Poster 3: Minimum CO_2 Saving Requirement for the Hydraulic-Pneumatic Flywheel System in the Rotor of a Wind Turbine

Abhinay Goga Clemens Jauch Laurence Alhrshy	Wind Energy Technology Institute, Flensburg University of Applied Sciences, Kanzleistraße 91-93, 24943 Flensburg, Germany
Andreas Gagel	AEROVIDE GmbH, Provianthausstr.9, 24768 Rendsburg, Germany
Peter Kloft	HYDAC Technology GmbH, Justus-von-Liebig Straße, 66280 Sulzbach, Germany

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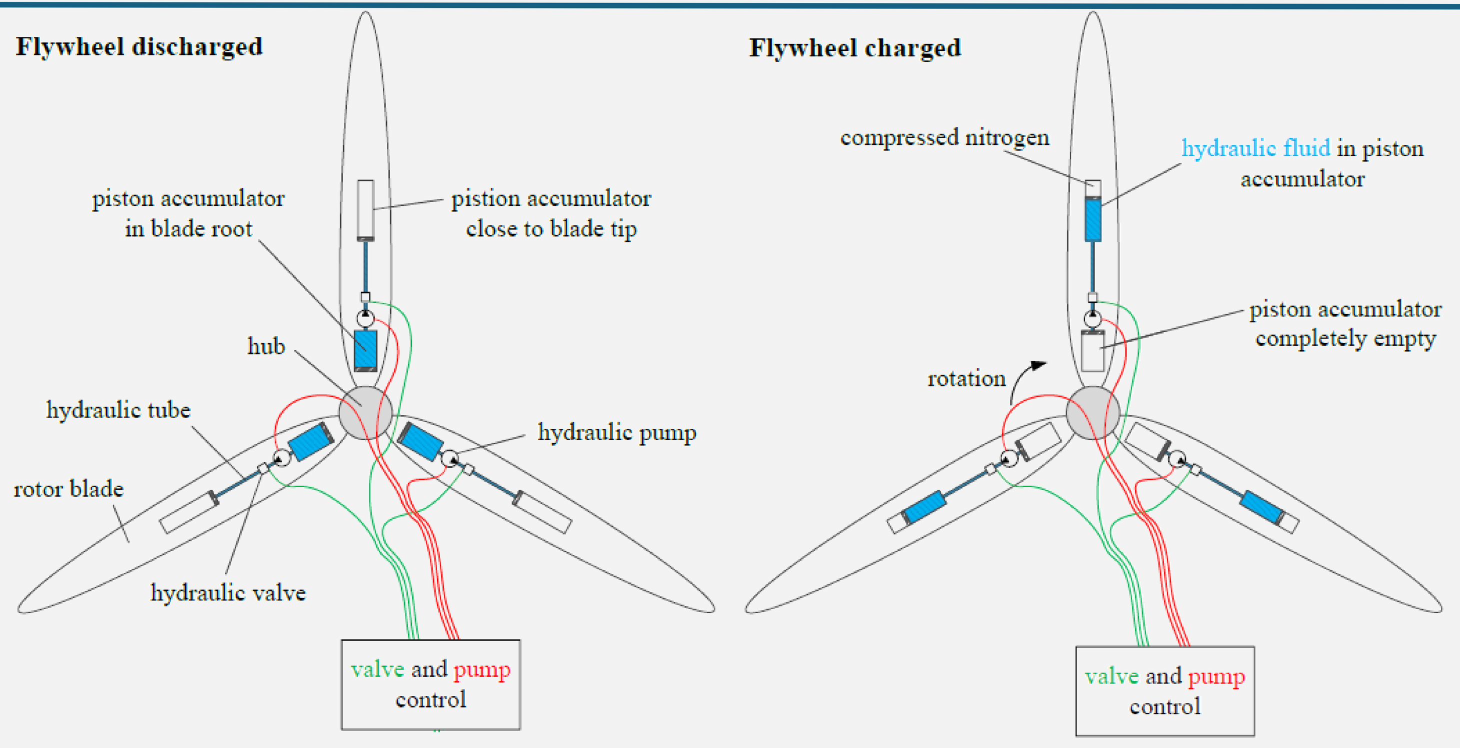
Introduction

