CO_2CoDe: Towards Carbon-Aware Hardware/Software Co-Design for Intermittently-Powered Embedded Systems

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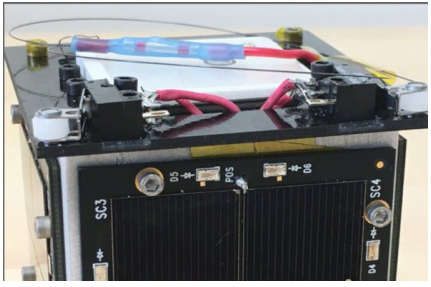
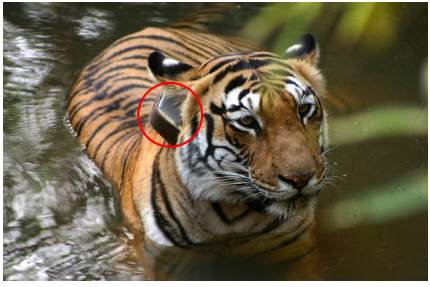
Project no 502947440 (Watwa)
Project no 502615015 (ResPECT)

Target Systems



Lucia, ACM SIGARCH Blog, 2022

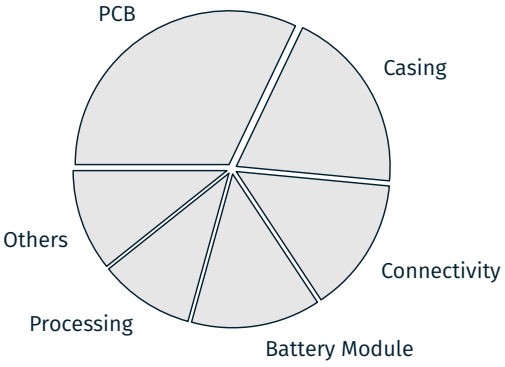


PR Ganapathy, CC BY-SA 4.0, 2015

Afanasov, SenSys, 2020

de Winkel, MobiSys, 2022

Ecological Footprint



Breakdown of the Global Warming Potential of a Mobile Device [kgCO_2]

after Maistriaux, IOT, 2022

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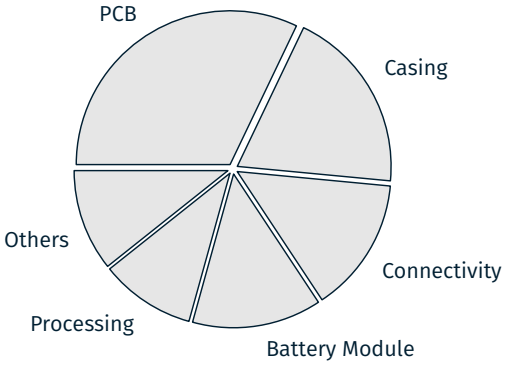

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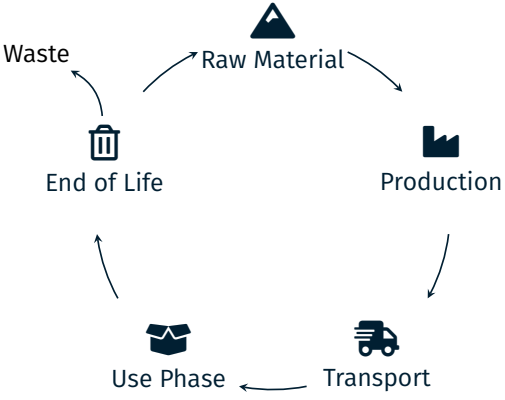

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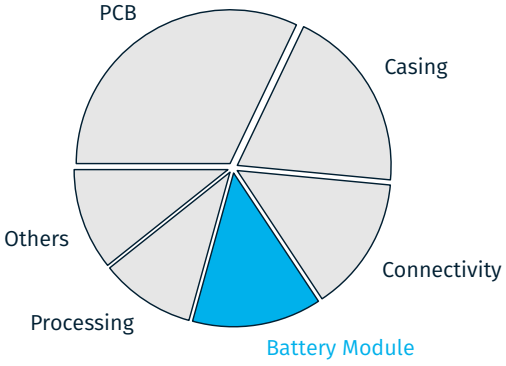

