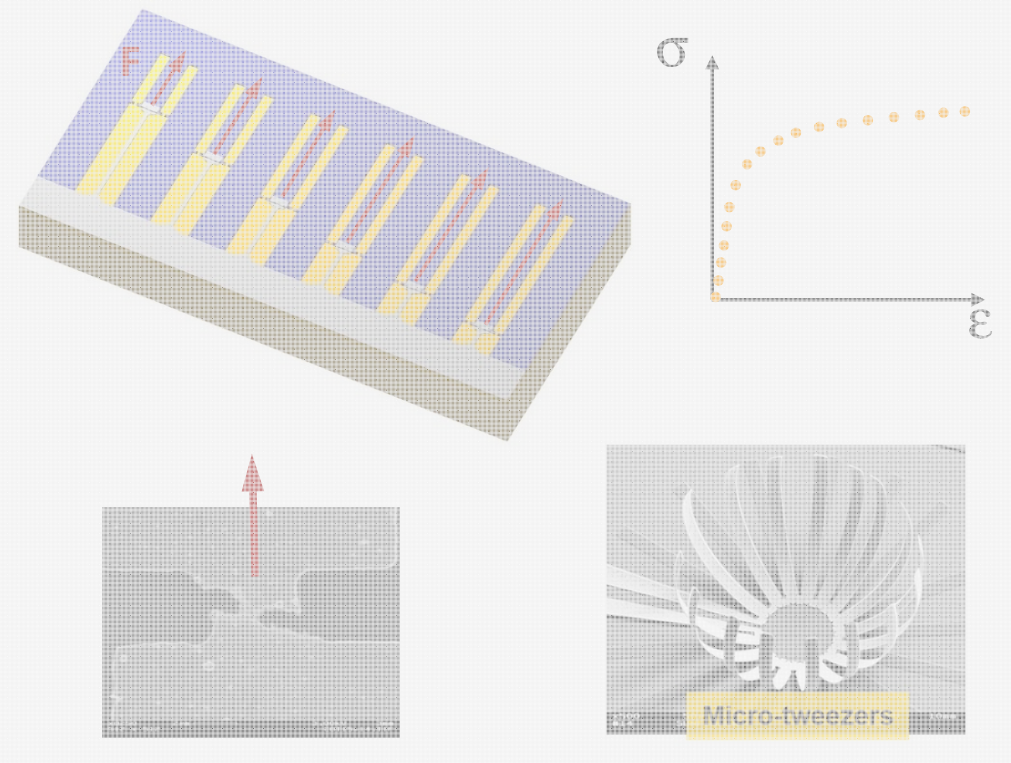
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[jean-pierre.raskin@uclouvain.be](mailto:jean-pierre.raskin@uclouvain.be)

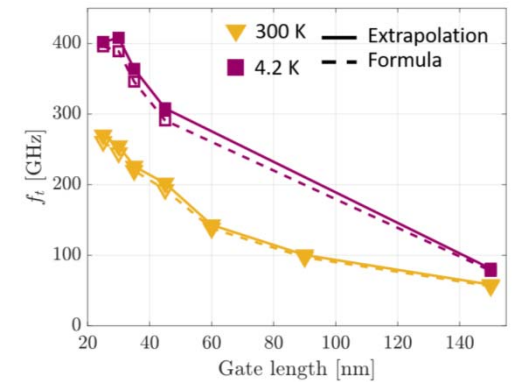
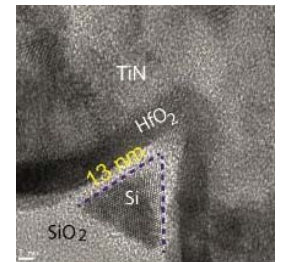
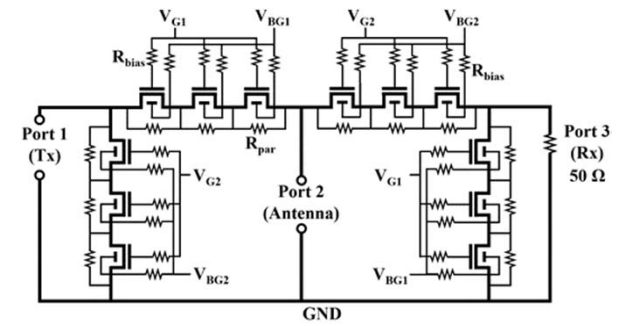
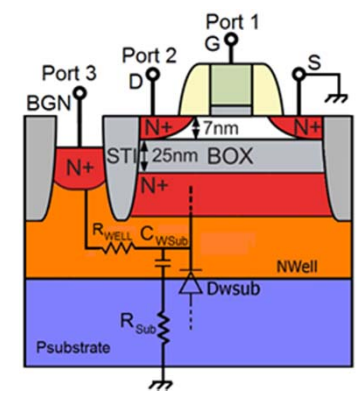


Team: 30 researchers

On-chip straining stage for materials characterization and properties tuning



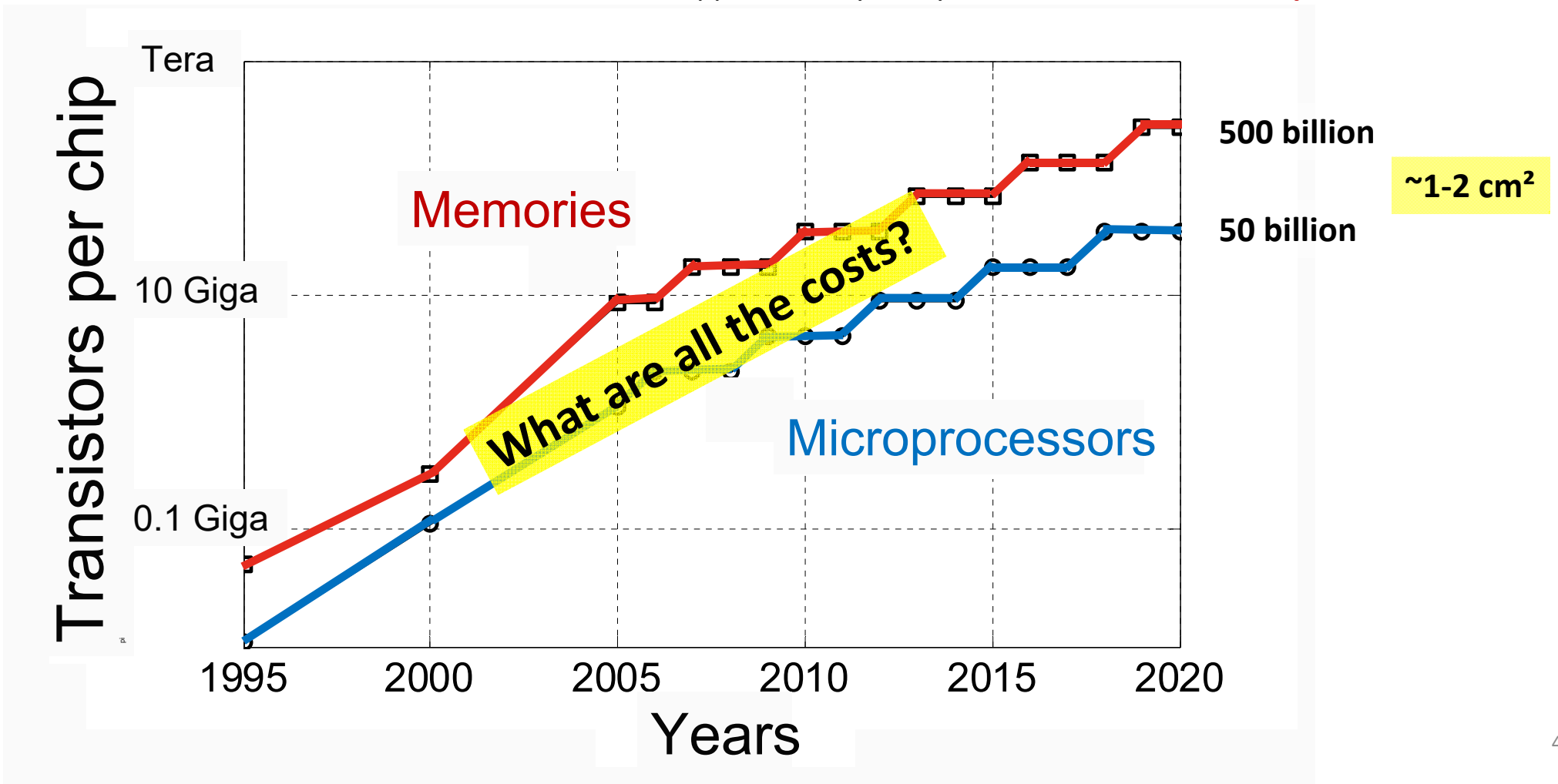
RF SOI in all wireless systems



# Factors explaining the environmental impact of ICT

# Moore's Law – an economic law

Number of transistors doubles approximately every 18 months **at a fixed low production cost**

