SUSTAIN-E
Summer School on Sustainable Electronics

June 16 - 20, 2025
Grenoble, France

Exploring the future of sustainable electronics: From raw materials and eco-design to recycling and economic perspectives.

GreenChips-EDU
Educate for a Sustainable Tomorrow

µElectronics
Université Grenoble Alpes

EECONE

Grenoble INP UGA Phelma

NANOELEC.

Beyond the quest for performance, let's target a *more* sustainable power electronics technology

Speaker : Jean Christophe CREBIER

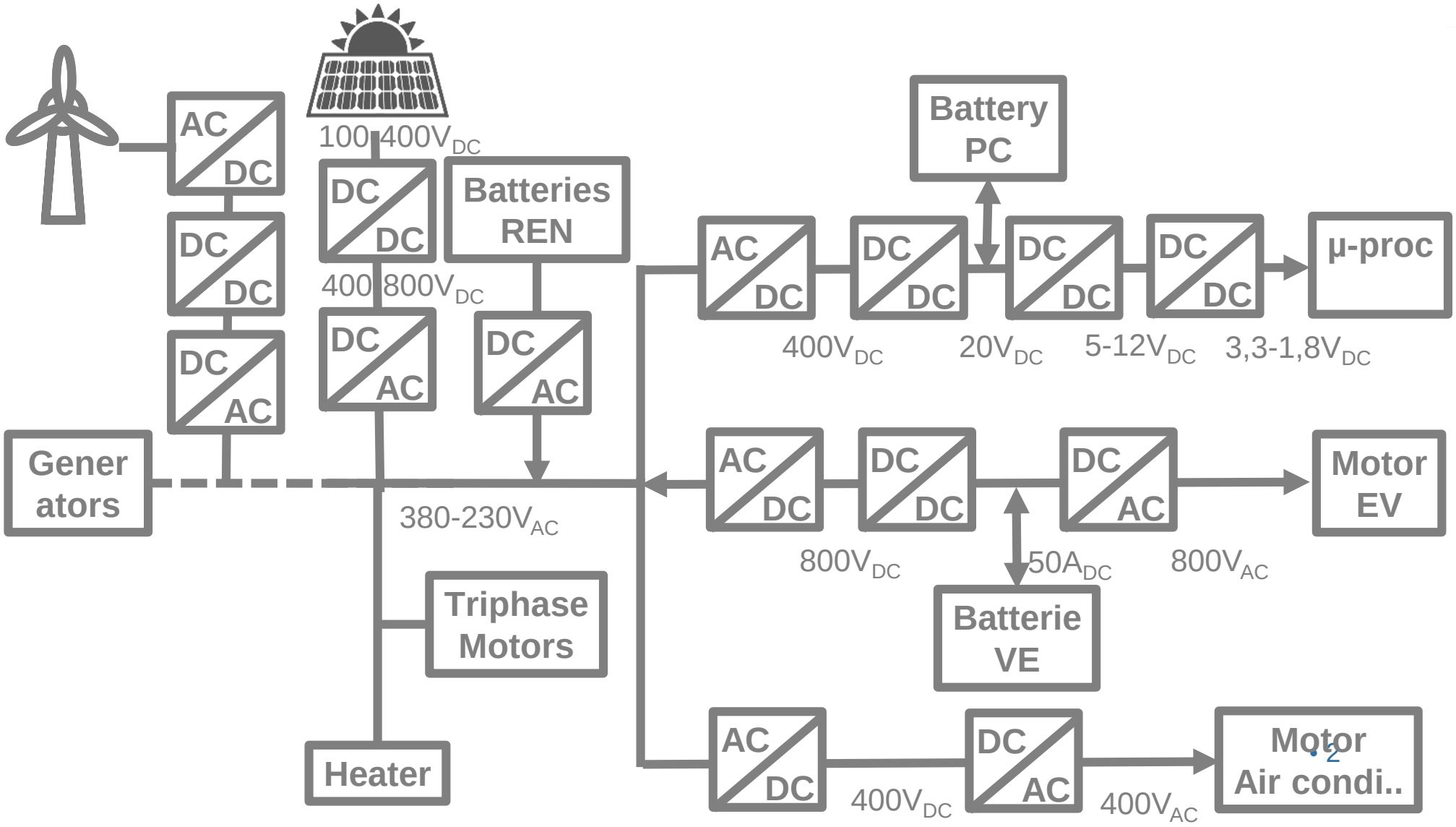
G2Elab
Grenoble Génie Electrique
Grenoble Electrical Engineering

UGA Université Grenoble Alpes

cnrs

Grenoble INP UGA

Power Electronics Converters (PEC) are everywhere



Decades of productive R&D in power electronics

-Great power converter efficiencies!

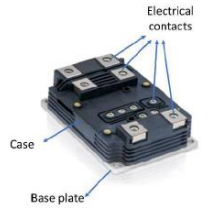
With efficiencies ranging from 95 up 99%, energy savings not anymore related to Power Electronic Converter (PEC) losses but the amount of energy actually converted

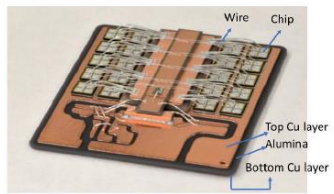
Project SiC-Mile

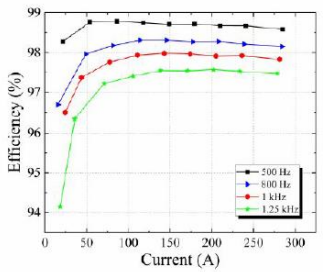
Energy efficiency of MV SiC vs. Si for railway applications

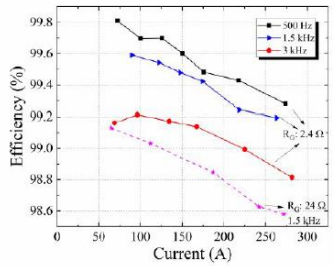
Hitachi Energy

LinPak
3.3kV 450A / 6.5kV 300A







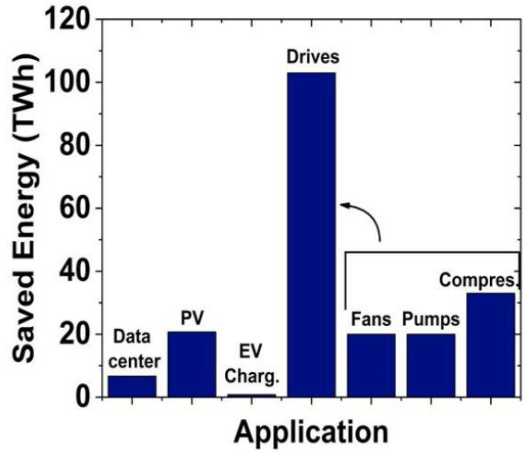


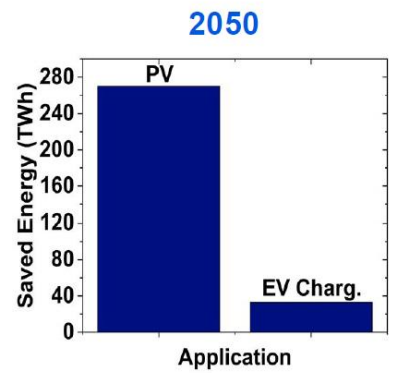
Energy potential saving of SiC PE

Worldwide estimations

IEA International Energy Agency

Power Electronic Conversion Technology Annex PECTA





Minamisawa et al., PECTA report, 2023

ECPE | Slide 6

University of Applied Sciences and Arts Northwestern Switzerland

ECPE | Slide 5

University of Applied Sciences and Arts Northwestern Switzerland

Extract from ECPE workshop on on Eco-Design Approaches in Power Electronics Nov. 2024.
Energy budget fro the lifecycle of Si and SiC power semiconductors for railway and solar applications,, R. Minamisawa et al.

