Sustainable Engineering Through Modeling and Simulation

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MathWorks

Sustainable Engineering

- **Sustainable engineering** → designing and operating systems in a way that uses resources efficiently and minimizes environmental impact

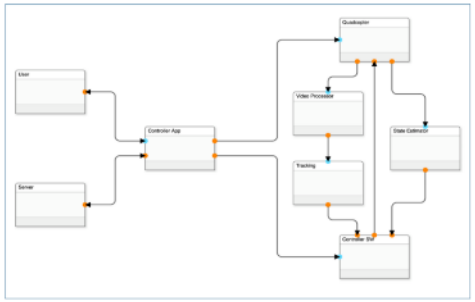
- **Power electronics** → pivotal in driving the transition towards a more sustainable and environmentally friendly energy landscape

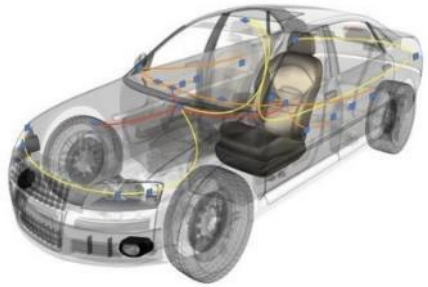
Sustainable Engineering Principles

- Resource **efficiency**
- Environmental impact **reduction**
- **Life cycle** thinking
- Economic **viability**
- Social **responsibility**

Modeling and Simulation

System-level





Software

```
loop_ub = bw_a_filled->size[0] - 2;
b_loop_ub = bw_a_filled->size[1] - 2;
i0 = bw_filled->size[0] * bw_filled->size[1];
bw_filled->size[0] = loop_ub + 1;
bw_filled->size[1] = b_loop_ub + 1;
emxEnsureCapacity((emxArray__common *)bw_filled, i0, (i
emxFree_boolean_T(&b_bw_b);
for (i0 = 0; i0 <= b_loop_ub; i0++) {
  for (i1 = 0; i1 <= loop_ub; i1++) {
    bw_filled->data[i1 + bw_filled->size[0] * i0] = (bw_
      bw_a_filled->size[0] * (1 + i0)) + 1] || bw_b_fil
      bw_b_filled->size[0] * i0) + 1] || bw_c_filled->d
      bw_c_filled->size[0] * i0] || bw_b->data[i1 + bw_
  }
}
```