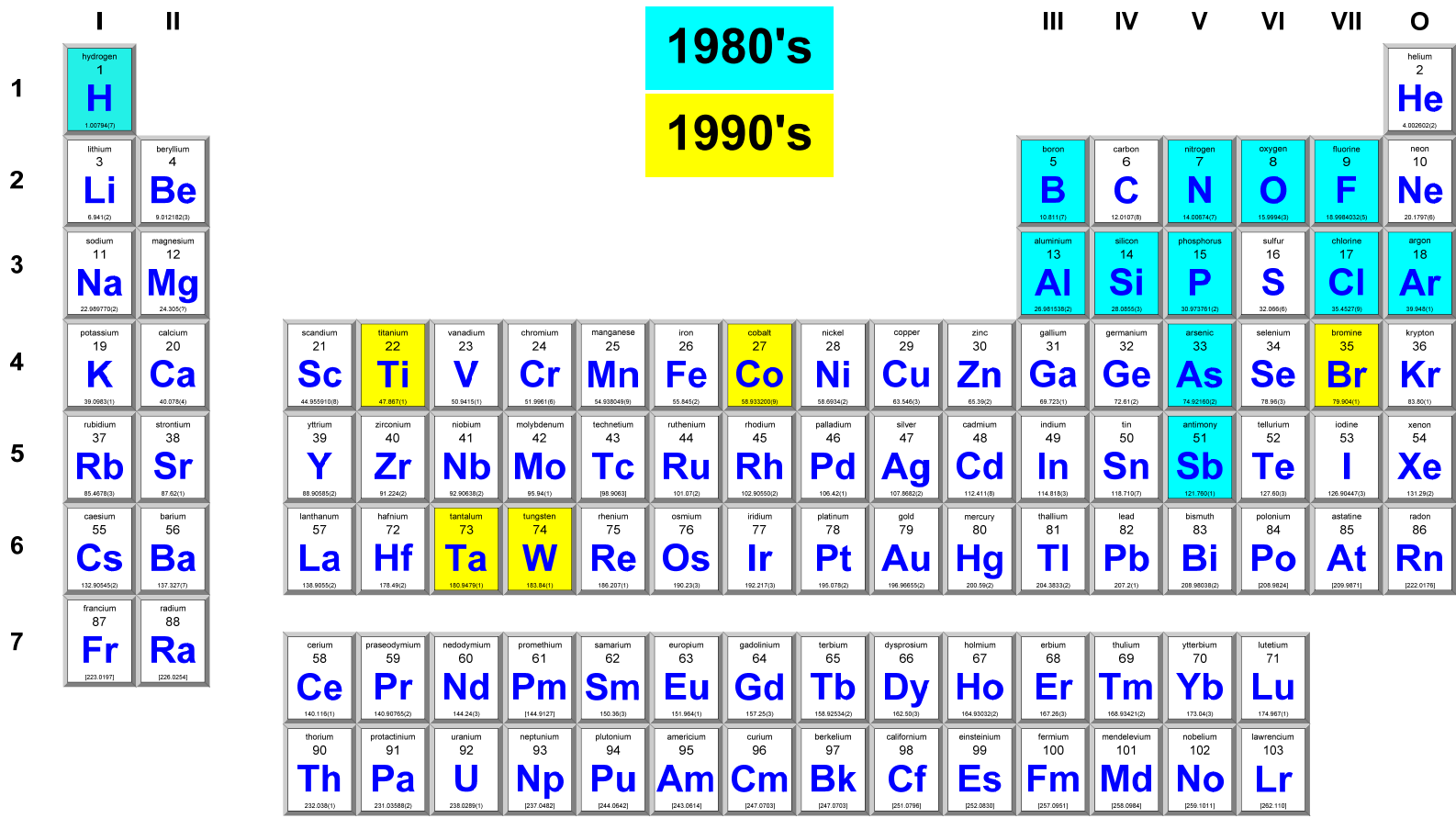


# Miniaturization – Pressure on materials

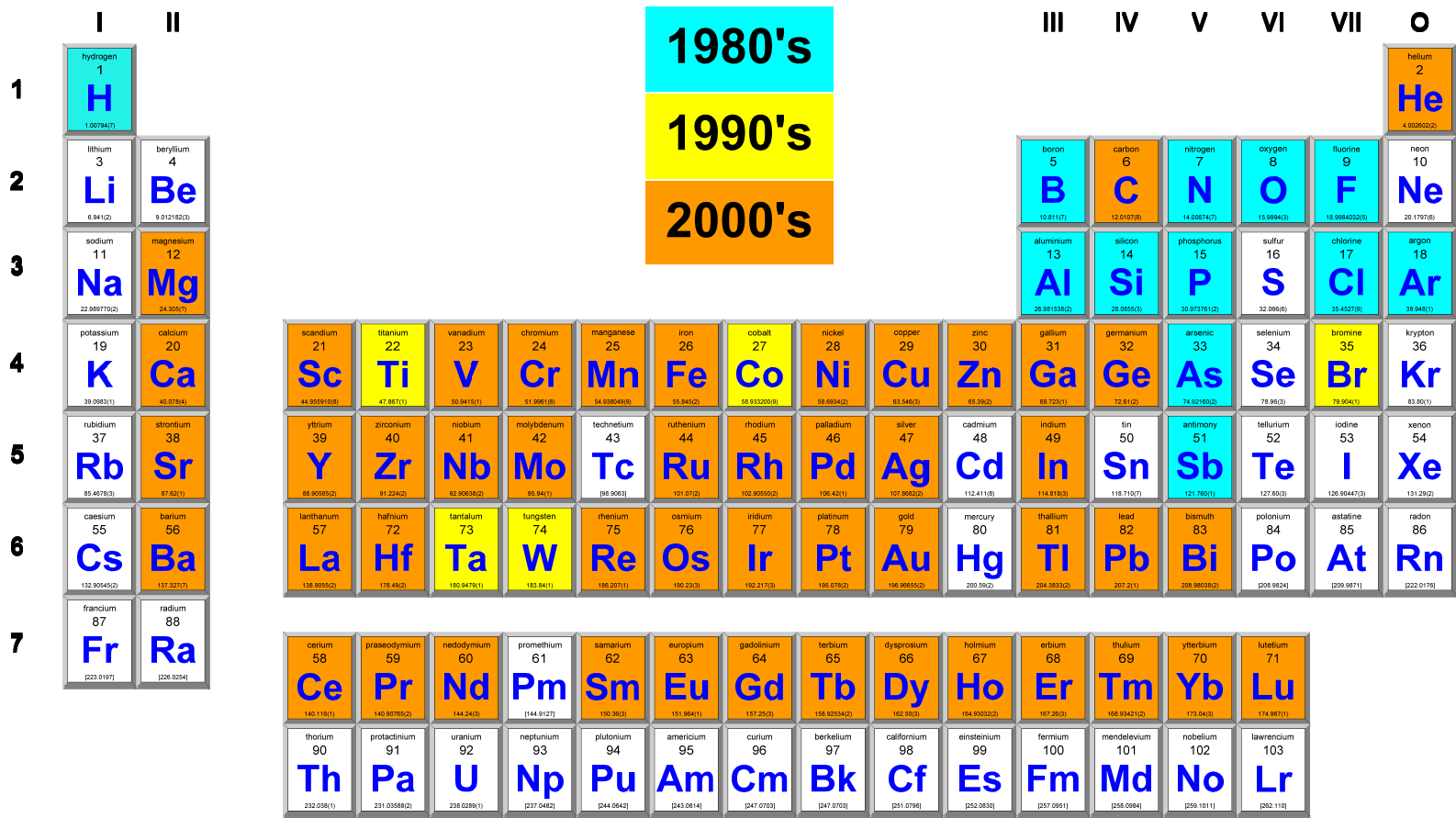
1980's

	I	II											III	IV	V	VI	VII	O												
1	1 <b>H</b> <small>1.00784(7)</small>																		2 <b>He</b> <small>4.00260(2)</small>											
2	3 <b>Li</b> <small>6.941(2)</small>	4 <b>Be</b> <small>9.01218(2)</small>											5 <b>B</b> <small>10.811(7)</small>	6 <b>C</b> <small>12.0107(8)</small>	7 <b>N</b> <small>14.0074(7)</small>	8 <b>O</b> <small>15.9994(3)</small>	9 <b>F</b> <small>18.998403(2)</small>	10 <b>Ne</b> <small>20.1797(6)</small>												
3	11 <b>Na</b> <small>22.989770(2)</small>	12 <b>Mg</b> <small>24.305(7)</small>											13 <b>Al</b> <small>26.981538(2)</small>	14 <b>Si</b> <small>28.0855(3)</small>	15 <b>P</b> <small>30.97376(2)</small>	16 <b>S</b> <small>32.06(6)</small>	17 <b>Cl</b> <small>35.453(7)</small>	18 <b>Ar</b> <small>39.948(1)</small>												
4	19 <b>K</b> <small>39.0983(1)</small>	20 <b>Ca</b> <small>40.078(4)</small>	21 <b>Sc</b> <small>44.95591(8)</small>	22 <b>Ti</b> <small>47.867(1)</small>	23 <b>V</b> <small>50.9415(1)</small>	24 <b>Cr</b> <small>51.9961(6)</small>	25 <b>Mn</b> <small>54.93804(3)</small>	26 <b>Fe</b> <small>55.845(2)</small>	27 <b>Co</b> <small>58.93320(9)</small>	28 <b>Ni</b> <small>58.6934(2)</small>	29 <b>Cu</b> <small>63.546(3)</small>	30 <b>Zn</b> <small>65.39(2)</small>	31 <b>Ga</b> <small>69.723(1)</small>	32 <b>Ge</b> <small>72.61(2)</small>	33 <b>As</b> <small>74.9216(2)</small>	34 <b>Se</b> <small>78.96(3)</small>	35 <b>Br</b> <small>79.904(1)</small>	36 <b>Kr</b> <small>83.80(1)</small>												
5	37 <b>Rb</b> <small>85.4678(3)</small>	38 <b>Sr</b> <small>87.62(1)</small>	39 <b>Y</b> <small>88.90585(2)</small>	40 <b>Zr</b> <small>91.224(2)</small>	41 <b>Nb</b> <small>92.90638(2)</small>	42 <b>Mo</b> <small>95.94(1)</small>	43 <b>Tc</b> <small>(98.9063)</small>	44 <b>Ru</b> <small>101.07(2)</small>	45 <b>Rh</b> <small>102.90550(2)</small>	46 <b>Pd</b> <small>106.42(1)</small>	47 <b>Ag</b> <small>107.8682(2)</small>	48 <b>Cd</b> <small>112.411(8)</small>	49 <b>In</b> <small>114.818(3)</small>	50 <b>Sn</b> <small>118.710(7)</small>	51 <b>Sb</b> <small>121.760(1)</small>	52 <b>Te</b> <small>127.60(3)</small>	53 <b>I</b> <small>126.90447(3)</small>	54 <b>Xe</b> <small>131.29(2)</small>												
6	55 <b>Cs</b> <small>132.90545(2)</small>	56 <b>Ba</b> <small>137.327(7)</small>	57 <b>La</b> <small>138.905(2)</small>	72 <b>Hf</b> <small>178.49(2)</small>	73 <b>Ta</b> <small>180.9478(1)</small>	74 <b>W</b> <small>183.84(1)</small>	75 <b>Re</b> <small>186.207(1)</small>	76 <b>Os</b> <small>190.23(3)</small>	77 <b>Ir</b> <small>192.22(7)</small>	78 <b>Pt</b> <small>195.078(2)</small>	79 <b>Au</b> <small>196.96655(2)</small>	80 <b>Hg</b> <small>200.59(2)</small>	81 <b>Tl</b> <small>204.3833(2)</small>	82 <b>Pb</b> <small>207.2(1)</small>	83 <b>Bi</b> <small>208.98038(2)</small>	84 <b>Po</b> <small>(208.9824)</small>	85 <b>At</b> <small>(209.9871)</small>	86 <b>Rn</b> <small>(222.0178)</small>												
7	87 <b>Fr</b> <small>(223.0187)</small>	88 <b>Ra</b> <small>(226.0254)</small>	58 <b>Ce</b> <small>140.118(1)</small>	59 <b>Pr</b> <small>140.90765(2)</small>	60 <b>Nd</b> <small>144.24(3)</small>	61 <b>Pm</b> <small>(144.9127)</small>	62 <b>Sm</b> <small>150.36(3)</small>	63 <b>Eu</b> <small>151.964(1)</small>	64 <b>Gd</b> <small>157.25(3)</small>	65 <b>Tb</b> <small>158.92534(2)</small>	66 <b>Dy</b> <small>162.50(3)</small>	67 <b>Ho</b> <small>164.93032(2)</small>	68 <b>Er</b> <small>167.26(3)</small>	69 <b>Tm</b> <small>168.93421(2)</small>	70 <b>Yb</b> <small>173.04(3)</small>	71 <b>Lu</b> <small>174.967(1)</small>	90 <b>Th</b> <small>232.038(1)</small>	91 <b>Pa</b> <small>231.03688(2)</small>	92 <b>U</b> <small>238.02891(1)</small>	93 <b>Np</b> <small>(237.0482)</small>	94 <b>Pu</b> <small>(244.0642)</small>	95 <b>Am</b> <small>(243.0614)</small>	96 <b>Cm</b> <small>(247.0703)</small>	97 <b>Bk</b> <small>(247.0703)</small>	98 <b>Cf</b> <small>(251.0796)</small>	99 <b>Es</b> <small>(252.0833)</small>	100 <b>Fm</b> <small>(257.0951)</small>	101 <b>Md</b> <small>(258.0684)</small>	102 <b>No</b> <small>(259.1011)</small>	103 <b>Lr</b> <small>(262.110)</small>