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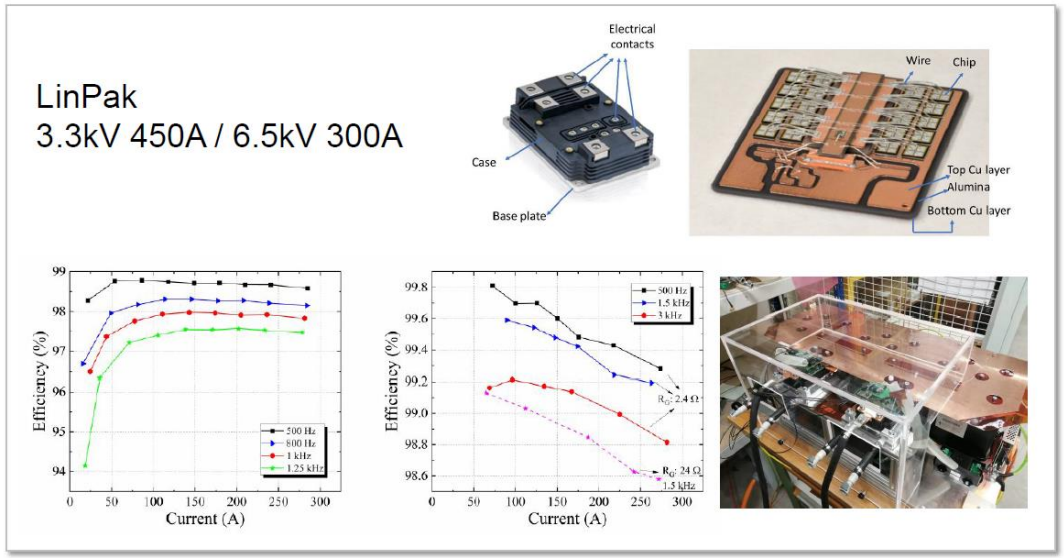

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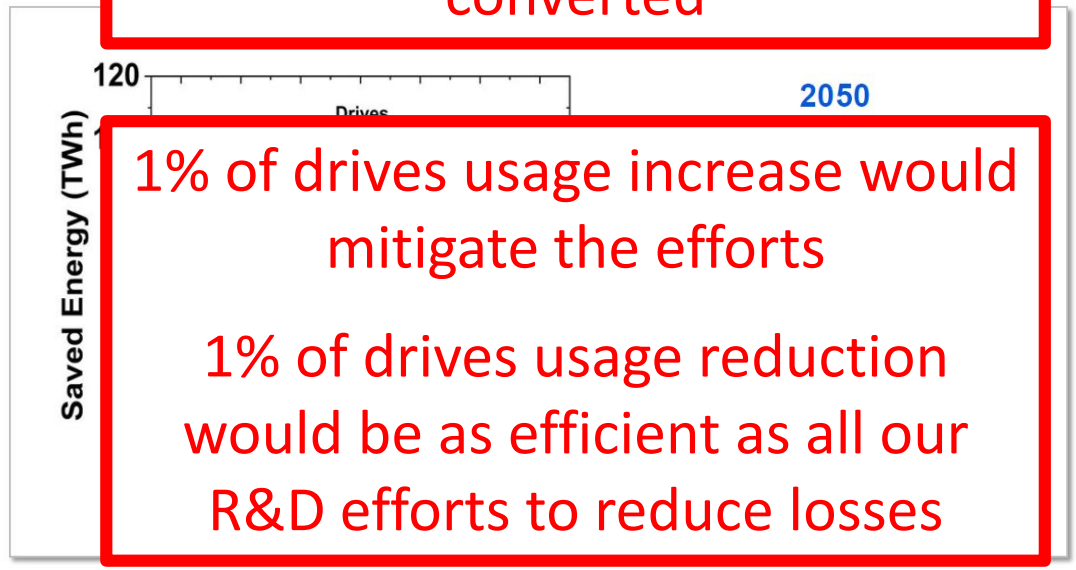

100 TWh savings in drives applications for 10 000 TWh converted

1% of drives usage increase would mitigate the efforts

1% of drives usage reduction would be as efficient as all our R&D efforts to reduce losses

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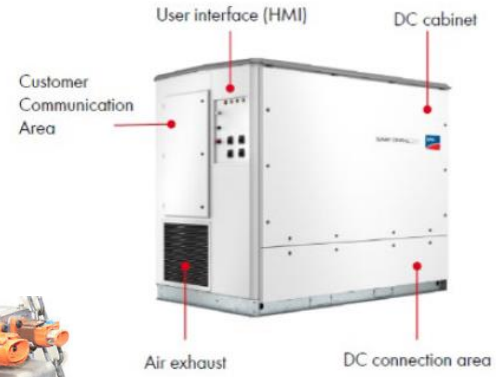
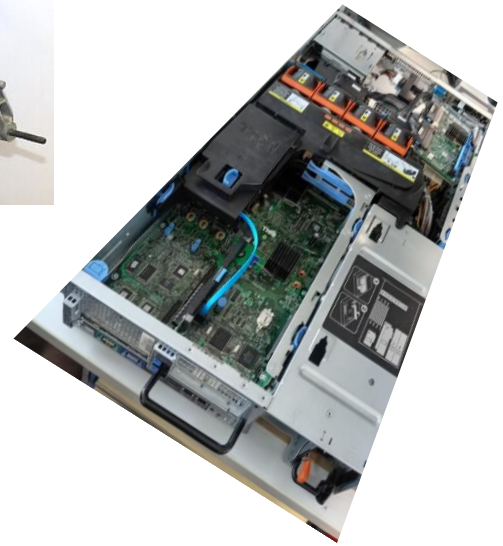
-Great power converter efficiencies!

-Great power converter power densities!

Power densities up to several kW/kg and kW/L, PE converters are most of the time 1 to 5% of the total product weight/volume they are part of!



PV inverters: 1 to 3kW/kg	for 0,01kW/kg for PV panels	
OBC: 0,5 to 1kW/kg	5kg	for an EV of 1600kg
EV drives: up to tens kW/kg	30kg	
DC/DC: up to 100kW/kg		
Laptop supplies : 100W,	less than 300gr & 0,2dm^3	
Server AC/DC supply : 800W	1kg for a 20kg server	



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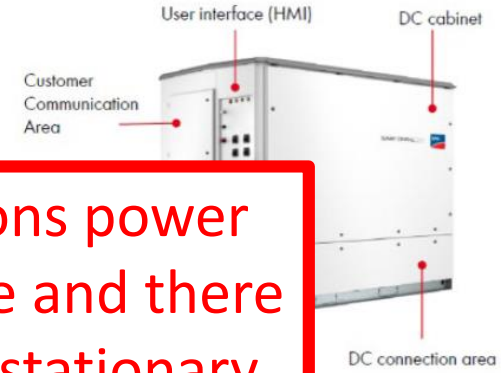

For mobility applications power densities are totally fine and there is no specific need for stationary applications

Automotive sector: most weight benefits are not invested to energy reduction but to provide more comfort or services

Decades of productive R&D in power electronics

-Great power converter efficiencies!

-Great power converter power densities!

-Cost effective power converter!

With manufacture costs as low as few cents per W,
prices of power converters are not much
than 1 to 5% of the product total cost

Automotive industry as low as 1 cent per watt !!!

Laptop charger : 20-40€ for 500 to several k€ laptop
Smartphone charger: few € for up to 1k€ smartphone

PV inverter versus PV panels : from 1/1 to 1/3 !

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PV inverter versus PV panels : from 1/1 to 1/3 !

Cost reduction and mass markets are already reached

Environmental and social impacts of further cost reduction to be questioned

Decades of productive R&D in power electronics

-Great power converter efficiencies!

-Great power converter power densities!

-Cost effective power converter!

-Satisfactory power converter reliability!

Even if **there is still room for improvement on this topic**, power converters are quite reliable with respect to the lifetime of the products they are associated to!

Decades of productive R&D in power electronics

-Great power converter efficiencies!

-Great power converter power densities!

-Cost effective power converter!

-Satisfactory power converter reliability!

Power Electronics is doing great. We have already all the ingredients / good technologies we need to shift to electricity to supply ICTs, mobility, air conditioning, heating,…!

We could even question our needs of Artificial Intelligence (AI) to improve further all this ?