Physics

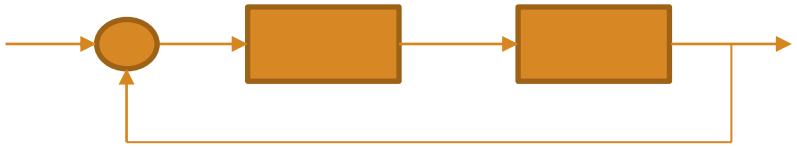
Component-level

Modeling and Simulation of Power Electronics

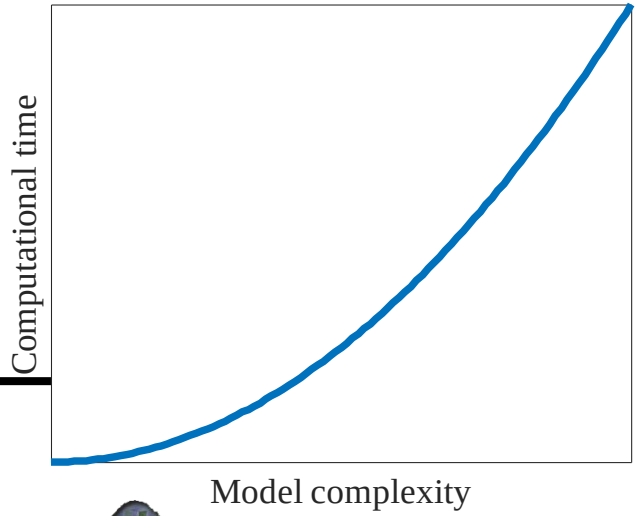
Fidelity levels

System-Level

Systems Engineers
Control Engineers
Software Engineers



Component Validation



Hardware Engineers
Motor Designers
Hardware Designers

Component Design

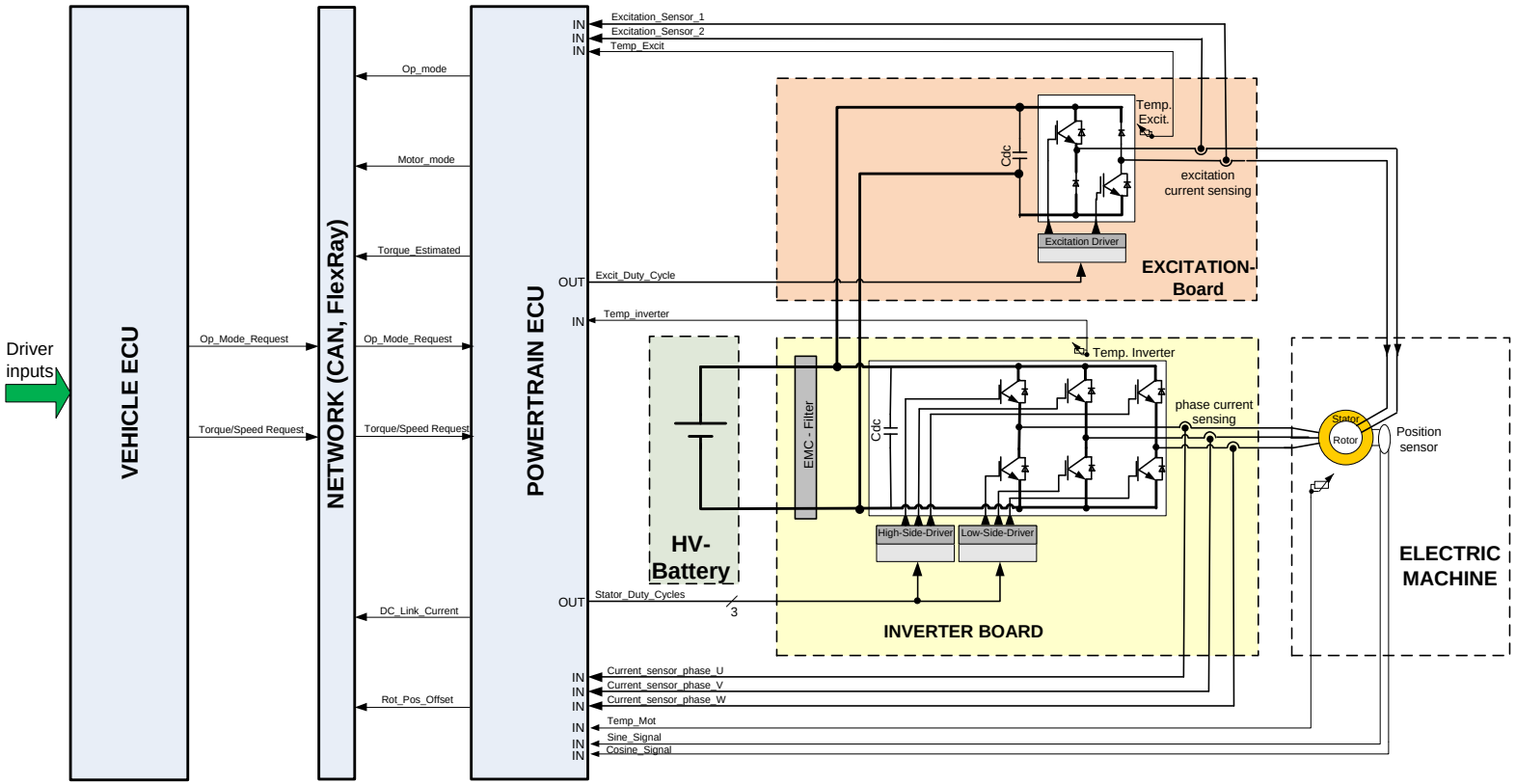
Domain

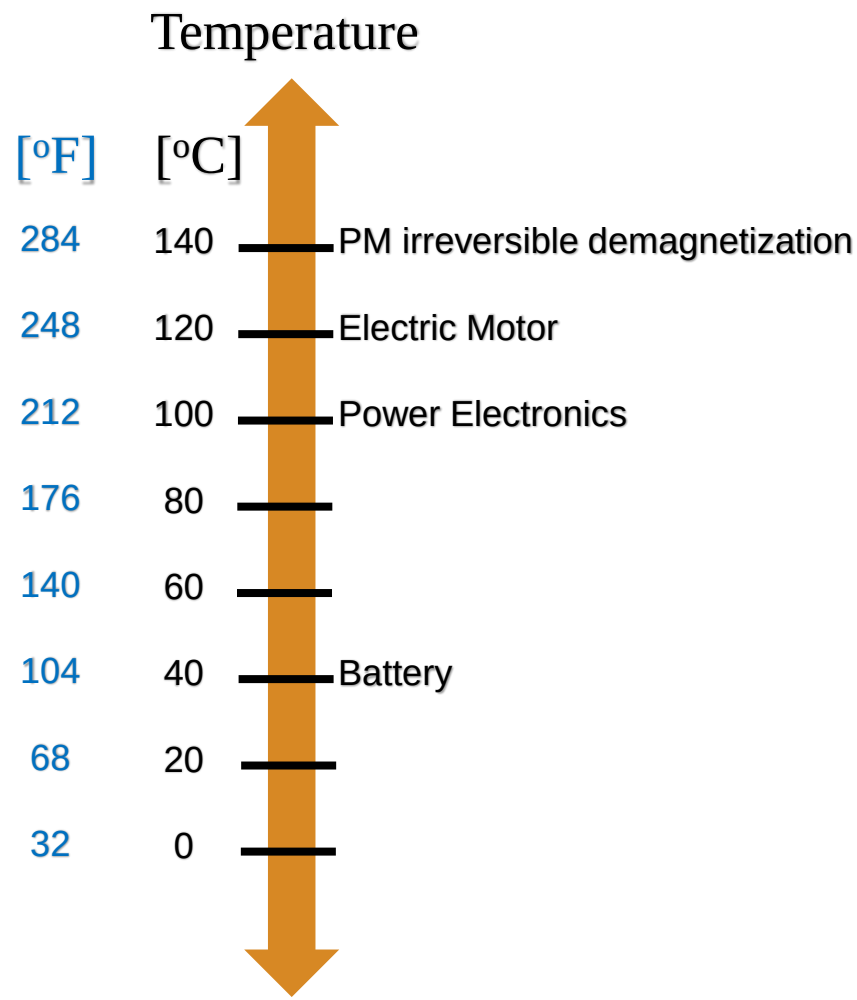
Electric only models

Electrothermal models

Transportation Electrification

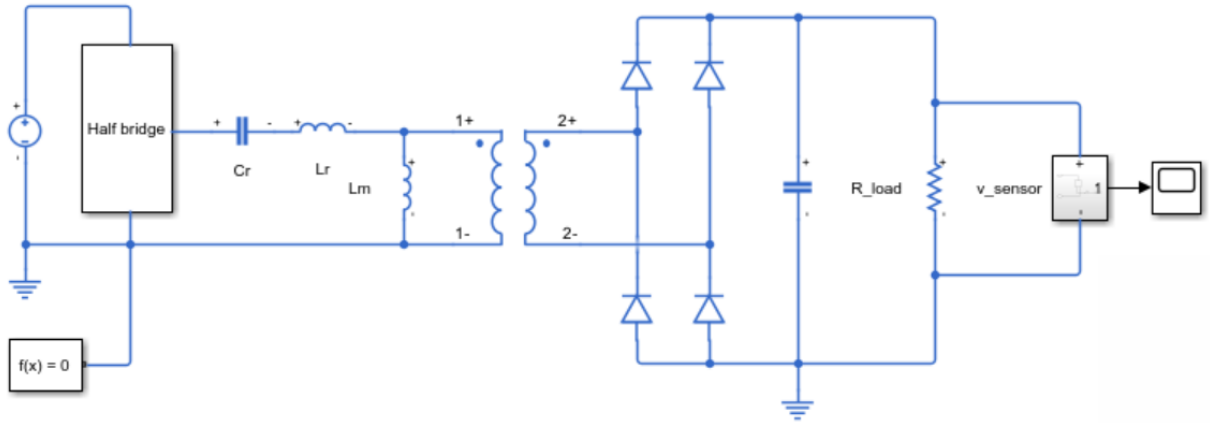
Electrical traction drives → Different temperature levels



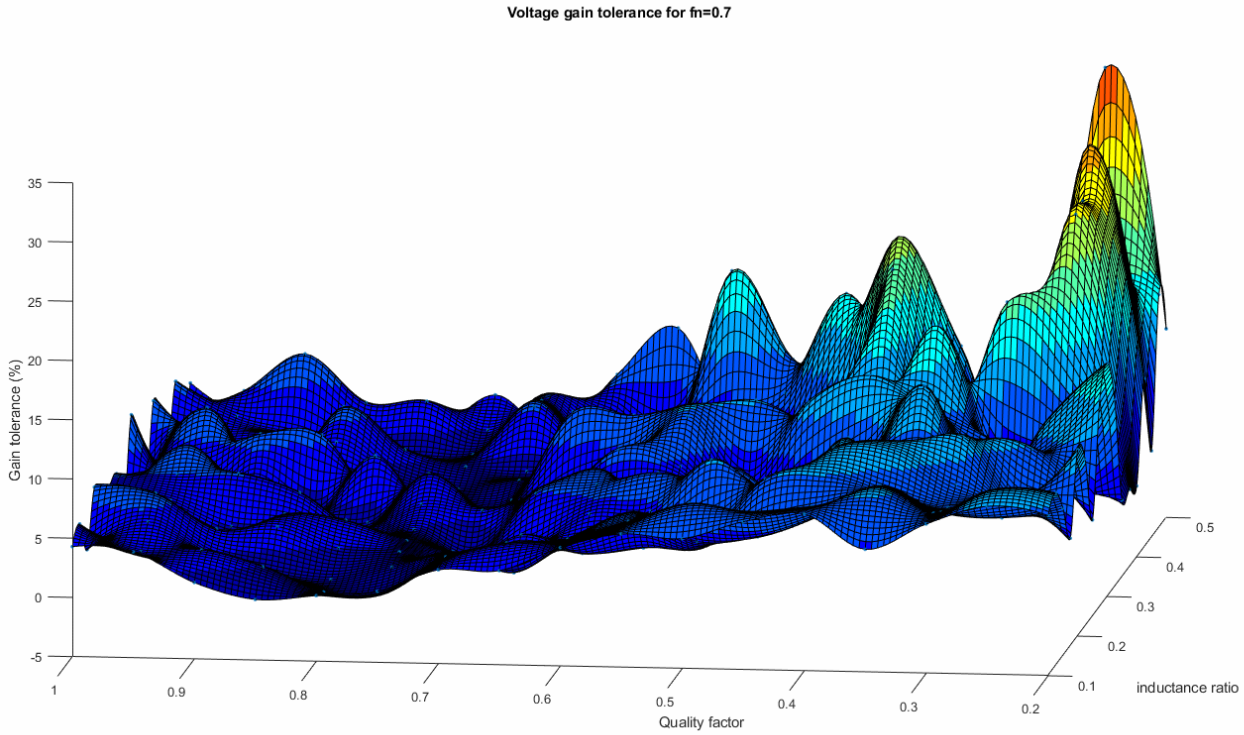


Transportation Electrification

Efficiency & Analysis



- Tolerance studies are very important to ensure **efficient** and **reliable** operation over a desired lifespan

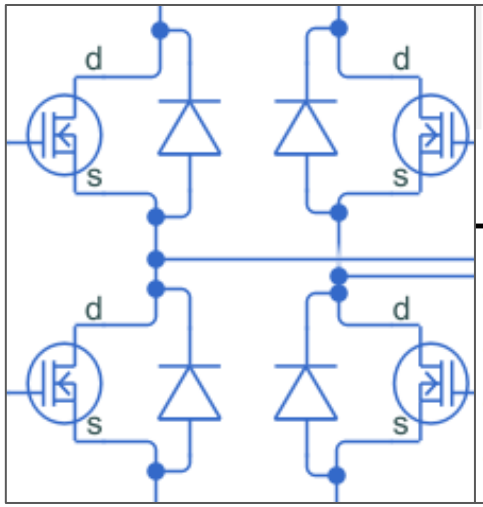


[Tolerance Study Using Monte Carlo Simulations in Resonant LLC DC-DC Converter]

