Move2zero - Full decarbonisation of the urban public bus system and integration of innovative on-demand services

Lisa Göttfried*, Andreas Solymos

Grazer Energieagentur, Kaiserfeldgasse 13, 8010 Graz, +43 316/811848-28, goettfried@grazer-ea.at, www.grazer-ea.at

Holding Graz – Kommunale Dienstleistungen GbmH, Andreas-Hofer-Platz 15, 8010 Graz, +43 316/887-4280, andreas.solymos@holding-graz.at

Abstract: Going beyond traditional technically oriented guidelines, within the lighthouse project move2zero a holistic concept for a full decarbonised flexible urban transport system will be developed. The system includes zero-emission technologies for power generation and supply, is based 100 % on zero-emission operation and supports components with low emission factors and high reuse- and recyclability. Within a one-year demonstration phase of seven battery electric buses and seven fuel cell buses, real-operation data will be generated in order to optimise the planning of the full decarbonisation. An additional test operation will investigate the introduction of innovative on-demand services with automated booking and charging. Finally, a concept for the autonomous operation of the on-demand shuttle will point the way towards a flexible and innovative mobility of the future. Therefore, the move2zero stands out for its integrative consideration of system components and shows a high transferability to other public transport systems.

Keywords: Innovative and flexible zero emission mobility, Clean urban public transport fleet, Mobility on demand, Automated charging, Modelling and simulation, User acceptance

1 Introduction

With the Paris climate agreement in force, the EU is committed to a global transition towards a low carbon economy more than ever. Therefore, the EU parliament enacted the “Clean Vehicles Directive” (CVD) [1] in February 2019 – a guideline for the procurement of zero-emission and low-emission public road vehicles. With this guideline, local and regional public transport organisations have a key role in cutting carbon emissions by upgrading transport systems, making them cleaner, more energy efficient and more sustainable. Hence, zero-emission mobility brings significant benefits to citizens, as public mobility is the most effective and efficient form of transport in regions and cities. Reductions in emissions of greenhouse gases, air pollutants and noise bring about considerable public health benefits. Moreover, moving on quietly and smoothly means greater passenger comfort and new opportunities for routes, making public transport more attractive. However, the potential of these innovative technologies is far from being fully utilized in the EU, owing also to still widespread concerns about technological reliability and high costs, particularly of battery-electric and fuel-cell electric buses. In 2019, the share of diesel buses in the European Union amounts 85 % while the natural gas buses (6.2%), hybrid buses (4.8%) and electric buses (4.0%) still have to share quite a small piece of the proportion. [2] Therefore, particular action needs to foster the growth of zero-emission buses. This action has to include substantial transport technology evaluation as well as development and demonstration actions for the necessary infrastructure, green energy supply and operational processes. Besides public transport systems with fixed schedules, the integration of on-demand services is necessary, in order to satisfy the broad range of user demands and to close the last mile gap. Following individualisation and convenience trends, more and more people demand for flexible services outside fixed schedules. Therefore, public transport often seems unpopular to people, who prefer high flexibility. Existing on-demand services are mainly operated by taxi service providers or other operators outside the public transport service provider (e.g. Uber, Lyft or Grab), resulting in limited public intervention possibilities regarding service quality and environmental impact as well as high costs for users. Furthermore, on-demand services show great potentials regarding an autonomous operation. Starting from autonomous charging and digital booking to autonomous driving, the on-demand service concept and autonomous driving concept have to be considered simultaneously.

2 Objectives

The overall goal of move2zero project is to develop a concept and demonstrate a fully zero-emission urban bus transport system, which

- includes zero-emission technologies for power generation (generation of emission free energy),
- is based 100% on zero-emission technologies for the operation of vehicles (emission free operation),
- supports components with low emission factors and high reuse- and recyclability (low emission production),
- perfectly matches the needs and expectations of public transport users by including their voice and integrating on-demand-services,
- includes several aspects of automated and connected mobility,
- can be immediately implemented to system operation of the public transport system of the City of Graz and other cities.

