DESTI-SMART
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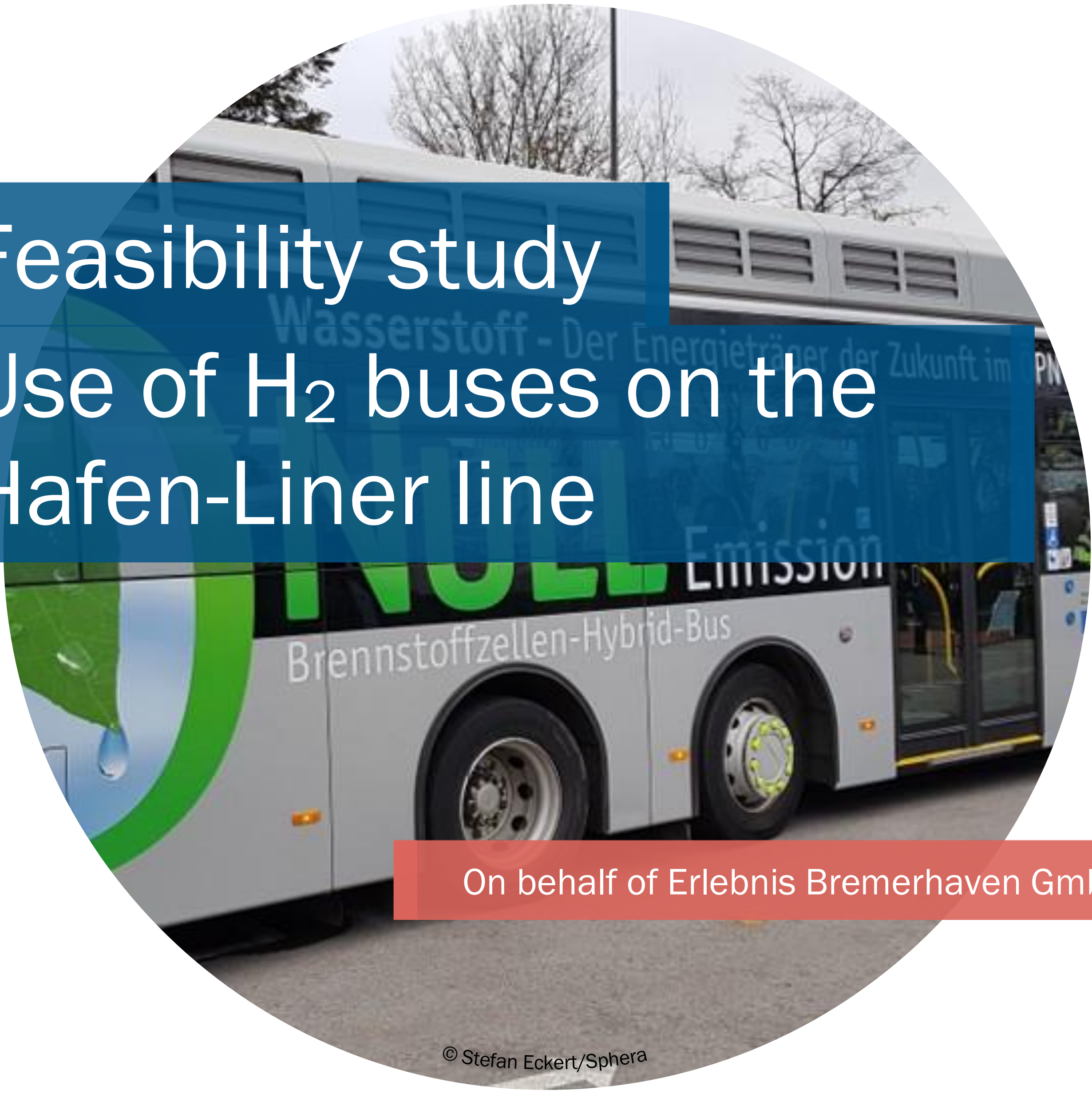
Erlebnis Bremerhaven
Gesellschaft für Touristik,
Marketing und Veranstaltungen mbH

Feasibility study
Use of H_2 buses on the Hafen-Liner line



On behalf of Erlebnis Bremerhaven GmbH

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This study was carried out based on activity 8, requiring 'feasibility studies for low-carbon mobility options and transport systems, accessibility, improvements to inter-modality and cycling/walking options to partner destinations'.

The study was carried out by Dr Stefan Eckert and Stefan Kupferschmid, Sphera Solutions GmbH, Helmut Berends, Berends Consult, the external experts responsible for developing the study, in close collaboration with local stakeholders Bremerhaven Bus, H2BX, the town planning office and city climate office of the Bremerhaven municipality as part of the DESTI-SMART project. All content of this document is based exclusively on the goals and activities of the DESTI-SMART project.

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Delivering Efficient Sustainable Tourism with low-carbon transport Innovations: Sustainable Mobility, Accessibility and Responsible Travel

Lead Partner

Advisory Partner

https://www.interregeurope.eu/desti-smart/

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Abbreviations

ATEX	Direction concerning explosion protection (French: *ATmosphères EXplosibles*)
BEV	Battery electric vehicle
CCS	Combined charging system
CO_2e	CO_2 equivalents
Desti-Smart	Delivering Efficient Sustainable Tourism with Low-Carbon Transport Innovations: Sustainable Mobility, Accessibility and Responsible Travel)
FC	Fuel cell (vehicle)
FC-REX	Fuel cell range extender (here: battery-powered electric vehicle with a fuel cell to expand range)
GaBi	Holistic balancing (*German: Ganzheitliche Bilanzierung*)
GAP	Gas system inspection (*German: Gasanlagenprüfung*)
GWP	Global warming potential
H_2	Hydrogen
H2BX	Wasserstoff für die Region Bremerhaven e.V. (Hydrogen for the Region of Bremerhaven)
HV	High-voltage
ISO	International Organization for Standardization
JIVE	Joint Initiative for Hydrogen Vehicles across Europe (EU project for the introduction of hydrogen buses)
kg	Kilogramme
kW	Kilowatt
kWh	Kilowatt hour
LCA	Lifecycle assessment
NO_x	Nitric oxide
ÖPNV	Local public transport (*German: Öffentlicher Personnennahverkehr*)
PM	Particulate matter
VdTÜV	Verband der Technischen Überwachungsvereine (Federation of Technical Inspection Associations)
VDV	Verband Deutscher Verkehrsunternehmen (Federation of German Traffic Businesses)

1. Introduction

1.1. Background and targets

In order to satisfy the increasing need for mobility in growing metropolises in Germany and Europe as sustainably as possible, effective public transport is required. Energy-efficiency and eco-friendliness are of central importance in order to guarantee cost-effective operation as well as a high quality of life for residents. Against a backdrop of constantly exceeded NO_x and fine particulate limits in multiple cities and resulting lawsuits from environmental associations as well as pending EU contractual violation proceedings, reducing local emissions, including by public transport, is becoming more and more urgent. When it comes to inner-city bus lines in metropolitan areas, zero-emission concepts, i.e. engine technologies without local emissions of harmful substances, are becoming increasingly important. The cities that have come together under the C40 initiative to form an international network (including metropolises such as Paris, London, Los Angeles, Barcelona, Mexico City, Rome and Tokyo) have decided to transition their bus fleets to emissions-free engines and intend to exclusively purchase emissions-free buses from 2025 (C40 Cities, 2018). Many other cities and municipalities are engaged in assuring emissions-free vehicles for their local public transport.

The study is being carried out as part of the EU-funded Desti-Smart project, which intends to establish improved transport and tourism policies in holiday destinations. As one focal point of this work, low-carbon transport systems should be provided that take the needs of tourists into consideration. The external costs of traffic should be internalised and reduced through an extension of low-carbon transport and electromobility.

In this regard, the city of Bremerhaven has decided to procure (at least) three hydrogen buses. These should be used on the new Hafen-Liner line, which was added to Bremerhaven's bus service in 2019, connecting various tourist hotspots such as the central station, the Schaufenster Fischereihafen and Havenwelten.

This feasibility study is intended to provide a basis for decision-making in order to investigate the viability of transitioning to hydrogen-powered vehicles and the resulting impacts. Relevant technical, economic and organisational aspects shall be portrayed along with the risks associated with the transition. In doing so, specific local framework conditions should be taken into account and a cost comparison with the current line operation undertaken. The results should be used to derive recommended actions and suggestions for possible optimisations.