# Miniaturization – Pressure on materials

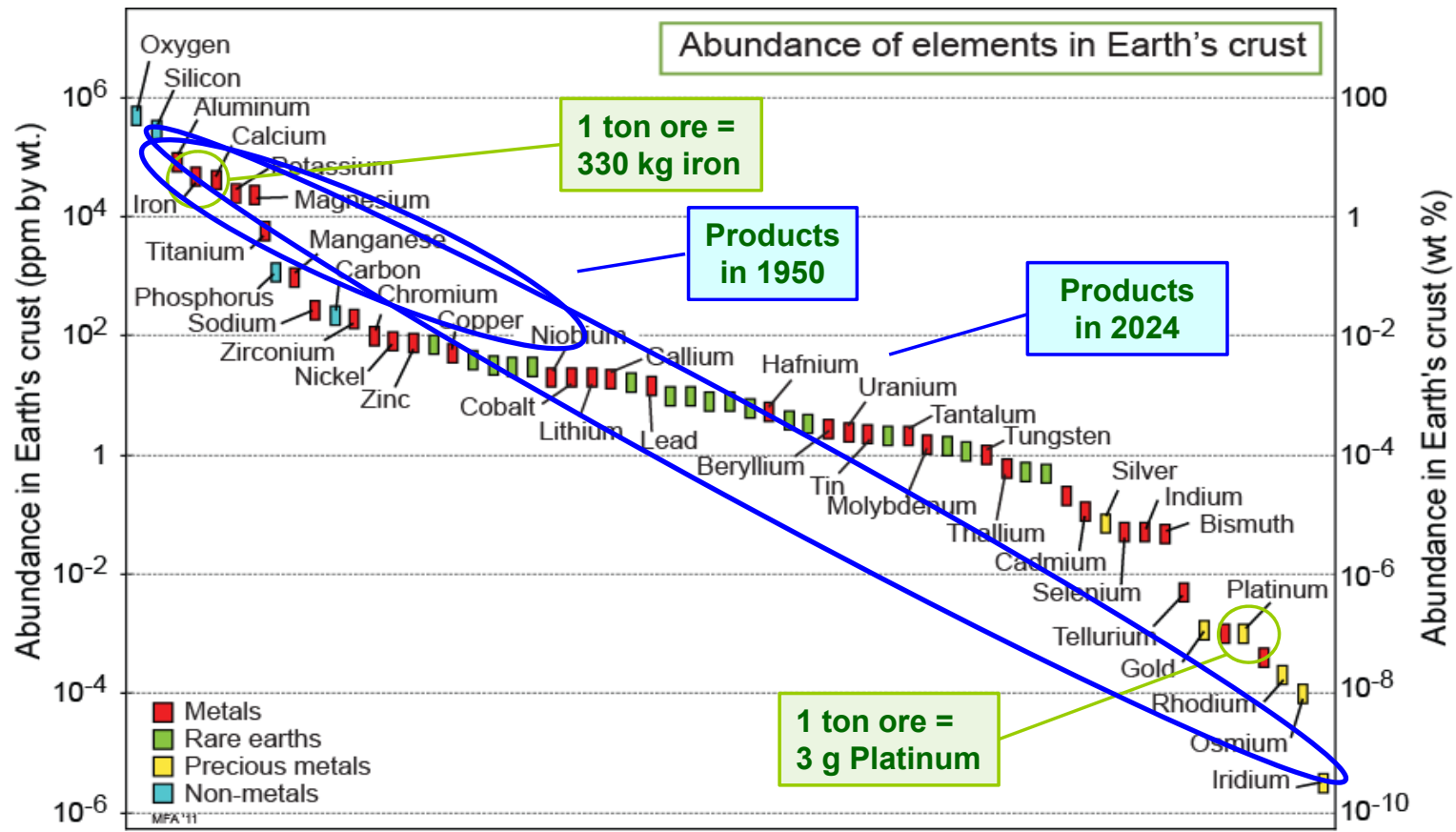


# Miniaturization – Pressure on materials



# Always more extraction, always more materials

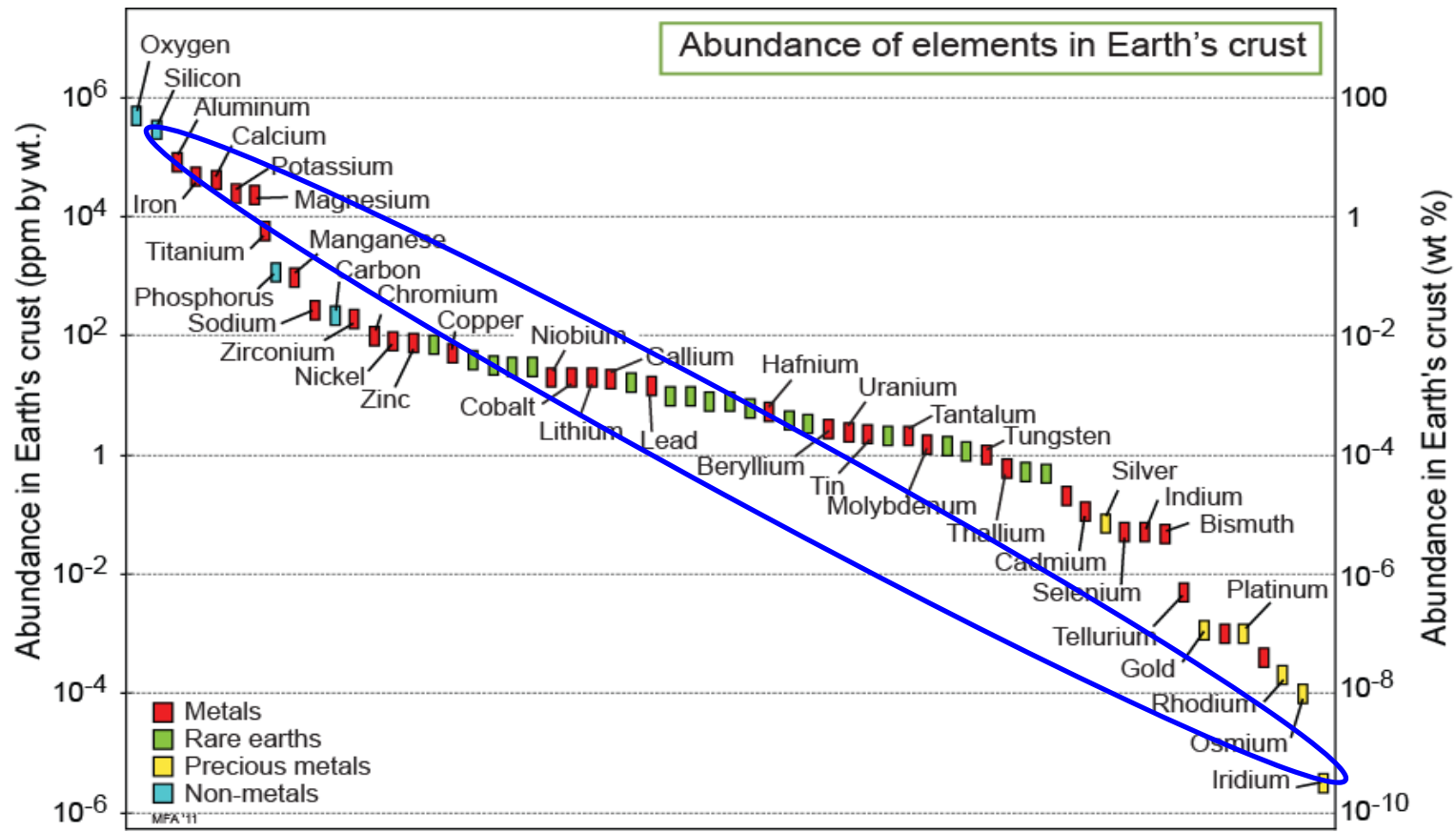
Factor of  $10^{10}$



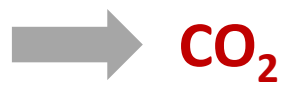
[Prof. M. Ashby, Cambridge Univ.]



# Always more extraction, always more energy

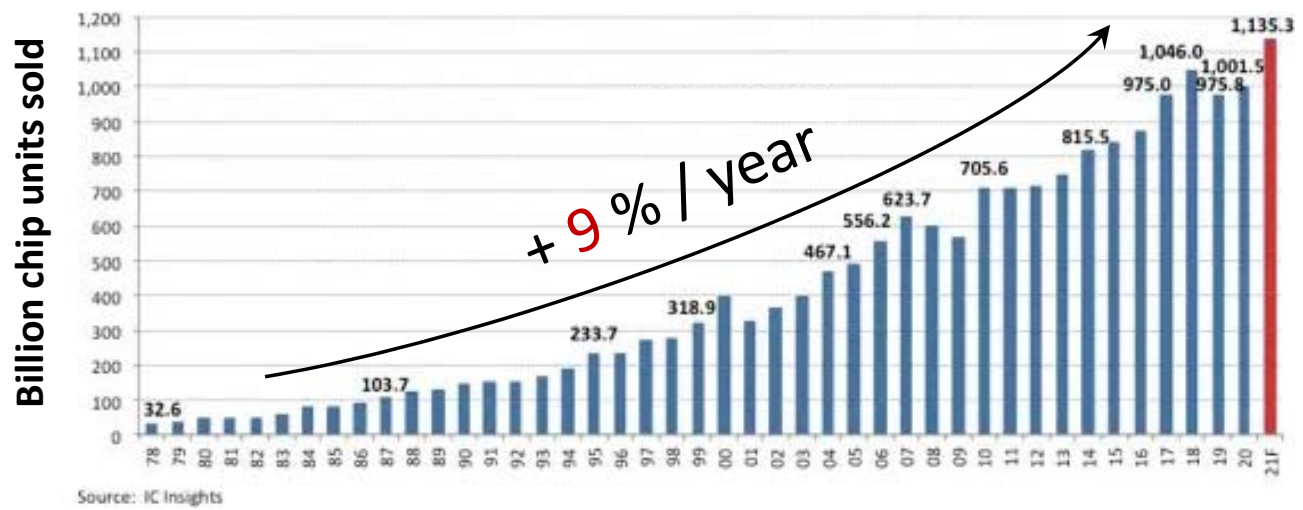
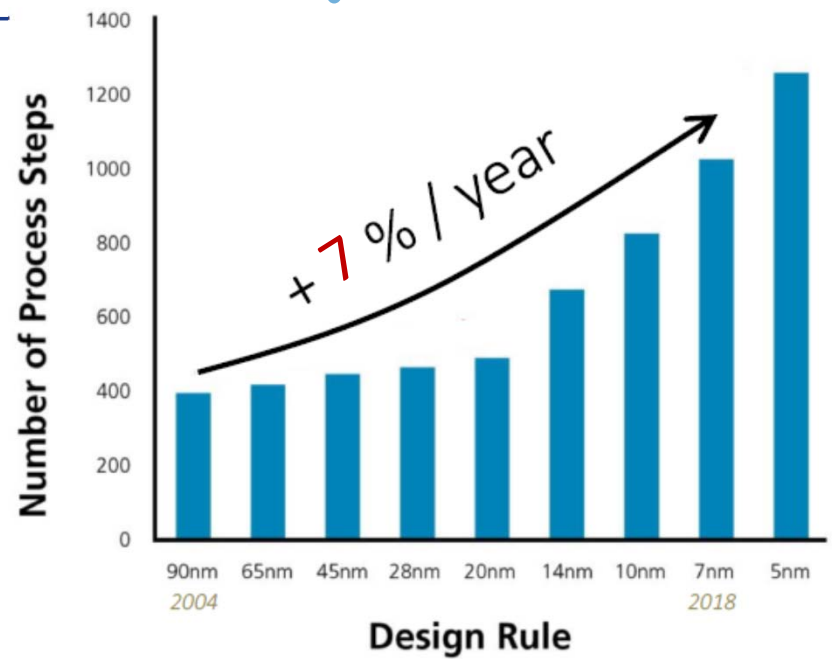


Quantity of energy is always larger per quantity of extracted materials



[Prof. M. Ashby, Cambridge Univ.]

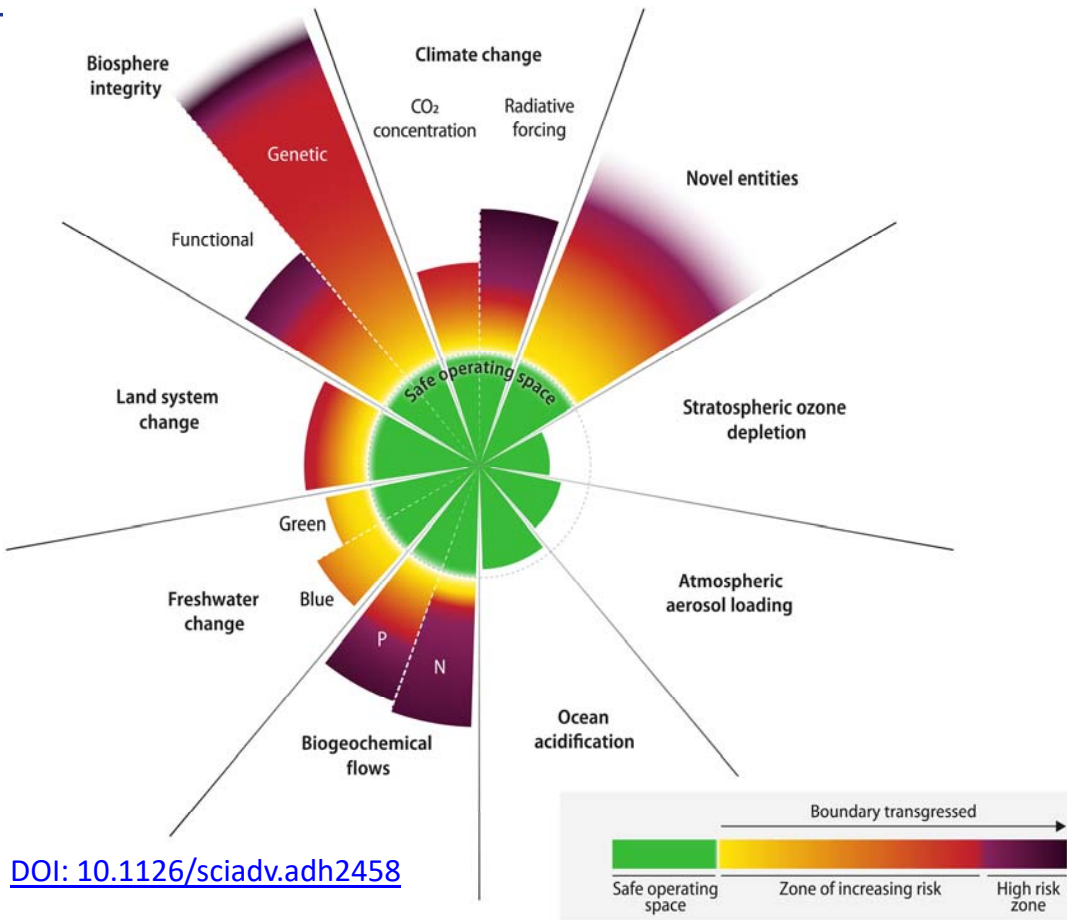
# Increase of process complexity



Chip unit **fab energy**: + 7% / year (techno scaling)  
 + Chip unit **sale**: + 9% / year (consumption, obsolescence)

Global chip fabrication **energy footprint**: + 16% / year → CO<sub>2</sub>

# Much more than climate change



- The scientists have demonstrated the **coupling** between the **way of living and the health of the planet**
- Several **planetary limits** have been already transgressed
- Not only CO<sub>2eq</sub> ... **16 impact indicators** addressing air, water and soil emissions and resource use
- There is an urgent need to move to **responsible innovation**

[DOI: 10.1126/sciadv.adh2458](https://doi.org/10.1126/sciadv.adh2458)