The other side of the coin

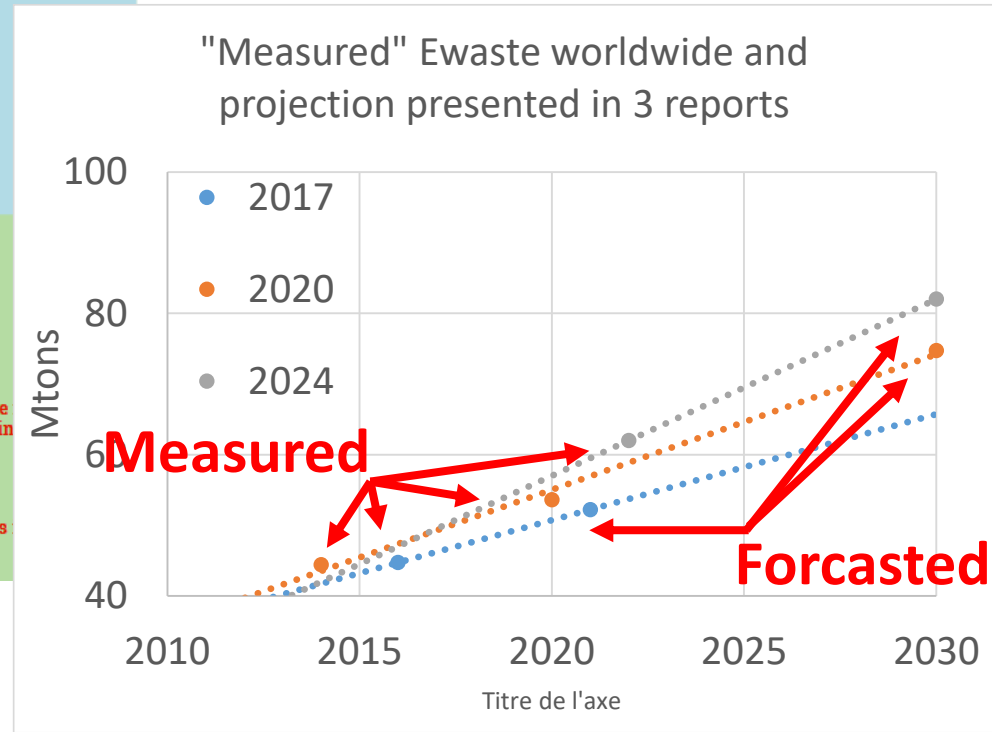
-Great increase in WEEE!

-Power Electronics part of it, and among the hardest to recycle !

-E-waste mass **growing faster than expected**, report after report !

-**Collection rates terribly low** (17,4% worldwide in 2020)

Extract from The Global E-waste Monitor 2020: Quantities, flows and the circular economy potential" 2020



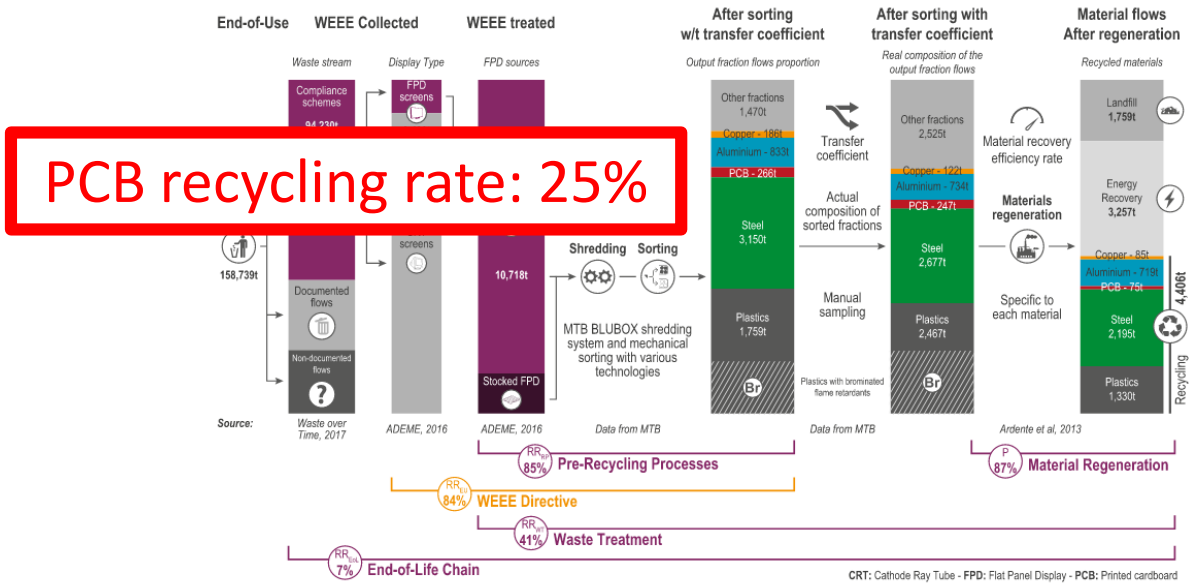
The other side of the coin

-Great increase in WEEE!

-Low to very low recycling / regeneration rates!

We must relies that recycling is far from being the solution of our problems

PCB recycling rate: 25%



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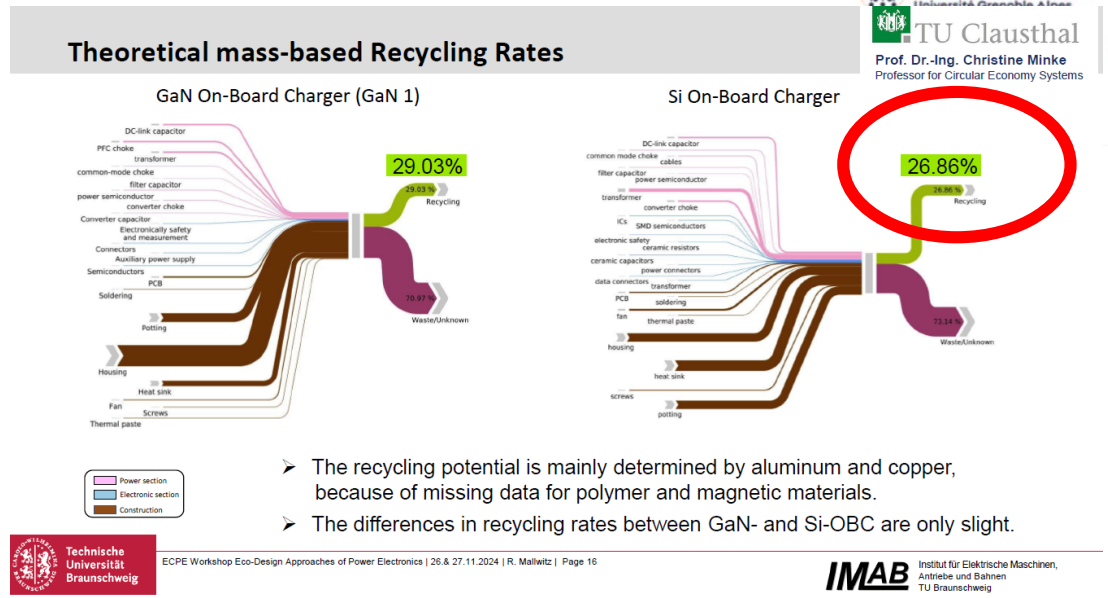
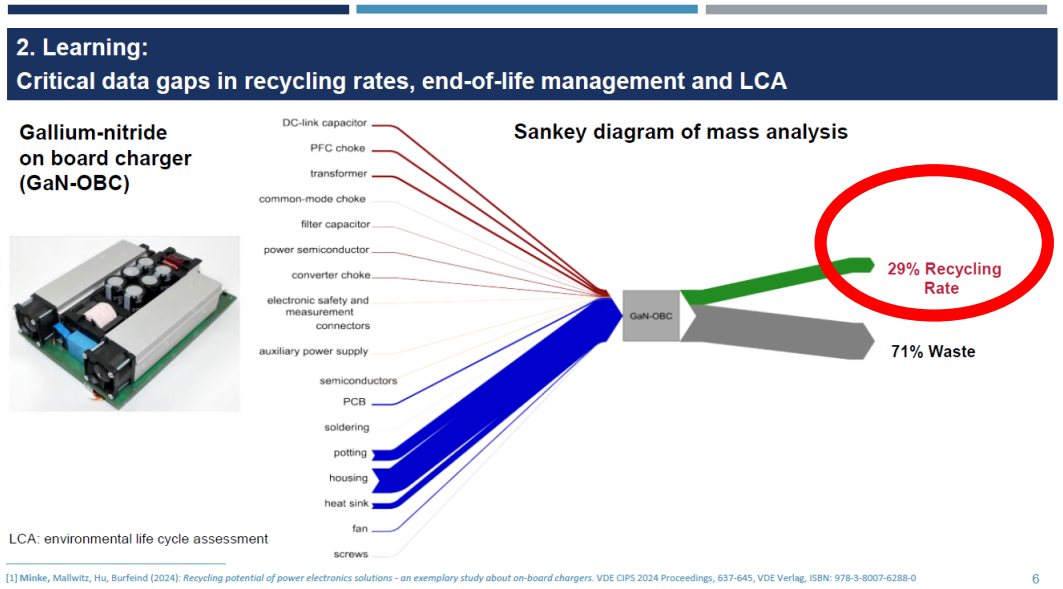
On board Charger – Design and sustainability screening, Prof. Regine Mallwits





