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Swiss Competence Center for Energy Research
Efficient Technologies and Systems for Mobility

In cooperation with the CTI
Energy funding programme
Swiss Competence Centers for Energy Research
Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
Swiss Confederation
Commission for Technology and Innovation CTI

Environmental and Cost Assessment of Current and Future Urban Buses

In this work we present a life cycle assessment and cost assessment of urban buses, with construction years 2000, 2015, and 2050. Conventional diesel (ICEV-D) and compressed natural gas (ICEV-CNG) buses as well as diesel hybrid (HEV-D), fuel cell (FCEV), and battery (BEV) electric buses are considered. Three electricity sources are included: the Swiss consumption mix (CH), hydroelectricity (Hydro), and natural gas combined cycle (NG). Hydrogen is produced by steam reforming of methane (SMR), or electrolysis using the above electricity sources. Results show that hybrid buses outperform conventional buses in terms of costs and environmental impacts today, and battery electric buses will likely become the technology of choice in the future if fast charging at bus stations becomes feasible and battery lifetimes meet expectations. The most important factor for reducing the costs and impacts of travelling by bus is increasing the average number of passengers per bus.

Brian Cox, Paul Scherrer Institute
brian.cox@psi.ch

Chris Mutel, Paul Scherrer Institute
christopher.mutel@psi.ch

Introduction

The ecoinvent life cycle inventory database is used as a basis for these calculations. The life cycle assessment has a 'cradle to grave' scope.

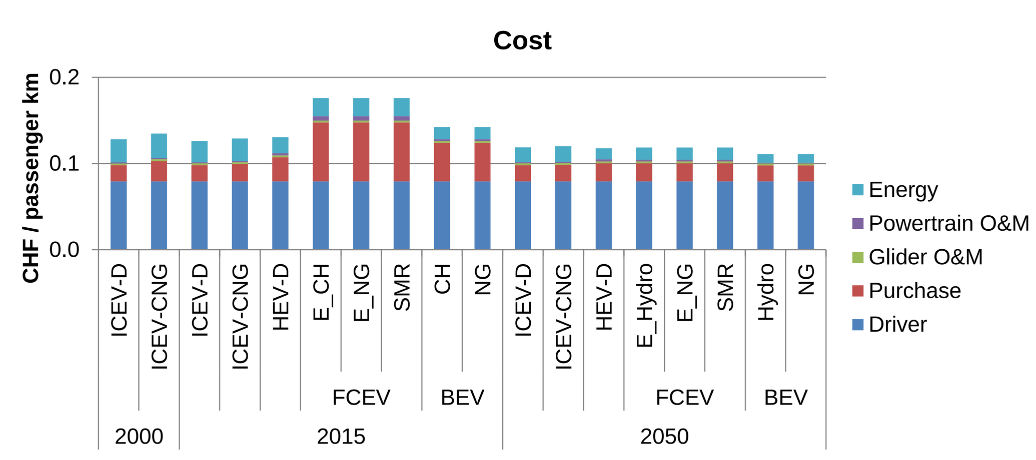
The model considers a bus frame that is common to all powertrains, and varies only those components that are required for each powertrain configurations. In this study we assume a 12 year bus lifetime with a major overhaul after 6 years, when the powertrain, fuel cells and batteries are replaced. BEV buses are designed for fast charging at several points along the bus route.

Though results are available for 4 bus sizes and production years from 1990-2050, results are presented here for standard 12m buses with average load factors and production years 2000, 2015 and 2050.

Cost

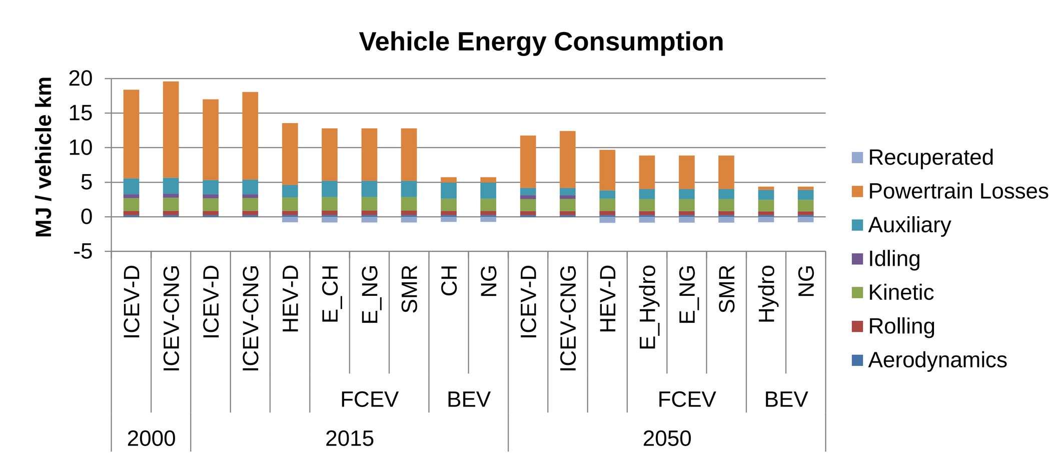
Costs are quantified as the costs that occur to a company operating the bus and thus don't include profit or other company costs. The driver's salary makes up a significant portion of the total costs.