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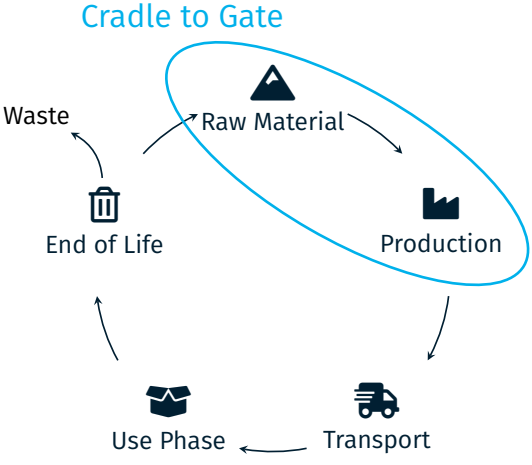
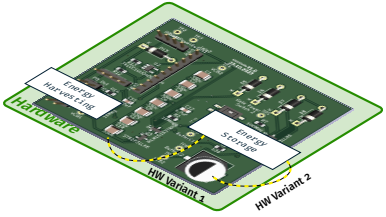
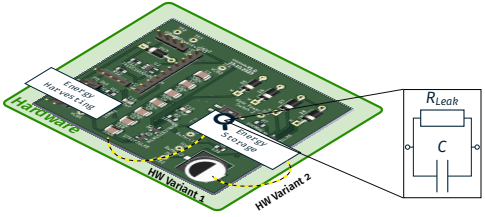


Pervasive System Traits



Pervasive System Traits

- Leakage resistance



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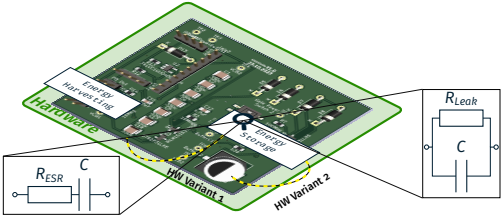
- Leakage resistance
- Equivalent Series Resistance (ESR)



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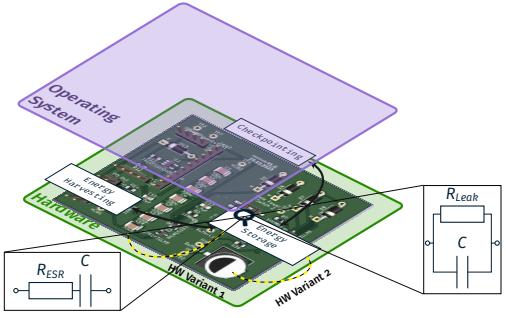

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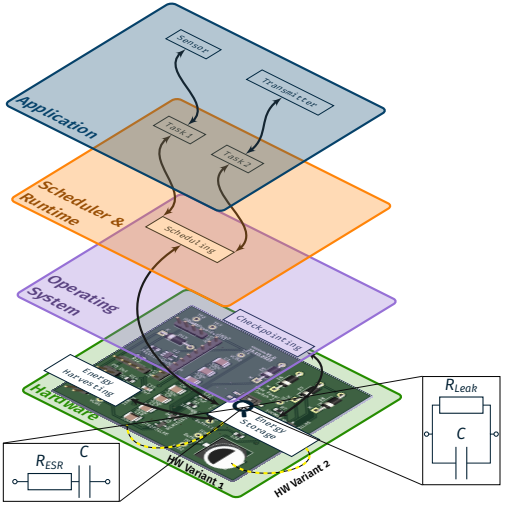