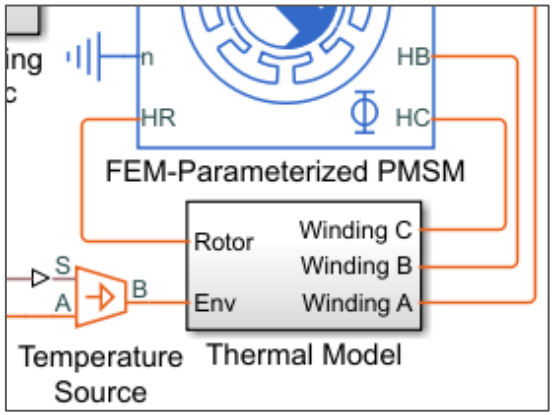
Transportation Electrification

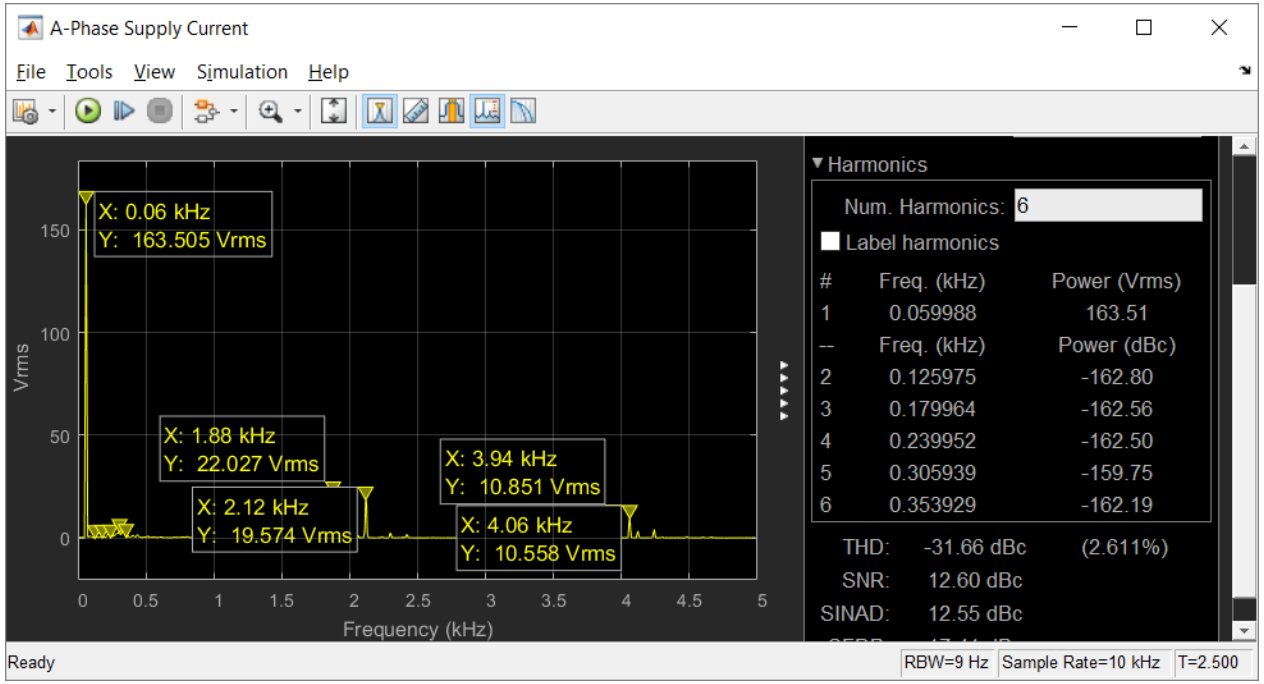
Efficiency & Analysis

- Calculating losses
- Harmonics
- Thermal effects



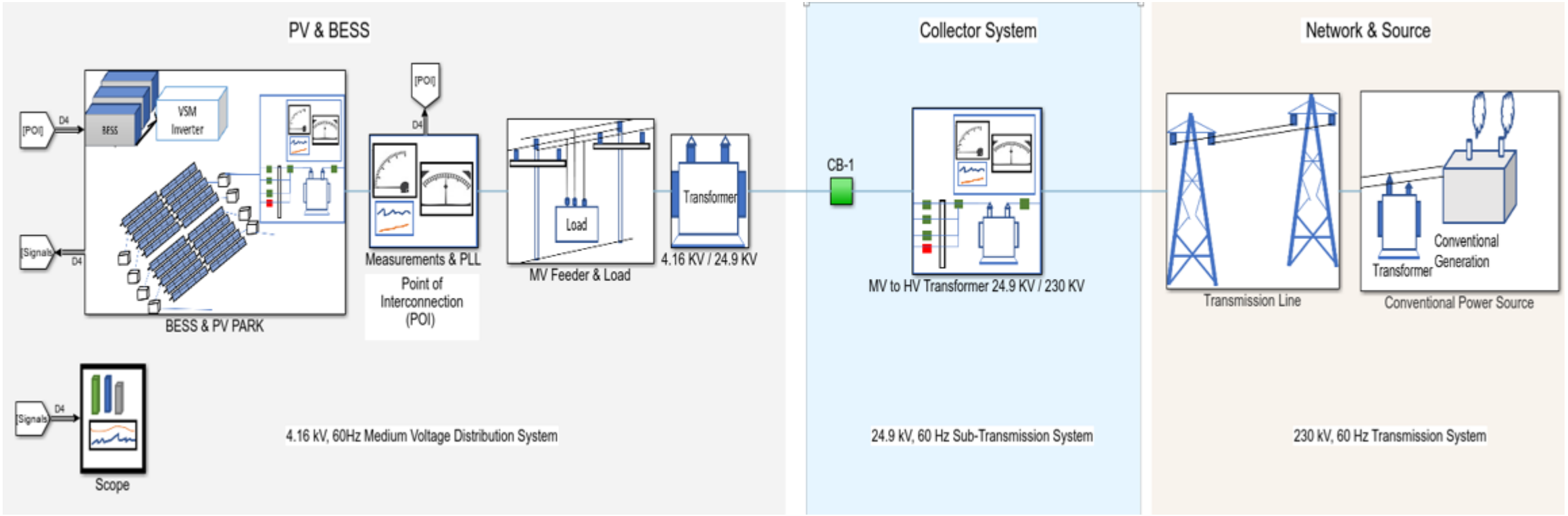

```
Efficiency = 96.3081%
Losses in watts by component:
                    LoggingNode                    Power
    ____________________________________________    _____

    'elec_solar_converter.MOS2'                    21.86
    'elec_solar_converter.MOS4'                    21.62
    'elec_solar_converter.MOS1'                    16.66
    'elec_solar_converter.MOS3'                    15.92
```





Renewable Energy Systems

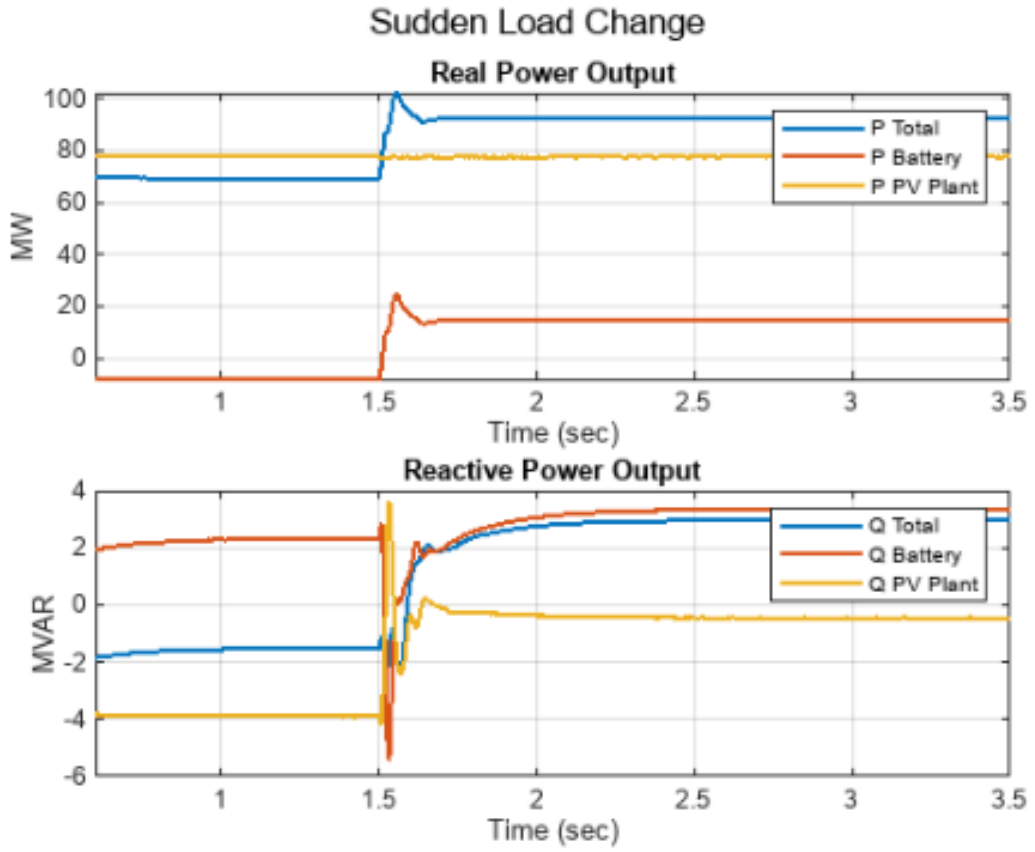
- **Inverter-based resources** (IBRs) are shaping the future of **power systems**