- **Research Focus:** Reducing structural loads on wind turbines to decrease material usage
- **Innovative Concept:** Integration of an active, controlled flywheel system into rotor blades to mitigate load peaks and/or level fatigue loads
- **Challenge:**
  - The flywheel system itself, while designed to reduce material usage in the entire wind turbine generator (WTG), requires initially an investment of additional materials
  - This increases the carbon footprint in the first step, which is finally to be reduced by material savings in other WTG components
- **Objective:**
  - To investigate the increase of material usage by the integration of a flywheel system into the rotor blades
  - To quantify the material-use increase in CO_2 emissions as a benchmark for the required effect of flywheel system

The flywheel system modulates the inertia of the WTG rotor through the management of integrated movable masses. By strategically controlling the flywheel system, the objective is to achieve a reduction in mechanical loads, which in turn reduces the material requirements for the WTG.



Focus on Rotor

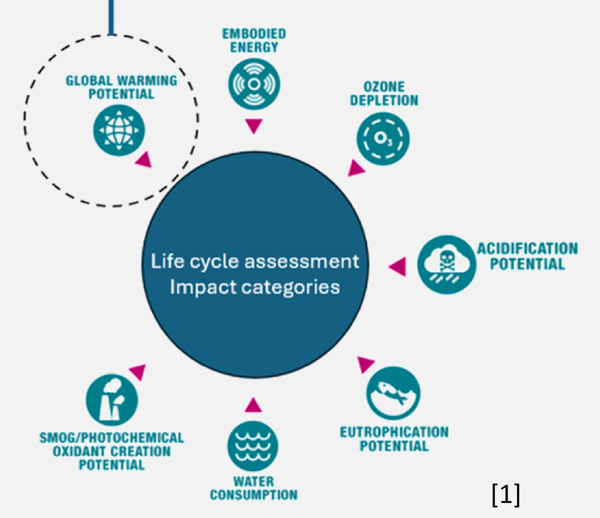
The analysis primarily targets the rotor, specifically the hub, blades, and pitch drives, as these components are most directly impacted by the implementation of the flywheel system. While the larger mass effects on the tower and foundation are not the focus of this work, it is important to note that the flywheel system also holds significant potential for material savings in these areas

CO_2 equivalent factors for resources

Material	GFRP	Epoxy	Balsa	PVC	Steel	CFRP	Copper	Cast iron
CO_2 EFR (tCO_2e/t)	8.50	4.99	0.12	1.89	2.08	83.38	6.86	1.66

Abbreviations: CFRP- carbon fiber reinforced plastic, GFRP- glass fiber reinforced plastic, PVC- Polyvinyl chloride [4]

Carbon Footprint of a Wind Turbine



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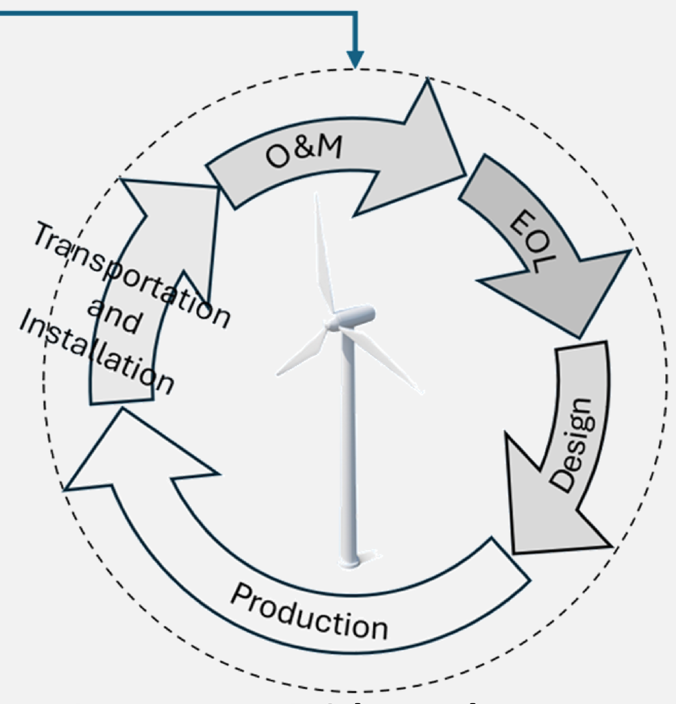

