

Life Cycle Assessment of Innovative Propulsion Technologies

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The environmental impact of aircraft throughout their entire life cycle, from raw material extraction to disposal or recycling, is receiving growing attention, particularly through the application of Life Cycle Assessment (LCA) methodology. This study is part of the activities carried out within the COLOSSUS (Collaborative system of systems exploration of aviation products, services & business models) project [1] and the Clean Aviation HERA (Hybrid Electric Regional Architecture) project [2], which targets a 50% reduction in greenhouse gas emissions in line with SRIA (Strategic Research and Innovation Agenda) objectives. The focus is on regional hybrid-electric aircraft, with emphasis on emerging technologies such as advanced batteries and hydrogen fuel cells. Special attention is given to the materials and manufacturing processes involved, particularly during the production phase, due to its significant environmental impact. Among the systems analyzed, lithium-sulphur (Li-S) batteries show a relatively low impact in terms of CO₂ emissions, despite being heavier than major structural components like the fuselage, as shown in Figure 1. However, their environmental burden is significant in categories such as marine and freshwater ecotoxicity, soil contamination, and human toxicity. These impacts are mainly due to the extraction and processing of sulphur and other raw materials, as well as the use of chemical substances such as the LiTFSI electrolyte and organic solvents (e.g., dioxolane, dimethoxyethane), which, if not properly managed, can lead to soil and water pollution. A second focus of the study addressed Proton Exchange Membrane Fuel Cells

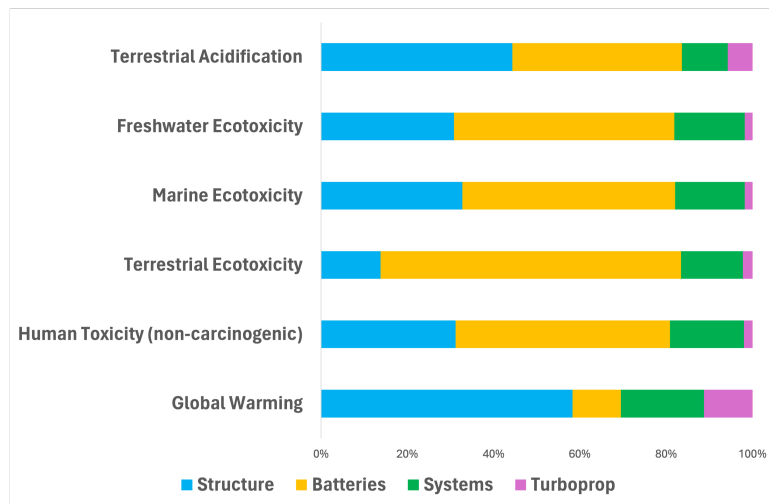


Figure 1: Environmental Impact Categories of a Battery-Powered Hybrid-Electric Aircraft

(PEMFCs), which show a higher environmental impact in terms of CO₂ emissions, as shown in Figure 2, primarily due to the use of platinum, a rare and extraction-intensive metal. Although platinum accounts for only 0.1% of the PEMFC module by mass, it is responsible for the majority of the associated environmental impacts. However, eco-design strategies involving platinum reduction or the use of recycled platinum can lower the carbon footprint by up to 54%. Permanent magnet electric motors and cryogenic tanks for liquid hydrogen were also analyzed.

Despite involving critical materials such as rare earths and energy-intensive composites, their environmental impact remains lower than that of more demanding subsystems like batteries or fuel cells.

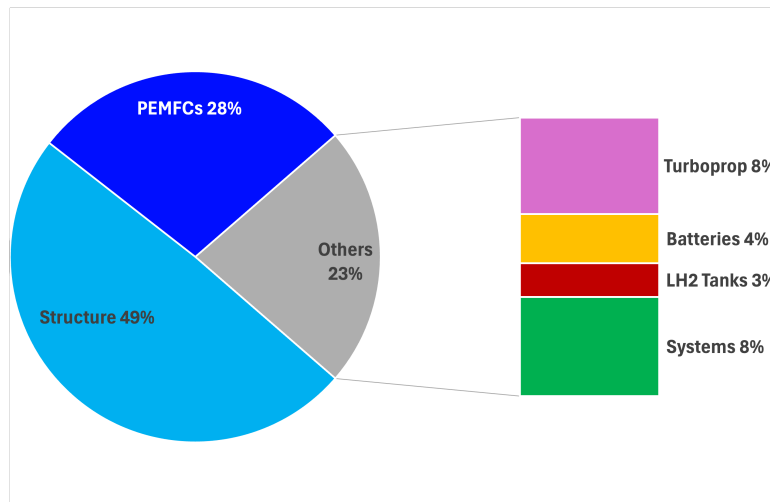


Figure 2: CO₂ emissions from the production phase using Li-S batteries and PEMFCs.

The LCA comparison between the two technologies, applied to a regional aircraft such as the ATR 72, shows that hybrid propulsion using batteries can reduce CO₂ emissions by 19% compared to a conventional aircraft, while a combined battery–fuel cell system can achieve reductions of up to 36%. Nonetheless, the production phase, particularly the manufacturing of electrochemical components, emerges as a dominant contributor in several impact categories, especially those related to human health and resource depletion.

The analysis confirms that the operational phase dominates the aircraft’s life cycle impact. Hybrid technologies like batteries and fuel cells reduce fuel use and emissions, though battery disposal remains uncertain. Current estimates rely on early data and projections. With better technologies, refined models, and strong policy and industry support, hybrid aviation could greatly cut its environmental footprint.

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References

- [1] COLOSSUS Project – Collaborative System of Systems Exploration of Aviation Products, Services and Business Models, <https://colossus-sos-project.eu/>
- [2] <https://cordis.europa.eu/project/id/101102007>