Influence of scope definition in recycling rate calculation for European e-waste extended producer responsibility, C. Charbuillet et al, Management Waste, 2019

The other side of the coin

-Great inc

-Low to ve

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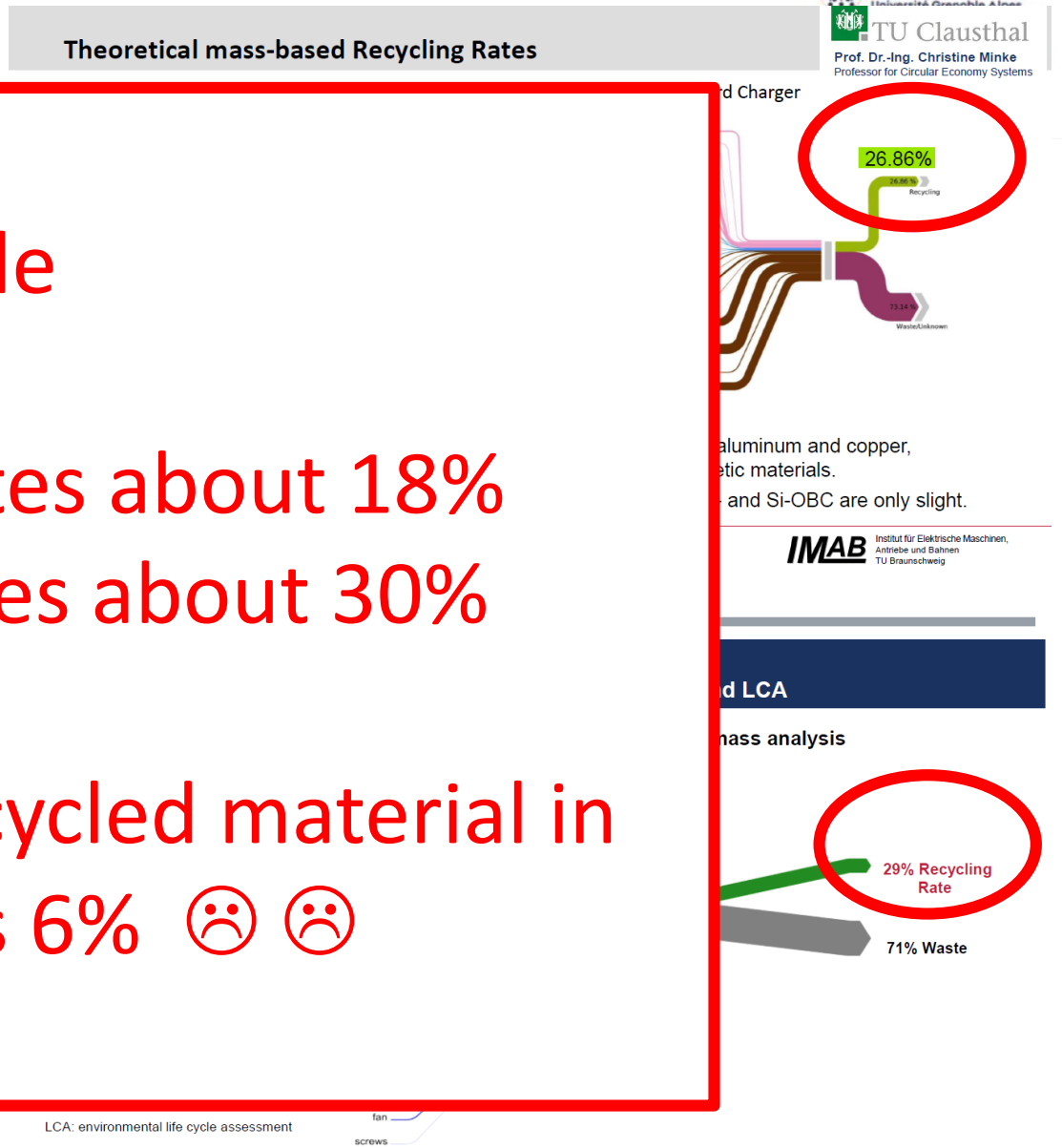
PCB recyclin

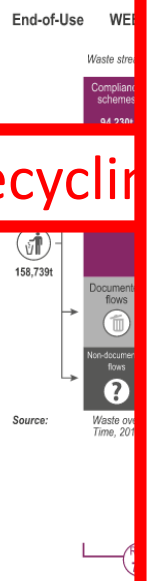
Worldwide

Average collection rates about 18%

Average recycling rates about 30%

Estimated amount of recycled material in Power Electronics 6% ☹☹





Extract

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PCB recyclin

European scale

Average collection rates about 43%

Average recycling rates about 80%

Estimated amount of recycled material in Power Electronics 33% ☺

And only 11% of the initial material after the second loop ☹

Extract

Toward

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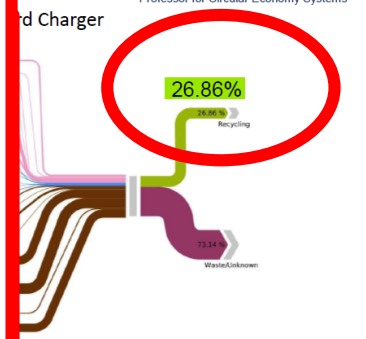
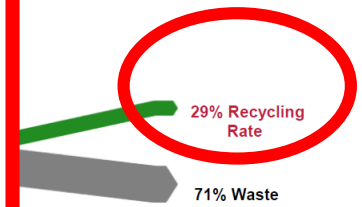


aluminum and copper,
etic materials.
and Si-OBC are only slight.

IMAB Institut für Elektrische Maschinen, Antriebe und Bahnen TU Braunschweig

d LCA

nass analysis



637-645, VDE Verlag, ISBN: 978-3-8007-6288-0

6

Influence of scope definition in recycling rate calculation for European e-waste extended producer responsibility, C. Charbuillet et al, Management Waste, 2019

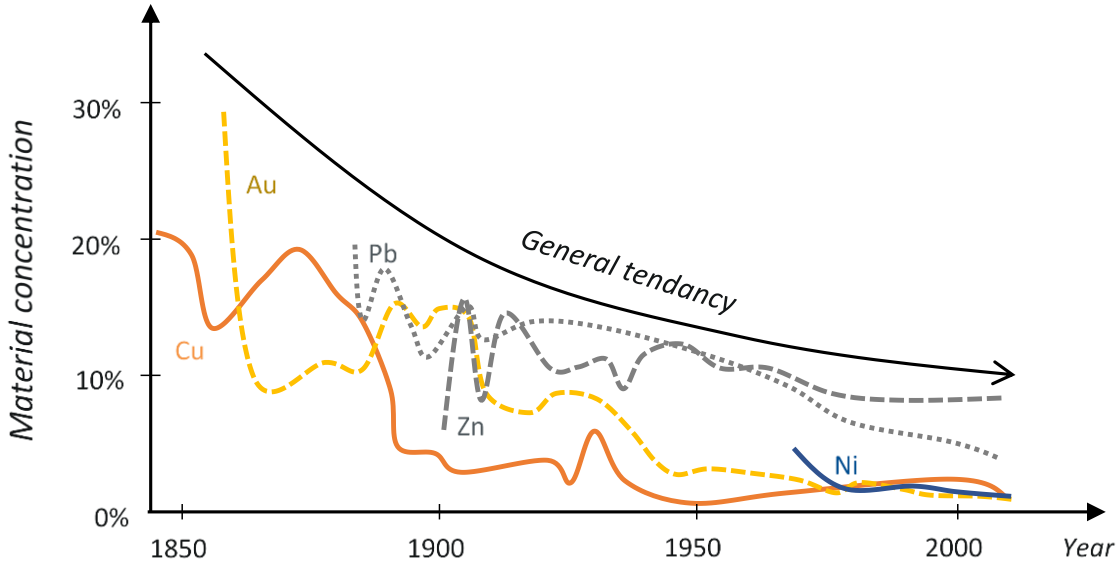
The other side of the coin

-Great increase in WEEE!