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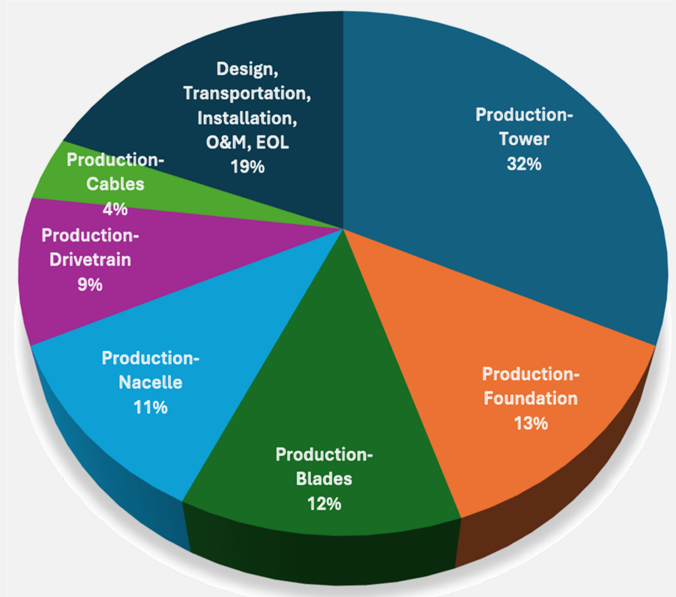
CO_2 as a Measure of Global Warming Potential (GWP)

- **CO_2 Basis:** Used by IPCC for GWP calculation
- **GWP-100:** Measures a gas's impact on global warming over 100 years
- **CO_2 Emission Factor (EFR):** Quantifies greenhouse gas emissions for specific products or processes

Focus on CO_2 Emissions from Production



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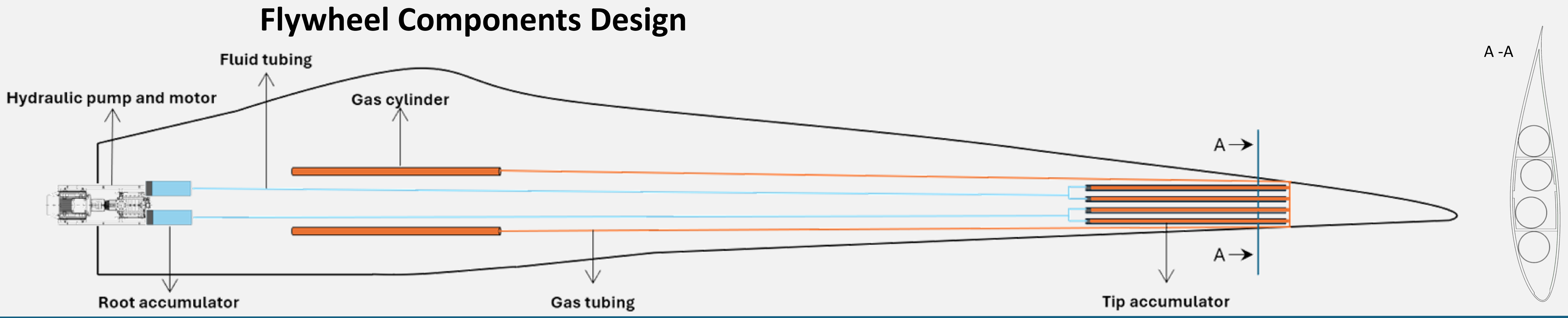
Cradle-to-grave or Cradle-to-gate?