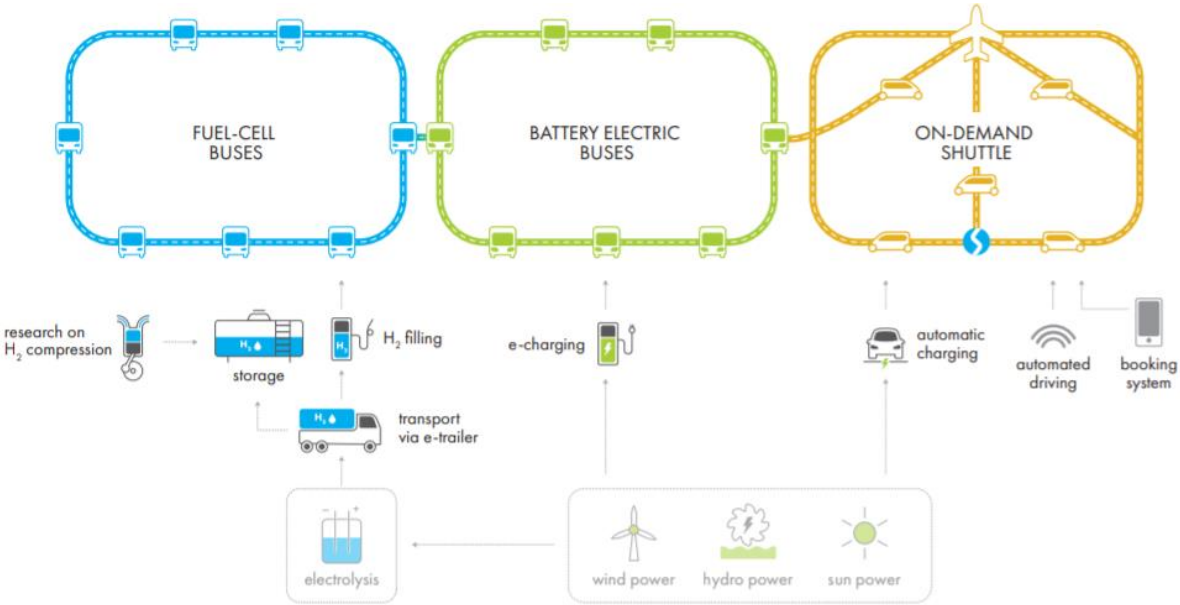

Figure 1 Project overview

3 Pilot and Research

Hence, when talking about "mobility of the future" different innovative approaches are discussed and the long-term solution is always a combination of reducing, sharing and decarbonising. For that reason, move2zero aims to decarbonise the entire public bus fleet in the city of Graz as well as introduce new innovative demand oriented public transport systems in order to make future public transport systems more flexible and attractive.

Since the project move2zero has started in 2019, several tasks such as executing feasibility studies, framework conditions and preparatory measures have been executed. Currently the tendering process for buses and infrastructure is about to start. Main parts of the project, such as the demonstration phase of buses and on-demand shuttle, the finalization of research models as well as the overall implementation concept and conclusions are still ahead.

3.1 E-Buses

The term "electric bus" includes three main types: the hybrid electric bus, the fuel cell electric bus and the battery electric bus. Hybrid electric buses use both an internal combustion engine, which is usually diesel powered, and an electric motor to power the vehicle. Full battery electric buses store all required energy in an on-board battery whereas fuel cell electric buses use a chemical reaction between stored hydrogen and ambient oxygen to create electricity. [3]

Following the zero-emission approach, within move2zero battery electric as well as fuel cell electric buses will be introduced and tested in order to being able to decide on the optimal technology, or technology mix for the full decarbonisation of the whole bus fleet. For the first real-operation demonstration phase of two zero-emission bus lines, seven battery-electric and seven fuel cell buses will be introduced. The technologies for power generation and supply will be "zero emission", the vehicles and the infrastructure will be operated emission-free and the components should have low emission factors and high levels of reuse- and recyclability.