https://www.mathworks.com/matlabcentral/fileexchange/123870-renewable-energy-integration-design-with-simscape

Renewable Energy Systems

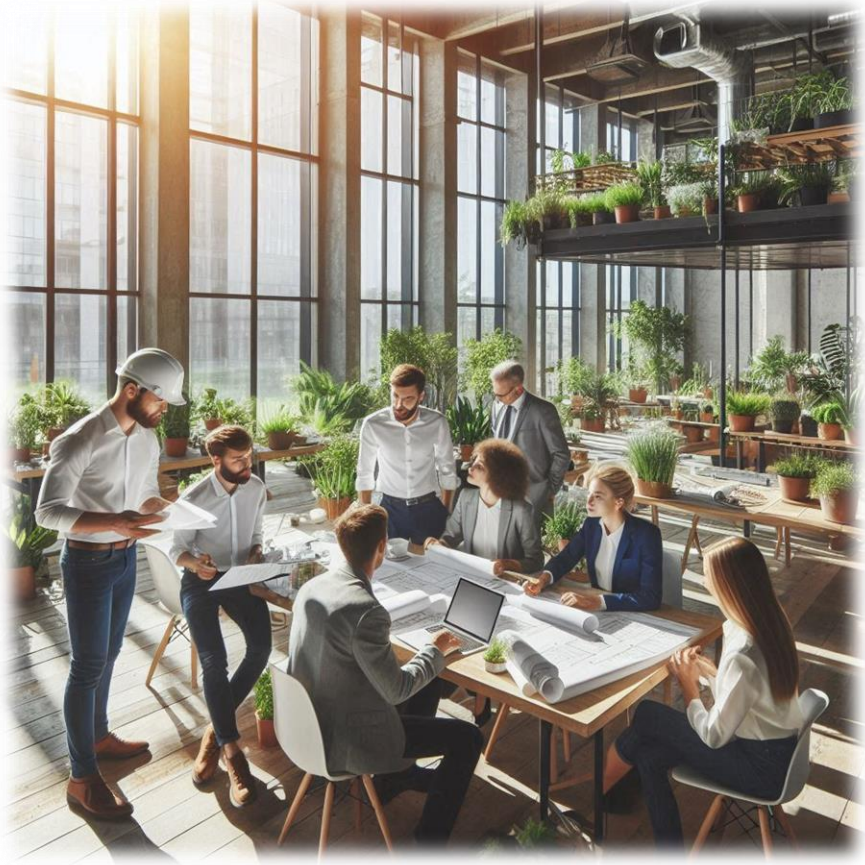
- Simulation can be utilized to evaluate the system behavior in response to changes in load



Response of Battery Energy Storage System (BESS) with grid forming control when the load increase

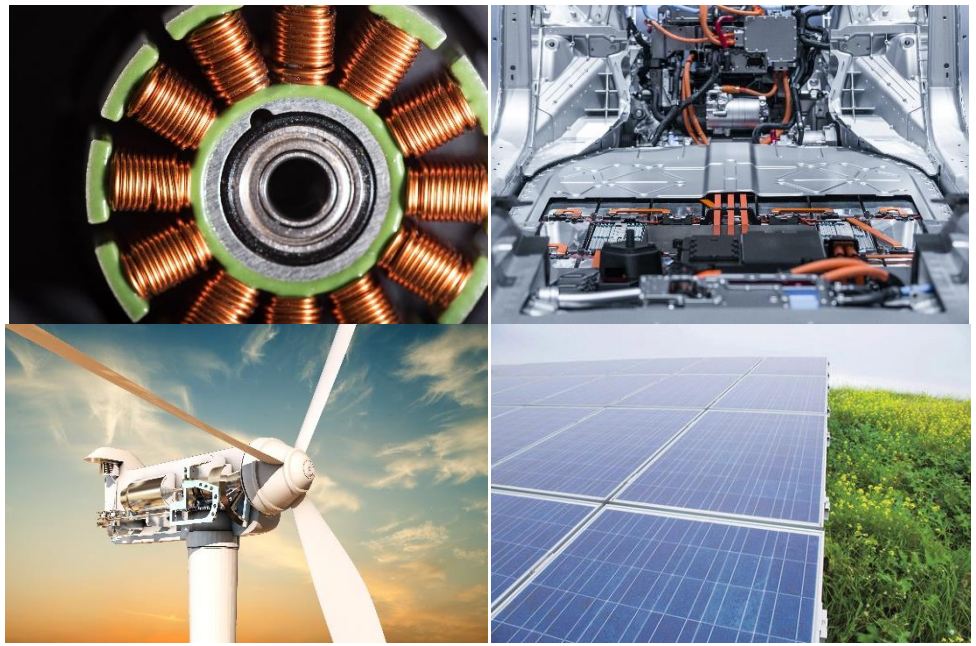
Sustainable Design Practices

- Design strategies
  - Use modular design and component reuse to minimize waste
- Simulation and testing
  - Simulation-driven development is key to reduce the need for physical prototypes
- Lifecycle Assessment
  - Simulate the entire lifecycle of a product to assess environmental and economic impact



