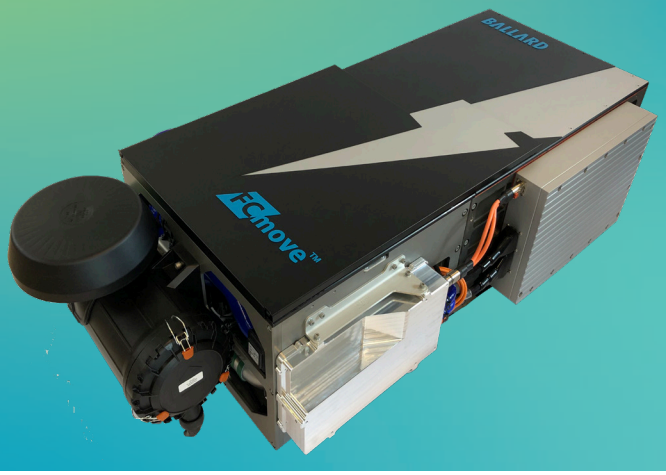
TECHNICAL NOTE




# TRANSIT BUS LIFE CYCLE ASSESSMENT COMPARISON WITH **FC**move®-HD

## Scope

Fuel cell and hydrogen technologies are expected to play a significant role in transitioning away from fossil fuels, in order to address climate change, air quality and other environmental issues. As such, it is important to understand their impacts throughout the entire product life cycle. The focus of this report is the greenhouse gas (GHG) emissions associated with the production, use and end of life phases of Ballard's FCmove®-HD product, in comparison to other fuel sources. It also compares the overall GHGs associated end-of-life with buses powered by FCmove®-HD and competing power sources.

Ballard undertook a cradle-to-grave and comparative life cycle assessment (LCA), evaluating the FCmove®-HD in bus applications. FCmove®-HD is Ballard's next-generation heavy-duty module for zero-emissions transportation. FCmove®-HD offers a durable, compact, and easily installed solution for system integrators and vehicle OEMs, backed by Ballard's unmatched fuel cell expertise and experience. It has a power output of 70 kW, and its most common application currently is full-sized hybrid electric buses.

## Life Cycle Assessment Methodology

Ballard collected product-specific data including the material and energy inputs for production of FCmove®-HD, and upstream transportation. SimaPro's LCA software was used to model the module's embodied carbon. Within the SimaPro package, the Ecoinvent database was referenced to obtain life cycle impact information for the product's materials and parts. When information was unavailable in this database for a particular component or material, secondary data from scientific literature was used.

The impact assessment methodology selected uses a 100- year Global Warming Potential (time horizon), which reflects current standard practice. After the cradle-to-gate impacts were assessed, Ballard collected additional information to calculate emissions associated with the use and end of life phases for FCmove®-HD. This included detailed information regarding product lifespan, maintenance, and parts replacement. Finally, a literature review was conducted to compile information regarding emissions throughout all life cycle phases for conventional and alternative bus types - Ecoinvent database for a particular component, secondary data from the scientific literature was used. Only climate change impacts were of interest and assessed in this LCA.

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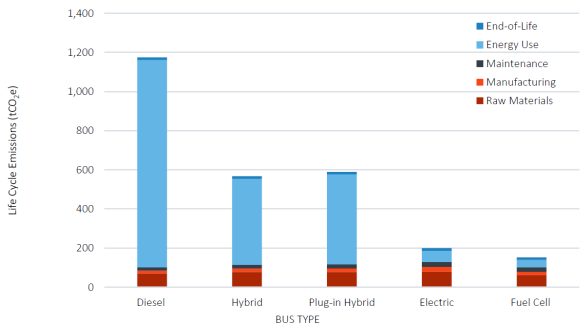
## Results

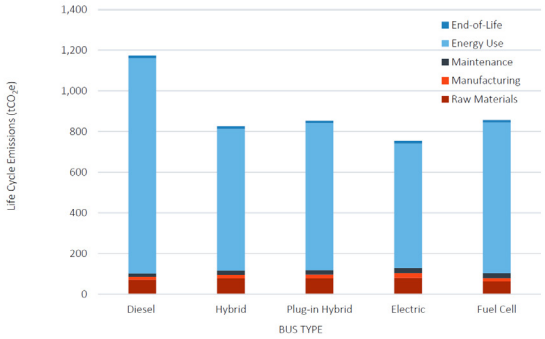
The first LCA analysis was conducted for the bus study assumed that FCmove®-HD was powered using green hydrogen, and that electric and hybrid buses were charged using a green grid throughout their lifespan.

The second LCA analysis was conducted for the bus study assumed that the FCmove®-HD module was powered using conventional hydrogen, and the electric and hybrid buses were charged on conventional grids (i.e., the US and EU averages) throughout the lifespan of the bus.

### Life Cycle Emission by Vehicle Type Clean Energy Scenario




### Life Cycle Emission by Vehicle Type Conventional Energy Scenario




Source of data for analysis: 2 Nordelof, A., Romare, M., Tivander, J. (2019). Life Cycle Assessment of City Buses Powered by Electricity Hydrogenated Vegetable Oil or Diesel. Transportation Research Part D: Transport and Environment, 75, 211-222. https://doi.org/10.1016/j.trd.2019.08.019

The FCmove®-HD performs well in comparison to a conventional diesel bus, resulting in significantly lower emissions. If FCmove®-HD is fuelled using green hydrogen, the life cycle GHGs of a bus are a spectacular 87% lower, and even using conventional hydrogen, emissions are 27% less. When comparing the FCmove®-HD powered bus to other types of renewable energy fuelled buses, FCmove®-HD also has favourable results. If green hydrogen is used, and electric and hybrid buses are charged using a green grid, the FCmove®-HD powered bus produced less emissions than all other bus types analyzed in this study.

When conventional hydrogen is consumed, and electric and hybrid buses were charged using a typical grid, the FCmove®-HD powered bus produced essentially the same GHGs as a plug-in hybrid.



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