Before the procurement process, a market research for both bus technologies as well as charging and filling infrastructure was carried out. The gained information served for a better preparation of the tendering documents as well as information about market availability and delivery times. Moreover, the information served as a base for the decision process of choosing the optimal charging technology for battery electric buses. Furthermore, Eco-Design criteria (such as the company's environmental management system, environmental product declaration or life cycle assessment, sourcing of material along the supply chain, reparability, reusability and recyclability) as well as specific approaches for Graz were discussed and defined in cooperation with the manufacturers.

Based on the market research, dialogues with bus manufacturers and expert workshops, the optimal charging technology for the demonstration phase of seven battery electric buses was selected. The following technologies were discussed and rated in detail: Overnight Charging (ONC) only, Overnight Charging (ONC) with reload during the day, Overnight Charging with H2 range extender, Opportunity Charging (OPC), Opportunity Charging with SuperCap and In Motion Charging (IMC). Because of operational conditions in Graz, old city protection zones and other requirements it turned out that ONC with reload during the day and ONC with H2 range extender will be optimal charging technologies for buses in Graz. Since there is no competitive market availability of articulated ONC buses with H2 range extender yet, it was decided to execute the demonstration phase with the ONC technology with reload during the day.

Since the demonstration phase of two different technologies aims to serve the base for a technology decision within a full conversion, the buses and infrastructure will be accompanied by several monitoring systems. Technical analysis will include the frequency of data recording and assessment, online/offline data, acquisition, necessary sensors and possible mounting scenarios for vehicles, demand sets, overall energy demand in operation, resulting CO2 emissions, etc.. To receive a comparable set, the current public transport situation (baseline scenario) was evaluated. Moreover, these technical data will be the base for the simulation and modelling described below.

For determining the optimal composition of technologies for the zero-emission bus line operation of the whole bus fleet of approx. 170 buses, a reliable optimization model was developed. The model considers the opportunity charging concept (OPC), the overnight charging concept (ONC), the overnight charging concept with H2-range extender and fuel cell technology (FC) as viable technology options. Each of these technology options comes with a set of vehicle-relevant, infrastructure-relevant, system-relevant and environmental impact-relevant parameters, which ultimately affect the optimal technology choice. Legal, organisational, technological and economic framework conditions for the model were determined following a mathematical formulation of the analysed problem. The determination of the optimal technology split, however, requires the provision of reliable data from the demonstration phase. The incorporation of environmental effects in the optimization model is reached through the consideration of environmental costs. Hence, various input scenarios will be created in order to understand major trade-offs and relationships. The results of the optimization model and that iterative process will be used as a decision making basis for determining the optimal composition of technologies for the whole bus fleet. Besides that, based upon the real data gathered through monitoring systems, the mathematical optimization will be validated and extended through a dynamic simulation, which will additionally be used to forecast the upscaling to a fully converted bus fleet. Preparatory and accompanying to the demonstration phase of e-buses, comprehensive measures for citizens engagement and citizens information will be developed and executed. Hence, introducing new technologies always creates space for fears and scepticism. In order to avoid these fears, citizens will be integrated at the earliest stage possible.

3.2 Charging and filling of e-buses

In order to fulfil the requirement of a "zero emission" operation, an emission-free way of electricity and hydrogen supply has to be secured.

The hydrogen required for the demo fleet of fuel cell buses – which equals to approximately 42 tons per year – will be locally produced and certificated as "green hydrogen. The hydrogen will be transported to the hydrogen fuelling station in Graz via e- trailer. Due to the high range of the fuel cell buses, they only need to be refuelled once a day and therefore, no changes in the current operating procedures of the bus service at Holding Graz are necessary. Taking into account the boundary conditions of the user requirement specifications, initial operation strategies for the hydrogen fuelling station and the trailer delivery were developed. Different options for the storage and refuelling concepts were considered and compared based on factors such as expandability or overall costs.