Challenges and Solutions

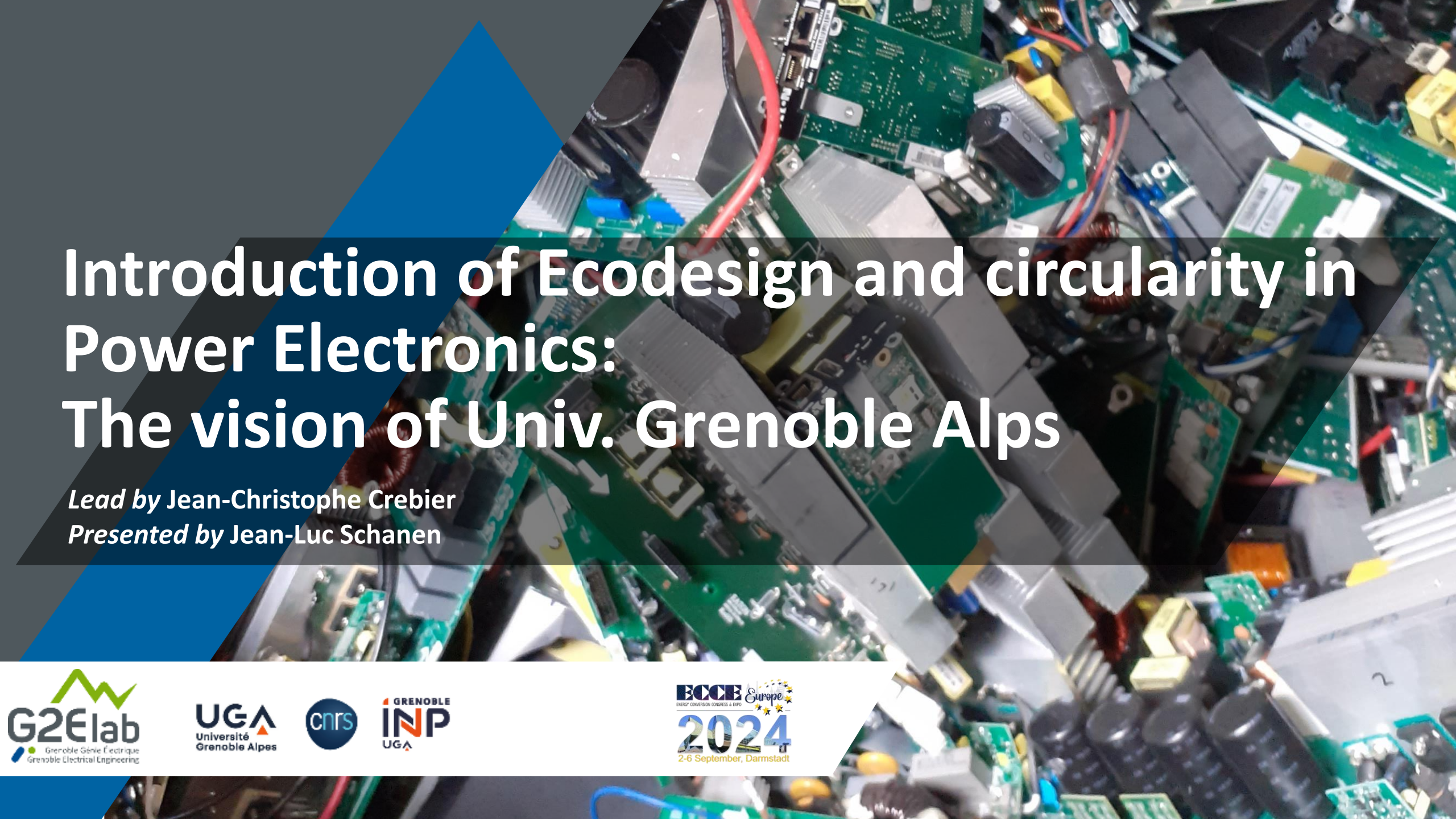
- **Electrification challenges**
  - Minimize **environmental impact** by optimizing performance indices
    - Power density [kW/m^3]
    - Power per Unit Weight [kW/kg]
    - Relative costs [kW/$]
    - Relative Losses [%]
    - Failure rate
  - **Complexity** of integrating new technologies
  - Regulatory **compliance**
  - **Skepticism** and adoption resistance



- **Addressing challenges through modeling and simulation**
  - Cost-effective way to test various scenarios
  - Help to ensure compliance with environmental standards

Key Takeaways

- **Simulation** can play a key role in designing **sustainable power electronics** and **power systems**
- Integrating **simulation tools** into **design workflows** at an early stage offers numerous **benefits**
- Simulation tools can model the **environmental impact** of engineering projects, allowing for the assessment of carbon footprints, emissions, and other ecological factors.



Introduction of Ecodesign and circularity in Power Electronics: The vision of Univ. Grenoble Alps

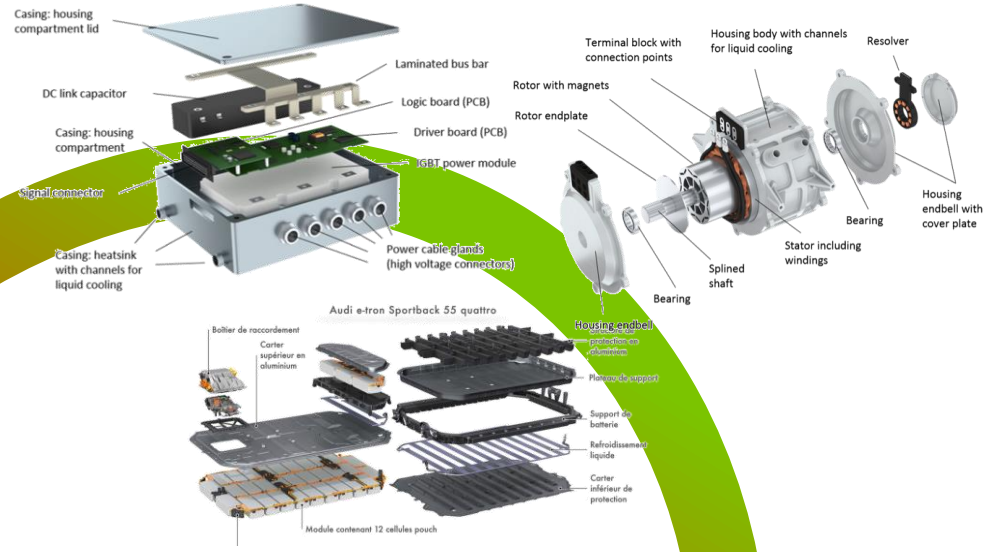
Lead by Jean-Christophe Crebier
Presented by Jean-Luc Schanen

G2Elab Grenoble Génie Électrique / Grenoble Electrical Engineering
UGA Université Grenoble Alpes
cnrs
GRENOBLE INP UGA

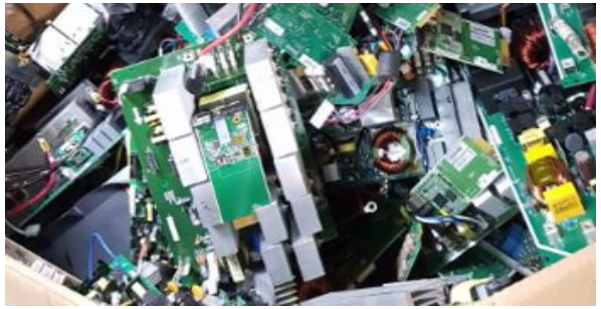
ECCE Europe 2024
2-6 September, Darmstadt

1. Context and motivations

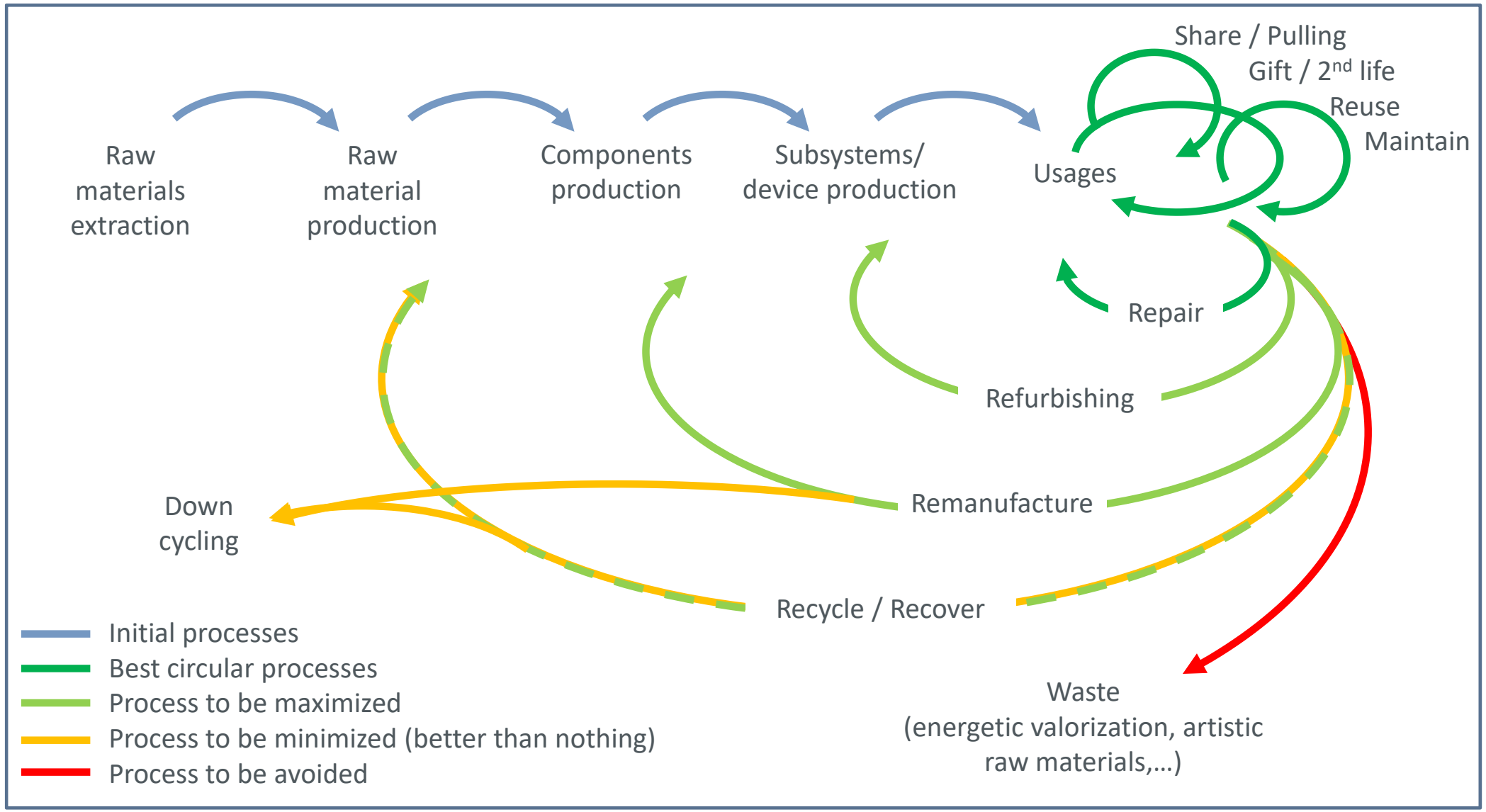
Electrical Engineering Products **require energy and lots of raw materials**. It induces **numerous pollutions** at every manufacturing step.