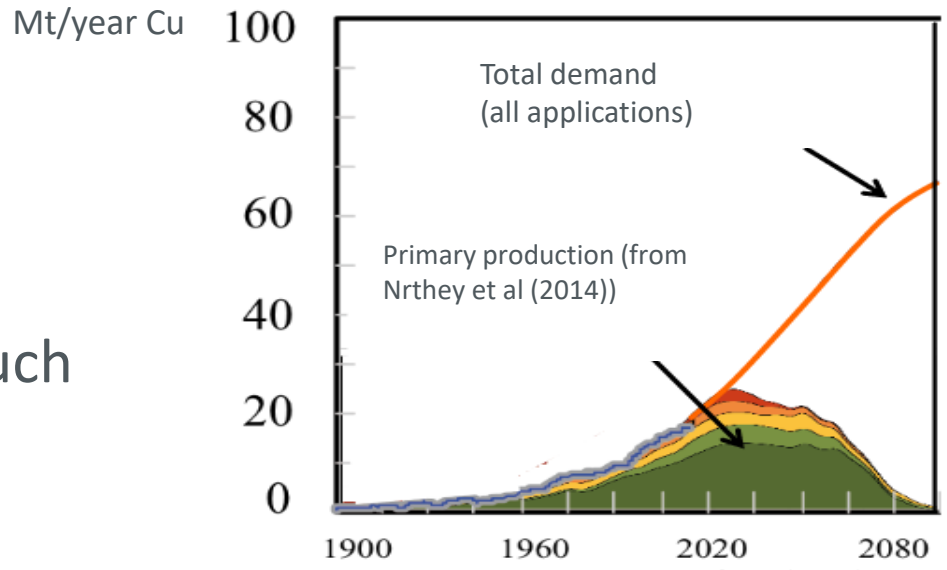
-Low to very low recycling / regeneration rates!

-Great pressure on raw materials!

Depletion of critical materials for the energy transition such as copper might be soon a real issue

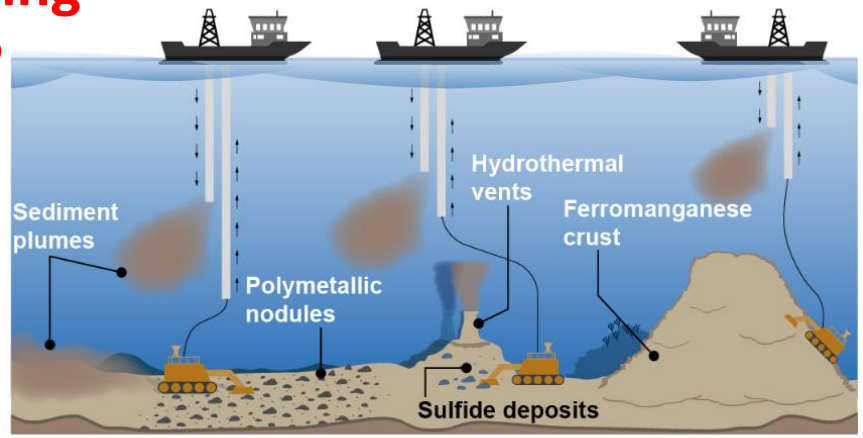


T. Prior, et al, « Resource depletion, peak minerals and the implications for sustainable resource management », Glob. Environ. Change, vol. 22, no 3, p. 577-587, 2012



olivier.vidal@uni-grenoble-alpes.fr

Deep sea mining perspectives?



Source: GAO analysis of peer reviewed journal articles. | GAO-22-105507

The other side of the coin

-Great increase in WEEE!

-Low to very low recycling / regeneration rates!

-Great pressure on raw materials!

-No or almost no circular economy on B2C products!

-Apart large power converters (PV plants, wind turbines, railway traction, grid services,…), **most PEC are not maintained, repaired** and even less refurbished or repurposed!

-Mass market **PEC are mostly wasted** with the products they are integrated in!

-**No ease to access, diagnose, replace, requalify, resell**… and ultimately to recycle truly !

Most PCB based PEC are likely not easily repairable today

So, what can we do? Get on strike? Stop research?

-First, if not already there, I hope I have put a **seed in our mind** with the numbers outlined. If not, definitively **rethink about it** on your own!

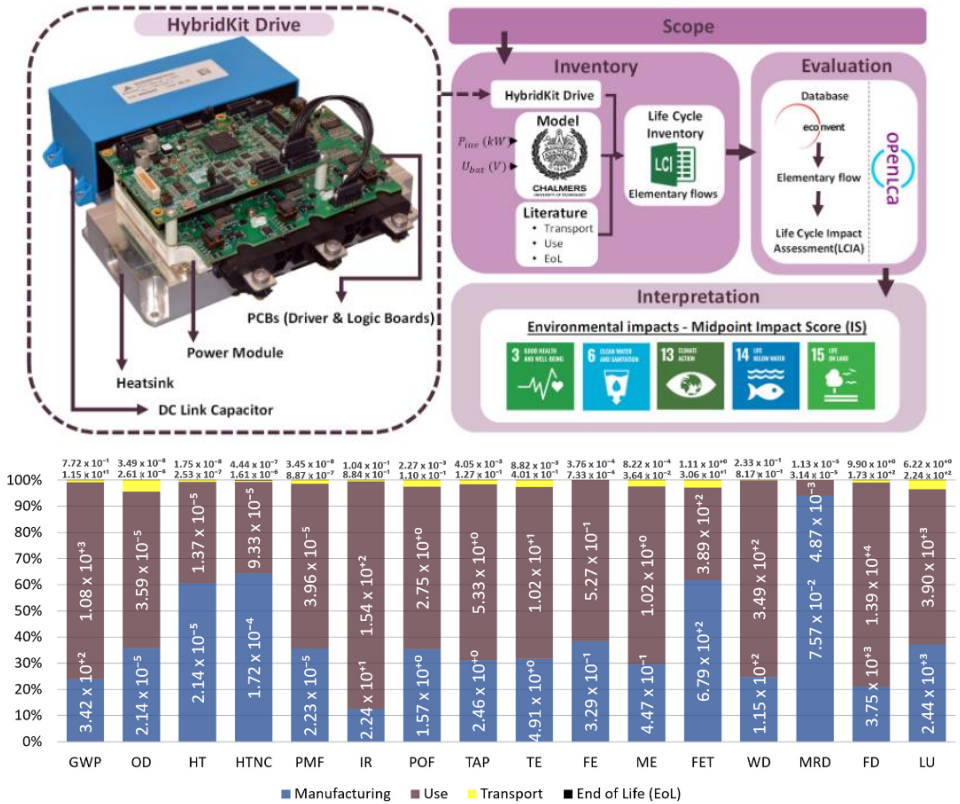
-Second, we need to work hard to make sure **decarbonation** is not going to produce significant and multiple **Environmental Impact (EI) transfers:**

-Regarding how to support **eco-design and design for circularity**, we can:

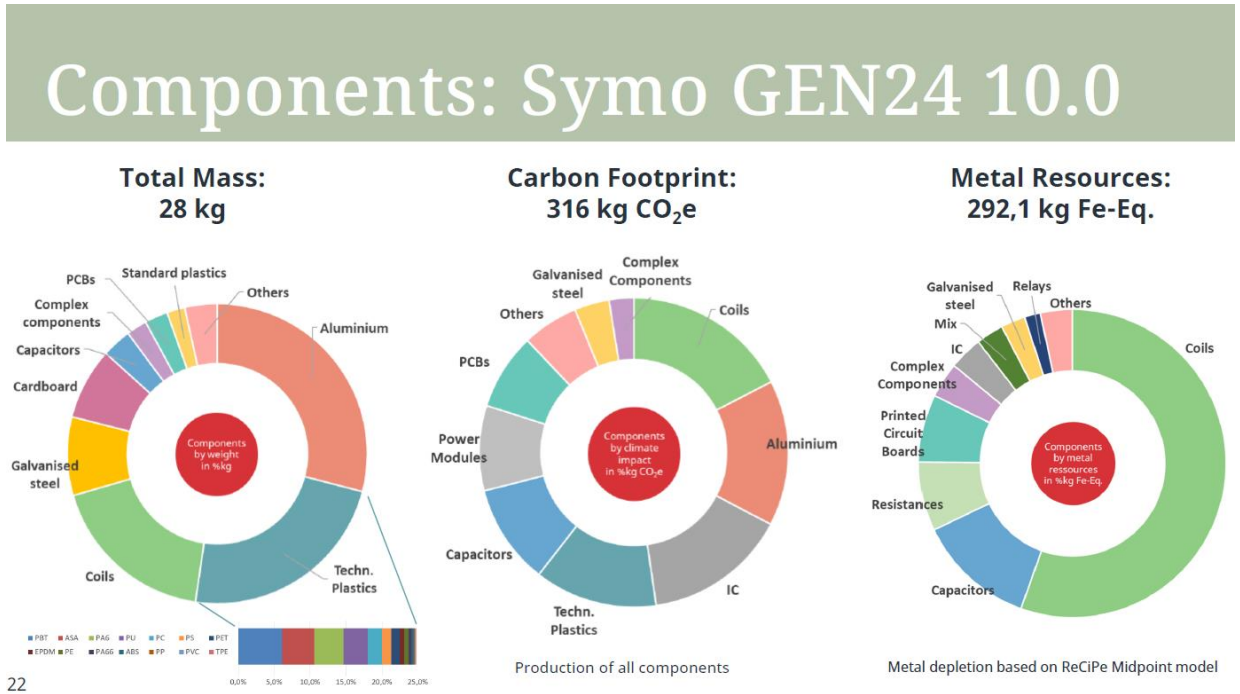
- -**Help assessing EI** from our technology and in the frame of our society
- -Develop **awareness** about design practices reinforcing EI (develop trainings)
- -Develop **tools and methods** and needed associated **data**
- -Develop **ecosystem and regulation frame** to speed up circular economy
- -Develop **design guidelines and metrics** to help technicians and decision markers
- -Stop looking usage phase only: **manufacture and end of life matter** as well!

Assessing Environmental Impacts (EI) in Power Elec.

BEYOND CO2 emission reduction topic, which is of course important, we start to read very nice work based on Life Cycle Assessment related to PE converters :



LCA results of an inverter operating point for a 150 kW load from a DC power source of 450 V, based on 15 years and 10,000 operating hours. This output conveys the standardized environmental impacts, according to the European Commission – Etrait from Baudais et al, MDPI Energies: Life Cycle Assessment of a 150 kW Electronic Power Inverter-



Extract from ECPE workshop on Eco-Design Approaches in Power Electronics Nov. 2024. Life cycle analyses and their contribution to a more sustainable converter design, Franz Musil, Fronius International GmbH

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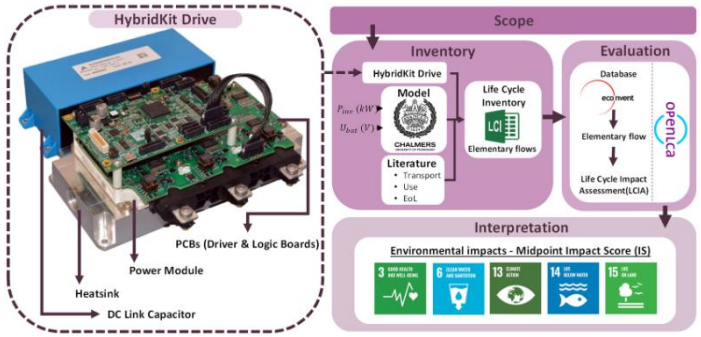
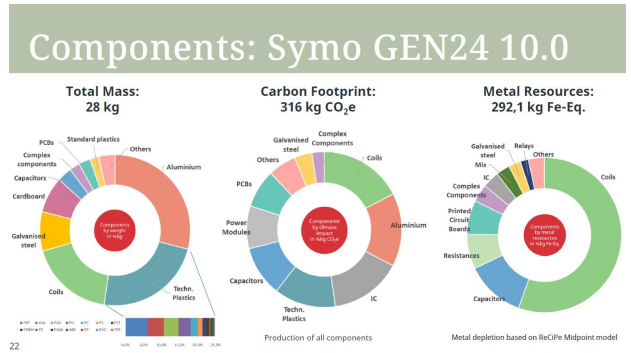




But we are still quite far from being able to integrate EI metrics in our “Eco-Design” flow!

-Huge **lack of precise and relevant data** to address the diversities in PE

-**Lack of parametric models** to support eco-design and optimization

-**Tools mostly made to attribute EI** to existing and well described products/services

-We need urgently a **cooperative task force** on this very hot topic!

Awareness about design practices reinforcing EI

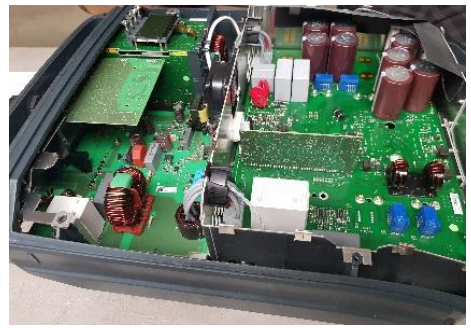
Strong heterogeneities at multiple levels prevent from effective circular loops !

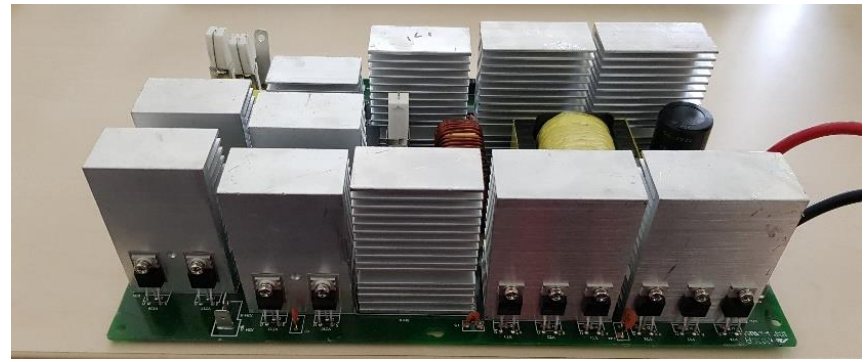
-Materials

-Components

-Assembly/interconnect technologies

-Topologies



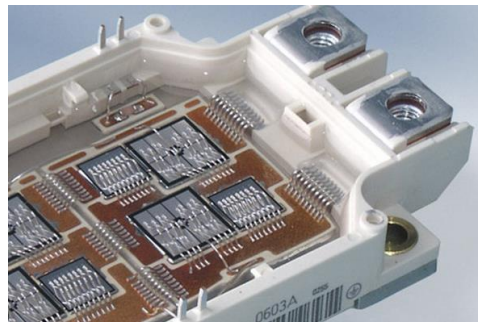


<u>But also</u>

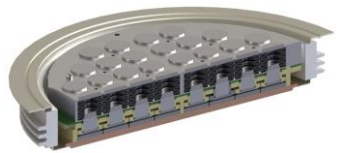
-Control strategies

-Reliabilities

-Form factors, thermal inertias, ….



Continuous tuning and dedicated optim. of PEC



Awareness about design practices reinforcing EI

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-Materials

-Components

-Assembly,

-Topologie

From better to good enough

Look at PE optimization from other perspectives

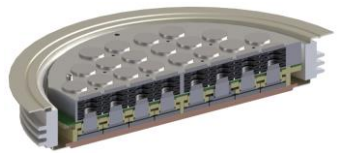
<u>But also</u>

-Control st

-Reliabilitie

-Form fact

Continuous tuning and dedicated optim. of PEC



PE converters manufacture and end of life (EOL) matter

R0	Refuse
R1	Rethink
R2	Reduce
R3	Re-use
R4	Repair
R5	Refurbish
R6	Remanu-facture
R7	Repurpose
R8	Recycle
R9	Recover

-Design/manufacture for circularity to ease one/several circular scenario

-Design for **multiple (infinite) loops**

-Develop **ecosystem** (logistics, repairer,… including training)