As the whole bus fleet of 170 buses should be converted within the next ten years, further fuelling strategies have to be developed. As an outcome of the discussions with local authorities it was decided that the maximum allowable amount of hydrogen storage that is just below the "SEVESO"-limit should be used as the goal for the overall concept. That means that on-site 4.5 tons of hydrogen can be stored. This concept is able to supply a maximum of 70 buses (based on reference line 66, 12 m buses and supply for 3 days) with hydrogen. Regarding this concept, the hydrogen demand would still be covered with trailer supply. Based on 300 bar trailers this would translate into roughly 11 deliveries per week. For the supply of the full fleet, different scenarios are considered. The main options are an on-site electrolysis at the hydrogen refuelling station at the bus centre, nearby electrolysis at one of the close hydro power stations with the transport via trailer or pipeline to the bus centre. The economic framework conditions are investigated in detail so that it is possible to decide on the best option combining high reliability and cost efficiency.

Another main goal within the project is the research of more efficient ways of hydrogen production. Right now, the compression of hydrogen causes high efficiency losses and the used technology significantly affects cost and hydrogen purity. Mechanical compression causes that hydrogen can be contaminated through leaks and mechanical compressors in general achieve low efficiencies. [4] As an alternative, the electrochemical compression is a new technology but for its production, expensive materials are needed. In order to detect the most suitable compression technology depending on use cases and restrictions of specific applications, an overall simulation model for various compression pathways and concatenation strategies is developed. By balancing out advantages and drawbacks of all applicable technologies an optimized configuration regarding energy demand, costs, CO2 footprint and compression time will be defined. Besides that, existing electro-chemical models for high pressure PEM electrolysis and fuel cells will be adapted for simulation of the electrochemical compression principle. A combination of several simulation tools (0 D-model in Matlab, 3 D-CFD and FEM) will be used to simulate the variety of different processes within the electrochemical compression system. Furthermore, a so-called crosshead-out solution for the next generation mechanical compression technology will be elaborated. The main idea is to exploit the strength and fatigue properties of carbon fibre in composite materials. Finally, prototypes for both compression technologies will be developed.

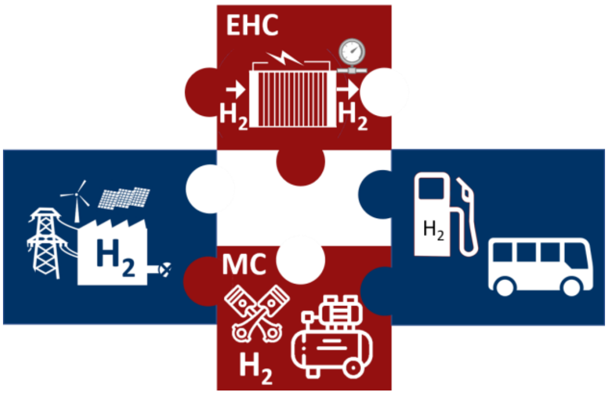

Figure 2 The further development of hydrogen compression as a missing building block between H2 generation from renewable energy sources and the refuelling system for FC buses

After deciding on an optimal charging technology for battery electric buses, the available power reserve at the current location of the bus depot was calculated, in order to secure a simultaneous charging of seven buses with quick recharging of individual buses during the day. However, this requires an adjustment of the operating procedures of the bus services at Holding Graz. In order to make this new procedure as efficient as possible, especially regarding the decarbonisation of the entire bus fleet, additional strategic loading locations were identified and will be considered within the optimization model for calculating the optimal technology mix. Moreover, this includes a concept for supplying energy for the entire bus fleet as well as ensuring the required space (transformers, switchgears and other station parts).