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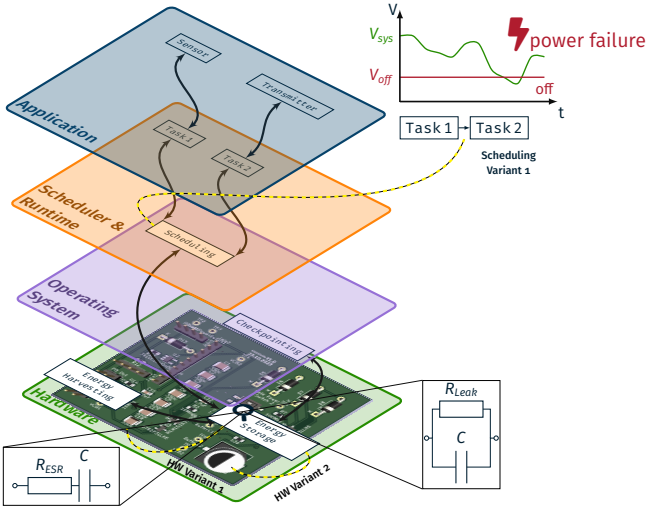

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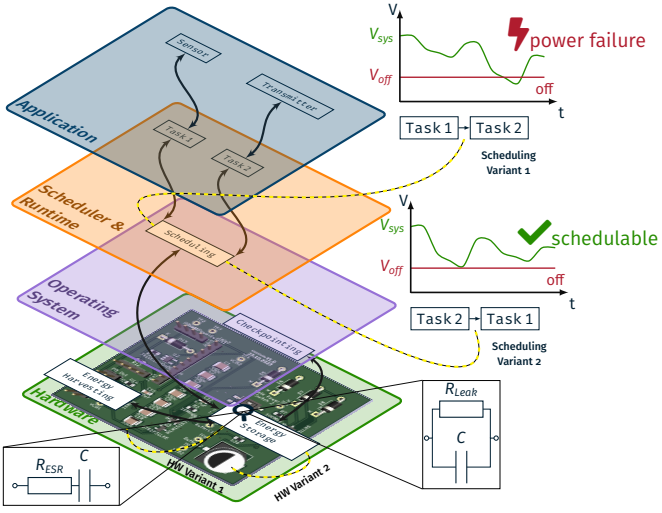

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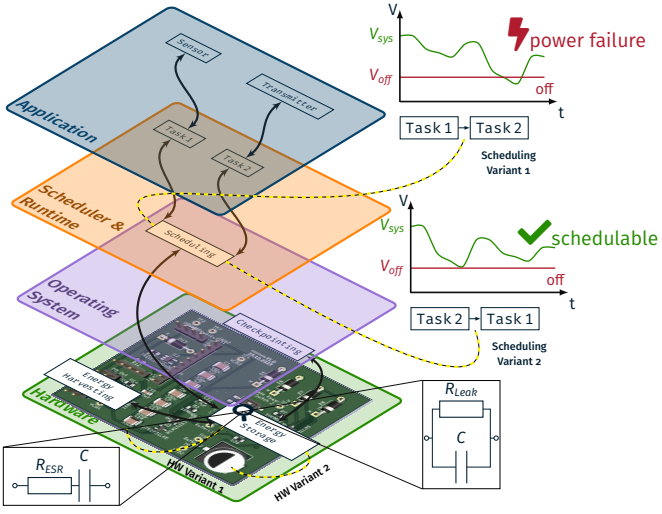

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- Equivalent Series Resistance (ESR)
- Leakage resistance affects checkpointing
- ESR affects scheduling
- **Effects propagate throughout the system stack**

Problems & Goals

Problems

- Propagation throughout whole system stack
  - Hardware $\mapsto$ Software
  - Software $\mapsto$ Hardware
- Multi-objective design choices
- Lack of proper abstractions

Goals

- HW/SW co-design framework for carbon-conscious design
- Achieve sustainable designs of battery-free systems

CO_2CoDe Case Study

Carbon-Conscious System Design

Multiple Objectives

- **Minimizing** the **embodied carbon** of the designed system
- **Maximizing** the **available energy** for execution

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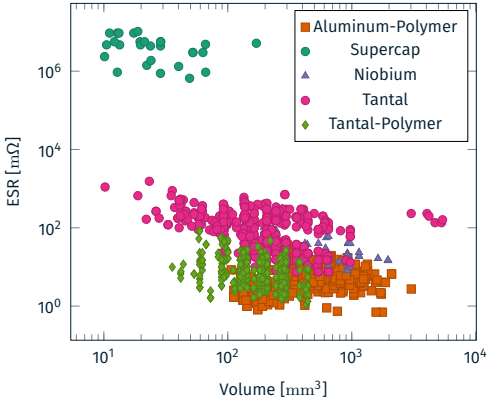
Maximizing Available Energy Through Task Schedules

