COMPARATIVE ASSESSMENT OF LCA FOR PEM FUEL CELL BUS WITH DIESEL AND ELECTRIC BUS: A CASE STUDY IN SAUDI ARABIA

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Overview

Climate change, overpopulation, rampant pollution, and resource depletion are significant environmental challenges that the world is facing. To combat climate change, Saudi Arabia seeks to alleviate the power sector's dependence on fossil fuels and develop technologies that help global decarbonization [1]. Hydrogen proton-exchange membrane (PEM) fuel cell vehicles (FCVs) is a promising novel solution for decarbonizing the transport sector. There are three primary forms of hydrogen to power the PEM fuel cell vehicle: “grey”, “blue”, and “green”. Grey hydrogen is produced from natural gas, blue hydrogen is also from natural gas that captures CO_2 emissions using carbon capture and storage (CCS), whereas green hydrogen is made from water electrolysis powered by zero/ low carbon energy sources [2]. In this study, the focus is on grey and blue hydrogen due to their cost-competitiveness and technological availability compared to green [3]. Furthermore, Saudi Arabia heavily relies on fossil fuels such as crude oil and natural gas as its main energy provider [4]. As the sixth largest natural gas reserve, with 333 trillion cubic feet (Tcf), Saudi Arabia has tremendous potential for natural gas development [5]. Therefore, grey and blue hydrogen sources are considered to be more accessible and feasible for PEM fuel cell vehicle development in Saudi Arabia. However, literature studies on the life cycle assessment (LCA) of heavy-duty vehicles are limited. There is a research gap in the environmental assessment of the application of electric and PEM fuel cell buses in Saudi Arabia, as well as the energy consumption and emissions. The complete LCA can be divided into 2 parts: fuel cycle and vehicle cycle, whereas there are just a few studies focusing on both. This study aims to bridge this gap and explored the decarbonization potential of using grey and blue hydrogen in PEM fuel cell vehicles in Saudi Arabia by comparing the life-cycle emissions of diesel engines, electric vehicles, and PEM fuel cell vehicles for heavy-duty transportation, considering both the fuel cycle and the vehicle cycle. Here, we assessed the global warming potential (GWP), abiotic depletion potential (ADP), and acidification potential (AP) of 10 PEM fuel cell (FC) buses operating in Makkah using grey and blue hydrogen produced in Saudi Arabia. For comparison, 10 battery electric buses using electricity from Saudi Arabia’s grid and 10 internal combustion engine (ICE) buses running on diesel are examined across their entire life cycle. Furthermore, the refueling infrastructure requirements in Makkah and LCA for transporting hydrogen from eastern Saudi Arabia to Makkah are also defined.

Methods

The ‘cradle-to-grave’ system assessment of the environmental impacts and GHG emissions was implemented according to the LCA methodology of the International Standards Organization (ISO 14040 and 14044). The GREET (Greenhouse gases, Regulated Emissions, and Energy use in Technologies) model was developed by the U.S. Department of Energy’s (DOE) Office of Energy Efficiency and Renewable Energy. It comprised two components and offered a comprehensive, lifecycle-based method to quantify the energy use and emissions resulting from the fuel cycle (calculated by GREET 1) and the vehicle cycle (calculated by GREET 2). A model was developed based on GREET 1 to quantify the energy use and emissions from feedstock extraction, feedstock production, feedstock transport, feedstock refining, fuel distribution, and fuel use by heavy-duty vehicles. The energy use and emissions required for extraction of raw material, material production, material transport, assembly of the vehicle, vehicle distribution, vehicle operation, and vehicle disposal and recycling were calculated by GREET 2. Since most vehicles in KSA were assembled overseas and delivered to Saudi Arabia, additional considerations were provided in the approach to account for the air emissions and energy use at the vehicle distribution stage.

All datasets used for the LCI compilation phase gave priority to data specific to Saudi Arabia. When these datasets were not available, other secondary data sources were used, including the GREET dataset. The data input and calculation method of GREET were not suitable for Saudi Arabia during the operation, further modifications were performed to adapt to the project’s requirements.

Results

This study explored the decarbonization potential of using grey and blue hydrogen in PEM FCVs for heavy-duty transportation in Saudi Arabia from the environmental impact point of view. Total system emissions are mainly composed of those from the vehicle production, fuel production, and vehicle usage phase. ICEV, PEM FCV, and BEV systems differ in the way how their emissions are distributed in these three stages. Based on previous research [6], we expect PEM FCVs using blue hydrogen and BEVs to deliver lower life-cycle emissions compared to ICEVs. A comparison between BEVs and PEM FCVs will be conducted. The final results are highly dependent on Saudi Arabia's specific data input and assumptions made under different scenarios.

It was shown that the ICEV's emissions mainly come from the usage stage. This is the least sensitive to the area-specific variation. For BEVs, the vehicle production phase usually accounts for a large portion of the total emissions, especially when BEVs are made abroad and imported to Saudi Arabia. At the same time, the BEV system's usage phase emissions are highly dependent on the grid emissions. This is one of the key areas where the KSA-specific number plays a role, particularly when we consider the movement of power generation systems from oil to natural gas and renewables in the future. In the case of PEM FCVs, the main focus is on the fuel production phase since there is less uncertainty for emissions in the usage stage.

Conclusions

A novel LCA has been performed to explore the decarbonization potential of using grey and blue hydrogen in PEM fuel cell heavy-duty vehicles in Saudi Arabia, employing both the fuel cycle and the vehicle cycle. For the hydrogen PEM FCVs, emissions from upstream fuel production and delivery (or well-to-pump) are the most critical since the emissions in the usage phase are practically zero. Hydrogen can be produced and used inside Saudi Arabia employing gas tube trailers for fuel transport. This has a potential to reduce the emissions at this stage. Because blue hydrogen has most of its production emissions captured, it delivers lower total emissions relative to grey hydrogen. However, the efficiency and energy use of carbon capture and storage system can also bring substantial uncertainty. Furthermore, improvements in battery recycling technology, the evolution of solid-state battery technology and its application in vehicles, the development of lightweighting of aluminum in vehicle production, and the utilization of pipelines to transport hydrogen all have implications for the assessment of life-cycle emissions and energy consumption. These areas of research are worth exploring in the future.

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