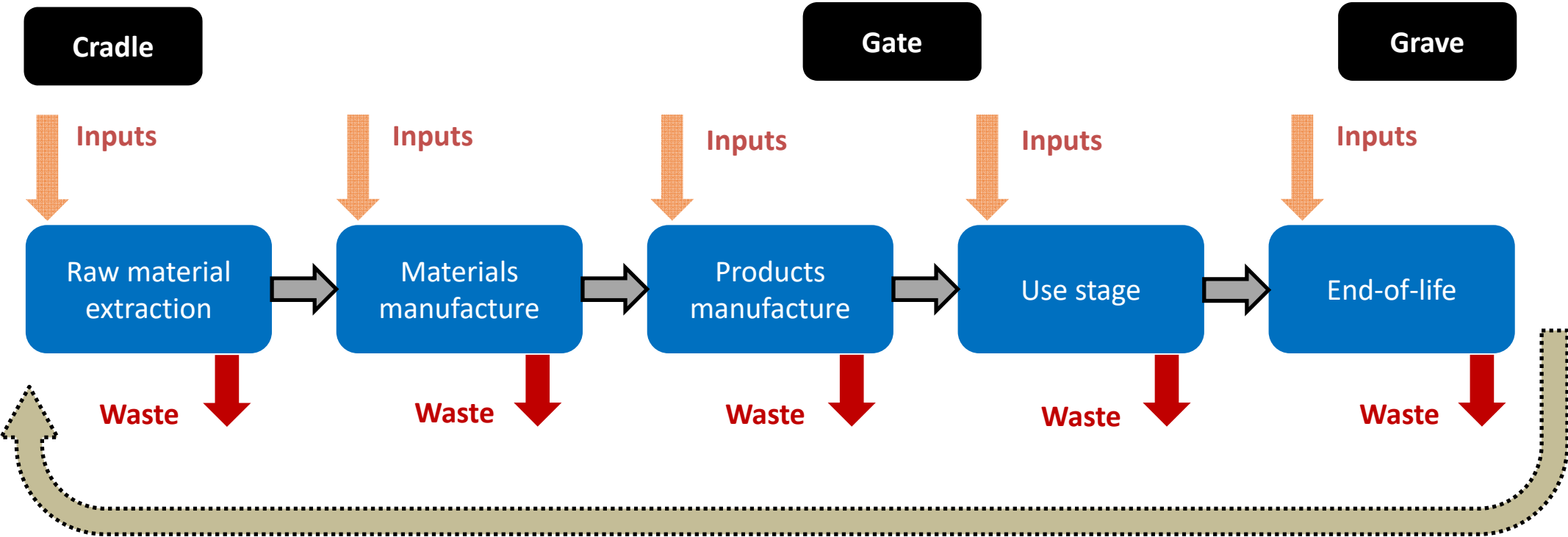
## On-going actions to reduce the footprint of ICT



# Life Cycle Assessment (LCA)



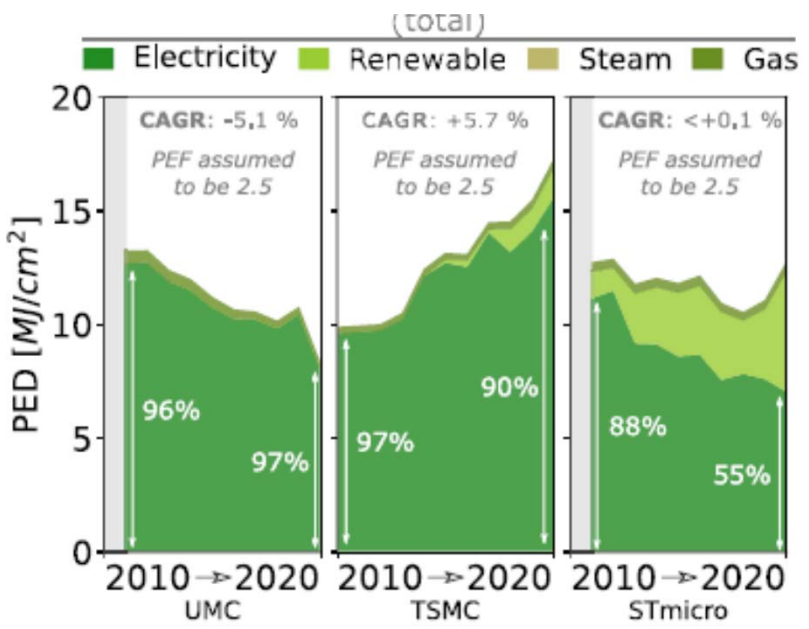
LCA studies (ISO 14040) the potential impacts on the planet ecosystems and human health from raw materials acquisition through production, use and disposal of a product or service.



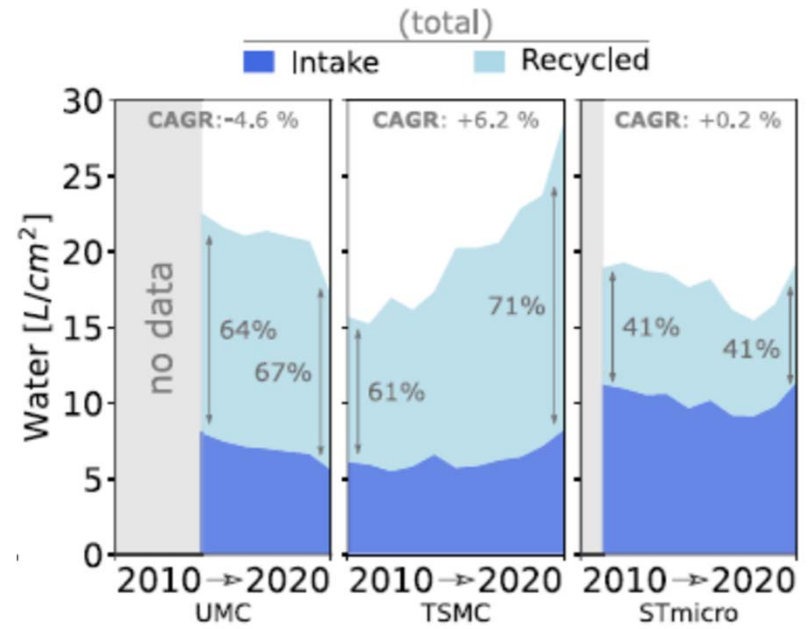
## Circular Economy

# Reduce energy and water used

## Primary Energy Demand



## Water consumption



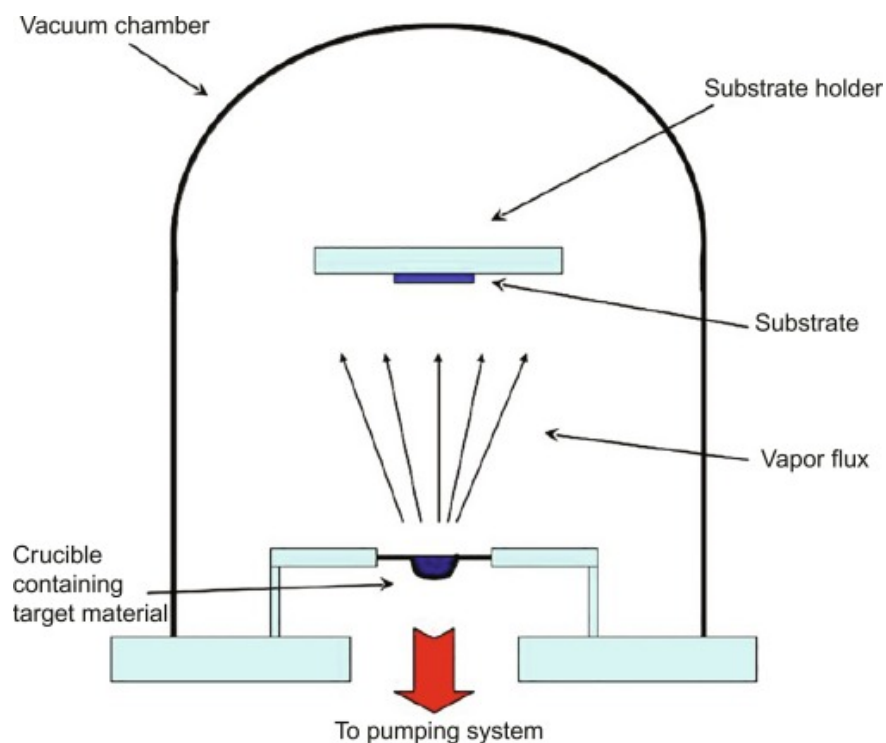
Data: industrial annual reports (CSR)

Good for the environment,  
good for the economic profit

But 70% of sold ICs between 2010-2020

[T. Pirson et al., IEEE Transactions on Semiconductor Manufacturing, February 2023, doi: 10.1109/TSM.2022.3228311]

# Recovery and Recycle of metals



- Evaporation or sputtering of metals
- Recovery and recycling techniques are currently tested
- Most of the metal is deposited over the chamber walls (>80%)
- The target is replaced while material remains

**Good for the environment,  
good for the economic profit**

# New chemistry in R&D

## To fulfill upcoming legislations

For stripping, wet etching, cleaning, decontamination

- $H_3PO_4$  free etchant of Al and  $Si_3N_4$
- Quaternary ammonium free Stripper
- Aqua regia free for decontamination
- Wet chemistry CMR free for post-etc cleaning

*Projet i-Demo CLEAN  
Contact: Thierry Chevolleau, CEA-Leti*

Evaluation of bio-sourced (chitosan) water-soluble resists, avoiding solvent and alkali-based developers