The purchase costs of advanced buses are currently prohibitive, though this is expected to decrease with increasing sales. Energy and operating costs are the lowest for electric buses, even today.



Energy Consumption

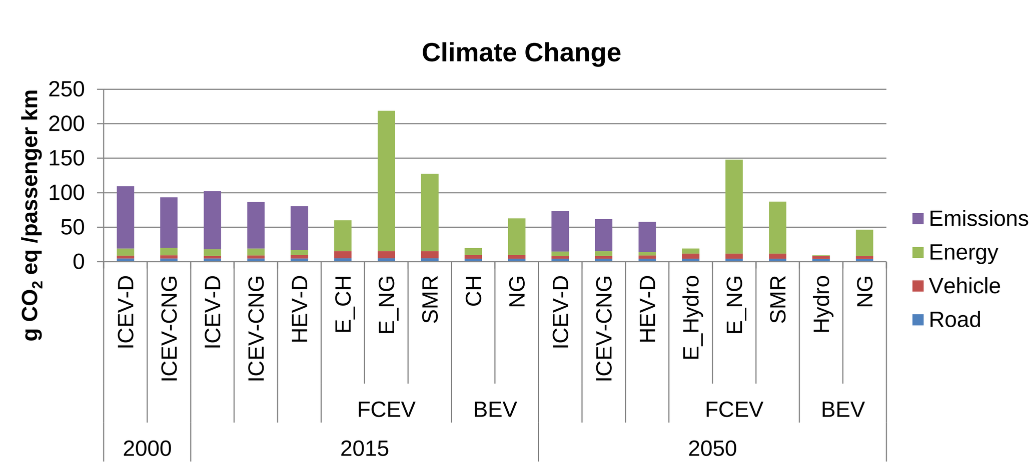
Energy consumption is calculated using a simple physics model based on the urban part of the World Harmonized Vehicle Cycle (WHVC). Powertrain losses are calculated using component efficiency factors. Auxiliary energy demands are significant, especially HVAC. The results shown here are 'Tank to Wheel' energy demands, and do not include the whole fuel cycle or bus production. BEVs are found to have very low energy consumption due to their very high tank to wheel efficiencies.



Climate Change

Climate change impacts are calculated using the IPCC 2013 100 year equivalence factors for the whole bus lifecycle.

When powered by the current Swiss electricity consumption mix, FCEVs and BEVs outperform even current hybrid buses in terms of climate change contributions. When hydrogen is produced by natural gas, FCEV climate impacts are quite high, even in the future. However, BEVs still perform quite well even when charged with electricity from natural gas combined cycle power plants.

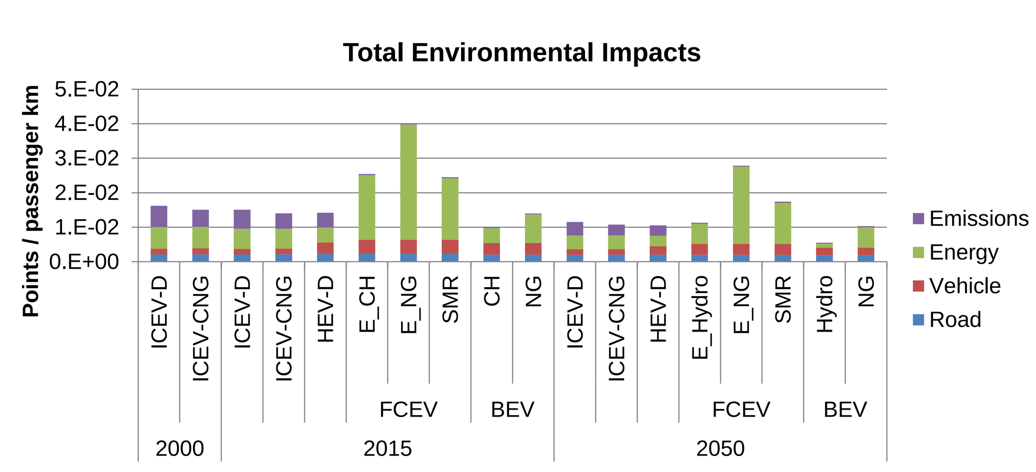


Total Environmental Impacts

Total environmental impacts are calculated using the ReCiPe endpoint method and include impacts on human health, ecosystem quality and resource use.

FCEVs do not perform very well for this indicator, mostly due to the upstream impacts of producing hydrogen, which are caused by fossil fuel use, and to a lesser degree, metals production.

BEVs charged with renewable electricity are found to have the lowest overall environmental impacts.



Conclusion

Conventional urban buses are improving significantly, and hybridization seems to be beneficial. Current schemes to rapidly charge buses along the route promise significant potential for battery electric buses in terms of energy consumption and climate change. Fuel cell buses also have the potential to produce zero local emissions, but climate change and other environmental impacts are strongly dependent on the hydrogen production chain. Battery electric buses seem to be less sensitive to the electricity production method and even provide advantages when charged with natural gas sources.

Image: www.ec21.com

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