1.2. Approach

In the preliminary meeting, it was determined that the investigation would be carried out with an open attitude towards fuel cell hybrid buses (FC) and battery-powered buses with a fuel cell range extender (FC-REX).

The inventory of the current Hafen-Liner operation served as the starting point for evaluating the use of fuel cell hybrid buses (chapter 2). Technical feasibility was then examined regarding energy consumption, vehicle avialability and power supply in chapter 3. Chapter 4 is dedicated to evaluating the environmental impact of the use of FC/FC-REX vehicles. Chapter **Fehler! Verweisquelle konnte nicht gefunden werden.** contains a rough cost estimate for transitioning the Hafen-Liner line to hydrogen buses. The implementation in chapter 6 sheds light on important organizational aspects of the transition relating to vehicle supply, spatial requirements and maintenance procedures. Finally, chapter 7 covers the fundamental risks of projects aiming to introduce alternative engines in bus fleets and deduces suitable recommendations for actions to ensure the successful transition of the Hafen-Liner line to hydrogen drive.

2. Inventory

In total, there are around 75 vehicles in circulation in Bremerhaven. The majority of these vehicles are articulated buses (62 vehicles). There are only eleven solo buses.

Figure 2-1: Hafen-Liner route

The Hafen-Liner runs between the Rotersand and Thünen Institut stops, connecting Bremerhaven's maritime attractions with the central station. The line almost constantly runs every 30 minutes from Monday to Saturday from six am to shortly before midnight. On Sundays and public holidays, the buses run from ten am to midnight with reduced 20-minute intervals between 11 am and 7 pm in order to accommodate the increased number of passengers at weekends. With a travel time of 24 minutes, the lines are run with two dedicated buses on week days[1], while a third vehicle is required at weekends. The Hafen-Liner route is operated continuously by articulated vehicles, whereby conventional diesel buses are being used up to now.

Table 2-1 shows all significant Hafen-Liner data as well as the overall network as used to work out the energy requirement (specific and absolute) and as input for environmental and cost evaluations.

Table 2-1: Bremerhaven Bus AG circulation data

	Hafen-Liner	Network
Average distance covered per day of use	217 km (Monday)[2]	194 km
Assumed vehicle availability	85 %	85 %
Resulting annual distance travelled per vehicle	68,167 km	60,000 km
Average speed	15.46 km/h	17.27 km/h

[1] One cycle represents the stretch travelled by a vehicle from exiting the depot to its removal from the route. Dedicated buses only travel on one line during a cycle.

[2] On Sundays and on Thursdays during Musiksommer events as well as public holidays during the week, the distance covered by the Hafen-Liner line increases to 279 km. The annual distance travelled is therefore slightly higher than would be calculated using the average route length and vehicle availability (in days).

3. Technical feasibility

3.1. Available vehicle models and engine concepts

Only articulated buses are used as Hafen-Liner. Currently, there are no 18 m fuel cell vehicles available on the market. The following table provides an overview of all hydrogen-operated articulated bus models that have been previously used, planned or announced by the manufacturers, as well as their foreseeable availability. Alongside FC hybrid buses, fuel cell range extender concepts (FC-REX) will also be considered, as relevant vehicles from EvoBus and New Flyer should be coming onto the market with an articulated option in the near future. FC-REX technology was therefore also considered within the scope of the study.

Table 3-1: Availability of articulated hydrogen buses

Model	Technology	Location/region	(Planned) market availability	Evaluation
APTS/VDL/ Vossloh-Kiepe	FC-REX	Münster	2019	Exclusively 12 m test vehicle in use. Unclear whether the concept will be pursued further.
ebe/Autosan	FC	Wiesbaden, Mainz	(2018)	Vehicles already ordered, delivery not yet foreseeable. Unclear whether the concept will be pursued further.
Hyzon Motors	FC	USA	(2022)	Reservation possible, European market availability unclear.
Mercedes-Benz eCitaro G REX	FC-REX	Germany	2021	First orders being taken.
New Flyer Excelsior charge H2 60	FC-REX	USA	2020	European market availability unclear.
Solaris FC-Catenary-Hybrid	FC-REX	Riga	2020	Exclusively overhead cable hybrid, no 18 m FC hybrid intended
Solaris Urbino 18.75 electric with fuel cell	FC-REX	Hamburg	2014	Test vehicles, concept discontinued, model no longer available.
Van Hool Exqui.City 18 FC	FC	Pau	2019	Eight test vehicles in use. Special BRT system, not suitable for normal line use.
Wrightbus	FC	Europe	2022/2023	Planned market availability as articulated bus.

From the table, it is obvious that market introduction is only planned for a few models, and not until 2021/2022. Based on experience from the European hydrogen bus projects JIVE and JIVE 2, the development of a hydrogen bus is so complex that significant numbers are sometimes only available for regular ordering long after the model's planned market introduction. This should be taken into consideration in planning the transition.

Figure 3-1 provides an overview of the two hydrogen engine technologies considered. Fuel cell hybrid vehicles (FC) turn hydrogen stored on board into electricity[3] in a fuel cell. Refuelling takes place in much the same way as with conventional petroleum vehicles. Compressed hydrogen is accessed via a pump, taking between five and ten minutes, depending on the tank size and refuelling station configuration (Kupferschmid & Faltenbacher, 2018). Refuelling a conventional diesel bus takes around five minutes (dena, 2018). The energy required to power the vehicle is primarily provided by the hydrogen.

In addition, EvoBus is developing the FC-REX as a battery-powered electric vehicle with a fuel cell range extender. This is a classic battery-powered vehicle (BEV) with external charging that also features a hydrogen tank and a fuel cell. This allows the benefits of a BEV (highly effective) and FC vehicle (good range) to be combined. However, with that the infrastructure for both energy formats - electric charging infrastructure and hydrogen refuelling infrastructure - must be held available.

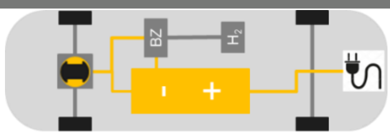
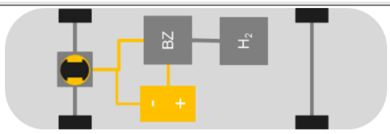
	Engine principle	Maturity
FC-REX		Testing/development
FC		(Small) Series

Figure 3-1: Overview of considered drivetrain concepts

3.2. Vehicle energy consumption

In order to establish the energy requirements of a FC-REX vehicle, Sphera can rely on detailed simulation results from EvoBus GmbH. The analysis is based on the route data provided by Bremerhaven Bus (route speed and length). In order to estimate the daily hydrogen demand which defines the infrastructure requirements, a worst case scenario was used to ensure that energy supply for the vehicles is ensured in all circumstances. Energy required for heating and air conditioning plays a particularly important role in electric vehicles. As fuel cells create heat when in use, using FC buses in winter is less critical than the use of battery-powered electric vehicles. For this reason, the worst case scenario shall consider the vehicle's energy consumption in summer (fully air conditioned in compliance with VDV).

The analysis of the energy required for FC-REX vehicles is based on the following vehicle data taken from manufacturer data:

- Battery technology: Solid state battery with solid state polymer as electrolyte
- Capacity of HV battery: 252 kWh (of which 226 kWh usable)
- Hydrogen storage capacity: 25 kg H_2 usable
- Electric motor capacity: max. 250 kW
- Fuel cell capacity: 30 kW

The calculation of FC vehicle consumption is based on the energy requirement of FC-REX vehicles. The power required for the FC-REX is converted to the corresponding hydrogen demand, based on an assumed

[3] Buses typically hold hydrogen at 350 bars. 700 bars is standard for cars.

effectiveness of the electric drive train at the wheel of 73 % and considering an assumed average effectiveness of the FC system of 50 %. The sum of both H_2 demands then gives the hydrogen demand of FC buses.[4]

Table 3-2 shows the specific energy requirement for the Hafen-Liner line and the whole network. Let it be known at this point that the energy required for FC-REX vehicles depends on energy management and the dimensioning of the battery and fuel cell components. Vehicles with a different configuration and other energy management may show significant differences when it comes to the weighting of electric and H_2 demand.

Table 3-2: Specific energy demand for the Hafen-Liner line and the network

		Hafen-Liner	Network	
		Articulated bus	Articulated bus	Solobus
Diesel	Diesel [l/100km]	52	52	38
FC-REX	H_2 [kg/100km]	8.4	7.8	5.2
	Electricity [kWh/100km]	69.1	64.6	41.2
FC	H_2 [kg/100km]	12.2	11.4	7.8

One of the Hafen-Liner vehicles is used in the network during the week, where it achieves a higher average speed across lesser distances (see Table 2-1), resulting in lower specific consumption (Table 3-2). However, this has minimal impact on the daily hydrogen demand of the three vehicles. The following table shows the daily energy demand for the two H_2 vehicle types (and for the diesel reference vehicle) in these two scenarios. For the Hafen-Liner line the maximum demand is shown (see footnote 2).

