INDIAN INSTITUTE OF TECHNOLOGY GUWAHATI
SHORT ABSTRACT OF THESIS

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Thesis Title: **Life Cycle Analysis (LCA) of Vehicles Powered by Clean Energy: An Indian Perspective**

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SHORT ABSTRACT

This dissertation conducts a comprehensive lifecycle assessment (LCA) of internal combustion engine vehicles (ICEVs), hybrid electric vehicles (HEVs), battery electric vehicles (BEVs), and fuel cell electric vehicles (FCEVs) within the context of the Indian energy mix. A cradle-to-grave system boundary was defined to evaluate emissions from vehicle and fuel cycles, incorporating a sensitivity analysis to assess the robustness of the results against key assumptions. This study uses GREET and SimaPro software to estimate GHG emissions and other environmental indicators. The findings indicate that BEVs and FCEVs exhibit lower lifecycle greenhouse gas (GHG) emissions than ICEVs; however, their efficacy depends upon grid electricity mix and hydrogen production pathways. Though their vehicle cycle emissions are maximum, BEVs demonstrate the lowest total lifecycle emissions when compared with ICEVs and HEVs, primarily due to lower fuel-cycle emissions. The transition to a renewable-energy-dominated electricity grid by 2030 could further reduce BEV emissions by 20%. Also, improving thermal power plant (TPP) efficiency beyond 30% further lowers BEV's lifecycle GHG emissions. However, sensitivity analysis reveals that factors such as shorter lifetime travel distances (<76000 km for passenger cars and <65000 km for SUVs), inefficient thermal power plants (<30% efficiency), and multiple battery replacements (up to two times) during vehicle lifetime can make BEVs emit more than ICEVs and HEVs. FCEVs, mainly green hydrogen-powered ones, yield the lowest lifecycle GHG emissions. However, given green hydrogen production's technological and economic

constraints, blue hydrogen emerges as a more viable near-term alternative, offering lower emissions than BEVs, even under the projected 2030 electricity mix. Furthermore, sensitivity studies reveal that fuel cell degradation has a negligible impact on FCEV lifecycle emissions. Lifecycle impact assessment (LCIA) further reveals trade-offs among environmental indicators. While BEVs and FCEVs reduce global warming potential (GWP) compared to ICEVs, BEVs have higher impacts on human toxicity and mineral resource scarcity. At the same time, FCEVs show elevated impacts in other categories. The conclusion drawn from the weighed impact (single score) on risk areas (end-point damage) concludes that FCEVs with blue hydrogen have the least impact on environmental indicators. This study underscores that while BEVs and FCEVs offer significant potential for reducing GHG emissions in India's transport sector, their environmental benefits depend highly on the energy mix, hydrogen production pathways, and battery lifecycle considerations. While BEVs can achieve lower emissions with a renewable dominated grid, their environmental impact in other categories, such as resource scarcity and human toxicity, remains a concern. FCEVs, particularly those utilizing blue hydrogen in the near term and green hydrogen in the long term, present a viable alternative with lower lifecycle emissions but concerns with hydrogen production costs and immature carbon capture infrastructure. However, achieving a sustainable transition requires a holistic approach, including advancements in renewable energy integration, hydrogen infrastructure development, and sustainable material management.

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