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Life Cycle Assessment of Gas Turbine Package Components Using Sustainable Materials and Robotic Additive Manufacturing

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ABSTRACT

With the industrial sector responsible for 30% of global greenhouse gas (GHG) emissions and 37% of global energy consumption, efforts to reduce environmental impacts are increasingly focusing on heavy manufacturing processes through sustainable materials and advanced production methods. This research addresses this challenge by investigating the potential of sustainable materials and Additive Manufacturing (AM) techniques in the development of Gas Turbine (GT) packages, which are critical components in the energy sector. This study uses Life Cycle Assessment (LCA) to evaluate the environmental impacts of using novel sustainable materials in two key components of GT package manufacturing: the baseplate and the air filter module. The existing GT package components are traditionally manufactured from steel, a material with significant environmental impacts. This research explores the transition from steel to alternatives such as wood-plastic composites and eggshell-filled concrete, manufactured through robotic AM processes. The LCA was conducted using OpenLCA, an open-source software, in combination with secondary data sourced from the Ecoinvent database. A cradle-to-gate assessment framework was applied, focusing on key environmental impact categories such as Global Warming Potential (GWP), resource depletion, and toxicity.

Initial results indicate that new materials demonstrate a 30% reduction in GWP compared to the existing GT packages. These findings suggest that integrating sustainable materials offers significant environmental benefits. Building on these findings, the research is currently focused on developing a dynamic unit process model for AM, primarily for Fused Deposition Modeling. Unlike traditional static LCA models, which rely on fixed datasets, this dynamic model integrates real-time simulations of energy consumption, material flow, and process specific data to enhance accuracy and flexibility. Key parameters such as deposition rates, extrusion temperatures, machine-specific energy demands, and material properties are incorporated to capture process-level variability. This enables scenario-based impact assessments and sensitivity analyses, allowing for the optimization of environmental performance during the design phase. In addition to dynamic modeling, Python-based automation tools are being developed to streamline the LCA workflow by enabling integration of the dynamic unit process data with LCA models. By integrating LCA into the early design phase, this research supports the shift toward more environmentally responsible manufacturing. The methodologies and tools developed in this study are designed to be scalable and adaptable across various AM processes.