Table 3-3: Calculated daily energy demand for the Hafen-Liner line and the whole fleet

		Hafen-Liner	Whole fleet
Diesel	Diesel [l/day]	435	7,160
FC-REX	H_2 [kg/day]	70	1,061
	Electricity [kWh/day]	579	8,720
FC	H_2 [kg/day]	102	1,556

3.3. Energy supply infrastructure

3.3.1. Hydrogen

Hafen-Liner

Daily energy demand can be used to deduce the requirements for H_2 infrastructure. When considering the Hafen-Liner line, the primary consideration was whether the intended H2 MOBILITY hydrogen refuelling station could be used.

[4] The simplified approach used here presumes the exclusive use of the energy for the propulsion, disregarding auxiliary units and air conditioning. This simplified approach tends to result in higher H_2 consumption values, as only part of the energy used in the form of hydrogen is actually subject to all losses related to the efficiency chain along the powertrain.

The hydrogen refuelling station planned by H2 MOBILITY at the Bremerhaven-Wulsdorf highway exit[5] should - information valid as of today - offer refuelling facilities at 700 bars (for cars) as well as 350 bars (Schott, 2020). The 350-bars technology complies with the current state of the art for buses, so would be necessary to carry out bus refuelling as well as car refuelling. The refuelling station should have a hydrogen capacity of 200 kg daily. The daily maximum hydrogen required for FC Hafen-Liner buses can therefore be theoretically covered without issue (70 kg or 102 kg, respectively, see Table 3-3). Insofar as the buses use this amount of hydrogen on a daily basis, the refuelling station capacity for other applications (cars, trucks and other commercial vehicles) would reduce to around 100 kg H_2. This would further facilitate refuelling of around 20 FC cars[6], which is considered sufficient at this point in time. However, this could be limiting if there were a higher density of FC cars or additional refuelling of FC goods vehicles.

<u>Total network:</u>

For further or complete potential transition of the bus fleet to hydrogen engines, the solution would possibly be an on-site hydrogen refuelling station at the depot with a daily refuelling capacity of around 1,100 kg H_2 (FC-REX) or 1,600 kg H_2 (FC). Public refuelling stations with today's planned capacity of around 200 kg H_2 would no longer suffice. Furthermore, an on-site depot refuelling station would come with significant benefits in terms of operational processes. Supplying the whole fleet via a public refuelling station is difficult to organize.

An on-site depot refuelling station with the aforementioned capacity would require around 550-650 square metres of space in the depot (plus refuelling lanes for the vehicles). An initial inspection of the space situation using Google Maps shows that there is enough space at the depot site available to this end. This should be reviewed in detail - especially regarding the necessary safety distances and protective measures. Further information on the technology of hydrogen refuelling stations can be taken from Sphera's guide on introducing hydrogen buses in local public transport, entitled 'Einführung von Wasserstoffbussen im ÖPNV – Fahrzeuge, Infrastruktur und betriebliche Aspekte' (Kupferschmid & Faltenbacher, 2018).

The on-site refuelling station would also have to be supplied with sufficient hydrogen. There are various projects for the generation of hydrogen being discussed in the Bremen and Bremerhaven region:

- Fraunhofer IWES electrolysers on the site of the former Luneort airport. Facilities with an output of 2 MW are currently planned for this site (Bremerhaven Green Economy, 2020). This means that around one tonne of hydrogen would be generated each day, making the system a sufficient sole source of H_2 for the whole fleet only if FC-REX vehicles were used.
- Green hydrogen generation at the Mittelsbüren site from 2021 on. The project idea discussed here envisages a gradual capacity expansion of these electrolysers up to 300 MW by 2030. The hydrogen generated should be used to decarbonise the steel sector as well as to supply mobility applications (Ingaver, 2020).

Within the conception of an on-site depot refuelling station, it should be established to what extent and under what conditions the hydrogen necessary for Bremerhaven Bus could be supplied using these local projects.

[5] Furthermore, a refuelling facility on Grimsbystraße, near the bus depot, is currently under consideration. This location is not taken into consideration for the Hafen-Liner line as the development is not yet foreseeable at the time of the study. Due to its proximity to the bus depot, this location would however be beneficial from an operational standpoint compared to the Bremerhaven-Wulsdorf location.

[6] Current fuel cell car models have a tank capacity of 4-6 kg H_2 (H2MOBILITY, 2020).

Figure 3-2: The planned site of the IWES electrolyser (yellow) and the H2 MOBILITY refuelling stations (green)

Furthermore, there is the opportunity to generate hydrogen internally using electrolysis at the depot if the whole fleet were switched over to hydrogen operation. The resulting H_2 costs depend significantly on the price of the electricity used to generate the hydrogen. Regarding current electricity pricing, this solution generally proves to be uneconomical at least under the given framework conditions.[7] Technical and economic feasibility should be examined in more detail in a separate study.

3.3.2. Electricity

Hafen-Liner

As well as a hydrogen refuelling station, charging infrastructure is also required to supply FC-REX vehicles. Typically, each vehicle is provided with separate charging equipment in order to guarantee complete operational flexibility. In the bus sector, in particular the CCS charger prevails for the charging of battery-electric vehicles.[8]

[7] According to the recently published national hydrogen strategy (BMWi, 2020), there is an effort to disburden the production of green hydrogen from the EEG apportionment, which would significantly improve the economic feasibility of on-site electrolysis.

[8] Another option would be to charge the vehicles using a pantograph. This would be prioritised for use along the route for the intermediate charging of buses, and would not generally be used for dedicated depot chargers.

With around 14 hours of operation each day, there are around 10 hours available for charging the vehicles at the depot. With the vehicle configuration outlined above, an average charging output of around 25 kW would theoretically suffice if the whole parking time were used. For further consideration, an installed charging output of 50 kW per vehicle is assumed in order to guarantee a sufficient time buffer. Greater charging output is not necessary from an operational perspective, and would simply inflate costs unnecessarily. For the three Hafen-Liner buses, an additional connected load of 150 kW must therefore be made available at the depot. According to Bremerhaven Bus, this is possible with the current installaiton without requiring any expansion of the grid connection.

For the Hafen-Liner line, the construction of three 50 kW charging posts is therefore assumed. The space required for this is limited to the charging columns themselves. Typical 50 kW charging poles require around one square metre. To ensure emergency exit routes between parked vehicles, actual space required - depending on the parking concept - may be considerably higher, and this would have to be considered in the plans.

<u>Total network:</u>

If the whole fleet were converted - at 50 kW charging power per vehicle - a connection power of around 3.7 MW would be necessary. Output requirements in the low MW range would typically require a connection to the local medium-voltage network. This must mandatorily be clarified with the local energy provider or mains operator to establish whether this output can be provided to the depot by the local network or whether measures would have to be undertaken to expand the local grid. This would be the subject of a more in-depth review into transitioning the whole fleet.

Regarding setting up charging infrastructure, it should also be checked whether the bus garages offer sufficient space to equip all parking spaces with charging poles while ensuring that emergency exit routes are considered. Power supply from above may be an alternative option. Alternatively, a mixed fleet of FC-REX and FC vehicles could be considered so that charging structure only had to be provided for part of the vehicles.

3.4. Vehicle supply

The Hafen-Liner schedule primarily encompasses the following hours of operation:

- Mondays - Fridays:
  - Normal case: 5 am – 7 pm: 14 hours of operation
  - On Musiksommer Thursdays, Fridays and before public holidays on weekdays: 5 am – 12 pm: 19 hours of operation
- Saturdays: 5 am – 12 pm: 19 hours of operation
- Sundays and public holidays: 10 am – 12 pm: 14 hours of operation

This theoretically results in a minimum of five hours (in the case of Musiksommer Thursdays, Fridays and before public holidays) and a maximum of ten hours when the vehicle is available at the depot for supply (refuelling and charging). A charging capacity of up to 50 kW is sufficient under any circumstances to charge the batteries of FC-REX vehicles over night.

