Risk assessment of Integrated Fuel Cell Systems for Rail Transport

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The rapid depletion of fossil resources and growing environmental concerns have driven the search for cleaner, more efficient energy carriers in mobile applications. In this study, the technical feasibility and safety performance of an on-board integrated high-temperature proton exchange membrane fuel cell (HT-PEMFC) system for railway traction was evaluated, comparing direct high-pressure hydrogen storage with alternative liquid carriers, such as methanol, ethanol, glycerol and ammonia, coupled to oxidative steam reforming (OSR) or catalytic decomposition. Through Aspen Plus® simulations, autothermal conditions were assessed. Each design incorporated reactant preheating, reaction and cooling stages, with heat integration between that dissipated by the fuel cell and endothermic reforming steps to achieve autothermal operation. The entire reactive and electrical systems were sized, to evaluate the possibility to install the system inside a common train car. Compared to a reference 350 bar hydrogen-storage system, that for the high volume and the mass due to the high pressure container must be installed on the roof of the train car, most of the liquid-carrier configurations demonstrated allowable weights and volumes. Notably, ammonia and methanol yielded the lightest overall system, whereas glycerol reforming imposed the largest system mass and volume and a further problem related to the production of CO on board.

A comprehensive risk assessment, encompassing release scenarios, pool fires, vapor-cloud explosion potential and toxic dispersion, highlighted distinct hazard profiles. Ethanol poses limited ignition risk due to inherent water content, methanol and ammonia raise significant toxicity concerns (with ammonia dispersions exceeding ERPG-1 thresholds up to kilometers downwind), and the high-pressure hydrogen system exhibits the greatest immediate ignition and overpressure risk. By integrating process design, dynamic performance modelling and quantitative safety analysis, this work demonstrates that liquid-carrier reforming with HT-PEMFCs can meet both spatial and safety requirements, offering a viable pathway toward sustainable and low-emission railway traction.

Keywords: *High-Temperature PEM Fuel Cells; Liquid Hydrogen Carriers and Reforming; Quantitative Risk Assessment; Railway Transport*

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