As part of the conversion to alternative buses and for securing an optimal operation process, an automated depot management system with an integrated smart charging management will be assured. Because of very different conditions within the operation of emission-free buses, an adaption of the whole bus center of Holding Graz is necessary. Especially regarding new requirements in maintenance and service, a new carport as well as a new maintenance shop will be set up.

Finally, in order to reduce the overall environmental impact, an eco-design and sustainability evaluation of vehicles and infrastructure will be carried out and only components with low environmental impact will be used.

3.3 On-demand Shuttle

In order to increase the attractiveness of public transport an innovative on-demand shuttle service was designed and will be tested within a demonstration phase. This on-demand service should help to close the “last-mile-gap” at the airport in Graz and thereby increase the use of public transports in Graz. To determine the potential as well as the level and nature of demand for such on-demand services, extrapolated, anonymized cellphone data were analysed. This data serves as a basis to develop a user-oriented operation concept for an on-demand service, which corresponds best to the mobility pattern of people. Cellphone data will be merged with anonymized GPS-movement data and already developed algorithms on recognition of activities and transport modes will be used to process the received data. The potential impact or improvement of the algorithms by using cellphone data together with GPS-data will be evaluated. Furthermore, a data driven demand analysis, combined with a traditional traffic model is examined. The potential will be simulated in the traffic model GUARD - a program to develop technical solutions for an optimized integrated system for public transport by providing reliable and fast connections and complete travel information.

In the first step, the on-demand shuttle will operate between airport Graz, train station, regional bus stop and the airport hotel nearby the airport. A possible extension of the operation route will be regularly evaluated. Two Mercedes eVito Tourer will be used in the shuttle service, as they are big enough to carry up to five passengers with big suitcases. Moreover, the Mercedes eVito Tourer is compatible with the innovative matrix charging system with which the two vehicles will be equipped. Matrix charging is an automated, conductive, fast charging system (22 kW AC, 50 kW DC), which charges automatically when parked over the matrix charging pad. Connector and pad communicate via a secure wireless connection. [5] As this system is a prototype and since the demonstration phase will be one of the first usages of the innovative charging system in public space, there will be several monitoring systems as well as an additional conventional charging possibility in order to ensure redundancy.

As innovative on-demand concepts are closely linked to autonomous driving, a concept for the autonomous operation of the on-demand shuttle at the airport Graz is developed. During the project, the focus for the on-demand service lies on the operation of a non-autonomous on-demand service, in order to offer a fast and comfortable service, which cannot be offered by autonomous driving shuttles as yet. However, since autonomous driving is expected to mature within the next decade, framework conditions for the autonomous operation will be elaborated. The concept will include potentials, challenges and hurdles expected, if the on-demand service will be integrated in the public transport service and will be operated autonomously. For determining the economic impact of the operation of autonomous operated shuttles within the public transport system, a user acceptance analysis as well as an economic assessment, based on the operational concept, will be conducted. Moreover, the impact of autonomous driving on the line schedule within the city will be evaluated, resulting in different scenarios for connections between different line types. Finally, the economic impact of the operation of an autonomous on-demand service on the public transport operator (lower staff costs, higher vehicle costs, etc.) will be analyzed. Results of the concept will be considered in the further development of innovative autonomous public transport projects and decisions.

To organize the booking of the on-demand service, a completely new automated mobility platform was developed. The booking works as a call-system via the website www.grz-shuttle.at. Users can either enter via link or via scanning QR-Codes, which are placed at the shuttle stations. That implies that users will state their demand right before they need the shuttle-transfer. For this reason, there is no need to announce personal data within the booking process. Hence, therefore there exists no seat guarantee.