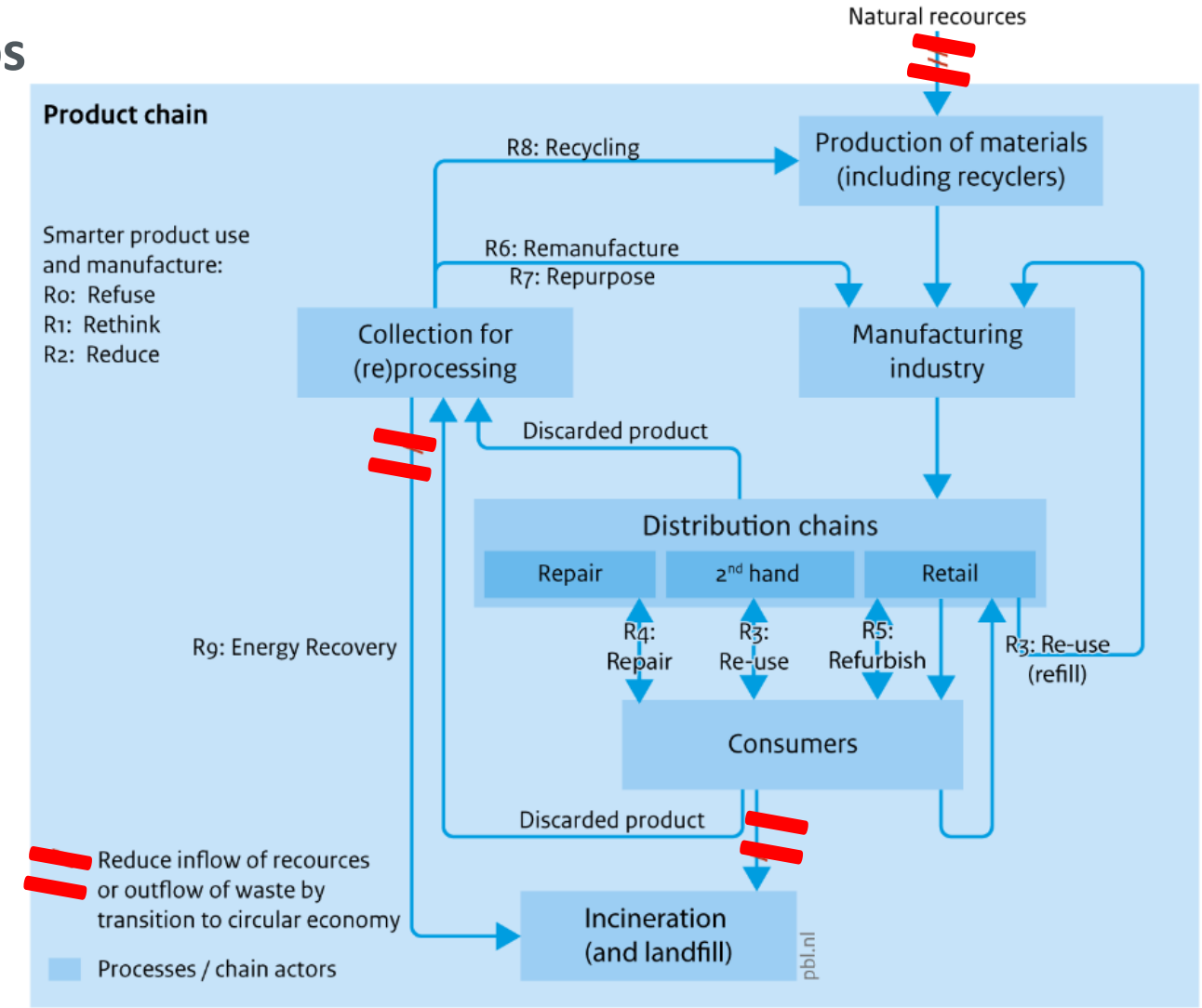
-Develop the **legal framework**

-**Manufacturer responsibility over the value chain**

-**Territorialization** of practices at least some of those needed

-THINK INFINITE LOOPING

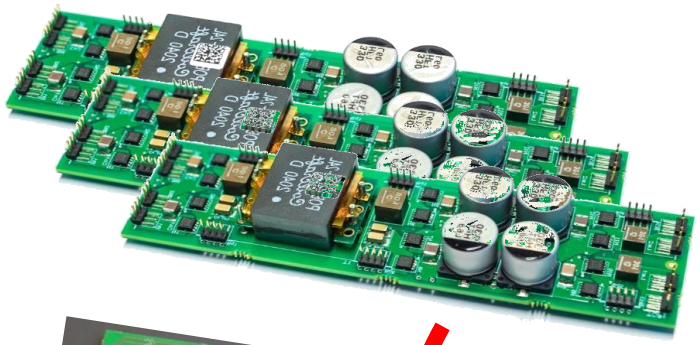
We are far from it!

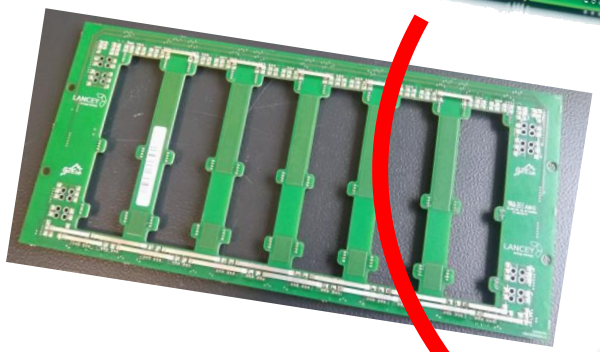


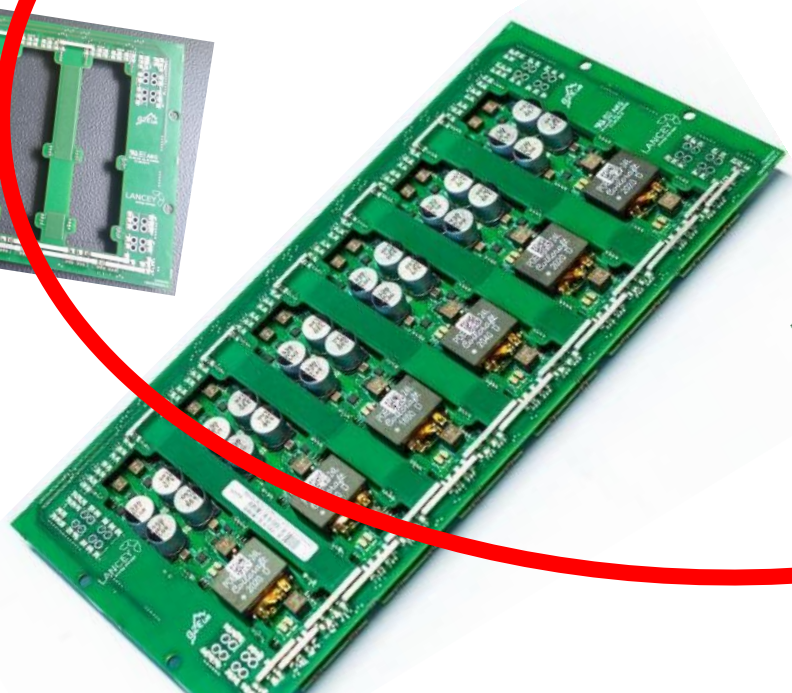
J. Potting et al, «Circular economy: measuring innovation in the product chain»