- Order tasks while taking maximum power demand into account

$\Rightarrow$ Diminish impacts of ESR-related voltage drop

Results

Capacitor Selection



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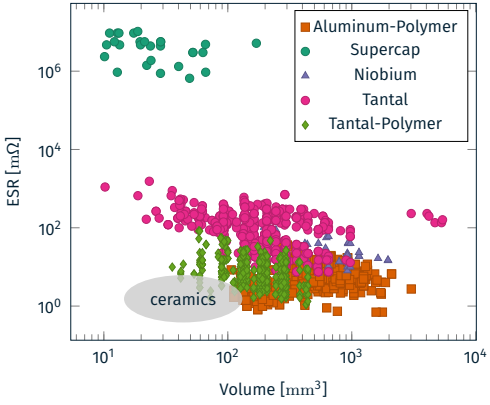

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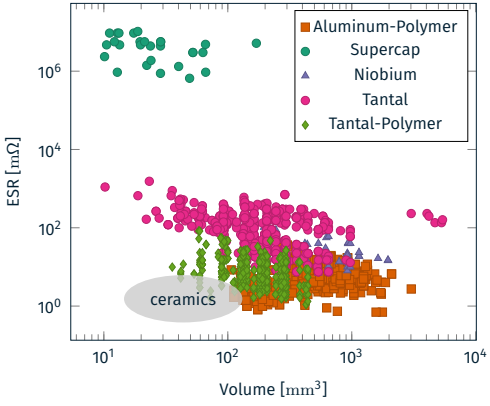

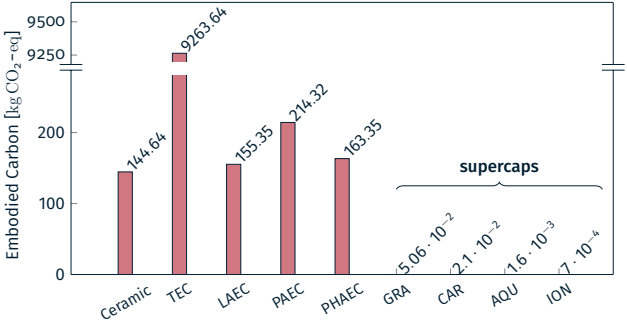

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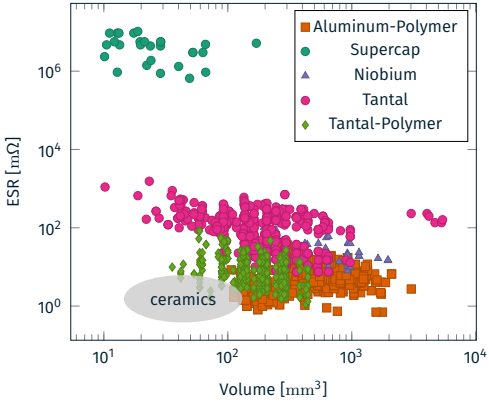
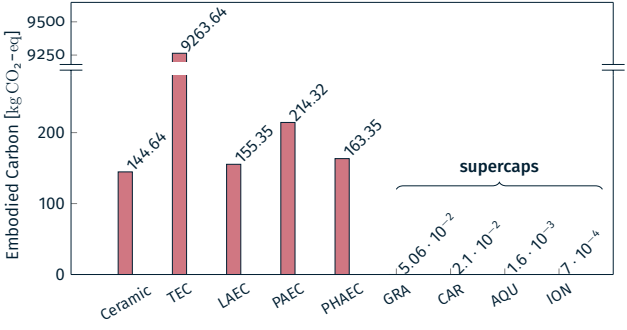
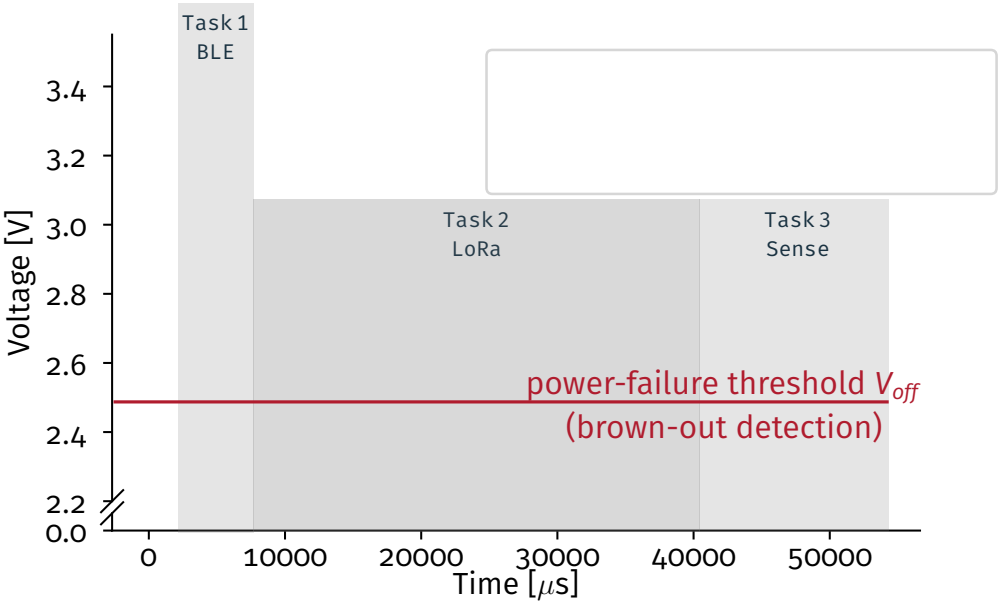