Vehicles are currently refuelled by regular workshop staff as part of vehicle maintenance. If required, repairs can also be carried out on the vehicles to ensure they are ready for use on the following day. Vehicle supply comprises the following tasks:

- Refuelling
- Going through the washing bay
- Small checks
- Parking in the bus garage

In total around 15 minutes are calculated for this (according to Bremerhaven Bus). If the Hafen-Liner hydrogen vehicles must be refuelled, additional time must be scheduled for travel to the hydrogen refuelling station. For the refuelling station in Bremerhaven Wulsdorf (see Figure 3-2), this encompasses 16 additional kilometres (from the depot), amounting to around 20 extra minutes of travel time per bus. This would be reduced by integrating the refuelling process into driver schedules so that refuelling took place directly after the day's route, for example.

From an operational perspective, it would be considerably more beneficial if the buses were refuelled at the previously discussed refuelling station at the corner of the Hexenbrücke bridge at the exit from B 212. This location is close to the bus depot, meaning that previous operational processes could be almost completely retained.

4. Environmental impact

The air quality and climate impact associated with various bus technologies are some of the main drivers in the use of emissions-free vehicles in public transport. Vehicles with electric engines (including vehicles with fuel cells) also offer benefits regarding noise pollution, which is noticeable in areas with low traffic in particular, as the bus becomes the main source of traffic. When it comes to air quality and/or health implications of air pollution on people, the local concentration of the hazardous substance is key. The location of pollutant emission is therefore significant. For this reason, only local emissions during bus operation shall be considered when examining pollutant emissions (nitric oxide and particle emissions). In contrast, the location of the emission of greenhouse gases is unimportant for the climate. That's why the climatic impacts of hydrogen generation and use are based on a lifecycle analysis.

When considering the lifecycle emissions and/or the accumulated savings of three articulated vehicles, average mileage per year (Hafen-Liner or fleet) is considered alongside a service life of 12 years and the annual values in Table 2-1.

4.1. Pollutant emissions

Using the latest HBEFA emissions factors (INFRAS, 2019), around 127 kg of NO_x could be saved each year by transitioning the Hafen-Liner to local emissions-free hydrogen technology (FC or FC-REX), compared to modern Euro VI diesel articulated buses. For particle emissions (PM), the annual savings achieved by local emissions-free vehicles on the Hafen-Liner line sums up to 8 kg of PM. Table 4-1 shows the prospective savings potential across the total lifecycles of the vehicles as well as for the whole fleet.

Table 4-1: Savings potential of local pollutant emissions throughout vehicle service life

	Hafen-Liner	Fleet
Nitric oxide emissions (NO_x)	1,526 kg	22,481 kg
Particle emissions (PM)	100 kg	1,807 kg

4.2. Greenhouse gas emissions

Greenhouse gas emissions are generally shown as CO_2 equivalents (CO_2e). In doing so, other climate-relevant gasses (e.g. methane) are considered alongside CO_2 in relation to their climatic impact.

As explained above, a lifecycle approach is used to analyse a vehicle's greenhouse gas emissions. Figure 4-1 shows this with an example of a hydrogen-powered bus. The lifecycle analysis hereby encompasses the following areas:

- raw material extraction, material production and vehicle production including recycling are added to the vehicle's lifecycle
- Usage
- Energy carrier provision (electricity and hydrogen supply or diesel supply)

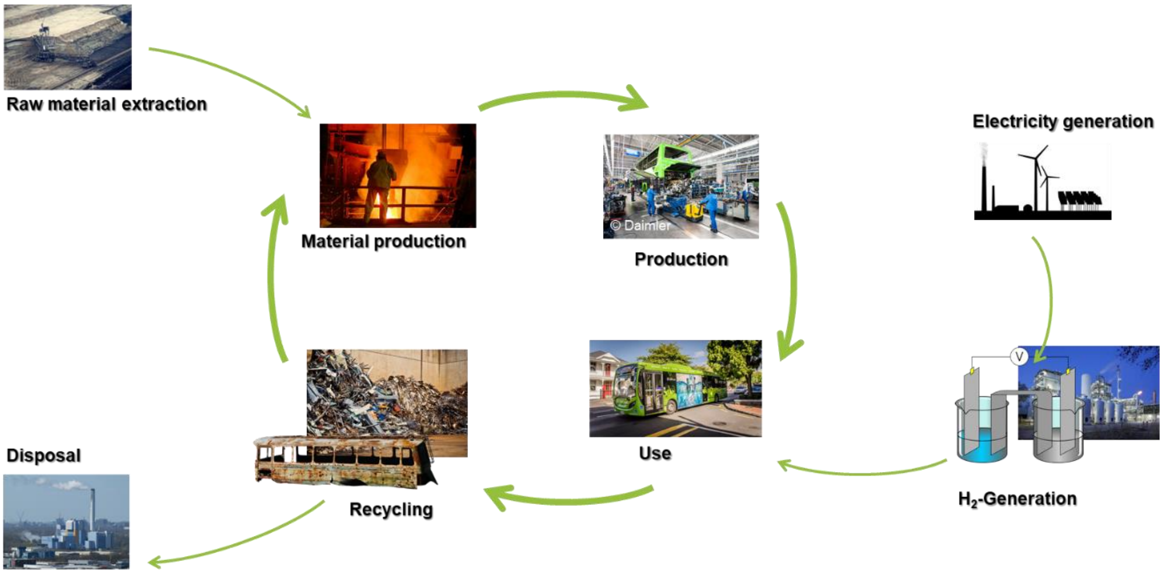


Figure 4-1: Lifecycle of a hydrogen bus including raw material extraction, material production, production, use and energy supply (thinkstep, 2019)

Hydrogen vehicles mostly do worse in terms of production related CO_2 emissions than conventional combustion engine vehicles due to the energy-intense production of fuel cells and high-voltage batteries. But they have the benefit of an emissions-free use phase. The emissions from the use phase (conventional vehicles) are therefore shifted to the vehicle production phase and power supply (hydrogen and/or electricity) insofar as these are not generated emissions-free.

Within the feasibility study, it is presumed that the hydrogen is provided via H2 MOBILITY refuelling stations. The aim of H2 MOBILITY is to provide green hydrogen from water electrolysis using renewable electricity in the long term. Due to the lack of supply of green hydrogen, the hydrogen sold via the H2 MOBILITY refuelling stations is currently primarily made up of grey hydrogen with the following composition (Riepe, 2020):

- 28 % green hydrogen generated by water electrolysis and from biomethane. Due to the high relevance of wind power in northern Germany, the use of wind power is presumed. For the biomethane generation pathway, steam reforming with biomethane input is used.
- 30 % byproduct from the chemical industry. For the purposes of the study, chlorine alkaline electrolysis is used based on CertifHy, and 21 % of the energy input is allocated to the hydrogen generated (Barth, 2019). Environmental impact is therefore worked out proportionately.
- 42 % via conventional generation from natural gas. Steam reforming is presumed to be the primary process here.[9]

It is presumed that the vehicles will be charged using the conventional electricity grid mix.

The acknowledged maintenance of FC vehicles in particular includes exchanging the main components HV batteries and fuel cells. Considering the average network speed of 17.3 km/h and an annual distance of 60,000 km (see Table 2-1), a 12-year service life results in a total of 42,000 hours of operation per vehicle and therefore per fuel cell. Currently, a service life of 30,000 hours is being communicated by the manufacturers for fuel cell systems (Ballard, 2019), so the fuel cell will generally have to be replaced. The replacement fuel cell will only have achieved around 40 % of its service life by the end of the bus' service

[9] In 2015, around 90 % of the hydrogen used in Germany was from hydrocarbon (primarily natural gas) (EY, LBST, BBH, TÜV Süd, 2016).

life, so it can be reused (potentially after refurbishment). For the ecological review, we can therefore presume that 1.4 fuel cells will be used during the full service life of each bus.

A new kind of solid-state battery with a significantly better service life will be used for the FC-REX buses, so these will not have to be replaced for the entire vehicle's 12-year service life, according to EvoBus. The combined energy provided by the battery and fuel cell is managed in a way that the fuel cell works within its optimal operating parameters as much as possible. Due to this specific operating concept, EvoBus claims that also the fuel cell's service life can be extended so that it does not have to replaced during the entire vehicle's 12-year service life, as presumed in this study. Emissions for the production of replacement components therefore do not apply.

Figure 4-2 shows greenhouse emissions from the three considered vehicles, taking into account vehicle production and maintenance as well as the generation of diesel, electricity and hydrogen for power across the vehicles' full service life (12 years). This shows that the use of FC vehicles even under these conditions can save around 1,090 tonnes of CO_2e (28 %) across the vehicles' full service life. For FC-REX vehicles, the savings fall to around 970 tonnes CO_2e (25 %).