The development process of the on-demand service was divided into four components:

- Customer
- Driver
- Operator dashboard
- Back-end – optimization process, matching and routing algorithm

Hence, this automated booking system will also be compatible with an automated operation of the on-demand shuttle. Moreover, the on-demand service platform generates defined real time data information and will be integrated in several national route-planning apps i.e. busbahnbim, quando Graz, AnachB, GrazMobil.

In order to develop efficient long-term business models for public on-demand services, the test operation will be accompanied by several data generating monitoring systems such as a data back-end of the booking system, vehicle sensors (e.g. seat sensors) as well as an innovative traffic count system called “Telraam”. The Telraam device is a combination of a Raspberry Pi microcomputer, sensors and a low-resolution camera. The device will be placed along the footpath between train/bus station and the airport and will provide information about the frequency of cars, heavy vehicles, public transport, cyclists and pedestrians before and during the test operation. The device shares the data straight to the central database and therefore needs a continuous Wi-Fi connection. For integrating user acceptance, different survey methods such as paper surveys, direct interview, feedback via platforms etc. will be conducted. Moreover, citizens will be directly included via co-creation processes (e.g. idea competitions). Based on that data and experiences, a comprehensive business model for on-demand shuttle services integrated in public transport systems will be developed.

4 Conclusion

Building on several national and international strategies, move2zero replaces 14 diesel buses by zero-emission battery electric and fuel-cell buses and will pave the way for the full decarbonisation of the urban bus fleet in Graz . Within the research project, optimal charging and filling concepts as well as the most efficient hydrogen production process will be developed. Besides that and in order to make public transport more attractive, an innovative on-demand shuttle using an automated charging system will be developed and tested at the airport in Graz. This shuttle system will be accompanied by an automated booking system as well as preparations for a fully automated operation. In order to reduce the overall environmental impact, an eco-design and sustainability evaluation of vehicles and infrastructure will be carried out and only components with low environmental impact will be used. Moreover, along the entire project, awareness-raising and acceptance measures will be implemented and the results of the project will be highly visible through marketing campaigns and public relations.

As one of the main project goals and in order to secure transferability, an overall strategy for decarbonising public transport as well as integrating automated on-demand services should support other cities within this process.

To sum up, based on a scientific, multi-disciplinary research (including industrial research) and a comprehensive demonstration phase move2zero will pave the way for an efficient and effective stepwise conversion of urban public transport fleets towards an emission-free, demand-oriented, autonomous and attractive mobility of the future.

Project Consortium

Project Lead

Holding Graz – Kommunale Dienstleistungen GmbH

Conception, Coordination and Project Partner

Grazer Energieagentur Ges.m.b.H

Project Partner

HyCentA Research GmbH, Energie Steiermark Technik GmbH, Energie Graz GmbH, Technical University of Graz, Planungsgruppe Gestering | Knipping | Schone Architekten | Generalplaner PartmbB, Upstream Mobility GmbH, Umweltbundesamt GmbH, Invenium Data Insights GmbH, Technoma GmbH, University of Graz, ARTI – Autonomous Robot Technology GmbH, Hoerbiger Wien GmbH

Acknowledgement

This project is funded by Klima- und Energiefonds and carried out as part of the “zero emission mobility” program.

References

[1] European Union (2019), Directive (EU) 2019/1161 of the European Parliament and of the council; Official Journal of the European Union.

[2] ACEA (2020). Fuel types of new buses: diesel 85%, hybrid 4.8%, electric 4%, alternative fuels 6.2% share in 2019, Brüssel.

[3] MRCagney (2017). Electric bus technology – transport research report, New Zealand

[4] G. Sdanghi, G. Maranzana, A. Celzard, V. Fierro (2019). Review of the current technologies and performances of hydrogen compression for stationary and automotive applications, Renewable and Sustainable Energy Reviews, Pages 150-170, https://doi.org/10.1016/j.rser.2018.11.028.

[5] Easelink (2021). Matrix Charging Key Facts, https://easelink.com/press/Matrix_Charging_Key_Facts.pdf

List of tables