Chosen Capacitors: ceramics and supercaps

- Low carbon footprint
- Ceramics: low ESR but low energy density
- Supercaps: high energy density but high ESR

Voltage Trace



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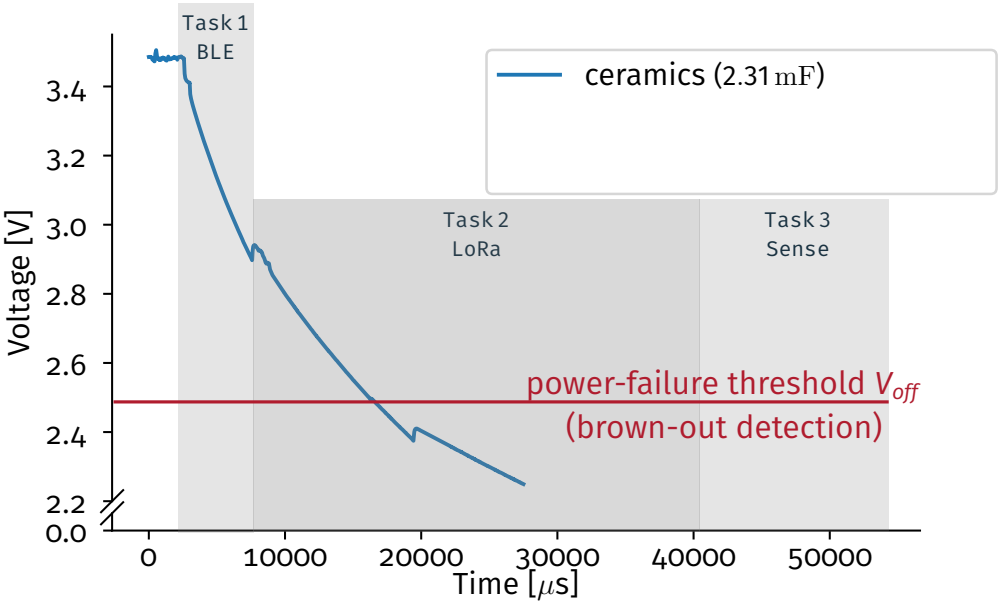