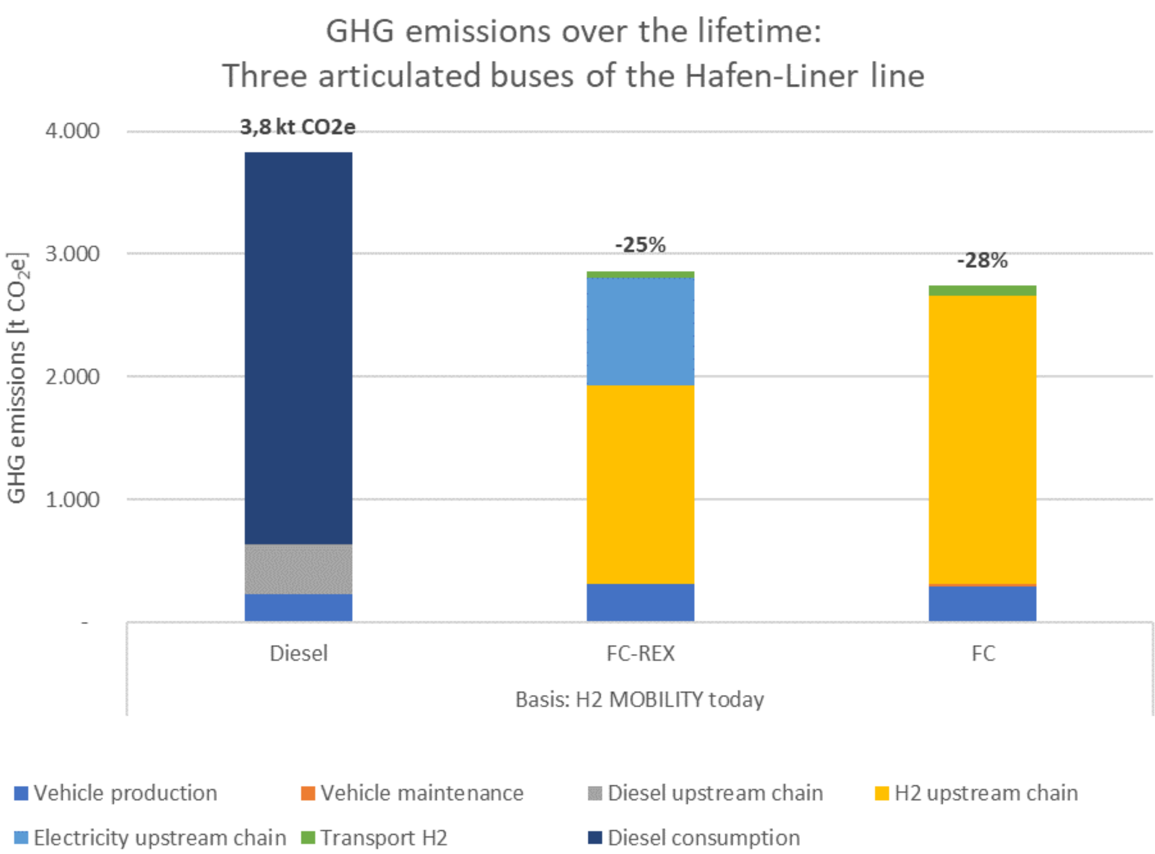


Figure 4-2: **Hafen-Liner's greenhouse emissions across the full 12-year service life using conventional grid electricity and the currently available H_2 mix from H2 MOBILITY.**

Table 4-2 shows the prospective savings potential across the vehicles' full service life for the Hafen-Liner line as well as the whole fleet insofar as wind power is exclusively used to charge the vehicles as well as to generate the hydrogen via electrolysis.

Table 4-2: Savings potential of greenhouse gas emissions across the vehicles' full service lives using green energy (average values for FC and FC-REX vehicles[10])

	Hafen-Liner	Fleet
Absolute reduction	3,200 t CO_2e	65,940 t CO_2e
Relative reduction	- 84 %	- 83 %

[10] Using green energy means that the reduction in emissions throughout the full service life of BZ-REX vehicles compared to diesel operation is 2 % higher than if BZ vehicles were used.

5. Economic viability

5.1. Capital value method and boundary conditions

The cost comparison was carried out using capital value as the standard approach for assessing investment projects. In order to make various cashflows at different times comparable, within the capital value method all due payments are discounted to the base year.

The initial investment (procuring the buses and the necessary infrastructure) flows directly into the capital value in its entirety. This applies to all expenses necessary at the beginning, e.g. workshop equipment, training etc. To simplify, it is assumed that the required investment in the vehicles and infrastructure as well as further starting expenses would all be made in the same year. All further costs are then discounted as annual expenses to the starting point.

The results are shown as annuity. The sum to be considered at the beginning (the capital value to be established) is transformed into a periodic payment that remains the same throughout the period under review.

It should be taken into account that the costs at the beginning (initial investment) and over the following years (operational and energy costs) significantly differ in terms of cost, while the annuities shown are identical over the whole period under review.

The vehicle's service life is used as the period under review. In consultation with Verkehrsgesellschaft Bremerhaven, a service life of 12 years has been assumed. The vehicle's residual value at the end of its use is taken as zero for the sake of simplicity.

The capital value comparison for Hafen-Liner took place based on the following further assumptions and framework conditions:

- The purchasing costs for vehicles and charging infrastructure is deduced from available pricing information or by scaling. Depending on the technology chosen, a price of € 825,000 is presumed for the articulated hydrogen buses, while around € 150,000 is suggested for the charging infrastructure. Funding amounting to 60 % of the additional expenses for the vehicles and amounting to 60 % of the investment for the charging infrastructure is presumed. A hydrogen refuelling station is not required as refuelling will exclusively take place via the H2 MOBILITY refuelling station. There is no funding considered for the diesel vehicles.
- The operating costs for the vehicles and the costs for replacing FC bus components were calculated based on the information on maintenance contracts with various bus operators as well as manufacturer information. In compliance with the assumptions outlined in chapter 4, components are replaced in FC hybrid buses after 30,000 hours of operation, i.e. in the 9th year. Around

€ 130,000 is established as the cost to replace both the fuel cell and HV battery. The remaining value of the replacement components at the end of the bus' service life is credited at 60 % and discounted. In compliance with the remarks in chapter 4.2, no replacement components must be considered with the FC-REX.

- The charging infrastructure should have a service life of 15 years. It is subject to linear depreciation and the residual value at the end of the period under review has been accounted for accordingly.
- 96 ct/l is taken as the cost of diesel. For charging, 15 ct/kWh is taken as the cost of electricity based on information provided by Bremerhaven Bus. Charging losses are not considered in this assessment. The regular net sales price of 7.98 €/kg H_2 is used as the cost of hydrogen. No additional empty runs are included for transport to and from the refuelling station.
- As converting the Hafen-Liner line is a relatively simple project without an on-site hydrogen refuelling station, a fixed sum of € 10,000 has been assigned for public outreach work (see chapter 6.1). Significantly higher public relations costs should be expected if a hydrogen refuelling station, or even an electrolyser, were planned for the depot.
- Costs for training measures are only estimated as relatively low for the conversion of just three buses, as few employees will require training (see chapter 6.2). A fixed sum of € 10,000 has been assigned here, too.
- Adapting the workshop and garage (see chapter 6.3) may be associated with considerable expense in certain circumstances, especially if existing buildings require retrofitting (roof ventilation) or need to be completely rebuilt. This type of expense could not be estimated within this feasibility study, and a fixed sum of € 30,000 has simply been assigned for fundamental fittings.
- Environmental costs are calculated using the Federal Environment Office's Method Convention 3.0 (Matthey & Bünger, 2019). Total emissions are split evenly across the duration of use and the relevant cost rate imposed. For climate costs, the current diesel and/or hydrogen mix offered by H2 MOBILITY were coupled with the CO_2 costs for 2028 (average value for procurement in 2022 and a 12-year service life) throughout the whole period under review.
- The calculatory interest rate is 4 percent.
- All cost values and the calculatory interest rate are implemented as constants, so price increases are generally not taken into account.

5.2. Results

As explained, the established capital value is converted into the relevant annuity across the period under review in order to present the results. In Figure 5-1, the annuities for both hydrogen-powered alternatives to diesel buses are presented for the Hafen-Liner line.

