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M3Or3K-02: [Invited] Thermodynamic Modeling of Gaseous Hydrogen Filling from Fueling Station to Fuel Cell Electric Vehicle -Lessons of Gaseous Hydrogen Fueling and Possibility and Expectation of Liquid Hydrogen Use-

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Hydrogen has tremendous potential to become a next-generation, environmentally friendly energy carrier that will help mitigate climate change, reduce the world's dependence on fossil energy, and complement renewable energy sources on or off the grid (i.e. wind, solar, and hydro). One commercial application for this technology is fuel cell electric vehicles (FCEVs), a technology that automotive companies have invested significantly. For the past decade, the FCEV industry focused primarily on the development of light-duty (LD) vehicles, and these cars were released to the market along with the first hydrogen fueling stations to support them. Recently, FCEV technology is moving into the medium-duty (MD) and heavy-duty (HD) markets. These vehicles require more fuel to operate due to size, extreme duty cycles, and range requirements, and they subsequently require larger associated fueling infrastructure. Most modern hydrogen stations and vehicles store hydrogen as compressed gas, however, in order to address increasing storage requirements for station and vehicles, it would be beneficial to store hydrogen at higher densities. One method that has been identified for storing hydrogen at higher density is to store it in liquid form. The density of liquid hydrogen is about 76% higher than that of gaseous hydrogen, enabling significant space savings.
The National Renewable Energy Laboratory (NREL) is in the process of adding the capabilities to perform experiments and numerical simulations of liquid hydrogen storage and fueling. Currently, liquid hydrogen is used for ground storage due to its high density, and it is converted to gaseous hydrogen when needed to fuel FCEVs. Therefore, to understand hydrogen fueling involving liquid storage, we need to model the two-phase flow including the thermodynamic behavior of both gaseous and liquid hydrogen phases and their interactions. NREL has previously completed a study focusing on the thermodynamic behavior of gaseous hydrogen during a fueling event from a station to a vehicle. The model has been validated with experimental data and has laid the groundwork for developing models of other hydrogen fueling types.
In future work, this study aims to model liquid hydrogen used by fueling stations with physics-based equations. To build a reliable model, various data would be required, including the geometry and materials of the storage system, how temperature and pressure are managed between fills, and other operational conditions of a fill including, e.g., what the flow rates are. The liquid hydrogen model could be integrated with the gaseous model, and insights from the integrated two-phase flow model would help station providers build an efficient and effective liquid storage system. In the future, it is expected that FCEV technology will expand into other applications such as rail, marine, and aviation. At that time, liquid hydrogen may be critical to the success of infrastructure and the associated transportation systems due to size of the vehicles, range requirements, and fueling requirements.

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