**Oil-based**

Mask → Source UV → Si

PGMEA, TMAH

**Bio-based**

Mask → Source UV → Si

DI Water, green solvents

**Litho DUV**

10 mm → 200 mm → 300 mm

Spin-coating Thickness. ~ 100nm

CD ~ 1µm

**Etch transfer**

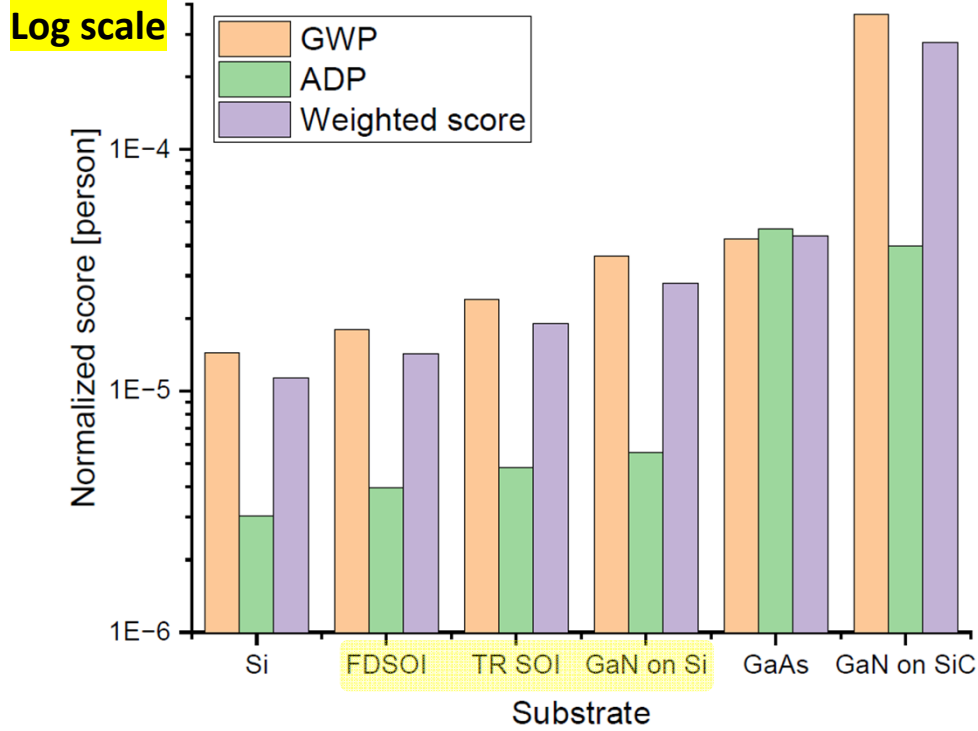
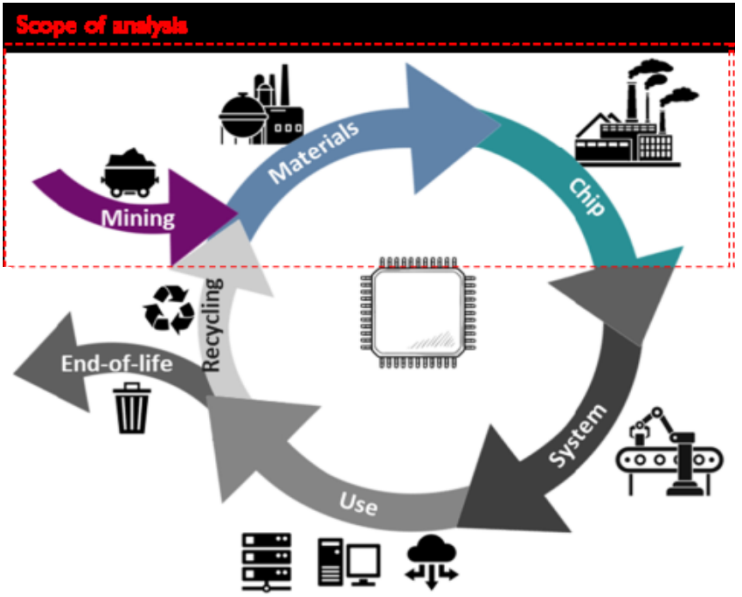
10 mm → 300 mm

Preserved profile

*Contact: Isabelle Servin, CEA-Leti*



# New engineered substrates

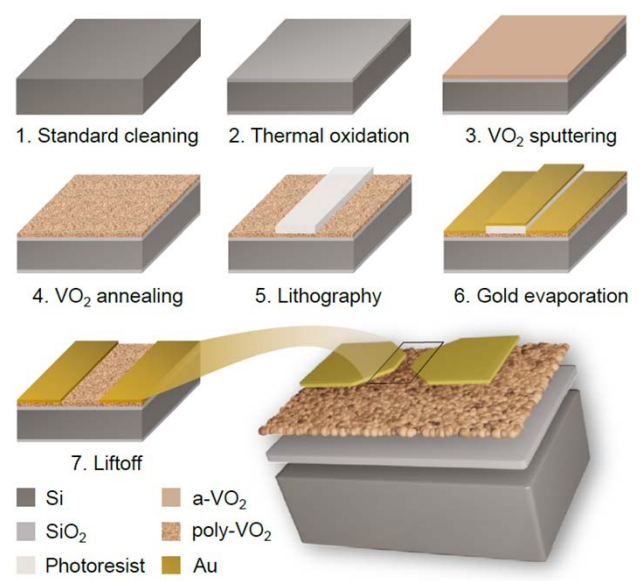


Global Warming Potential and Abiotic Depletion Potential

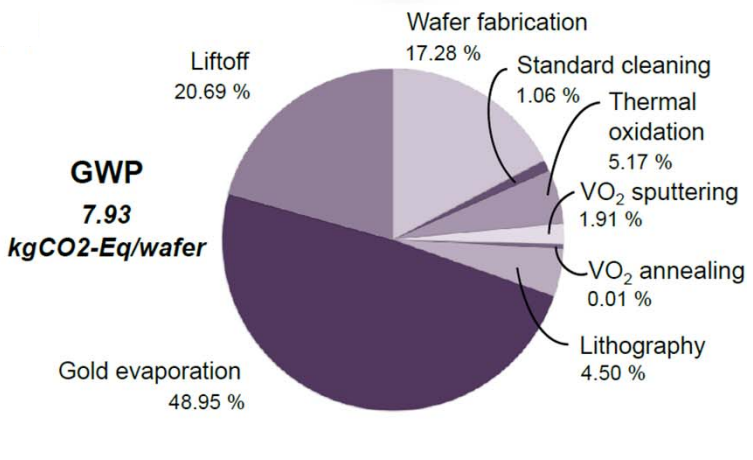
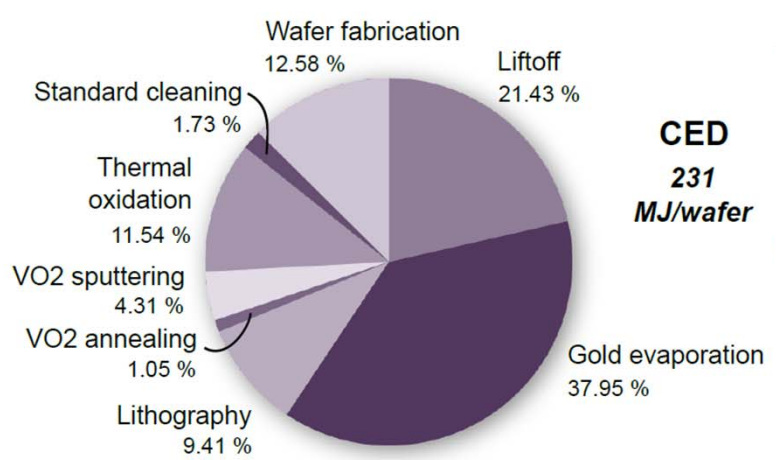
[B. Vanhouche et al., *Electronics Goes Green 2024*, Berlin, Germany, June 17-20, 2024]

# Substitution of materials

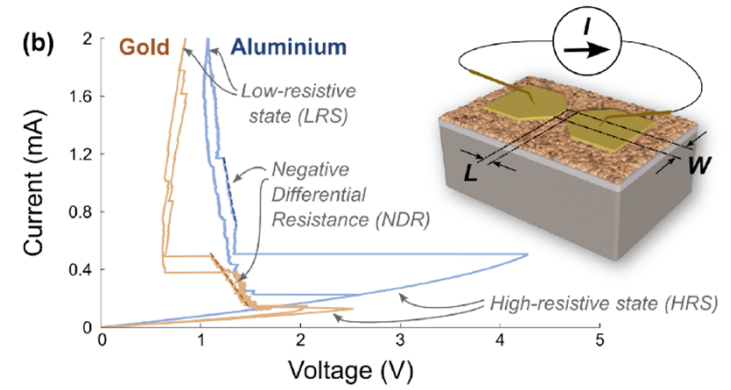
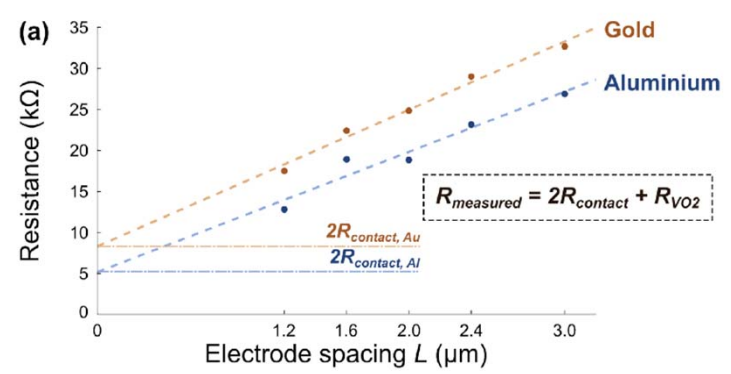
## Spiking neurons for neuromorphic systems



[N. Bidoul et al., Electronics Goes Green 2024, Berlin, Germany, June 17-20, 2024]



## Gold replaced by Aluminium: -25 % CED and -43 % GWP





# GENESIS – EU project



- 60 partners
- 12 countries

The image displays a grid of 10 colored boxes, each representing a different sector of the GENESIS project. Each box contains logos of participating companies and organizations. The sectors and their associated logos are:

- Gas abatement:** CS CLEAN SOLUTIONS, centrotherm, PFEIFFER, VACUUM, VOC Sens.
- water:** ICRA, FATHGROUP, MOLYMEM, Abatement systems, EDWARDS.
- Materials and chemicals:** ARKEMA, PiBond, Heraeus, LayerOne, MERCK, MERSEN, sitec.
- Semiconductor:** APPLIED MATERIALS, GlobalFoundries, BOSCH, IBM, ST, infineon, AIXTRON, intel, LEONARDO, SCREEN, Trymax, NXO, ThermoFisher.
- Research:** A? (Aalto University), csem, CO2, VTT, SINTEF, TOR VERGATA, TNO, Tyndall, Fraunhofer, UCLouvain, UNIVERSITY OF LEICESTER.
- Media:** ArgYou.com, semi.
- Packaging:** Besi.
- Recycling:** WEEE Cycling.
- Sensors & equipment:** TEL (Tokyo Electron & Europe), SH (SCHMIDT HAENSCH), GASERA, VARIOLYTICS, TOFWERK.