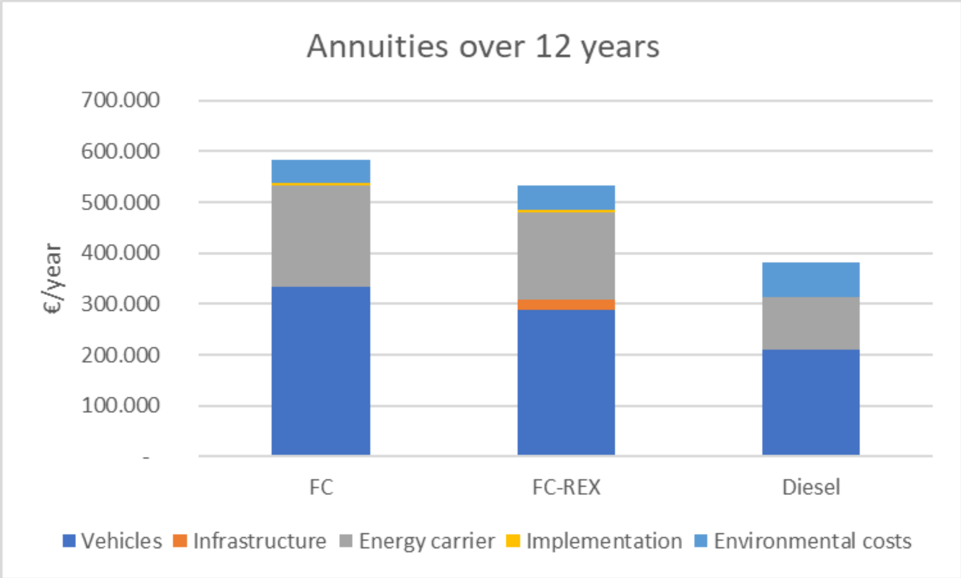


Figure 5-1: Comparison of annuity for converting the three Hafen-Liner buses

Both technology options are therefore associated with significant additional expense compared to diesel buses, resulting mainly from higher procurement and power costs despite funding. The following statements can be derived:

- Costs for the FC hybrid are around 10 % greater than for the FC-REX. The key here is the increased vehicle costs due to replacing the fuel cell, which far outweighs the costs for the additional charging infrastructure required for the FC-REX.
- Despite assumed funding covering 60 % of additional expenses, the purchase costs for hydrogen vehicles are almost 40 % (FC-REX) to 60 % above those for articulated diesel buses.
- With the price assumptions applied, energy carrier costs for the FC-REX are around 15 % below those for the FC hybrid. The FC hybrid will benefit from a reduction in the H_2 price due to its higher hydrogen consumption. However, only if hydrogen prices reach around 4.50 €/kg will both engine types offer comparable power costs (if the price of electricity remains unchanged).
- It is clear that the assumed hydrogen price of almost 8 €/kg H_2 (net) is in no way competitive with today's diesel prices. For cost parity regarding energy carrier costs, the diesel price would have to be 1.65 €/l or above. Even in its final stage (55 €/t CO_2), the intended CO_2 tax will only lead to a price increase of 17 ct/l for diesel (FOCUS online, 2019), so this would not come close to resulting in cost parity.
- The environmental costs are clear to see and amount to around 50 % more for diesel buses than for zero-emission engines. However, their contribution is too little to change the order of results for the capital value comparison.

The cost comparison made is only valid under the assumed conditions. In particular, the following must be considered:

- Under the assumption that also FC hybrids will no longer require components to be exchanged in future, vehicle costs would be almost comparable with the FC-REX.
- The costs shown for charging infrastructure would significantly increase if an additional medium-voltage connection was required. This has not been taken into account here.

6. Implementation

6.1. Stakeholder involvement

Experience from previous projects introducing hydrogen buses to local public transport has shown that the public has varying levels of understanding regarding hydrogen as a fuel. Current projects in Germany (such as the ESWE project in Wiesbaden) have been met with fundamental approval for the technology. At the same time, people are still concerned about safety. This applies particularly and primarily to nearby residents in the case of a hydrogen refuelling station and/or electrolysis facility being set up at the depot. Despite an approx. 200 m distance between the depot and the nearest residential area (bordering Geeste to the north), it is therefore advisable to clarify things with residents and the wider public with targeted campaigns. The companies that produce the refuelling stations often have experience in this regard. In doing so, the issue of noise pollution can be addressed by referencing the fact that electric drivetrains are beneficial compared to diesel motors. Additional noise pollution caused by the refuelling station through operating the compressors (possibly also at night) can be minimised by using suitable sound insulation measures.

The following formats have proven helpful in similar projects:

- Public introduction of the concept and presentation of the perceptibility of the technology
  The technology can be presented at an 'open day' or 'fuel cell experience day', e.g. offering a ride on a FC bus in combination with an introductory talk about the project. Often, people's personal experiences help to establish a positive relationship with the technology (e.g. see (Stolzenburg, Whitehouse, & Whitehouse, 2019) and (Hoelzinger & Luedi-Geoffroy, 2013)).
- Communication about the project, e.g. on the Bremerhaven city website, flyers, newsletters etc. as early and as widespread as possible.

As part of the active societal discourse on the climate crisis, the public is increasingly asking to what extent new technologies can contribute to solving the climate crisis. In terms of hydrogen buses, this primarily relates to the origin or the production process of the hydrogen. Insofar as the hydrogen production processes outlined in this study apply, the reduction of greenhouse gas emissions described in chapter 4.2 may be referenced and communicated as a resulting benefit.

As well as the residents and the public or citizens of the city, the concerns of Bremerhaven Bus employees should also be taken into consideration. Here too, a suitable internal information campaign would be advisable. Furthermore, the affected employees should be given dedicated training to prepare for the new technology (see chapter 6.2).

Of course, the project partners that will be taking part in the project, such as Bremerhaven Bus itself, suppliers, vehicle and fuel station manufacturers as well as political decision-makers and approval bodies, are also relevant to the project's implementation. Regarding the H_2 supply, potential hydrogen suppliers should be involved at an early stage (e.g. as part of the discussed hydrogen generation projects, see chapter 3.3). During the further approval process, the involvement of further specialist bodies may also make sense, as well as the emergency services, in particular the fire service.

One special characteristic of the Hafen-Liner line is its touristic relevance. As part of the DESTI-SMART project, Bremerhaven is one of nine European cities to stand out with its sustainable transport for tourists. The use of hydrogen buses for the Hafen-Liner line constitutes an active contribution to the promotion of sustainable tourism, and shows that the city of Bremerhaven as well as Erlebnis Bremerhaven GmbH are dedicated to taking on a pioneering role. This can actively be included in external branding, increasing the city's attractiveness as a tourist destination.

For more detailed information on the concept of stakeholder involvement in the implementation of hydrogen bus projects, please see (Reuter, Faltenbacher, Schuller, Whitehouse, & Whitehouse, 2017). The NOW brochure on introducing hydrogen buses in local public transport, 'Einführung von Wasserstoffbussen im ÖPNV', (Kupferschmid & Faltenbacher, 2018) also covers the issues of 'societal acceptance' and 'planning and approval of infrastructure'.

6.2. Qualification requirements

The qualification of the affected employees is of vital importance to the technology's successful introduction. Suitable training can be used to ensure employees are familiar with the technology and prepared for the transition to emissions-free local public transport. Besides the drivers, this also includes supply and workshop staff as well as other depot workers.

Due to the special features of driving electric vehicles (especially energy-efficient driving through sensible use of recuperation), each driver should receive driver training in how to operate hydrogen vehicles as preparation. The special features of the drive are just one aspect of training, which should contain all other vehicle-specific issues such as the location and functionality of operating elements.

Workshop employees that will be working with high-voltage components must be specifically trained depending on their area of work. The guide on electromobility and working on omnibuses with high-voltage systems, 'Elektromobilität – Arbeiten an Omnibussen mit Hochvolt-Systemen', from the VBG specialist range covers the various qualification profiles dependent on the relevant task (see Figure 6-1). For specific qualification content, see (DGUV, 2012) and (VBG, 2016). Furthermore, special training on electric air conditioning (heat pumps) is also advisable, as this is significantly different from classic air conditioning systems in diesel vehicles.