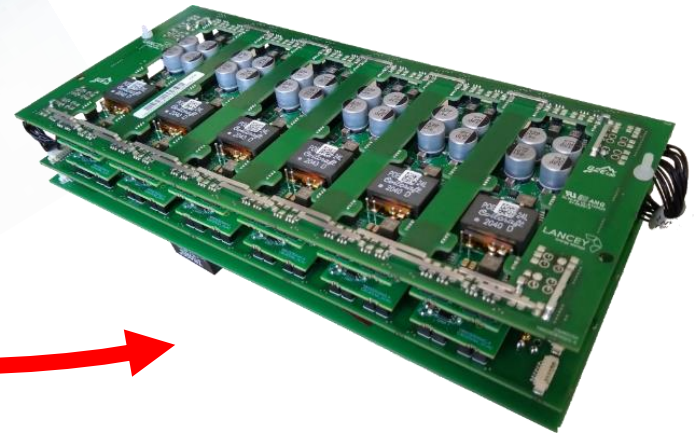
Eco-design guidelines and metrics in PE

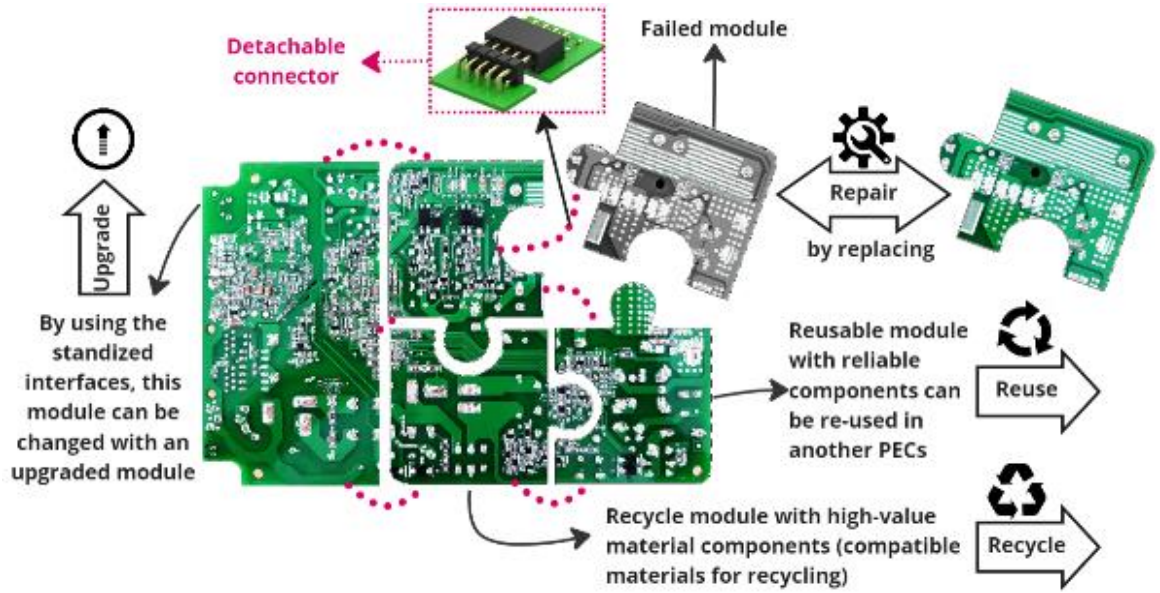
Modular design from standardized functional blocs: MMC, PEBB, PCA,…











Eco-design guidelines and metrics in PE

It is a story of PE experts !

Strong insight is needed about the relationships that eco-design choices will induce:

in terms of reduction of Environmental Impacts (EI)

in terms of PE characteristics affecting EI

Modular design

Higher circularity

Eco-design choice

Expected direct effects on EI

End of usage lower EI

Assess total effects on EI

Direct effects on converter characteristics

More materials

More components

Lower reliability

Unexpected direct effects on EI

Manufacture and usage higher EI

Eco-design guidelines and metrics in PE

It is a story of PE experts !

Strong insig e:
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There is a need to supply PE designers with adapted design guidelines and metrics to support enlightened decision making

Mod
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ects on EI

choice

Direct effects on converter characteristics

More materials
More components
Lower reliability

Unexpected direct effects on EI

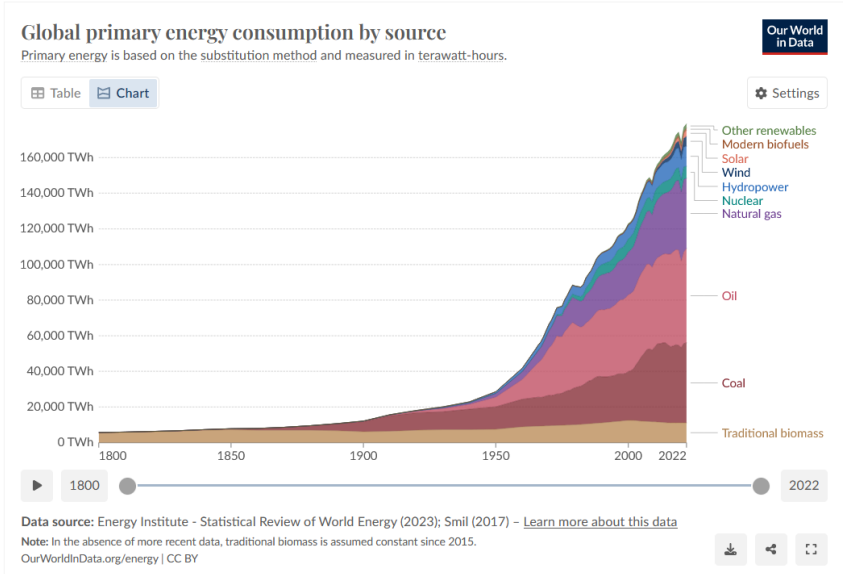
Manufacture and usage higher EI

It is already time to conclude

F**ossil energy demand still increasing** ! Coal consumption new record!

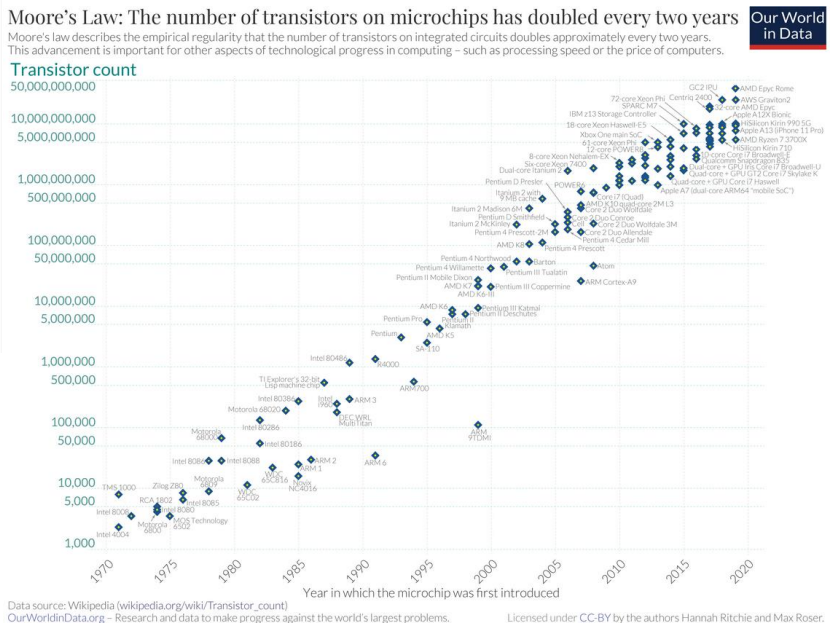
Performance quest does not lead to energy consumption reductions

Competitive & linear economy **= pollutions & material depletions**



Continuous (fossil) energy consumption **growth** worldwide

ICT performance increase totally **overbalanced** by usage “explosion”

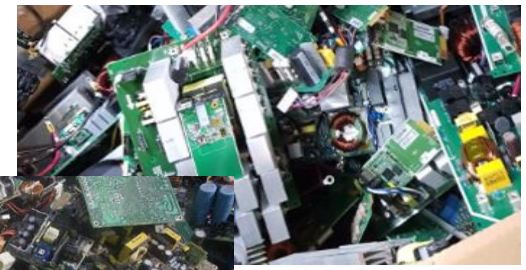


E-waste continuous ramp up due to linear

It is already time to conclude

Some may think that sustainable electronics will be quickly hidden by geopolitics (wars, sovereignty, …)

Sustainable Electronics (including PE) is a topic, just thinking about an industry relocalization like this front of our doors:



We must act for and be part of a sustainable industry, re-industrialization

Coming up next directly related to PE topics

Directly related to more sustainable power electronics, four complementary contributions will follow :

-**Evaluating the environmental impacts of circularity scenarios in power electronics using Life Cycle Assessment** - Pierre Yves Pichon - MERCE

-**Parametric LCA (P-LCA) based integrated eco-design methodology for Power Electronics** - Li Fang – VIVAE ANR project

-**Power electronic circularity in Automotive** Olivia Belorgeot & Dominique Martineau (Schaeffler/EECONE)

-**Analysis and decision support of circular economy strategies in power electronics** - Tugce Turkbay-Romano – VIVAE ANR Project

To be discussed during the lunch?

We should **not foolish ourselves** any longer

Even if we have to/should work to optimize performance/costs etc… we can still **recognize the limits of our techno solution** efforts for sustainability !

And we should/must **share** widely internally and/or externally about **our doubt and/or fear (if we have)** regarding our collective ability to solve the sustainability issue from a technical way.

It is **our (technicians) duty to clarify** what we believe we can reach or not from technical solution in order to point **out the need to look for complementary solutions**.