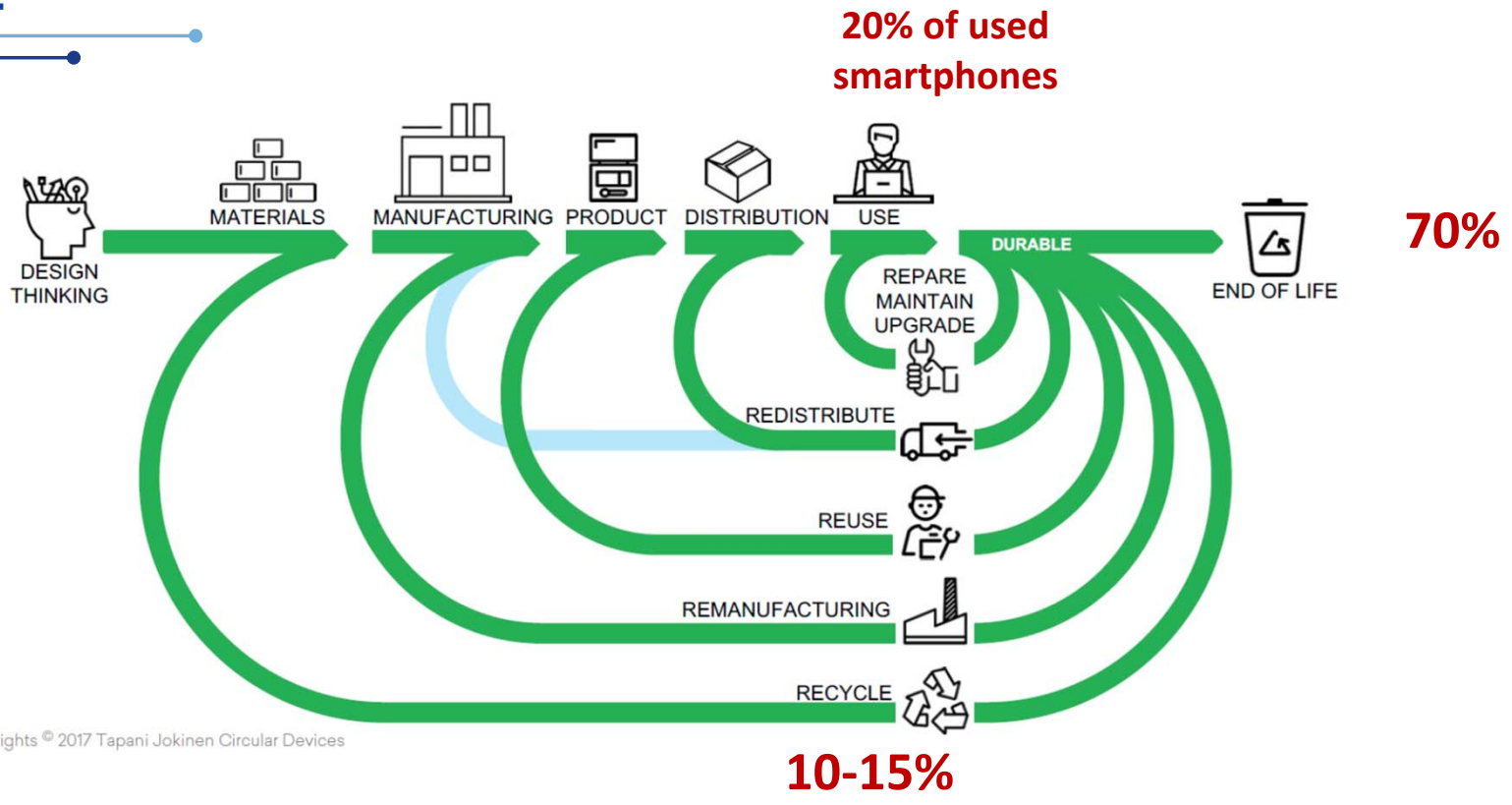
At the bottom of the grid, there is a row of 12 national flags representing the countries of the participating partners.

- A sustainable semiconductor industry must be the concern of everybody
- Not a source of competition
- COLLABORATION IS KEY

GENESIS project ambitious targets:

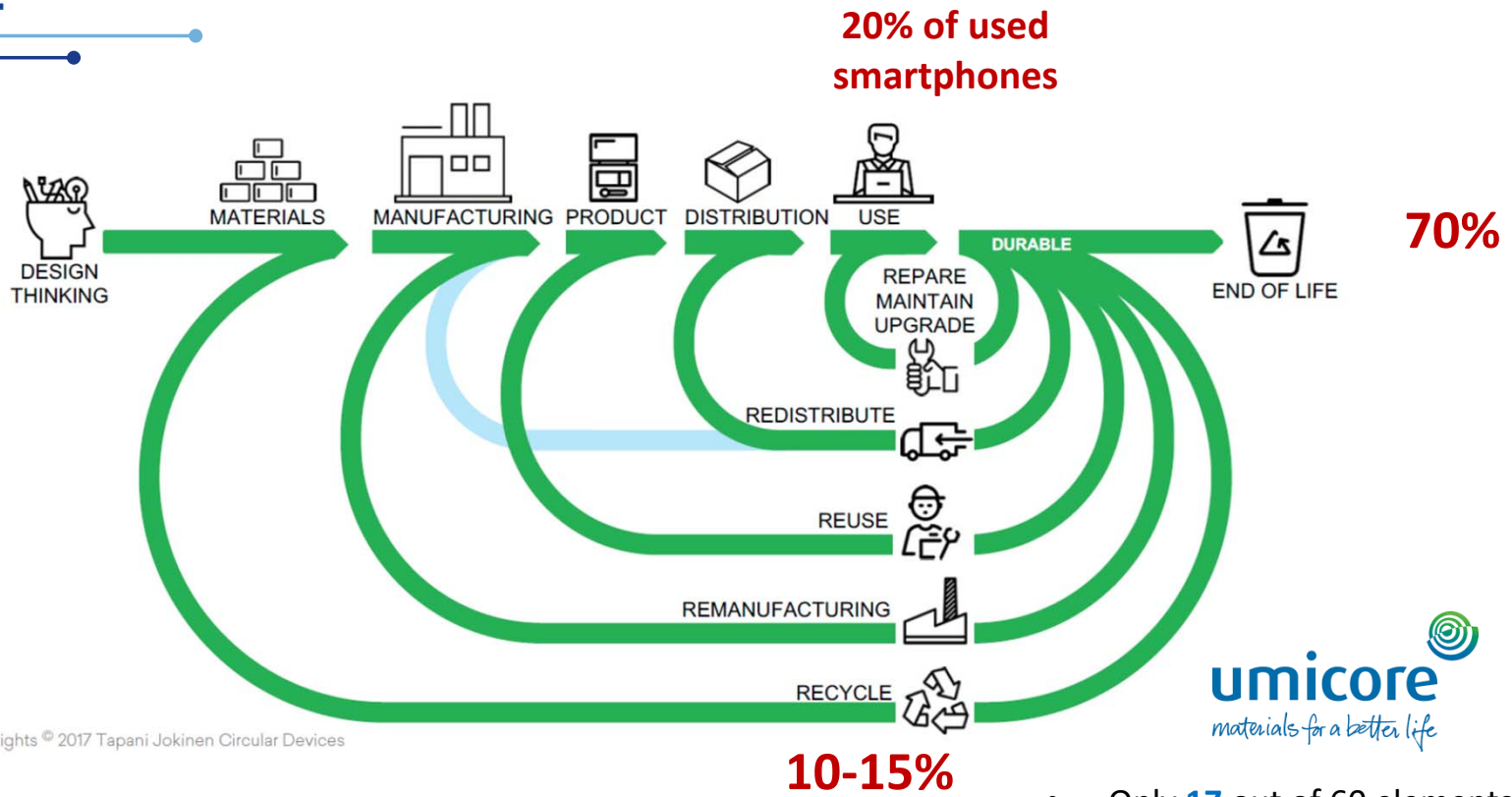
- 50% reduction in **hazardous materials**
- 30% decrease in **emissions and waste**,
- and improved **recycling of rare materials**