The end of usage of Electrical Engineering products induces **lots of waste, difficult to recycle** or even to « valorize »



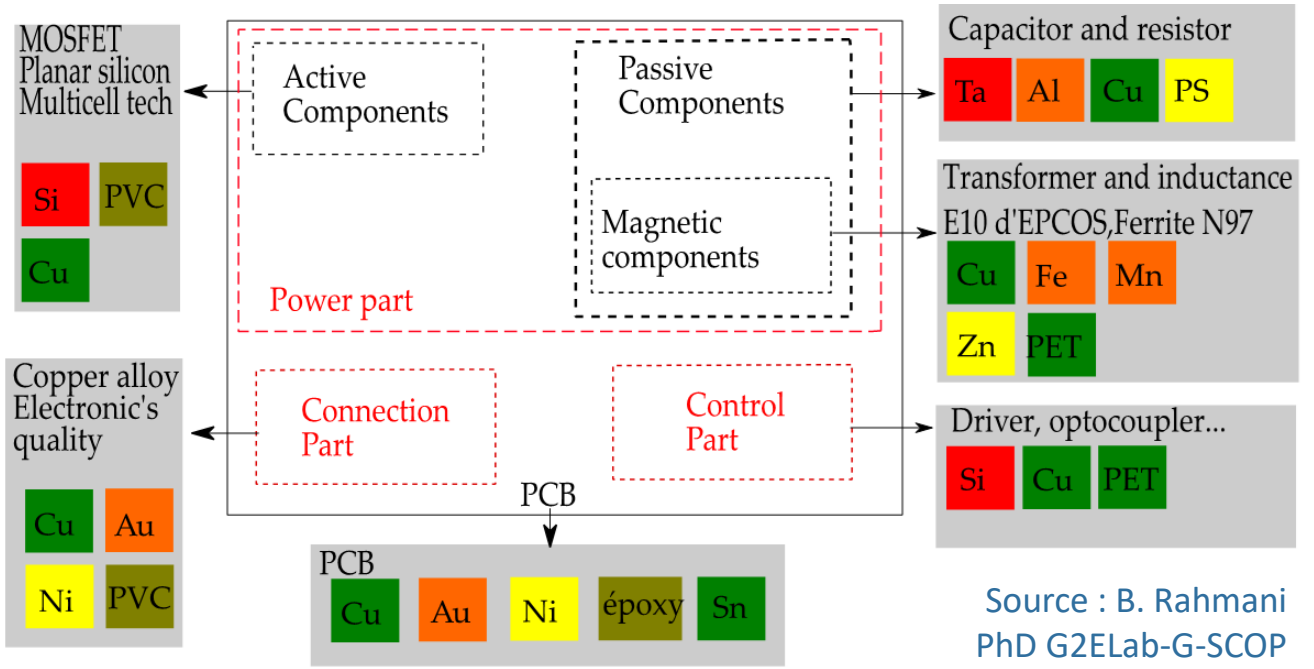
2. Circular economy needs to be developed !



Source : ANR VIVAE Project

2. The conditions for infinite recycling/circularity:

-Infinite recycling = **full recovery of the functionalities of all materials**.
-**Heterogeneities** partially responsible of low recycling rates of collected materials

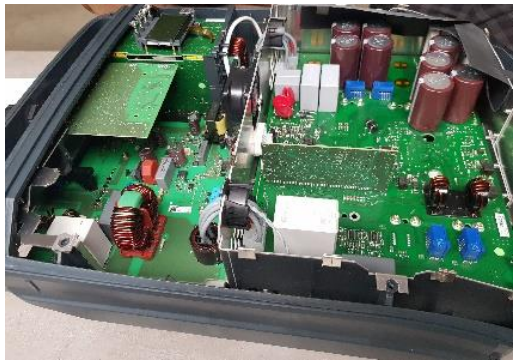


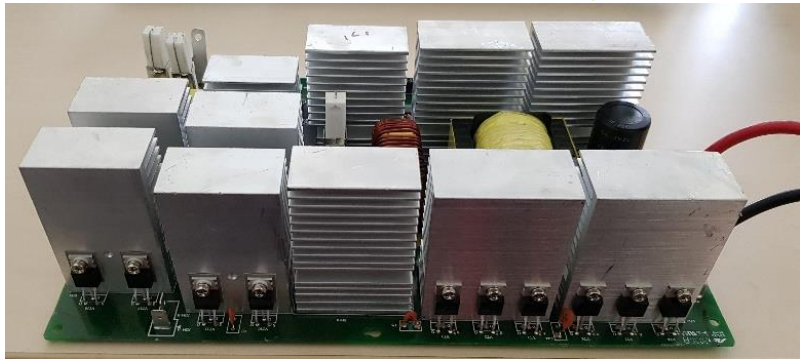
Source : B. Rahmani
PhD G2ELab-G-SCOP

If not 100% achievable, design options to be considered:

-**Reduce** as much as possible **heterogeneities** (material, assembly technics,…) inside converter
-**Reduce** converter **diversities** to optimize recycling technics (not just grinding…)
-**Maximize disassembility rate** to sort components and materials as much as possible
-*Improve recycling technologies*
-Provide **insight** for recycling optimization (Bill of Material, assembly technologies, tools,…)

2. Reduce heterogeneities in PE to allow Circularity

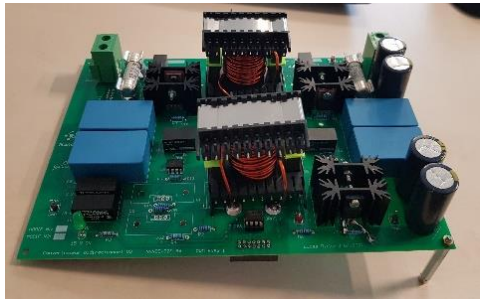




Reduce **material** diversities
Reduce **BOM/components** diversities
Reduce **assembly technology** diversities
Rely on **generic subsystems**

But also
Reduce **topology** diversities
Reduce **control hardware and firmware** diversities
Reduce component **lifetime heterogeneities**
And even **form factor and shape** diversities

Source : T. Turkbay
PhD candidate G2ELab-I2M



2. Power Electronics Building Block concept (PEBB) another pathway toward circularity in Power Electronics ?

Why PEBB concept could bring to circularity and sustainability in PE?

Standardization of sub-systems

Modularity = opportunities for upgrade, spare parts, repair, easier sort out for recycling….