Employees tasked with the maintenance of hydrogen vehicles should also receive various training on fuel cells as well as gas system inspections (GAP) alongside a general introduction to hydrogen. For further information regarding training units, please see (Kupferschmid & Faltenbacher, 2018) and/or BGI5108 'Wasserstoffsicherheit in Werkstätten' on hydrogen safety in workshops. Suitable training is offered by the TÜV SÜD Akademie[11], the TAK Akademie Deutsches Kraftfahrzeuggewerbe[12], the Weiterbildungszentrum Brennstoffzelle Ulm (WBZU)[13], and various chambers of industry and commerce.[14]

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11 https://www.tuvsud.com/de-de/store/akademie/seminare-technik/elektromobilitaet-hochvolttechnik/ batterie-wasserstoff

12 https://www.hv-fahrzeuge.de/

13 http://www.wbzu.de/

14 https://bit.ly/2V8QbTT

		Level 3	For example
		Working with live HV systems and working near live parts at risk of contact	- Troubleshooting - Changing live components
	Level 2	For example	
	- Cutting voltage - Electrical/technical work in a non-live environment	- Activation - Preventing reactivation - Establishing a non-live environment - Exchanging HV components - Pulling the plug + exchanging components (e.g. DC/DC converters, electric air conditioning)	
Level 1	For example		
Non-electronic work	- Test drives - Chassis work - Changing oil and wheels		

Figure 6-1: Qualification levels for working on HV vehicles (DGUV-Information 200-005, 2012 (BGHM - Berufsgenossenschaft Holz und Metall, 2012); currently under review)

Within the scope of the working group ‘Innovative Antriebe Bus’ on innovative bus operation, the training content from various transport operators has been compiled including all content related to battery-powered electric vehicles. For more detailed information, please see the relevant publication (Arbeitsgruppe Innovative Antriebe Bus, 2016).

The following qualification modules can be principally ascertained for Bremerhaven Bus employees:

- Workshop employees (depending on the desired scope of maintenance by the manufacturer and the existing qualification level)
  - Training in levels 1 – 3 (electricians for specified tasks, Figure 6-1)
  - Training on the topic of fuel cells as well as at least gas system inspection (GAP) with additional training for hydrogen
  - Training in how to handle refuelling equipment in collaboration with the manufacturer
- Drivers
  - Familiarisation with hydrogen
  - Introduction to electric vehicle operation
  - Driver training

6.3. Adjustments to the workshop and garage

During the transition to / introduction of hydrogen vehicles, certain adaptations will have to be made to existing equipment. The workshop must offer an opportunity to turn off the voltage for the vehicle’s high-voltage components. Insofar as buses with HV components (e.g. diesel hybrids) are already used, this should already be in place. Furthermore, a roof work structure and underslung crane would also be helpful as the tanks and/or HV batteries are often stored on the top of hydrogen buses, and access must be guaranteed for maintenance work.

As well as adaptations due to the special technical features of hydrogen vehicles, changes are required due to the physical properties of hydrogen. Closed buildings (e.g. workshops, possibly also garages) must have suitable technology to ensure that there can be no explosive compounds if there is a hydrogen leak. This encompasses suitable ventilation combined with gas warning systems (H_2 sensors) as well as ATEX equipment. For more detailed information, please see VdTÜV factsheet number 514. An expert inspection will provide clarity as to what must be done in a specific case. For further information, please see (BGBahnen, 2009). The costs to this end may differ drastically (lower five-figure to lower six-figure area) and depend greatly on local circumstances such as building construction, existing equipment etc. (Kupferschmid & Faltenbacher, 2018). In consultation with the vehicle manufacturer, outdoor vehicle parking may be considered so that the necessary safety changes would only have to be made to the workshop.

As an alternative to workshop maintenance, a full maintenance contract may be considered so that all upkeep, including replacing any components as required, would be the manufacturer's responsibility. This is a very simple solution for the operator. The associated costs are estimated at around 75 ct/km for an articulated bus. A full maintenance contract for just three vehicles may create significant difficulties for the manufacturer, however, as also such a small number of vehicles would still require the organisation of comprehensive, rapid, local customer service. Experience from other projects indicates that a full maintenance contract for the three Hafen-Liner buses may not be offered by the manufacturer under these circumstances.

6.4. Outlook: Converting the whole bus fleet

Converting the whole fleet to hydrogen-powered vehicles is significantly more extensive than transitioning the Hafen-Liner line alone. For one, the use of a public refuelling station to supply the vehicles would no longer be practical for operational reasons. Secondly, the bus operator could outsource the maintenance work on a small number of vehicles insofar as this service is offered by the manufacturer, so that extensive know-how does not necessarily have to be established internally. If a complete transition is made, full outsourcing would no longer be advisable for operational and cost reasons. Here, it therefore makes sense to install an on-site refuelling station at the depot and establish comprehensive specialist knowledge internally.

As part of the New Bus Fuel project (Reuter, Faltenbacher, Schuller, Whitehouse, & Whitehouse, 2017), it has been established that the costs of hydrogen infrastructure significantly depend on the stored capacity. A gradual expansion of the refuelling station while bundling vehicle procurement has proven a decisive factor in avoiding unnecessary capital binding and ensuring the expansion of infrastructure in the most cost-effective way. As a consequence, if the full fleet were to be switched to hydrogen power, procurement should ideally take place in larger batches (e.g. three lots of 25 vehicles), whereby the hydrogen infrastructure is expanded in parallel.

Insofar as FC-REX vehicles are to be used, the local mains operator should be informed early on as to what measures are necessary to supply the required charging output on site. Furthermore, the charging concept and required hardware (poles, overhead charging cables etc.) should be selected. Depending on the concept, there may be different challenges to overcome (building stock, emergency exit routes, space availability etc.).

For further aspects (energy requirements, H_2 supply, space requirements), please see chapter 3 as well as the risks and recommendations in chapter 7.

7. Risks and recommendations

7.1. Vehicle availability

At the time of this report, there is only one 18 m hydrogen-powered bus model available on the market. This is the Van Hool ExquiCity18 Fuel Cell, which has been in use since December 2019 in Pau (France) on an especially created express bus line. These buses are prototypes that are not yet commercially available. Other operators have not received any bids on their tenders for articulated fuel cell buses in 2020. This situation is not expected to change in the short term. The overall impression from manufacturers is that articulated fuel cell buses will be available in 2022 at the earliest (see chapter 3.1). EvoBus has also announced the delivery of its first articulated FC-REX buses for 2022 (Evobus GmbH, no date).

Insofar as hydrogen buses are to be introduced as quickly as possible, the option of first using a few solo buses could be considered. Here, vehicle availability has significantly improved over the last few years due to major funding projects, with multiple manufacturers offering suitable vehicles. However, manufacturers are struggling to keep up with their supplier obligations even for solo buses (regardless of the current restrictions due to the coronavirus epidemic). The procurement situation regarding fuel cell buses is therefore relatively difficult, which should be taken into consideration in planning the transition.

7.2. H_2 supply

With just a few FC buses, a simple and economically logical solution would be to use existing refuelling infrastructure insofar as operational processes allow. Regarding operational changes, a refuelling station near to the depot (the second H2 MOBILITY fuel station site as discussed) would be significantly more beneficial. The demand for the three Hafen-Liner buses increases the utilisation of the external hydrogen fuel station significantly, as it would otherwise be fairly low even over the next years for a refuelling station purely for cars (Smolinka, et al., 2018). A long-term agreement with set purchase volumes should be the aim here in order to negotiate beneficial purchase conditions.[15]

With an increasing number of fuel cell buses, a refuelling station at the depot makes more and more sense in order to optimise operational processes and avoid extra trips along with the associated time this would cost. With an increasing number of buses and, particularly, due to the expected future use of fuel cell trucks, the risk of a refuelling lane being blocked by another vehicle increases. An on-site refuelling station at the depot would circumnavigate this risk. The depot refuelling centre would also be explicitly set up in a way that a multitude of buses could be refuelled in the comparably short amount of time during which the fleet returns in the evening (high back-to-back capacity), which may not be possible at an external refuelling station.

With an increasing foreseeable hydrogen demand, even an on-site electrolysis facility to supply the refuelling centre may make sense. The feasibility and profitability of this would have to be reviewed in a separate implementation study. Regarding high electricity supply costs, yet the supply of hydrogen is often the more economic alternative, especially as long-term purchase contracts can be used to achieve cheaper H_2 prices.

Insofar as the operation of a hydrogen refuelling station is intended, this should be expanded stepwise, as a low initial number of vehicles will otherwise result in high capital-intensive excess capacity. This will

[15] As there is no information in this regard, this could not be taken into consideration within this study.

impact vehicle procurement, which should be synchronised with the expansion of the fuel station. The most economic option is to procure batches of vehicles in parallel to the expansion of the refuelling station's capacity. For a more precise description, please see (Reuter, Faltenbacher, Schuller, Whitehouse, & Whitehouse, 2017).