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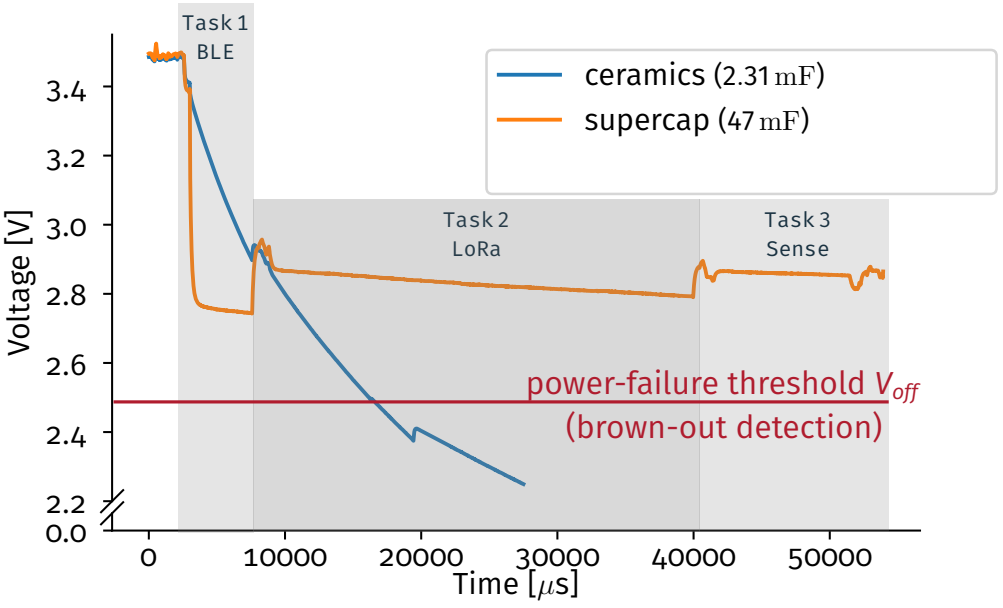

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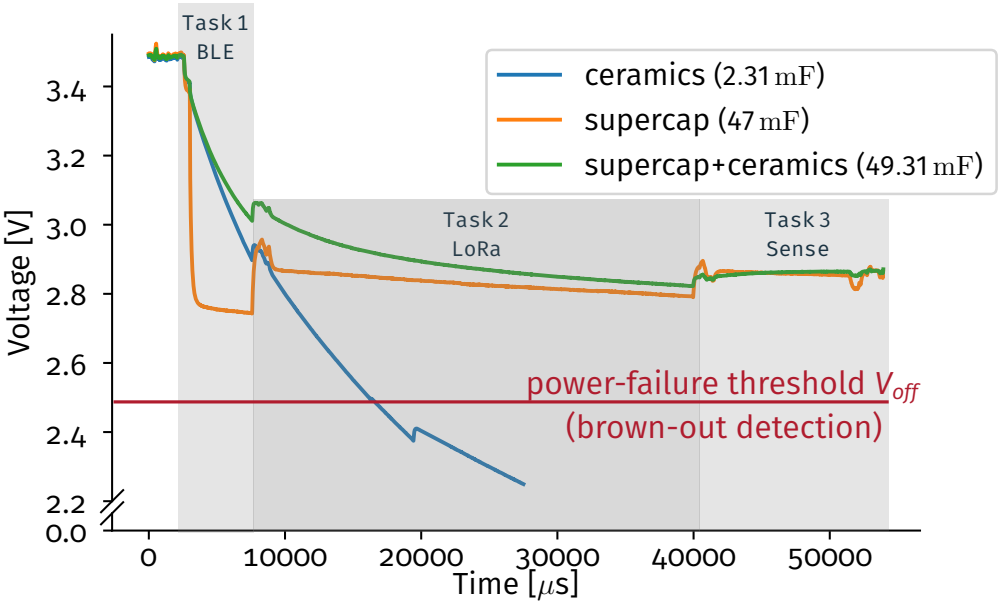

Conclusion

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Recap

- Multi-objective, **contradicting** design choices
- Current lack of proper abstractions
- Case study: capacitor selection with **conflicting properties**
- Energy-storage design **propagates** through entire system stack

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Future Work

- Create a hardware/software co-design framework for carbon-conscious design decisions
- Bridge gap between system-level functionality and carbon awareness
- Sustainable design of carbon-aware and battery-free systems

CO_2CoDe's project repository: https://gitos.rrze.fau.de/co2code