- **Materials Considered :**
  - **Metals:** Circular economy integration is relatively advanced
  - **Composite Materials:** Still under research, with ongoing developments
- **Circular Economy Impact:** Not included in the analysis
  - Life cycle assessment is limited to cradle-to-gate

Flywheel Components Design

- **Rotor Blade:**
  - **Length:** 68.7 meters
  - Designed by AEROVIDE for a 4MW wind turbine
- **Components per Rotor Blade:**
  - 2 Root accumulators, 4 tip accumulators, 2 gas cylinders, fluid and gas tubings



Selection Criteria for Hydraulic Pump and Motor

- **Fluid:** Mixture of water and glykosol-N (34% volume concentration)
- **Fluid Mass:** Total: 956 kg
  - Movable mass: 743 kg
  - Mass in tubes: 213 kg
- **Gas:** Compressed nitrogen
  Gas mass: 180 kg
- **Environmental Conditions:**
  Lowest ambient temperature: -20°C
  Highest ambient temperature: +40°C
- **Charging Time:** minimum time considered for charging the flywheel from entirely discharged to fully charged is 20 seconds

Selected Pump and Motor Unit (PMU) Details:

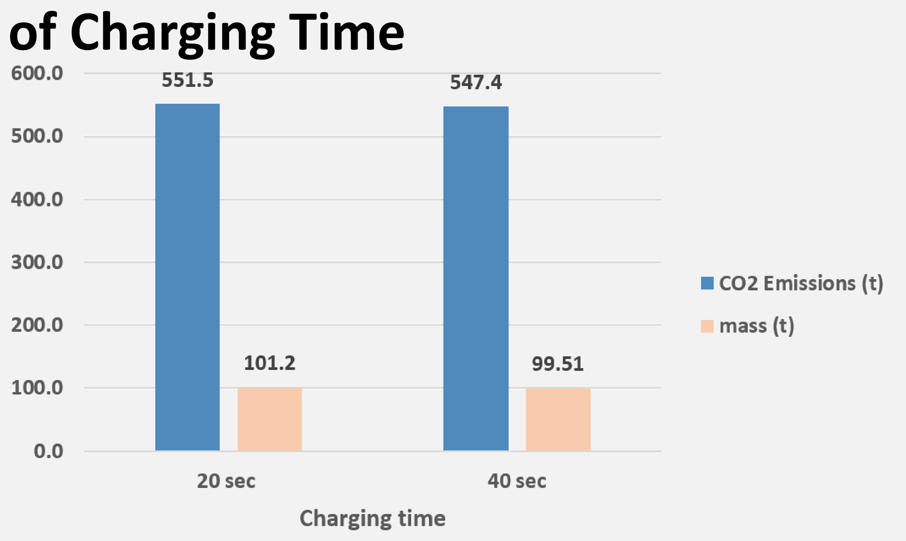
Pump model	MPA 100B/07C
Motor model	315L 250kW
Pump and motor mass (kg)	2059

[5]

The PMU contributes significantly to the total system mass:

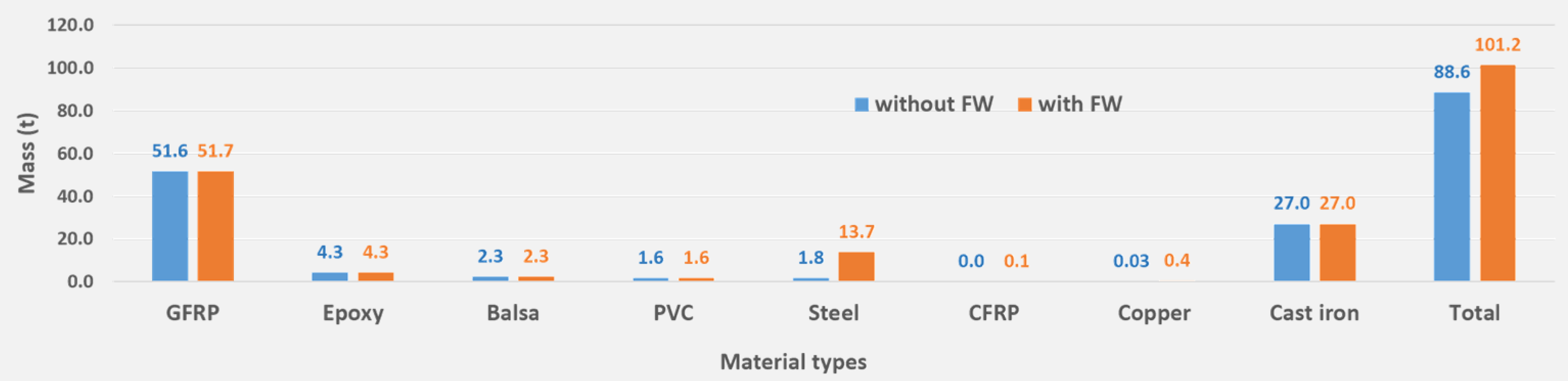
- Out of a 12.6-ton total mass increase, the PMU for the three blades alone accounts for 6.2 tons.
- This emphasizes the critical importance of optimal dimensioning for the PMU in achieving efficiency.

Influence of Charging Time

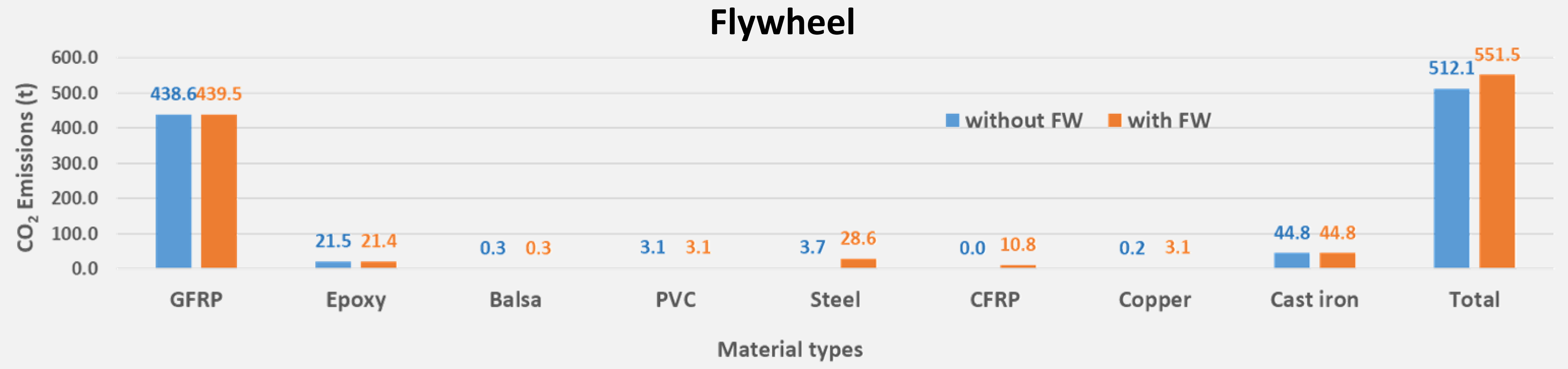


Research [6] shows that longer charging times reduce load mitigation, making the flywheel less efficient. To enhance resource conservation, a 20-sec charging time considered moving forward as an optimal choice.

Comparison of Material Masses (t) between Rotor Without and With Flywheel



Comparison of CO_2 Emissions (t) from Material Types between Rotor Without and With Flywheel



Conclusion

The CO_2 emissions of the exemplary rotor increases by 39.4t (7.6%) due to the implementation of a flywheel system, which is worthwhile if it can be overcompensated in other WTG components by the load reduction effect of an active, controlled flywheel system.

References

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