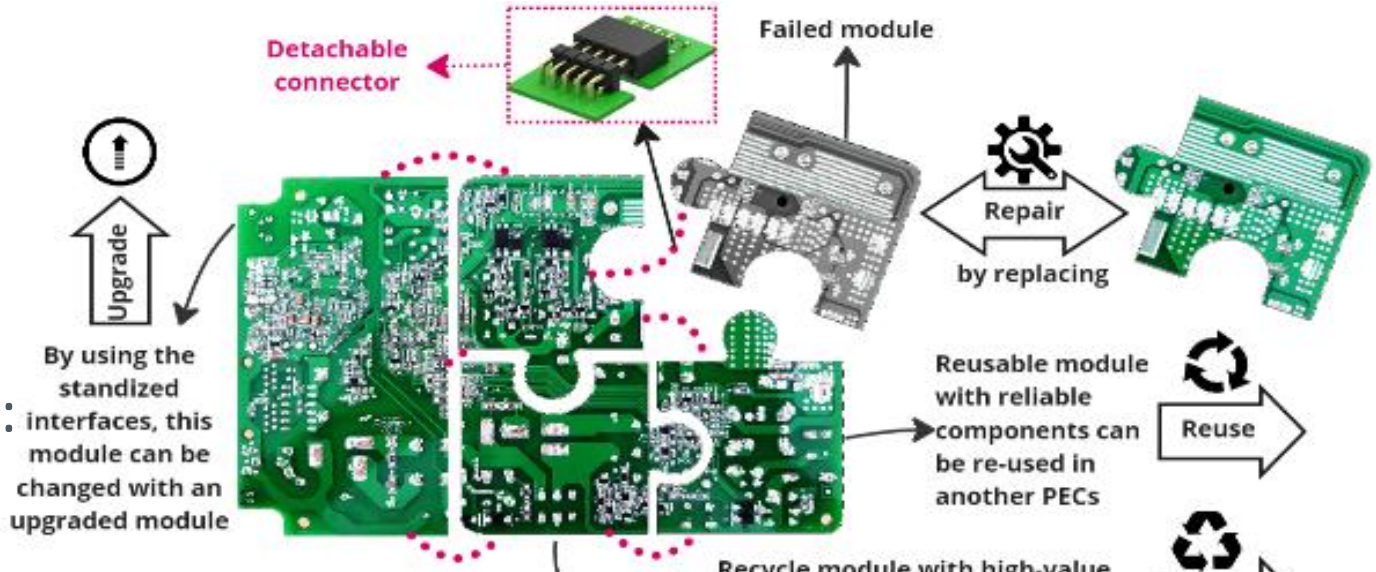
Fewer subsystems that can concentrate efforts :

Longer lifetime and higher performances

Mass production of standardized sub-systems for cost effectiveness

Introduce an abstraction level to facilitate:

- -Diagnostic
- -Disassembly
- -Repair, reuse, repurpose…



Source : T. Turkbay
PhD candidate G2ELab-I2M

3. Tools for the PE eco-designer: role of metrics.

To help eco-designer in their design choices, and to help selecting end of usage optimal circularity scenario, index and metrics may be useful :

- **Ease of Disassembly Metric.**
- **Residual Value index.**
- **Repair Index**
- **Life Cycle Analysis**
- **…**

P. Vanegas *et al.*, "Ease of disassembly of products to support circular economy strategies," *Resources, Conservation and Recycling*, vol. 135, pp. 323–334, Aug. 2018, doi: 10.1016/j.resconrec.2017.06.022