7.3. Costs

Fuel cell vehicles will still be considerably more expensive than diesel vehicles in the foreseeable future. Costs for an articulated FC bus are currently estimated at around € 850,000. Even in the case of a significant cost saving over the next 10 years (assuming procurement in three batches), it is expected that the costs will still exceed those of diesel buses by at least around 75 % (EMCEL, 2018). Switching the whole fleet of 73 vehicles would therefore amount to around 25 million euros additional costs (without considering possible funding).

Regarding the hydrogen fuel station for the whole fleet, the costs may amount to at least 3 to 5 million euros depending on the bus technology selected, and therefore the amount of hydrogen required. Depending on the desired storage capacity (back-up in the case of a supply shortage) and redundancy (multiple versions of significant components), these costs could end up considerably higher. While the FC-REX requires less investment when it comes to the refuelling station, around 3.7 million euros extra must be estimated for the charging infrastructure. Insofar as the hydrogen is to be generated using an on-site electrolyser, significant investments of several million euros would be required here.

With the assumed consumption, operating the buses would also lead to 70 % higher fuel costs, even with a price reduction of 10 % meaning a net hydrogen price of 7.18 €/kg H_2, resulting in a good 1.5 million euros per year considering the total fleet's average annual travel distance of 60,000 km/a.

Additional costs that have not been further quantified here may be incurred due to changing the whole fleet, e.g. through measures to adapt the workshop and garage, stakeholder involvement, staff qualification and considerable internal costs for planning, project management, tenders etc. Expanding the depot, which would also come with significant costs, is currently not required to the best of our current knowledge, even if the full fleet were switched to hydrogen operation. The existing depot in principle has sufficient space for the hydrogen fuelling station[16].

These additional costs pose a considerable challenge to the bus operator (and/or the local council), for the financing of which suitable funding may be considered. Relevant funding programmes must therefore be sufficient to cover in particular the high initial investment costs. Furthermore, it must also have a sufficiently long duration in order to make a dent in the operating expenses. It should also be suitably broadly defined in order to cover as many different cost categories as possible. CO_2 charges, e.g. in the form of a CO_2 tax, could reduce the monetary disadvantages of switching the fleet to hydrogen operation, meaning that funding could also fall.

7.4. Time delays and technical issues

It has been shown that the introduction of fuel cell hybrid buses poses a complex challenge for most operators. This begins with vehicle availability and the monopoly enjoyed by a few manufacturers, meaning that ordering and delivery are expected to be subject to considerable delays of up to one year.

If it is planned to transition the majority of the bus fleet to hydrogen and therefore build an on-site hydrogen fuel station at the depot, the bus operator must plan the construction of hydrogen infrastructure alongside

[16] A more precise review would require a specific fuel station plan taking vehicle routes, safety distances and any possible noise pollution measures etc. into account.

procuring vehicles, which would be virgin territory for the operator. In particular if an on-site electrolysis facility should also be constructed alongside the on-site fuel station, this undertaking requires careful long-term planning that must take place in parallel with bus procurement.

The fuel cell hybrid buses and the hydrogen infrastructure do not currently constitute completely established technologies, so significant starting difficulties and decreased availability must be expected at least at the beginning. There are also recurring problems with the interface between the two systems, as there is no recognised fuelling standard for commercial vehicles so far. Currently, for example, there is great uncertainty regarding to what extent the new type 4 hydrogen tanks require the hydrogen to be pre-cooled, which has so far not been considered at most bus refuelling stations (350 bars). Pre-cooling causes above-average downtime at car refuelling stations.

7.5. Stakeholder involvement

Transitioning a bus fleet to fuel cell hybrid vehicles is a lengthy and complex project. For implementation to run as smoothly as possible, all relevant project partners and decision-makers should be involved early on. Furthermore, the residents near the depot and the wider public should be made familiar with the new technology and the measures required in order to prevent any possible doubts or resistance through communal discourse in advance.

Comprehensive internal communication is advised, as all employees and operational processes related to bus operation will be affected by the change in the short or long term (drivers, workshop, administration etc.).

7.6. Employee qualification

Sufficient time and budget must be assigned for the necessary employee training as well as any required adaptations to operational processes, which should be considered in ongoing operation. To ensure that there are sufficient trained employees available when the buses are delivered, the determination of qualification requirements and the carrying out of training sessions should be conducted in advance. To achieve the maximum training standard to comply with the qualification of a fully trained technician employed by the manufacturer, around two years during ongoing operation should be expected. The specific training plan depends on the number of staff as well as existing skills and the required qualifications.

7.7. Workshop and garage

If there is a small number of buses, there is the option of full maintenance contracts so that responsibility for the buses' roadworthiness is delegated to the manufacturer. If there is no intention to set up a suitable workshop, the necessary transportation for maintenance and repairs will negatively impact availability. Furthermore, this service is associated with a considerable increase to procurement costs or a high cost per kilometre travelled, and is not profitable for larger numbers of vehicles in general. In addition, manufacturers tend to be less willing to offer a full maintenance contract for small vehicle numbers (see chapter 6.3).

Here, the question is which solution is the most organizationally and economically favourable option, regarding the first three buses as well as in view of the further fleet transformation, taking into account the conditions offered by the manufacturer.

7.8. Involvement in further local hydrogen concepts

In order to optimally integrate the Hafen-Liner project into the hydrogen landscape through its transition to H_2 power, it may make sense to establish a network with other local hydrogen projects (e.g. the Brake region or the Osterholz district, also funded as part of the Hyland programme). This may result in bulk vehicle orders, for example.

Contact with other bus operators that are also planning to introduce or already use fuel cell vehicles also facilitates an exchange of experiences, which has proven very helpful and sparked great interest within the JIVE projects. Here, the operators can keep each other informed, and use their experiences to support each other during the various phases of project implementation as well as bus operation.[17]

Close collaboration with other local hydrogen projects should be sought when it comes to hydrogen supply. This would include the hydrogen generation project at the Mittelsbüren (Bremen) site from 2021 as well as the hydrogen generation facility planned by Fraunhofer IWES at the Flugfeld Lune in Bremerhaven.

7.9. Project timeline

There are several points to consider in introducing hydrogen buses to the Hafen-Liner line, as summarised hereafter. The order provided describes the suggested timeline, although the individual implementation steps are interconnected and often run into one another. E.g., already the rough planning should consider whether and in what way changes to the workshop are necessary. Detailed planning and implementation can take place later, as a project duration (until line operation is commenced) of at least two years is expected, within which the workshop changes can be carried out flexibly.

[17] A supra-regional platform is offered by the workgroup Innovative Antriebe Bus (AG Bus), in which bus operators, politicians and councils discuss issues such as procurement, vehicle availability and energy consumption etc. on a biannual basis.

Setting up a project group

- Setting up a dedicated project group with overarching project management (preferably within Bremerhaven Bus) and representatives of all relevant stakeholders (at least Stadt Bremerhaven, Erlebnis Bremerhaven, H2 MOBILITY, H2BX). If applicable, involving additional representatives e.g. from local hydrogen projects

Project preparation

- Contact with possible manufacturers in order to clarify the deliverability of articulated hydrogen buses as well as available bus types and engine concepts.
- Creation of a rough plan for the transition of the Hafen-Liner line, taking into account relevant time periods and deadlines (for funding applications, tenders and procurement, construction measures, organisation, training etc.).
- If applicable, creating a rough concept for switching the whole fleet to hydrogen power. Further steps should be orientied towards this end.
- Applying for funding, especially for investing in vehicles and charging infrastructure if applicable, retrofitting the workshop and garage, as well as all costs relating to introducing H_2 buses that may be eligible for funding.

Fine tuning / fundamental decisions

- Defining the procurement criteria (if desired, e.g. regarding bus type, engine concept, guarantee and maintenance) and tendering vehicles and, if applicable, infrastructure.
- Fine tuning the plans for necessary construction work on the garage (especially any work required on the roof if applicable)
- Fine tuning the plans for construction and installation work for charging infrastructure (for BZ-REX).
- Negotiating a long-term purchase agreement and relevant purchase conditions for hydrogen fuel (if applicable, taking any further planned expansion into account).

Ancillary measures

- Developing a communication and advertising concept.
- Fine tuning plans for changes to the workshop.
- Establishing the required qualifications and creating a detailed training plan for staff.

Figure 7-1: Project timeline for the introduction of hydrogen buses

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