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A techno-economic assessment of battery-electric and fuel cell electric powertrain systems for the transformation of the heavy-duty transport

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The transformation of the energy system also provides the transport sector with the opportunity to reduce primary energy use, increase overall efficiency, and reduce greenhouse gas emissions. While the light-duty vehicle fleet is increasingly being electrified by battery-electric powertrains, challenges of road-based freight and passenger transportation in moving large masses over long distances remain due to high weights and costs of batteries. In this regard, hydrogen from green electricity or e-fuels can provide gravimetric and economic advantages under certain operating conditions. This requires an individual, thorough decision-making process for determining the most economically optimal technology. A comparative assessment of the techno-economic performance of respective powertrains is necessary to identify preferrable combinations of powertrain technology and vehicle application, exhibited in the context of the provision of renewable electricity and hydrogen by the energy system.

This investigation presents the results of a bottom-up, simulation-based analysis of zero emission vehicle powertrains, integrating detailed technical and user cost analyses methods incorporated in an overall energy system scenario. Zero emission powertrains under consideration include battery-electric vehicles (BEVs) and hybrid fuel cell electric vehicles (FCEVs) incorporating a hydrogen fuel cell and a battery. Among alternative powertrains, both systems offer the greatest potential for reducing end-user related emissions, noise and efficiency. Furthermore, there is an opportunity to complement the energy supply in the future energy system by building on the two forms of energy within hydrogen and electricity.
This study considers a variety of on-board storage technologies for hydrogen storage and different cell chemistries for the batteries in the specified powertrains. The former is considered using high pressure vessels or liquid phase storage tanks. The electrical storage characteristics of batteries vary within several available cell chemistries. In order to ensure application-oriented comparability, vehicle application combinations are analyzed that represent typical German national transport operations. For this purpose, vehicle classes are predefined for the simulation based on the respective transport operation, using vehicle type and body, axle configuration, and specific application profile. The required transport data are obtained from the European and national transport registers of Eurostat, Destatis and the 'Kraftfahrt-Bundesamt'. Application-oriented driving profiles are derived from the European Automobile Manufacturers' Association. Due to the specific simulation of vehicle powertrain configurations, the energy consumption and the technical constraints required for the evaluation can be compared

for different powertrain configurations. This approach is suitable for a wide range of vehicle segments and application scenarios beyond the configurations considered in this investigation. To perform energy demand calculations, a longitudinal dynamic vehicle model was developed that incorporates case-specific velocity and topography information. The investment costs of the components required for the powertrain configuration are calculated in an integrated bottom-up cost model based on component cost analyses. It integrates the learning curve approach based on cumulative production volumes and dimensioning as a result of an optimization. The cost model is extended to include fixed and variable operating costs to calculate the total cost of ownership (TCO) of a vehicle for the operating period under consideration. In order to incorporate the infrastructure costs, a spatially resolved modeling approach [1] is applied, which takes into account the hydrogen provision costs related to production, transport, distribution and refueling.
The results provide an application-specific evaluation of BEV and FCEV powertrain systems for heavy-duty vehicles in terms of expected TCO. Thus, a comparative analysis is performed for different vehicle classes and specific scenarios based on energy demand, TCO as well as infrastructure requirements. Finally, the results of this study are used to identify appropriate vehicle powertrain and application combinations. The economic efficiency is found to be highly dependent on the vehicle energy costs as well as the associated availability of the required energy demand. The findings provide valuable insights for policymakers and industry stakeholders, supporting strategic decisions for sustainable road transport.

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