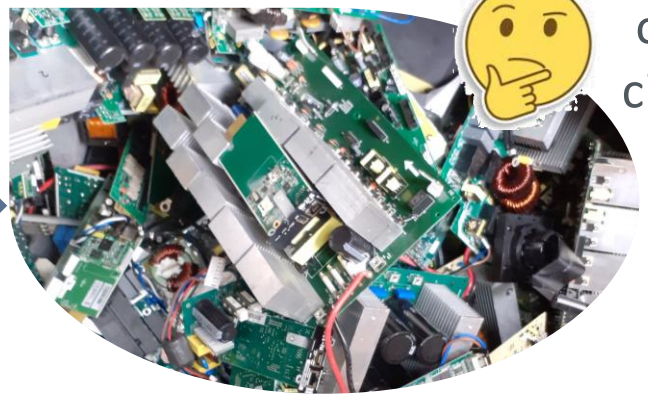
Design and manufacturing stage

Trying to maximize index

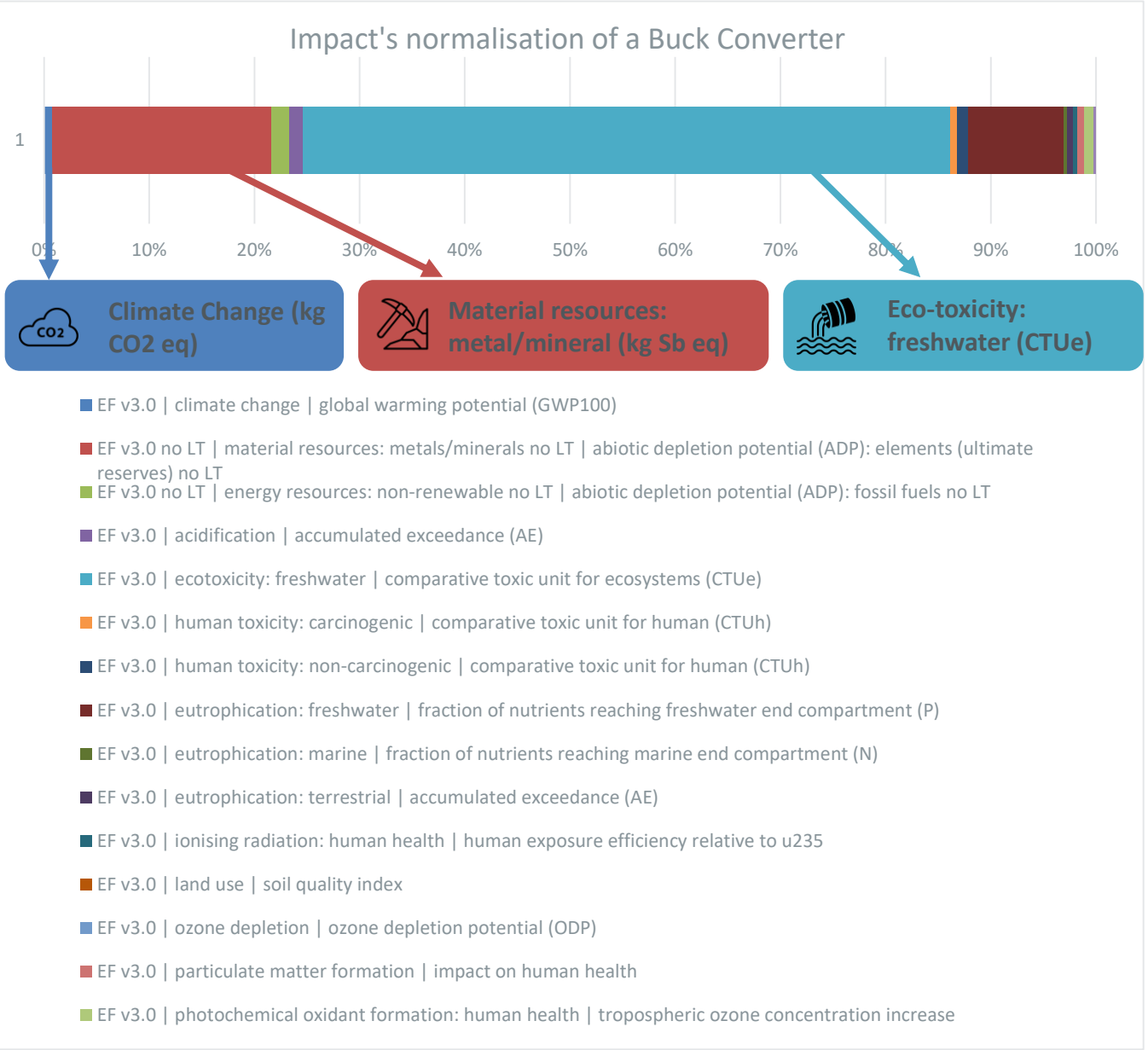
Usage

End of usage stage

Using index to optimize circularity



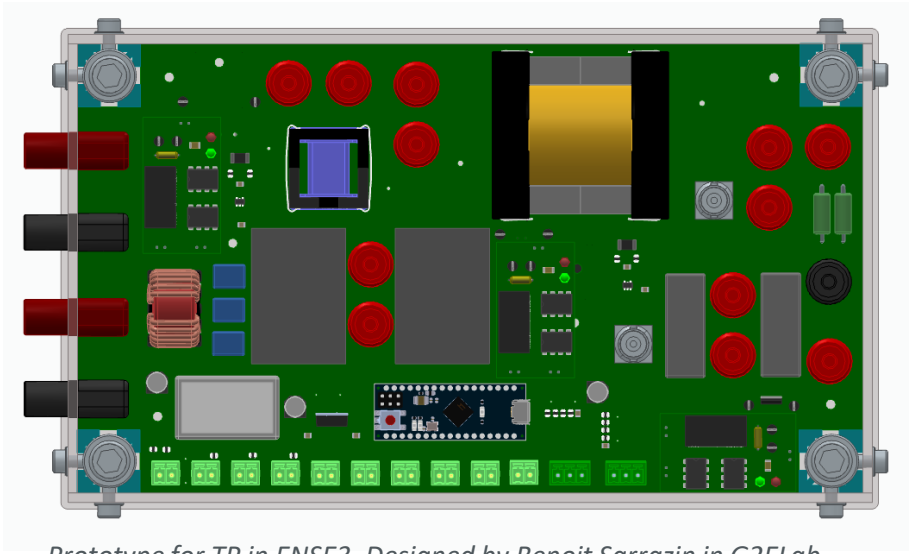
Application of LCA for ecodesign in Power Electronics



Functional Unit : To ensure the **function** of generating a DC voltage ranging from 9V to 15V for a variable load, using a 15V to 30V DC source, over a operational **lifespan** of 30 years (450h) (Service lifetime of converter).

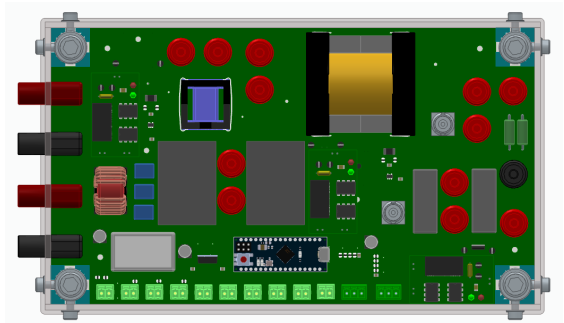
Reference flow : 1 converter with a **reference lifetime** of 100 years (Average physical lifetime of the product)

Repair scenario : 2 repair operations are necessary for the target fragile components during the operation lifespan.

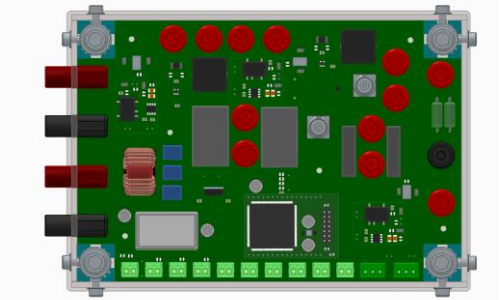


Prototype for TP in ENSE3, Designed by Benoit Sarrazin in G2ELab

Application of LCA for ecodesign in Power Electronics



Reference product



Redesign product

(GaN based to save passives, design for better reparability, …)

(% compared to reference product)

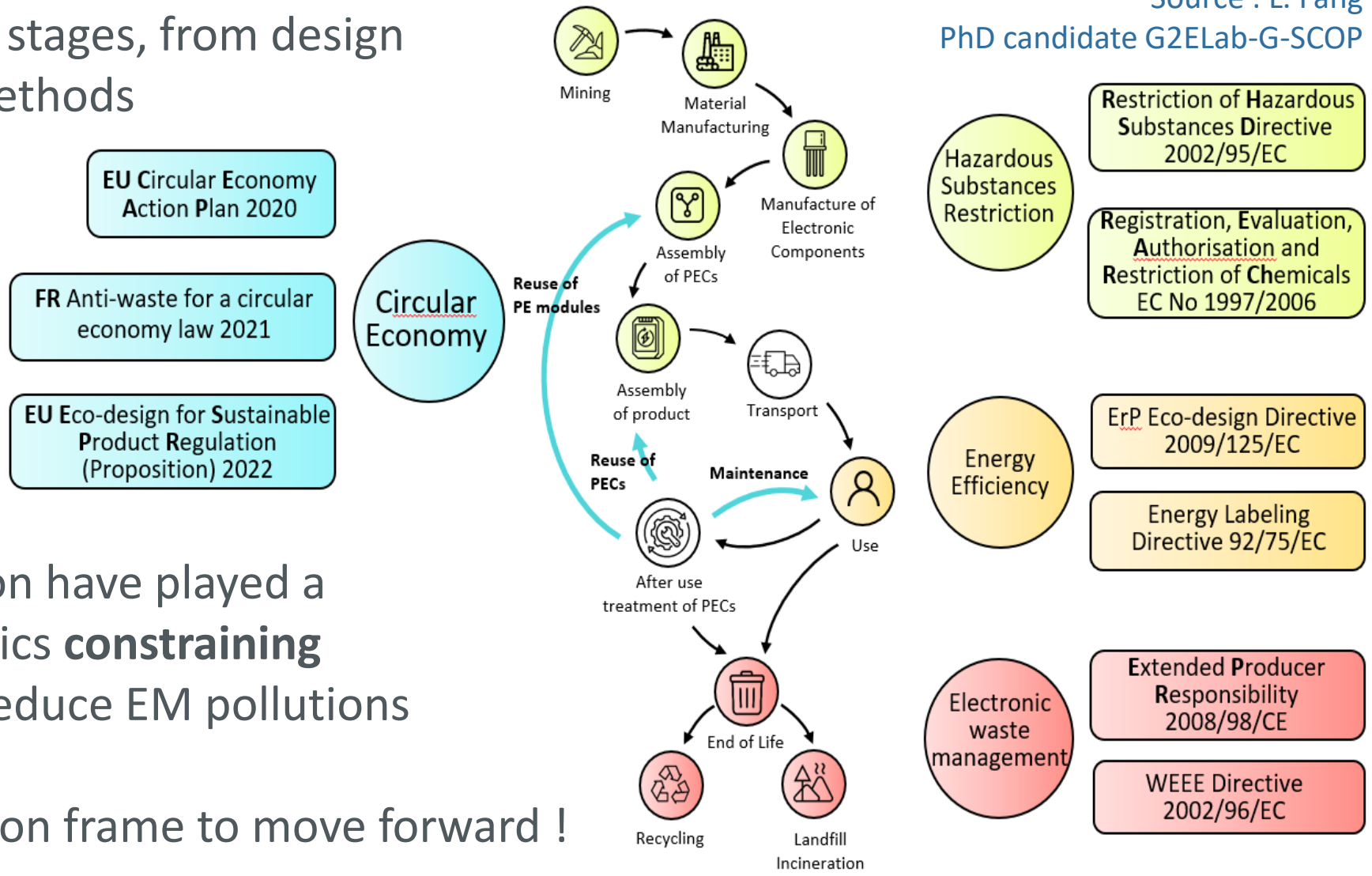
	Parameters	GWP100 (kg CO2eq)	Mineral resources depletion (kg Sbeq)	Ecotoxicity, freshwater (CTUe)
Ecodesign space	Filters size	-16.3%	-4%	-8.8%
	Design's compatibility to repair	-12.1%	+8.6%	-1.5%
Secondary effects	Transistor's technology	-1.0%	+1.3%	0.0%
	Gate driver's technology	-0.1%	-0.6%	-0.3%
	Microcontroller's technology	-0.3%	-1.1%	-0.5%
	PCB's size	-4.1%	-3.1%	-4.1%
	Total mass	-0.3%	0.0%	0.0%
	Energy efficiency	0.0%	0.0%	0.0%
	Total	-34.6%	+3.7%	-14.1%

Strong need to improve the quality of database for Power Electronics !

9

4. Regulation context

Regulations are in place but **only few are constraining**.
They deal with all product stages, from design to end of life, providing methods and recommendations.



Source : L. Fang
PhD candidate G2ELab-G-SCOP

30 years ago EMI regulation have played a key role in power electronics **constraining to comply with limits** to reduce EM pollutions

We need a similar regulation frame to move forward !

Thank you !

ECCE Europe
ENERGY CONVERSION CONGRESS & EXPO
2024
2-6 September, Darmstadt