# Electronics Waste

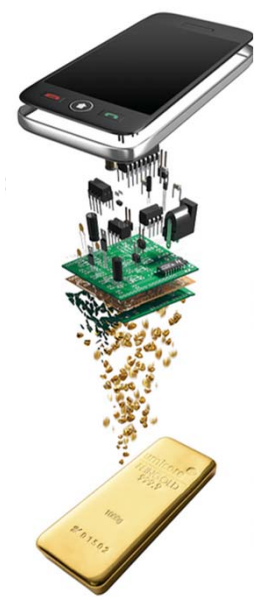


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# Electronics Waste

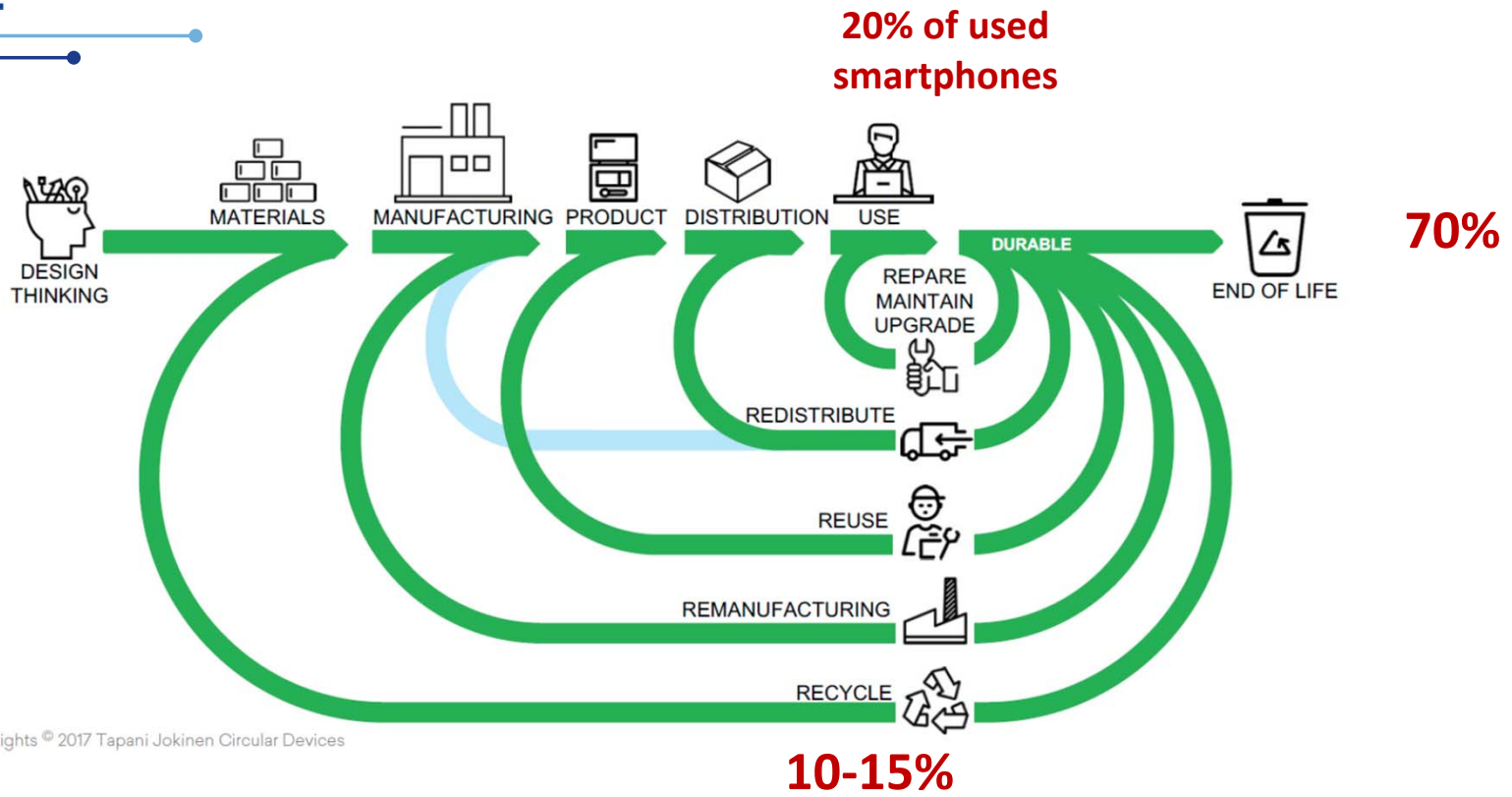


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- Only **17** out of 60 elements
- Only **4-5** are profitable
- Not profitable because **raw materials** are really **too cheap**

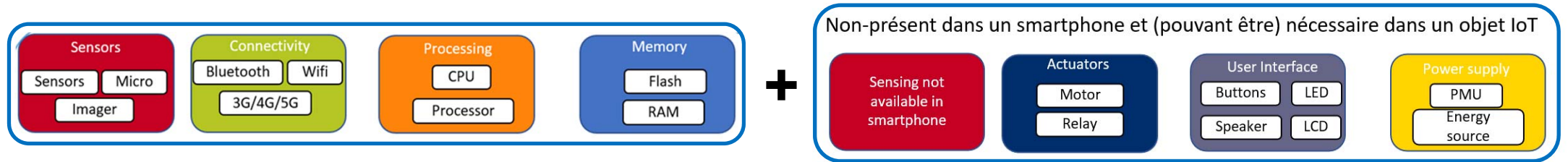
# Electronics Waste



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We must implement solutions for **more circularity**  
 The shorter the loop is, the better is ... **Reuse, Repair, Repurpose, ...**

# Reuse, Repair, Repurposing



- Battery control and space location of electric scooters
- Monitoring of cryogenic batteries for solar energy storage

[N. Brusselmans *et al.*, *Electronics Goes Green 2024*, Berlin, Germany, June 17-20, 2024]

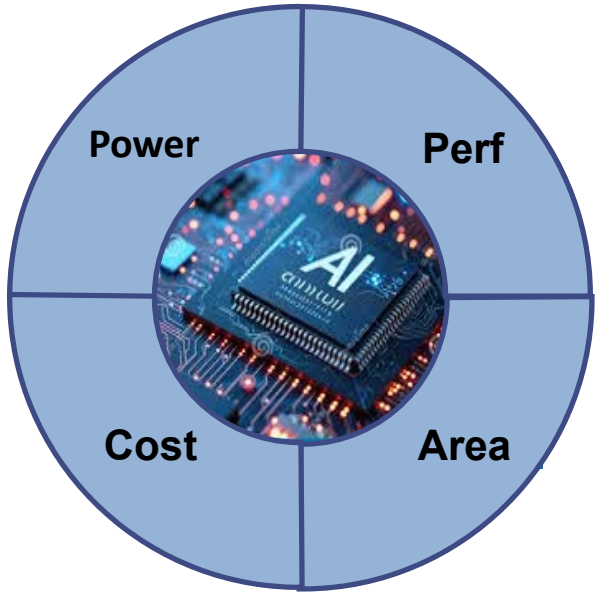
# Conclusions

- Use **LCA to reveal trends** in **early stage of a technology development** and consider the whole life-cycle of a product or service
- However, **complexity** in fab, supply chain and IP make **data collection a challenge**
- LCA is not sufficient, study **rebound effects** and consumer behaviour!
- Need for **transversal collaborations & a holistic approach** (industry, academy, regulations, citizens, social sciences) along the entire life of the product or the service
- Our techno-liberal societies encourage us to develop **creative destruction** (Joseph Schumpeter)
- We should start thinking about **appropriate and appropriable technologies**



# What is a route towards sustainable microelectronics?

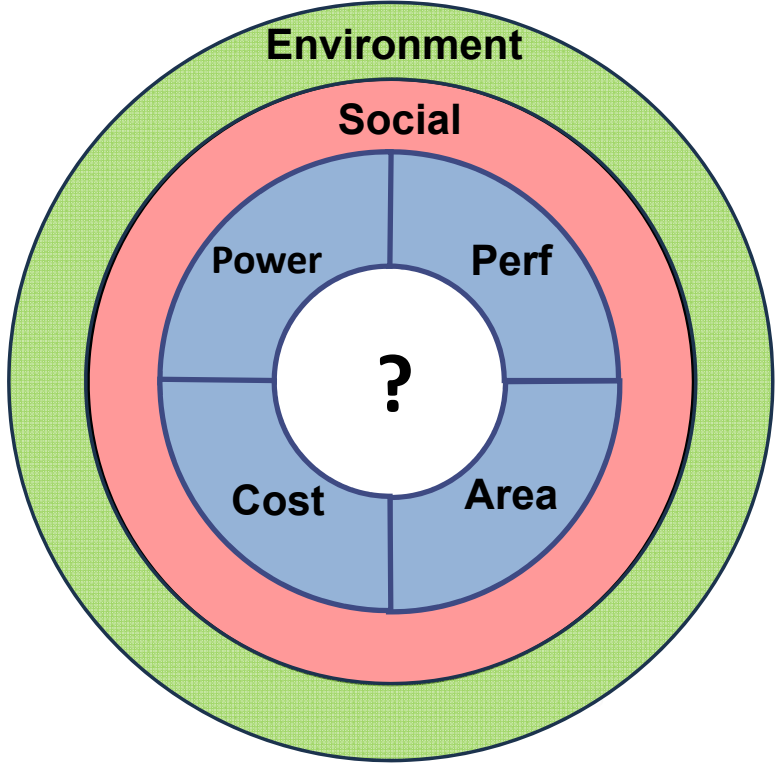
**Today's Drivers**  
Performance & economy



**PPAC**



**Tomorrow's Drivers?**



**PPAC - E & S**



# Acknowledgements



- Chair of Excellence Carnot at CEA-Leti
- Researchers of the RF-SOI group
- Prof. David Bol, Dr. Sébastien Toussaint, Dr. Grégoire Le Brun, Mr. Nicolas Brusselmans, Mrs. Margo Hauwaert, Mrs. Justine Lebrun, Prof. Ignace Adant



welcome  
wallonia electronics  
and communications  
measurements





THANK YOU



EU – INDIA – Joint Researchers Workshop on Semiconductors

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[www.icos-semiconductors.eu](http://www.icos-semiconductors.eu)